Estimated Average Annual Water Balance For Piceance and Yellow Creek Watersheds

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ESTIMATED AVERAGE ANNUAL WATER BALANCE FOR PICEANCE AND YELLOW CREEK WATERSHEDS

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Evapotranspiration methodology from a thesis submitted by the author to the Graduate Faculty of Colorado State University in partial fullfillment of the requirements for the degree of Doctor of Philosophy.

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Symbols		Definition
D	=	deep percolation below the normal root zone of the plants
E_1	=	elevation of the evaluated site in thousands of feet
E_t	=	evapotranspiration demand for a specific vegetation type with water not limiting
E_{ta}	=	actual evapotranspiration which is determined by the availability of water from precipitation and/or soil water
E_{tp}	=	potential evapotranspiration which represents the upper limit of use that occurs over periods of 10 days or longer under given climatic conditions
E_{tps}	=	potential evapotranspiration for the April-October growing season
E_{tpw}	=	potential evapotranspiration for the November-March water accumulation period
I	=	irrigation water use by irrigated crops, native hay, and pasture lands
K_c	=	plant water use coefficient
P	=	precipitation (total annual in inches)
Q	=	net outflow from the watershed area
R	=	surface runoff from watershed areas
R_i	=	run-in water use by sagebrush bottomlands and phreatophyte areas
R_{cf}	=	radiation correction factor
R_s	=	total solar and sky radiation converted to inches of evaporation equivalent (langleys X 0.000673 = inches)
S_m	=	estimated evapotranspiration (E_t) for months during the April-October period when normal precipitation exceeds horizontal surface E_t for the specific vegetation type

LIST OF SYMBOLS (continued)

Symbols		Definition
S	=	change in soil water content (initial minus final)
T	=	mean air temperature for the evaluated period (°F)
T_{cf}	=	temperature correction factor in °F.

SYNOPSIS

Summary

This report provides a surface water balance estimate by elevation zones and vegetation types for the Piceance and Yellow Creeks watersheds. The original purpose of this study was to provide the U.S. Geological Survey with data for checking and calibrating the ground-water model for the Piceance Basin, but the resulting estimates have considerable application in answering plant water use questions related to the developing oil shale industry. The estimates developed are generally consistent with known water balance factors and vegetation indicators, but the water balance model is based on linear relationships to the maximum possible extent and the necessary simplifying assumptions ignore a number of complex relationships.

The climate of the Piceance Basin is arid-steppe and is subject to dramatic changes within short distances, or over short time periods. The Piceance and Yellow Creek watersheds have elevation zones from less than 6,000 to more than 9,000 feet, wide variations in topography, at least seven major vegetation types, and many barren cliffs or canyons that create hot upslope winds. It is also in an area of water deficient sparce vegetation. These factors all emphasize the need for special evapotranspiration methodology, and the impossibility of providing specific evapotranspiration estimates for individual vegetation sites, or years, using any form of generalized methodology.

The Jensen-Haise method of estimating evapotranspiration was chosen for this study because, with modification, it can be used to estimate annual evapotranspiration by elevation zone, and provide quantification of observed differences in water use for various slopes and aspects. This method was also specifically developed for use in the arid or semiarid western United States. The modified Jensen-Haise method used in this report provides monthly water use estimates for both the winter (moisture accumulation period) and the growing season use. The methodology was also adapted to providing evapotranspiration estimates for specific vegetation types, and cover densities, on different slopes and aspects, and for areas having different temperature

relationships. The study provides relatively simple equations that can be used to estimate evapotranspiration (or irrigation requirements) for specific vegetation types growing on 0-50 percent slopes and eight aspects.

The water balance evaluations for Piceance Creek watershed (629 sq. miles) provide average annual precipitation estimates of 17.40 inches, of which 17.01 inches are used by evapotranspiration, and the net outflow is 0.39 inch. In terms of acre-feet this would be a net outflow of 13,102 acre-feet which checks with the available stream-gaging records for Piceance Creek at the White River if estimated irrigation by-pass at the gaging site is considered. The Yellow Creek watershed (258 sq. miles) water balance study estimates an average precipitation of 15.67 inches, with 15.58 inches evapotranspiration, and 0.19 inches (2,578 acre-feet) net outflow. The evaluations, as conducted, also provided specific estimates of water use by native vegetation, irrigated cropland, sagebrush bottomland and seep or phreatophyte areas, and a division of evapotranspiration estimates for each vegetation type during the November-March and April-October periods.

Conclusions and Recommendations

The elevation zone water balance evaluations, by vegetation types, provide generalized answers for average conditions, but they should be used with caution for specific years, or site evaluations. From the water balance standpoint, the elevation zone precipitation rates are subject to question, and there are some areas where the vegetation indicators point to higher precipitation amounts. This is particularly true in the Upper Piceance Creek watershed area and the upper reaches of Black Sulphur Creek.

As more detailed climatological and runoff information becomes available the water balance for Piceance and Yellow Creeks should be attempted for specific years to check the methodology and provide more detailed information.

INTRODUCTION

This study was developed to provide the Colorado District, U.S. Geological Survey with an estimate of the surface water balance relationships for the Piceance and Yellow Creeks watersheds. This information was used to check and calibrate the ground-water model for the Piceance Basin. To provide the water balance information it was necessary to develop estimates of precipitation, available water holding capacity of soils, potential evapotranspiration, and actual evapotranspiration by elevation zones for the major vegetation types or water using areas. The evapotranspiration methodology was developed for estimating water requirements in the revegetation of spent shale and includes a means of adjusting elevation zone evapotranspiration for differences in slope and aspect (Wymore, 1974). Details of the evapotranspiration methodology are provided in a later section.

It should be recognized that the true water balance of Piceance and Yellow Creeks is complex, and extremely variable. This analysis represents a long-term average situation for some of the variables, and is based to a large extent on data from off-site regional weather stations and personal judgement. From a water balance standpoint, the elevation zone precipitation rates are the weakest parameter, with one somewhat atypical weather station (Little Hills at 6,148 ft.) as the only on-site data source. Elevation zone precipitation can only be partially correlated with vegetation indicators, and surface runoff at the limited gaging stations.

Drainage Areas by Elevation Zone

The drainage boundaries of Piceance and Yellow Creeks were outlined on USGS 7.5' Quadrangle Maps (1:24,000 scale) and measured by planimeter. The measured areas above the gaging sites were approximately 3% greater than the official drainage areas for the streamgaging sites. Therefore, the official drainage areas were used for total area evaluation purposes. For Piceance Creek, the drainage area is 629.0 sq. miles, or 402,600 acres (USGS streamgage No. 93062.22 Piceance Creek at White River). For the Upper Piceance Creek (above streamgage No. 93060 Piceance Creek near Rio Blanco) the area measured was 142.2 sq. miles against the area of 153 sq. miles. The measured area was used for evaluation purposes because it was made from the most recent base maps. Yellow Creek has a drainage area of 258.0 sq. miles or 165,100 acres (USGS streamgage No. 93062.55 Yellow Creek near White River). Figure 1 provides a location map for the Piceance and Yellow Creek watersheds.

The 1,000 ft. contours were emphasized on the USGS topographic base maps and the elevation zone areas measured. The totals were then adjusted to the official drainage areas. Table 1 provides a summary of the drainage areas of Piceance and Yellow Creeks by elevation zone.

Natural Vegetation by Elevation Zone

The vegetation for the Piceance and Yellow Creeks basin, as mapped by Charles Terwilliger, Jr. and P. G. Threlkeld[1/], was transferred to the 7.5' quadrangle maps. The area of Upper Piceance Creek east of Colorado Highways 789 and 13, was mapped by field inspection in September 1973. On the Roan Plateau at the extreme south side of the Piceance Creek drainages only advance copies of the topographic maps were available, and vegetation acreage was estimated from aerial photos and by field inspection without developing a vegetation map.

The land use was divided into upland and bottomland areas. For the bottomland areas irrigated cropland, irrigated meadow and pasture, and seep or phreatophyte acreages were estimated using the annual reports from Division VI (formerly Water District No. 43) of the Colorado State Engineer's office, and the 1/2 inch/mile base maps from the USDA (1966) White River Basin Report. These estimates were field checked in September 1973, and discussed with Clarence Johnson, local water commissioner for the Colorado State Engineer's office. Total bottomland was delineated and measured on topographic base maps, and

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1/ Vegetation Map-Piceance and Roan Plateau, Colorado, Range Science Dept. College of Forestry and Natural Resources, December 1973. In Surface rehabilitation of land and disturbances resulting from oil shale development. Final Report, March 1, 1974, phase I. C. Wayne Cook (Coordinator). Environmental Resources Center, Colo. State Univ., Ft. Collins, Colorado.

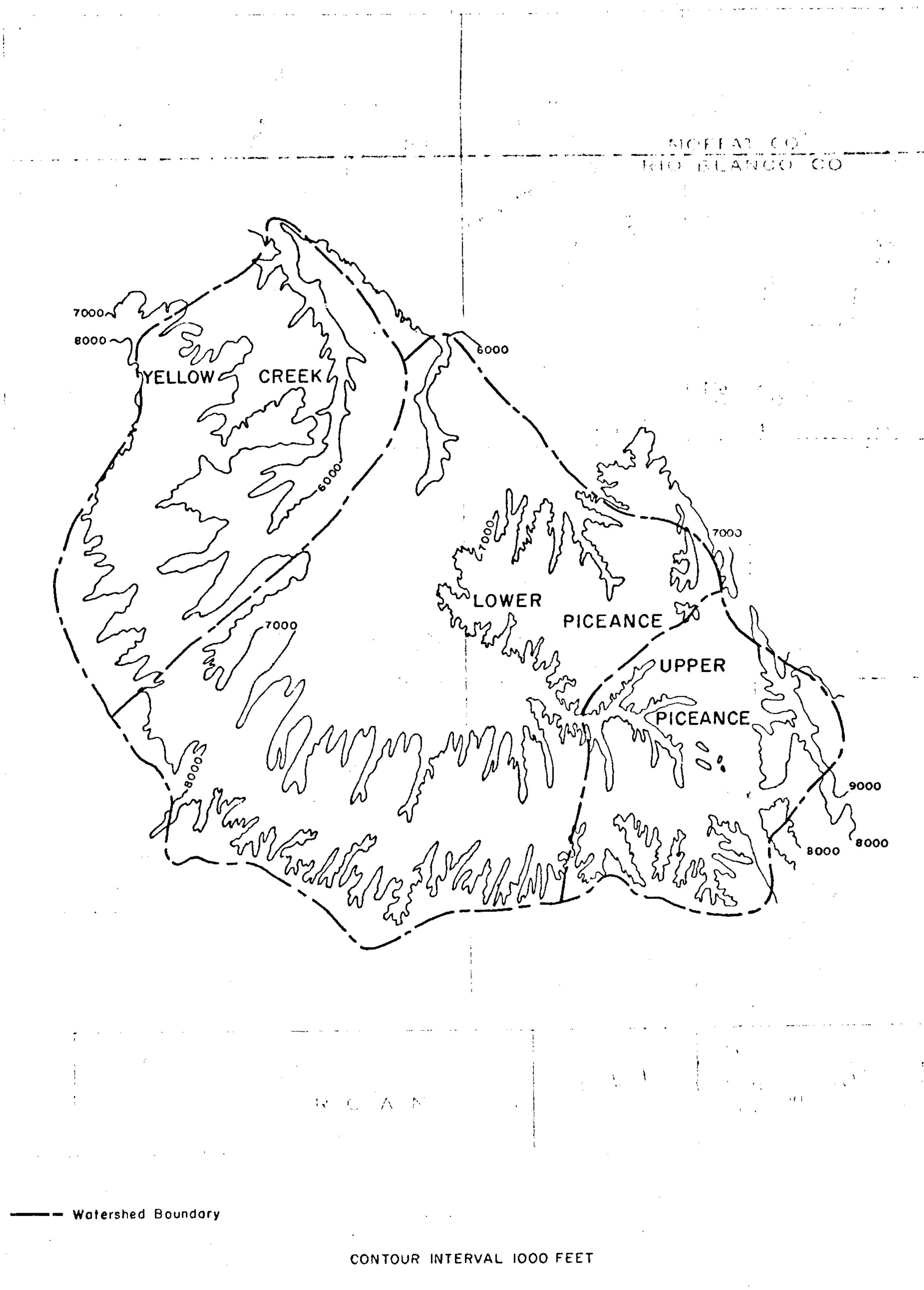

Figure 1. Piceance and Yellow Creek watersheds location map.

Table 1. Drainage area of Piceance and Yellow Creeks by elevation zone.

Drainage area	Elevation zones (feet) <6,000	6-7,000	7-8,000	8-9,000	>9,000	Total
Area in Acres:						
Upper Piceance Creek 1/		3,300	63,900	22,900	900	91,000
Lower Piceance Creek 2/	2,800	132,600	142,500	33,700		311,600
Total Piceance	2,800	135,900	206,400	56,600	900	402,600
Yellow Creek 3/	3,900	105,400	46,500	9,300		165,100
Total	6,700	241,300	252,900	65,900	900	567,700
Area in Square Miles:						
Upper Piceance Creek		5.2	99.8	35.8	1.4	142.2
Lower Piceance Creek	4.4	207.2	222.6	52.7		486.9
Total Piceance	4.4	212.4	322.4	88.5	1.4	629.1
Yellow Creek	6.1	164.7	72.7	14.5		258.0
Total	10.5	377.1	395.1	103.0	1.4	887.1
Percent of Area:						
Upper Piceance Creek		3.6	70.2	25.2	1.0	100.0
Lower Piceance Creek	0.9	42.6	45.7	10.8		100.0
Total Piceance	0.7	33.7	51.3	14.1	0.2	100.0
Yellow Creek	2.4	63.8	28.2	5.6		100.0
Total	1.2	42.5	44.5	11.6	0.2	100.0

SOURCE: Areas planimetered from USGS 7.5' Quads (Scale 1:24,000).

1/ Upper Piceance Creek - drainage area above USGS streamgage No. 93060 Piceance Creek near Rio Blanco.

2/ Lower Piceance Creek - drainage area between USGS streamgage No. 93060 and 93062.22 Piceance Creek at White River.

3/ Yellow Creek - drainage area above USGS streamgage No. 93062.55 Yellow Creek near White.

land not considered to be irrigated, or seep and phreatophytes was designated as sagebrush run-in areas. These run-in areas were used to account for the sagebrush, rabbitbrush, and greasewood vegetation using more water than provided by direct precipitation. A large part of the estimated total of 17,000 acres (Table 2) categorized as sagebrush run-in shows some indication of phreatophytic type water use, such as increased growth and seed production.

Table 2 summarizes the estimated land use and vegetation by drainage area for Piceance and Yellow Creeks. The land use and vegetation types by elevation zone for Upper and Lower Piceance Creek are shown in Table 3, and for Yellow Creek in Table 4.

For the detailed water balance estimate, the upland vegetation types were measured and estimated for generalized slope and aspect groupings. Because of time limitations, the estimates were generalized for 100 acre minimum areas (about one sq. in. on the base maps) from the USGS 1:24,000 topographic and vegetation base maps. Slope estimates were generalized using a 20 scale and calculator division to determine slope percent for areas. Short steep canyon wall areas were ignored for the most part. Slopes of from 5 to 50% (by 5% increments) and eight aspects were estimated by one technician[2/], with very limited supervision. The resulting estimates are consistent but make no claim to a high degree of accuracy. Details of the slope aspect acreages and evaluations are not shown in this report because space limitations, but copies may be obtained from the author if desired.

2/ Robert ("Tim") Sullivan, Senior Student in Watershed Science, Colorado State University, Ft. Collins, Colorado.

Table 2. Estimated land use and vegetation by drainage area for Piceance and Yellow Creeks.

Land use and vegetation types	Piceance Creek			Yellow Creek	Total Piceance and Yellow Creek watersheds	
	Upper Acres	Lower Acres	Total Acres	Acres	Acres	Percent
Upland						
Sagebrush	21,300	99,000	120,300	62,200	182,500	32.2
Desert shrubs		500	500	100	600	0.1
Pinyon-juniper	4,500	126,700	131,200	69,200	200,400	35.3
Mixed mountain shrub	37,400	53,000	90,400	20,400	110,800	19.5
Coniferous forest	12,500		12,500	100	12,600	2.2
Aspen forest	8,100	6,000	14,100	2,300	16,400	2.9
Rockland & misc. uses	3,000	13,600	16,600	5,000	21,600	3.8
Total upland	86,800	298,800	385,600	159,300	544,900	96.0
Bottomland						
Irrigated cropland	400	1,700	2,100	100	2,200	0.4
Irrigated meadow & pasture	200	600	800		800	0.1
Irrigated pasture	300	1,900	2,200	100	2,300	0.4
Total irrigated	900	4,200	5,100	200	5,300	0.9
Seep & phreatophyte areas	100	300	400	100	500	0.1
Sagebrush run-in	3,200	8,300	11,500	5,500	17,000	3.0
Total bottomland	4,200	12,800	17,000	5,800	22,800	4.0
Total watershed	91,000	311,600	402,600	165,100	567,700	100.0

Table 3. Estimated land use and vegetation types by elevation zone for Upper and Lower Piceance Creek.

Land use & vegetation types	Elevation zone (feet) <6,000 Acres	6-7,000 Acres	7-8,000 Acres	8-9,000 Acres	>9,000 Acres	Total Acres
Upper Piceance Creek:						
Upland						
Sagebrush		200	17,500	3,300	300	21,300
Pinyon-juniper			4,500			4,500
Mixed mountain shrub			24,700	12,600	100	37,400
Coniferous forest			11,200	1,300		12,500
Aspen forest			2,200	5,400	500	8,100
Rockland & misc. uses		1,900	800	300		3,000
Total upland		2,100	60,900	22,900	900	86,800
Bottomland						
Irrigated cropland		200	200			400
Irr. meadow & pasture		100	100			200
Irrigated pasture		200	100			300
Subtotal irrigated		500	400			900
Seep & phreatophyte area			100			100
Sagebrush run-in		700	2,500			3,200
Total bottomland		1,200	3,000			4,200
Total Upper Piceance Creek		3,300	63,900	22,900	900	91,000

Table 3. Estimated land use and vegetation types by elevation zone for Upper and Lower Piceance Creek. (Continued).

Land use & vegetation types	Elevation zone (feet) <6,000 Acres	6-7,000 Acres	7-8,000 Acres	8-9,000 Acres	>9,000 Acres	Total Acres
Lower Piceance Creek:						
Upland						
Sagebrush	1,100	33,000	46,500	18,400		99,000
Desert shrub	200	300				500
Pinyon-juniper		79,400	47,300			126,700
Mixed mountain shrub		1,700	40,800	10,500		53,000
Aspen forest			1,400	4,600		6,000
Rockland & misc. uses	100	7,500	5,800	200		13,600
Total upland	1,400	121,900	141,800	33,700		298,800
Bottomland						
Irrigated cropland	200	1,500				1,700
Irr. meadow & pasture	100	500				600
Irrigated pasture	100	1,800				1,900
Total irrigated	400	3,800				4,200
Seep & phreatophyte areas	100	200				300
Sagebrush run-in	900	6,700	700			8,300
Total bottomland	1,400	10,700	700			12,800
Total Lower Piceance Creek	2,800	132,600	142,500	33,700		311,600
Total Piceance Creek Watershed	2,800	135,900	206,400	56,600	900	402,600

Table 4. Estimated land use and vegetation types by elevation zone for Yellow Creek.

Land use & vegetation types	Elevation zone (feet) <6,000 Acres	6-7,000 Acres	7-8,000 Acres	8-9,000 Acres	>9,000 Acres	Total Acres
Upland						
Sagebrush	1,900	45,400	12,300	2,600		62,200
Desert shrub	100					100
Pinyon-juniper		51,900	17,300			69,200
Mixed mountain shrub		600	15,100	4,700		20,400
Coniferous forest				100		100
Aspen forest			500	1,800		2,300
Rockland & misc. uses	400	3,200	1,300	100		5,000
Total upland	2,400	101,100	46,500	9,300		159,300
Bottomland						
Irrigated cropland		100				100
Irr. meadow & pasture						
Irrigated pasture		100				100
Total irrigated		200				200
Seep & phreatophyte areas		100				100
Sagebrush run-in	1,500	4,000				5,500
Total bottomland	1,500	4,300				5,800
Total Yellow Creek	3,900	105,400	46,500	9,300		165,100

THE WATER BALANCE APPROACH

Water constitutes the primary limiting factor to plant growth in all arid or semiarid regions. Unfortunately, knowledge of the quantities of water that periodically replenish the root zone of soils and the forces that retain it, or the water use rates by vegetation and bare soil are not well understood. Obtaining the knowledge necessary for efficient use of available water supplies, and for maximization of desired products (range forage, timber, water, scenic values, etc.) from the nation's watersheds has only recently received much attention from researchers.

Data limitations make a detailed description of the hydrologic cycle for Piceance and Yellow Creek watersheds very difficult; therefore, the approach taken was to quantify the components of a simple water balance model. The water balance approach requires that any water entering the watershed system (precipitation) must equal the water moving out of the system (runoff, evaporation, transpiration, interception, or deep percolation) plus that stored in the soil root zone.

The water balance for Piceance and Yellow Creeks can be stated by the equation:

> Precipitation + Irrigation Water Use + Sagebrush Bottomland and Phreatophyte Run-in Use = Evapotranspiration + Deep Percolation + Runoff - Changes in Soil Water (initial minus final)

or

$$P + I + R_i = E_t + (D + R) - \Delta S \text{ (initial minus final)} \qquad (2\text{-}1)$$

Evapotranspiration (E_t) is a coined word to describe the combination of evaporation from water surfaces, moist soil, and transpiration from growing plants. For this report the terms evapotranspiration and consumptive use are used interchangeably. The irrigation water use (I) and sagebrush bottomland and phreatophyte run-in ("negative runoff") use (R_i) are shown on the left side of equation

(2-1) to emphasize that they are water supplies in addition to precipitation for the bottomland areas. From the watershed standpoint, net outflow (Q) is equal to runoff and deep percolation minus irrigation water use minus run-in water use by sagebrush and phreatophyte areas, or $Q = (D + R) - I - R_i$.

Although the water balance is simple and readily understandable, the quantification of specific factors is difficult. Therefore, some simplifying assumptions are necessary. Irrigation water will be applied only on the irrigated crop and meadow areas and can be ignored for upland evaluations. Run-in and phreatophyte use are also assumed to occur only on the bottomlands. In computing average annual water balance estimates, changes in soil water (ΔS) are negligible between years and can be assumed to equal zero. Recent research has also emphasized that natural plant associations have normal evapotranspiration rates that far exceed normal precipitation during the growing season, which effectively prevents deep percolation losses during most of the year (Branson et al. 1970; Galbraith, 1971, and Johnston et al. 1969). These studies indicate that for sites similar to the Piceance and Yellow Creek watersheds summer runoff is minimal during average years. A study of the streamgaging records of Piceance, Roan and Parachute Creeks verified that most growing season streamflow is from base flows. For evaluation purposes, surface runoff and deep percolation were not considered for average conditions except where they would occur as a part of spring snowmelt. This ignores the problem of thunderstorm runoff, but it was a necessary assumption with the limited data available.

These simplifying assumptions allow equation (2-1) to be reduced to a simpler form for the April through October growing season, which can be expressed as:

$$E_{ta} = P + \Delta S - (D + R) \qquad (2\text{-}2)$$

where actual evapotranspiration E_{ta} is used to denote the rate of water use taking place under existing soil, vegetal and climatic factors during the growing season. For this evaluation, E_{ta} is used to explain water use where precipitation and soil water are insufficient to meet the plants' water requirements at some time during the evaluation period. This includes all natural vegetation types in the Piceance Basin during, at least, the later portion of the growing season.

For the winter (November-March) snow accumulation period equation (2-1) may be reduced to:

$$P - E_{tw} = (D + R) - \Delta S \qquad (2\text{-}3)$$

or

$$-\Delta S = P - E_{tw} - (D + R)$$

where E_{tw} is the November-March E_t for a specific vegetation type. If we know the available water-holding capacity of the root zone soil profile, we can assume that this provides a limit on the change in soil water (ΔS). Since the Piceance basin is definitely a water deficient area, we can generally assume that the major portion of the root zone is at or near the wilting point toward the end of the growing season. Therefore, the entire available water-holding capacity of the soil can be used for storage if the water is available. This approach ignores the problem of frozen ground snowmelt runoff, but it is also one of the necessary simplifying assumptions. For low elevation areas and south slopes the November-March period may result in no soil water accumulation and even soil moisture deficits. For evaluation purposes, however, it was assumed that November-March $E_{ta} = E_{tw}$, or that the water demand was fully met by precipitation or soil water.

The surface runoff (R) and deep percolation (D) components of the water balance equation were evaluated as contributing to the ultimate water yield of Piceance and Yellow Creeks. This postulation that surface runoff and deep percolation both contribute to the water yield seems to be in error only for the portion of runoff and deep percolation that becomes run-in to lower areas, where it is subsequently used by vegetation. This is not a serious problem in the water balance calculations, because this run-in use can be treated the same as irrigation water use for calculation purposes.

The water balance bookkeeping involves six items: (1) Estimated evapotranspiration for the specific vegetation type with water not limiting; (2) Mean monthly precipitation; (3) Soil water storage up to the available water holding capacity; (4) Actual evapotranspiration; (5) Water surplus, including both surface runoff and deep percolation; and (6) Water deficit.

The next sections of this report briefly describe the determination of specific parameters for the water balance equation.

Precipitation

There is an almost total lack of long-term weather station data for the Piceance Basin. This is particularly true for the high elevation zones. A large number of factors influence precipitation, and these factors interact and change in relative importance from season to season. The seasonal distribution of precipitation influences its effectiveness and the importance of available water holding capacities of soils. Therefore, seasonal or monthly precipitation amounts are more useful in estimating the water balance than annual values.

Unfortunately, the only long-term weather station in the Piceance and Yellow Creeks watersheds is the Little Hills station (elevation 6,148 ft.) with a 12.90 average annual precipitation. As with the other weather stations in the region, this station is located in a valley and protected by the surrounding high terrain, and it is considerably below the elevation of most of the watershed areas.

A regression analysis of long-term precipitation records for eight regional weather stations against elevation was used to develop an estimate of the monthly precipitation by elevation zone[3/]. This analysis estimates total annual precipitation to vary from 9.79" at 5,000 ft. to 30.95" at 9,000 ft. An examination of the vegetation within the Piceance and Yellow Creeks watersheds show that these precipitation

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3/ Available from the Department of Earth Resources, Colorado State University as Appendix B - Regional Climatology for Chapter 7 - Water Requirements for Stabilizing and Vegetating Spent Shale in the Piceance Basin by I. F. Wymore, W. D. Striffler and W. A. Berg.

rates are definitely high for these watersheds. This is also indicated by the fact that Rangely and Little Hills stations have 17 to 19% less precipitation than predicted for their elevation zones.

An examination of the basic isohyetal normal precipitation map for Colorado[4/] also indicates a much lower precipitation for the Piceance Basin area. The report by Iorns and others (1965), however, indicates an area of 25-inch annual precipitation in the headwaters of Black Sulphur Creek, and an area of more than 30-inch annual precipitation in the headwaters of Piceance Creek.

For evaluation purposes the value of 80% of the regional analysis by elevation zones was found to provide the best general equations for the Piceance and Yellow Creeks (Table 5). These values also seem to correlate well with the vegetation types found on most of the sites. The exception seems to be an area in the immediate vicinity of Rio Blanco where orographic influences seem to produce higher precipitation rates.

The outstanding characteristic of all weather records in the Piceance Basin region is the relative uniformity of long-term monthly precipitation for the eight regional weather stations. The average monthly precipitation is 1.17", and the largest deviations are in August with 1.59" and November with 0.99". Marlatt and Reihl (1963) also note this lack of pronounced wet and dry seasons for precipitation stations in the Upper Colorado River Basin.

While long-term precipitation records show considerable uniformity between months the true climate is extremely variable, and marked by consecutive months with little or no precipitation. As an indication of precipitation variability the 20-year (1951-70) annual precipitation was analyzed for the eight regional weather stations. Table 6 provides

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4/ U.S. Department of Commerce, Environmental Science Services Administration, Weather Bureau. 1959. Normal Annual Precipitation (1931-60) Maps for State of Colorado.

Table 5. Estimated precipitation relationships by elevation zones for Piceance and Yellow Creek watersheds.

Elevation zone		Precipitation (inches) November-March	April-October	Total Annual
Intercept	(a)	-5.93	-7.44	-13.37
Increase per 1,000 ft.	(b)	1.76	2.47	4.23
Lower Piceance and Yellow Creeks:				
<6,000	(5,900)	4.45	7.14	11.59
6-7,000	(6,500)	5.51	8.62	14.13
7-8,000	(7,500)	7.27	11.09	18.36
>8,000	(8,200)	8.50	12.81	21.31
Total watershed	(7,040)	6.46	9.96	16.42
Upper Piceance Creek:				
<7,000	(6,800)	6.04	9.35	15.39
7-8,000	(7,500)	7.27	11.09	18.36
8-9,000	(8,500)	9.03	13.56	22.59
>9,000	(9,100)	10.09	15.03	25.12
Total watershed	(7,742)	7.70	11.68	19.38
Estimated average for Piceance and Yellow Creek watersheds	(7,145)	6.66	10.23	16.89

SOURCE: Based on evaluations of regional precipitation records, isohyetal maps, vegetation indicators, and preliminary water balance calculations.

Table 6. Average annual precipitation, minimum and maximum annual precipitation for the 95% confidence limits, and 80% chance annual precipitation based on precipitation records for the 1951-70 period (inches).

Station	Elevation (feet)	Annual precipitation (inches) 1951-70 average	95% Confidence limits Minimum	95% Confidence limits Maximum	80% Chance of > than
Grand Junction	4,849	8.18	2.45	13.91	5.82
Rangely	5,216	9.03	2.59	15.57	6.40
Rifle 2ENE	5,319	11.27	3.82	18.72	8.20
Altenbern	5,690	15.83	7.48	24.18	12.37
Glenwood Springs	5,823	15.84	6.78	24.90	12.12
Little Hills	6,148	12.91	6.70	19.10	10.35
Meeker	6,242	17.52	10.99	24.05	14.84
Marvine	7,200	20.54	11.34	29.74	16.76
Average	5,810	13.89	6.52	21.27	10.86
Intercept	(a)	-16.88	-18.41	-15.23	-17.51
Change per 1,000 ft.	(b)	5.29	4.29	6.28	4.88
Coefficient of determination		0.82	0.83	0.75	0.84

the average annual, minimum and maximum for the 95% confidence limits, and the 80% chance annual precipitation for each of the eight regional weather stations. For the stations evaluated the 95% confidence interval minimum precipitation averages about 47% of average annual, and maximum about 153% of average annual. The 80% chance precipitation averages about 78% of annual precipitation.

Irrigation (I)

Irrigation water is normally applied to about 5,300 acres of crop and pasture land in the Piceance and Yellow Creeks watersheds. For water balance calculations the portion of actual evapotranspiration in excess of precipitation is subtracted from total runoff from higher elevation areas to arrive at net runoff estimates. For this report, consumptive water use by seep and phreatophyte or sagebrush run-in areas are accounted for by treating them as a net reduction in total runoff to the extent that estimated actual evapotranspiration exceeds normal precipitation.

Actual consumptive use for irrigated cropland is based on a full water supply. For irrigated meadow and pasture the actual consumptive use is based on a 6.00" AWC (available water holding capacity) in the soils, and a full water supply through July. Irrigated pastures are evaluated on the basis of a 5.00" AWC, and a full water supply through June. Using these criteria, and the specific evapotranspiration rates explained later in this report, the net consumptive use of irrigation water varies from 21.78 inches on irrigated cropland at the less than 6,000 ft. elevation zone to 5.85 inches for irrigated pastures at the 7-8,000 ft. elevation zone.

Water Holding Capacity of Soils (ΔS)

The primary source of water to growing plants is that held within the volume of soil invaded by plant roots. The available soil water for this report is considered to be that portion of soil water between the field capacity and the permanent wilting point. It is a function of the soil depth, texture of the surface and subsurface soils, stoniness, specific water-holding capacity of the soil materials, and the plant rooting depths. Therefore, the average available water-holding capacity (AWC) of soils can only be generalized with even the best field and laboratory measurements, and in the Piceance Basin there are essentially no detailed soil surveys available. The estimates used for this evaluation were developed from generalized soil maps, U.S. Soil Conservation Service Range Site and Soil Series Descriptions[5/], special soil surveys by Fox and others (1973) as a part of the Regional Oil Shale Study, and generalized soil-moisture constants by Broadfoot and Burke (1958). The study also used AWC information contained in a water balance study of similar vegetation and soils in the Ruby Mountains of Nevada (Nevada Dept. of Cons. and Natural Res. and the USDA, 1963), and from the Davis Gulch water balance study (Wymore, 1973).

Table 7 summarizes the available water-holding capacity estimates, by vegetation type and elevation zones, used in the Piceance and Yellow Creeks water balance studies. Rather obviously, these estimates are subject to revision as more detailed information becomes available.

Evapotranspiration (E_t)

The methodology for estimating evapotranspiration by the modified Jensen-Haise method is discussed in the next chapter. Unfortunately, there is a general void of information on the water requirements for natural vegetation in arid and semiarid climatic zones. Irrigation studies and consumptive use methodology provide a good measure of potential evapotranspiration under full ground cover where water is not limiting, but these estimates must be adjusted for actual water use by limited vegetation and widely varying water supplies. Because the Piceance and Yellow Creeks have such a wide range in elevation, cover, precipitation, soil development, slopes, and slope facings it is impossible to accurately estimate all the variables in potential water use that occur in the watersheds.

5/ Personal communication Thomas K. Eaman, Range Conservationist, Colorado State Office of the U.S. Soil Conservation Service.

Table 7. Estimated available water-holding capacity (inches) by vegetation type for typical soil profiles by elevation zones.

Vegetation type	Elevation zone (feet)				
	<6,000	6-7,000	7-8,000	8-9,000	>9,000
	Inches	Inches	Inches	Inches	Inches
Upland areas:					
Sagebrush	5.80	5.40	4.30	3.80	3.80
Desert shrub	6.50	6.50			
Pinyon-juniper		2.50	3.00		
Mountain shrub		3.50	4.00	4.50	4.50
Coniferous forest		3.50	3.50	3.50	
Aspen forest		5.00	5.00	5.00	5.00
Rockland & Misc.	2.00	2.00	3.00	3.00	
Bottomland areas:					
Irrigated cropland	6.00	6.00	6.00		
Irr. meadow & past.	6.00	6.00	6.00		
Irrigated pasture	5.00	5.00	5.00		
Seep & phreatophyte	10.00	10.00	10.00		
Sagebrush run-in	7.00	7.00	7.00		

Surface Runoff (R) and Deep Percolation (D)

Streamflow is generally ephemeral in the upper reaches of all streams in the Piceance Basin. Piceance Creek below Ryan Gulch (USGS streamgage No. 93062) has eight years of data for the 1965-72 period. The gage show average discharge of 15.0 cfs (10,870 acre-ft. per year). After accounting for irrigation diversion by-pass, the average discharge at the site would total 11,766 acre-ft. or 0.45 inches of runoff for the 485 sq. mile drainage area. Annual runoff is extremely variable with the 8-years of record showing a standard of deviation of 3,660 acre-ft. The Piceance Creek at the White River (USGS streamgage No. 93062.22) has only 4-years of data during the 1965-72 period. This gage site shows an average runoff of 12,788 acre-ft. when irrigation by-pass is considered[6/]. A regression analysis for the 4-years of comparable data allows the 8-year period prediction of 13,377 acre-ft. (0.40 area inches of runoff) for Piceance at the White River.

6/ Personal communication George Leavesley, U.S. Geological Survey.

EVAPOTRANSPIRATION ESTIMATION: THE JENSEN-HAISE METHOD

Methods of Measuring and Estimating Evapotranspiration

A number of empirical methods are used to estimate consumptive use and irrigation water requirements for the standard irrigated farm crops. These methods all provide a good estimate of water use for the specific crop, or region, for which they were originally developed. Unfortunately, these equations were developed to estimate agricultural growing season water use for flat irrigated fields, below 5,000-ft. elevations, within large areas of irrigated cropland, and for a strictly monocultural vegetation. These conditions minimize the effects of heat transfer, differences in the drying power of the air, and uneven wind currents.

In contrast to irrigated crop consumptive use, native vegetation evapotranspiration estimation requires estimates for the entire year. The Piceance and Yellow Creeks have elevation zones from about 6,000 ft. to more than 9,000 ft., wide variations in topography, at least seven major vegetation types, and many barren cliffs or canyons that create hot upslope winds; and the Basin is in the middle of a large area of water-deficient, sparse vegetation. These factors all emphasize the need for special evapotranspiration methodology. They also emphasize the impossibility for the generalized methodology to provide specific water requirements for individual sites or years.

Jensen-Haise Method

The Jensen-Haise (1963) method was chosen for this study because, with modification it can be used to estimate annual evapotranspiration, and because it can provide quantification of observed differences in water use for different slopes and aspects. It was also specifically developed for use in the arid or semiarid western United States. The Jensen-Haise method uses the energy of solar radiation as the main parameter and modifies it by a linear formula using mean air temperature in °F.

The evapotranspiration estimates contained in this report are bookkeeping methods, and make no pretense toward theoretical elegance. The Jensen-Haise method was modified to provide annual estimates by elevation zones. The original equation is used only to estimate the April-October potential evapotranspiration for the 5,000-ft. elevation zone. The modifications were made to add estimated E_t for elevation zones up to 9,000 ft. and to estimate water losses during the November-March moisture accumulation period. The modified Jensen-Haise method provides quantification for differences in water requirements by slope, aspect, and vegetation type.

The Jensen-Haise method of estimating evapotranspiration is an energy budget approach based on an evaluation of the ratio of evapotranspiration to solar radiation as a function of air temperature. The Jensen-Haise (1963) equation was developed from the regression of E_{tp}/R_s on air temperature for 100 selected measurements of crops in which the evaporation and transpiring surfaces were not limiting.

The original Jensen-Haise (1963) equation for potential evapotranspiration is:

$$E_{tp} = (0.014\ T - 0.37)R_s \qquad (3\text{-}1)$$

where

E_{tp} = Potential evapotranspiration (inches), which represents the upper limit or maximum E_t that occurs over periods of 10 days or longer under given climatic conditions. This use rate is approximated by well watered alfalfa with 12 to 18 inches of top growth.

T = Mean air temperature for the period (°F)

R_s = Total solar and sky radiation converted to inches of evapotranspiration equivalent.

Native vegetation water requirements for the Piceance Basin require estimates for the entire year. Therefore, the evaluation of evapotranspiration is conducted as

$$E_{tp} = E_{tps} + E_{tpw} \tag{3-2}$$

where

E_{tps} = April-October growing season potential evapotranspiration.

E_{tpw} = November-March water accumulation period (mostly as snow) potential evapotranspiration.

<u>April-October Equation</u>

The special requirements for estimating the growing season evapotranspiration in the Piceance Basin required major revisions in the original Jensen-Haise equation. The first, was to permit a rapid evaluation of temperatures that differ from the regional mean monthly temperatures. These differences may result from heat flux from spent shale piles, differences in slope facing (aspect), or from ridgetop or valley sites. The temperature correction factor (T_{cf}) also permits a rapid estimate of expected E_t rates for any regional weather station by comparison with the Piceance Basin regional equations. The second, was to provide an altitude correction factor by varying the intercept (-0.37) in the original equation for high elevation cold sites. This was also used to correct for some under estimation of mean monthly temperatures by the regional temperature analysis. The third, was to provide a means of evaluating the effect of various slopes and aspects in terms of available energy for evapotranspiration. The radiation correction factor (R_{cf}) used is the decimal percentage of potential radiation, which permits a rapid evaluation of the effect of specific slopes and aspects on evapotranspiration rates.

The revised Jensen-Haise equation for estimating April-October (7 months) potential evapotranspiration is:

$$E_{tps} = \sum_{i=1}^{7} [0.014(T+T_{cf}) - (0.57 - 0.04E_1)] \, R_s R_{cf} \qquad (3\text{-}3)$$

where

T_{cf} = Temperature correction factor in °F

R_{cf} = Radiation correction factor which is the decimal percentage of solar radiation incident to a horizontal plane that effectively reaches a given slope and aspect calculated from tables in Frank and Lee (1966).

E_1 = Elevation of the evaluated site in thousands of feet.

Specific values used in computing the Piceance Basin regional water use rates are discussed later in this section. It might be noted, however, that for a horizontal surface at 5,000 ft. the equation for E_{tps} is equal to the original Jensen-Haise equation.

Recent research by Kruse and Haise (1973) indicates that the Jensen-Haise provides good estimates of water use by high altitude wet mountain meadows by changing the entercept value for high-elevation cold sites. For example, the corrected equations for South Park (9,100 ft.) is $E_t = (0.014T - 0.194)R_s$ and for Gunnison (8,000 ft.) is $E_t = (0.139T - 0.202)R_s$.[7/] They also noted that the original Jensen-Haise equation resulted in significantly low estimates, "generally less than 75 percent of measured values". This research was conducted on wet mountain meadows with water at or near the surface (soil surface damp) so the water use rate should approximately equal potential evapotranspiration rates for the May-September growing season at these experimental sites.

November-March Equation

The original Jensen-Haise equation was developed for mean air temperatures of from 40-90°F, and provides estimates of zero consumptive

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7/ A special equation derived from a regression analysis of 1968 South Park data, $E_t = (0.123T-0.147)R_s$, gave the best estimate of measured water use rates.

use at mean daily temperatures of approximately 26°F. Since average winter evaporation losses from snow cover are about 1/2-inch water equivalent per month (Garstka, 1964), estimation of the November-March water losses required a revised estimation equation. Water losses in winter are complex and related to the amount and type of precipitation and interception, amount of drifting, radiation (heat) balance of the snowpack, slope, aspect and vegetation cover as well as the complex factors that affect the sublimation of snow by evaporation or condensation.

The equation for estimating November-March E_{tpw} was developed by the same basic methodology as the original Jensen-Haise equation except that pan evaporation (E_{pan}) rates were used to estimate maximum use rather than growing crops with a full water supply. The regression analysis of E_{pan}/R_s ratio versus air temperature was conducted with monthly values from the Montrose, Colorado (5,830 ft.) station and solar radiation from the Grand Junction airport weather station. Comparable pan evaporation, mean monthly temperatures, and solar radiation data for November-March are available for a total of 66 months during the 1951-71 period. As expected, the data from two stations over 50 miles apart (during the winter months when inversions and localized snowstorms are common) does not show a high correlation ($R^2 = 0.29$). But when the equation was checked with long-term (30-year) Montrose station data it provided a good approximation of pan evaporation rates. The pan evaporation equation was then adjusted to provide potential evapotranspiration rates that are 83 percent of pan evaporation to make estimates of E_{tpw} equivalent to those for the April-October equation.

The November-March (5 months) equation for estimating potential evapotranspiration for various slopes, aspects, and temperature relationships can be stated as:

$$E_{tpw} = \sum_{i=1}^{5} [0.006\ (T + T_{cf}) + 0.05]\ R_s R_{cf} \qquad (3\text{-}4)$$

where all of the factors have the same definition as previously described, but are specific for the November-March period.

Piceance Basin Potential Evapotranspiration

As noted in defining potential evapotranspiration, E_{tp} represents the upper limit of water use that occurs from revegetation and soil surfaces under given climatic conditions. Conditions for this high water use rate seldom occur in the Piceance Basin, except for a few days after a good rain when water is readily available from the soil surface. The scattered vegetation (less than 100% ground cover), limitations in water availability, and a native vegetation largely adapted to xeric conditions (mature rapidly during the season when water is available) all tend to limit water use to much less than potential.

To even a casual observer the climatic effects of different slopes and exposures of the Piceance Basin are evident from the vegetational differences. The climate of slopes facing different directions is affected by moisture conditions, solar radiation, and winds; and to some extent by the height and density of vegetation. The most xeric slopes are generally south or southwest facing, and the most mesic slopes are the north or northeast facing. There is also a definite increase in size and density of vegetation with an increase in elevation throughout the Piceance Basin. The balance of this section attempts to quantify the effects of temperature and solar radiation on potential evapotranspiration.

Temperature Factors

The mean monthly air temperature (T) in °F is the value required to provide E_{tp} estimates for specific locations. Unfortunately, the local climate is strongly affected by microclimatic features of slope, aspect, elevation, vegetation, and surface wind patterns. Temperatures adjacent to the surface will sometimes differ 20-30°F between north-facing and south-facing slopes (Marlatt, 1973). Mean daily temperatures, of course, show much less variation.

Calculation of the basic monthly E_{tp} rates for a horizontal surface used temperature relationships developed by a regression analysis of mean monthly temperature records for 8 long-term regional weather stations. These predicted mean monthly temperatures (°F) by elevation zones are summarized in Table 8.

It should be noted that the regional weather stations are generally located in valley sites that tend to be heat sinks. Therefore, the regional analysis of temperatures by elevation zones underestimates the true temperatures for areas with good air drainage.

The use of a variable intercept (-0.04/1,000 ft. change in elevation) in equation 3-3 is equivalent to reducing the average April-October lapse rate shown in Table 8 from 6.0 to 3.2°F/1,000 ft. change in elevation. Stated in other terms it is equivalent to raising the mean monthly temperature by 11.4°F at the 9,000 ft. elevation zone for the original Jensen-Haise equation. Underestimation of the true temperature regime for the Piceance Basin region is only one of the reasons for needing the variable intercept to compute E_{tp}, but it is the visible one for a temperature related empirical equation such as the Jensen-Haise.

<u>Aspect Temperature Correction Factors</u> - As noted by Marlatt (1973) there are large temperature differentials between North and South facing slopes during the daytime, but there are no long-term records of temperature differentials related to slopes for the Piceance Basin. Geiger (1961) reports that temperature stratification exists even on steep slopes, and that daytime temperatures are highest on the valley bottoms and plateaus. At night the temperature tends to increase with height because of the negative radiation balance.

Research on the ecosystems of the east slope of the front range in Colorado (Marr, 1961) found that north-facing slopes averaged 1.2°F colder than ridge sites. South-facing slopes were 1.9° warmer in the winter months, and 0.7°F warmer in the summer months. Valley sites averaged 5.5°F colder than the ridge sites. This research was conducted at ridge site elevations of 7,200 and 8,500 ft., with April-October average temperatures of 57.3 and 52.0°F respectively for an average lapse rate of about 4.1°F/1,000 ft. The November-March average temperatures were 33.2 at 7,200 ft. and 28.4°F at 8,500 ft. for an average lapse rate of 3.7°F/1,000 ft.

Table 8. Predicted mean monthly temperatures (°F) by elevation.

Month	Elevation (feet) 5,000	6,000	7,000	8,000	9,000	Intercept (a)	Change per 1,000 ft (b)
November-March Period:							
November	37.4	35.2	32.9	30.6	28.4	48.78	-2.27
December	26.1	24.6	23.2	21.7	20.2	33.38	-1.46
January	23.3	21.3	19.4	17.5	15.6	32.92	-1.93
February	30.8	27.2	23.5	19.9	16.3	49.06	-3.64
March	39.4	33.9	28.4	22.9	17.4	66.99	-5.51
Average	31.4	28.4	25.5	22.5	19.6	46.13	-2.95
April-October Period:							
April	49.3	44.0	38.8	33.6	28.3	75.39	-5.23
May	59.7	52.7	45.8	38.8	32.0	94.42	-6.94
June	67.9	61.7	55.1	48.7	42.3	99.88	-6.40
July	75.4	68.6	61.7	54.9	48.1	109.52	-6.82
August	72.7	66.2	59.8	53.3	46.8	104.98	-6.46
September	64.0	57.6	51.3	44.9	38.5	95.69	-6.35
October	50.8	47.0	43.2	39.4	35.7	69.62	-3.77
Average	62.8	56.8	50.8	44.8	38.8	92.80	-6.00
Annual	49.8	45.1	40.3	35.5	30.8	73.60	-4.76

SOURCE: Regional analysis of 8 long-term weather station average mean monthly temperatures versus station elevation.

In the absence of definite air temperature relationships for the various aspects in the Piceance Basin, it was necessary to postulate the probable relations. The approach taken was to use the minimum temperature differentials that would provide logical distribution of evapotranspiration rates in combination with variations in solar radiation rates using the modified Jensen-Haise method. Basically, this was the rate found in the Colorado front range studies noted above (Marr, 1961), with specific aspect adjustments suggested by research on soil and air temperatures (Geiger, 1961). Figure 2 provides the aspect temperature correction factors suggested for use in the Piceance Creek Basin. These aspect adjustment factors were used to adjust the horizontal surface E_{tp} rates for all evaluations with the knowledge that they tend to underestimate the true differences for winter months, for poorly vegetated sites, and for spent shale disposal areas.

The temperature correction factor (T_{cf}) provided in the E_{tp} equations (3-3 & 3-4) provide a means of adjusting the regional estimates to any specific temperature measurements. All that is necessary is to determine the extent that the measured temperature varies from the November-March or April-October regional averages shown in Table 8 and apply this differential as the temperature correction factor.

Solar Radiation Factors

The energy budget approach of the Jensen-Haise method recognizes solar radiation as the driving force for the hydrologic cycle. For this evaluation, the Grand Junction WBAP solar radiation data (1951-71) were used as the basis for all evapotranspiration calculations. Table 9 provides a summary of the available solar radiation data, and the conversion to average monthly inches evaporation equivalent.

The use of measured solar radiation for regional studies was evaluated by Jensen (1966), and in the relatively cloudless western United States he found a high correlation between data from widely separated stations.

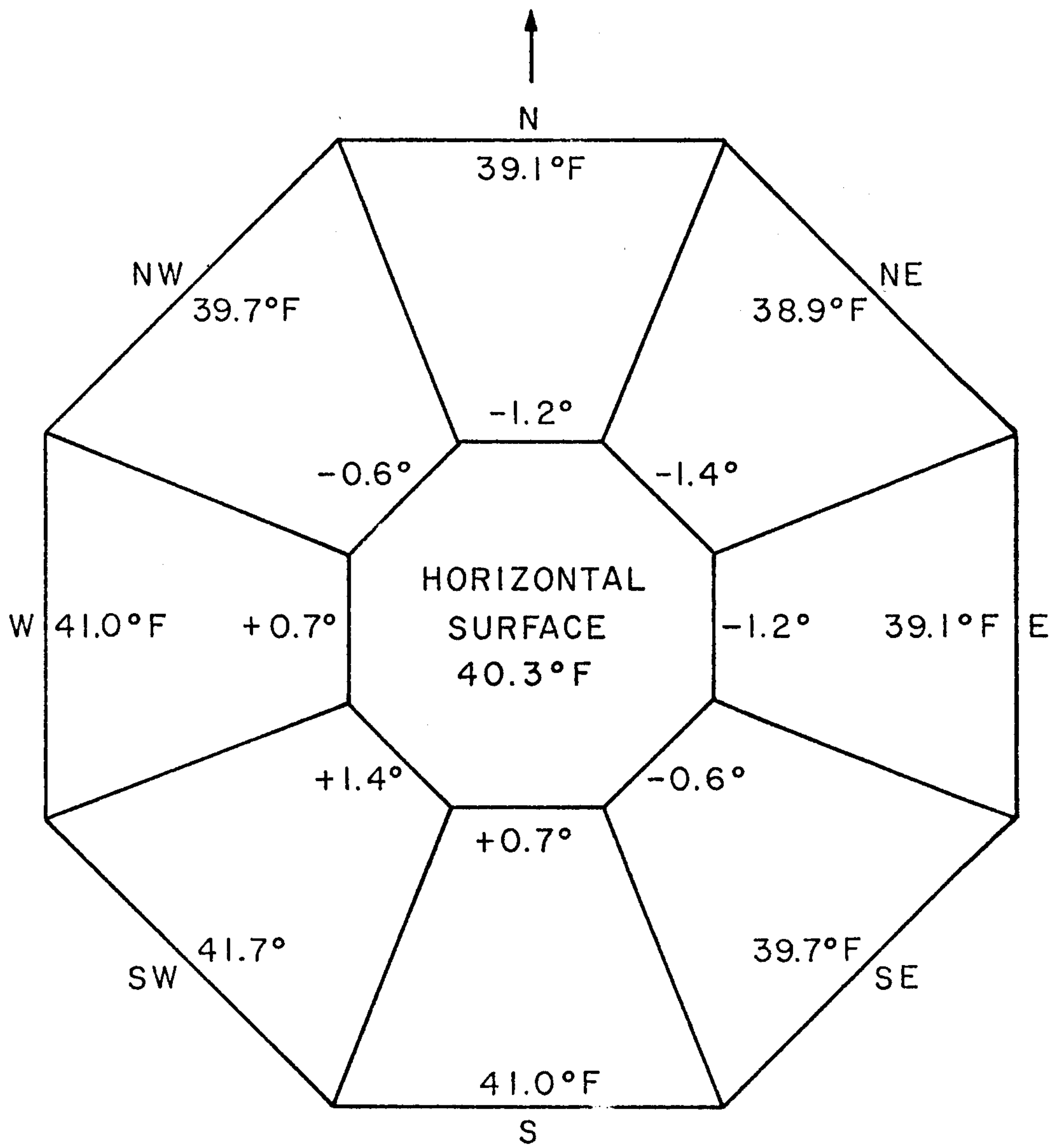

Figure 2. Estimated departure from mean monthly air temperatures (°F) according to slope-facing, and the resulting mean annual temperature estimates for the 7,000 ft. elevation zone.

Table 9. Grand Junction WBAP solar radiation - average daily values (direct and diffuse) received on a horizontal surface (1951-71).

Months	Average daily langleys[1/]	Years of record	Inches evaporation equivalent[2/]
November-March:			
November	265	19	5.35
December	217	20	4.52
January	243	20	5.08
February	326	20	6.14
March	440	19	9.18
Subtotal	298		30.27
April-October:			
April	540	18	10.90
May	620	20	12.94
June	688	17	13.89
July	663	18	13.83
August	581	19	12.12
September	509	17	10.27
October	382	19	7.97
Subtotal	569		81.92
Annual	457		112.19

1/ Average daily solar radiation on a horizontal surface tabulated in langleys (langley = one gram calorie per cm^2).

2/ Calculated for total days in month and converted to equivalent depths of evaporation assuming heat of vaporization of 585 cal/g (Langleys x 0.000673 = inches).

SOURCE: Environmental Data Service, ESSA, U.S. Dept. of Commerce. 1968. Climatological Atlas of the United States, and 1963-70 Climatological Data National Summary.

The monthly solar radiation rates received at Grand Junction are relatively uniform between years (Ave. std. dev. = 40 langleys/day) for the 1951-71 period. From a practical viewpoint, in fact, the use of a simple 65% of the theoretical solar beam irradiation for horizontal surfaces at 40° North latitude (Frank and Lee, 1966) produces the same estimates of potential evapotranspiration.

Slope or exposure climate is determined to a large extent by the amount of direct solar radiation and heat received by an inclined surface in comparison with a horizontal surface. The ratio of solar radiation received on a specific slope and aspect in relation to that for a horizontal surface provides a factor for adjusting the measured solar radiation, or calculated E_{tp} rates for the horizontal surface. These radiation correction factors are computed for the desired slope and aspect from published tables (Frank and Lee, 1966).

Table 10 provides the radiation correction factors (R_{cf}) for 5-50% slopes during the November-March and April-October periods in the Piceance Basin region. They were developed by applying the individual months ratios to the evaporation equivalent of Grand Junction solar radiation and suming for the November-March and April-October periods then dividing by the 30.27 and 81.92 inches evaporation equivalent on a horizontal surface for these periods.

Therefore, the specific ratios are only for regional evaluations using the Grand Junction solar radiation rates and should not be used for other evaluations.

An examination of the radiation correction factors shown on Table 10 provides an indication of the reason for many of the ecological factors, related to slope and aspect, that are observed in nature. One of the more important factors for spent shale disposal is that south facing slopes tend to be more xeric because they receive much higher insolation rates in the winter months. This results in greatly increased winter evaporation losses, and reduced water supplies available for soil water recharge from spring snowmelt. The growing season is also initiated much sooner on the south facing slopes.

Table 10. Slope aspect radiation correction factors (R_{cf}) for 5-50% slopes during the November-March and April-October periods for the Piceance Basin.

Percent Slope	November-March Factors					April-October Factors				
	N	NE-NW	E-W	SE-SW	S	N	NE-NW	E-W	SE-SW	S
5	.912	.939	1.001	1.059	1.084	.979	.985	.999	1.011	1.016
10	.824	.879	1.001	1.119	1.168	.959	.971	.998	1.023	1.031
15	.735	.822	1.002	1.173	1.245	.934	.953	.996	1.031	1.042
20	.647	.765	1.004	1.226	1.322	.909	.936	.994	1.040	1.052
25	.571	.713	1.004	1.266	1.379	.882	.916	.990	1.045	1.061
30	.494	.662	1.005	1.305	1.435	.855	.895	.986	1.050	1.066
35	.415	.618	1.007	1.353	1.505	.826	.875	.981	1.053	1.068
40	.335	.574	1.009	1.401	1.575	.797	.854	.977	1.055	1.070
45	.274	.529	1.010	1.433	1.624	.766	.833	.971	1.055	1.069
50	.212	.500	1.012	1.466	1.673	.736	.812	.965	1.054	1.068

SOURCE: Composite correction factors developed by applying ratios developed from 40°N latitude tables in Frank and Lee (1966) to Grand Junction solar radiation evaporation equivalent.

Elevation Zone Potential Evapotranspiration

The individual monthly elevation zone potential evapotranspiration (E_{tp}) rates on the horizontal surface were computed using equations 3-3 and 3-4 with temperature factors from Table 8 and solar radiation rates from Table 9. The resulting horizontal surface monthly E_{tp} rates by elevation zones are provided in Table 11.

The deliberate assumption of linearity for elevation zone evapotranspiration permits a simplification of E_{tp} estimates for the different elevation zones, slopes, aspects, and water use periods. The April-October equation (3-3) can be stated as:

$$E_{tps} = (61.94 - 3.78\ E_1 + 1.147\ T_{cf})R_{cf} \qquad (3\text{-}5)$$

and the November-March equation (3-4) can be stated as:

$$E_{tpw} = (10.42 - 0.60\ E_1 + 0.182\ T_{cf})R_{cf} \qquad (3\text{-}6)$$

where

$1.147T_{cf} = (0.014T_{cf})\ 81.92$ The factor 81.92 being the total inches evap. equiv. of Grand Junction solar radiation for the April-Oct. period.

$0.182T_{cf} = (0.006T_{cf})\ 30.27$ The factor 30.27 being the total inches evap. equiv. for the Nov.-March period.

The E_{tp} rates for 5-50% slopes and eight aspects can be estimated with the above equations, the T_{cf} information from Figure 2, and the R_{cf} from Table 10. For example, if the E_{tp} for a 25% NE slope at 7,000 ft. is desired [(E_{tps} = 61.94 - 26.46 - 1.606) 0.916 = 31.03 inches, plus E_{tpw} = (10.42 - 4.20 - 0.254) 0.713 = 4.25 inches] the potential evapotranspiration would total 35.28 inches. The equivalent E_{tp} for a horizontal surface would be 41.70 inches (Table 11).

Table 11. Potential evapotranspiration (inches) on a horizontal surface by elevation zones.

Month	Elevation (feet) 5,000	6,000	7,000	8,000	9,000	Intercept (a)	Change per 1,000 ft. (b)
	Inches	Inches	Inches	Inches	Inches	Inches	Inches
November-March period:							
November	1.47	1.40	1.32	1.25	1.18	1.835	-0.073
December	.93	.89	.86	.82	.78	1.115	-0.037
January	.96	.90	.84	.79	.73	1.243	-0.057
February	1.44	1.31	1.18	1.04	.91	2.107	-0.133
March	2.62	2.32	2.02	1.72	1.42	4.120	-0.300
Subtotal	7.42	6.82	6.22	5.62	5.02	10.420	-0.600
April-October period:							
April	3.49	3.12	2.76	2.39	2.03	5.315	-0.365
May	6.02	5.29	4.55	3.81	3.08	9.702	-0.736
June	8.08	7.39	6.69	6.00	5.31	11.545	-0.693
July	9.48	8.71	7.94	7.18	6.41	13.313	-0.767
August	7.85	7.24	6.63	6.01	5.40	10.916	-0.613
September	5.40	4.89	4.40	3.90	3.39	7.903	-0.501
October	2.72	2.62	2.51	2.41	2.30	3.246	-0.105
Subtotal	43.04	39.26	35.48	31.70	27.92	61.940	-3.780
Total	50.46	46.08	41.70	37.32	32.94	72.360	-4.380

Evapotranspiration for Specific Vegetation Types

Once the E_{tp} rates have been calculated, estimates of evapotranspiration for specific vegetation types (with water not limiting) can be calculated as follows:

$$E_t = K_c E_{tp} \tag{3-7}$$

where K_c is a plant water use coefficient that would ideally be determined experimentally with many years of data. Different monthly coefficients are needed for each major vegetation type and cover density for accurate estimation purposes. Fortunately, we are most interested in actual evapotranspiration ($E_{ta} = P + \Delta S$) during the growing season, and the bookkeeping method used prevents serious errors, because water is not limiting only during the winter months, or the early part of the growing season when soil water is plentiful.

Seasonal and monthly water use coefficients for irrigated crops are reasonably well defined. Crop coefficients for irrigated cropland growing season are available from irrigation studies (Jensen and Haise, 1963; Pair et al. 1969; Jensen, 1972; and Kruse and Haise, 1973). The monthly water use coefficients for native vegetation were adopted from those used for irrigated pasture and hay. The adjustments for revegetation areas were made using the growth characteristics of western wheatgrass (Agropyron smithii Rydb.) from research by Blaisdell (1958), and Hyder and Sneva (1963). This adjustment in the K_c coefficients accounts for the reduced water requirements by native grasses and other plants that are allowed to mature and produce seed rather than being harvested to maintain vegetative growth.

The K_c values for estimating E_t (water not limiting) for native vegetation were adjusted to account for known plant characteristics estimated plant populations (% ground cover), interception losses, estimated winter evaporation, and seasonal variations in plant growth rates. Table 12 provides a summary of the monthly plant water use coefficients (K_c) for native vegetation and irrigated revegetation areas or cropland.

These K_c values are definitely subject to refinement. Therefore, the specific E_t rates computed using $E_t = K_c E_{tp}$ relationship are only as accurate as the K_c values, and should be used with caution. In areas such as the Piceance and Yellow Creeks watersheds with wide ranges of elevation (hence climatic zones) the monthly K_c values should also be adjusted for changes in the growing season. For this study, the K_c values shown on Table 12 are based on the 7,000 ft. elevation zone to the extent possible.

For this study, a complete evaluation of evapotranspiration for a horizontal surface was made by months for each of the vegetation types for the elevations where they occur. The climatic water balance calculations for sagebrush sites in the 7-8,000 feet elevation zone provided in Table 13 is an example of these calculations. These horizontal surface calculations were used to calibrate the slope aspect calculations for determining evapotranspiration and actual evapotranspiration from the E_{tp} rates developed from equations 3-5 and 3-6.

Table 14 summarizes the estimated evapotranspiration rates (water not limiting) for each of the vegetation types by elevation zones. Users of these estimates are cautioned to remember that they are generalized for the Piceance and Yellow Creeks areas and have limited application for other sites, or for specific years.

Actual Evapotranspiration (E_{ta})

Actual evapotranspiration rates are computed by a month-to-month bookkeeping system, whereby demand (E_t) is balanced against supply (precipitation plus available soil water), as shown in the climatic water balance calculations of Table 14. As long as the evapotranspiration demand is being met by precipitation plus soil water, actual evapotranspiration is equal to E_t . When precipitation plus soil water are insufficient to meet the water demand, actual evapotranspiration is less than E_t .

For this study, it was assumed that evapotranspiration demands are fully met during the November-March moisture accumulation period. The rapidly rising E_t rates in the spring result in water use rates

Table 12. Estimated water use coefficients (K_c) for native vegetation and irrigated cropland.

Months	Native vegetation types						Irrigated Meadow Hay and Pasture	Seep, stream channel and Phreatophyte areas
	Sagebrush grass	Pinyon-Juniper	Mixed Mountain shrub	Coniferous forest	Aspen forest	Rockland and misc. land uses		
January	.50	.65	.60	.70	.60	.50	.50	1.00
February	.50	.65	.60	.70	.60	.50	.50	1.00
March	.50	.65	.60	.70	.60	.50	.50	1.00
April	.60	.70	.67	.71	.67	.60	.60	1.00
May	.80	.80	.81	.80	.85	.65	.80	1.00
June	.80	.80	.85	.80	.90	.65	.80	1.00
July	.80	.80	.82	.80	.86	.65	.80	1.00
August	.71	.80	.74	.79	.75	.60	.80	1.00
September	.53	.69	.65	.75	.65	.50	.71	1.00
October	.50	.65	.60	.71	.60	.50	.53	1.00
November	.50	.65	.60	.70	.60	.50	.50	1.00
December	.50	.65	.60	.70	.60	.50	.50	1.00

Table 13. Estimated climatic water balance for sagebrush range sites on a horizontal surface as calculated by the Jensen-Haise Method for the 7-8,000 ft. elevation zone.

Item	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean monthly temperature °F 1/	18.4	21.8	25.7	36.2	42.4	51.9	58.4	56.5	48.1	41.3	31.8	22.4	37.9
E_{tp}/R_s ratio 2/	.160	.181	.204	.237	.324	.457	.548	.521	.403	.308	.241	.184	(.352)
Evaporation equivalent of Solar radiation (R_s) 3/	5.08	6.14	9.18	10.90	12.94	13.89	13.83	12.12	10.27	7.97	5.35	4.52	112.19
Potential evapotranspiration (E_{tp})	.81	1.11	1.88	2.58	4.18	6.34	7.57	6.32	4.14	2.46	1.29	.83	39.51
Plant water use coefficient (K_c)	.50	.50	.50	.60	.80	.80	.80	.71	.53	.50	.50	.50	
$E_t = K_c E_{tp}$ (water not limiting)	.41	.55	.94	1.55	3.34	5.07	6.06	4.48	2.19	1.23	.64	.42	26.88
Precipitation (P) inches	1.38	1.37	1.49	1.81	1.39	1.47	1.41	1.98	1.60	1.43	1.29	1.74	18.36
Prec. minus Evapotr. ($P-E_t$)	.97	.82	.55	.26	-1.95	-3.60	-4.65	-2.50	- .59	.20	.65	1.32	
Actual evapotranspiration with 4.30 inches AWC													
Soil moisture storage (S)	3.14	3.96	4.30	4.30	2.35					.20	.85	2.17	
Change in soil moisture storage (ΔS)	.97	.82	.34		-1.95	-2.35				.20	.65	1.32	
Actual evapotranspiration (E_{ta})	.41	.55	.94	1.55	3.34	3.82	1.41	1.98	1.60	1.23	.64	.42	17.89
Water deficit						1.25	-4.65	-2.50	-8.59				8.99
Water surplus			.21	.26									.47

1/ Mean monthly temperatures developed from regression equations.

2/ April-October $E_{tp}/R_s = (0.014T - 0.27)$, November-March $E_{tp}/R_s = (0.006T + 0.05)$.

3/ Grand Junction solar radiation calculated for total days in month and converted to inches evaporation equivalent (langleys X 0.000673 = inches).

Item	November-March	April-October	Total Annual
Potential evapotranspiration (E_{tp})	5.92	33.59	39.51
Est. E_t for sagebrush	2.96	23.92	26.88
Actual evapotranspiration	2.96	14.93	17.89

Table 14. November-March and April-October evapotranspiration (water not limiting) for specific vegetation types on a horizontal surface by elevation zones (inches).

Vegetation type	Average elevation (feet)[1/] 5,900	6,500	6,800	7,500	8,200	8,500	9,100	Intercept (a)	Change per 1,000 ft. (b)
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
November-March									
Sagebrush	3.44	3.26	3.17	2.96	2.75	2.66	2.48	5.210	-0.300
Desert shrub	3.44	3.26						5.210	-0.300
Pinyon-juniper		4.24		3.85				6.773	-0.390
Mixed mountain shrub		3.91		3.55	3.30	3.19	2.97	6.252	-0.360
Coniferous forest				4.14	3.85	3.72		7.294	-0.420
Aspen forest				3.55	3.30	3.19	2.97	6.252	-0.360
Rockland & misc.	3.44	3.26	3.17	2.96	2.75	2.66		5.210	-0.300
Irrigated cropland	3.44	3.26	3.17	2.96				5.210	-0.300
Seep & phreatophyte	6.88	6.52	6.34	5.92	5.50	5.32	4.96	10.420	-0.600
April-October									
Sagebrush	28.30	26.66	25.84	23.92	22.00	21.18	19.54	44.461	-2.739
Desert shrub	28.30	26.66						44.461	-2.739
Pinyon-juniper		28.70		25.79				47.615	-2.910
Mixed mountain shrub		28.48		25.57	23.50	22.66	20.91	47.412	-2.913
Coniferous forest				26.13	24.06	23.17		48.327	-2.959
Aspen forest				26.41	24.31	23.41	21.60	48.956	-3.006
Rockland & misc.	24.11	22.73	22.04	20.39	18.76	18.09		37.825	-2.323
Irrigated cropland	29.93	28.19	27.34	25.32				46.915	-2.879
Seep & phreatophyte	39.64	37.37	36.24		30.94			61.940	-3.780

[1/] Average elevation for the elevation zones evaluated in the Piceance and Yellow Creek watersheds.

that exceed precipitation by May for most native vegetation sites. The combination of precipitation and soil moisture storage is usually sufficient to maintain maximum use rates through early June, after which a deficit generally exists. In most years, the deficit persists from June through September, except at the highest elevation zones.

The slope aspect evaluations for upland areas presents a special problem in estimating actual evapotranspiration. Because the estimated E_t is increased or decreased from the horizontal surface estimate it changes both the estimated total water use and the timing of the use. An accurate water use estimate for each slope and aspect would require a specific site evaluation and an estimate of actual evapotranspiration by monthly or shorter periods. Since this would require computerization of the water balance model, and a much larger information base, the alternative chosen was a ratio method of correcting the estimated runoff and deep percolation. The method is based on the assumption that the changes in evapotranspiration ΔE_t (E_t horizontal surface - E_t for specific slope and aspect) would affect total (D + R) by a fixed percentage. Somewhat arbitrarily, this percentage was based on the growing season months in which normal precipitation exceeds normal horizontal surface evapotranspiration, which is generally limited to April, September and October even at high elevations.

The change in the runoff and deep percolation $\Delta(D + R)$ can be estimated by the following equation:

$$\Delta(D + R) = \frac{S_m}{E_t} \quad \Delta E_t \qquad (3\text{-}8)$$

where

$\Delta(D + R)$ = Net estimated change in deep percolation and runoff from that estimated for the horizontal surface at the site.

S_m = Estimated evapotranspiration for months during the April-October period when normal precipitation exceeds horizontal surface E_t for the specific vegetation type

E_t = Estimated annual evapotranspiration for the specific vegetation type on a horizontal surface

ΔE_t = Annual evapotranspiration estimated for the horizontal surface minus annual evapotranspiration for the specific slope and aspect.

The S_m/E_t ratio in equation (3-8) is a constant (ranging from zero to about 0.24) for each elevation zone and vegetation type. The $\Delta(D + R)$ is actually a change in actual evapotranspiration, because it is part of the water balance for the specific site and any reduction or increase in deep percolation or runoff will change the amount of water available for evapotranspiration.

Table 15 summarizes the estimated November-March, April-October, and total annual actual evapotranspiration on horizontal su-faces for upland vegetation types in the Piceance and Yellow Creek watersheds. Specific upland slope aspect evaluations by elevation zone for each vegetation type were developed by using: (1) E_{tps} and E_{tpw} from equations 3-5 and 3-6, (2) a generalized K_c value from the horizontal surface evaluation for the vegetation type to determine E_{ts} and E_{tw} from equation 3-7, (3) estimation of the runoff and deep percolation for the site using $\Delta(D + R)$ from equation 3-8, and (4) estimating the slope aspect actual evapotranspiration using the relationships for November-March $E_{ta} = E_{tw}$, and for April-October $E_{ta} = P - E_{tw} - (D + R)$. This simplistic approach assumes no change in available water holding capacity, or tendency for runoff to occur, from that estimated for the horizontal surface. Details of the calculations are not shown in this report because of space limitations, but the results of the calculations are summarized in the next chapter.

Table 16 provides a summary of the water balance calculations for the bottomland uses and vegetation types. These calculations all assumed evapotranspiration rates for the horizontal surface, and available water holding capacities or availability of irrigation water previously described.

Table 15. November-March and April-October actual evapotranspiration for specific vegetation types on a horizontal surface by elevation zones (inches).

Upland vegetation type	Average elevation (feet)[1/]						
	5,900	6,500	6,800	7,500	8,200	8,500	9,100
	Inches	Inches	Inches	Inches	Inches	Inches	Inches
November-March							
Sagebrush	3.44	3.26	3.17	2.96	2.75	2.66	2.48
Desert shrub	3.44	3.26					
Pinyon-juniper		4.24		3.85			
Mixed mountain shrub		3.91		3.55	3.30	3.19	2.97
Coniferous forest				4.14	3.85	3.72	
Aspen forest				3.55	3.30	3.19	2.97
Rockland & misc.	3.44	3.26	3.17	2.96	2.75	2.66	
April-October							
Sagebrush	8.15	10.87	12.22	14.93	15.44	15.88	16.41
Desert shrub	8.15	10.87					
Pinyon-juniper		9.89		14.08			
Mixed mountain shrub		10.22		14.81	16.04	17.00	17.86
Coniferous forest				14.22	15.82	16.32	
Aspen forest				14.81	17.04	17.50	18.36
Rockland & misc.	8.15	10.62	11.65	13.62	14.64	14.98	
Total Annual							
Sagebrush	11.59	14.13	15.39	17.89	18.19	18.54	18.89
Desert shrub	11.59	14.13					
Pinyon-juniper		14.13		17.93			
Mixed mountain shrub		14.13		18.36	19.34	20.19	20.83
Coniferous forest				18.36	19.67	20.04	
Aspen forest				18.36	20.34	20.69	21.33
Rockland & misc.	11.59	13.88	14.82	16.58	17.39	17.64	

[1/] Average elevation for the elevation zones evaluated in the Piceance and Yellow Creek watersheds.

Table 16. Estimated water balance factors for bottomland uses and vegetation types on a horizontal surface by elevation zones (inches).

Bottomland vegetation type	Average elevation[1/]	Mean annual precipitation	Run-in and irrigation water	Actual evapotranspiration: November-March	Actual evapotranspiration: April-October	Actual evapotranspiration: Total annual
	Feet	Inches	Inches	Inches	Inches	Inches
Irrigated cropland	5,900	11.59	21.78	3.44	29.93	33.37
	6,500	14.13	17.32	3.26	28.19	31.45
	6,800	15.39	15.12	3.17	27.34	30.51
	7,500	18.36	9.92	2.96	25.32	28.28
Irrigated meadow and pasture	5,900	11.59	20.39	3.44	28.54	31.98
	6,500	14.13	17.11	3.26	27.98	31.24
	6,800	15.39	12.82	3.17	25.04	28.21
	7,500	18.36	9.18	2.96	24.58	27.54
Irrigated pasture	5,900	11.59	13.25	3.44	21.40	24.84
	6,500	14.13	10.53	3.26	21.40	24.66
	6,800	15.39	9.17	3.17	21.39	24.56
	7,500	18.36	5.85	2.96	21.25	24.21
Seep, channel and phreatophyte areas	5,900	11.59	34.93	6.88	39.64	46.52
	6,500	14.13	29.76	6.52	37.37	43.89
	7,500	18.36	21.15	5.92	33.59	39.51
Sagebrush run-in	5,900	11.59	5.99	3.44	14.14	17.58
	6,500	14.13	4.75	3.26	15.62	18.88
	6,800	15.39	4.13	3.17	16.35	19.52
	7,500	18.36	2.23	2.96	17.63	20.59

1/ Average elevation for the elevation zones evaluated in the Piceance and Yellow Creek watersheds.

ANNUAL WATER BALANCE FOR PICEANCE AND YELLOW CREEKS

From the hydrologic standpoint, runoff may be considered the last phase in the hydrologic cycle of a small watershed, and the resulting streamflow is the end product of all that precedes it. Surface runoff measurements are also generally the most accurate of the variables in the water balance equation. In the Piceance and Yellow Creeks watersheds, however, the streamgaging records are available for only a few years. The longest term streamgaging record is for an eight-year period (1965-72) at the Piceance Creek below Ryan Gulch (USGS streamgage No. 93062), which has an average discharge of 15.0 cfs (10,870 acre-feet). Unfortunately, the standard deviation of the eight years total flow is 3,387 acre-ft. and the 95% confidence interval for annual flows would be from a minimum flow of 2,860 acre-ft. to a maximum of about 18,900 acre-ft. per year. With such a wide variability in annual streamflows, it is impossible to accurately predict average water yields without perhaps 20-years of record. It should be noted, however, that this variability represents a range of from 0.11 to 0.73 inches of runoff from 485 sq. miles above the gage, indicating very low water yield rates for the Upper Piceance Creek.

The average annual analyses contained in this report probably represents an overextension of conclusions from the limited information available. Certainly, it represents a considerable reliance on the judgement of the author. Unfortunately, it will require a good network of weather and soil moisture stations at all elevations to materially improve the estimates, or to attempt an analysis for individual years. Therefore, users are cautioned to remember that consumptive use of water by forest or range depends on the distribution and occurence of precipitation, the amount of water held by the soil, the type and density of the vegetation, and many other factors. Since the reliability of estimates for any of these factors is less than the net runoff estimated for either Piceance or Yellow Creeks, the matching of estimated net water yield for the watersheds with the approximate true runoff rates can be viewed as a happy circumstance rather than a scientific finding.

Actual Evapotranspiration and Runoff by Vegetation Types

The calculation of annual water balance estimates for each vegetation type by slope and aspect for each elevation zone was not typed for this report, because it is long and complicated. Summaries of the results by vegetation type for each elevation zone are shown in this section.

Table 17 provides a summary of estimated actual evapotranspiration and runoff by elevation zones for Upper Piceance Creek. Table 18 provides the same summary for Lower Piceance Creek, and Table 19 for Yellow Creek. For these tables irrigation, phreatophyte, or sagebrush run-in water use is shown as a negative value for surface runoff or deep percolation, rather than being shown as an addition to water supply as shown in the water balance equation (2-1).

Because certain upland vegetation types are typically found on specific aspects in the Piceance Basin, the actual evapotranspiration shown in Tables 17 through 19 will differ noticeably from those for horizontal surface upland areas in Table 15. This variability is most noticeable during the November-March moisture accumulation period, because during much of the April-October growing season water use is generally limited by water availability rather than variations in demand. For at least the lower elevation zones the difference in winter use rates is responsible for vegetation type and density differences exhibited between north and south facing slopes. Because the north facing slopes have considerably less winter use, there is more moisture available for soil water storage and, hence, growing season use.

Annual Water Balance by Elevation Zones

The elevation zone annual water balance for Piceance and Yellow Creeks required several minor revisions in the water balance equations (2-2 and 2-3). The bottomland sagebrush shows growth characteristics that indicate water use that is definitely greater than natural precipitation. Some of the sagebrush and greasewood bottoms show definite indications of phreatophytic use from groundwater, but most areas seem to be using only the extra recharge of the soil water supplies from

Table 17. Estimated actual evapotranspiration and runoff (inches) by elevation zones in the Upper Piceance Creek watershed.

Vegetation type	Acres	Actual evapotranspiration November-March	Actual evapotranspiration April-October	Actual evapotranspiration Total annual	Surface runoff and deep percolation
		Inches	Inches	Inches	Inches
<7,000 ft. elevation zone:					
Upland					
Sagebrush	200	2.50	12.89	15.39	
Rockland & Misc.	1,900	2.78	11.02	13.80	1.59
Total Upland	2,100	2.76	11.19	13.95	1.44
Bottomland					
Irrigated cropland	200	3.17	27.34	30.51	-15.12
Irr. meadow & past	100	3.17	25.04	28.21	-12.82
Irrigated past.	200	3.17	21.39	24.56	- 9.17
Sagebrush run-in	700	3.17	16.35	19.52	- 4.13
Total bottomland	1,200	3.17	19.75	22.92	- 7.53
Total elevation zone	3,300	2.90	14.31	17.21	0.92
7-8,000 ft. elevation zone:					
Upland					
Sagebrush	17,500	2.80	14.80	17.60	0.76
Pinyon-juniper	4,500	3.66	13.90	17.56	0.80
Mountain shrub	24,700	3.40	14.70	18.10	0.26
Conifer forest	11,200	4.17	14.07	18.24	0.12
Aspen forest	2,200	2.79	15.51	18.30	0.06
Rockland & Misc.	800	2.68	13.50	16.18	2.18
Total Upland	60,900	3.36	14.57	17.93	0.43
Bottomland					
Irrigated cropland	200	2.96	25.32	28.28	- 9.92
Irr. meadow & past	100	2.96	24.58	27.54	- 9.18
Irrigated past.	100	2.96	21.25	24.21	- 5.85
Seep & phreatophyte100 phreatophyte	100	5.92	33.59	39.51	-21.15
Sagebrush run-in	2,500	2.96	17.63	20.59	- 2.23
Total bottomland	3,000	3.06	19.03	22.09	- 3.73
Total elevation zone	63,900	3.34	14.78	18.12	0.24

Table 17. Estimated actual evapotranspiration and runoff (inches) by elevation zones in the Upper Piceance Creek watershed (Continued).

Vegetation type	Acres	Actual evapotranspiration November-March	Actual evapotranspiration April-October	Actual evapotranspiration Total annual	Surface runoff and deep percolation
		Inches	Inches	Inches	Inches
8-9,000 ft. elevation zone:					
Upland					
Sagebrush	3,300	2.41	15.68	18.09	4.50
Mountain shrub	12,600	3.13	16.95	20.08	2.51
Conifer forest	1,300	4.04	15.98	20.02	2.57
Aspen forest	5,400	2.23	17.18	19.41	3.18
Rockland & Misc.	300	3.64	15.44	19.08	3.51
Total elevation zone	22,900	2.79	16.75	19.54	3.05
>9,000 ft. elevation zone:					
Upland					
Sagebrush	300	2.61	16.87	19.48	5.64
Mountain shrub	100	3.13	18.40	21.53	3.59
Aspen forest	500	3.10	18.66	21.76	3.36
Total elevation zone	900	2.93	18.04	20.97	4.15
Total Upper Piceance	91,000	3.18	15.29	18.47	0.91

Table 18. Estimated actual evapotranspiration and runoff (inches) by elevation zones in the Lower Piceance Creek watershed.

		Actual evapotranspiration			Surface run-off and deep percolation
Vegetation type	Acres	November -March	April-October	Total annual	
		Inches	Inches	Inches	Inches
<6,000 ft. elevation zone:					
Upland					
Sagebrush	1,100	3.38	8.21	11.59	
Desert shrub	200	3.34	8.25	11.59	
Rockland & Misc.	100	3.51	8.08	11.59	
Total upland	1,400	3.39	8.20	11.59	
Bottomland					
Irrigated cropland	200	3.44	29.93	33.37	-21.78
Irr. meadow & past.	100	3.44	28.54	31.98	-20.39
Irrigated pasture	100	3.44	21.40	24.84	-13.25
Seep & phreatophyte	100	6.88	39.64	46.52	-34.93
Sagebrush run-in	900	3.44	13.87	17.31	- 5.72
Total bottom-land	1,400	3.68	19.58	23.26	-11.67
Total elevation zone	2,800	3.54	13.89	17.43	- 5.84
6-7,000 ft. elevation zone:					
Upland					
Sagebrush	33,000	3.24	10.89	14.13	
Pinyon-juniper	79,400	4.18	9.95	14.13	
Mountain shrub	1,700	3.89	10.24	14.13	
Desert shrub	300	3.17	10.96	14.13	
Rockland & Misc.	7,500	3.15	10.54	13.69	0.44
Total upland	121,900	3.85	10.25	14.10	0.03
Bottomland					
Irrigated crop-land	1,500	3.26	28.19	31.45	-17.32
Irr. meadow & past	500	3.26	27.98	31.24	-17.11
Irrigated pasture	1,800	3.26	21.40	24.66	-10.53
Seep & phreatophyte	200	6.52	39.37	45.89	-29.76
Sagebrush run-in	6,700	3.26	15.62	18.88	- 4.75
Total bottom-land	10,700	3.32	19.34	22.66	- 8.53
Total elevation zone	132,600	3.81	10.98	14.79	- 0.66

Table 18. Estimated actual evapotranspiration and runoff (inches) by elevation zones in the Lower Piceance Creek watershed (Continued).

Vegetation type	Acres	Actual evapotranspiration November -March	April- October	Total annual	Surface run-off and deep percolation
		Inches	Inches	Inches	Inches
7-8,000 ft. elevation zone:					
Upland					
Sagebrush	46,500	2.76	14.80	17.56	0.80
Pinyon-juniper	47,300	3.79	13.90	17.69	0.67
Mountain shrub	40,800	3.40	14.69	18.09	0.27
Aspen forest	1,400	2.92	15.41	18.33	0.03
Rockland & Misc.	5,800	2.91	13.57	16.48	1.88
Total upland	141,800	3.30	14.42	17.72	0.64
Bottomland					
Sagebrush run-in	700	2.96	17.63	20.59	-2.23
Total elevation zone	142,500	3.29	14.44	17.73	0.63
>8,000 ft. elevation zone:					
Upland					
Sagebrush	18,400	2.59	15.33	17.92	3.39
Mountain shrub	10,500	3.24	16.46	19.70	1.61
Aspen forest	4,600	2.60	16.79	19.39	1.92
Rockland & Misc.	200	2.10	14.41	16.51	4.80
Total upland	33,700	2.79	15.87	18.66	2.65
Total elevation zone	33,700	2.79	15.87	18.66	2.65
Summary for Piceance Creek Watershed:					
Upper Piceance Creek	91,000	3.18	15.29	18.47	0.91
Lower Piceance Creek	311,600	3.46	13.12	16.58	0.24
Total Piceance	402,600	3.40	13.61	17.01	0.39

Table 19. Estimated actual evapotranspiration and runoff (inches) by elevation zones in the Yellow Creek watershed.

Vegetation type	Acres	Actual evapotranspiration: November-March (Inches)	Actual evapotranspiration: April-October (Inches)	Actual evapotranspiration: Total annual (Inches)	Surface run-off and deep percolation (Inches)
<6,000 ft. elevation zone:					
Upland					
Sagebrush	1,900	3.75	7.84	11.59	
Desert shrub	100	3.51	8.08	11.59	
Rockland & Misc.	400	3.20	8.39	11.59	
Total upland	2,400	3.65	7.94	11.59	
Bottomland					
Sagebrush run-in	1,500	3.44	14.14	17.58	-5.99
Total elevation zone	3,900	3.56	10.33	13.89	-2.30
6-7,000 ft. elevation zone:					
Upland					
Sagebrush	45,400	2.94	11.19	14.13	
Pinyon-juniper	51,900	3.83	10.30	14.13	
Mountain shrub	600	3.21	10.92	14.13	
Rockland & Misc.	3,200	2.88	10.56	13.44	0.70
Total upland	101,100	3.40	10.71	14.11	0.02
Bottomland					
Irrigated cropland	100	3.26	28.19	31.45	-17.32
Irr. meadow & past.	100	3.26	21.40	24.66	-10.53
Seep & phreatophyte	100	6.52	37.37	43.89	-29.76
Sagebrush run-in	4,000	3.26	15.62	18.88	
Total bottomland	4,300	3.33	16.55	19.88	-5.75
Total elevation zone	105,400	3.39	10.95	14.33	-0.21
7-8,000 ft. elevation zone:					
Upland					
Sagebrush	12,300	2.74	14.71	17.45	0.91
Pinyon-juniper	17,300	3.39	13.74	17.13	1.23
Mountain shrub	15,100	2.97	14.70	17.67	0.69
Aspen forest	500	2.79	15.57	18.36	
Rockland & Misc.	1,300	2.44	13.40	15.84	2.52
Total elevation zone	46,500	3.05	14.32	17.37	0.99

Table 19. Estimated actual evapotranspiration and runoff (inches) by elevation zones in the Yellow Creek watershed (Continued).

Vegetation type	Acres	Actual evapotranspiration: November-March Inches	Actual evapotranspiration: April-October Inches	Actual evapotranspiration: Total annual Inches	Surface run-off and deep percolation Inches
>8,000 ft. elevation zone:					
Upland					
Sagebrush	2,600	2.97	15.44	18.41	2.90
Mountain shrub	4,700	3.72	16.53	20.25	1.06
Aspen forest	1,800	2.68	16.79	19.47	1.84
Conifer forest	100	4.16	15.82	19.98	1.33
Rockland & Misc.	100	3.14	14.66	17.80	3.51
Total elevation zone	9,300	3.31	16.25	19.56	1.75
Total Yellow Creek	165,100	3.30	12.18	15.48	0.19
Summary for Piceance and Yellow Creek Watersheds:					
Upper Piceance Creek	91,000	3.18	15.29	18.47	0.91
Lower Piceance Creek	311,600	3.46	13.12	16.58	0.24
Total Piceance	402,600	3.40	13.61	17.01	0.39
Yellow Creek	165,000	3.30	12.18	15.48	0.19
Total Piceance and Yellow Creeks	567,700	3.37	13.19	16.56	0.33

run-in to the bottomland. For evaluation purposes, sagebrush run-in areas were assumed to have the 7.00" available water capacity filled by spring snowmelt. There are also some areas of seep, stream channel, and large phreatophytes that use water at the potential rate. Phreatophyte areas are assumed to have a full water supply available at all times. Native vegetation water requirements also required the estimation of evapotranspiration as November-March evapotranspiration plus April-October actual evapotranspiration, or $E_t = E_{tw} + E_{ta}$.

The specific evaluation of Piceance and Yellow Creeks water balance was conducted using the equation:

Precipitation + Irrigation Water Use + Sagebrush and Phreatophyte Run-in Use = E_{tw} (November-March) + E_{ta} (April-October) + (D + R) - ΔS

or $P + I + R_i = E_{tw} + E_{ta} + (D + R) - \Delta S$.

For evaluation purposes, changes in soil water (ΔS) is assumed to equal zero for average years. As previously indicated, net outflow (Q) is equal to runoff and deep percolation minus irrigation water use minus run-in water by sagebrush and phreatophyte areas, or $Q = (D + R) - I - R_i$.

Table 20 summarizes the elevation zone water balance calculations for Piceance and Yellow Creeks. The average annual water balance for the 629 sq. mile Piceance Creek watershed can be summarized as

$$P + I + R_i = E_{tw} + E_{ta} + (D + R) - \Delta S$$

Inches 17.40 + 0.18 + 0.14 = 3.40 + 13.61 + 0.71 - 0.00

Acre-ft. 583,713 + 5,902 + 4,879 + 114,055 + 456,556 + 23,833 - 0 .

The net outflow from Piceance Creek is estimated to average 13,102 acre-ft. annually (0.39 area inches) from the water balance calculations. This is almost exactly the same value as the 13,377 acre-ft. predicted for Piceance Creek at the White River using regression techniques and considering irrigation by-pass. This rather exact fit, however, can only be considered as a fortunate circumstance rather than a precision answer because the probable error in any of the variables is more than the estimated runoff for the watershed.

Table 20. Estimated average annual water balance for Piceance and Yellow Creeks Watersheds by elevation zones.

Elevation zones	Acres	Water balance (inches)					Water balance (acre-feet)				
		Mean annual precip-itation	Run-in and irrig. water	Actual Evapotranspiration		Surface runoff and deep perc.	Annual precip-itation	Run-in and irrig. water	Actual Evapotranspiration		Surface runoff and deep perc.
				November -March	April-October				November -March	April-October	
Upper Piceance Creek											
<7,000 ft.	3,300	15.39	2.74	2.90	14.31	.92	4,232	753	799	3,934	252
7-8,000 ft.	63,900	18.36	.17	3.34	14.78	.41	97,767	931	17,809	78,687	2,202
8-9,000 ft.	22,900	22.59		2.79	16.75	3.05	43,111		5,324	31,959	5,828
>9,000 ft.	900	25.12		2.93	18.04	4.15	1,884		220	1,353	311
Total area	91,000	19.38	.22	3.18	15.29	1.13	146,994	1,684	24,152	115,933	8,593
								Run-in and irrigation use			1,684
								Net outflow			6,909
Lower Piceance Creek											
<6,000 ft.	2,800	11.59	5.84	3.54	13.89		2,705	1,362	825	3,242	
6-7,000 ft.	132,600	14.13	.69	3.81	10.98	.03	156,141	7,605	42,123	121,348	275
7-8,000 ft.	142,500	18.36	.01	3.29	14.44	.64	218,025	130	39,112	171,457	7,586
>8,000 ft.	33,700	21.31		2.79	15.87	2.65	59,848		7,843	44,576	7,429
Total area	311,600	16.82	.35	3.46	13.12	.59	436,719	9,097	89,903	340,623	15,290
								Run-in and irrigation use			9,097
								Net outflow			6,193
Total Piceance Creek Watershed											
<6,000 ft.	2,800	11.59	5.84	3.54	13.89		2,705	1,362	825	3,242	
6-7,000 ft.	135,900	14.16	.74	3.79	11.06	.05	160,373	8,358	42,922	125,282	527
7-8,000 ft.	206,400	18.36	.06	3.31	14.54	.57	315,792	1,061	56,921	250,144	9,788
8-9,000 ft.	56,600	21.83		2.79	16.23	2.81	102,959		13,167	76,535	13,257
>9,000 ft.	900	25.12		2.93	18.04	4.15	1,884		220	1,353	311
Total area	402,600	17.40	.32	3.40	13.61	.71	583,713	10,781	114,055	456,556	23,883
								Run-in and irrigation use			10,781
								Net outflow			13,102

Table 20. Estimated average annual water balance for Piceance and Yellow Creeks Watersheds by elevation zones (Continued).

		Water balance (inches)					Water balance (acre-feet)				
				Actual Evapotranspiration					Actual Evapotranspiration		
Elevation zones	Acres	Mean annual precip-itation	Run-in and irrig. water	November -March	April-October	Surface runoff and deep perc.	Annual precip-itation	Run-in and irrig. water	November -March	April-October	Surface runoff and deep perc.
Yellow Creek Watershed											
<6,000 ft.	3,900	11.59	2.30	3.56	10.33		3,767	749	1,159	3,357	
6-7,000 ft.	105,400	14.13	.23	3.39	10.94	.03	124,111	2,062	29,832	96,155	186
7-8,000 ft.	46,500	18.36		3.05	14.32	.99	71,145		11,815	55,487	3,843
>8,000 ft.	9,300	21.31		3.31	16.25	1.75	16,515		2,562	12,593	1,360
Total area	165,100	15.67	.20	3.30	12.18	.39	215,538	2,811	45,368	167,592	5,389
								Run-in and irrigation use			2,811
								Net outflow			2,578
Total Piceance and Yellow Creek Watersheds											
<6,000 ft.	6,700	11.59	3.78	3.55	11.82		6,472	2,111	1,984	6,599	
6-7,000 ft.	241,300	14.15	.52	3.62	11.01	.04	284,484	10,420	72,754	221,437	713
7-8,000 ft.	252,900	18.36	.05	3.26	14.50	.65	386,937	1,061	68,736	305,631	13,631
8-9,000 ft.	65,900	21.75		2.86	16.23	2.66	119,474		15,729	89,128	14,617
>9,000 ft.	900	25.12		2.93	18.04	4.15	1,884		220	1,353	311
Total area	567,700	16.89	.29	3.37	13.19	.62	799,251	13,592	159,423	624,148	29,272
								Run-in and irrigation use			13,592
								Net outflow			15,680

The average annual water balance for the 258 sq. mile Yellow Creek watershed can be summarized as:

$$P + I + R_i = E_{tw} + E_{ta} + (D + R) - \Delta S$$

Inches	15.67 + 0.02 + 0.18 = 3.30 + 12.18 + 0.39 - 0.00
Acre-ft.	215,538 + 213 + 2,598 = 45,368 + 167,592 + 5,389 - 0 .

The net outflow of Yellow Creek is estimated to average 2,578 acre-ft, but there is no way of checking this estimate because streamgaging records are too short.

A number of questions, as to specific components of the water balance equation remain unanswered, but the above distribution of factors is generally realistic. The use of a uniform linear precipitation versus elevation distribution is questionable in light of slope, aspect, elevational, orographic, and other relationships known to occur in similar watersheds. Certainly, as additional precipitation information becomes available this factor can be refined. The evapotranspiration estimates for specific vegetation types by slope and aspect are also relatively untried and are subject to refinement.

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