REPLY TO PAUL SMITH'S COMMENT

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Smith stated that he is skeptical about taking point estimates of the seeding effect literally. That is a valid concern. They should not be taken literally. After all, point estimates are statistical estimates with an inherent degree of uncertainty that is quantified by the standard error of estimate. A point estimate with its standard error of estimate is generally used in null hypothesis testing to infer if there is any effect at all. The best estimate of the strength of a seeding effect is given by its confidence interval because it infers a range within which the true effect lies at the specified level of confidence. That is why I emphasized the use of confidence intervals in the Kern program evaluation using a 90% level of confidence.

Any attempt to use point estimates literally will undoubtedly lead to problems in reconciling the numbers generated from them since they don't take into account the uncertainty in the point estimates. In addition, it should be noted that the point estimates are obtained from the regression ratio that is empirically adjusted for bias due to the non-randomization of the seeding operations. The main purpose of the bias adjustment is to obtain confidence intervals that are statistically comparable to those obtained through re-randomization analysis. As such, it is not possible to generate an internally consistent set of streamflow estimates by taking the point estimates literally.

The important thing to note from Smith's Table 1 is that the ratio of the estimated average target streamflow during the operational period in the absence of seeding (row 4) to the average target streamflow during the historical period (row 1) is greater than one, and that is qualitatively correct. This factor is taken into account in a more quantitatively accurate way by the regression ratio, enabling it to produce the most precise estimate of the seeding effect.

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Smith stated that he is skeptical about viewing a variation in point estimates of the seeding effect with increasing length of record as an indication of the time trend in the seeding effect and points out that there was no plot of the variation of the confidence interval for the 3 Kern targets in Silverman (2008). Taking the second point first, I hasten to point out that 90 percent confidence limits were not shown for clarity of presentation only. For each of the targets the 90 percent confidence limit lines follow the pattern of their point value plot and narrow with time, albeit relatively little, as the standard error of estimate decreases with increasing sample size.

As for Smith's first point, Smith does not provide any theoretical or empirical basis for his skepticism. On this point, we have a difference in scientific opinion. I believe that a significant, multi-year change in the slope of the plot of the cumulative year seeding effect and its confidence limits with time is indicative of a possible change in one or more of the factors that determine seeding effectiveness, such as the quantity/quality of seeding opportunities and/or the seeding procedures. It signals a change in events that is worthy of further investigation. The interpretation of the plot of the cumulative year seeding effect and its confidence limits with time is similar in concept to the interpretation of a double-mass curve. In the evaluation of cloud seeding based on streamflow, for example, the cumulative target (seeded) runoff is plotted against the cumulative control (non-seeded) runoff. A break in slope is assumed to be change in the mean of the target series and the ratio of the slopes is an estimate of the multiplicative change in that mean (see, e.g., NAWC, 1978).

I became convinced of the value of this statistical tool (plot of the cumulative year seeding effect and its confidence limits with time) when I applied it to the evaluation of the Pitman Creek target in the San Joaquin Basin operational cloud seeding program which was done to compare and pool the results from the Kern, King River and San Joaquin seeding programs (Silverman, 2008).

The time evolution plot for Pitman Creek (PIT) showed a significant increase in the slope starting in 1975 (see Fig. 1). It was found that it was consistent with the introduction of aircraft seeding as a supplement to the ongoing ground-based seeding. It is likely that the addition of aircraft seeding to the ongoing ground-based seeding was the cause of the dramatic increase in seeding effectiveness. With the addition of the supplemental aircraft seeding, a statistically significant seeding effect became evident.

Smith presents data that he suggests indicates the seeding effect occurs mainly in high-flow years. If true this is an important finding; therefore, I agree that the observed behavior is worthy of further investigation. In fact, I believe that follow-up physical studies prompted by both expected and unexpected statistical and physical findings are warranted since they will help establish the physical plausibility of the statistical results and they will provide insights on how to improve the seeding operations.

REFERENCES

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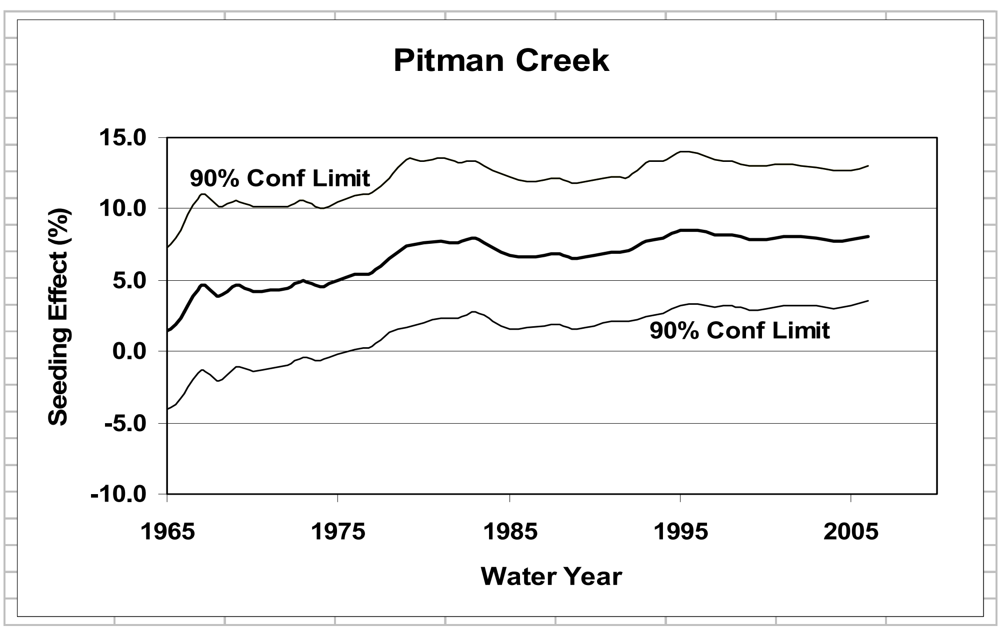

Fig. 1. The proportional seeding effect for PIT, δ(%) = 100(RR_A-1) where RR_A is the bias-adjusted Regression Ratio, as a function of the cumulative number of seeded years. Also shown are the 90% confidence limits. The seeding effect calculated for each seeded water year is the value that would have been obtained if the evaluation were done for all seeded years up to and including that water year.*