Research Report 274

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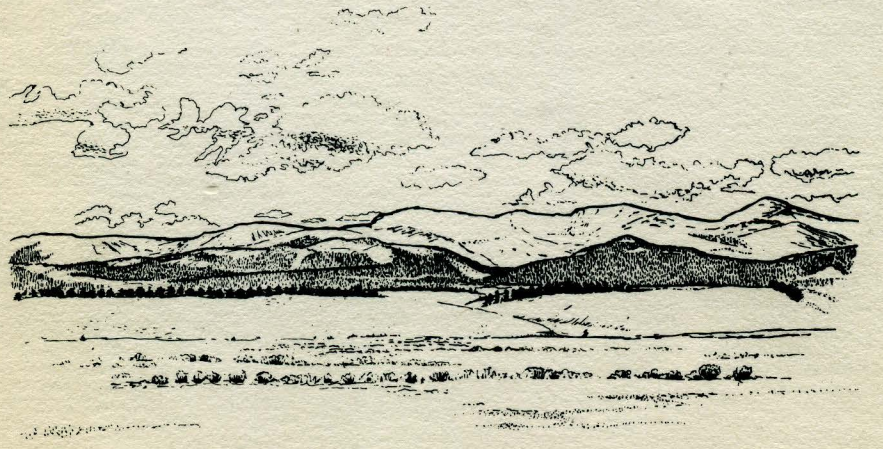

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SNOWMELT RUNOFF EFFICIENCIES ON ARIZONA WATERSHEDS

by

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Table of Contents

Summer 1975 2500

INTRODUCTION

Recognition of the potential of land management practices for increasing water yield has inspired a considerable research effort in Arizona. Interest in water yield improvement from snowpacks, a primary source of recoverable water, has become an area of investigation for both the USDA Forest Service and the School of Renewable Natural Resources at the University of Arizona.

Conceptually, snowpack water yield is dependent upon two factors: (1) the snowpack accumulation on-site, and (2) the snowmelt runoff efficiency, which is defined as the portion of the snowpack on-site that is converted into surface runoff. Continuing research efforts have been directed toward analyses of the first factor. However, to prescribe and implement land management practices for water yield improvement, it is essential that new knowledge be gained regarding the second factor. For maximum benefit, water yield improvement practices aimed at increasing snowmelt runoff should be designed to increase snowpack accumulation on those sites characterized by relatively high snowmelt runoff efficiencies.

The purpose of this report is to document snowmelt runoff efficiencies for several experimental watersheds located in different vegetation zones throughout those parts of Arizona where snowmelt water yield is a significant contributor to the annual water yield budget. This documentation is based on years of record when on-site snowpack water-equivalent measurements were taken on the watersheds. Nearby standard SCS snow course data were utilized to extend the measurement base in some instances, however. In addition, inventory-prediction variables which may affect snowmelt runoff efficiencies have been empirically identified.

SNOWMELT RUNOFF EFFICIENCIES FOR EXPERIMENTAL WATERSHEDS

Snowmelt runoff efficiencies are presented for 14 experimental watersheds in the Appendix. The experimental watersheds documented, located across a range of vegetative, physiographic, and climatic conditions common to the "snow-zone" in Arizona, are generally characterized by mixed conifer forests, mountain grasslands, and ponderosa pine forests. Detailed descriptions of each experimental watershed are given in the Appendix.

Snowmelt runoff efficiency values were derived from the following equation, which can be evaluated for any arbitrary time span:

$$PE = \frac{R}{(P - S_W)} \times 100$$

where PE = percent snowmelt runoff efficiency

R = surface runoff

P = precipitation input

S_W = change in snowpack water-equivalent (a decrease is negative).

Although precipitation and surface runoff were continuously recorded on the experimental watersheds, the above-mentioned equation could only be evaluated for time periods when snowpack water-equivalent had been measured on a watershed basis. Generally, these latter measurements were scheduled to coincide with a particular hydrologic event, i.e., winter snowpack accumulation-melt periods, peak snowpack accumulation, maximum daily snowmelt runoff, and cessation of snowmelt runoff.

Theoretically, snowmelt runoff efficiency values should be an integrator of many watershed and meteorologic variables, such as vegetation

types, physiographic shape, drainage density, precipitation input, etc. A knowledge of these values could eventually become a land management aid in predicting snowpack water yields if long-term values are consistent. Furthermore, as suggested above, knowledge of these values may be helpful in selecting sites for the implementation of water yield improvement practices.

Basic descriptive data are given for 14 experimental watersheds, with a combined total of 32 data-years. Although only a beginning, it is hoped that the information presented can be supplemented in future years, thereby providing additional insight to this important hydrologic attribute.

INVENTORY-PREDICTION VARIABLES AFFECTING SNOWMELT RUNOFF EFFICIENCIES

Knowledge of snowmelt runoff efficiencies could be useful in assessing potential water yields from watersheds of interest if relationships between efficiencies and relevant inventory-prediction variables can be developed. An initial step in the synthesis of such relationships is the identification of inventory-prediction variables affecting snowmelt runoff efficiencies. In an exploratory attempt to accomplish this identification, 10 potential variables were assessed on a sub-sample of five experimental watersheds, with 14 data-years.[1]

The potential inventory-prediction variables assessed were: (1) forest overstory basal area; (2) forest overstory stems; (3) average watershed

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[1]Specific field procedures and analytic techniques employed to identify inventory-prediction variables affecting snowmelt runoff efficiencies are outlined by: Solomon, Rhey M. 1974. An assessment of snowpack depletion-surface runoff relationships on forested watersheds. Unpublished Master's thesis, Department of Watershed Management, University of Arizona, 109 p.

slope; (4) average watershed aspect; (5) elevation; (6) drainage density; (7) antecedent moisture prior to snowpack accumulation; (8) total seasonal precipitation; (9) peak snowpack accumulation; and (10) duration of surface runoff. In addition to the 10 primary variables, several interaction variables were also evaluated.

The relative significance of the inventory-prediction variables was determined through step-wise regression analysis. This method of regression analysis allows the step-wise inclusion of variables in equations in terms of increasing the coefficient of determination (r^2).

Step-wise regression analyses were implemented to derive (1) equations for empirically relating snowmelt runoff efficiencies to inventory-prediction variables that can be measured prior to peak snowpack accumulation, and (2) equations for empirically relating efficiencies to inventory-prediction variables that can be measured after the completion of snowmelt runoff. The first set of equations could be of use by land managers interested in knowing the portion of a snowpack generated from a watershed as surface runoff. The second set of equations has its utility in characterizing watersheds as to their past efficiency history and water yielding potentials.

Significant equations for describing snowmelt runoff efficiencies and their step-wise development are displayed in Table 1. Although these equations must be considered tentative, they may provide some preliminary knowledge in explaining the relative significance of inventory-prediction variables affecting snowmelt runoff efficiencies.

Of interest, for example, is that seasonal precipitation was not among those variables most significantly related to snowmelt efficiencies

TABLE 1. - SNOWMELT RUNOFF EFFICIENCY REGRESSION EQUATIONS AND THEIR STEP-WISE DEVELOPMENT.

Run	Step	Significant Equations[1/]	F. Ratio	r^2	Standard Error
1	1	$Y_1 = 6.77 + 0.0017X_7$	7.1	0.295	16.1
2	1	$Y_1 = -8.02 + 0.57X_2$	12.0	0.500	14.1
	2	$Y_1 = -16.9 + 0.617X_2 + 1.47x10^{-8}X^3_4$	8.9	0.616	13.1
3	1	$Y_1 = -6.34 + 17.92(\ln X_1)$	5.6	0.293	17.2
	2	$Y_1 = -109.6 + 17.28(\ln X_1) + 0.014X_5$	4.7	0.388	16.8
4	1	$Y_2 = 4.06 + 0.0022X_7$	8.1	0.402	17.6
	2	$Y_2 = -6.97 + 0.001X_7 + 11.0(\ln X_1)$	6.2	0.465	17.1
5	1	$Y_2 = -12.16 + 0.68X_2$	16.7	0.581	14.7
	2	$Y_2 = -22.44 + 0.74X_2 + 1.7X10^{-8}X^3_4$	13.3	0.714	12.8
6	1	$Y_2 = 4.51 + 15.9(\ln X_3)$	6.8	0.361	18.1
	2	$Y_2 = -115.2 + 15.1(\ln X_3) + 0.017X_5$	5.2	0.453	17.5
	3	$Y_2 = -128.0 + 8.6(\ln X_3) + 0.17X_5 = 12.8X_1$	4.3	0.511	14.5
7	1	$Y_2 = -11.45 + 22.35X_6$	7.7	0.368	18.2
	2	$Y_2 = -136.9 + 21.6X_6 + 0.017X_5$	5.7	0.457	17.3

[1/] Variables:

Y_1 = seasonal snowmelt runoff efficency (percent)

Y_2 = snowmelt runoff efficiency from peak snowpack accumulation to the end of the season (percent)

X_1 = peak snowpack accumulation (inches)

X_2 = duration of runoff (days)

X_3 = antecedent moisture (inches)

X_4 = stems per acre

X_5 = elevation (feet from sea level)

X_6 = ln peak snowpack accumulation

$X_7 = X_3X_5$

prior to peak snowpack accumulation, whereas peak snowpack accumulation appears in some of the equations (Table 1). From this observation, it might be hypothesized that the timing of precipitation throughout the snowpack accumulation-melt period, as well as total season precipitation, is of importance in establishing the snowmelt runoff efficiency value for that year.

Also of interest is the positive relationship between snowmelt runoff efficiencies and the forest overstory stem variable after the completion of snowmelt runoff (Table 1). Many researchers have defined inverse relationships between expressions of forest density, such as forest overstory stems, and water yielding capacities of watersheds, whereas the equations presented in Table 1 imply the opposite situation. One possible explanation is that forest overstory stems is indexing some other inventory-prediction variable, such as elevation, with this latter variable being positively correlated with snowmelt runoff efficiencies.

CONCLUSIONS

Although tentative, the regression equations empirically relating snowmelt runoff efficiencies to inventory-prediction variables may provide knowledge useful in assessing potential water yields from watersheds. However, further study is needed to provide a greater understanding of snowmelt runoff efficiency values in terms of differences among watersheds within a year, differences within a watershed among years, and differences among both watersheds and years. With additional investigation, it might also be possible to better identify those inventory-prediction variables which affect snowmelt runoff efficiencies, thereby providing insight to probable causal relationships.

APPENDIX

MIXED CONIFER FORESTS

North Fork of Thomas Creek

(A) Description of Area

(1) Location: approximately 14 miles south of Alpine, Arizona, west side of Rt. 666, on the Apache National Forest.

(2) Size of Watershed: 441 acres.

(3) Overstory Vegetation: Engelmann spruce (Picea engelmannii), blue spruce (Picea pungens), Douglas-fir (Pseudotsuga menziesii), white fir (Abies concolor), corkbark fir (Abies lasiocarpa var. arizonica), ponderosa pine (Pinus ponderosa), southwestern white pine (Pinus strobiformis), and quaking aspen (Populus tremuloides).

(4) Physiography

(a) Soils: basalt parent material.

(b) Elevation: 8,600 to 9,300 feet.

(c) Slope and Aspect: steep slopes, with 20 percent of the watershed at least 40 percent; aspects variable.

(5) Precipitation: 22 to 38 inches annually, with 50 percent of the annual precipitation occurring during October through May.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design

(1) 1966, 1969, 1972: Standard SCS snow course (Hannegan Meadow) adjusted for elevational difference by linear regression to expand the data base. (Only a few measurements taken on the watershed).

(2) 1973: 60 to 80 temporary sample points arranged in a diamond-shaped pattern and spaced at 50-foot intervals.

(c) Schedule of Measurements

(1) 1966, 1969, 1972: Beginning and middle of each month from January 1 until snow is gone -- usually April 1.

(2) 1973: variable; immediately following snowfall during the accumulation period, and at 10 to 15 day intervals during the melt period.

(2) Streamflow

(a) Instrumentation: 120° V-notch weir.

(b) Type of Record: 5 minute digital.

(3) Years of Record: 1966, 1969, 1972, 1973.

(C) Land History

Uncut mixed conifer forest conditions for all years of record.

(D) Snowmelt Runoff Efficiencies

Water Year 1966

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
27 Feb- 13 Mar	0.4	0.3	75.0
14 Mar- 29 Mar	1.4	1.3	92.9
30 Mar- 14 Apr	2.6	1.4	53.8
15 Apr- End	3.5	1.2	34.3
Total	7.9	4.2	53.2

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Mar- End	7.5	3.9	52.0

Water Year 1969

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
15 Jan- 29 Jan	1.0	0.0	0.0
30 Jan- 13 Feb	0.4	0.0	0.0
14 Feb- 26 Feb	1.0	0.0	0.0
27 Feb- 13 Mar	0.6	0.1	16.7
14 Mar- 28 Mar	0.7	0.2	28.6
29 Mar- 14 Apr	1.9	0.5	26.3
15 Apr- 30 Apr	2.9	0.3	10.3
1 May- End	4.0	0.4	10.0
Total	12.5	1.5	12.0

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Mar- End	9.5	1.4	14.7

Water Year 1972

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Jan- 13 Feb	0.2	0.0	0.0
14 Feb- 27 Feb	0.4	0.0	0.0
28 Feb- End	4.3	0.2	4.6
Total	4.9	0.2	4.1

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Jan- End	4.9	0.2	4.1

Water Year 1973

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
10 Jan- 24 Feb	2.0	0.3	15.0
25 Feb- 10 Mar	2.5	0.4	16.0
11 Mar- 24 Mar	1.1	0.3	27.3
25 Mar- 7 Apr	0.9	0.5	55.6
8 Apr- 28 Apr	5.3	3.1	58.5
29 Apr- 12 May	4.5	3.3	73.3
13 May- 29 May	2.6	1.4	53.8
30 May- End	0.3	0.1	33.3
Total	19.2	9.4	49.0

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
8 Apr- End	12.9	7.9	61.2

South Fork of Thomas Creek

(A) Description of Area

(1) Location: approximately 14 miles south of Alpine, Arizona, west side of Rt. 666, on the Apache National Forest.

(2) Size of Watershed: 581 acres.

(3) Overstory Vegetation: Engelmann spruce, blue spruce, Douglas-fir, white fir, corkbark fir, ponderosa pine, southwestern white pine, and quaking aspen.

(4) Physiography

(a) Soils: basalt parent material.

(b) Elevation: 8,600 to 9,300 feet.

(c) Slope and Aspect: steep slopes, with 25 percent of the watershed at least 35 percent; aspects variable.

(5) Precipitation: 20 to 43 inches annually, with approximately 50 percent of the annual precipitation occurring during October through April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: Standard SCS snow course (Hannegan Meadow) adjusted for elevational difference by linear regression to expand the data base. (Only a few measurements taken on the watershed).

(c) Schedule of Measurements: Beginning and middle of each month from January 1st until snow is gone -- usually April 1.

(2) Streamflow

(a) Instrumentation: 120° V-notch weir.

(b) Type of Record: 5-minute digital.

(3) Years of Record: 1966, 1969, and 1972.

(C) Land History

Uncut mixed conifer forest conditions for all years of record.

(D) Snowmelt Runoff Efficiencies

Water Year 1966

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
27 Feb- 13 Mar	0.3	0.1	33.3
14 Mar- 29 Mar	1.4	0.9	64.3
30 Mar- 14 Apr	2.6	1.9	73.1
15 Apr- End	3.5	2.0	57.1
Total	7.8	4.9	62.8

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Mar- End	7.5	4.8	64.0

Water Year 1969

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
15 Jan- 29 Jan	1.0	0.0	0.0
30 Jan- 13 Feb	0.4	0.0	0.0
14 Feb- 26 Feb	1.0	0.0	0.0
27 Feb- 13 Mar	0.6	0.0	0.0
14 Mar- 28 Mar	0.7	0.0	0.0
29 Mar- 14 Apr	1.9	0.4	21.0
15 Apr- 30 Apr	2.7	0.4	14.8
1 May- End	4.2	0.3	7.1
Total	12.7	1.1	8.7

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Mar- End	9.5	1.1	11.6

Water Year 1972

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Jan- 13 Feb	0.2	0.0	0.0
14 Feb- 27 Feb	0.4	0.0	0.0
28 Feb- End	4.3	0.1	2.3
Total	4.9	0.1	2.0

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Jan- End	4.9	0.1	2.0

North Fork of Workman Creek

(A) Description of Area

(1) Location: approximately 45 miles north of Globe, Arizona, east of State Rt. 288 on the Tonto National Forest.

(2) Size of Watershed: 248 acres.

(3) Overstory Vegetation: Originally predominately ponderosa pine with white fir, Douglas-fir, and Gambel oak (Quercus gambelii).

(4) Physiography

(a) Soils: Workman gravelly sandy clay loam. Quartzite, sandstone and diabase parent materials.

(b) Elevations: 6,700 to 7,700 feet.

(c) Slope and Aspect: Slopes commonly between 20 and 30 percent, but ranging to 70 percent; 28 percent of watershed at least 35 percent. Southeast through Southwest aspects predominate.

(5) Precipitation: 17 to 61 inches annually with an average of 31 inches annually. 67 percent of the annual precipitation occurs from October through April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: Standard SCS snow course (Workman Creek) adjusted for elevational difference by linear regression to expand the data base. (Only a few measurements taken on the watershed).

(c) Schedule of Measurements: Beginning and middle of each month from January 1 until snow is gone -- usually April 1.

(2) Streamflow

(a) Instrumentation: 90° V-notch weir.

(b) Type of Record: 5-minute digital.

(3) Years of Record: 1969 and 1970.

(C) Land History

Mixed conifer forest overstory is being converted to perennial grass and shrubs in steps. Years of record represent conditions after (1) removal of riparian vegetation, (2) conversion of 80 acres of moist-site vegetation and (3) conversion of another 100 acres of dry-site vegetation.

(D) Snowmelt Runoff Efficiencies:

Water Year 1969

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
11 Jan- 31 Jan	6.8	3.4	50.0
1 Feb- 14 Feb	1.0	0.4	40.0
15 Feb- 27 Feb	2.7	0.4	14.8
28 Feb- 13 Mar	2.5	1.0	40.0
14 Mar- 27 Mar	0.6	0.5	83.3
28 Mar- End	1.3	0.4	30.8
Total	14.9	6.1	40.9

(2) Peak Snowpack Accumulaiton to Cessation of Surface Runoff.

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
15 Feb- End	7.1	2.3	32.4

Water Year 1970

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
11 Jan- 30 Jan	0.6	0.2	33.3
31 Jan- 12 Feb	0.7	0.1	14.3
13 Feb- 27 Feb	0.4	0.1	25.0
28 Feb- 12 Mar	3.6	0.6	16.7
13 Mar- 27 Mar	0.5	0.4	80.0
28 Mar- End	1.6	0.3	18.8
Total	7.4	1.7	23.2

(2) Peak Snowpack Accumulation to Cessation of Surface Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
13 Mar- End	2.1	0.7	33.3

MOUNTAIN GRASSLANDS

West Fork of Seven Springs

(A) Description of Area

(1) Location: approximately 13 miles southwest of Springerville Arizona, along Rt. 70, on the Apache National Forest.

(2) Size of Watershed: 482 acres.

(3) Vegetation: Arizona fescue (*Festuca arizonica*), miscellaneous forbs and sedges (*Carex* spp.)

(4) Physiography

(a) Soils: basalt parent material.

(b) Elevation: 9,200 to 9,500 feet.

(c) Slope and Aspect: gentle slopes, with 60 percent of the watershed less than 6 percent; southeast aspect.

(5) Precipitation: 22 to 32 inches annually, with 50 percent of the annual precipitation occurring during October through April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: 36 permanent sample points located along five transects (variable length) and spaced at 440-foot intervals, with two measurements taken per sample point.

(c) Schedule of Measurements: variable; main emphasis on measurement of peak accumulation.

(2) Streamflow

(a) Instrumentation: 120° V-notch weir.

(b) Type of Record: 5-minute digital.

(3) Years of Record: 1971 and 1972.

(C) Land History

High-elevation grassland range subjected to summer grazing by domestic livestock.

(D) Snowmelt Runoff Efficiencies:

Water Year 1971

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
29 Jan- 12 Feb	1.8	0.0	0.0
13 Feb- 26 Feb	0.2	0.0	0.0
27 Feb- 15 Mar	0.8	0.0	0.0
16 Mar- End	0.3	0.0	0.0
Total	3.1	0.0	0.0

(2) Peak Snowpack Accumulation to Cessation of Surface Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
29 Jan- End	3.1	0.0	0.0

Water Year 1972

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Jan- 28 Jan	0.6	0.0	0.0
29 Jan- 14 Feb	0.6	0.2	33.3
15 Feb- 29 Feb	2.1	0.2	9.5
1 Mar- 14 Mar	3.4	0.3	8.8
15 Mar- End	0.2	0.0	0.0
Total	6.9	0.7	10.1

(2) Peak Snowpack Accumulation to Cessation of Surface Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Jan- End	6.9	0.7	10.1

East Fork of Seven Springs

(A) Description of Area

(1) Location: approximately 13 miles southwest of Springerville, Arizona, along Rt. 70, on the Apache National Forest.

(2) Size of Watershed: 748 acres.

(3) Vegetation: Arizona fescue, miscellaneous forbs and sedges.

(4) Physiography

(a) Soils: basalt parent material.

(b) Elevation: 9,200 to 9,500 feet.

(c) Slope and Aspect: gentle slopes, with 60 percent of the watershed less than 6 percent; southwest aspect.

(5) Precipitation: 22 to 32 inches annually, with 50 percent of the annual precipitation occurring during October through April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: 41 permanent sample points located along five transects (variable length) and spaced at 440-foot intervals, with two measurements taken per sample point.

(c) Schedule of Measurements: variable; main emphasis on measurement of peak accumulation.

(2) Streamflow

(a) Instrumentation: 120° V-notch weir.

(b) Type of Record: 5-minute digital.

(3) Years of Record: 1971 and 1972.

(C) Land History

High-elevation grassland range subjected to summer grazing by domestic livestock.

(D) Snowmelt Runoff Efficiencies

Water Year 1971

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
29 Jan- 12 Feb	1.8	0.0	0.0
13 Feb- 26 Feb	0.2	0.0	0.0
27 Feb- 15 Mar	0.8	0.1	12.5
16 Mar- End	0.3	0.0	0.0
Total	3.1	0.1	3.2

(2) Peak Snowpack Accumulation to Cessation of Surface Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
29 Jan- End	3.1	0.1	3.2

Water Year 1972

(1) Season

Date	Snowpack Abaltion inches	Streamflow inches	Efficiency percent
14 Jan- 28 Jan	0.6	0.0	0.0
29 Jan- 14 Feb	0.6	0.1	16.7
15 Feb- 29 Feb	2.1	0.4	19.0
1 Mar- 14 Mar	3.4	0.2	5.9
15 Mar- End	0.2	0.0	0.0
Total	6.9	0.7	10.1

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Jan- End	6.9	0.7	10.1

PONDEROSA PINE FORESTS

West Fork of Castle Creek

(A) Description of Area

(1) Location: approximately 10 miles south of Alpine, Arizona, east side of U.S. Highway 666 on the Apache National Forest.

(2) Size of Watershed: 900 acres.

(3) Overstory Vegetation: Ponderosa pine with small amounts of white fir and Douglas-fir.

(4) Physiography

(a) Soils: basalt parent material.

(b) Elevations: 7,850 to 8,583 feet.

(c) Slope and Aspect: Average slopes are about 14 percent. The average aspect is S43E for West Fork.

(5) Precipitation: 14 to 37 inches annually with an average of 25 inches annually. 52 percent of the annual precipitation occurs from October through April.

(B) Measurements Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: 54 permanent sample points located along four transects (variable length) and spaced at 440-foot intervals. Standard SCS snow course (Beaverhead) adjusted for elevational difference by linear regression to expand the data base.

(c) Schedule of Measurements: variable; on 54 permanent sample points, measurements beginning in January through peak accumulation; on SCS snow course, beginning and middle of each month from January until snow is gone -- usually April 1.

(2) Streamflow

(a) Instrumentation: 120° V-notch weir.

(b) Type of Record: 5-minute digital.

(3) Years of Record: 1969 and 1972.

(C) Land History

Years of record were obtained after one-sixth of the watershed was clearcut in blocks, and the residual forest stand was places in good growing conditions.

(D) Snowmelt Runoff Efficiencies:

Water Year 1969

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Jan- 29 Jan	0.8	0.0	0.0
30 Jan- 13 Feb	0.2	0.0	0.0
14 Feb- 25 Feb	0.9	0.0	0.0
26 Feb- 13 Mar	0.5	0.0	0.0
14 Mar- 28 Mar	1.8	0.4	22.2
29 Mar- End	1.8	0.2	11.1
Total	6.0	0.6	10.0

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Mar- End	3.6	0.6	16.7

Water Year 1972

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
15 Jan- 31 Jan	0.6	0.0	0.0
1 Feb- 14 Feb	0.6	0.0	0.0
15 Feb- End	0.9	0.1	11.1
Total	2.1	0.1	4.8

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
15 Jan- End	2.1	0.1	4.8

East Fork of Castle Creek

(A) Description of Area

(1) Location: approximately 14 miles south of Alpine, Arizona, east side of U.S. Highway 666 on the Apache National Forest.

(2) Size of Watershed: 1,163 acres.

(3) Overstory Vegetation: Ponderosa pine with small amounts of white fir and Douglas-fir.

(4) Physiography

(a) Soils: basalt parent material.

(b) Elevations: 7,835 to 8,477 feet.

(c) Slope and Aspect: Average slopes are about 14 percent. The average aspect is N14W for East Fork

(5) Precipitation: 14 to 37 inches annually with an average of 25 inches annually. 52 percent of the annual precipitation occurs from October through April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: 49 permanent sample points located along four transects (variable length) and spaced at 440-foot intervals. Standard SCS snow course (Beaverhead) adjusted for elevational difference by linear regression to expand the data base.

(c) Schedule of Measurements: variable; on 49 permanent sample points, measurements beginning in January through peak accumulation; on SCS snow course, beginning and middle of each month from January until snow is gone -- usually April 1.

(2) Streamflow

(a) Instrumentation: 120° V-notch weir.

(b) Type of Record: 5-minute digital.

(3) Years of Record: 1969 and 1972.

(C) Land History

Uncut ponderosa pine forest conditions represent all years of record.

(D) Snowmelt Runoff Efficiencies:

Water Year 1969

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Jan- 29 Jan	0.5	0.0	0.0
30 Jan- 13 Feb	0.2	0.0	0.0
14 Feb- 25 Feb	1.0	0.0	0.0
26 Feb- 13 Mar	0.2	0.0	0.0
14 Mar- 28 Mar	2.4	0.7	8.3
29 Mar- End	1.8	0.1	5.6
Total	6.1	0.3	4.9

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Mar- End	4.2	0.3	7.1

Water Year 1972

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
15 Jan- 31 Jan	0.9	0.0	0.0
1 Feb- 14 Feb	0.7	0.0	0.0
15 Feb- End	0.9	0.1	11.1
Total	2.5	0.1	4.0

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

	Snowpack Ablation inches	Streamflow inches	Efficiency percent
15 Jan- End	2.5	0.1	4.0

Heber Watershed HE-2

(A) Description of Area

(1) Location: Approximately 13 miles southeast of Heber, Arizona, off the Rim Road on the Sitgreaves National Forest.

(2) Size of Watershed: 28 acres.

(3) Overstory Vegetation: ponderosa pine, Douglas-fir, white fir, and Gambel oak.

(4) Physiography

(a) Soils: alluvial parent material (Overgaard soil series).

(b) Elevation: 7,400 to 7,700 feet.

(c) Slope and Aspect: steep southwest and east slopes near the stream channel, average 40 percent, with gradually decreasing to five percent toward the watershed boundaries.

(5) Precipitation: 18 to 25 inches annually, 50 percent of which occurs during November through April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: 30 sample points traversing the watershed on three transect lines.

(c) Schedule of Measurements: variable; usually at 7- to 14-day intervals during snowpack accumulation and melt periods.

(2) Streamflow

(a) Instrumentation: three-foot H-flume.

(b) Type of Record: 5-minute digital.

(3) Year of Record: 1973.

(C) Land History

Selectively cutover ponderosa pine forest conditions.

(D) Snowmelt Runoff Efficiencies

Water Year 1973

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
24 Mar- 1 Apr	1.2	0.6	50.0
2 Apr- 7 Apr	1.2	0.6	50.0
8 Apr- 16 Apr	4.7	2.6	55.3
17 Apr- 30 Apr	6.0	2.6	43.3
1 May- End	1.1	0.2	18.2
Total	14.2	6.6	46.5

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
2 Apr- End	13.0	6.0	46.2

Heber Watershed HE-3

(A) Description of Area

(1) Location: approximately 6 miles south of Heber, Arizona, on the Sitgreaves National Forest.

(2) Size of Watershed: 60 acres.

(3) Overstory Vegetation: ponderosa pine, Gambel oak, alligator juniper.

(4) Physiography

(a) Soils: sandstone parent material (McVickers soil series).

(b) Elevation: 6,900 to 7,050 feet.

(c) Slope and Aspect: slopes average 10 percent, with few slopes exceeding 15 percent; primary drainage to the northwest.

(5) Precipitation: 18 to 25 inches annually, 50 percent of which occurs during November through April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: 30 sample points traversing the watershed on three transect lines.

(c) Schedule of Measurements: variable, usually 7- to 14-day intervals during snowpack accumulation and melt periods.

(2) Streamflow

(a) Instrumentation: three-foot H-flume.

(b) Type of Record: 5-minute digital.

(3) Year of Record: 1973.

(C) Land History

Selectively cutover ponderosa pine forest conditions.

(D) Snowmelt Runoff Efficiencies.

Water Year 1973

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
28 Jan- 4 Feb	0.7	0.0	0.0
5 Feb- 11 Mar	1.1	0.0	0.0
12 Mar- 17 Mar	1.0	0.0	0.0
18 Mar- 24 Mar	0.7	0.0	0.0
25 Mar- 1 Apr	2.6	0.0	0.0
2 Apr- 8 Apr	1.8	0.2	11.1
9 Apr- 15 Apr	4.2	0.4	9.5
16 Apr- End	2.7	0.2	7.4
Total	14.8	0.8	5.4

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
25 Mar- End	11.3	0.8	7.1

Beaver Creek Watershed 9

(A) Description of Area

(1) Location: approximately 31 miles south of Flagstaff, Arizona, on the Beaver Creek watershed within the Coconino National Forest.

(2) Size of Watershed: 1,121 acres

(3) Overstory Vegetation: Ponderosa pine, Gambel oak, and alligator juniper (Juniperus deppeana).

(4) Physiography

(a) Soils: basalt parent material.

(b) Elevation: 6,900 to 7,600 feet.

(c) Slope and Aspect: Gentle slopes with 76 percent of the watershed below 20 percent; aspects variable, with main channel oriented at 246°.

(5) Precipitation: 20 to 36 inches annually, with 67 percent of the annual precipitation occurring during October through April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: 19 sample points along fourteen 180-foot transects randomly located on the watershed.

(c) Schedule of Measurements: variable; during the accumulation period, and at 7- to 15-day intervals during the melt period.

(2) Streamflow

(a) Instrumentation: Beaver Creek flume.

(b) Type of Record: 5-minute digital.

(3) Years of Record: 1968, 1969, and 1973.

(C) Land History

One-third of the overstory removed in uniform, parallel strips, with no cultural treatment on the two-thirds not cut. Treatment completed in Water Year 1968.

(D) Snowmelt Tunoff Efficiencies

Water Year 1968

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
12 Jan- 23 Jan	0.1	0.0	0.0
24 Jan- 5 Feb	2.4	0.0	0.0
6 Feb- 27 Feb	5.2	1.6	30.8
28 Feb- 15 Mar	3.3	2.2	66.7
16 Mar- 4 Apr	2.6	2.3	88.5
5 Apr- 11 Apr	0.7	0.6	85.7
12 Apr- End	1.1	1.1	100.0
Total	15.4	7.8	50.6

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
12 Jan- End	15.4	7.8	50.6

Water Year 1969

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
18 Feb- 28 Feb	1.8	0.0	0.0
1 Mar- 19 Mar	0.5	0.2	40.0
20 Mar- 26 Mar	1.8	1.8	100.0
27 Mar- 3 Apr	3.6	3.6	100.0
4 Apr- 7 Apr	1.1	1.0	90.9
8 Apr- 14 Apr	1.0	0.8	80.0
15 Apr- End	0.4	0.1	25.0
Total	10.2	7.5	73.5

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
20 Mar- End	7.9	7.3	92.4

Water Year 1973

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
28 Apr- 9 May	6.0	6.0	100.0
10 May- End	1.5	0.9	60.0
Total	7.5	6.9	92.0

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
28 Apr- End	7.5	6.9	92.0

Beaver Creek Watershed 12

(A) Description of Area

(1) Location: approximately 37 miles south of Flagstaff, Arizona, on the Beaver Creek watershed within the Coconino National Forest.

(2) Size of Watershed: 455 acres.

(3) Overstory Vegetation: Ponderosa pine, Gambel oak, and alligator juniper.

(4) Physiography

(a) Soils: basalt parent material.

(b) Elevation: 6,780 to 7,300 feet.

(c) Slope and Aspect: gentle slopes, with 91 percent of watershed below 20 percent; aspect variable.

(5) Precipitation: 20 to 32 inches annually, with 61 percent of the annual precipitation occurring during October through April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: 16 sample points along twenty 120-foot transects, randomly located on the watershed.

(c) Schedule of Measurements: variable; during the accumulation period, and 7- to 15-day intervals during the melt period.

(2) Streamflow

(a) Instrumentation: Beaver Creek flume.

(b) Type of Record: 5-minute digital.

(3) Years of Record: 1966, 1968, 1969, and 1973.

(C) Land History

Cutover ponderosa pine forest conditions represent 1966 record. The 1968, 1969, and 1973 records were obtained after complete clearing of all forest overstory vegetation and windrowing of slash.

(D) Snowmelt Runoff Efficiencies

Water year 1966

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
4 Mar- 10 Mar	1.1	0.8	72.7
11 Mar- 13 Mar	1.0	1.0	100.0
14 Mar- 16 Mar	0.6	0.6	100.0
17 Mar- 20 Mar	0.4	0.2	50.0
Total	3.1	2.7	87.1

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
4 Apr- End	3.1	2.7	87.1

Water Year 1968

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
8 Feb- 21 Feb	4.0	4.0	100.0
22 Feb- 29 Feb	4.3	2.3	53.4
1 May- 12 Mar	1.4	0.6	42.8
13 Mar- 22 Mar	1.4	1.0	71.4
23 Mar- End	0.1	0.0	0.0
Total	11.2	7.9	70.5

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
8 Feb- End	11.2	7.9	70.5

Water Year 1969

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
18 Mar- 24 Mar	3.8	3.1	81.6
25 Mar- End	1.3	0.5	38.5
Total	5.1	3.6	70.6

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
18 Mar- End	5.1	3.6	70.6

Water Year 1973

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
13 Feb- 26 Feb	1.6	0.3	18.8
27 Feb- 11 Apr	6.5	6.5	100.0
12 Apr- 25 Apr	10.8	8.0	74.1
26 Apr- End	1.9	0.6	31.6
Total	20.8	15.4	74.0

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
12 Apr- End	12.7	8.6	67.7

Beaver Creek Watershed 15

(A) Description of Area

(1) Location: approximately 20 miles south of Flagstaff, Arizona, and two miles east of the Schnebly Hill turnoff on Interstate 17.

(2) Size of Watershed: 163 acres.

(3) Overstory Vegetation: ponderosa pine, Gambel oak, and alligator juniper.

(4) Physiography

(a) Soils: Brolliar soils, derived from basalt parent material.

(b) Elevation: 6,735 to 7,160 feet.

(c) Slope and Aspect: average slope is 15 percent, primarily directed toward the south and southwest.

(5) Precipitation: approximately 25 inches annually, 50 percent of with occurs between November and April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sample Desgin: 86 sample points traversing the watershed on six transect lines.

(c) Schedule of Measurements: variable; usually 7- to 14-day intervals during snowpack accumulation and melt periods.

(2) Streamflow

(a) Instrumentation: trapezodal flume.

(b) Type of Record: 5-minute digital.

(3) Years of Record: 1968, 1969, and 1973.

(C) Land History

Selectively cutover ponderosa pine forest conditions.

(D) Snowmelt Runoff Efficiencies

Water Year 1968

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
28 Dec- 6 Jan	0.8	0.0	0.0
7 Jan- 31 Jan	2.9	0.0	0.0
1 Feb- 11 Feb	2.2	0.3	13.6
12 Feb- 17 Feb	0.9	0.1	11.1
18 Feb- 24 Feb	3.0	1.0	33.3
25 Feb- 6 Mar	2.2	0.4	18.2
7 Mar- End	2.0	0.1	5.0
Total	14.0	1.9	13.6

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
28 Dec- End	14.0	1.9	13.6

Water Year 1969

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
2 Mar- 8 Mar	0.7	0.0	0.0
9 Mar- 15 Mar	0.1	0.0	0.0
16 Mar- 22 Mar	2.8	0.9	32.1
23 Mar- 29 Mar	1.7	0.5	29.4
30 Mar- End	1.3	0.2	15.4
Total	6.6	1.6	24.2

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
16 Mar- End	5.8	1.6	27.6

Water Year 1973

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
10 Jan- 17 Feb	0.4	0.0	0.0
18 Feb- 1 Mar	1.9	0.2	10.5
2 Mar- 17 Mar	1.4	0.3	21.4
18 Mar- 24 Mar	0.8	0.2	25.0
25 Mar- 1 Apr	0.6	0.0	0.0
2 Apr- 14 Apr	6.0	2.9	48.3
15 Apr- 1 May	6.1	2.6	42.6
2 May- End	1.1	0.2	18.2
Total	18.3	6.5	35.5

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
2 Apr- End	13.2	5.7	43.2

Beaver Creek Watershed 17

(A) Description of Area

(1) Location: approximately 24 miles south of Flagstaff, Arizona, on the Beaver Creek watershed within the Coconino National Forest.

(2) Size of Watershed: 299 acres.

(3) Overstory Vegetation: ponderosa pine, Gambel oak, and alligator juniper.

(4) Physiography

(a) Soils: basalt parent material.

(b) Elevation: 6,820 to 7,270 feet.

(c) Slope and Aspect: gentle slopes, with 91 percent of the watershed below 20 percent; aspect variable.

(5) Precipitation: 20 to 39 inches annually with 65 percent of the annual precipitation occurring during October through April.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: 186 sample points along a systematic point sample design with three random starts, with 1.5 chains between sample points.

(c) Schedule of Measurements: variable; during the accumulation period, and at 7- to 15-day intervals during the melt period.

(2) Streamflow

(a) Instrumentation: Beaver Creek flume.

(b) Type of Record: 5-minute digital.

(3) Year of Record: 1969 and 1973.

(C) Land History

Selectively cutover ponderosa pine forest conditions represent 1969 record. The 1973 record was obtained after uniform thinning of forest overstory (to 30 square feet of basal acre per acre) and windrowing of slash.

(D) Snowmelt Runoff Efficiencies

Water Year 1969

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
1 Feb- 22 Feb	0.4	0.2	50.0
23 Feb- 8 Mar	0.4	0.2	50.0
9 Mar- 15 Mar	0.3	0.0	0.0
16 Mar- 22 Mar	2.7	1.2	44.4
23 Mar- 29 Mar	2.1	1.7	80.9
30 Mar- End	2.1	0.8	38.1
Total	8.0	4.1	51.2

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff'

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
16 Mar- End	6.9	3.7	53.6

Water Year 1973

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
31 Mar- 21 Apr	7.8	7.2	92.3
22 Apr- End	10.3	6.9	67.0
Total	18.1	14.1	77.9

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
31 Mar- End	18.1	14.1	77.9

Hutch Mountain Watershed

(A) Description of Area

(1) Location: approximately 34 miles south of Flagstaff, Arizona, on the Beaver Creek watershed within the Coconino National Forest.

(2) Size of Watershed: 72 acres.

(3) Overstory Vegetation: ponderosa pine, Gambel oak, alligator juniper, and white fir.

(4) Physiography

(a) Soils: basalt parent material.

(b) Elevation: 8,200 to 8,530 feet.

(c) Slopes and Aspects: mild slopes with 70 percent of the watershed below 20 percent; aspect variable.

(5) Precipitation: no record.

(B) Measurement Procedures

(1) Snowpack

(a) Instrumentation: Federal snow tube and scale.

(b) Sampling Design: 30 sampling points systematically located on the watershed.

(c) Schedule of Measurements: variable; during the snow accumulation period, and at 7- to 15-day intervals during the melt period.

(2) Streamflow

(a) Instrumentation: 2-foot H flumes.

(b) Type of Record: 5-minute digital.

(3) Year of Record: 1973.

(C) Land History

Selectively cutover ponderosa pine forest conditions.

(D) Snowmelt Runoff Efficiencies

Water Year 1973

(1) Season

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
21 Mar- 13 Apr	3.5	0.3	8.6
14 Apr- 4 May	3.3	3.3	100.0
5 May- 7 May	4.0	0.6	15.0
8 May- End	13.4	3.7	27.6
Total	24.2	7.9	32.6

(2) Peak Snowpack Accumulation to Cessation of Snowmelt Runoff

Date	Snowpack Ablation inches	Streamflow inches	Efficiency percent
14 Apr- End	20.7	7.6	36.7

1975

2500