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Comment on "Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon: A second opinion" by R. B. Thomas and W. F. Megahan

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1. Introduction

Thomas and Megahan [1998] provide a thoughtful reanalysis of our earlier paper [*Jones and Grant*, 1996]. *Thomas and Megahan* [1998] (hereinafter referred to as T&M) reacted to three assertions made by *Jones and Grant* [1996] (hereinafter referred to as J&G): (1) "forest harvesting has increased peak discharges by as much as 50% in small basins and 100% in large basins" (p. 959), (2) "the major mechanism responsible for [increased peak discharges in patch clear-cut and roaded basins] is the increased drainage efficiency of basins attributable to the integration of the road/patch clear-cut network with the preexisting stream network" (p. 972), and (3) "the statistical analysis strongly suggests that the entire population of peak discharges is shifted upward by clear-cutting and roads; we see no reason to expect the biggest storms to behave differently from the rest of the population" (p. 972).

We believe T&M's reanalysis of our data confirms and, in some cases, strengthens the conclusions of the original paper, while highlighting critical areas for future work. Seemingly contradictory findings of J&G and T&M are a direct result of different decisions about sample sizes, critical statistical significance levels, and data transformation; these decisions may tip the balance between findings of "significance" or "nonsignificance" in statistical analyses of a single data set. In this comment we examine the objectives and conceptual approaches of the two studies and differences and similarities in statistical approaches, findings, and interpretation of findings.

2. Small Basins

The objective of J&G's small-basin analysis was to assess how hydrologic processes might explain variation in peak flow response to forest harvest, whereas T&M's analysis focused on the statistical significance of peak flow changes. There is a direct tradeoff between the attempt to differentiate multiple hydrologic mechanisms and the quest for statistical power from a sample of a given size. J&G used analysis of variance (ANOVA) and subdivided peak discharges into categories in order to separate the effects of event size, season, and time since treatment, but this reduced statistical power. T&M used regression, or analysis of covariance (ANCOVA), and subdivided the sample into larger categories than J&G in order to evaluate effects of time, with greater statistical power, but multiple hydrologic mechanisms may have been confounded. ANOVA and linear regression are closely related, but some differences in statistical results between T&M and J&G arose from choices about how or whether to subdivide the sample of peak discharge events and the consequent effects upon degrees of freedom and statistical power.

The ANOVA approach used by J&G tested for the significance of the difference in a dependent variable (log-transformed ratios of peak discharge events in the treated versus the control basin) among subsets of events broken down by time period, size, and season. Only one parameter (this ratio) was compared between subsets of data. The advantage of ANOVA, as used by J&G, is that subdividing data allows for heterogeneity, i.e., peak discharge events of different sizes, seasons, or times, since treatment may respond differently to a given treatment because of different hydrologic processes. The disadvantage of this approach is that tests comparing small subsets of data have fewer degrees of freedom, the power of the statistical test is lower than for larger samples, and it is more likely that the test will fail to detect a change that in fact occurred. This inability of the ANOVA approach to detect a significant change is particularly important for the largest peak discharge events, where sample sizes are small.

Linear regression could be performed on the same small subsets of data used in J&G's ANOVA. However, the linear regression approach used by T&M tested for significant differences in regression models (of log-transformed peak discharges in the treated versus control basins) among subsets of events broken down by time period only. Two parameters (the slope and intercept) were compared among subsets of data. The advantage of linear regression, as used by T&M, is that tests comparing large subsets of data have more degrees of freedom and the power of the statistical test is higher than for smaller samples. The disadvantage of the linear regression approach, as used by T&M, is that pooling all events from a given time period assumes homogeneity; that is, it treats all peak discharge events as if they respond in the same way to a given treatment. The estimated response for the whole sample (represented by slope and intercept terms) will be strongly influenced by the most numerous event type. This inability of the linear regression approach to detect responses to treatments produced by different hydrologic processes is particularly important in cases where large numbers of small events (which may be controlled by one hydrologic process, such as evapotranspiration) obscure the behavior of less numerous events (which may be controlled by another mechanism, such as snow accumulation and melt rate).

Despite their uses of different statistical methods, J&G and T&M reported very similar peak discharge responses to forest

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Table 1. Maximum Percent Increases in Peak Discharge Events of Various Event Size Categories and Basin Sizes, Estimated by *Jones and Grant* [1996] and *Thomas and Megahan* [1998] From Statistical Models Using Data Sets Compiled by *Jones and Grant* [1996]

		Small (<0.2 Years)		Large (>0.4 Years)		Extreme (>10 Years)	
Basin Size	Treatment	J&G	T&M	J&G	T&M	J&G	T&M
Small[a] (<1 km^2)	100% clear-cut, no roads	U, 75; C, 67	90	U, 30; C, 20, ns[b]	40	not estimated	20, ns
Small[a] (<1 km^2)	25% clear-cut, 6% roads	U, 50; C, 41	40	U, 50; C, 23	20	not estimated	15, ns
Large[c] (60–600 km^2)	12–25% distributed patch cuts with roads	...[d]	...[d]	L/B, 1.6 (40); S/N, 5 (80–135); BS, 2.5 (30–90)	L/B, 1.5 (38); S/N, 5 (80–100); B/S, ns[b]	not estimated; noted for B/S	not estimated

[a]Maximum percent changes calculated by J&G and T&M for different sizes of events. The index for percent change in peak discharges in small basins used by J&G [1996] is incorrect [*Jones and Grant*, this issue]; U indicates the uncorrected and C indicates the corrected percent changes. Numbers for J&G are from Table 2 of J&G and revised Table 2 of *Jones and Grant* [this issue]. Numbers for T&M are visually estimated from their Figure 3.

[b]Here "ns" means not significant.

[c]Percent changes for large basins are percent increases in 1-year event (J&G) or any size of event (T&M) attributable to a 1% difference in cumulative harvest area in the Lookout/Blue River (L/B), Salmon/North Fork Willamette (S/N), and Breitenbush/North Santiam (B/S) basin pairs. Estimated increases over the period of logging are shown in parentheses; they were calculated by multiplying the percent changes in peak discharges associated with a 1% difference in harvest area by the percent of basins harvested. Numbers for J&G are taken from Table 4 of J&G; numbers for T&M were estimated from statistical models in Table 5 of T&M.

[d]Events with return periods of <0.4 years were not included in the large basin analysis.

harvest in the two small basins. Maximum percent increases in small (<0.2 years) peak discharges ranged from 40 to 70% in J&G and 40 to 90% in T&M, while percent increases in large (>0.4 years) peak discharges ranged from 20 to 25% in J&G and 20 to 40% in T&M (Table 1). T&M used linear regression models to show that significant increases occurred for peak discharges as large as 2-year events [*Thomas and Megahan*, 1998, Figure 3], while J&G found significant increases in >0.4 year events in two of 10 posttreatment periods [*Jones and Grant*, 1996, Tables 2 and 3].

The choice of different statistical methods did produce different indications of how long forest harvest and road effects persist. For the small basin with roads, peak discharges (pooled across all event sizes) were significantly higher in all five 5-year posttreatment periods in J&G's analysis but only in the first two 5-year periods in T&M's analysis. This difference is a simple consequence of the fact that to achieve a given experimentwise error in any multiple comparison procedure, the regression approach uses p values that are half as large as those used by the ANOVA because it has two parameters, while the ANOVA approach has only one (that is, to achieve an experimentwise $p < 0.05$ for five comparisons, a Bonferroni-corrected p value would be $p < 0.005$ for regression and $p < 0.01$ for ANOVA).

3. Large Basins

For the analysis of large basins, both J&G and T&M used linear regression, but decisions involving data transformations and choice of critical significance levels produced differences in what were called "statistically significant findings." In particular, J&G used untransformed data, while T&M used log-transformed data, and J&G used a 95% significance level, while T&M used several tests whose effect was equivalent to a ~99.99% significance level.

The linear regression approach used by J&G for large-basin data tested for the significance of the slope term relating a dependent variable (the difference in peak discharge between two basins for an event) to an independent variable (the between-basin difference in cumulative area cut in that year). Because there was no control, J&G estimated the possible increases in peak discharges over the multidecade period of harvesting in these basins from the regression slope, which is a measure of the average percent increase in peak discharges corresponding to a given between-basin difference in cumulative percent of area cut. However, J&G did not log-transform peak discharges in their analysis, and large between-basin differences in peak discharges, which often occur for the largest events, may have unduly influenced the regression in J&G.

T&M developed an improved linear regression approach for large-basin data, but J&G's and T&M's models indicate quite similar peak discharge responses to forest harvest in large basins. T&M's linear regression relates the log-transformed peak discharges in one basin to those in the other basin and to a second term, the difference in cumulative area cut. Maximum percent increases in large (>0.4 years) peak discharges per 1% difference in basin area harvested ranged from 1.6 to 5% in J&G and 1.5 to 5% in T&M (Tables 1 and 2). J&G reported that peak discharge responses in large basins implied as much as a doubling of peak flows over the 25–60-year periods of record used in the analysis, when up to 25% of these basins were cumulatively harvested; T&M's results are consistent with this statement.

J&G and T&M reported differences in what were called significant findings from their large-basin analyses not because they used different regression models but rather because they made different choices about data transformations and critical significance levels. J&G found that the slope term was significant and positive for all three basin pairs despite very low r^2 values, and T&M found significant relationships between forest harvest and peak discharges for two of three large basin pairs using two standard statistical significance tests (p values and a sequential F test) [*Thomas and Megahan*, 1998, Table 5]. T&M found no significant relationship between peak discharges and forest harvest in the Breitenbush/N. Santiam basin pair because log transformation reduced the influence of the largest events (noted by J&G as the only ones which showed a response [see *Jones and Grant*, 1996, Figure 3c, p. 967]). For the two large basin pairs with significant model fits at $p <$

Table 2. Percent Increase in Peak Flows Attributable to 1% Difference in Cumulative Harvest Area (Harvest Difference) for Two Pairs of Large Basins Based on Models Presented in Table 5 of T&M

y_2	$\ln y_2$	$\ln y_1$ Predicted Without Harvest Difference[a]	$\ln y_1$ Predicted With Harvest Difference[b]	y_1 Predicted Without Harvest Difference	y_1 Predicted With Harvest Difference	Percent Increase Attributable to 1% Harvest Difference[c]
			Lookout Creek/Blue River[d]			
1	0	0.175	0.1895	1.1913	1.2087	1.5
10	2.303	1.8536	1.8681	6.3827	6.4759	1.5
100	4.605	3.5322	3.5467	34.1981	34.6975	1.5
			NFWillamette/Salmon Creek[e]			
1	0	−0.115	−0.0662	0.8914	0.9359	5.0
10	2.303	2.1669	2.2157	8.7039	9.1675	5.0
100	4.605	4.4487	4.4975	85.5174	89.7942	5.0

[a]Predicted assuming no differences in cumulative area harvested, i.e., $(x_1 - x_2) = 0$.
[b]Predicted assuming 1% difference in cumulative area harvested, i.e., $(x_1 - x_2) = 1$.
[c]Percent increase in y_1 predicted with harvest difference relative to y_1 predicted without harvest difference.
[d]The fitted model for Lookout/Blue River (Table 5, T&M) is $\ln(y_1) = 0.175 + 0.729 \ln(y_2) + 0.0145 (x_1 - x_2)$, where y_1 is peak flow in index basin, y_2 is matched peak flow in the other basin, and $(x_1 - x_2)$ is harvest difference, with x_1, x_2 the cumulative percent of basin area harvested in basins 1 and 2.
[e]The fitted model for NF Willamette/Salmon Creek (Table 5, T&M) is $\ln(y_1) = -0.115 + 0.991 \ln(y_2) + 0.0488 (x_1 - x_2)$.

0.05, T&M (p. 3401) imposed an additional criterion, a measure of "usefulness" of the model for predictive purposes, whose F statistic was equivalent to $p < 0.0001$. The fact that their models fail to meet this more stringent criterion led T&M (p. 3393) to state that "results were inconclusive in the other two basin pairs." T&M's use of this additional test protects against type 1 errors, the probability of falsely detecting a forest harvest effect upon peak flows when in fact there is none, but it reduces protection against type 2 errors, the probability of falsely accepting that forest harvest has no effect upon peak flows when in fact it does. Critical p values of 0.05 control for type 1 and type 2 errors; by this criterion, T&M found statistically significant increases in peak discharges in two of three large basin pairs.

4. Interpretation of Hydrologic Processes

Whether or not extreme (i.e., >10 year return period) floods respond to forest harvest has been a controversial issue in the Pacific Northwest. Only a handful of such events occurred in the 50–60-year records analyzed by J&G and T&M. Because they are rare, each extreme flood occurs under a distinct set of forest succession, road, and climate conditions. Because a large, homogenous sample of postharvest extreme flood events will never be obtained, statistical analysis of extreme flood events from long-term records will always be inconclusive. This does not mean that extreme floods do not respond to forest harvest but rather that we cannot rely simply upon statistical analyses of the types described by J&G and T&M to determine whether an effect exists. Inferences about the behavior of extreme events based on extrapolations from small events [e.g., *Thomas and Megahan*, 1998, Figure 3] will be biased downward by the acknowledged larger relative response of small events, whose numerical dominance influences the regression slope term.

The role played by forest roads in peak discharge response to forest harvest also has been a contentious issue. J&G proposed that by intercepting subsurface flow on hillslopes, roads could alter flood routing and increase large flood events. Both J&G's and T&M's findings support the interpretation that roads increase the magnitude of peak discharge events because the effect of forest harvest, when roads are present, is greater than would be expected from cutting alone. For example, results from T&M and J&G indicate that peak discharge increases in the 100% clear-cut basin were only 12% greater than in the 25% cut and roaded basin. Prior to treatment, peaks at watershed 1 were roughly 23% higher than at watershed 3, while peak discharges after 100% clear-cut (watershed 1) were, on average, 35% higher than peak discharges after 25% clear-cut with roads (watershed 3) (calculated from data in Table 2 of J&G and substitution of values in equations (4) and (5) of T&M). Subsequent field investigations and modeling [*Bowling and Lettenmeier*, 1997; *Wemple*, 1998] have demonstrated that flow routing altered by roads may augment peak discharges. As both J&G and T&M noted, peak discharges in watershed 3 also may have been augmented by reduced stream roughness as a result of debris flows from roads in 1964.

5. Conclusions

In summary, both T&M and J&G showed that forest harvesting has increased peak discharges by as much as 50% in small basins and 100% in large basins. Both J&G and T&M, not surprisingly, obtained similar results from the same data set, but T&M claimed that the only valid increases were for small events in small basins, whereas J&G argued that increases had occurred in all event sizes and in both small and large basins. In both studies, statistically significant increases were harder to detect for large events because they are relatively rare. T&M dismissed their own statistically significant models showing increases in peak discharges in large basins because their models failed to meet a special, additional statistical criterion for predictive power. T&M did not refute that the road network may contribute to increased peak discharges; instead, a variety of field and modeling efforts have supported J&G's hypothesis that roads can affect flow peaks. Both T&M and J&G speculate as to whether forest harvest and roads affect extreme floods, but while increases in smaller floods are suggestive, the issue cannot be resolved with statistics based on a mere handful of extreme flood events. Future physical process-based modeling and field studies will improve our understanding of forest harvest effects on these rare big floods and also should address the geomorphic and ecological consequences of changes in all sizes of peak discharge events.

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