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Calibration methods for detecting changes in streamflow quantity and regime

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Abstract. Calibration methods for detecting streamflow changes after treatment of experimental basins are discussed. Two treatment sub-basins of Marmot Creek experimental basin on the eastern slopes of the Rocky Mountains in Alberta, Canada, are used as examples. Cabin Creek was commercially harvested in 1974 giving calibration and post-treatment periods of 12 and four years, respectively. Using the method of covariance analysis, changes were detected in total flow for May and for the spring period April–June, and for the date of maximum daily flow. No changes were detected in annual flow, maximum seven-day flow and its beginning date, maximum daily flow, shortest half-flow interval, or in rise-in-stage and time-to-peak in response to individual storms. Twin Creek was treated in 1979 to delay time of peak flow and to prolong snowmelt recession flow. Assuming a four-year post-treatment period, minimum detectable differences were calculated for the streamflow variables noted above.

Méthodes de tarage pour la détection des modifications des quantités d'écoulement et du régime hydrologique

Résumé. On discute les méthodes de tarage pour la détection des variations de débit des cours d'eau d'un bassin modifié par l'homme. A titre d'exemple on présente deux sous-bassins du bassin expérimental de Marmot Creek sur le versant oriental des Montagnes Rocheuses, Alberta, Canada. En 1974, on a procédé à la coupe à blanc commerciale sur le sous-bassin de Cabin Creek, les périodes de tarage et après le traitement étaient respectivement de 12 et quatre ans. On emploie la méthode de l'analyse de co-variance pour détecter les variations de débit pour le mois de mai ainsi que pour la période de printemps (avril–juin), et pour la date du débit de pointe journalier. Il n'y avait pas eu de modification pour l'écoulement annuel, l'écoulement maximum de sept jours et sa date de commencement, le débit maximal journalier, l'intervalle le plus court correspondant à la moitié de ce débit, le temps de montée et le temps de réponse aux averses individuelles correspondant à la pointe de crue. On a aménagé le bassin forestier de Twin Creek en 1979 en vue de retarder le temps de réponse et pour prolonger l'écoulement dû à la fonte des neiges. Pour toutes les caractéristiques d'écoulement citées plus haut on a calculé la variation minimale qui serait significative pour une période de quatre ans après le traitement.

INTRODUCTION

Marmot Creek experimental basin was established in 1961 on the eastern slopes of the Rocky Mountains in Alberta, Canada. The research programme and basin description were dealt with in detail by Jeffrey (1965). Briefly, the objective was to determine the hydrology and develop guidelines for harvesting the Engelmann spruce (*Picea engelmannii*)–sub-alpine fir (*Abies lasiocarpa*) stands consistent with the importance of the eastern slopes as a water supply area for Alberta and Saskatchewan.

Marmot Creek experimental basin is comprised of three sub-basins of which Middle was to be maintained in its natural state as control. Cabin sub-basin was harvested in 1974 to demonstrate the effects of commercial clearcut on streamflow quantity and quality. Twin sub-basin was cut in 1979 to alter the streamflow hydrograph as described below.

The objectives of this paper are (1) to describe the streamflow calibrations for the two treatment sub-basins, Cabin and Twin, on the control sub-basin, Middle, and (2) using these as examples, to discuss calibration methods.

CALIBRATION

Calibration is the pre-treatment relationship between the streamflow characteristic of interest and some other variable or variables. A brief review of calibration methods is in order. Firstly, there is the paired-basin approach in which the variable of interest from the basin to be treated is calibrated with that same variable on a control basin. This may be a one-to-one calibration, i.e. one treatment basin and one control basin, in which many years may be necessary to attain the level of precision required. This is most common and there are numerous examples of this approach. Wilm (1944) outlines the method which is basically an analysis of covariance in which post-treatment streamflow is adjusted for any change in climate. In 1949 Wilm suggested successive approximations to determine the length of the calibration and post-treatment period to detect a specified change. Kovner and Evans (1954) substituted a graphic technique for the successive approximations. Singh (1974) provided tables of calibration and post-treatment length to detect changes of specified size.

Instead of one treatment and one control basin, streamflow from a number of treated basins may be compared to that from a number of untreated basins, thus eliminating the need for a pre-treatment calibration period. Swanson and Hillman (1977) used this approach to determine the effects of clearcutting on streamflow in west-central Alberta. With estimates of streamflow variance from an adjacent experimental basin they determined the number of basins required to detect a specified increase in water yield at a given probability level. Nine logged and nine unlogged basins were gauged and with only one year's data, changes were statistically significant: greater streamflow during the spring snowmelt period; greater yield over the gauged season; and an increase in storm peaks. While this approach requires a greater input of resources over the short term, results are obtainable in a much shorter period and the danger of losing either the treatment or the control basin due to natural calamity is much reduced.

Distinct from the paired-basin approach is the calibration of a treatment basin on itself using climatic data (Reigner, 1964). During the calibration period the flow characteristic of interest is related to climatic variables. This method is more informative than the paired-basin method because it relates streamflow to the factors that influence it. It costs less than instrumenting two basins and does not require two basins sufficiently similar to allow calibration. However, there is the possibility that the developed relation will not be of high enough precision to detect changes.

A third approach, that of double-mass curves, can be used with either paired basins or climatic calibration. Accumulated totals of the characteristic of interest are plotted over accumulated totals of the control variable. A treatment effect is indicated by a break in the trend line. The method is not amenable to statistical analysis and an objective conclusion is difficult to reach.

STREAMFLOW VARIABLES STUDIED

Selection of streamflow variables for analysis should depend on perception of the problem in the particular situation. However, with data available and considering the time and resources expended in an experimental basin programme, researchers are often reluctant to limit their analyses. A wide range of variables may be considered to avoid overlooking any possible hydrological change. This approach is taken in the study reported here mainly because the objective of the Cabin treatment was to demonstrate any effect of clearcutting on streamflow.

For most of the variables analysed in this study, only one item of data is obtained per year of record. The exceptions are the variables rise-in-stage and time-to-peak resulting from individual storms. Because there are many storms per year, calibration for these variables may be completed in a year or two, providing the benefits such a short calibration entails (Bethlahmy, 1963). Changes in the timing and magnitude of storm peaks can be quickly detected, but if other flow characteristics are of interest then the longer calibration periods are required.

METHODS

Description of Marmot Creek experimental basin

Each of the three sub-basins of Marmot Creek are approximately 250 ha in area with a mature forest cover of Engelmann spruce, sub-alpine fir, and lodgepole pine (*Pinus Contorta var. latifolia*). The basin elevation is 1600–2800 m, with tree line at 2100 m.

In 1974 a commercial harvest was carried out on Cabin sub-basin. Six blocks averaging 250 x 375 m were clearcut for a total of 55 ha. This was 20 per cent of the sub-basin and 40 per cent of the forested part of the sub-basin. Roads had been constructed two years before logging to isolate the impact on sediment production and to allow the area to stabilize before logging impacts were imposed.

Treatment of Twin sub-basin was completed in 1979 and was designed to prolong recession flow from snowmelt and to delay peak runoff. This was to be done by creating a micro-environment conducive to concentration of snow and reduction of its overall melt rate. Treatment consisted of clearcutting 40 per cent of the forest in circular patches of 0.75–1.5 H diameter (where H is mean tree height), based on a study reported by Golding and Swanson (1978). The treatment objective dictated the variables of interest in the Twin analysis, namely, seasonal flow (spring and summer) and shortest half-flow interval. However, other variables were included for comparison with Cabin sub-basin.

Analyses

Except for a few short periods, continuous streamflow records are available for the three sub-basins from May 1963 to December 1978. Therefore, calibration periods are 12 years (1963–1974) for Cabin and 16 years (1963–1978) for Twin, with four years (1975–1978) post-treatment record for Cabin and none for Twin. Calibration relationships were developed for the following: annual (for each of 12 water years), seasonal (for each of four periods), and monthly flow; maximum daily flow and the date of its occurrence; maximum seven-day flow and its beginning date; shortest half-flow interval (minimum number of days in which half the annual flow occurred for the January–December water year); half-flow date (the date by which half the flow of the January–December water year occurred); rise-in-stage (change in stage from beginning of the hydrograph rise to its peak) and time-to-peak (time from beginning of the hydrograph rise to its peak), in response to a single storm.

Calibration consisted of analysis of covariance for Cabin and regression analysis for Twin. A four-year post-treatment period was assumed for Twin for determination of detectable least significant differences using Singh's (1974) tables. The 95 per cent confidence level was used for both Cabin and Twin analyses.

RESULTS

Cabin Creek sub-basin

For none of the 12 water years was there a significant change in annual flow. Correlation was highest for the August–July water year, for which an 11 per cent change in flow would have been detectable had it occurred. The April–June period had a seven per cent increase in flow mainly because of a 24 per cent increase in May.

Maximum daily flow was not significantly changed by the treatment but the date on which it occurred was significantly earlier by two weeks (from 13 June to 31 May).

A total of 34 summer storms was considered in the calibration period and 23 in the post-treatment period for rise-in-stage and time-to-peak. There was no change in either of these variables.

There was no significant change in maximum seven-day flow or the date on which it began. However, the beginning date was earlier by eight days and was significant at the 90 per cent confidence level.

No significant changes in shortest half-flow interval or half-flow date resulted from the treatment.

Twin Creek sub-basin

The standard errors of estimate of the regressions of Twin Creek streamflow on Middle Creek streamflow are sufficiently low that with a four-year post-treatment record changes of the following magnitude will be detectable: a 5.5 per cent change in annual flow, a 10 per cent change in spring and summer flows, a less than 20 per cent change in maximum seven-day flow and maximum daily flow, a 7.5 per cent change in shortest half-flow interval and a change of 1.7 days in beginning date of the shortest half-flow interval.

DISCUSSION

Little change in streamflow was expected from Cabin because of the nature of the treatment (only 20 per cent of the basin was harvested and cut blocks were located on upper and mid-slope positions) and because of the nature of the basin (the topographic divide is difficult to determine on the northeast side of the basin, and the geological strata are such that leakage out of the sub-basin is suspected). However, statistically significant changes did occur: a seven per cent increase in April–June flow, a 24 per cent increase in May flow, and an earlier date for maximum daily flow.

Shortest half-flow interval

The *shortest* half-flow interval was used in this study rather than the half-flow interval defined by Court (1961) as the length of time between the one-quarter and three-quarter flow dates. Shortest half-flow intervals ranged from 20 to 58 days for the three sub-basins (excluding 1977, a very low snow year, for which the interval was 78–97 days). These values are much less than those reported by Satterlund and Eschner (1965) for central New York (27–178 days) but similar to those for the southern Sierra Nevada (27–49 days) (Court, 1961). This is as expected because, as pointed out by Satterlund and Eschner (1965), in the western mountains annual flow consists mainly of snowmelt which occurs in spring. On Marmot basin larger meltwater flows are not necessarily later in the spring as reported by Court (1961). In fact, the correlation between magnitude of flow and half-flow date is very low, the half-flow date occurring in the last 10 days of June every year.

Some of the assumptions for valid covariance analysis are probably not satisfied by the calibration and post-treatment data from paired basins. Whatever the treatment effect it is expected to diminish with time, so that the conditions following treatment are not stable as they should be. There is no basis for combining post-treatment data into a single mean because sampling is not from the same population each year. The alternative is to follow Reinhart's (1967) suggestion that only the first observation after treatment should be used to test for significant changes and following years' data should be used only to indicate the trend. This creates the problem that only much larger changes can then be detected. Sizeable changes will remain undetected. However, for Marmot Creek the assumption may be reasonably made that data from the first four post-treatment years are samples from the same population because regrowth has been very slow, typical of sub-alpine areas on the eastern slopes of the Rockies.

Regarding confidence level, the 95 per cent level was used in this study, although it is suggested that for this type of study the 90 per cent level may be more appropriate. This would lead to rejecting the null hypothesis more often and concluding that the treatment had changed flow. Of course, it would also increase the chance of rejecting the null hypothesis when in fact it should not be rejected. But this may be warranted where the wrong land management decision will not endanger lives but the right decision may produce an economic benefit.

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