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# TREE-RINGS AND RUNOFF IN THE SOUTH PLATTE RIVER BASIN

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The usefulness of centuries-long tree-ring histories of river runoff in such phases of water-supply as hydroelectric power, irrigation, and conservation, has led in recent years to intensive work in this branch of dendrochronology at the Tree-Ring Laboratory. Although specific attention is directed to one basin, the present notes concern problems which appear to be applicable to all basins in the western United States.

It will be convenient to consider the problems in tree-ring hydrology on the framework of a particular case—a preliminary index of the runoff of the South Platte River in central Colorado, which has just been derived. Although these problems are numerous, it may perhaps be emphasized here that they are subordinate to and should be considered in the light of the principal need in this work, *to recognize and sample in the field those tree groups carrying the most sensitive, long histories of rainfall.*

## A PRELIMINARY INDEX

*Groups.* A preliminary index for the South Platte, 1500-1944, given in the figure, is based on increment borings of Douglas firs (*Pseudotsuga taxifolia*) near or at the lower, "dry" forest border, as follows:

Lake George (PIKw). Collected September, 1941. 39°00′ N, 105°23′ W, elevation 9,000 feet. Pikes Peak granite. Along a ridge top 1 mile N of Lake George. Roughly 30 miles WNW of Colorado Springs. 2 trees, 1600-1699; 4 trees since 1700. A skeleton plot for this group is given in the April, 1942 *Bulletin* (group no. 59).

Trout Creek Pass (HRT). Collected September, 1944. 38°56′ N, 105°57′ W, elevation 9,200 feet. Sandstone. Foothill crest. Roughly 62 miles W of Colorado Springs. At the edge of timber on the road out of the tree-less valley. 1 tree, 1500-1699; 4 trees since 1700.

Mount Evans (EVN). Collected September, 1944. 39°42′ N, 105°36′ W, elevation 9,200 feet. Granite. 45° slope, thin soil and bedrock. Roughly 75 miles NW of Colorado Springs. 7 miles along road from Idaho Springs to Mount Evans. 2 trees, 1500-1699; 5 trees since 1700.

A stand of old bristle-cone pine (*P. aristata*) on the Mount Evans highway at the upper, "cold" timberline, elevation 12,000 feet, was also sampled. In this grove, which has been set aside as a "Natural Area," ring records up to about 600 years in length were found, but since these were characteristically complacent, erratic, and did not seem to contain a determinable rainfall record, they were reserved for later study.

All dating, measurement, and analysis of these ring series were done by the writer with the exception of the measurement of the PIKw cores.

While these groups straddle the headwaters area in South Park, one of them, the Mount Evans group, comes from a site just north of this drainage basin and would probably be omitted if a larger number of groups from the basin itself was available.

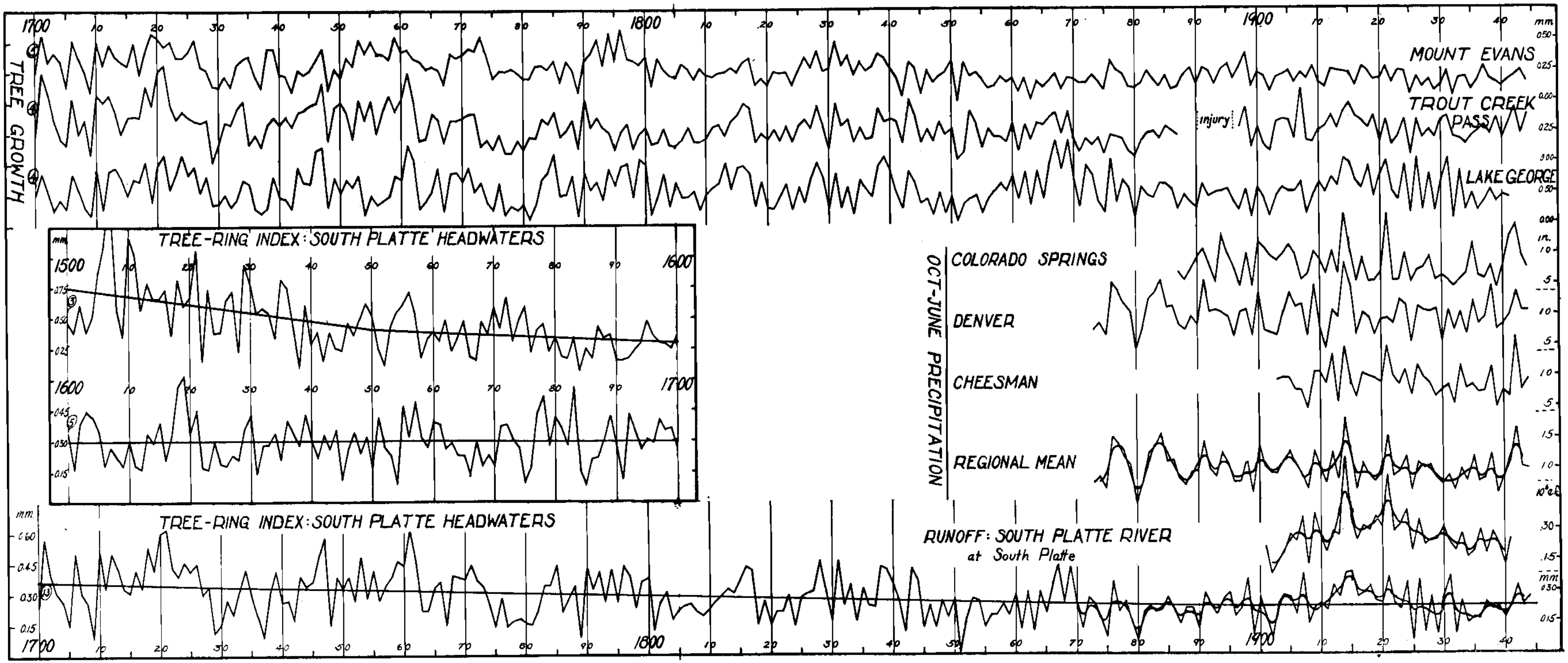
*Species.* The PIKw and the HRT groups represent almost pure stands of Douglas fir, the species which seems to carry the most sensitive and consistent ring chronology in the Rocky Mountains. At the Mount Evans site the stand is mixed, with limber pine (*P. flexilis*), bristle-cone pine, ponderosa pine (*P. ponderosa*), and Colorado blue spruce (*Picea pungens*), subordinate to Douglas fir. Single cores of these proved datable; but, as previous experience has shown, the chronologies were somewhat erratic compared with the chronology in Douglas fir.

*Problems of dating.* The crossdating quality was particularly excellent within these groups. Although false rings were not uncommon, especially in the earliest century of growth, they were all of the easily recognized Douglas fir type—diffuse boundary, red color continuous from the false to the true annual latewood when viewed at a low angle to the specimen surface—and introduced no ambiguity in the dating. Locally absent rings were common only for 1851; scattered instances occurred in the HRT group at 1925, 1880, 1861, 1789, 1729, 1709, 1685, 1654, and 1584, and in the EVN group at 1884, 1863, 1861, 1842, 1676, 1654, and 1645.

*Constructing the growth index.* To obtain a mean growth curve representing trees of various ages, the usual procedure is to "standardize" the individual tree curves by computing percentage departures from a trend line fitted to the curve and then to average the standardized values. Thus the large average growth rate of youth is reduced to conform with the slower growth of maturity and old age. The arbitrary nature of such trend lines, which may introduce local errors of scale in the data, is taken as a lesser evil than the discontinuities which would exist if young and old trees were averaged without regard to age trends and absolute growth rates.

By the use of long-lived trees it is possible to derive a more direct and thus more readily interpretable index. Only the record since 1700 A.D. was used for most trees, supplemented by a few trees beginning at 1500 or 1600. By deleting the decades of fast growth preceding these dates, and in several cases by applying a factor of ½ to an entire series of ring measures in order to roughly reduce especially fast-growing trees to the general normal of the group, straight averages of the measured ring-widths could be derived. The dominance of younger trees since 1700 introduces only a very slight discontinuity in the South Platte index at that date, as the estimated trend line shows.

An injury effect is evident in the 1890 latewood of *all* Trout Creek Pass specimens; this may be related to the cutting-over of the site and subsequent release from suppression. For a few years following this date there was a characteristic surge in growth rate, and the interval has therefore been excluded from the mean curve.


TREE GROWTH
MOUNT EVANS
TROUT CREEK PASS
LAKE GEORGE
injury
TREE-RING INDEX: SOUTH PLATTE HEADWATERS
OCT-JUNE PRECIPITATION
COLORADO SPRINGS
DENVER
CHEESMAN
REGIONAL MEAN
TREE-RING INDEX: SOUTH PLATTE HEADWATERS
RUNOFF: SOUTH PLATTE RIVER
at South Platte

## ERROR ANALYSIS

The tree groups thus far developed for the headwaters area of the South Platte are too limited to justify detailed analysis for statistical probabilities of drought recurrence and similar parameters. It is, however, evident from the figure that in a general way this preliminary index gives a chronology of (1) the winters of drought, such as 1851; (2) with less fidelity the wet winters; and (3) the general maxima and minima in precipitation and runoff. Various factors reduce the apparent correlation between tree growth and the recorded rainfall and runoff.

*Errors in archaeologic* vs *climatic chronologies*. The demands on a climatic index in tree-rings are far more severe than on an archaeologic one, for though the latter requires essentially only precise dating of the rings, the former also involves obscure ecologic relationships. Although in archaeologic specimens the unknown outside or cutting date and the usually small number and brevity of the ring series often present grave difficulties in dating, one needs to give only passing attention to the general changes in absolute growth rate under the impact of such factors as age, pests, fire, mechanical injuries, and release from suppression. But these are very important in the decadal if not in the year-to-year changes in growth, and thus need careful consideration in interpreting the climatic history in tree-rings.

*Dating errors.* Missing rings have been noted under *Problems in dating.* The possibility of an error in dating is precluded during the interval 1700-1944 by the large number of specimens of superior crossdating quality, the wide areal distribution of these, the absence of difficult false rings, and the control by occasional young or relatively complacent series. Since the razor-cut 40° surfaces (see previous *Bulletins* on techniques) make visible even rings 0.02 mm wide consisting of a single compressed cell of earlywood and one of latewood, an error preceding 1700 could come about only if the ring for a given year was completely absent in all specimens. This is highly improbable but not unknown when as few as five trees are involved and the sensitivity is high. The early dating cannot be conclusively checked by the chronology in the many other groups now available from even the nearer areas west of the Continental Divide, for there is a substantial change in ring chronology in some decades between the Colorado drainage basin and that of the South Platte.

*Ecologic errors.* The only case of serious injury by fire or mechanical agent in these specimens has already been mentioned for the Trout Creek Pass group, 1890-1895. No abnormal sub-series of rings of the type characteristic of severe pest outbreaks could be found. Trees obviously subject to suppression and release by neighboring trees could easily be avoided during the field sampling in these open, drought-site stands; no buried events of this sort were found in the rings. General growth release by human activity, if present in the outer decades, seems negligible.

Seed years, basal flare effects, obscure changes in the vitality of local areas of the cambium, and similar influences seem to be important in radial-growth fluctuations in optimum sites and regions: the characteristic, temporary surges in growth along a given radius, so frequently found in wet-site trees, are often difficult to interpret otherwise. On the severely limited sites of the South Platte groups these influences appear to be of secondary importance. Such subtle departures from normal mean growth rate may usually be substantially averaged out if many widely scattered groups of specimens are available. The South Platte index is tentative partly for this reason.

*Rainfall-tree growth errors.* a. Effective interval. Duration of growth, experience in other areas, and comparison with various precipitation intervals indicate that the total precipitation of October-June is over a long period most closely proportional to growth. The long-time record of July-September precipitation at Colorado Springs when compared with growth shows no correlation.

b. Rainfall spottiness. It is obvious from the graph that serious differences in the march of seasonal rainfall exist between Denver, Colorado Springs, and Cheesman. The latter station is well within the headwaters area of the South Platte, and probably represents a closer approximation to true areal conditions than do the longer records to the east; the shorter guage record from nearby Hartsell supports the Cheesman series. Thus the growth curve is an even better record of rainfall than the comparison with the "regional mean" precipitation would indicate.

c. Rainfall distribution. In a region where a single storm may provide a substantial portion of the total winter precipitation the distribution of rainfall within the season undoubtedly affects seriously the tree growth-rain relationship in some years. A well-documented average of many widely scattered groups is less affected by but not free of this "error." Detailed study may be left to the time when such a series is available.

d. Carryover effects. Lag effects of years of excessive rainfall are undoubtedly present in the South Platte index, but are generally of minor importance because of the sensitivity of the individual ring series.

e. Effects of temperature or other climatic factors. Secondary influences of the variations from year to year in seasonal temperature are probably present in the growth fluctuations, but in these drought-site trees moisture exercises so dominating a control that variations due to other climatic factors are of the same order of magnitude as "random" forces.

*Rainfall-runoff errors.* In spite of the numerous well-known factors tending to destroy any direct precipitation-runoff relationship,[1] there is obviously, as in other river basins of the Southwest and California, a general parallelism between October-June precipitation and water-year (October-September) runoff. Thus there exists also a general parallelism between tree growth and runoff. Disturbing influences, such as the component of runoff due to summer precipitation, evaporation losses, basin characteristics with respect to intense storms, and "errors" in the river guage records dependent on approximations and on upstream diversions may be left for later analysis of more extensive ring data.

[1]See W. G. Hoyt and Others, Rainfall and runoff in the United States, U. S. Geological Survey Water-Supply Paper 772, 1936; also, many papers in recent years in Reports, Section of Hydrology, Trans. Amer. Geophysical Union.

## FURTHER DEVELOPMENT

The possibility of improvement of the data by the repeated refining of field sampling criteria is a magnificent property of tree-ring indices, which in a very basic way cuts the Gordian knot of errors in the relationship of these indices to rainfall and runoff. A clearer record of the rainfall fluctuations in past centuries is to be obtained not by minute statistical manipulation of the ring data and application of "correction factors," but by the further selection of specimens giving ring indices of the maximum possible fidelity to these fluctuations. In the South Platte area, reconnaissance indicates that a dozen or more series from sites throughout the entire basin, of sensitivity comparable to that in the groups comprising the preliminary index, are readily obtainable. A well-supported 500-year history thus seems assured on further sampling.

## AVAILABLE INDICES FOR OTHER BASINS IN THE ROCKY MOUNTAINS

In connection with a report on the history of the runoff of the Colorado River the writer assembled growth indices for some 100 groups of specimens collected during 1939-1942. These represent measurements of some 90,000 dated rings and provide the data to construct preliminary indices for a number of drainage basins listed in Table 1. It is planned to publish this set on microfilm; the outstandingly narrow rings, largely representative of drought years, have already been noted for most of these groups in the skeleton chronology map in the April, 1942 *Bulletin.*

Except for the basins of the Gila and Salt Rivers and for the Colorado basin as a whole, the data thus far available can provide at best only tentative indices. It appears that from six to ten sensitive (quality A) and well-scattered groups are desirable to average out local effects in the smaller basins, and from ten to twenty such groups for the larger basins.

In the following list the group numbers 1 to 75 are identified in the April, 1942 *Bulletin.* Groups mentioned below which were analysed since that publication are identified in footnote 1. The estimate of ring quality, repeated for numbers 1-75 from the 1942 paper, is based on a scale of A (excellent) to D (very poor); three especially sensitive groups are graded AA. These will furnish an approximate idea of the value of the series as a runoff index; for comparison, the quality of the groups plotted in the figure is AA—Lake George, A—Trout Creek Pass, and A—Mount Evans.

TABLE 1. SOME MEASURED TREE GROUPS USEFUL FOR RUNOFF INDICES, ROCKY MOUNTAINS.

| Basin | Group No. | Earliest Ring, A.D. | No. Trees at 1600 A.D. | No. Trees at 1700 A.D. | No. Trees at 1800 A.D. | No. Trees at 1900 A.D. | Quality |
|---|---|---|---|---|---|---|---|
| Animas | 42[2] | 1689 | 0 | 2 | 3 | 3 | B |
| | 44 | 1611 | 0 | 5 | 5 | 5 | A |
| | 45 | 1721 | 0 | 0 | 2 | 2 | B |
| | 46 | 1631 | 0 | 1 | 1 | 1 | B |
| | 47 | 1454 | 1 | 1 | 1 | 2 | B |
| | 48 | 1390 | 7 | 7 | 7 | 7 | A |
| | 49 | 1721 | 0 | 0 | 3 | 3 | A |
| | 50 | 1700 | 0 | 1 | 4 | 4 | B |
| | 51 | 1680 | 0 | 2 | 2 | 2 | B |
| Arkansas | 56a | 1416 | 3 | 4 | 3 | 2 | A |
| | 56b | 1623 | 0 | 3 | 3 | 3 | A |
| | 57 | 1720 | 0 | 0 | 2 | 2 | AA |
| Colorado[3] | .... | 1366 | 14 | 31 | 60 | 61 | A |
| Colorado (Upper) | 60 | 1441 | 1 | 3 | 3 | 3 | A |
| | 61 | 1528 | 2 | 2 | 2 | 2 | C |
| | 87 | 1656 | 0 | 3 | 4 | 4 | A |
| | 88 | 1417 | 3 | 3 | 3 | 3 | A |
| | 89 | 1571 | 2 | 3 | 3 | 3 | A |
| | 90 | 1592 | 1 | 2 | 3 | 3 | A |
| Dolores[4] | .... | ....... | .... | .... | .... | .... | .... |
| Duchesne | 63 | 1751 | 0 | 0 | 4 | 4 | C |
| | 64 | 1622 | 0 | 4 | 4 | 4 | C |
| | 65 | 1811 | 0 | 0 | 0 | 2 | C |
| Gila[5] | .... | 1414 | 2 | 23 | 54 | 74 | A |
| Green | 68a | 1665 | 0 | 3 | 3 | 3 | B |
| | 68b | 1757 | 0 | 0 | 2 | 2 | B |
| | 69a | 1653 | 0 | 3 | 3 | 3 | C |
| | 69b | 1792 | 0 | 0 | 2 | 3 | C |
| | 73 | 1766 | 0 | 0 | 1 | 2 | C |
| Gunnison | 55 | 1482 | 3 | 3 | 3 | 3 | A |
| | 85 | 1700 | 0 | 2 | 2 | 2 | A |
| | 86 | 1521 | 1 | 2 | 2 | 2 | A |
| Little Colorado | 14[6] | 1620 | 0 | 1 | 4 | 4 | B |
| North Platte | 62a | 1657 | 0 | 2 | 2 | 2 | C |
| | 62b | 1701 | 0 | 0 | 3 | 4 | C |
| Pecos (Upper) | 11 | 1571 | 1 | 2 | 2 | 2 | B |
| | 12 | 1640 | 0 | 3 | 5 | 5 | AA |
| Pecos (Lower) | 10 | 1640 | 0 | 1 | 5 | 5 | B |
| Rio Grande (Upper) | 52 | 1500 | 1 | 4 | 4 | 1 | B |
| | 53 | 1741 | 0 | 0 | 1 | 1 | B |
| Salt[7] | .... | ....... | .... | .... | .... | .... | .... |
| San Juan[8] | .... | ....... | .... | .... | .... | .... | .... |
| Verde | 31 | 1833 | 0 | 0 | 0 | 4 | B |
| Virgin | 35[9] | 1698 | 0 | 2 | 3 | 4 | C |
| | 38a | 1665 | 0 | 3 | 3 | 3 | A |
| | 38b | 1366 | 2 | 2 | 2 | 2 | A |
| | 39 | 1523 | 1 | 1 | 1 | 1 | C |
| | 40 | 1411 | 2 | 2 | 2 | 2 | A |
| | 41 | 1466 | 1 | 2 | 2 | 2 | A |
| | 79 | 1332 | 3 | 3 | 3 | 3 | A |
| | 80 | 1500 | 4 | 4 | 4 | 4 | A |
| | 81 | 1268 | 2 | 2 | 2 | 2 | A |

[1]Bryce Canyon National Park, Utah—79, 80, 81. Black Canyon of the Gunnison National Monument, Colorado—85, 86. Eagle, Colorado—87. Redcliff, Colorado—88. Hot Sulphur Springs, Colorado—89, 90.

[2]Includes series no. 43 in the April, 1942 map.

[3]A mean index based on 21 groups, 1366-1942, has been derived, the outer four centuries of which are probably subject to only slight improvement with additional material. These groups are: 38a, 42, 44, 51, 53, 60, 61, 62a, 62b, 63, 64, 66, 67, 68a, 69, 85, 86, 87, 88, 89, 90. These are supplemented preceding 1500 A.D. by groups 38b, 48, and 55. The quality listed is that of the mean curve, some account being taken of the substantial averaging-out of local effects.

[4]See Animas.

[5]A mean index based on 14 groups, 1414-1940, has been derived, the outer three centuries of which are essentially final. These groups are: 1, 2, 3, 4, 5-6, 7, 8, 17-18, 19-20, 21-22, 23-24, 25, 26, 29.

[6]Includes series no. 15 in the April, 1942 map.

[7]The index for the Gila seems to be applicable directly to the neighboring Salt River.

[8]See Animas.

[9]Includes series nos. 36 and 37 in the April, 1942 map.