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## FREQUENCY OF STREAMFLOW MEASUREMENTS REQUIRED TO DETERMINE FOREST TREATMENT EFFECTS

Most of the stream-discharge records for our experimental watersheds are taken by continuous measurements. But the question arises: are continuous measurements necessary to determine effects of forest treatments? Or could treatment effects be determined by measurement of discharge at intervals, say, once a day or once a week?

Data collected on our Fernow Experimental Forest in West Virginia offered a good opportunity to test this possibility. The control-watershed approach was and is used on the Fernow. After a 6-year calibration period, treatments were applied, and results were tested for significance of treatment effects. All analyses were based on continuous records.

### Analysis

For the analysis reported in this note, data from two watersheds — a commercial clearcutting and a control watershed — were utilized. Treatment effects were compared for these six frequencies of measurement: (1) continuous; (2) daily; (3) semi-weekly or 3½-day (Monday and Thursday); (4) weekly or 7-day (Monday); (5) semi-monthly or 15-day (the 8th and 23rd); and (6) monthly or 30-day (the 15th).

Treatment effects included these ten measurements of water yield: (1) annual discharge, (2) growing-season discharge (May-October), (3) dormant-season discharge (November-April), (4) May discharge, (5) June discharge, (6) July discharge, (7) August discharge, (8) September discharge, (9) October discharge, and (10) low flow — number of days in year with discharge below 0.05 cubic feet per second per square mile (csm.).

With 6 frequencies and 10 kinds of treatment effect, 60 separate analyses were involved. All data analyzed were in area-inches except for the low-flow data, which were in number of days. Storm flows or peak flows were not considered in these analyses. They might better be studied by installation of crest gages and would thus present a somewhat different problem from that treated here.

First, stage and csm. were tabulated for each day at midnight. Midnight was chosen for convenience; any other time would have worked as well. It was decided that the nuisance of using different randomly selected times for each day would offset any theoretical advantage of that method. Tabulations were made for 6 calibration years and for 3 years after start of treatment.

Next, estimated flows by month, season, and year were prepared for each watershed, using each frequency of measurement. For example, for the 30-day frequency it was assumed that flow at midnight on the 15th represented average flow for the month. This led to some strange estimates. For example, discharge for the month of October 1954 on the control watershed was estimated at 74 area-inches by the 30-day frequency method.

Prediction equations were prepared. For each, the smallest difference required to show significance was computed. The 5-percent level of significance was used and a one-tailed test was assumed (the area under only one end of the probability curve was considered). One assumption was made: the value for the control in the treatment year being tested would not differ from the corresponding mean value for the calibration period by more than one standard deviation.

**Table 1.**—*Annual discharge in area-inches, by frequency of measurement, control watershed*

| Water-year | Frequency of measurement | | | | | |
|---|---|---|---|---|---|---|
| | Continuous | Daily | 3½-day | 7-day | 15-day | 30-day |
| 1951-52 | 25.95 | 24.70 | 21.09 | 21.16 | 21.91 | 26.26 |
| 1952-53 | 18.02 | 18.11 | 19.08 | 16.11 | 27.35 | 17.42 |
| 1953-54 | 17.93 | 18.99 | 17.32 | 17.91 | 18.12 | 27.38 |
| 1954-55 | 28.74 | 29.15 | 24.87 | 22.90 | 22.57 | 86.74 |
| 1955-56 | 22.97 | 22.25 | 23.96 | 20.38 | 18.47 | 25.34 |
| 1956-57 | 33.49 | 34.70 | 29.21 | 33.19 | 33.69 | 17.96 |
| Mean | 24.52 | 24.65 | 22.59 | 21.94 | 23.68 | 33.52 |

## Results

Annual discharges for the 6 calibration years on the control watershed, as determined by the different frequencies of measurement, are given in table 1. The same discharges expressed as percentages of the values determined by continuous measurement are shown in table 2. For the

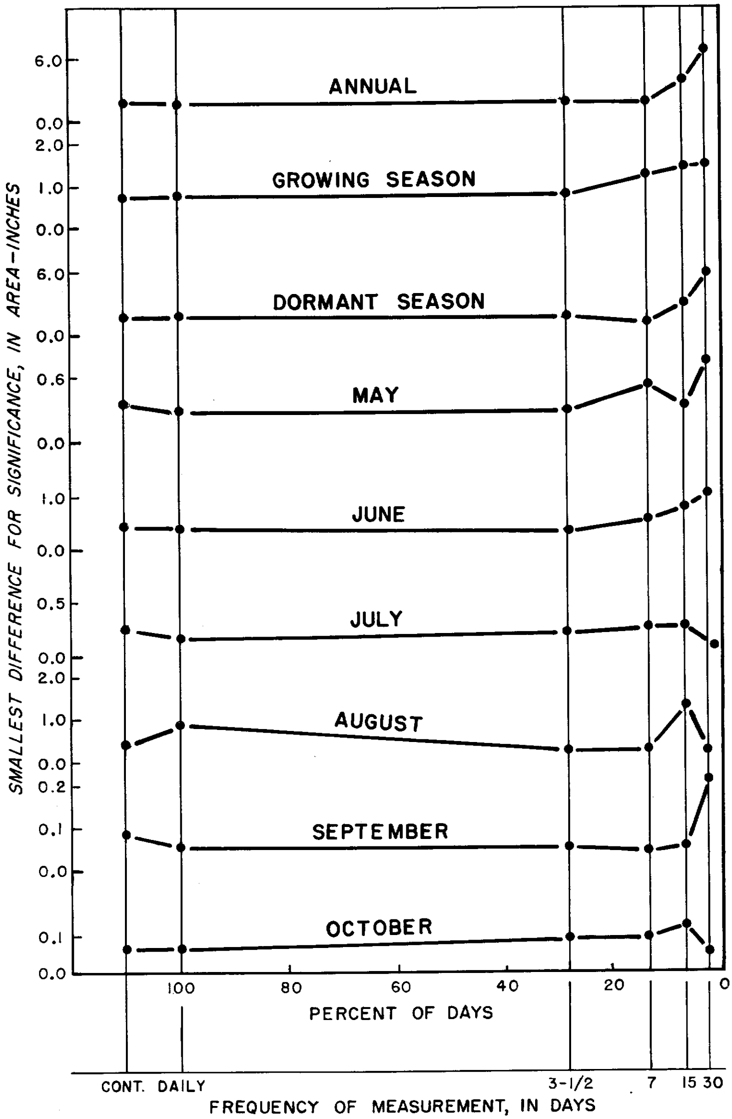
Table 2. — *Annual discharge by frequency of measurement, as percentage of discharge determined by continuous measurement, control watershed*

| Water-year | Frequency of measurement | | | | |
|---|---|---|---|---|---|
| | Daily | 3½-day | 7-day | 15-day | 30-day |
| 1951-52 | 95 | 81 | 82 | 84 | 101 |
| 1952-53 | 100 | 106 | 89 | 152 | 97 |
| 1953-54 | 106 | 97 | 100 | 101 | 153 |
| 1954-55 | 101 | 87 | 80 | 79 | 302 |
| 1955-56 | 97 | 104 | 89 | 80 | 110 |
| 1956-57 | 104 | 87 | 99 | 101 | 54 |
| Mean | 101 | 92 | 89 | 97 | 137 |

Table 3. — *Discharge in area-inches by month, season, and year, based on different frequencies of measurement, control watershed, water-year 1955-56*

| Period | Frequency of measurement | | | | | |
|---|---|---|---|---|---|---|
| | Contin-uous | Daily | 3½-day | 7-day | 15-day | 30-day |
| May | 1.24 | 1.26 | 0.82 | 0.94 | 0.49 | 3.53 |
| June | .61 | .59 | .52 | .69 | .36 | 1.76 |
| July | .34 | .38 | .29 | .44 | .10 | .18 |
| August | 1.56 | 1.42 | 1.97 | .51 | .44 | 1.21 |
| September | .03 | .03 | .03 | .02 | .07 | .01 |
| October | .03 | .05 | .07 | .02 | .01 | .03 |
| Growing season | (3.82) | (3.72) | (3.70) | (2.62) | (1.47) | (6.72) |
| November | 0.36 | 0.37 | 0.34 | 0.25 | 0.98 | 0.81 |
| December | 1.27 | 1.33 | .95 | 1.35 | .71 | .39 |
| January | 2.53 | 2.39 | 2.77 | 4.61 | .44 | .39 |
| February | 7.11 | 6.87 | 8.77 | 6.61 | 3.18 | 8.35 |
| March | 5.41 | 5.11 | 5.43 | 3.01 | 8.21 | 7.34 |
| April | 2.47 | 2.46 | 2.00 | 1.93 | 3.48 | 1.34 |
| Dormant season | (19.15) | (18.53) | (20.26) | (17.76) | (17.00) | (18.62) |
| Year | 22.97 | 22.25 | 23.96 | 20.38 | 18.47 | 25.34 |

Figure 1. — Smallest difference for significance for various frequencies of measurement.




6 years, the daily estimates ranged from 95 to 106 percent of the continuous-measurement record; 30-day estimates ranged from 54 to 302 percent.

Similar data for months and seasons in one water-year are given in table 3. Generally, estimates based on daily measurement are fairly close to the continuous-measurement discharges; for less frequent measurements, the estimates are not so close.

Table 4. — *Number of significant changes due to treatment in the 3 years after start of treatment, for 6 measurement frequencies*

| Data analyzed | Frequency of measurement | | | | | |
|---|---|---|---|---|---|---|
| | Continuous | Daily | 3½-day | 7-day | 15-day | 30-day |
| 1 Annual | 3 | 3 | 2 | 2 | 1 | 1 |
| 2 Growing season | 3 | 3 | 2 | 3 | 2 | 1 |
| 3 Dormant season | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 May | 0 | 0 | 1 | 1 | 1 | 0 |
| 5 June | 1 | 1 | 1 | 1 | 0 | 1 |
| 6 July | 3 | 3 | 2 | 2 | 2 | 2 |
| 7 August | 2 | 0 | 2 | 2 | 0 | 1 |
| 8 September | 2 | 3 | 2 | 3 | 3 | 2 |
| 9 October | 3 | 3 | 3 | 3 | 3 | 3 |
| 10 Low flow | 3 | 3 | 3 | 3 | 3 | 3 |
| Sum | 20 | 19 | 18 | 20 | 15 | 14 |
| Significant and valid[1] | 20 | 18 | 17 | 18 | 13 | 14 |
| Significant but not valid[1] | 0 | 1 | 1 | 2 | 2 | 0 |

[1]Assuming results of continuous record are standard and correct.

Figure 1 shows the smallest differences required to show significance for most of the analyses. The lines on the graph are almost horizontal until the 15- or 30-day frequencies.

Tests of significance using the measured values (by the different methods) in the 3 years after start of treatment are shown in table 4. In 30 tests, the continuous record showed 20 significant values. The daily and 3½-day records showed close to the same results. And the 7-day record also showed 20 significant values. The 15-day and 30-day record showed 15 and 14 significant values, respectively.

The last two lines in table 4 are based on the debatable assumption that significant results of the discontinuous measurements are valid only if the continuous record showed significant results in the corresponding analysis. As can be seen, in almost all cases when the discontinuous method showed significance, the continuous record substantiated it. The 30-day record showed 14 significant changes, and 14 corresponded to significant results by the continuous record.

The yes or no of significance is only part of the story. Quantitative estimates of the amount of change due to treatment are also important.

Table 5 presents, for the first water-year after completion of treatment, the estimates of increases in discharge after treatment, and their fiducial limits. For annual discharge, estimates by both continuous and 30-day measurement indicated significant increases. However, the estimated in-

**Table 5.—*Increase in discharge following treatment as determined by different frequencies of measurement, in area-inches, water-year 1958-59***

| Data analyzed | Frequency of measurement | | | | | |
|---|---|---|---|---|---|---|
| | Continuous | Daily | 3½-day | 7-day | 15-day | 30-day |
| Annual | 5.09 ± 1.50* | 5.47 ± 1.58* | 4.22 ± 1.71* | 4.21 ± 1.73* | 2.30 ± 4.26 | 8.39 ± 6.18* |
| Growing season | 4.40 ± 0.98* | 4.47 ± 0.96* | 4.17 ± 0.98* | 3.67 ± 1.52* | 4.21 ± 2.72* | 7.76 ± 1.36* |
| Dormant season | 0.60 ± 2.01 | 1.21 ± 1.69 | 0.61 ± 1.76 | 0.50 ± 1.05 | —0.40 | —0.44 |
| May | 0.09 ± 0.33 | 0.18 ± 0.26 | 0.27 ± 0.31 | 0.41 ± 0.54 | 0.21 ± 0.34 | 0.32 ± 0.71 |
| June | 1.27 ± 0.35* | 1.60 ± 0.36* | 0.99 ± 0.29* | 0.75 ± 0.51* | —0.26 | 1.81 ± 1.45* |
| July | 1.60 ± 0.64* | 1.65 ± 0.43* | 0.78 ± 0.30* | 1.33 ± 0.30* | 3.17 ± 1.83* | 3.17 ± 0.10* |
| August | 1.14 ± 0.65* | 0.47 ± 0.95 | 1.12 ± 0.25* | 0.65 ± 0.25* | 0.96 ± 1.78 | 2.92 ± 0.35* |
| September | 0.46 ± 0.07* | 0.46 ± 0.05* | 0.40 ± 0.06* | 0.48 ± 0.05* | 0.76 ± 0.05* | 0.07 ± 0.02* |
| October | 0.16 ± 0.05* | 0.16 ± 0.05* | 0.15 ± 0.08* | 0.17 ± 0.08* | 0.13 ± 0.11* | 0.10 ± 0.04* |
| | *Number of days of discharge below 0.05 csm* | | | | | |
| Low flow | —38 ± 13* | —38 ± 8* | —41 ± 28* | —48 ± 38* | —30 ± 11* | —64 ± 26* |

*Significant at 5-percent level.

crease based on continuous measurement was 5.09 $\pm$ 1.50 inches, and based on 30-day measurement the estimate was 8.39 $\pm$ 6.18 inches. Obviously the continuous-measurement estimate in this example was much better.

## Discussion

The results are encouraging. Perhaps discontinuous measurements may be used to determine treatment effects. But four qualifications must be made.

First, the records for this comparison were based upon carefully constructed gaging stations, painstaking maintenance, and meticulous data collection. If daily or weekly measurements had been done at a station with a shifting control or with inaccurate measurement of head, results might have been quite different.

Second, the treatment tested (clearcutting) was a drastic one, with sizable treatment effects. If a less severe treatment had been made, results might not have been so promising.

Third, the significance of effects here depends largely on the 6-year calibration period. In many administrative studies it might not be feasible to wait 6 years before treatment. Perhaps a full-scale assault upon the problem of time-serial correlation is in order; or, to put it another way: How can we get more than one "n" in a year?

And fourth, simultaneous measurement at both watersheds was assumed. In actual practice, the time of measurement on the two would probably differ slightly because of the travel time between measurements.

The results suggest that, under some situations, much might be learned from relatively few measurements. For instance, for the Fernow clearcutting, weekly measurements in September and October by themselves would have been rewarding.

Values in the control and treated watersheds were not so well correlated during or immediately after a storm as they were at other times. Depending on objectives, a rule for a 7-day measurement program might be to avoid measurement within 24 hours after a storm of a given magnitude — say 0.50 inch.

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