AN ANALYSIS OF YEARLY DIFFERENCES IN SNOWPACK INVENTORY-PREDICTION RELATIONSHIPS

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INTRODUCTION

Inventory-prediction relationships between snowpack conditions and forest attributes may be useful in estimating water yields derived from snow. Conceivably, these relationships may also provide insight relative to potential changes in water yields resulting from land management re-directions (e.g., thinning and clearing of forest overstories). Thus, snowpack inventory-prediction relationships may be considered an integral part of water yield forecasting and improvement programs.

Unfortunately, it is often necessary to develop snowpack inventory-prediction relationships from source data collected over a limited time period (e.g., one, two, three years of record). This constraint has been common to previous studies designed to develop snowpack inventory-prediction relationships in Arizona (Ffolliott and Hansen, 1968; Garn, 1969; Ffolliott and Thorud, 1972), possibly restricting the usefulness of these investigations.

Inventory-prediction relationships developed from source data representing a limited time period may be strictly applicable to the conditions (e.g., precipitation inputs, temperature patterns, etc.) encountered in the time period. Analyses of long-term data available from the USDA Soil Conservation Service (SCS) Federal - State - Private Cooperative Snow Survey (Enz, 1970) suggest inventory-prediction relationships developed from limited data may have more general application, however.

Snowpack inventory-prediction relationships satisfy the following objectives: (1) to estimate the mean snowpack water equivalent on a watershed or basin, and (2) to describe the trade-off (e.g., the rate of exchange) between snowpack water equivalent and forest attributes. In many instances, inventory-prediction relationships developed from limited data are of restricted value in satisfying the first objective. But, if defining the trade-off between snowpack water equivalent and forest attributes is the objective, the results of the study suggest more general application of relationships developed from limited data.

DESCRIPTION OF STUDY

This paper describes a study designed to empirically analyze inventory-prediction relationships developed from long-term Snow Survey records. Specifically, regression equations defining relationships between snowpack water equivalent at peak seasonal accumulation and different expressions of forest density were evaluated. Snowpack water equivalent at peak seasonal accumulation was selected as the dependent variable in the regression equations because, conceptually, this quantity represents one of the best estimates of potential water yields derived from snow (Ffolliott and Thorud, 1972). Expressions of forest density selected as independent variables included measures easily obtained for direct application in snowpack inventory-prediction relationships.

Available records from 18 snow courses (Table 1) located throughout the ponderosa pine (*Pinus ponderosa* Laws.) type in Arizona (Figure 1) provided source data in the study. Courses selected for study were located within forest stands vis-a-vis in natural openings adjacent to forest stands or in cienegas and parks.

TABLE 1. Mean of Variables on Snow Courses.

Name	Basal Area	Aspect	Slope	Elevation
	-- sq. ft./ac. --		-- percent --	-- feet --
Bear Wallow	134	NE	35	8100
Beaver Head	34	NW	5	8000
Canyon Creek	88	N	5	7500
Chalender	43	N	15	7100
Copper Basin Divide	42	NE	5	6720
Forest Dale	23	NE	5	6430
Fort Valley	81	S	5	7350
Gentry	81	--	0	7650
Happy Jack	53	--	0	7630
Heber	53	--	0	7600
Mingus Mountain	68	SW	5	7100
Mormon Lake	38	NW	5	7350
Mormon Mountain	46	--	0	7500
Munds Park	37	--	0	6500
Newman Park	28	E	5	6750
Nutrioso	78	SW	5	8500
Rose Canyon	46	NW	30	7300
White Spar	70	NE	25	6000

Each snow course consisted of a series of individual sample points at regular intervals within relatively homogeneous forest cover and site conditions. The number of sample points and the interval between the points were variable, however; eight to 12 points at 50-foot intervals was the most common sample design, although as few as five points at 25-foot intervals was encountered.

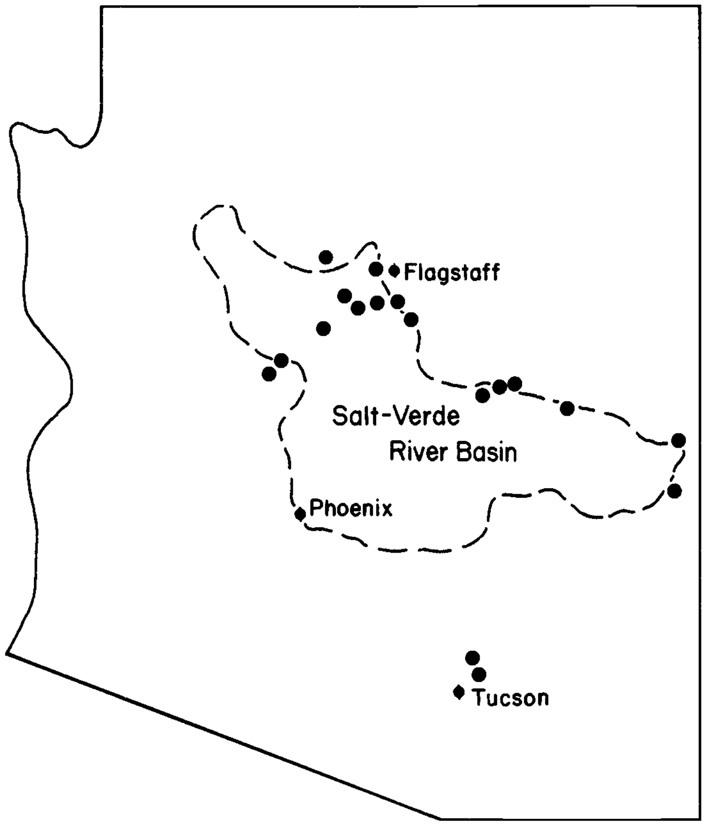

Fig. 1. Location of the 18 snow courses within the ponderosa pine type in Arizona.

Since the snow courses were established in locations where the snowpack is expected to persist throughout the winter-spring water yield forecasting period, the courses are not necessarily an unbiased sample of forest cover and site conditions occurring within the ponderosa pine type. Therefore, interpretations of the results of the study should be restricted to the range of conditions sampled.

Measurements of snowpack water equivalent are made on a regular bi-monthly schedule, starting January 15 and extending through April 15. Measurements taken on this schedule, and representing maximum snowpack accumulation on each course for each year of record, were assumed indicative of peak seasonal accumulation.

Snowpack measurements have been obtained on the snow courses evaluated for a variable number of years, depending on the installation date. Over 30 years of record were available from the older courses, with only five years of record from the course most recently installed. All available data were utilized, though, because of the need to analyze as many among year variations in snowpack inventory-prediction relationships as possible.

Expressions of forest density were developed from point sampling procedures using standard mensurational techniques (Beers and Miller, 1964; Dilworth and Bell, 1968). Employing a basal area factor (BAF) of 25, the tally of trees from all sample points comprising a snow course provided the basis for developing the expressions of forest density.

Initially, basal area, number of trees, and cubic-foot volume were considered for evaluation. Only basal area will be discussed in this paper, however, as this expression of forest density is more widely accepted and applied than the others. Furthermore, basal area is easily and objectively determined in the field, is readily converted to other expressions of forest density, and is an important term for many multiple use land management relationships.

For each snow course, regression equations describing snowpack water equivalent as a function of basal area was developed for each year of record. The family of regression equations representing an individual snow course was then analyzed in terms of similar statistical characteristics.

Snow courses were analyzed individually (e.g., discrete "case histories") because of discontinuities in forest cover and site conditions among the courses.

The primary hypothesis tested in the study, and evaluated by statistically analyzing the family of regression equations representing a snow course, was that, given a precipitation input, the distribution of snowpack water equivalent at peak seasonal accumulation is determined by the spatial arrangement of the forest cover (e.g., basal area).

The hypothesis was tested and evaluated within the framework of the following assumptions: (a) the linear mathematical model selected to empirically describe snowpack water equivalent at peak seasonal accumulation and basal area was appropriate; (b) a regression intercept, which indicates regression elevation, reflects the precipitation input for the year of record; therefore, considering a family of regression equations representing a snow course, regression intercepts can be expected to vary with different precipitation inputs; and (c) a regression coefficient, which indicates regression slope, reflects the trade-off between snowpack water equivalent at peak seasonal accumulation and basal area; therefore, considering a family of regression equations representing a snow course, it was assumed that regression coefficients will remain statistically constant with varying magnitudes of precipitation input.

Covariance analyses (a = 0.10) were used in testing the hypothesis (Snedecor, 1959). In these analyses, it was assumed that all source data were drawn from normal populations with homogeneous variances.

RESULTS AND DISCUSSION

Essentially, the purpose of the above-mentioned analyses was to test for statistical similarities among regression coefficients developed for each snow course in the study. Discontinuities in conditions among the courses resulted in different regression coefficients among the courses. However, the purpose of the analyses was to ascertain within snow course changes in regression coefficients as attributed to time, and not to demonstrate similarities in regression coefficients among the courses.

Of the 18 snow courses in the study, nine possessed a family of regression equations with at least one statistically significant regression coefficient (Table 2). Families of regression equations on three of these courses possessed both statistically significant and non-significant regression coefficients. These courses were dropped from further analyses, and they were considered not to support the primary hypothesis of the study.

TABLE 2. Summary of Regression Coefficient Analyses on Snow Survey Courses

Name	Years of Record	Remarks[1/]
Bear Wallow	21	1 *
Beaver Head	31	2 **
Canyon Creek	11	3 *

TABLE 2. (continued)

Name	Years of Record	Remarks[1/]
Chalender	22	4 ***
Copper Basin Divide	6	1 *
Forest Dale	30	2 **
Fort Valley	22	1 *
Gentry	18	1 *
Happy Jack	18	1 *
Heber	19	3 *
Mingus Mountain	22	2 **
Mormon Lake	23	1 *
Mormon Mountain	6	1 *
Munds Park	19	3 *
Newman Park	6	4 ***
Nutrioso	32	1 *
Rose Canyon	21	4 ***
White Spar	5	1 *

1/ Explanation:

1 No single regression coefficient statistically significant; therefore, regression coefficients considered similar.
2 Statistically significant and non-significant regression coefficients.
3 Statistically significant and similar regression coefficients, with exception of years of low precipitation input.
4 Statistically significant, but not similar, regression coefficients.
* Supports primary hypothesis in the study.
** Does not support primary hypothesis in the study.
*** Inconclusive.

Families of regression equations characterizing the remaining six snow courses were analyzed for statistical similarities among regression coefficients. With the exception of years with low precipitation input (e.g., total seasonal precipitation input less than one-fourth of the long-term mean), families of regression equations on three courses possessed statistically similar regression coefficients (Table 2). The regression intercept values differed (Figure 2), but, again, this was attributed to varying magnitudes of precipitation input. These three

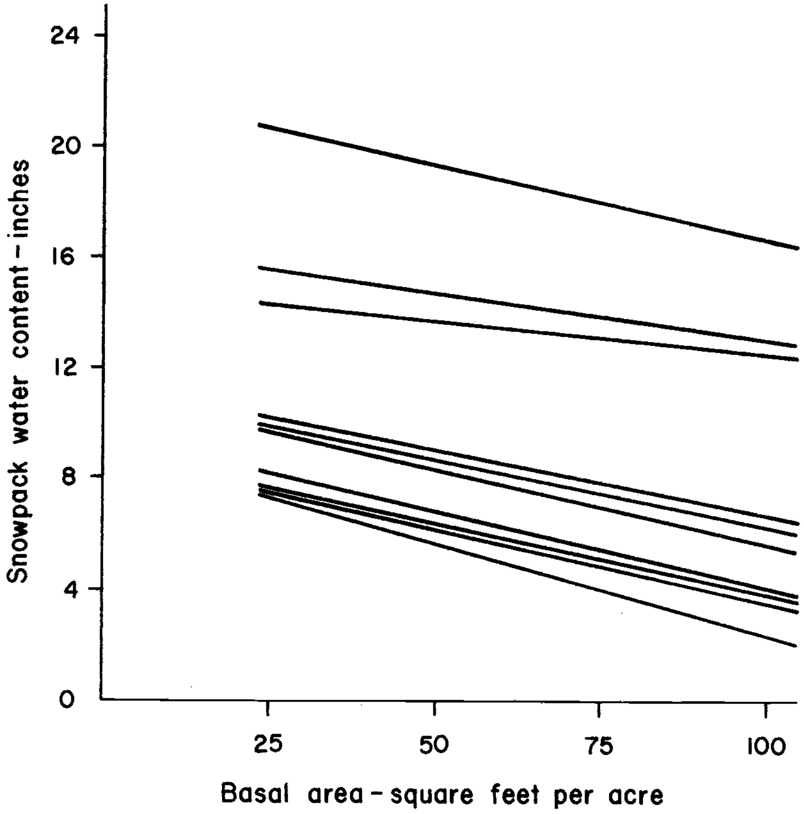

Fig. 2. Family of regressions illustrating relationships between snowpack water equivalent at peak seasonal accumulation and basal area for different years of record (1958-67) on the Canyon Creek snow course.

courses appeared to support the assumption of constant regression coefficients with different precipitation inputs.

On two snow courses, regression coefficients associated with two-thirds of the regression equations in the respective families were statistically similar, while regression coefficients associated with one-half of the regression equations in the family representing the other course were statistically similar (Table 2). These three courses were considered inconclusive regarding substantiation of the primary hypothesis of the study.

Of the 18 snow courses analyzed, nine possessed a family of regression equations in which no single regression coefficient was statistically significant (Table 2). The families of regression equations did differ in regression intercept values (Figure 3), however, which was attributed to different magnitudes of precipitation input. With all regression coefficients similar, the assumption of regression coefficients remaining constant with varying magnitudes of precipitation input was seemingly upheld.

CONCLUSIONS

Generally, 12 of 18 snow courses evaluated in the study appeared to support the hypothesis that, given a precipitation input, the distribution of snowpack water equivalent at peak seasonal accumulation on a site is determined by the spatial arrangement of the forest cover (e.g., basal area). Three courses did not support the hypothesis, while three courses were considered inconclusive. More testing may be desirable before accepting the hypothesis as fact. However, until additional long-term source data are available, the results of the study may provide information re-

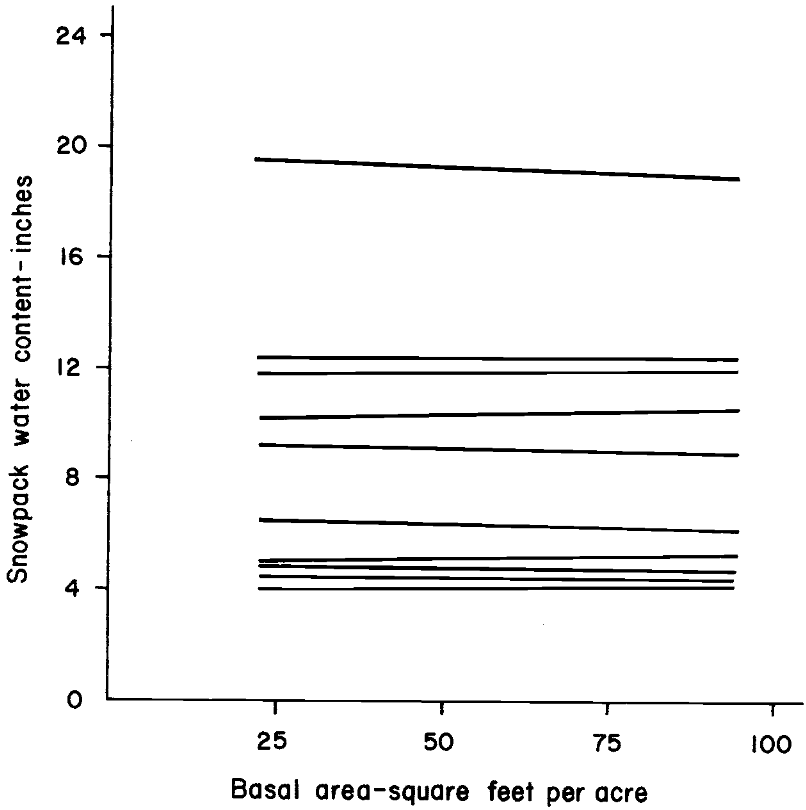

Fig. 3. Family of regressions illustrating relationships between snowpack water equivalent at peak seasonal accumulation and basal area for different years of record (1958-67) on the Mormon Lake snow course.

lative to applying inventory-prediction relationships developed from limited data to define the trade-off between snowpack water equivalent and forest attributes characterizing a given site.

While snowpack water equivalent may change as a function of precipitation input, the trade-off between snowpack water equivalent and forest attributes frequently remain statistically unchanged. Therefore, given a precipitation input, the distribution of snowpack water equivalent may be described by applying an inventory-prediction relationship developed from limited data, with knowledge of pertinent forest attributes.

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