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by Teja Singh

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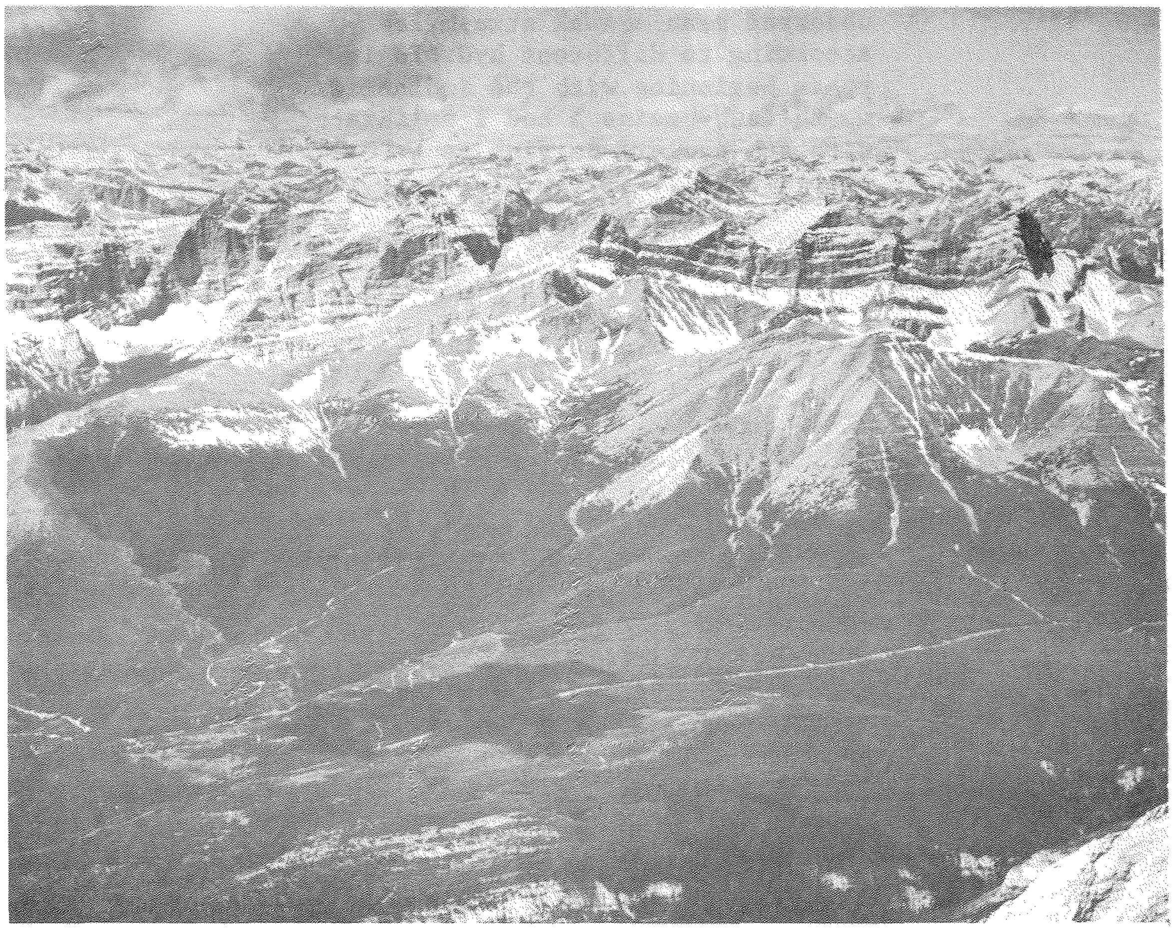

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ABSTRACT

The number of samples needed to detect true change of a given magnitude is an important consideration in assessing treatment effects. A simplified procedure is presented here for designing a sampling program for detecting specified changes due to treatments applied on paired plots or watersheds. Use of a table, with a family of solutions, makes it convenient to choose a suitable combination of the intensity of sampling needed during the pre- and post-treatment periods. The method was applied to three cases where the variables of interest were annual and seasonal streamflows and water temperature. The same technique can be used for other response variables in case calibration among the control and the treated experimental units is essential for successful conduct of the experiment.

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INTRODUCTION

The paired watershed analysis is an accepted procedure for evaluating treatment effects on experimental watersheds. A control basin is set aside and measurements on a hydrological variable of interest are collected for this and nearby similar catchments included in the experiment. After satisfactory correlation has been attained on basis of such comparative measurements in the pre-treatment period, different treatments may be applied on all basins except the control. During the post-treatment period, the difference between the actually observed values and those predicted on the basis of the correlation previously established is considered to be a measure of the change caused by a particular treatment. A literature review of the various calibration methods has been provided by Rinehart (1966).

A high degree of correlation is a prerequisite to successful calibration, otherwise the error band may be wider than the effect of treatment which the analysis procedure set out to evaluate (Toebes and Ouryvaev, 1970). Also, as the hydrologic responses like streamflow are determined primarily by the input precipitation, the measurements should cover a sufficiently long time during the pre-treatment period to include a wide range of climatic conditions.

Wilm (1949) was first to use the regression and covariance techniques to detect differences of specified magnitude in the mean pre-treatment streamflow in case the pre-treatment and post-treatment periods were of equal duration. Kovner and Evans (1954) extended the method to cases involving unequal sampling periods and gave a graphical solution for determining the length of pre-treatment calibration for specified post-treatment periods. The solution by Wilm, however, was through a trial-and-error procedure for solving the resultant quadratic.

The method presented here is essentially an extension of the procedure suggested by Wilm and Kovner and Evans with the modification that instead of the trial-and-error and graphical approach, theoretical entries are listed in a table arranged according to total number of samples for the pre- and the post-treatment periods. Different tables are provided to suit the probability level at which the test of significance is desired. From the family of solutions thus available, the experimenter can readily obtain appropriate combinations of samples needed in the two periods of experimentation.

Application of the method is demonstrated for three experimental situations. First application is the case where the interest is in annual flows. The second illustration is in connection with seasonal flows which may be of particular interest from the point of view of forest management, e.g. the effect of management practices (cutting patterns, etc.) on changes in snowmelt and regime. The third example is a case of intermittent sampling to detect changes in a water quality variable like stream temperature. In all examples the numbers of samples needed in equal and unequal sampling schemes are derived and discussed.

PROCEDURE

I. Equal Samples ($n_1 = n_2 = n$)

The equation from Wilm (1949) can be written in a modified form as:

$$\frac{R.M.S.}{d^2} = \frac{n}{F\left(2 + \frac{F}{n-1}\right)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where R.M.S. is the residual (i.e. error or deviations about regression) mean square, n is the number of observations applied equally over the pre- and post-treatment periods, F is the tabulated variance ratio for a chosen probability level, and d is the specified change to be detected in the mean of the pre-treatment samples. F has (1, 2n-3) degrees of freedom.

As the R.H.S. (i.e. right hand side) of the equation utilizes theoretical F-values for various n, a table of theoretical values for the expression R.M.S./d^2 can be easily constructed. The L.H.S. (i.e. left hand side) of equation (1) can be computed from the correlation and regression analysis of the paired watersheds. The computed and theoretical values can thus be compared and the two sides of the equation matched so as to provide identical or nearly identical solution for the required n. Table 1 lists the theoretical values in case equal samples are taken before and after applying the treatment.

Table 1. Critical points (95 percent confidence) to determine n for calculated R.M.S./d^2 on paired watersheds having equal number of samples during pre- and post-treatment periods. (R.M.S. is residual mean square, and d is the desired per cent change, expressed as a decimal fraction, which needs to be detected in the mean).

n	R.M.S./d^2	n	R.M.S./d^2
3	0.0419	17	1.8082
4	0.1440	18	1.9379
5	0.2633	19	2.0690
6	0.3875	20	2.1986
7	0.5153	21	2.3291
8	0.6423	22	2.4607
9	0.7721	23	2.5898
10	0.9009	24	2.7196
11	1.0301	25	2.8500
12	1.1609	26	2.9812
13	1.2889	27	3.1122
14	1.4195	28	3.2396
15	1.5486	29	3.3654
16	1.6798	30	3.4987

II. <u>Unequal Samples</u> ($n_1 = n_2$)

The equation of Kovner and Evans (1954) can similarly be written in the above-mentioned notation as:

$$\frac{R.M.S.}{d^2} = \frac{n_1 n_2}{n_1 + n_2} \cdot \frac{1}{F\left(1 + \frac{F}{n_1 + n_2 - 2}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where n_1 and n_2 are unequal and represent the number of samples in the pre- and post-treatment periods; $\underline{F}$ has ($1, n_1 + n_2 - 3$) degrees of freedom. For the special case $n_1 = n_2$, the equation becomes identical to equation (1).

A table similar to Table 1 can be prepared for the R.H.S. of equation (2) from the theoretical values of $\underline{F}$ to be compared with the computed R.M.S./d^2 value from the experimental data as in the previous case. Table 2 lists the theoretical values when one $\underline{n}$ is taken to be 6. A general table providing a family of solutions is presented later on.

The experimental values of R.M.S./d^2 were obtained by running correlation and regression analyses among three sub-basins (identified here as 1, 2, and 3) of an experimental watershed. Although the analyses were run for all possible paired combinations of the three sub-basins, the results are listed only for the case where sub-basin 2 was used as control, i.e. was left untreated. The experimental data from sub-basin 2 were correlated separately with sub-basins 1 and 3. The choice of sub-basin 2 as a control was determined by its higher degree of correlation than obtained in any other arrangement.

For the purpose of analyzing annual flows, the monthly streamflows for 12 months were summed according to calendar year. The annual totals

Table 2. Critical points (95 per cent confidence) to determine $\underline{n}$ in case of unequal number of observations when $\underline{n}$ = 6 for either of the pre- and post-treatment periods.

$\underline{n}$	R.M.S./d^2	$\underline{n}$	R.M.S./d^2
1	0.0437	14	0.7568
2	0.1080	15	0.7886
3	0.1800	16	0.8173
4	0.2527	17	0.8444
5	0.3221	18	0.8708
6	0.3875	19	0.8934
7	0.4489	20	0.9152
8	0.5048	21	0.9360
9	0.5551	22	0.9560
10	0.6021	23	0.9752
11	0.6459	24	0.9911
12	0.6863	25	1.0064
13	0.7233	26	1.0236

were also obtained according to different hydrologic years, each starting with a different month. The objective in trying different hydrologic years in this fashion was to determine the hydrologic year that would provide the best correlation for calibration purposes. Evidently such a correlation and minimum total variance would mean a minimum number of samples needed during the pre- and post-treatment periods. Six-year data collected during the pre-treatment period were regrouped according to different hydrologic years for this analysis.

For analyzing seasonal flows, which may be of more direct interest in ascertaining the precise management effects on seasonal changes in streamflow and regimen, the calendar year was divided into four quarters: January to March, April to June, July to September, and October to December. Each quarter constituted a separate data set for the paired watershed analysis. In view of the special importance of the snowmelt period when affected by cutting patterns, another quarter extending from May to July was also included in the analysis.

In case of intermittent sampling, the data used consisted of water temperature measurements obtained from the main creek of each sub-basin. Although measurements of the three creeks were made within a short time on the same day, the interval between successive sampling dates ranged from weekly samples during the summer, when streamflow changed more often, to monthly samples during the winter when the streamflow fluctuations were minimum. As these sampling plans were drawn sufficiently in advance, it can be safely assumed that they incorporate random variations of weather and wide variety of experimental conditions especially when repeated over many years.

A stratification scheme was also adopted in the correlation and regression analysis of water temperature data. The criterion used for this purpose was the total daily streamflow on sampling dates for the non-winter months April to November; flows greater than the arithmatic mean were classified as high flows and the rest as low flows. The 4-month period December to March was treated separately under the category of winter months. Such stratifications, however arbitrary, are generally conducive to achieving a high degree of correlation; any other stratification can be similarly used. If high correlation is achieved otherwise, such stratifications are not essential to obtaining suitable calibration.

RESULTS

Annual Flows

Tables 3 and 4 show the results of correlation and regression analyses for data arranged according to different hydrologic years. Fig. 1 shows how the correlation coefficient and standard error of estimate expressed as a per cent of the mean streamflow change with the choice of a particular hydrologic year.

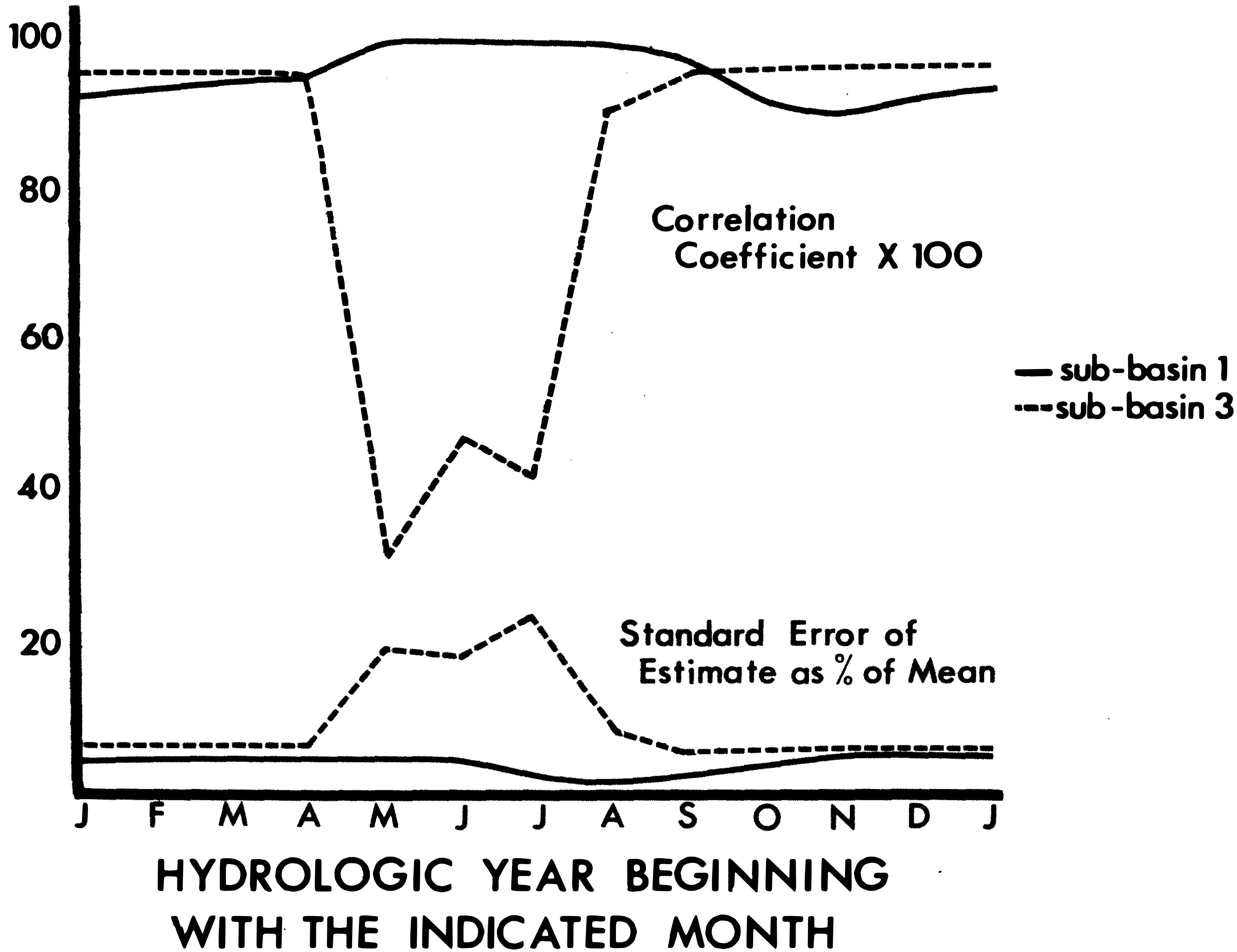
The correlation coefficients varied from 0.304 to 0.957 when sub-basins 2 and 3 were correlated; the highest correlation in this case was for the calendar year data set. The correlation coefficients ranged from 0.897 to 0.992 for sub-basins 2 and 1, the highest being

Table 3. Calibration of sub-basins 1 and 3 on sub-basin 2; correlation coefficients and errors of estimate derived from annual flows (acre-feet) by different hydrologic years.

Hydrologic year beginning with	Correlation coefficient x 100		Standard error of estimate		Standard error of estimate expressed as percent of the mean	
	1	3	1	3	1	3
January	92.6	95.7	68.2	39.2	5.3	6.1
February	93.5	95.6	65.2	40.0	5.0	6.3
March	94.0	95.6	63.5	40.6	4.9	6.4
April	94.6	95.4	61.1	41.7	4.7	6.5
May	99.1	30.4	63.6	120.3	5.6	19.4
June	99.2	46.9	61.6	115.8	5.2	18.2
July	98.9	42.0	30.9	147.7	2.5	23.1
August	98.9	90.8	24.2	58.2	1.9	9.0
September	97.0	94.8	35.2	39.6	2.7	6.2
October	91.6	94.3	52.5	39.0	4.1	6.1
November	89.7	94.7	72.3	40.4	5.6	6.3
December	91.7	95.6	70.4	38.5	5.4	6.0

Table 4. Mean flow, residual mean square (R.M.S.) and R.M.S./d^2 for specified d (the difference to be detected in the observed mean) for sub-basins 1 and 3 when data are grouped according to different hydrologic years.

Hydrologic year beginning with	Mean flow (acre-feet)		R.M.S.		R.M.S./d^2 for specified d					
					d = 20%		d = 10%		d = 5%	
	1	3	1	3	1	3	1	3	1	3
January	1293	638	4650	1536	0.0695	0.0943	0.2781	0.3774	1.1125	1.5094
February	1293	637	4255	1597	0.0636	0.0984	0.2545	0.3936	1.0180	1.5743
March	1293	637	4026	1651	0.0602	0.1017	0.2408	0.4069	0.9632	1.6275
April	1293	637	3737	1740	0.0559	0.1072	0.2235	0.4288	0.8941	1.7153
May	1130	621	4048	14465	0.0793	0.9377	0.3170	3.7509	1.2681	15.0036
June	1179	637	3799	13399	0.0683	0.8255	0.2733	3.3021	1.0932	13.2085
July	1239	639	955	21804	0.0156	1.3350	0.0622	5.3399	0.2488	21.3597
August	1292	643	588	3386	0.0088	0.2047	0.0352	0.8190	0.1409	3.2759
September	1300	639	1236	1565	0.0183	0.0958	0.0731	0.3833	0.2925	1.5331
October	1296	639	2761	1522	0.0411	0.0932	0.1644	0.3727	0.6575	1.4910
November	1294	638	5234	1632	0.0781	0.1002	0.3126	0.4009	1.2503	1.6038
December	1294	638	4957	1486	0.0740	0.0913	0.2960	0.3651	1.1842	1.4603


100
80
60
40
20
Correlation Coefficient X 100
Standard Error of Estimate as % of Mean
sub-basin 1
sub-basin 3
J F M A M J J A S O N D J
HYDROLOGIC YEAR BEGINNING WITH THE INDICATED MONTH

for the data grouped according to the hydrologic year beginning with the month of June.

The standard error of estimate expressed as a percentage of the mean annual flow ranged from 1.9 to 5.6, and 6.0 to 23.1 for sub-basins 1 and 3, respectively. The minimum error for sub-basin 1, however, was for the hydrologic year beginning August, and for sub-basin 3 the hydrologic year beginning with December. The correlation response from sub-basin 1 was more or less uniform for all hydrologic years; for sub-basin 3, however, the correlation coefficients were quite low, and consequently the standard errors of estimate expressed as a percentage of the mean quite high for each of the three hydrologic years beginning May, June, and July.

The adjunct response from sub-basins 1 and 3 on the whole showed best results for the hydrologic year beginning with September, although the correlation coefficient and standard error of estimate for the calendar year and the commonly used water year (starting from October 1) were not much different. The calendar year was therefore chosen to compute necessary statistics for determining the number of years needed for the desired calibration.

Computed values of R.M.S./d^2, from the experimental data taking $\underline{d}$ equal to 5, 10, and 20% of the mean annual streamflow during the pre-treatment period, are listed in Table $\underline{4}$ according to 12 different hydrologic years. The computed values for the calendar year data only, however, are compared with the critical values of Tables 1 and 2. The number of years ($\underline{n}$) needed for detecting a difference ($\underline{d}$) of 10 and 20%

at 95% confidence level was found to be:

	Sub-basin 1		Sub-basin 3		
d	R.M.S./d^2	Calibration Period	R.M.S./d^2	Calibration Period	Sampling Scheme
(a) 20%	0.0695	4 yrs.	0.0943	4 yrs.	$n_1=n_2=n$
	0.0695	2 yrs.	0.0943	2 yrs.	one n = 6
(b) 10%	0.2781	6 yrs.	0.3774	6 yrs.	$n_1=n_2=n$
	0.2781	5 yrs.	0.3774	6 yrs.	one n = 6

Other solutions are similarly possible for n, other than 6, in the unequal sampling case.

Seasonal Flows

Tables 5 and 6 show the results of correlation and regression analyses for the seasonal flows. On comparing the computed values of R.M.S./d^2 from Table 6 with the critical values of Tables 1 and 2, the number of samples can be easily determined for any given quarter for a specified d. The April to June period, for example, would require the following number of years of calibration to detect a change of d = 20% at 95% confidence level:

	Sub-basins 2 and 1	Sub-basins 2 and 3
(a) $n_1 = n_2 = n$	4 yrs.	5 yrs.
(b) when one n is 6	2 yrs.	4 yrs.

Solutions can similarly be obtained for d = 10 and 5%

Table 5. Mean discharge, correlation coefficient and error of estimate for seasonal flows (sub-basins 1 and 3 calibrated on sub-basin 2).

Item	Discharge (acre-feet)			Correlation coefficient x 100		Standard error of estimate		Standard error of estimate expressed as percent of the mean	
	1	2	3	1	3	1	3	1	3
A. Low flow:									
January to March	27	39	21	89.7	38.8	3.0	7.1	11.0	33.4
October to December	110	107	60	99.5	91.2	7.2	19.3	6.5	31.9
B. High flow:									
April to June	716	675	365	91.4	92.8	36.9	32.3	5.2	8.9
May to July	861	820	474	99.0	32.6	50.0	95.1	5.8	20.1
C. Intermediary flow:									
July to September	440	422	192	98.5	79.8	19.2	46.8	4.4	24.4
D. Half-yearly flow:									
October to March	136	144	81	99.5	87.4	7.9	26.6	5.8	33.0
April to September	1157	1097	556	87.2	97.3	60.5	27.5	5.2	4.9

Table 6 Mean flow, residual mean square (R.M.S.), and R.M.S./d^2 for detecting a specified difference (d) in seasonal flows (Sub-basins 1 and 3 calibrated on sub-basin 2).

Item	Mean flow (acre-feet)		R.M.S.		R.M.S./d^2					
					d = 20%		d = 10%		d = 5%	
	1	3	1	3	1	3	1	3	1	3
A. Low flow:										
January to March	27	21	9	51	0.3086	2.8912	1.2346	11.5646	4.9383	46.2585
October to December	110	60	52	373	0.1074	2.5903	0.4298	10.3611	1.7190	41.4444
B. High flow:										
April to June	716	365	1364	1043	0.0665	0.1957	0.2661	0.7829	1.0643	3.1315
May to July	861	474	2504	9037	0.0844	1.0056	0.3378	4.0222	1.3511	16.0889
C. Intermediary flow:										
July to September	440	192	371	2191	0.0479	1.4859	0.1916	5.9435	0.7665	23.7739
D. Half-yearly flow:										
October to March	136	81	63	710	0.0852	2.7054	0.3406	10.8215	1.3625	43.2861
April to September	1157	556	3657	757	0.0683	0.0612	0.2732	0.2449	1.0927	0.9795

Water Temperature

Tables 7 and 8 show the results from the correlation and regression analyses of water temperature data. The computed R.M.S./d^2 of Table 8 can be matched with the theoretical values of Tables 1 and 2. At 95% confidence level, the number of samples (n) needed to detect a change of 5% in the mean temperature when $n_1 = n_2$ is thus readily determined as:

	Sub-basin 1	Sub-basin 3
1. Winter months	6	9
2. April to November:		
Low flows	8	11
High flows	7	11

To show comparative results for the high flows in case of unequal sampling, the number of samples needed when sub-basin 2 is calibrated with sub-basin 3 is as follows:

one n	other n	Total samples
30	5	35
20	6	26
15	8	23

Different combinations are similarly possible to fit a specific experimental situation.

Equal samples for intermittent sampling, like the water temperature measurements mentioned above, are preferable because the samples are equitably distributed over both the periods. If a sampling scheme can be designed so that a variety of experimental conditions for

Table 7. Correlation coefficient and standard error of estimate for water temperature data (intermittent sampling) when sub-basins 1 and 3 are calibrated on sub-basin 2.

Item	Correlation coefficient x 100		Standard error of estimate		Standard error of estimate expressed as percent of the mean		Mean water temperature (° F)		
	1	3	1	3	1	3	1	2	3
April to November:									
Low Flow	95.5	95.0	1.4	2.0	3.7	5.0	39	37	40
High Flow	93.6	89.1	1.3	2.0	3.0	4.6	42	39	42
December to March:	46.8	20.6	1.0	1.2	2.9	3.7	34	33	34

Table 8. Mean water temperature, residual mean square (R.M.S.), and R.M.S./d^2 for detecting a specified difference (d) in stream temperatures for seasonal flows.

Item	Mean water temperature (° F)			R.M.S.		R.M.S./d^2					
						d = 20%		d = 10%		d = 5%	
	1	2	3	1	3	1	3	1	3	1	3
April to November:											
Low Flow	39	37	40	2	4	.0329	.0625	.1315	.2500	.5260	1.0000
High Flow	42	39	42	2	4	.0283	.0567	.1134	.2268	.4535	.9070
December to March:	34	33	34	1	2	.0216	.0433	.0865	.1730	.3460	.6920

the population to be tested are included in the sampling, the approach can be more efficient in time and cost than that involving unequal samples. Thus, in the case illustrated above the total number of samples needed for detecting a change of 5% vary from 35 to 23 and this total is minimum (22, i.e. 11 each in the pre- and post-treatment periods) when the equal sampling scheme is adopted. Moreover, in case of a suitably designed intermittent sampling scheme, the measurements are relatively easy to make and are not stretched over an entire year (as in the case with annual flows). The sampling plan, therefore, becomes more flexible and at the same time easily applicable to a specific experimental situation. As long as the ratios R.M.S./d^2 remain reasonably low and the data comparable, the procedure can be profitably extended to study of changes in other water quality variables.

The procedure has been illustrated by three specific examples. The same technique can be applied to any response event in which the paired watershed or paired plot method is considered essential, and a correlation analysis among the two is necessary for evaluating the treatment effects. Table 2, which deals only with the specific case of one _n_ being 6, can be generalized to incorporate other cases. Table 9 provides a family of solutions that are available to an experimenter for any combination of sample sizes ranging from 1 to 30 at a probability level $\alpha = .05$; Table 10 similarly shows such combinations at $\alpha = .01$. The two tables can provide answers for most of the experimental situations in case of equal as well as unequal number of samples needed during the pre- and post-treatment periods. The procedure is

Table 9. Generalized table providing family of solutions at 95 per cent confidence (α = .05) for the number of samples needed during pre- and post-treatment periods for a specified R.M.S./d^2. (R.M.S. is residual mean square, and d is the desired per cent change, expressed as a decimal fraction, which needs to be detected in the mean).

N_1 / N_2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	25	30
1	---	---	---	.01	.02	.04	.06	.08	.09	.11	.12	.13	.14	.14	.15	.16	.16	.17	.17	.18	.19	.20
2	---	---	.01	.04	.07	.11	.14	.17	.19	.22	.23	.25	.27	.28	.29	.30	.31	.32	.33	.34	.37	.39
3	---	.01	.04	.09	.14	.18	.22	.26	.29	.32	.35	.37	.39	.41	.43	.44	.46	.47	.49	.50	.54	.58
4	.01	.04	.09	.14	.20	.25	.30	.34	.38	.42	.45	.48	.51	.53	.56	.58	.60	.61	.63	.64	.71	.75
5	.02	.07	.14	.20	.26	.32	.38	.43	.47	.51	.55	.59	.62	.65	.68	.70	.72	.74	.76	.78	.86	.92
6	.04	.11	.18	.25	.32	.39	.45	.50	.56	.60	.65	.69	.72	.76	.79	.82	.84	.87	.89	.92	1.01	1.08
7	.06	.14	.22	.30	.38	.45	.51	.58	.63	.69	.73	.78	.82	.86	.89	.93	.96	.99	1.01	1.04	1.15	1.23
8	.08	.17	.26	.34	.43	.50	.58	.64	.70	.76	.82	.86	.91	.95	.99	1.03	1.07	1.10	1.13	1.16	1.28	1.38
9	.09	.19	.29	.38	.47	.56	.63	.70	.77	.83	.89	.95	1.00	1.04	1.09	1.13	1.17	1.20	1.24	1.27	1.31	1.52
10	.11	.22	.32	.42	.51	.60	.69	.76	.83	.90	.96	1.02	1.08	1.13	1.18	1.22	1.26	1.30	1.34	1.38	1.53	1.65
11	.12	.23	.35	.45	.55	.65	.73	.82	.89	.96	1.03	1.09	1.15	1.21	1.26	1.31	1.35	1.40	1.44	1.48	1.64	1.78
12	.13	.25	.37	.48	.59	.69	.78	.86	.95	1.02	1.09	1.16	1.22	1.28	1.34	1.39	1.44	1.49	1.53	1.57	1.76	1.90
13	.14	.27	.39	.51	.62	.72	.82	.91	1.00	1.08	1.15	1.22	1.29	1.35	1.41	1.47	1.52	1.57	1.62	1.67	1.86	2.02
14	.14	.28	.41	.53	.65	.76	.86	.95	1.04	1.13	1.21	1.28	1.35	1.42	1.48	1.54	1.60	1.65	1.70	1.75	1.97	2.14
15	.15	.29	.43	.56	.68	.79	.89	.99	1.09	1.18	1.26	1.34	1.41	1.48	1.55	1.61	1.67	1.73	1.78	1.83	2.06	2.24
16	.16	.30	.44	.58	.70	.82	.93	1.03	1.13	1.22	1.31	1.39	1.47	1.54	1.61	1.68	1.74	1.80	1.86	1.91	2.15	2.35
17	.16	.31	.46	.60	.72	.84	.96	1.07	1.17	1.26	1.35	1.44	1.52	1.60	1.67	1.74	1.81	1.87	1.93	1.99	2.24	2.45
18	.17	.32	.47	.61	.74	.87	.99	1.10	1.20	1.30	1.40	1.49	1.57	1.65	1.73	1.80	1.87	1.94	2.00	2.06	2.33	2.55
19	.17	.33	.49	.63	.76	.89	1.01	1.13	1.24	1.34	1.44	1.53	1.62	1.70	1.78	1.86	1.93	2.00	2.07	2.13	2.41	2.64
20	.18	.34	.50	.64	.78	.92	1.04	1.16	1.27	1.38	1.48	1.57	1.67	1.75	1.83	1.91	1.99	2.06	2.13	2.20	2.49	2.74
25	.19	.37	.54	.71	.86	1.01	1.15	1.28	1.41	1.53	1.64	1.76	1.86	1.97	2.06	2.15	2.24	2.33	2.41	2.49	2.85	3.15
30	.20	.39	.58	.75	.92	1.08	1.23	1.38	1.52	1.65	1.78	1.90	2.02	2.14	2.24	2.35	2.45	2.55	2.64	2.74	3.15	3.50

Table 10. Generalized table providing family of solutions at 99 per cent confidence (δ = .01) for the number of samples needed during pre- and post-treatment periods for a specified RMS/d^2. (R.M.S. is residual mean square, and d is the desired per cent change, expressed as a decimal fraction, which needs to be detected in the mean).

N_1 / N_2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	25	30
1	---	---	---	---	---	.01	.01	.02	.03	.04	.04	.05	.05	.06	.06	.07	.07	.07	.08	.08	.09	.10
2	---	---	---	---	.01	.02	.04	.05	.06	.08	.09	.10	.11	.12	.13	.13	.14	.15	.15	.16	[illegible]	.20
3	---	---	---	.02	.03	.05	.07	.09	.10	.12	.14	.15	.16	.18	.19	.20	.21	.22	.22	.23	.27	.29
4	---	---	.02	.03	.05	.08	.10	.12	.14	.16	.18	.20	.22	.23	.25	.26	.27	.28	.29	.30	.35	.38
5	---	.01	.03	.05	.08	.11	.13	.16	.18	.21	.23	.25	.27	.29	.30	.32	.34	.35	.36	.37	.43	.47
6	.01	.02	.05	.08	.11	.14	.17	.20	.22	.25	.28	.30	.32	.34	.36	.38	.40	.41	.43	.44	.50	.55
7	.01	.04	.07	.10	.13	.17	.20	.23	.26	.29	.32	.35	.37	.39	.41	.43	.45	.47	.49	.50	.57	.63
8	.02	.05	.09	.12	.16	.20	.23	.27	.30	.33	.36	.39	.42	.44	.47	.49	.51	.53	.55	.57	.64	.71
9	.03	.06	.10	.14	.18	.22	.26	.30	.34	.37	.40	.43	.46	.49	.51	.54	.56	.58	.61	.63	.71	.78
10	.04	.08	.12	.16	.21	.25	.29	.33	.37	.41	.44	.47	.50	.53	.56	.59	.61	.64	.66	.68	.78	.85
11	.04	.09	.14	.18	.23	.28	.32	.36	.40	.44	.48	.51	.54	.58	.61	.63	.66	.69	.71	.74	.84	.92
12	.05	.10	.15	.20	.25	.30	.35	.39	.43	.47	.51	.55	.58	.62	.65	.68	.71	.74	.76	.79	.90	.99
13	.05	.11	.16	.22	.27	.32	.37	.42	.46	.50	.54	.58	.62	.66	.69	.72	.75	.78	.81	.84	.96	1.05
14	.06	.12	.18	.23	.29	.34	.39	.44	.49	.53	.58	.62	.66	.69	.73	.76	.80	.83	.86	.89	1.01	1.12
15	.06	.13	.19	.25	.30	.36	.41	.47	.51	.56	.61	.65	.69	.73	.77	.80	.84	.87	.90	.93	1.07	1.18
16	.07	.13	.20	.26	.32	.38	.43	.49	.54	.59	.63	.68	.72	.76	.80	.84	.88	.91	.94	.98	1.12	1.23
17	.07	.14	.21	.27	.34	.40	.45	.51	.56	.61	.66	.71	.75	.80	.84	.88	.91	.95	.98	1.02	1.17	1.29
18	.07	.15	.22	.28	.35	.41	.47	.53	.58	.64	.69	.74	.78	.83	.87	.91	.95	.99	1.02	1.06	1.22	1.35
19	.08	.15	.22	.29	.36	.43	.49	.55	.61	.66	.71	.76	.81	.86	.90	.94	.98	1.01	1.06	1.10	1.26	1.40
20	.08	.16	.23	.30	.37	.44	.50	.57	.63	.68	.74	.79	.84	.89	.93	.98	1.02	1.06	1.10	1.14	1.31	1.45
25	.09	.18	.27	.35	.43	.50	.57	.64	.71	.78	.84	.90	.96	1.01	1.07	1.12	1.17	1.22	1.26	1.31	1.51	1.68
30	.10	.20	.29	.38	.47	.55	.63	.71	.78	.85	.92	.99	1.05	1.12	1.18	1.23	1.29	1.35	1.40	1.45	1.68	1.88

applicable to any other hydrological event, correlated in a similar fashion, and subject to fulfillment of the underlying assumptions inherent in such analyses.

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