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CUMULATIVE IMPACTS:
CURRENT RESEARCH AHD CURRENT OPINIONS AT PSW

R. M. Rice
Pacific Southwest Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture
Arcata, California

INTRODUCTION

Consideration of cumulative watershed effects (CWEs) has both political and physical aspects. Regardless of the practical usefulness of present methods of dealing with CWEs, the legal requirement to address them remains. Management of federal land is regulated by the National Environmental Policy Act (NEPA) and the Federal Water Pollution Control Act of 1972. The state of California has passed analogous laws: California Environmental Quality Act (CEQA) and the Porter-Cologne Act--both of which affect management on private land, primarily through the Forest Practice Regulations that they have fostered.

Although both NEPA and CEQA mandate that cumulative impacts be addressed, the exact nature of that mandate has beer. ambiguous from the start. Neither the record of legislative deliberations, the subsequent laws, nor the resulting regulations give any clue as to the mechanisms that were expected to be operating or how dealing with them might be different in any way from mitigating individual effects. On private land, addressing cumulative effects becomes a way of thinking about possible environmental effects of a proposed project. As Ted Cobb, a former California Department of Forestry (CDF) attorney, puts it: "Most of the time you ask yourself just two questions: 1. Is there anything near my proposed project of which I should be aware that will make any environmental effects of my project worse than they would otherwise have been the case? 2. Are there any future plans in the vicinity of my proposed project which would have those effects? If the answer to either question is 'yes,' then you ask two more: 3. Are the possible effects significant? 4. If they are significant, can they be mitigated so they will cease to be significant?" (Cobb, In Press)

The cumulative effects mandate, therefore, is to look at each individual project within the context of other projects which are close to it in both time and space. There is nothing, however, in the law or regulations which requires sheer speculation. The general thrust of both is, in fact, that responses may be limited to what is reasonable, feasible, or practicable. They do not specify any particular mode of analysis of cumulative impacts. They do require, however, that the nature of the analysis be described and the basis for a particular decision be identified. Court cases suggest that it is expected that decisions will be supported by empirical evidence or scientific theory.

Scientists at the Forest Service's Pacific Southwest Forest and Range Experiment Station (PSW) have been considering CWEs for over a decade, but it was only two years ago that we began to collect data in a study which was specifically designed to address CWE questions. .That particular study involves 14 intensely instrumented experimental watersheds in Caspar Creek on

the Jackson Demonstration State Forest near Fort Bragg, in northern California. This spring, we expect to start the second study which will use measurements from watersheds of varying sizes in several locations throughout the state. Since the second study is still in the planning phase its final form and execution may differ somewhat from what I describe here.

THE CASPAR CREEK CUMULATIVE EFFECTS STUDY

The Caspar Creek cumulative effects study is a joint undertaking by the California-Department of Forestry and Fire Protection's, Jackson Demonstration State Forest and the Pacific Southwest Forest and Range Experiment Station. Planning for the study began in fall 1979, but it was not until 1984 that construction of the necessary stream Gauging stations began. The study now includes 14 stream gauging stations. One of them, the South Fork of Caspar Creek, is a holdover from a previous paired watershed experiment. The others were constructed specifically for this study (Figure 1). The study will include 4 control watersheds and 10 logged watersheds. The logged watersheds range in size from 40 to 946 acres. The control watersheds range from 26 to 1047 acres. Both tractor and skyline yarding will be employed.. Tractor yarding will be used on from 12 to 60 percent of the area of individual logged watersheds: averaging about 30 percent of the area logged. Cable yarding will be used on between 17 and 69 percent of the area of individual watersheds, averaging about 70 percent of the area logged. Clearcutting will be the oily silvicultural system employed.

Measurements

A number of different physical and biological measurements will be made to interpret the effects of logging the North Fork of Caspar Creek. The biological measurements, for the most part, will not deal with cumulative effects directly. Rather, their aim will be to determine the magnitude of biological changes and, in some cases, investigate the mechanisms by which those changes occurred. We currently have underway a study of benthic invertebrates and a study of fish habitat. The latter will attempt to measure logging effects on (1) fish growth, condition, and survival; (2) vertebrate community structure; (3) habitat availability; and, (4) habitat capacity. These studies will deal with steelhead trout. The comparable physical studies will include a plot study of surface erosion from newly constructed roads, investigations of sediment routing before and after logging, and continuously updated history of logging related disturbances. Although some of the foregoing measurements may be used in the statistical analyses of cumulative. effects, their main function will be to explain what is going on in the various watersheds and why our downstream measurements are the values that we observe.

Our objective evaluation of the magnitude of cumulative effects will be based on a statistical analysis of four hydrologic variables. They are hydrograph lag time, storm runoff volume, peak storm discharge, arid sediment discharge. All of them have been proposed (or reported) to be affected by logging.

Of the four dependent variables to be tested in the cumulative effects study, only lag time showed statistically significant changes after logging the South Fork in 1971-1973 (Sendek 1985). In that study data were only available from

one treated watershed, the South Fork of Caspar Creek. Our new study will benefit by having data from 10 treated watersheds and by having much more precise records of both precipitation and streamflow. The increased precision results from our conversion to rain .gauges and stream gauges using digital quartz clocks to measure time. We will be interested in seeing if there are still detectable changes in lag time with the-much lower anticipated watershed disturbance; and, if there are detectable differences, is-there a cumulative effect?

Neither peak flow nor volume of storm runoff showed statistically significant changes after logging in the South Fork (Wright, 1985; Ziemer, 1981). Other paired watershed experiments in Oregon, however, have reported increases in the magnitude of large winter runoff events (Harr and others, 1975, 1979). Since runoff increases are the presumed mechanism underlying some timber harvest scheduling approaches to the management of CWEs, these two dependent variables will be tested again.

Change in sediment discharge was the most important effect observed in the South Fork study (Rice and others, 1979). Excess sediment, in itself, harms water quality. Furthermore, increased-sedimentation is one of the presumed mechanisms by which logging and the construction of forest roads may adversely affect fish habitat. Stoma sediment discharge is, therefore, our most important physical measure of cumulative watershed effects. Fortunately, we have been able to improve the quality of our suspended sediment estimates to a very considerable degree over what we, or others, have been able to accomplish in the past. In order to appreciate how these improvements have been effected, the characteristic pattern of flow frequency, flow volume, and sediment volume discharges needs to be considered.

In Caspar Creek, as in most streams, discharge is at a very low level most of the tine and at a very high level for only short periods of time. This yields a markedly "J"-shaped curve of flow frequency against discharge (Figure 2). When this frequency is multiplied by discharge, however, the curve is elevated appreciably, with a large proportion of the total volume of runoff occurring at the higher flows. Since sediment concentration is a power function of water discharge, the sediment volume runoff curve is elevated still higher. As a result of these characteristics, in the South Fork, discharges greater than 45 cfs occur approximately 1 percent of the time, but carry 26 percent of the volume of water and 81 percent of the suspended sediment discharged annually by the stream. The shape of these three curves suggests that the best estimates of suspended sediment discharge should be based a scheme which emphasized the higher discharges. Such a scheme has been developed (Thomas, 1985). The system samples discharges approximately in proportion to their contribution to total sediment discharge. Previously, we had used a sediment sampling procedure which approximated the flow duration, curve supplemented by a few extra samples from the higher discharges. Our procedure was similar to that used for most such estimates throughout the world. Thomas (1985) used a computer simulation to test the efficacy of his procedure compared to the flow duration curve sediment rating curve procedure that we had used in the past (Figure 3).

Data from the North Fork of Caspar Creek were the basis of his simulation. Fifty estimates using his procedure missed the "true" value by less than 1 percent. Fifty estimates using our former procedure, while showing a similar

degree of variability, gave a mean underestimation of almost 51 percent. In order to use Thomas' procedure, the collection of sediment samples must be governed by a microprocessor. In fact, except for a backup water level recorder. our entire data collection system is now electronic. Discharge through our flumes and weirs is proportional to the depth of the water. This depth is sensed by a pressure transducer that transmits the information to the microprocessor which, in turn, converts it to water and estimated sediment discharge. The microprocessor then decides whether water discharge has changed sufficiently since the last reading to warrant recording a new measurement and, on the basis of estimated accumulated sediment discharge, whether a sediment sample should be taken by the automatic suspended sediment pumping sampler. In 1986, this system produced high quality data. In fact, we had many more malfunctions with our backup mechanical system than with the new electronic parts of the system. Because of these innovations in monitoring, we are confident that we will not only have a more precise estimate of the relative change in sediment discharge due to logging, but also a more accurate estimate of the absolute change. These improvements in accuracy and precision may rake it possible for us to detect cumulative watershed effects which would have otherwise gone undetected.

Analysis

In the study we face the problem of defining cumulative effects in a way that leads to testable hypotheses. The simplest definition of CWEs is the joint, occurrence of two or more watershed effects. From a research point of view, this definition is trivial and need not be tested since cumulative effects will always occur if effects co-mingle. Amore plausible rationale for the management of cumulative effects by controlling the level of disturbance above a point of concern is that effects are the results of accidents. The best management practices (BMPs) are, obviously, neither perfect nor perfectly implemented. Consequently, environmental conditions or errors in application of the BMPs may lead to unacceptable cumulative effects at some downstream point of concern. This rationale leads to the hypothesis that the probability of cumulative effects occurring increases as the proportion of the disturbed area above a point of concern increases. Although this hypothesis seems reasonable, it is not a refutable hypothesis, since it can always be argued that any test yielding negative results did so because BMP's were well applied or that the environmental stress was not great enough to cause cumulative effects. The foregoing lead to the conclusion that this experiment must be based on the hypothesis that cumulative effects always occur. This seems the only way to bring the question of the existence of cumulative effects within the scope of empirical science: This will be done by assuming that for any level of watershed disturbance, the farther downstream the point of concern is located, the greater will be the effect.

Specifically, watershed area will be assumed to be a surrogate for "distance downstream" and a 'statistically significant positive partial correlation coefficient for watershed area will be taken as supporting the hypothesis of the existence of cumulative effects. Other outcomes of the analysis will be taken as a refutation of the hypothesis. If the hypothesis is supported, the practical significance of the estimated cumulative effect remains to be decided: That, of course, is a question of social policy, but for the purposes of this study, the estimated cumulative effect will be deemed of

practical importance if the effect of area over the entire range of data exceeds the span of the standard error of the regression.

The analysis will begin very much like the traditional paired watershed experiment. We have 10 subwatersheds that will be logged (Figure 1). Three of the subwatersheds and the South Fork of Caspar Creek will remain undisturbed throughout the study. During the calibration period (hydrologic years (HY) 1986-1989) data will be collected to compute equations by which the undisturbed performance of the. watersheds to be logged can be predicted. These equations will then be used to estimate streamflow and sediment discharge during the post-logging period (HY 1990-1996, depending on the pace of logging). The differences between the observed values of our various dependent variables (lag time, peak flow, water discharge, sediment discharge) and the predicted values will be considered to be the effects of logging. These differences will become the dependent variables in the cumulative effects analysis. They will be regressed against watershed area and various descriptions of watershed disturbance, such as the proportion of the watershed in roads, landings, and skid trails. As stated previously, it is assumed that if there are no cumulative effects, the area variable will have no predictive capability.

THE EXTENSIVE CUMULATIVE EFFECTS STUDY

The extensive cumulative watershed effects study is still in the planning stages. Data collection is scheduled to begin in summer 1987. The objective of the study is to assess the recent (past one to two decades) cumulative effects and current sensitivity to effects in different-size watersheds. The study will be undertaken in two important geologic-climatic provinces of northern California. The provinces will be chosen so as to differ in how CWEs originate, move through the hydrologic network, and affect stream resources. At present, we plan to complete the experiment in provinces which yield widely different types of bed material in higher order channels. One province will be in an area where sediment sources produce predominantly sand and finer materials, whereas the second province will be composed of sediment sources producing predominantly coarser material. Watersheds will fall into three drainage-area classes: 200-500 ac; 2,000-5,000 ac; and 20,000-50,000 ac (fourth order).

Approach

The problem will be addressed simultaneously from two approaches:

1. To develop and quantify a physically and biologically based model of how watershed products are routed through drainage networks and affect stream channels and critical components of fish habitat. The goal would be to define the important compartments and linkages in the model and to research the weakest and most approachable components.

2. To detect CWEs by a statistical approach using independent variables quantifying disturbance from land use practices and dependent variables quantifying effects on stream resources.

Thus the study is designed to advance scientific understanding of CWEs and to provide managers with tested and scientifically valid methods for predicting and detecting them.

Physical-Biological Modeling

Cumulative effects in the physical-biological approach are defined broadly as offsite effects in order to be concerned entirely with watershed processes. The primary objectives are to quantify the variations of this system in a watershed due to the production and delivery over time of watershed products (sediment, water; woody debris, and nutrients) to alluvial streams. The conceptual model is that accelerated runoff and sediment production from hillslopes are transported rapidly through steep low-order tributaries, which store little sediment, to alluvial channels which are affected by increased sediment supply. Changes in alluvial channels result in changes in the abundance and distribution of critical habitats. Changes in riparian vegetation, woody debris, nutrients, and solar insolation may also have important indirect effects. We will appraise the inherent sensitivity of channels having different patterns, geometries, and grain size, and the distribution and abundance of key fish habitats.

Key problems we face in planning this research approach are:

1. How to quantify the volume of sediment recently reaching stream channels relative to background rates.

2. How to quantify storage and flux of sediment in channels.

3. How to relate changes in sediment load to response of alluvial stream channels.

4. How to determine critical habitat variables that respond to changes in channels.

5. What important, tractable components of the model should be studied in greater detail.

Statistical Test of CWEs

In addition to understanding the mechanisms responsible for CWEs it is desirable to have an objective appraisal of their magnitude. Such an appraisal is the purpose of this part of the study. For this approach, CWEs are defined as a detrimental change in some hydrological factor or beneficial use.....

1. Resulting from the combined effects of more than one land management treatment.

2. Occurring at a point of interest in the stream system at or below the constituent treated areas. and

3. Which exceeds either a meaningful physical threshold, a regulation, or a policy limit-at that point but not at the constituent treated areas

The analytical framework we contemplate using is the analysis of covariance. The experiment on each geologic type will contrast two groups of watersheds: heavily impacted and relatively pristine. Within each group we will measure six triplets of nested watersheds (Figure 4). The analysis of each geologic type will include: (6 replicates) x (3 size classes) x (2 levels of impact) 36 watersheds. The magnitude of a particular CWE would be estimated by how much the regression of the impacted watersheds differs from that of the pristine watersheds. For example. if the dependent variable was the ratio of deposition in the channel to estimated erosion in the watershed, regressions indicating significant cumulative effects-might look like those in Figure 5. We have assumed that in smaller watersheds, steep channel gradients would ensure that most of the eroded material passes through the watershed and is deposited in higher order drainage channels of lower gradient (Figure 5). The fact that the slope of-the hypothetical regression line for the impacted watersheds is steeper than that for the pristine watersheds indicates that not only is more sediment being delivered to the channel network, but that it is depositing proportionately more in the high order channels. This, then, is a synergistic cumulative effect. The impact is being magnified downstream. We hope that this study will help us bridge the gap between tightly controlled experiments on small watersheds such as we are conducting at Caspar Creek and watersheds of a size more typical of cumulative effect planning currently being done by forest managers.

OPINIONS CONCERNING CUMULATIVE WATERSHED EFFECTS

Research Considerations

Although many of us at PSW are skeptical about the importance of CWE concerns for forested watersheds. we are doing our best to ensure that the design of our two experiments does not reflect that bias. In the case of the Caspar Creek experiments, for example, we have gone to great lengths to increase the precision and accuracy of our measurements so that we may be able to detect even very slight indications of cumulative effects. Furthermore, the timber harvest will proceed from the headwaters of the watershed downstream. This cutting pattern should improve the opportunity for slower moving sediments to accumulate in the lower reaches of the watershed during the study. In planning our extensive cumulative effects study, we have sought the advice of 16 scientists, half of whom are convinced of the existence of cumulative effects or who are the proponents of particular cumulative effects methodologies. We will continue to consult with them in order to ensure that CWEs get a "fair shake" and to lend credibility, we hope, to our results.

Why are we undertaking two such costly studies of what we believe an unimportant phenomenon? There are three reasons. First of all, no previous attempts have been made at definitive studies. Consequently, both proponents and skeptics have based their opinions on rather shaky ground. It will be valuable, therefore, regardless of the outcome of our experiments, to have more quantitative data upon which to base opinions. Second, an estimate of the magnitude of cumulative effects is important. If these effects are large, addressing them should form a large portion of the effort related to forest watershed management. If they appear to be insignificant, the resources currently devoted to CWEs could be more profitably expended mitigating adverse on-site effects. Third, cumulative effects are an important issue in public

policy debates concerning the management of forested watersheds. They need, therefore, to be defined to the fullest extent possible so that they play their most appropriate role in these public policy debates: All of the above considerations cause us to believe that our cumulative effects studies constitute two of the most important watershed management research activities currently under way.

Management of Cumulative Effects

Dispersion of land disturbing activities in time and space seems reasonable. Whether or not there are important cumulative effects, there are certainly some adverse off-site effects. Dispersion will tend to minimize these. I have heard it argued that dispersion leads to more road construction and, therefore, greater cumulative effects. I consider this argument specious since it deals with short-term effects only. If a piece of property is to be managed, eventually a complete road system will have to be constructed. Over a rotation or two, it will matter little when the roads are constructed so long as they are adequately maintained. Beyond simple-dispersion, on-site mitigation seems to be the most effective way of dealing with CWEs. On-site, it is much easier to identify cause and effect. This identification increases the likelihood of choosing appropriate mitigation measures. Concentrating on on-site mitigation trill tend to focus an organization's technical expertise where it can be most effective. Directing attention to on-site mitigation will make it easier for ail concerned to judge whether prudent land management is being employed. This precept applies to the land owner, regulatory agencies, and as well to those segments of the public that may be concerned about forest management. Although there are contrary examples (Figure 5), it is, in general, difficult to envision the circumstances whereby the effects of several land-disturbing activities. all of which are environmentally acceptable, come together along with the outputs of undisturbed areas to yield an environmentally unacceptable result.

Assuming that focusing on BMPs is not an adequate way of dealing with CWEs, how should they be dealt with? Most approaches involve some form of timber harvest scheduling. Most timber harvest scheduling methodologies rest either implicitly or explicitly on the assumption that logging and, particularly, the construction of forest roads will increase surface runoff. The increased surface runoff is presumed to have adverse cumulative watershed effects in the form of higher flood peaks, which lead to increased sedimentation. stream channel instability, and degradation of fish habitat. I find this rationale difficult to accept, especially for typical levels of watershed disturbance due to logging and forest road construction.

Studies at Caspar Creek support my skepticism. Two similar studies conducted there by Ziemer (1981) and Wright (1985) failed to find increases in flood peaks or flood volumes for any but the smallest early season storms. There have been about equal numbers of studies finding, and failing to find, significant peak flow increases resulting from logging and forest roads. Most cumulative effects methodologies, based on peak flow effects, are traceable to the results of Harr and others (1975) and Harr and others (1979). Both studies are compromised, however, by data deficiencies. In the Alsea Study (Harr and others, 1975) in Oregon, no large post-logging peak streamflows were measured. In the Coyote Creek study (Harr and others, 1979), also in Oregon, the pre-treatment period contained no measurements of large storms. On the

other hand, the Caspar Creek studies (Wright, 1985; Ziemer, 1981) benefited from having two large storm streamflow peaks during the calibration period and two more after logging.

We wondered whether the difference between our conclusions and Harr's was due to our good fortune in having large peaks before and after treatment. To test this hypothesis, we first removed the two highest peaks from our calibration period (similar to the Coyote Creek data) and obtained results suggesting a reduction in the higher peak flows. When we removed the two highest post-logging peaks (similar to the Alsea study) we obtained results-very similar to the two Oregon studies. These regressions showed both small and large peak flows were increased after logging (Wright 1985). Although our results may simply be caused by the unique characteristics of the Caspar Creek watersheds, it seems more likely that the Alsea and Coyote Creek results illustrate the dangers in extrapolating statistical results far beyond the range of the data. Consequently, I conclude that important management decisions ought not to be predicated on presumed peak flow increases due to logging or forest roads.

Even if significant peak flow increases do occur, a strong case can still be made for addressing CWEs through mitigation of on-site effects. Rice and Datzman (1981) estimated an approximately fourfold decrease in erosion could be achieved by the conversion from tractor to cable yarding. The equation developed by Harr and others (1979) would predict about a 23 percent increase in suspended sediment discharge due to the logging of the South Fork of Caspar Creek. The measured increase was about 450 percent (Rice. 1981). It would appear, therefore, that even if the equation is valid for the Alsea and Coyote Creek experimental watersheds, it is not applicable to some other watersheds.

CONCLUSIONS

Accepting the preceding arguments does not mean that CWEs can be ignored. The public and the courts will not permit that. Furthermore, it is reasonable when undertaking a land-disturbing activity to evaluate how what you are doing may interact with what others are doing or will be doing. For broad scale planning, it seems to me that simple dispersion in time and space ought to be adequate. At tile project or Timber Harvest Plan (THP) level, a site-specific analysis seems to be a more effective approach. The checklist recently added to the THP is a reasonable start. It should not be employed perfunctorily. Rather, the Registered Professional Forester (RPF) should take it seriously and consider the points raised and other similar environmental concerns. RPFs would be wise to keep written records of their considerations of cumulative effects so that, if challenged they have documentation of the thoroughness of their analyses. For the present, I feel that that is about all than can or should be done. It will have to suffice for the next 5 to 10 years, because it will take us that long to complete our research and shed what we hope is more light on the important problem of cumulative watershed effects.

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Figure 2. FLOW AND SEDIMENT REGIMES OF SOUTH FORK CASPAR CREEK

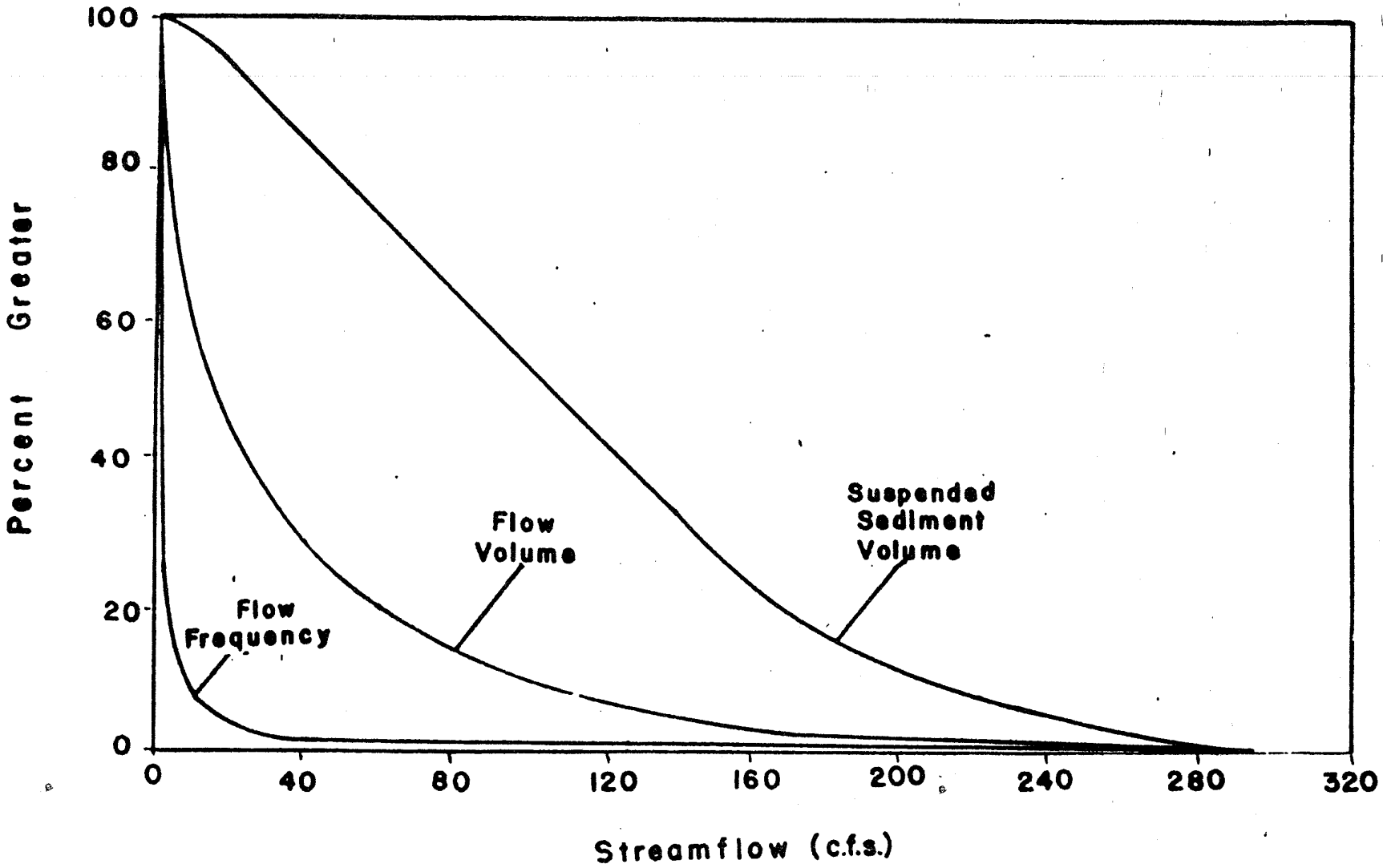
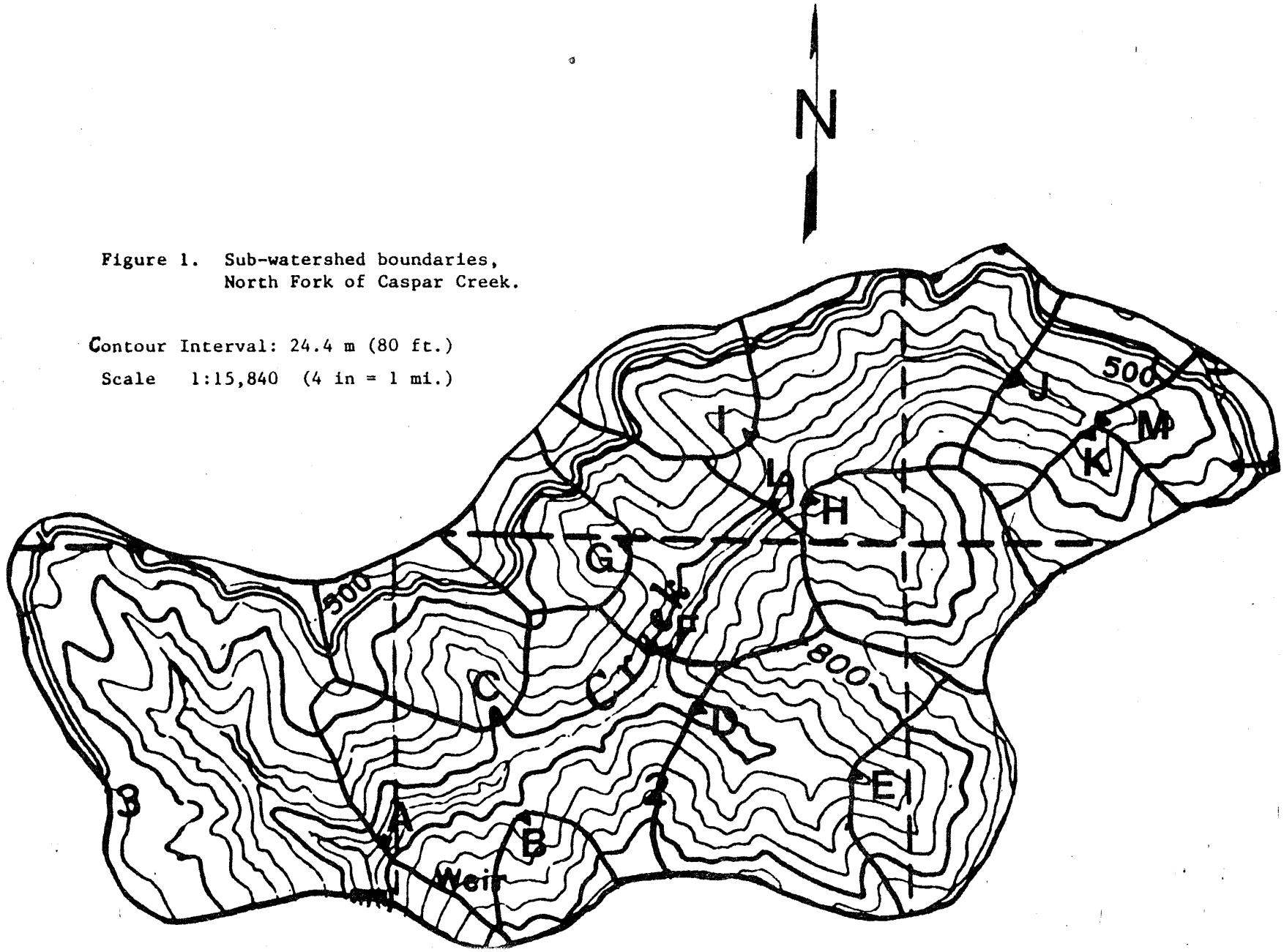


Figure 1. Sub-watershed boundaries, North Fork of Caspar Creek.

Contour Interval: 24.4 m (80 ft.)

Scale 1:15,840 (4 in = 1 mi.)



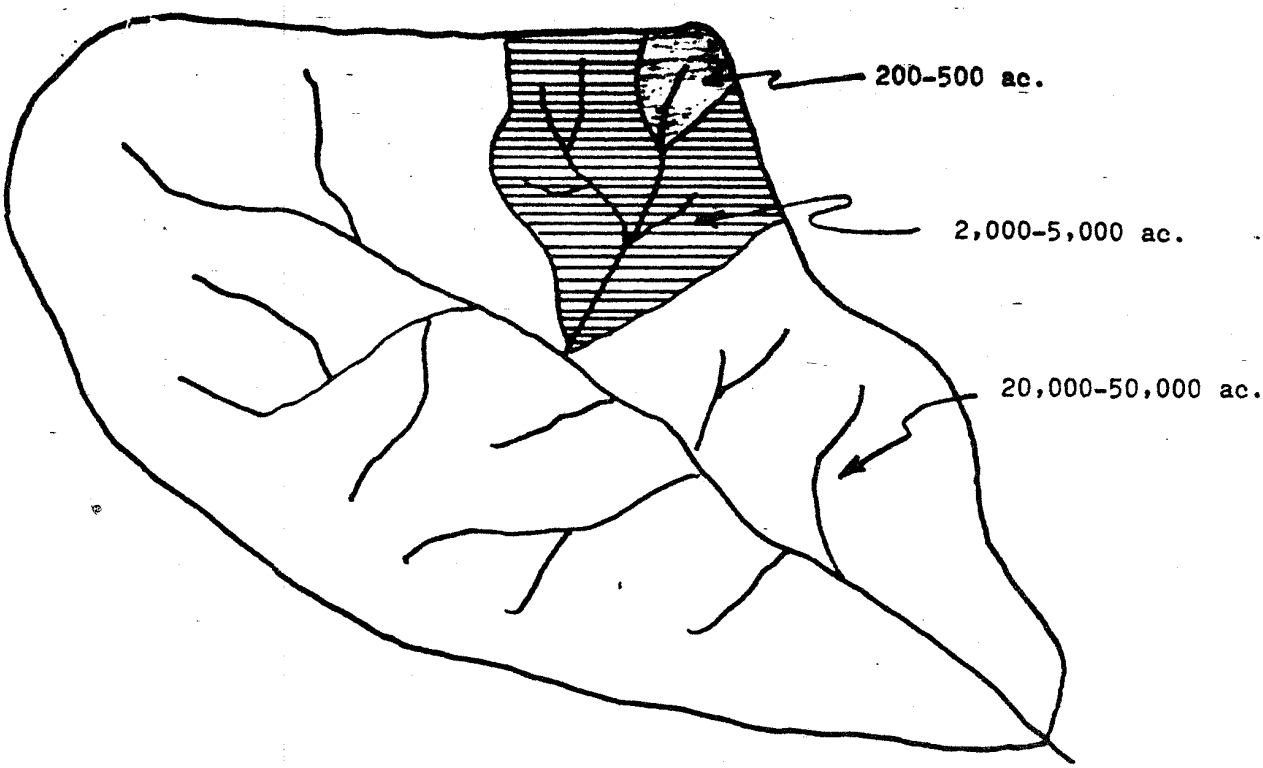


Figure 4. Hypothetical "nest" of study watersheds used in the Extensive Cumulative Effects Study.

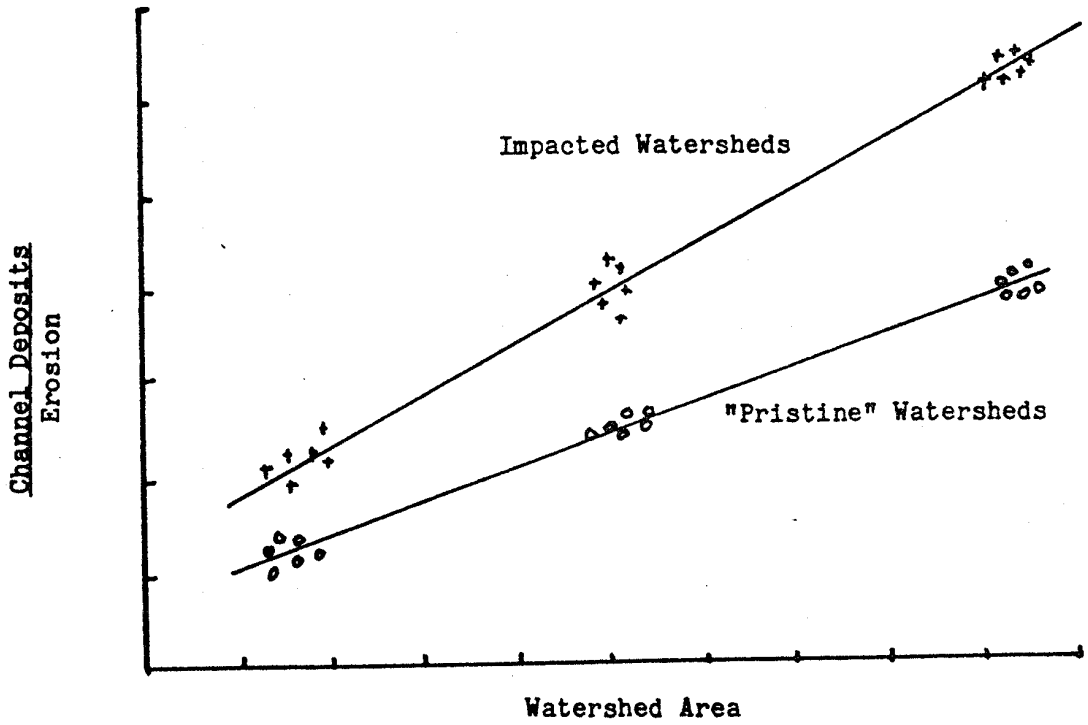


Figure 5. Hypothetical result of the Extensive Cumulative Effects Study illustrating a synergistic cumulative sedimentation effect.

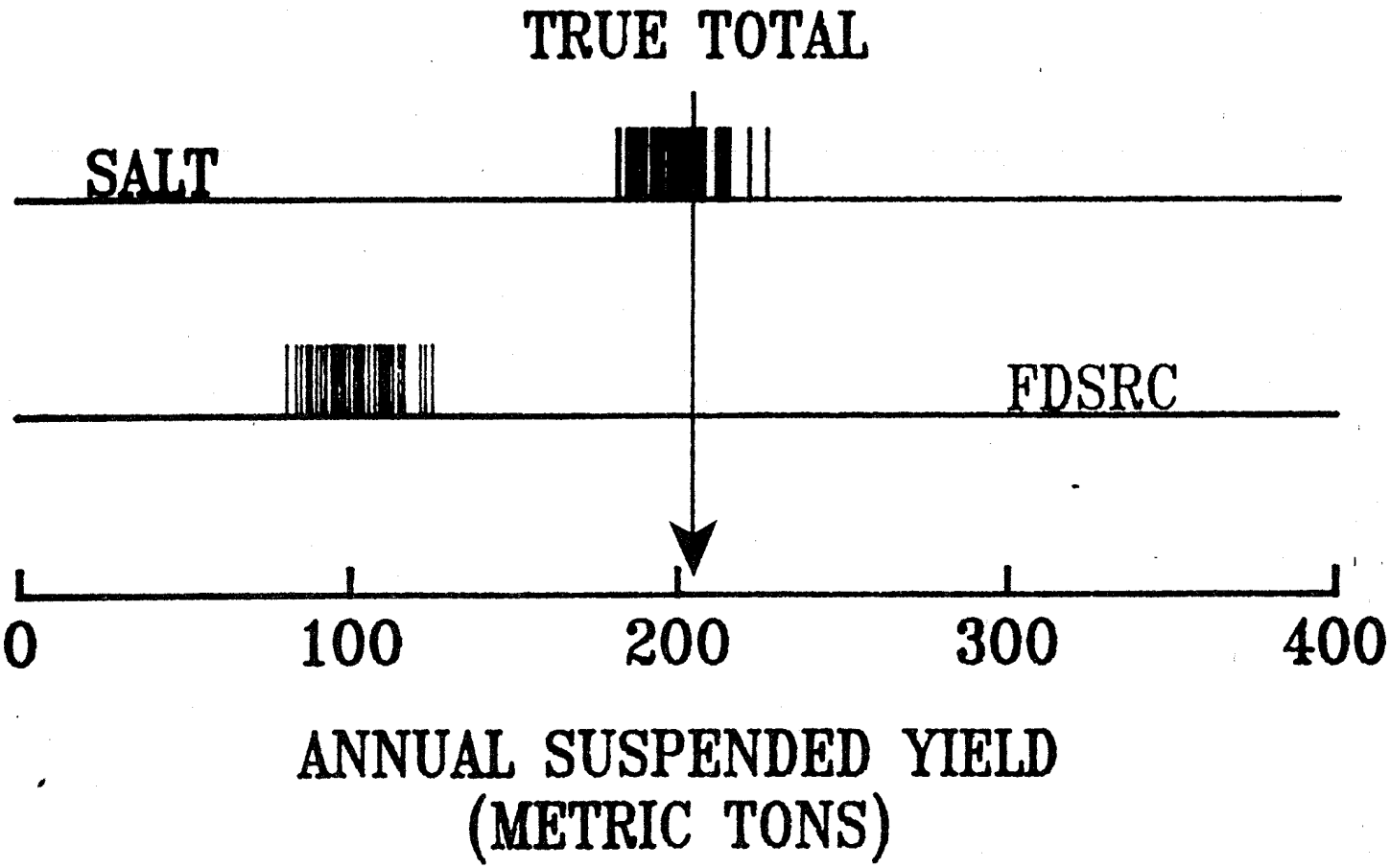


Figure 3. Comparison of the accuracy of Thomas' SALT procedure with that of the conventional Flow Duration Curve - Sediment Rating Curve method when applied to 50 simulated records based on the North Fork of Caspar Creek.