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DEVELOPMENT OF EOS-AIDED PROCEDURES FOR THE DETERMINATION OF THE WATER BALANCE OF HYDROLOGIC BUDGET OF A LARGE WATERSHED

Principal Investigator

Prof. Russell G. Congalton
Dept. of Forestry and Resource Management

Co-Principal Investigators

Dr. Randall W. Thomas
Space Sciences Laboratory

Prof. Paul J. Zinke
Dept. of Forestry and Resource Management

Co-Experimenters

Dr. George F. Smoot
Space Sciences Laboratory

Prof. John A. Helms
Dept. of Forestry and Resource Management

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Progress Report

1.0 Introduction

Work during the period from August 1 through December 31, 1986 on NASA Grant No. NAGW-881 has focused on (1) acquisition of the remotely sensed data for the 1985-86 hydrologic year, (2) continuation of the field measurement program, (3) continued acquisition and construction of passive microwave remote sensing instruments, (4) a compilation of data necessary for an initial water balance computation, and (5) participation with the EOS Simultaneity Team in reviewing the Feather River watershed as a possible site for a simultaneity experiment. These activities combined with the activities reported in our last progress report will provide a basis for characterizing the process of water loss from plants and soils.

2.0 Acquisition of Remotely Sensed Data

The following table summarized the remotely sensed data acquired for the 1985-86 hydrologic year. These data will be analyzed in the first half of 1987 as input into the water balance models.

Imagery Type	Acquisition Date and Extent
TM data	July 27, 1986 August 28, 1986
TMS data	6/31/86 (temperature transect and field measurement sites only)
AIS data	9/29/86 (field measurement sites only)
AVHRR data	22 passes (Oct 85 - Aug 86)
Photography	1:24000 color 9-11-86 (field measurement 1:12000 color 7-13-86 sites only)

3.0 Continuation of the Field Movement Program

Two of the three proposed sets of transpiration measurements were obtained during the 1986 field measurement program. Foul weather forced the cancellation of the third measurement set. The following paragraphs outline the measurements taken and describe the analysis to be performed.

3.1 Seasonal/Diurnal Measures of Water Relations

Two seasonal sets of diurnal measurements of water relations were obtained: 1) late July representing late summer, or peak water stress conditions; and 2) late August/September, just prior to fall rains.

Five sites were selected within the watershed in which the vegetation was relatively uniform within an area 30 x 30 m. This will permit ready identification of the thermal signature from a pixel-sized area within the sample area.

The following measures were obtained on each site:

1) leaf conductance: LI-COR 1600 leaf diffusion porometer.
2) xylem pressure potential: Scholander-type pressure bomb.
3) leaf temp., relative humidity, light intensity (at the time of each measure of water relations).
4) soil water depletion: Nuclear-chicago neutron probe. (Site 5 and 6 only).

Six sites were sampled:

#1. Mixed Conifer

A group of three adjacent trees, one each of ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and white fir (*Abies concolar*). Each tree was 25-m tall with a live crown extending almost to the ground. Water relations were sampled on the south side of the crown, at five vertical positions form the top of the tree to the base of the live crown, using a hydraulic bucket truck.

Leaf conductance was measured on each tree, on each of three age classes of foliage, at each height position.

Xylem pressure potential was measured on current year's foliage for Douglas-fir and white fir, and on each of three age classes for ponderosa pine.

Measures were made four times during the day, from dawn to dark.

#2. Serpentine Soil

These shallow soils, which are common in the watershed, are low quality, high in magnesium content, and support scattered 20-m tall Jeffrey pine trees (*Pinus jeffreyi*). Ground vegetation is whitehorn (*Arctostaphylos cordulatus*). This low site site probably has rapid soil water depletion resulting in early plant water stress.

Water relations were measured on two similar trees, on three leaf ages, at each of five height positions, four times during the day.

#3 Meadow Vegetation

a) Willow (*Salix* spp.)

Sampling was done on one leaf age, at three crown positions within the canopy, with four replications, and five times during the day.

b Sedge (Carex spp.)

This sample, growing in a non-stress condition in free water, consisted of one leaf age replicated three times, five times during the day.

#4 Hardwood

Quercus kelloggii, one tree 3-m tall: two leaf ages, at mid-crown, replicated two times, and measured four times during the day.

#5 Brushfield

Uniform cover of deerbrush (Ceanothus integerriumus), manzanita (Arctostaphylos patula), and planted Jeffrey pine, all 1-m tall. More than 95% of the leaf area on the site consisted of the two shrub species. One foliar age was sampled on the shrubs, and three on the conifer saplings, at one crown positions, five times during the day.

#6. Conifer

Three 4-m-tall trees from the same seed source were selected in a large uniform plantation of 7-year-old ponderosa pine trees. Measures of water relations were made on three age classes of foliage, at three heights within the crown, on both the north- and south-facing sides, five times during the day.

On each sampling date, reflected temperature above the canopy was measured four times during the day, at six locations within the stand, using a hydraulic bucket truck and a hand-held infra-red temperature sensor.

3.2 Measures of Crown Cover and Leaf Area

Brushfield: Seven transects totalling 800 m were installed to estimate crown cover by species. Eight 0.1 m^2 samples were obtained from each transect to determine the amount of foliage, by species, per unit of surface area.

Conifer: Total leaf number per whorl, in each of three age classes of foliage, was counted on each of the three trees on Site #6, and on the small saplings in Site #5. These measures will provide accurate estimates of total leaf area and weight.

3.3 Analyses

All data have been entered into the computer and analyses are in progress for an evaluation of:

1) end of season soil water depletion on Sites 5 and 6.

2) comparison of watershed vegetation in terms of:
   a) relative capacity to control water use through stomatal closure.
   b) relative rates of transpiration.
   c) relative capacity for diurnal use of water.

d) within-crown variability in water use.

3) ground truth data of water use per unit of ground area, and above canopy temperature, for interpreting remotely-sensed ET.

4.0 Passive Microwave

Construction of the passive microwave instruments continue and should be fully operational by this year's field measurement program. A support structure for the dish has been assembled, and motorized actuators have been added. They allow automatic scans of 100° in horizontal direction, and 50° in vertical direction. The mount and dish are now stored away for the winter. Since we do not expect to use them during the bad season, we preferred to avoid the chance of gusty winds damaging the structure. We are working on the interface between the actuators' control unit and the computer; we plan to modify the electronics so that we will be able to control the speed and extent of the scan from the computer keyboard. We are using an LSI 11/23 unit for development and testing, but we plan to acquire and modify one (or two) smaller processors, battery powered for ease of use in the field, for instrument controlling and data acquisition. The Toshiba (IBM compatible) PC's seems to be our best possibility.

The C- and K-band dual polarization receivers have been tested for radiometric characteristics, and matched together. The size of the front and amplifier-downconverters assembly (which is housed at the prime focus of the dish) is larger than we expected originally; its shadow might reduce efficiency and sidelobes rejection, but we will have to test for this effect.

DC amplifiers and integrators have been designed, and are currently being built in our electronic shop. A major concern of ours has been the possibility of cross-talk between channels, with so many different lines running next to each other; the final design calls for 2 K-, 2 C-, and 12L-band channels. The RF amplifiers have been tested for this effect, and have shown to be immune under laboratory conditions. We will test also cables and connectors, and make sure that no coupling exists through the power lines. As a cheaper and more versatile alternative to commercially available detectors, we are assemblying the detector diode elements.

Laboratory studies of sample properties have continued.

5.0 Initial Water Balance Computations

During the past 6 months represented by this progress report an initial water balance was made of the 184 square mile Spanish Creek watershed, a tributary of the Feather River for a range of very dry to very wet years. This was made using no remote sensing data. A series of such water balances will ultimately serve as the basis for the improved assessment techniques using remote sensing data during the coming year.

5.1 Procedure

The choice of the Spanish Creek watershed for initial trial water balance estimates was made for the following reasons:

- This watershed contains a mosaic of soil and vegetation types typical of much of the Feather River Basin.

- The elevation range within the watershed is broad enough, (about 6000') to cover much of the elevation range in the Feather River Basin, and to include a major snow storage component.
- The watershed is one of the few in the Feather River Basin which has flow unimpeded by reservoir storage and diversions.
- Adequate stream gaging data exist.
- The watershed includes the Meadow Valley area where detailed plots for research on interactions between vegetation and soil moisture have been established.

The procedure used was essentially a bookkeeping method based upon evaluating Precipitation - Evaporative Losses to determine an estimated water yield. The following equations represent the main basis for the calculations, and are based upon a similar approach used by the U.S. Army Corp. of Engineers1/

$$P - L = Q_{gen} \qquad (1)$$
$$P - (W_2 - W_1) - L = Q_{gen} \qquad (2)$$
$$L = L_i + Q_{sm} + L_{et} \qquad (3)$$
$$P = P_r + P_s = P_n + L_i = P_{rn} + L_{ri} + P_{sn} + L_{si} \qquad (4)$$

$$Q_{gen} = P_{rn} + P_{sn} - (W_2 - W_1) - Q_{sm} - L_{et} \qquad (5)$$
$$Q_{gen} = P_{rn} + M - Q_{sm} - L_{et} \qquad (6)$$

$$Q_{gen} = Q + Q_s \qquad (7)$$

Symbols used are: P, areal or watershed precipitation; L, areal or watershed loss; Q_{gen}, quantity of runoff generated; Q, quantity of water yielded at gauging station; W_1, water equivalent of snowpack (depth of H_2O) ;at beginning of period; W_2, at end of period; L_i, areal interception loss (with subscripts s - interception loss as snow, r - interception loss as rain); L_{et}, evapotranspiration loss; P_n, net precipitation reaching ground, with subscript s - as snow, r - as rain; Q_{sm}, change in soil moisture storage; Q_s, bank and channel storage. All measurements as in units of water depth over the defined area which is usually a watershed. M is snow melt for the period which is equal to $P_{sn}-(W_2-W_1)$.

1/U.S. Army Corp of Engineers, North Pacific Division, 1956 SNOW HYDROLOGY. Portland Oregon

The losses are mainly those due to interception loss of snow and rain stored by vegetation canopies using data form the various western Snow Hydrology laboratories, and estimated actual evapotranspiration losses derived from potential evapotranspiration by the Thornthwaite2/ equation and dependent upon water being available to meet this potential. Soil moisture and snow storage amounts were determined based upon soil surveys, and current snow survey data. Precipitation inputs and temperature data for evapotranspiration calculations used available weather station data. All calculations were made on an areal basis over the Spanish Creek Watershed for monthly periods through hydrologic years beginning October 1. The water balance estimates were made for the years beginning October 1 1976, 1979, and 1981. 1976 was one of the driest years on record, 1981 one of the wettest, and 1979 an average year.

5.2 Results

The results of the estimates are shown in tables 1-3. The abbreviations for the components are those used in the explanation above, except Q_{act} is the actual runoff as measured at the gaging station.

2/Thornthwaite, C.W. 1958. Graphical solution of Thornthwaite method. U.S. Weather Bureau, Monthly Weather Review. Vol 80. U.S. Govt. Printing Office, Washington, D.C. pp 124-128.

TABLE 1
SPANISH CREEK WATER BALANCE
Hydrologic Year, October 1, 1976-September 31, 1977

COMPONENT	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL TOTAL
	MONTH												
P	.35	1.08	.12	2.29	2.56	1.47	.35	1.54	.97	.24	.02	1.29	12.28
L_i	.20	.43	.05	.56	.52	.43	.21	.53	.42	.24	.02	.65	
P_n	.15	.65	.06	1.7	2.0	1.0	.14	1.01	.55	.17	.00	.64	8.15
W_1	0	0	0	.03	.56	.54	.64	.09	0	0	0	0	
W_2	0	0	.03	.56	.54	.64	.09	0	0	0	0	0	
Qsm_1	0	0	.01	.04	1.21	2.8	3.3	1.95	1.06	0	0	0	
Qsm_2	0	.01	.04	1.21	2.8	3.3	1.95	1.06	0	0	0	0	
L_{et} (Pot.)	1.55	.64	0	0	.48	.44	2.04	1.99	4.67	4.78	5.14	2.91	24.64
L_{et} (Act.)	.15	.64	0	0	.48	.44	2.04	1.99	1.61	.17	.02	.64	8.18
Q_{gen}	0	0	0	0	0	0	0	0	0	0	0	0	0
Q_{act}	.18	.22	.22	.30	.32	.35	.27	.32	.11	.07	.05	.09	2.5

Units are inches of water over the 184mi^2 watershed.

TABLE 2
SPANISH CREEK WATER BALANCE
Hydrologic Year, October 1, 1979 to September 31, 1980

COMPONENT	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL TOTAL
	MONTH												
P	5.94	2.07	7.65	9.01	11.60	3.12	2.33	2.56	0.66	0.56	.03	.05	45.58
L_i	.69	.46	1.94	2.28	2.94	.79	.41	.45	.28	.24	.03	.04	
P_n	5.24	1.61	5.71	6.73	8.66	2.33	1.92	2.11	.38	.32	0	.01	35.02
W_1	0	0	.31	4.37	3.69	12.06	6.48	1.96	.8	0	0	0	
W_2	0	.31	4.37	3.69	12.06	6.48	1.96	.8	0	0	0	0	
Qsm_1	0	2.98	3.64	4.94	6.0	5.61	6.0	6.0	6.0	4.57	.42	0	
Qsm_2	2.98	3.64	4.94	6.0	5.61	6.0	6.0	6.0	4.57	.42	0	0	
Let (Pot)	2.26	.64	.35	.62	.68	.84	1.73	2.13	2.61	4.47	3.59	2.23	22.15
Let (Act)	2.26	.64	.35	.62	.68	.84	1.73	2.13	2.61	4.47	.42	.01	16.76
Qgen	0	0	0	5.73	0	6.68	4.71	1.14	0	0	0	0	18.26
Qact	.38	.45	.77	7.5	6.83	3.03	2.59	2.11	.95	.38	.20	.21	25.40

Units are inches of water over the 184mi^2 watershed.

TABLE 3
SPANISH CREEK WATER BALANCE
Hydrologic Year, October 1,1981-September 31, 1982

COMPONENT	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL TOTAL
	MONTH												
P	9.3	20.2	10.8	6.2	5.2	11.0	12.2	0.0	1.8	.5	.2	2.0	79.4
L_i	1.0	2.0	1.8	1.6	.6	2.7	1.2	0.0	.6	.2	.1	.4	12.2
P_n	8.3	18.2	9.0	4.6	4.6	8.3	11.0	0	1.2	0.3	0.1	1.6	67.2
W_1	0	0	2.8	3.9	6.7	2.5	8.8	4.1	1.6	0.2	0	0	0
W_2	0	0	2.8	6.7	2.5	8.8	4.1	1.6	.2	0	0	0	
Qsm_1	0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.2	2.8	0	0	
Qsm_2	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.2	2.8	0	0	0	
Let (Pot)	1.4	1.1	.6	0	.6	1.0	1.8	3.3	4.0	4.6	4.3	2.9	25.6
Let (Act)	1.4	1.1	.6	0	.6	1.0	1.8	3.3	4.0	3.3	.1	1.6	18.8
Qgen	1.9	17.1	5.6	2.7	8.2	1.0	13.9	0	0	0	0	0	48.4
Qact	.4	6.2	6.1	2.6	5.7	3.9	10.1	4.7	1.4	.6	.3	.3	42.4

Units are inches depth of water over the 184mi^2 watershed.

The summary results of tables 1-3 are shown in the following Table 4:

Water Year	Discharge (acre feet)	Q generated (inches)	Q actual (inches)	Difference (inches)
1976-1977	24,500	0.0	2.5	-2.5
1979-1980	250,000	18.3	25.4	-7.1
1981-1982	416,000	47.4	42.4	+5.0

These preliminary results indicate that in wet years, losses are underestimated, and for medium to dry years, losses are overestimated.

A significant role may be played by interception losses in these discrepancies.

The underestimate of the yield in the very dry year probably represents and underestimate of groundwater and bank storage yields to flows, and the converse, the overestimates for wet years may represent a lack of accounting for recharge of ground water storage.

5.3 Role of Remote Sensing in Improving the Water Balance Estimate

It is the plan of this study during the future phases of the research to improve upon these water balance estimates by the following measures:

1. Improved estimates of snowpack storage amounts and distribution over the watersheds of the Feather River Basin through remote sensing measurements combined with snow course survey data.

2. Improved estimates of the temperature parameter utilizing AVHRR thermal band data as an index to the temperature at the evaporating and transpiring surfaces to use in an improved potential evapotranspiration estimate.

3. Use of temperature differences day and night from AVHRR data to determine when water is no longer available to meet the demand imposed by potential evapo-transpiration on vegetation, and to indicate areas of shallow soil moisture storage and the time of exhaustion of such storage.

4. Use of remote sensing data to determine the location and extent of land and vegetation surfaces on the watershed which are using water at the full potential evapo-transpiration draft during the water year.

5. Use of remote sensing data to determine anomalies in precipitation distribution over tributary watersheds in the Feather River Basin.

11. Continuation of ground control surface temperature studies during the drying period of the water balance in 1987 on the extensive test sites established in 1986 on the north fork Feather River watershed.

6.0 Participation with the EOS Simultaneity Team

The investigators of this study participated with the EOS Simultaneity Team led by Dr. JoBea Cimino in a three-day review of the Feather River Watershed for possible use for future simultaneity experiments. This review, held October 27-29, 1986, consisted of a windshield visit through the watershed with stops at our field measurement study sites. In addition, the temperature transects described in our first progress report were also visited and an aerial reconnaissance of the watershed was performed. Finally, a discussion of the possible use of the watershed for experiments in 1989 was conducted on the last day.

7.0 Work Planned for the First Six Months of 1987

Analysis of the field measurement data and corresponding remotely sensed data will continue resulting in improved estimates of water balance. Techniques for combining data at different resolutions will be explored using spatial analysis techniques. In addition, the microwave instruments will be completed, tested, and prepared for 1987 field experiments. Detailed plans for the 1987 field experiments will be made including plans to measure more between vegetation species variability.