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HYDROLOGIC BALANCE FROM AN EXPERIMENTAL WATERSHED

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Abstract: A small, natural watershed has been instrumented for measurement of the hydrologic factors necessary for the calculation of consumptive use from an annual hydrologic balance. The 42.6-acre woodland grass watershed in Placer County, California, is at an elevation of 500 feet with an average annual rainfall of about 25 inches. Rainfall and runoff are measured with continuous recording devices. Twenty-four observation wells are sounded weekly to provide data for calculation of changes in groundwater storage and groundwater outflow. The groundwater components of the hydrologic balance, which are usually not available, provide a considerable insight to the redistribution of rainfall on an experimental watershed. Results from three years of record indicate the value of this method of determining water use by native vegetation.

1. Introduction

It is the aim of this paper to amplify the importance of detailed measurements of the components of the groundwater cycle on experimental watersheds. In addition, the importance of including the groundwater components in calculating the hydrologic balance for the runoff cycle of an experimental watershed will be demonstrated.

An experimental watershed is a natural drainage basin where a physical hydrologist can measure the occurrence of water in space and time. Furthermore, the experimental watershed can be subjected to variations in the vegetation to permit determination of the effects of vegetation on the timing, quantity, and quality of water yield.

A hydrologic balance is a systematic accounting of physical hydrologic measurements to check on the accuracy of input and output measurements or to solve for an unmeasured quantity. Such a balance is not normally calculated for the complete hydrologic cycle, which includes movement of water from the oceans to land masses and back to the oceans. Rather, hydrologic balances are usually calculated for one of the subcycles within the hydrologic cycle according to the general equation:

$$\text{Input} = \text{Output} + \text{Change in Storage.}$$

The hydrologic balance for the runoff cycle, which includes the occurrence of precipitation on land mass drainage units and the subsequent discharge, is pictured in Fig. 1. The input to the runoff cycle is precipitation and the output is divided among surface outflow, groundwater outflow, and evapotranspiration. As water passes through the runoff cycle, storage occurs on

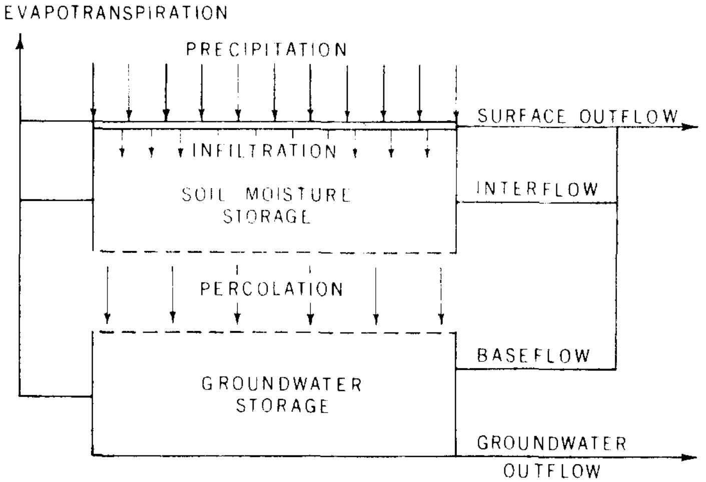

Fig. 1. Block diagram of the runoff cycle.

the land surface, in the stream channel, in the soil moisture zone, and in the groundwater zone. Changes in storage occur rapidly in the surface locations and slowly in the latter two zones.

Referring to Fig. 1, the two sub-cycles may be termed the soil moisture cycle, having an input of infiltration and outputs of interflow, deep percolation, and evapotranspiration; and the groundwater cycle, having an input of deep percolation and outputs of groundwater outflow, baseflow, and evapotranspiration.

In some situations it is doubtful that groundwater recharge will occur frequently enough to introduce serious errors in a hydrologic balance neglecting the groundwater cycle. In other situations, particularly that of high average rainfall and shallow soil, groundwater recharge will occur annually. For these situations the importance of the groundwater cycle will depend on the relative magnitude of precipitation, soil moisture storage capacity, and groundwater storage and outflow characteristics.

In general, the passage of water through the soil moisture and groundwater cycles lags far behind the surface runoff produced by a given storm. Oftentimes, these cycles have seasonal inputs and outputs depending largely on the seasonal distribution of precipitation and evapotranspiration. Because of the length of time water is stored in these cycles, there is an opportunity to increase water storage and water yields by manipulating their evapotranspirational outputs. This, of course, is accomplished by management of watershed vegetation.

2. Basic principles

For a small, natural watershed, a hydrologic balance equation can be written as follows:

$$P = I \pm \Delta SMS + RO \pm \Delta GW\,\mathrm{Stor} + GW\,\mathrm{Out} + E\text{–}T \tag{1}$$

where

P = Precipitation
I = Interception Loss
ΔSMS = Change in Soil Moisture Storage
RO = Surface Runoff
ΔGW Stor = Change in Groundwater Storage
GW Out = Groundwater Outflow
E–T = Use of Water by Evaporation and Transpiration

In the balance equation, the terms can be evaluated as follows:

P – Measured directly.
I – Since interception loss is due to the vegetation, this term may be combined with evapotranspiration in a Consumptive Use term.
ΔSMS – Not measured directly, but can be eliminated by assuming the same soil moisture storage at the beginning and end of each water year.
RO – Measured directly.
ΔGW Stor – Measured directly.
GW Out – Estimated directly, but the estimate does not contain contribution to base flow which is included in RO.
Cons. Use – Determined by the balance of the other terms.

Therefore one may write for an annual hydrologic balance:

$$P = \mathrm{Cons.\ Use} + RO \pm \Delta GW\,\mathrm{Stor} + GW\,\mathrm{Out} \tag{2}$$

or

$$\mathrm{Cons.\ Use} = P - RO \pm \Delta GW\,\mathrm{Stor} - GW\,\mathrm{Out} \tag{3}$$

The use of eq. (3) implies the following assumptions:

(a) there is no surface inflow to the watershed,
(b) there is no subsurface inflow to the watershed and
(c) there is no surface storage within the watershed.

The solution of the equation for Consumptive Use places all errors of measurement in this unmeasured term.

Precipitation on a watershed can be measured in a standard rain gage or in a weighing-recording rain gage. Care must be exercised in the selection of sites and exposures for rain gages and in the establishment of rain gage networks to measure the areal variation of precipitation.

The surface runoff from a watershed is determined from a recording of water stage versus time in a gaging structure. The streamflow is computed from a stage discharge relationship and summations of runoff are made for the duration of surface flows.

Change in groundwater storage is calculated from eq. (4).

$$\Delta GW \text{ Storage} = A \Delta h S_y \tag{4}$$

where

A = Area
Δh = Change of GW Elevation
S_y = Specific Yield

In eq. (4), the terms $A \times \Delta h$ give the volume of rock which has been recharged or dewatered during the period for which a balance is being calculated. The value of this volume can be determined in two ways. In the first method, a map showing lines of equal change of groundwater storage is prepared and the volume is calculated by multiplying the planimetered area enclosed by a given line by the average change in elevation within that area. This method requires that a new map of lines of equal change in elevation be prepared for each period for which a balance is calculated.

The second method uses Thiessen polygons formed by the intersection of the perpendicular bisectors of the lines joining adjacent wells. The area of each polygon times the change in groundwater elevation in the well at the center of the polygon gives the volume of recharged or dewatered rock. The total volume for the watershed is computed by summing the volumes for each of the polygons. In this method an additional refinement can be added by including a specific yield for each polygon. Just as in the determination of average precipitation, the polygon method for computing groundwater storage changes requires a sufficiently dense network of wells to permit areal differences in groundwater storage characteristics to be properly weighted in the total.

Groundwater outflow from the watershed can be estimated from a two-dimensional seepage equation such as eq. (5).

$$GW \text{ Outflow} = \Delta h \frac{N_f}{N_d} KD \tag{5}$$

where

Δh = Total potential drop
N_f = Number of flow channels
N_d = Number of equipotential drops
K = Permeability
D = Saturated thickness

The determination of the terms of eq. (5) requires a detailed hydrogeologic study of the groundwater outflow area of the watershed. The permeability should be determined from field pumping tests. The interpretation of the results of such tests has many interesting ramifications which have been discussed elsewhere by Lewis and Burgy[1].

The terms $\Delta h \times N_f/N_d$ are determined from a map of water table contours and the associated groundwater flow lines.

The saturated thickness D must be determined from a detailed hydrogeologic exploration of the groundwater outflow area. This depth D must be adjusted for water table fluctuations and for local geologic variations. Oftentimes a weathered zone of considerable thickness underlies the stream channel of a watershed but the porosity of the material decreases as distance from the stream increases. In addition, it has been observed that the thickness of the highly porous zone may decrease as distance from the stream channel increases.

Because of the geologic variations in saturated thickness and permeability, a three-dimensional flow net adjusted for the variations in saturated thickness and then adjusted for variations in permeability is needed to accurately depict the normal groundwater outflow from a watershed.

3. Placer County watersheds

Three experimental watersheds are operated in Placer County, California. These watersheds have areas of 47, 42.6, and 12 acres. They are located approximately 10 miles northeast of Lincoln, California, near 39° North Latitude and range in elevation from 400 to 800 feet.

The climate of these watersheds is typical of the Mediterranean climate which prevails in most of California, having an average annual rainfall of 25 inches occurring between the months of October and May and at least 4 months without precipitation during the summer.

The vegetation on these watersheds is composed of woodland and woodland grass types. Oak trees predominate in the landscape cover and annual grasses occur in the clear spaces between the oaks. There is an understory of poison oak which occurs with the trees over the entire area.

The shallow residual soils on these watersheds are clay loams and loams from 15 to 30 inches deep. Unweathered parent material occurs in the third foot of the profile, which is otherwise undeveloped.

Underlying the shallow soil mantle on these watersheds is a zone of highly weathered rock from 3 to 5 feet deep. Below this highly weathered zone is fractured and jointed metamorphosed sedimentary and igneous rock. This rock contains two open joint systems and vertical foliations which are open

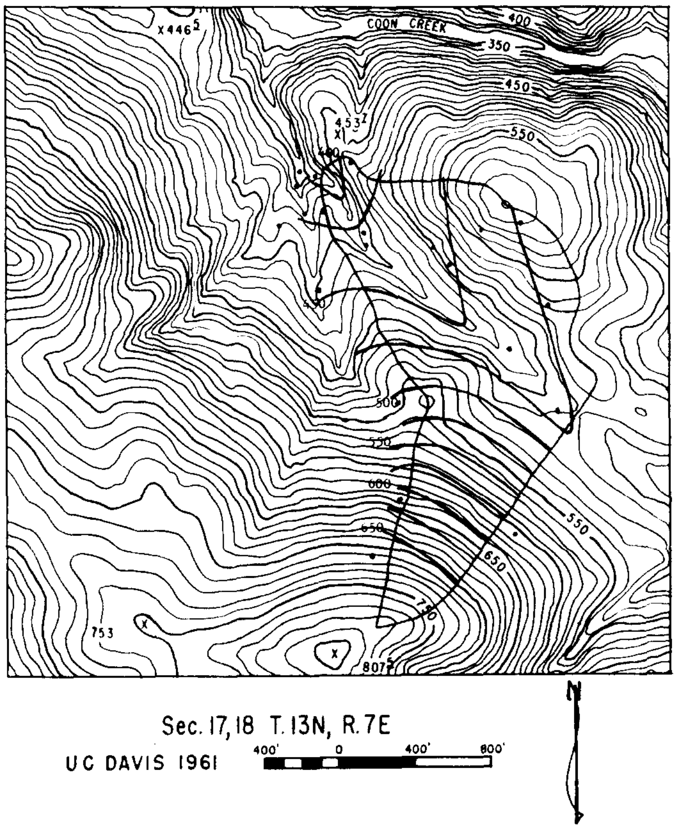

Fig. 2. Placer County Watershed B Groundwater Contour Map, April 13, 1961.

at depths of 50 feet. Diamond drill cores recovered during the drilling of observation wells on the Placer County watersheds are photographically logged and analyzed. Evidence of iron staining or mineral deposition or dissolution on the fractures and joints in these cores is used to identify those joints which are open to the seepage and storage of water. Other joints and fractures in the cores appear to have opened only when internal stresses were relieved by the penetration of the core barrel. The freshly opened joints show fresh crystals on the joint plane but the iron-stained joints show very few crystal faces.

The open joints in the cores appear to be of supercapillary size. Some have widths of 0.01 feet. The frequency of joint occurrence and the width of the joint openings generally decrease as depth increases. Values of the specific yield for the groundwater storage zone in the fractured and jointed rock are

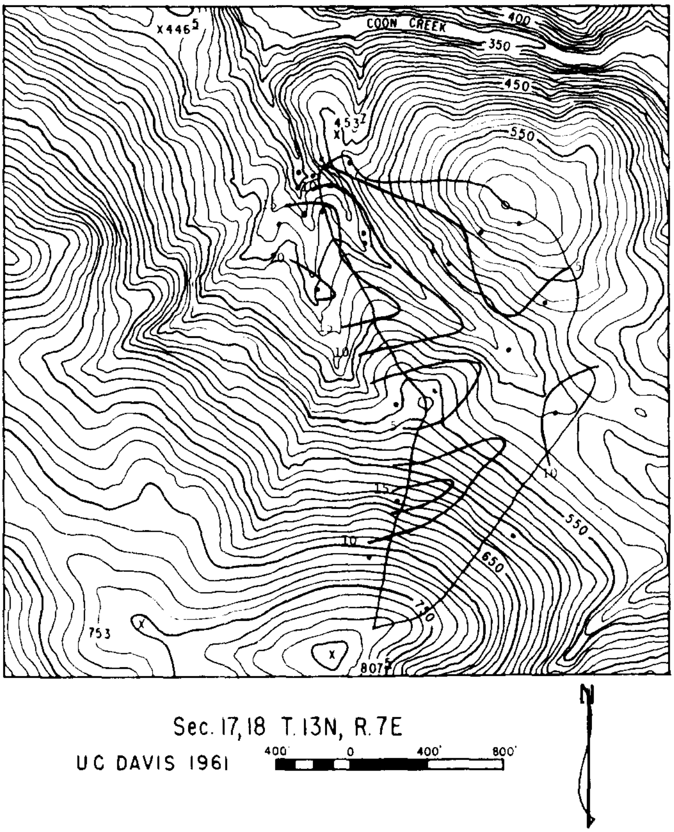

Fig. 3. Placer County Watershed B Decrease in Groundwater Elevation, April 13, 1961 to October 17, 1961.

estimated from the number of open joints occurring and the estimated physical dimensions of these joints.

Fig. 2 is a topographic map with the boundary of the 42.6-acre Placer County Watershed B drawn in. Also shown in Fig. 2 are the 24 groundwater observation wells in and around watershed B and the groundwater contours for April, 1961. From groundwater contour maps such as Fig. 2, it has been determined that the assumption of no subsurface inflow to this watershed is valid. It can be further seen in Fig. 2 that the groundwater outflow will occur at the lowest elevation in the watershed in the area where the stream flow is gaged.

Fig. 3 shows lines of equal change of groundwater elevation plotted on Placer County Watershed B. From these lines, using planimetered areas and average ordinates, the volume of groundwater storage change can be calculated. As has been pointed out earlier, the polygon method can also be used to obtain this volume. Volumes of groundwater storage change for several half-year cycles of recharge and discharge were computed using both the polygon method and the change in groundwater contour method. Results from both methods are not significantly different. The polygon method is now used to reduce the time needed for calculation.

4. Changes in groundwater storage

The weekly elevations of the groundwater table in 24 wells provide data on which to base calculations of the change in groundwater storage. The change in groundwater storage is evaluated by first calculating the change in groundwater elevation from the beginning to the end of the time period. The volume of material which has been dewatered or recharged is calculated using the polygon method described earlier, and the change in groundwater storage is equal to the volume of material which has been dewatered or recharged times the specific yield of the material as shown in Table 1.

TABLE 1

Changes in Groundwater Storage for Watershed B

Time Period	Occurrence	Volume of Rock (acre-ft)	S_Y	Volume of Water (acre-ft)	Depth of Water (in.)
	1960–61 *Hydrologic Year*				
10-21-60 to 4-13-61	Recharge	228.4	0.024	5.48	1.54
4-13-61 to 10- 3-61	Use & Outflow	319.6	0.024	7.67	2.16
	1961–62 *Hydrologic Year*				
10- 3-61 to 4- 2-62	Recharge	693.0	0.024	16.63	4.68
4- 2-62 to 10- 1-62	Use & Outflow	548.8	0.024	13.17	3.71
	1962–63 *Hydrologic Year*				
10- 1-62 to 4-22-63	Recharge	975.2	0.024	23.41	6.59
4-22-63 to 10- 1-63	Use & Outflow	839.6	0.024	20.15	5.67

In order to estimate the specific yield for Watershed B, it is assumed that an average of 2.4 joints per vertical foot is representative for the entire watershed and that these joints have an average opening of 0.01 foot. Thus, the open space in the fractured rock amounts to 0.024 cubic feet per cubic foot of rock. Since little is known about the water retention ability of the jointed rock, the specific yield is assumed to be equal to the void space in the rock. Thus, the specific yield is 2.4%. In preparing this estimate, the frequency of the joints assumed is believed to be a conservative estimate, and the size of the joint openings is believed to be a high estimate. Considering the presence of more porous material near the stream channel, it appears that this estimating procedure yields a reasonable value of specific yield.

5. Groundwater outflow

Groundwater contour maps for Placer County Watershed B have consistently shown that the groundwater contours have a shape very similar to that of the topographic contours. It has been concluded that the groundwater basin underlying Watershed B coincides with the surface watershed unit and

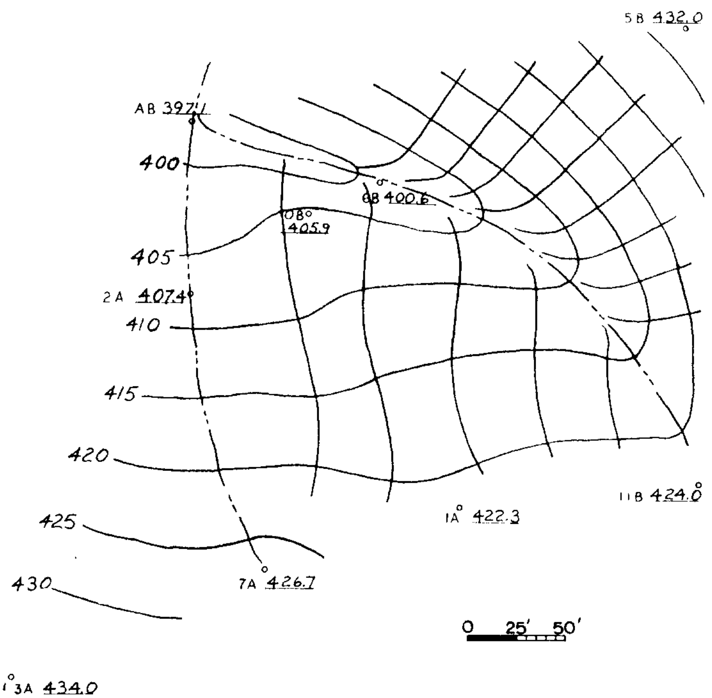

Fig. 4. Plan of groundwater outflow gaging wells, Placer County Watersheds, showing the groundwater elevations and flow net for April 22, 1963.

that the subsurface outflow from Watershed B generally follows the path of the surface runoff. Under these conditions, the subsurface outflow from Watershed B can be estimated from groundwater elevation data obtained from a network of wells across the stream channel near the gaging station and a knowledge of the permeability of the fractured rock.

Fig. 4 shows the plan of the outflow gaging wells at the confluence of the channels of Placer County Watersheds A and B. The two stream channels are indicated and the wells are identified by small circles with a small number and letter beside them. The groundwater elevations of April 22, 1963, are noted next to the well numbers. The groundwater equipotential lines constructed from these groundwater elevations are shown. A network of curvilinear orthogonal squares has been constructed on the determined equipotential lines to produce an approximate two-dimensional groundwater flow net. This approximate flow net, drawn from measured values of potential, reflects variations in the permeability and saturated thickness.

The groundwater outflow estimation procedure involves calculation of the groundwater flow in each channel of the orthogonal flow net as shown in Table 2.

The groundwater outflow of 1022 cubic feet per day calculated in Table 2 for April 22, 1963, represents the maximum outflow rate, since groundwater levels at this time are at the high for the season. Data from additional pumping tests will provide more accurate values of permeability for use in

TABLE 2

Groundwater Outflow from Watershed B, April 22, 1963

$$Q = \Sigma K \Delta h \frac{N_f}{N_d} D$$

where

Q = total groundwater outflow, ft.^{3} per day
K = coefficient of permeability, ft. per day
Δh = total potential drop, ft.
N_f = number of flow channels
N_d = number of equipotential drops
D = saturated thickness, ft.

Flow Channel Number	$\frac{\Delta h}{N_d}$	N_f	K	D	Q
1, 2, 3	5	3	0.08	70	84
4, 5	5	2	1.1	70	770
6, 7, 8, 9, 10, 11	5	6	0.08	70	168
Total					1022 ft^3/day

outflow estimation calculations. Further refinement of groundwater outflow estimates would be possible if a precise value of the saturated thickness could be determined for each flow channel. One possible way to determine this is by means of an intensive survey using a portable refraction seismograph.

TABLE 3

Runoff Cycle
Placer County Watershed B
(Direction of Accretion or Disposition)

Component	P	Cons. Use	ΔSMS	RO	ΔGW Stor.	GW Outflow
Month			1960–61			
October	0	+	0	0	0	+
November	+	+	+	+	↑	+
December	+	+	+	+		+
January	+	+	+	+	+ 1.54	+
February	+	+	+	+	|	+
March	+	+	−	+	↓	+
April	+	+	−	0	↑	+
May	+	+	−	0	|	+
June	0	+	−	0	|	+
July	0	+	0	0	− 2.16	+
August	0	+	0	0	|	+
September	0	+	0	0	|	+
October	0	+	0	0	↓	+
Net Totals (inches)	19.73	Cons. Use	0	0.11	− 0.62	0.75
			1961–62			
October	+	+	0	0	0	+
November	+	+	+	0	0	+
December	+	+	+	+	0	+
January	+	+	+	+	0	+
February	+	+	+	+	↑	+
March	+	+	−	+	+ 4.68	+
April	+	+	−	0	↓	+
May	+	+	−	0	↑	+
June	0	+	−	0	|	+
July	0	+	0	0	|	+
August	0	+	0	0	− 3.71	+
September	0	+	0	0	|	+
October	0	+	0	0	↓	+
Net Totals (inches)	25.06	Cons. Use	0	3.30	+ 0.97	0.75

TABLE 3. *Continued*

Component	P	Cons. Use	ΔSMS	RO	ΔGW Stor.	GW Outflow
			1962–63			
October	+	+	+	+	↑	+
November	+	+	+	+	|	+
December	+	+	+	+	|	+
January	0	+	0	0	+ 6.59	+
February	+	+	+	+	|	+
March	+	+	−	+	|	+
April	+	+	−	+	↓	+
May	+	+	−	+	↑	+
June	0	+	−	+	|	+
July	0	+	0	0	− 5.67	+
August	0	+	0	0	|	+
September	0	+	0	0	↓	+
Net Totals (inches)	34.41	Cons. Use	0	5.67	+ 0.92	1.98

6. Hydrologic balances

6.1. ANNUAL

To visualize the activity in the runoff cycle during each month, Table 3 has been prepared based on the data for the 1960–61, 1961–62, and 1962–63 seasons. For each month an entry has been listed under each of the major components. A zero indicates no change, while a plus indicates a positive accretion or disposition and a minus indicates a negative accretion or disposition. The last line of Table 3 lists the net totals of each component for the three hydrologic years.

Table 4 summarizes the hydrologic balances for three consecutive hydrologic years. These balances list the terms as indicated in eq. (3). In the 1960–61 hydrologic year, which includes the time from October 1960 through

TABLE 4

Hydrologic Balances

Placer Watershed B

Year	P	RO	ΔGW Stor.	GW Out	Cons. Use
60–61	19.73	0.11	− 0.62	0.75	19.49
61–62	25.06	3.30	+ 0.97	0.75	20.04
62–63	34.41	5.67	+ 0.92	1.98	25.84

September 1961, the groundwater storage change for the entire year shows a net decrease in groundwater storage of 0.62 inches. This is typical of the response expected for a rainfall deficient year and is analogous to the situation which occurs in low elevation valleys in years of low rainfall when pumping wells for water supply causes a lowering in the water table over the entire area. The change in groundwater storage, being a negative quantity, is algebraically added to the precipitation figure in calculating the consumptive use of 19.49 inches from eq. (3).

In the 1961–62 hydrologic year, groundwater storage shows a net increase of 0.97 inches. This quantity represents a positive addition to the groundwater storage taken from the total precipitation for that year and the consumptive use calculation from eq. (3) yields a value of 20.04 inches which is very close to the value for the preceding year. It must be pointed out here that the difference in sign of the groundwater storage terms for these two years would cause a difference in the total consumptive use of approximately 1.5 inches if these terms were not included.

In the 1962–63 year, a net increase of 0.92 inches occurred in the groundwater storage. The groundwater outflow for this year was considerably higher than the two previous years due to the high levels of groundwater which were built up during the recharge portion of the hydrologic year. In fact, the groundwater levels for this hydrologic year were the highest in the three years. The consumptive use of 25.85 inches calculated for this year was higher than the values of the two previous years. This was partially due to the fact that 12 inches of the rainfall occurred in mid-October and were followed by a month of practically no rainfall. This permitted higher than normal consumptive use during October and November. Also, data from other watersheds have generally shown that consumptive use or total losses are usually highest in the years of highest rainfall.

Table 5 lists the rainfall redistribution for Placer County Watershed B for the three hydrologic years which were described in Tables 3 and 4 and discussed in the previous paragraphs. The tabulation is broken down as follows:

TABLE 5

Rainfall Redistribution

Placer Watershed B

Year	P	% RO	% Use	GW Recharge	GW U + O
60–61	19.73	0.5	98.78	1.54	2.16
61–62	25.05	13.1	79.96	4.68	3.71
62–63	34.41	16.5	75.09	6.59	5.67

percent of the rainfall occurring as runoff, the percent occurring as consumptive use, the total amount of groundwater recharge during the rainy season, and the total amount of groundwater use and outflow occurring during the spring and summer months. In Table 5 it can be seen that as the amount of rainfall increased, the percent of runoff increased, and the percent of consumptive use decreased. However, the important information in Table 5 is the depth of water which was recharged to the saturated zone and then subsequently used directly from that zone or discharged as base flow in the stream or subsurface outflow from the watershed. In 1960–61, which was a below normal rainfall year, it is seen that 1.54 inches were added to the groundwater system and 2.16 inches were used or discharged from the system. For 1961–62, these amounts are 4.68 inches and 3.71 inches and for 1962–63 an above normal rainfall year, the amounts are 6.59 and 5.67 inches. These data indicate the importance of the groundwater portion of the runoff cycle in buffering the rainfall-runoff response of the watershed and in controlling the timing of the water yield from the watershed.

6.2. SHORT TERM

The use of shorter term balances requires evaluation of changes in soil moisture storage. This can be accomplished by periodic soil moisture determinations using gravimetric, electrical, or neutron-scattering methods. Short term balances on weekly, monthly, or stormlength time periods can be used to determine the disposal or redistribution of precipitation in the soil moisture cycle. A hydrologic balance for a three-week period in January and February of 1964 is presented in Table 6 to demonstrate the inclusion of soil moisture changes in the balance.

The data of Table 6 demonstrate the calculation of Consumptive Use from the hydrologic balance. The end of the balance period was selected at the time when groundwater levels had ceased to rise. An estimate of the Consumptive Use for the same period is the sum of the estimated interception losses and estimated evapotranspiration. As shown in Table 6, the difference between calculated and estimated values of Consumptive Use is 0.69 inches. Thus the hydrologic balance accounts for the disposal of 5.19 inches of precipitation with 13% error. The possible errors in ΔGWS, GW Outflow, and ΔSMS may account for the 13% discrepancy. However, another possible cause for this discrepancy is an increase in storage in the unsaturated zone in the fractured rock. This zone is 5 to 80 feet thick within the watershed.

Short term balances of this sort with added refinement of the measurements in the groundwater and soil moisture cycles can account for the redistribution of rainfall on a continuous time incremented basis.

TABLE 6

Hydrologic Balance for Watershed B
From 1-13-64 to 2-4-64

Consumptive Use = Precip. − $RO \pm \Delta GWS \pm \Delta SMS - GW$ Out

Precip. = 5.19 inches

RO = 0.84 inches

ΔGWS = + 1.85 inches

ΔSMS = + 0.61 inches

GW Out = 0.11 inches

Consumptive Use = 5.19 − 0.84 − 1.85 − 0.61 − 0.11 = 1.78 inches

Precip. occurred between 1–13 and 1–22

Interception loss estimated for the storm = 10% of Precip.

Interception Losses (est.) = 0.10 × 5.19 = 0.52 inches

Pan Evaporation = 0.57 inches

Evapotranspiration estimate = Pan Evaporation = 0.57 inches

Estimated Error in Consumptive Use = Computed − Estimated

Estimated Consumptive Use = Interception Losses + Evapotranspiration
= 0.52 + 0.57
= 1.09 inches

Error in Consumptive Use = 1.78 − 1.09
= 0.69 inches

Percent Error in Accounting for Disposition of Precip. $= \frac{0.69}{5.19} \times 100 = 13.3\%$

7. Discussion

The data presented for Placer County Watershed B clearly demonstrate the necessity for considering the groundwater portion of the hydrologic cycle in experimental watershed studies. The magnitudes of groundwater recharge and groundwater use and outflow which were presented show the importance of increased understanding that can be gained from consideration of the complete hydrologic cycle.

Removal of deep-rooted vegetation from experimental watersheds is certain to influence the groundwater portion of the hydrologic cycle[2]).

The hydrologic balance for both short and long time periods can be a valuable tool for assessing the effects of watershed treatments on rainfall redistribution and on the timing and quantity of water yields. Balances may also be calculated for any of the sub-cycles of the runoff cycle.

For example, the determination of the *ET* output from the groundwater cycle may be made from a groundwater cycle balance. To solve for Use one may write the following equation, referring to Fig. 1.

$$(U + O) = \text{Use} + \text{Outflow} + \text{Baseflow}$$
$$\text{Use} = (U + O) - \text{Outflow} - \text{Baseflow}$$

The term $(U+O)$ is the total decrease in groundwater storage as indicated in Table 5. The groundwater outflow can be determined as discussed previously and the baseflow can be determined from streamflow records by separation of hydrograph components. This approach provides an indirect means of quantitatively assessing the influence of deep-rooted vegetation on the groundwater portion of the hydrologic cycle. Such assessments can be made before and after watershed treatments to aid in fully evaluating treatment effects.

8. Conclusion

Depending on the relative thicknesses of the soil and weathered zone and the fractured rock zone, watershed management for increased water yield may be broadly classed into two categories. These are 1) soil moisture management, 2) groundwater management. These categories are necessarily exclusive of surface runoff management, which – while it is directly influenced by the watershed vegetation – does not contain that water which may be yielded due to a reduction in transpirational use by vegetation. Careful inventories of the transmission and storage characteristics of the soil moisture and groundwater zones are needed to determine which category of watershed management will be in effect when a vegetation conversion is applied to a given watershed.

Potential water production by watershed management must be predicted quantitatively so that watershed management projects can be evaluated as economic alternatives in resources planning. The efficiency of water production by watershed management should be evaluated by some means. The following definition is proposed:

$$\text{Efficiency} = \frac{\text{Increased water yield}}{\text{Evapotranspiration reduction}}.$$

Such considerations cannot be made without careful assessment of both the soil moisture and groundwater cycles in experimental watershed research.

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