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Department of Water Resources
Adjudication Bureau

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COPY

1 Claimant:

Hagerman Water Right Owners, Inc. and
its individual members

2
3 Attorney Name and Address:

HEPWORTH, LEZAMIZ & HOHNHORST,
CHARTERED
133 Shoshone St. North
P.O. Box 389
Twin Falls, ID 83303-0389
Telephone: (208)734-7510

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8 IN THE DISTRICT COURT OF THE FIFTH JUDICIAL DISTRICT OF THE
9 STATE OF IDAHO, IN AND FOR THE COUNTY OF TWIN FALLS

10 * * * * *

11 In Re SRBA

)

) Subcase No. See Attached Exhibit A

)

12 Case No. 39576

)

AFFIDAVIT OF CHARLES E.
BROCKWAY, PH.D.

)

13 * * * * *

14 STATE OF IDAHO

)

) ss.

15 County of Twin Falls

)

16
17
18 Charles E. Brockway, Ph.D., being first duly sworn upon oath, deposes and
19 says:

20 1. Your affiant's name is Charles E. Brockway, residing in Twin Falls,
21 Idaho. Your affiant is a ground water hydrologist that has been employed by, among others,
22 the claimants in the above entitled matter. This affidavit is filed in support of the motions
23 for summary judgment that have been filed by the claimants in the subcases identified in

36-3A
H_LH
Chartered
Hepworth,
Lezamiz &
Hohnhorst

AFFIDAVIT OF CHARLES E. BROCKWAY - 1

1 Exhibit "A" attached.

2 2. Attached to this affidavit as Exhibit "B" and incorporated into this
3 affidavit is a true and accurate copy of my curriculum vitae which sets forth my
4 qualifications as an expert in the field of hydrology, generally, and as it relates to crop water
5 requirements.

6 3. I am generally familiar with crop water usage in the State of Idaho and
7 more particularly in the Hagerman Valley based on work I have done as a consultant and
8 as a researcher in relationship to the crop water usage and irrigation practices.

9 4. I have been qualified to testify and have testified as an expert witness
10 on many issues relating to hydrology and ground water use in the Snake River Basin
11 Adjudication.

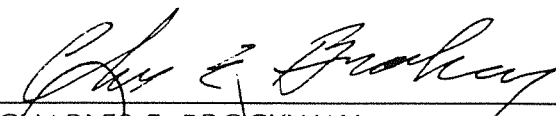
12 5. I have been asked by the claimants in the subcases to calculate the
13 "consumptive use" of water used for irrigation in the Hagerman Valley as that term is
14 defined in I.C. §42-1401A(2). For purposes of this study, consumptive use is defined as
15 evapotranspiration (ET) for the most water consumptive crop which can be grown in the
16 area, which in this case is alfalfa hay.

17 6. I have consulted several publications relating to crop ET in Idaho to
18 determine the amount of water required per season related to the yield of the alfalfa crop.
19 The most applicable research and published data is that included in the 1988 publication
20 entitled "Daily and Seasonal Evapotranspiration and Yield of Irrigated Alfalfa in Southern
21 Idaho" by James L. Wright, published in the Agronomy Journal, Vol. 80, No. 4 in 1988, a
22 copy of which is attached as Exhibit "C." Dr. Wright is a nationally recognized soil scientist
23

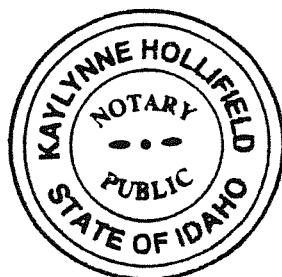
1 in the area of crop evapotranspiration and water use. The Agronomy Journal is a peer
2 reviewed, recognized scientific journal in the field. Data from the 1988 publication was
3 used to construct the graph on Exhibit "D" attached. This graph shows the relationship
4 between alfalfa yield and consumptive water requirement for the season. The numbers on
5 the axes of the graph are converted from metric units in Exhibit "C" to more familiar units
6 of tons per acre for yield and inches of water for consumptive use. If the yield of alfalfa is
7 known in an area of Southern Idaho, then the estimated seasonal consumptive use can be
8 determined from Exhibit "D." For example, if the alfalfa yield is 10 tons per acre, Exhibit
9 "D" indicates that the seasonal consumptive use would be near 45 inches per acre or 45
10 divided by 12 = 3.75 acre feet per acre.

11 7. It is my opinion that 3.75 acre feet per acre per annum is the amount
12 of consumptive use that is reasonable based upon a yield of ten tons per acre. I based the
13 ten tons per acre figure on the affidavits of Dan McFadden and John W. Jones, Jr., which
14 indicate that ten tons per acre is a reasonable expected yield for alfalfa in the Hagerman
15 Valley.

16 Dated this 31st day of May, 1996.

17
18 
CHARLES E. BROCKWAY

19 SUBSCRIBED and SWORN to before me this 31st day of May, 1996.



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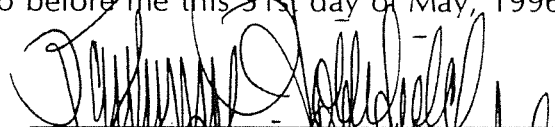

NOTARY PUBLIC FOR IDAHO
Residing at: _____
My Commission Expires: 12/1/99

EXHIBIT "A"

List of Subcases

Lynn J. Babington and Karen L. Babington	36-00003C
Walter J. Bonning, II and Judy L. Bonning	36-00108B
Dale E. Boyer and Elaine Boyer	36-00079
William E. Norris, David L. and Linda C. Cropper, Blaine Richard and Vivian Cropper, Dave and Nancy Anderson	36-00047
Mildred Culbertson	36-10409
Frank C. Erwin and Peggy Erwin	36-00092
Michael J. Fleming	36-00064B
Keith L. Fuell and Jolene Fuell	36-00086C
Frank L. Glauner and Jean Glauner	36-00039E
Mattie P. Grigg	36-10283B
George J. Korbis and Nellie W. Korbis	36-00039N
Marilyn J. Miller	36-00085A
Howard L. Morris and Rhonda K. Morris	36-00061
Howard L. Morris and Rhonda K. Morris	36-00062
Howard L. Morris and Rhonda K. Morris	36-00063
Mark Potter and Susan Potter	36-00039J
Edna M. Rea	36-00003A
Roger Shaffer	36-00034B
Doyt H. Simcoe and Roxie Simcoe	36-00003F
Richard D. Simon	36-00035J
Dick J. Veenendaal and Sigrid E. Veenendaal	36-00039C
Edith L. Vernon	36-00003E
Paul E. Watkins and Inez S. Watkins	36-00106
Basil Lester Zink and Myrle Hyde Zink	36-00103F

Charles E. Brockway, P.E., Ph.D.

**University of Idaho
Research and Extension Center
3793 North 3600 East
Kimberly, Idaho 83341
(208) 423-6601 Office
(208) 733-0938 Residence
E-mail: Brockway@Kimberly.uidaho.edu**

February 1995

Present title and definition of individual position:

Research Professor - Civil and Agricultural Engineering: Supervision of research conducted by the University Water Resources Research Institute and the College of Engineering at Kimberly, Idaho. Graduate student supervision and directed studies instruction in Water Management and Water Resources related subjects.

Associate Director - Idaho Water Resources Research Institute

Summary of education beyond high school:

<u>Institution</u>	<u>Degree</u>	<u>Year</u>
University of Idaho 1955-59	B.S.-C.E.	1959
California Institute of Technology 1959-60	M.S.-C.E.	1960
University of Colorado, Denver, Colorado	Management	1963
University of Denver, Denver, Colorado	Civil Engineering	1964
Utah State University	Ph.D.-Water Resources Engineering	1977

Number of years service on this faculty: 30

Date of original appointment: 1965

Dates of advancement in rank:

Associate Research Professor: 1974

Professor-50% Agricultural Engineering, 50% Civil Engineering : 1978

Subjects and courses taught:

CE 500, CE 600, CE 502

Summary of academic experience:

University of Idaho - Research Professor - Civil and Agricultural Engineering	1978-
University of Idaho - Associate Research Professor, Civil Engineering	1974-78
University of Idaho - Assistant Research Professor, Civil Engineering	1965-74
Boise College - Instructor in Engineering	1961-63

Summary of other experience:

University of Idaho - USAID Pakistan Project on Irrigation Systems Management Research	1984 -
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U.S. Bureau of Reclamation - Hydraulic Research Laboratory, Denver. Colorado - Hydraulic Research Engineer	1963-65
U.S. Bureau of Reclamation - Boise, Idaho - Hydraulic Engineer	1961-63
Converse Foundation Engineering, Inc. - Pasadena, California - Foundation Engineer	1960-61
California Institute of Technology - Pasadena, California - Assistant Project Engineer, U.S. Public Health Service Research Project	1959-60

Consultant:

Twin Falls Canal Company - Twin Falls, Idaho - Hydrology and water use.
 Cedar Mesa Reservoir and Canal Co., Redding, California - Water management consultant.
 Clear Springs Trout Company, Buhl, Idaho - Water supply and distribution systems.
 Idaho Power Company, Boise, Idaho - Relationships of groundwater and surface water - Upper
 Snake River Basin - water right adjudication.
 Little Pilgrim Irrigation Co., Twin Falls, Idaho - Feasibility Study - Mutual Water Company for
 Desert Entry project.
 Idaho Department of Fish and Game - Evaluation of groundwater stream relationship for
 litigation - Parma vicinity.
 Blaine County, Idaho - Evaluation of waste disposal systems for high density rural
 subdivisions.
 Reynolds and West Reynolds Irrigation Districts - Irrigation water requirements, systems
 analysis.
 U.S. Bureau of Reclamation (was Maricopa County Water District) - Arizona. Flood study.
 Office of Technology Assessment - U.S. Congress - Paper on Irrigation Distribution Systems.
 U.S. Department of Justice - Indian Water Rights
 Valley Trout Company - Buhl, Idaho. Hydropower feasibility evaluations.
 Montgomery Engineers - Ground-water quality evaluations
 J.U.B. Engineers, Twin Falls, Idaho - Ground-water and hydraulics
 Engineering Construction Company, Twin Falls, Idaho - Land application of food processing
 wastes.

Registered Professional Engineer: Idaho and Colorado**Special Awards or Honors:**

Recipient of Bausch & Lomb Science Award
 Member - Phi Beta Sigma, Freshman honorary, University of Idaho
 Outstanding Freshman Engineer Award - University of Idaho, 1955
 Member and secretary of Sigma Tau, National Engineering Honorary
 Member and Vice-president of ASCE student chapter, University of Idaho
 University of Idaho undergraduate scholarship 1957-58, 1958-59
 Honorary Membership ASTM, 1959

Special Awards, cont'd.

U. S. Army National Defense Transportation Award, 1958

Distinguished Military Graduate - University of Idaho
Top Ten Graduating Senior - University of Idaho, 1959
No. 2 in graduating class of 889, University of Idaho, 1959
Representative of USBR Division of Research at 1963 Intergovernmental Training Program,
Denver, 1964
Scholarship - University of Denver, Graduate School of Management, 1964
National Science Foundation Fellowship - Utah State University, 1967-68
Outstanding Young Engineer Award for Idaho, National Society of Professional Engineers,
1968

Membership in professional and scholarly organizations:

National Society of Professional Engineers, 1967 - present
Idaho Society of Professional Engineers, 1967 - present; President 1978
American Society of Civil Engineers - Irrigation & Drainage Division Committee Chairman:
1) Operation and Maintenance of Irrigation and Drainage Systems, 1975-1981
2) Water Quality Committee, 1980-1984, Chairman
3) Task Committee on Guidelines for Erosion and Sediment Control in Irrigated
Agriculture, 1980-1983, Chairman
4) Publications Committee, 1985-1992
Research Society of America
National Council of Examiners for Engineering and Surveying, 1981-1991
Idaho Board of Professional Engineers and Professional Land Surveyors, 1981-1991,
Chairman
American Water Resources Association

Offices held in such organizations:

National Society of Professional Engineers
Member - Young Engineers Committee, 1973-74
Chairman - Young Engineers Committee, 1975-77
Member - President's Committee on Board of Directors Organization, 1977
Member - Registration and Qualification for Practice Committee, 1979-81
Chairman - Registration and Qualification for Practice Committee, 1982-84
Member - Participating Organizations Liaison Committee to NCEE, 1982-84
Idaho Society of Professional Engineers
President, 1978
President, Magic Valley Chapter, 1970-71
Member - State Ethical Practices Committee, 1966, 1977
Member - State Intersociety Relations Committee, 1968
Member - State Nominating Committee, 1975-76
Member - Board of Directors, 1972-73
Member - Board of Directors, Past President Chairman - Nominating Committee, 1979
State Director - Representative for Idaho to NSPE, 1982-83

Offices Held, cont'd.

Nominating Committee for Idaho Board of Professional Engineers & Land Surveyors member.

American Society of Civil Engineers

Member - Operation and Maintenance of Distribution Systems Committee - Irrigation and Drainage Division, 1975-81

Chairman - Irrigation and Drainage Division, Operations and Maintenance Committee, 1977-79

Member - Water Quality Committee, Irrigation and Drainage Division, 1980-84

Chairman - Water Quality Committee, Irrigation and Drainage Division, 1982-84

Member - Task Committee on Water Measurement, 1980-83

Chairman - Task Committee on Guidelines for Erosion and Sediment Control in Irrigated Agriculture, 1984 - Present

Member - Publications Committee, 1985 - Present

Corresponding Member - ASCE Irrigation and Drainage Division Committee on Operation and Maintenance of Irrigation Systems

Reviewer - ASCE Irrigation and Drainage Division Committee on Publications

Idaho Board of Professional Engineers and Land Surveyors

Member, 1981 -

Vice Chairman, 1983-1984

Chairman, 1984 - 1986, 1990 - 1992

National Council of Engineering Examiners

Assistant Vice President, Western Zone

Member, Professional Examinations Advisory Committee

Member, Committee on Uniform Procedures and Legislative Guidelines, 1984

Member, Communications and Publications Committee, 1983

Member, Uniform Examinations and Qualifications Committee, 1984 - Present

Member, Committee on Examination Policies and Procedures, 1987 - Present

Member, Advisory Committee on Council Activities, 1986 - 1987

Assistant Vice President - Western Zone, 1986 - 1987

Member, Fundamentals Examination Review Committee, 1986 - Present

Scholarly and creative activity:

Research in progress:

Development of systems analysis procedures for optimization of irrigation system designs with environmental, physical, and social constraints.

Evaluation of crop consumptive use, irrigation requirements, and methods of determining basin depletion from agricultural development.

Systems analysis of water use to develop mathematical methods for studying complex groundwater-surface water systems - mathematical modeling of aquifers.

Ground water quality and river system water quality evaluations for nutrient load determination and river system modeling.

Research completed:

- Development of guidelines for design of sediment removal facilities for on-farm and irrigation distribution system wasteways.
- Evaluation of attainable impacts on water quality of irrigation return flows due to implementation of best management practices for sediment and nutrient control.
- Evaluation of alternate energy sources for irrigation and municipal needs in Idaho.
- Analysis of operation and maintenance costs of water distribution systems and determination of the relationship of costs to known physical and organizational parameters and water use efficiency.
- Evaluation of the economic potential for use of geothermal hot water and steam in Idaho.
- Study of the movement of water from canals to local water tables under saturated and partially saturated conditions.
- Studies of the mechanisms of microbial action, sedimentation and soil-water-chemical interactions involved in natural sealing phenomenon in canals and reservoirs.
- Evaluation of irrigation management practices for sustained land disposal of geothermal fluids.
- Evaluation of practices and systems for controlling sediment and other pollutant losses from irrigated lands.
- Investigation of the response of aquifer systems to changes in recharge or withdrawal due to change in land use.
- Evaluation of procedures for estimating crop water requirements.
- Development of cost effective procedures and equipment for measurement of irrigation diversions and power use in open and closed systems.

Community services and other relevant activities:

- Member - Intermountain District Church of the Nazarene: Camps Board - 1976 - 1984; Board of Church Properties - 1976-79
- Member - Twin Falls City Planning and Zoning Commission 12/78-9/79
- Member - College of Southern Idaho Geothermal Energy Commission
- Member - Governor's Committee on Energy Use - 1980-81
- Member - Idaho Technical Advisory Committee for Sediment in Surface Water
- Chairman - Snake River Technical Advisory Committee - Idaho Legislative Council. 1983-85
- Advisor - Governor's Snake River Advisory Committee - 1985
- Member - Water Resources Foundation Board of Directors - 1985
- Chairman - Idaho Technical Committee on Hydrology
- Member - Idaho Department of Health & Welfare Sediment Criteria Committee
- Member - Snake Plain Advisory Committee of Idaho Department of Health & Welfare
- Member - Idaho Water Users Water Quality Committee - 1980-
- Member - INEL Dose Evaluation and Risk Assessment Committee
- Member - Columbia River System Operations Review
- Member - Mid Snake River Nutrient Management Advisory Committee
- Member - Mid Snake River Irrigation Water Quality Coordination Committee
- Technical Advisor - Middle Snake River Committee

Community services, cont'd.

Member - Liaison Committee, U.S. Geological Survey National Water Quality Assessment Program, Snake River Basin.

Member - Snake River Studies Committee, Idaho Department of Water Resources

Member - City of Twin Falls Wellhead Protection Committee

Publications:

Brockway, C.E. 1964. Progress Report - Investigation of a Seepage Meter Designed by the Agricultural Research Service -- Lower Cost Canal Lining Program. Bureau of Reclamation Hydraulic Branch HYD-529.

Brockway, C.E. 1964. Flow Resistance Coefficients of Three Sizes of Cast-in-Place Concrete Pipe. Bureau of Reclamation Hydraulic Branch, HYD-533, 1964.

Brockway, C.E. 1965. Investigation of the Effect of Turnout Geometry on the Registration Accuracy of a Propeller-Type Open Flowmeter. Bureau of Reclamation, HYD-545, 1965.

Brockway, C.E. 1966. Groundwater Investigations and Canal Seepage Studies. Engineering Experiment Station, University of Idaho, Progress Report No. 1, 1966.

Schuster, J.C. and C.E. Brockway. 1967. Investigation of a 4-Inch Magnetic Flowmeter. Bureau of Reclamation, HYD-574.

Worstell, R.V. and C.E. Brockway. 1967. Estimating Seasonal Changes in Irrigation Canal Seepage. Presented at Spokane, Washington, October 20, 1967.

Worstell, R.V. and C.E. Brockway. 1967. Groundwater Investigations and Canal Seepage Studies. Engineering Experiment Station, University of Idaho, Progress Report No. 2.

Bloomsburg, G.L. and C.E. Brockway. 1968. Movement of Water from Canals to Groundwater Tables. Research Technical Completion Report. Idaho Water Resources Institute.

Worstell, R.V. and C.E. Brockway. 1968. Field Evaluation of Seepage Measurement Methods. Presented at 2nd Seepage Symposium, Phoenix, Arizona, February 1968.

Bondurant, J.A., C.E. Brockway, and R.V. Worstell. 1968. Plastic Casings for Soil Cores. Soil Science, Vol. 107, No. 1.

Herbig, A.E. and C.E. Brockway. 1970. Operations and Maintenance Costs of Irrigation Distribution Systems. Proceedings, National Irrigation Symposium, Lincoln, Nebraska.

Bondurant, J.A., C.E. Brockway, and R.V. Worstell. 1971. Systems Analysis of Irrigation Water Management in Eastern Idaho. Progress Report No. 1, University of Idaho Engineering Experiment Station.

- Brockway, C.E. 1971. What Does it Cost to Operate an Irrigation District?. Proceedings, Fifth Regional Water Users' Conference, Bakersfield, California.
- Bondurant, J.A., R.V. Worstell, and C.E. Brockway. 1972. Water Resources Management in the Upper Snake River Valley. Proceedings, Irrigation & Drainage Division, Specialty Conference, ASCE, Spokane, Washington.
- Nichols, C.R., C.G. Warnick, and C.E. Brockway. 1972. Geothermal Water and Power Resources Exploration and Development for Idaho. Research Technical Completion Report, University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Brockway, C.E. 1972. Estimating Irrigation Distribution System Operation and Maintenance Costs. Paper presented at the Annual Meeting, Pacific Northwest Region ASAE, Calgary, Alberta, Canada, October 10-12, 1972.
- Bondurant, J.A., R.V. Worstell, and C.E. Brockway. 1973. Implications of Changes in Water Management in the Upper Snake River Basin. Paper presented at the ASCE Water Resources Conference, Washington, D.C., January, 1973.
- Brockway, C.E. 1973. Investigation of Natural Sealing Effects in Irrigation Canals. Research Technical Completion Report, Project A-023-IDA, Idaho Water Resources Research Institute.
- Reese, D.L. and C.E. Brockway. Operation and Maintenance Costs on Irrigation Distribution Systems. Progress Report, University of Idaho, College of Engineering.
- de Sonnevile, Jos L.J. and C.E. Brockway. 1973. Systems Analysis of Irrigation Water Management in Eastern Idaho. Research Technical Completion Report, Project B-018-IDA, University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Reese, David L., H.F. Mayland, and C.E. Brockway. 1973. Alternative Methods of Estimating Snow Water Parameters. Water Resources Research, Vol. 9, No. 5.
- Bondurant, J.A. and C.E. Brockway. 1974. Operation and Maintenance Costs on Irrigation Distribution Systems. Proceedings, VIIIth International Congress of Agricultural Engineering, Flevohof, Netherlands.
- Bondurant, J.A. and C.E. Brockway. 1974. Sediment Ponds Clean Irrigation Runoff Water. Idaho Farmer.
- Brockway, C.E. 1974. Water Resources of the Upper Snake River Basin. Proceedings, National Environmental Research Park Symposium, Idaho Falls, Idaho.
- Watts, F.J., C.E. Brockway, and A.E. Oliver. 1974. Analyses and Design of Settling Basins for Irrigation Return Flow. Research Technical Completion Report, Project A-042-IDA.

University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Warnick, C. and C.E. Brockway. 1974. Hydrology Support Study, A Case Study of Federal Expenditures on a Water and Related Land Resource Project. Boise Project. Idaho and Oregon Project C-4202. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Brockway, C.E. 1975. Energy Plant Siting Position Paper. Idaho Society of Professional Engineers, February, 1975 (member of Committee on Energy Plant Siting).

Bondurant, J.A., M.J. Brown, and C.E. Brockway. 1975. Some Aspects of Sedimentation Pond Design. Proceedings, National Symposium on Urban Hydrology and Sediment Control. Lexington, Kentucky.

Brockway, C.E. 1975. Issues Involved in Peoples Choices in Resources-Water. Idaho Academy of Science, Caldwell, Idaho.

Brockway, C.E. 1975. Science in Idaho's Future. Idaho Academy of Science, Panel Symposium.

Claiborn, B.A. and C.E. Brockway. 1975. Impact of Changes in Irrigation Water Management in Eastern Idaho. Research Technical Completion Report, Project A-040-IDA. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Bondurant, J.A., C.E. Brockway, and M.J. Brown. 1976. Characterizing Irrigation Return Flow Streams. 7th U.S. Technical Conference and 10th ICID Congress.

Brockway, C.E. 1977. Vegetative Buffer Strips for Sediment Retention in Irrigation Runoff. Proceedings, ASCE Irrigation and Drainage Division Specialty Conference on Water Management for Irrigation and Drainage, Reno, Nevada.

Brockway, C.E. 1977. Sediment Ponds for Irrigation Return Flow and Potato Fresh Pack Effluent. Research Technical Completion Report, Project A-042-IDA. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Fitzsimmons, D.W., G.C. Lewis, J.R. Busch, G. M. McMaster and C. W. Berg. 1977. On-Farm Methods for Controlling Sediment and Nutrient Losses. Proceedings, National Conference on Irrigation Return Flow Quality Management, Fort Collins, Colorado.

Brockway, C.E. 1977. Investigation of Natural Sealing Effects in Irrigation Canals. Ph.D. Dissertation, Utah State University.

Brockway, C.E. and K.P. Grover. 1977. Water Management and Groundwater in the Henry's Fork-Upper Snake River Basin of Idaho. Research Technical Completion Report, ASCE Henry's Fork Project, Idaho Water Resources Research Institute.

Bondurant, J.A., M.J. Brown and C.E. Brockway. 1977. Predicting Irrigation Return Flow Rates.

ASAE-SW-192.

Claiborn, Brent and C.E. Brockway. 1977. Predicting Attainable Irrigation Efficiencies. ASCE.

Grover, K.P. and C.E. Brockway. 1978. Evaluation of Urbanization and Changes in Land Use on the Water Resources of Mountain Valleys. Research Technical Completion Report. Project B-038-IDA. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Robbins, C.W. and C.E. Brockway. 1978. Irrigation Water Salt Concentration Influences on Sediment Removal by Ponds. Soil Sci. Soc. Am. J. 42:478-481.

Longley, T.S., C.E. Brockway, and E.C. Larsen. 1978. Low Energy Sprinkler Equipment. ASAE Annual Meeting, Spokane, Washington. PN-78-406.

Brockway, C.E. 1978. Systems Analysis of Irrigation Water Use in Eastern Idaho. OWRT.

Brockway, C.E. 1978. Alternative Irrigation Systems for Flood Damaged Irrigation Lands Below Teton Dam. Research Technical Completion Report, Idaho Water Resources Research Institute.

Busch, J.R., R.G. Allen and C.E. Brockway. 1978. Irrigation Rehabilitation Plans in the Teton Flood Area. ASCE Convention and Exposition, Chicago, Illinois.

Allen, R. G. , J. R. Busch, and C.E. Brockway. 1979. Optimal Irrigation Systems Subject to Available Resources Constraints. IX Congress CIGR 1979.

Brockway, C.E. 1979. Relationship of Costs and Water-Use Efficiency for Irrigation Projects in Idaho. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Brockway, C.E. 1979. Effects of Changing Irrigation Efficiencies on Water Supplies. ASCE Irrigation and Drainage Division Specialty Conference. Albuquerque, New Mexico.

Brockway, C.E. 1979. Snake Plain Aquifer Model Studies. Idaho's Water, September 1979. Vol. 6, No. 4.

Brockway, C.E., editor. 1980. Manual on Operation and Maintenance of Irrigation and Drainage Districts. American Society of Civil Engineers, prepared by Committee on Operation and Maintenance of Irrigation and Drainage Division.

Allen, R.G. and C.E. Brockway. 1980. Problems in Developing and Applying an Optimal Irrigation Plan. ASCE Journal of the Water Resources Planning and Management Division. Vol. 106, No. WR 1.

Mayland, H.F. and C.E. Brockway. 1980. Frequency Analysis of Western Snow Data.

- Proceedings. 1980 ASCE Watershed Management Symposium. Boise, Idaho.
- Robison, C.W. and C.E. Brockway. 1980. Vegetal Filters for Controlling Sediment in Irrigation Return Runoff. Proceedings. 1980 ASCE Irrigation and Drainage Division Specialty Conference. Boise, Idaho.
- Busch, J.R. and C.E. Brockway. 1980. Systems Approach to Irrigation Planning Research. 1980 ASCE Irrigation and Drainage Specialty Conference. Boise, Idaho.
- Brown, M.J., C.E. Brockway, and J.A. Bondurant. 1981. Ponding Surface Drainage Water for Sediment and Phosphorus Removal. Transactions ASAE, Vol. 24, No. 6, pp. 1478-1481.
- Brockway, C.E. and R.G. Allen. 1982. Impact of the Energy Crisis on Irrigation and Drainage. Part IV: System Design and Management Practices to Reduce Energy Requirements and Consumption. Paper presented at the 9th Congress of the International Committee on Irrigation and Drainage, National Conference. Jackson, Mississippi.
- Everts, Chris and C.E. Brockway. 1982. Reducing Soil Losses with Filter Strips. Current Information Series No. 587. University of Idaho College of Agriculture. January 1982.
- Luttrell, S.P. and C.E. Brockway. 1982. Impacts of Individual on-site Sewage Disposal Facilities on Mountain Valleys - Phase I. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Wells, R., C.E. Brockway, and J. R. Busch. 1983. Management, Maintenance and Operation of Pump Supplied Irrigation Resources Projects. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Freeman, G., C.E. Brockway, and R.G. Allen. 1983. Management and Systems for Water and Energy Savings. Bruneau Proj, Idaho. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Allen, R.G., C.E. Brockway, and J.L. Wright. 1983. Weather Station Siting and Consumptive Use Estimates. Journal of the Water Resources Planning and Management Division, American Society of Civil Engineers.
- Allen, R.G. and C.E. Brockway. 1983. Estimating Consumptive Irrigation Requirements for Crops in Idaho. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Allen, R.G. and C.E. Brockway. 1983. Weather and Consumptive Use in the Bear River Basin. Idaho during 1982. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

- Allen, R.G. and cb31983. Operation and Maintenance Costs and Water Use by Idaho Irrigation Projects. Proceedings of the 1983 Specialty Conference, Irrigation and Drainage Division, American Society of Civil Engineers, Jackson Hole, Wyoming.
- Allen, R.G. and C.E. Brockway. 1983. Estimating Consumptive Use on a Statewide Basis. Proceedings of the 1983 Specialty Conference, Irrigation and Drainage Division, American Society of Civil Engineers, Jackson Hole, Wyoming.
- Johnson, G.S. and C.E. Brockway. 1983. Users Manual for University of Idaho Ground-Water Flow Model and Recharge Program. Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Johnson, G.S., C.E. Brockway, and S.P. Luttrell. 1984. Application of a Numerical Ground-Water Flow Model to the Mud Lake Area in Southeastern Idaho. Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Johnson, G.S., C.E. Brockway, and S. Ramseyer. 1984. Water Resource References for the Snake River Basin Above Swan Falls. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Luttrell, S.P. and C.E. Brockway. 1984. Impacts of Individual On-Site Sewage Disposal Facilities on Mountain Valleys - Phase II - Water-Quality Considerations. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Robison, C.W., C.E. Brockway, C.W. Robbins, and G. S. Johnson. 1984. Evaluation of Irrigation Management Procedures for Geothermal Effluent. Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Fitzsimmons, D.W. and C.E. Brockway. 1984. Irrigation Systems Management Research Design. Final report submitted to USAID/Pakistan under contract no. 391-0467-C-00-4028 prepared by Research Definition Team in cooperation with Washington State University and Development Alternatives, Inc. University of Idaho, Moscow, ID. 354 p.
- Johnson, G.S., C.E. Brockway, J.L. Wright, and A.L. Coiner. 1984. Remote Sensing for Irrigated Crop Water Use Phase I. Technical Completion Report. Idaho Water Resources Research Institute, submitted to NASA-Ames Research Center.
- Johnson, G.S., C.E. Brockway, and A.L. Coiner. 1985. Evaluation of Methods for Estimation of Aquifer Recharge from Precipitation on Semi Arid Lands. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Brockway, C.E. and G.S. Johnson. 1985. Calibration of the Snake Plain Aquifer ground-water flow model. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

- Johnson, G.S., C.E. Brockway, and S.P. Luttrell. 1985. Ground-water model calibration for the Henry's Fork Recharge Area. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Brockway, C.E. 1986. Remote sensing for crop water use. Presented at Idaho Potato School January 29, 1986, Pocatello, Idaho.
- Robison, C.W. and C.E. Brockway. 1986. Modelling erosion and sedimentation in irrigation. Presented at ASCE Water Forum '86, at Long Beach, CA, August, 1986.
- Brockway, C.E. 1987. Swan Falls Data and Research Program Status Report by Idaho Technical Committee on Hydrology. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Brockway, C.E. and C.W. Robison. 1987. Evaluation of Closed Conduit Measuring Devices for Irrigation Diversions. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Brockway, C.E. and C.W. Robison. 1987. Pump System Evaluation Using Microprocessor-Based Monitors. American Society of Agricultural Engineers, Paper No. 87-3502. Presented at the ASAE International Winter Meeting December 15-18, 1987, Chicago, IL. December 1987.
- Brockway, C.E. 1987. Report on "Evaluation of the Idaho-USGS Cooperative Water Data Collection Program". A Report to Ken Dunn, Director of the Idaho Department of Water Resources from the Idaho Technical Committee on Hydrology.
- Hill, R.W., C.E. Brockway, et al. 1987. Duty of Water Under Bear Rive Compact: Field Verification of Empirical Methods. Summer 1987 Progress Report to the Bear River Commission.
- Robison, C.W. and C.E. Brockway. 1987. Demonstration of Monitors for Pumping Stations. Research Technical Completion Report for the Idaho Department of Water Resources, Contract No. DWR-86-03-21-704-37. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- France, K.E. and C.E. Brockway. 1987. Flow measurement using ramped broad crested weirs. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Robison, C.W. and C.E. Brockway. 1987. Demonstration of monitors for pumping stations. Research Technical Completion Report, contract no. DWR-86-03-21-704-37. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Brockway, C.E. and C.W. Robison. 1988. Development and Demonstration of Pump Station and

Surface Diversion Monitor Systems for Water and Energy Efficiency Improvements. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Brockway, C.E. and C.W. Robison. 1988. Water Resources Data and Management Model for Beaver Creek, Camas Creek and Mud Lake Area of Eastern Idaho. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Hill, R.W., C.E. Brockway, R.D. Burman, L.N. Allen, and C.W. Robison. 1989. Field Verification of Empirical Methods for Estimating Depletion; Research Report 125; Utah Agricultural Experiment Station, Logan, Utah, Two Volumes.

Brockway, C.E. 1989. Mud Lake Standing Operating Procedures. Draft operating procedures manual for Mud Lake Water Users and Water District 31.

Robison, C.W., C.E. Brockway, T. Gray, and T. Henschied. 1990. Irrigation Water Allocation System for Bell Rapids Mutual Irrigation Company.

Brockway, C.E., C.W. Robison and J.S. Kolar. 1991. Municipal Pump Monitor Demonstration Project. Final Report to the Idaho Department of Water Resources. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Hamilton, B. and C.E. Brockway. 1991. Effects of Non-Continuous Turnout Operation on the Aberdeen-Springfield Canal System. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Sandoval, V.B. and C.E. Brockway. 1991. Ground-water Investigations for the Fremont-Madison Irrigation District, Southeastern Idaho. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Sandoval, V.B. and C.E. Brockway. 1992. Water Rights Accounting on the Upper Snake River. Water District 01, Southeastern Idaho. Research Technical Completion Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID. In press.

Brockway, C.E. and C.W. Robison. 1992. Middle Snake River Water Quality Study, Phase I: Final. Technical completion report submitted to Idaho Department of Health and Welfare, Division of Environmental Quality. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Brockway, C.E., C.W. Robison, G.S. Johnson. 1992. Evaluation of Water Quality in Shallow Ground-water Systems. Final Report to the Division of Environmental Quality, Contract No. 82-600945. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Robison, C.W. and C.E. Brockway. 1991. Operations Manual for Electronic Pumping System

- Monitors. Research Technical Completion Report. University of Idaho. Idaho Water Resources Research Institute. Moscow, ID.
- Robison, C.W. and C.E. Brockway. 1992. "Thinking about Post-Project Evaluation - START NOW!". In: Proceedings of the National RCWP Symposium - 10 Years of Controlling Agricultural Nonpoint Source Pollution: The RCWP Experience. Orlando, Florida. September 13-17, 1992. US-EPA Office of Research and Development Office of Water. Washington DC. EPA/625/R-92/006.
- Brockway, C.E., H. Neibling, C.W. Robison, S.J. Trundy, and A. Wetzstein. 1992. Water Quality Project, Twin Falls and North Side Canal Companies First Quarterly Report, June 1-September 30, 1992.
- Brockway, C.E., H. Neibling, C.W. Robison, S.J. Trundy, A. Wetzstein, and J.F. Hansen. 1992. Water Quality Project, Twin Falls and North Side Canal Companies Second Quarterly Report. October 1 through December 31, 1992.
- Brockway, C.E. and C.W. Robison. 1992. Middle Snake River Water Quality for Snake River at Star Falls. Submitted to B and C Energy. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Brockway, C.E. and C.W. Robison. 1992. Middle Snake River Water Quality for Kanaka and Boulder Rapids. Submitted to L.B. Industries. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.
- Brockway, C.E. et al. 1993. Proposed Nutrient Management Plan for Middle Snake Irrigated Agriculture. Submitted to Idaho Department of Health and Welfare Division of Environmental Quality by the Mid Snake Irrigation Water Quality Coordination Committee.
- Carter, D.L., C.E. Brockway, and K.K. Tanji. Controlling Erosion and Sediment Loss from Furrow Irrigated Cropland. Journal of Irrigation and Drainage Engineering, American Society of Civil Engineers, Vol 119, No. 6.
- Brockway, C.E., H. Neibling, and C.W. Robison. Water Quality Project, Twin Falls and North Side Canal Companies Third and Fourth Quarterly Report, January 1, 1993 to June 30, 1993.
- Brockway, C.E., and A. Kahlow. Big Wood River-Silver Creek Hydrology Study. Quarterly Reports.
- Brockway, C.E. and A. Kahlow. Big Wood River-Silver Creek Hydrology Study, Phase I. Final Report. University of Idaho, Idaho Water Resources Research Institute, Moscow, ID.

Daily and Seasonal Evapotranspiration and Yield of Irrigated Alfalfa in Southern Idaho

James L. Wright*

ABSTRACT

Daily water-use data are needed for the development of modern irrigation scheduling techniques, the optimum allocation of water and energy resources, and improved irrigation management practices. This field study was conducted to measure evapotranspiration (ET) of well-irrigated alfalfa (*Medicago sativa* L.) in the arid region of southern Idaho. The relationship of ET to forage yield was also investigated. The soil was Portneuf silt loam (coarse-silty, mixed, mesic Durixerollic Calciorthids) common to much of the region. Daily and seasonal ET data were calculated for seven growing seasons from measurements obtained with mechanical weighing lysimeters equipped with electronic load cells. Daily alfalfa ET was highly variable. It occasionally exceeded 10 mm d⁻¹ and averaged 8 mm d⁻¹ during peak ET periods. From April through October, measured ET averaged 1022 mm for three harvests per season for 5 yr when soil water was nonlimiting. Corresponding average forage yield was 17.6 Mg ha⁻¹ (120 g kg⁻¹ water content) giving an overall water requirement of 58.1 mm (depth equivalent) to produce 1 Mg ha⁻¹ of forage (581 m³ Mg⁻¹) for a water-use efficiency of 17.2 kg ha⁻¹ mm⁻¹. Harvest period and seasonal ET appear linearly related to pan evaporation and forage yield. The actual ET of well-irrigated, high-yielding alfalfa may be as much as 50% greater than previous estimates indicated for southern Idaho.

Additional Index Words: Consumptive water use, Water use efficiency, Weighing lysimeters, Pan evaporation, *Medicago sativa* L.

ALFALFA is an important forage crop in irrigated areas of the western United States and other similar areas throughout the world. High-producing irrigated alfalfa has one of the greatest seasonal water requirements of irrigated crops, yet it is a desirable crop because it produces high-quality forage, has relatively low production costs as a perennial, supports symbiotic dinitrogen fixation, and provides favorable soil conditioning in crop rotations. Few detailed and accurate daily and seasonal evapotranspiration data for alfalfa have been reported. Reliable data are needed in the development of improved irrigation management technologies, such as irrigation scheduling (Jensen et al., 1971; Wright and Jensen, 1978), and irrigation project management to permit optimum allocation of water and energy resources.

Evapotranspiration (ET) is the main use of water by a growing crop and is strongly influenced by the nature and amount of leaf area, the water content of

USDA-ARS, Soil and Water Management Res. Unit, Rt. 1, Box 186, Kimberly, ID 83341. Contribution from the USDA-ARS. Received 26 Aug. 1986. *Corresponding author.

Published in Agron. J. 80:662-669 (1988).

the root zone, and weather conditions. Other water requirements include the small amount incorporated into plant tissues and, depending on soil and water conditions, some for leaching excess salt from the root zone. The term *consumptive use* includes water incorporated into plant tissue, but often is used interchangeably with ET.

Most previous studies on alfalfa water use have utilized soil sampling methods to determine soil water depletion with time, usually by harvest period, utilizing gravimetric sampling (Erie et al., 1965), the neutron moisture-meter (Bauder et al., 1978; Daigger et al., 1970; Retta and Hanks, 1980), or combinations of the neutron meter and nonweighing lysimeters (Sammis, 1981). Sutter and Corey (1970) estimated the monthly and seasonal water use for alfalfa in southern Idaho with the USDA-SCS modified Blaney-Criddle (SCS-BC) method using limited climatic data and an empirically derived crop coefficient (USDA-Soil Conservation Service, 1967). Alfalfa water use determined from soil sampling data at best only provides averages for several-day periods. Seasonal water-use values obtained by these methods are also subject to uncertainties in accounting for small changes in soil-water content, spatial variability and water movement into or out of the root zone during the sampling interval.

All the terms of the water balance equation can be measured with a lysimeter (Tanner, 1967), and reliable ET data are possible with lysimeters if the measurements are representative samples of the surrounding conditions. Sensitive mechanical weighing systems provide an accurate means of measuring daily water loss (McIlroy and Angus, 1963; Ritchie and Burnett, 1968). Weighing and nonweighing lysimeters are subject to errors due to the effects of containment in the soil bin, which can distort thermal, water-content, and rooting conditions, resulting in unrepresentative vegetative cover. The effects of exposure and the uniformity of the surroundings can also be limiting.

When the intent is to study potential ET, i.e., when water loss is unrestricted by soil water contents, the lysimeter requirements and limitations are much less critical (McIlroy and Angus, 1963; Tanner, 1967). Filled lysimeters are suitable, provided the soil bin is deep enough to permit sufficient rooting, with adequate aeration, to produce representative plant growth.

An evaporation pan integrates the effects of solar radiation, wind, temperature, and humidity on evaporation from a specific open water surface. Plants also respond to these climatic conditions, but the daily evaporation rates from a pan and a crop are usually different. Water loss from a pan and a crop can be compared for periods of 10 d or longer (Pruitt, 1966).

The main objectives of this study were to determine the daily ET of well-irrigated alfalfa in an irrigated region of the Snake River Plains in southern Idaho, to compute growth period and seasonal ET from summations of daily ET, and to relate crop ET to pan evaporation and forage yields. Daily alfalfa ET was measured for the April through October season for 7 yr, utilizing weighing lysimeters at two evapotranspiration field-study sites established for these purposes.

MATERIALS AND METHODS

The ET field research was conducted 1 km south of the USDA, Snake River Conservation Research Center, about 1.5 km east of Kimberly, ID. This site, at latitude 42°33' N, longitude 114°21' W and elevation 1207 m, is in the interior of a large irrigated region about 10 km east of Twin Falls and about 45 km in the prevailing downwind direction from nonirrigated sagebrush-grass rangeland to the west. The climate is arid, with much of the annual precipitation occurring during the nongrowing season. The average frost-free period is about 120 d, from mid-May to mid-September. The Portneuf silt loam soil at the site is about 4 m deep and is underlain by basalt bedrock. This soil has a hard layer at a depth of 0.5 to 1 m consisting of rounded nodules of very hard soil material that is partly restrictive to root penetration, but is permeable to water flow. The soil is well drained, without a water table, and is well suited for irrigation.

Evaporation Measurements

A weighing lysimeter (Lys. 1) was installed in 1968 near the center of a 2.6-ha field, while a second unit (Lys. 2) was similarly installed in 1971 in an adjoining westward field of about 2.2 ha. In each case, the surrounding field provided an upwind fetch of at least 75 m in the prevailing wind directions. The steel lysimeter soil tank was 1.83 m square by 1.22 m deep and rested on a mechanical platform scale. The scale mechanism transferred the downward force exerted by the soil bin to a tension-measuring electronic load cell. A pliable rubber seal was installed to cover the gap between the soil bin and outer steel retaining wall, forming a rim about 2.5 cm above the soil and 2.5 cm wide. While the rim area was about 5.6% of the surface area of the soil bin, it was mostly shaded from the overhang of plants from inside and outside the lysimeter. The sensitivity of the weighing system was enhanced because the scale assembly included a counter balance so that only about 10% of the total mass of the system was sensed by the load cell. An array of sintered stainless steel candles in the bottom of the soil tank permitted the evacuation of drainage water.

Evaporative loss of water from the soil and plant surfaces caused a decrease in tension at the load cell. The load cell signals were continuously recorded on strip chart recorders and at hourly or more frequent intervals with an automatic data acquisition system. The chart records were used to monitor lysimeter performance and to adjust for irrigations, precipitation, harvest, and other events. The load-cell tension data were converted to an equivalent water depth per unit area assuming a water density of 1 Mg m⁻³ and an effective surface area (mid-rim to mid-rim) of 3.44 m². Daily ET (ET_d) was calculated on a midnight-to-midnight basis. Total ET was calculated for each month, growth period, and the season from summations of ET_d.

The sensitivity of the lysimeter system was more than sufficient for daily ET measurements during the growing season. Considering hysteresis effects, nonlinearity, and seasonal drift, the complete system was capable of resolving a net change in mass equivalent to a water depth of 0.07 mm over the entire surface, about 1% of daily ET on a summer day. Daily ET data were lost during the 7-yr period on a few occasions for a day or two at a time. Lightning was the major cause of equipment failures.

Pan evaporation data, obtained by the National Weather Service with a U.S. Class A evaporation pan, were used to characterize general climatic conditions. On the average, water depth was maintained between 220 and 180 mm, or from 35 to 75 mm below the pan rim. The weather station was located about 0.8 km north of the lysimeter field site in a 45- by 36-m irrigated, clipped-grass plot surrounded by irrigated field plots planted to various crops each year.

Management Practices

Fertilizer was applied to maintain soil P concentrations above 16 mg kg^{-1} and K above 200 mg kg^{-1} , in accordance with University of Idaho fertilizer guides (University of Idaho, 1972). Traffic was limited near the lysimeters so that crop growth on and immediately around the lysimeters would be representative of the field.

The Lys. 1 site was planted to 'Ranger' alfalfa in May 1968 at a seeding rate of 9 kg ha^{-1} , without a nurse crop, and was harvested twice during 1968 so that the stand was well established at the beginning of this study on 1 Apr. 1969. The stand was maintained until mid-October 1971.

Alfalfa was similarly seeded at the Lys. 2 site, but in late August 1971, so that the plants were still in the young seedling stage on 1 Apr. 1972. The stand was maintained at this site until October 1975. Local farmers maintain alfalfa stands from 2 to 4 yr in typical rotations.

The alfalfa fields were surface-irrigated with furrows spaced at 0.76-m intervals. Soil-water status on and in the vicinity of the lysimeters was measured with tensiometers at depths of 0.15, 0.30, and 0.45 m. These were read two to three times per week. Irrigations were scheduled so that the soil-water tension at the 0.45-m depth did not exceed 75 kPa. The duration of irrigation was usually 24 h. Total available soil water for the top meter of the local soil is approximately a 160-mm water depth equivalent per meter of soil depth. At a tension of 75 kPa, about 60% of available soil water is depleted. The transpiration of alfalfa is not restricted until tensions exceed 100 kPa (Van Bavel, 1967).

During a field irrigation, water was pumped onto the lysimeter surface from a nearby furrow with a small submersible pump. Only the amount of water necessary to replenish the depletion was applied, usually a 100- to 150-mm depth equivalent. Occasionally, when it was not possible to irrigate the field, water was hauled to irrigate the lysimeter to prevent the restricted root zone from becoming excessively dry. Soil-water contents are normally near field capacity at the beginning of spring growth due to wintertime precipitation. The local irrigation season begins in the latter part of April or early May.

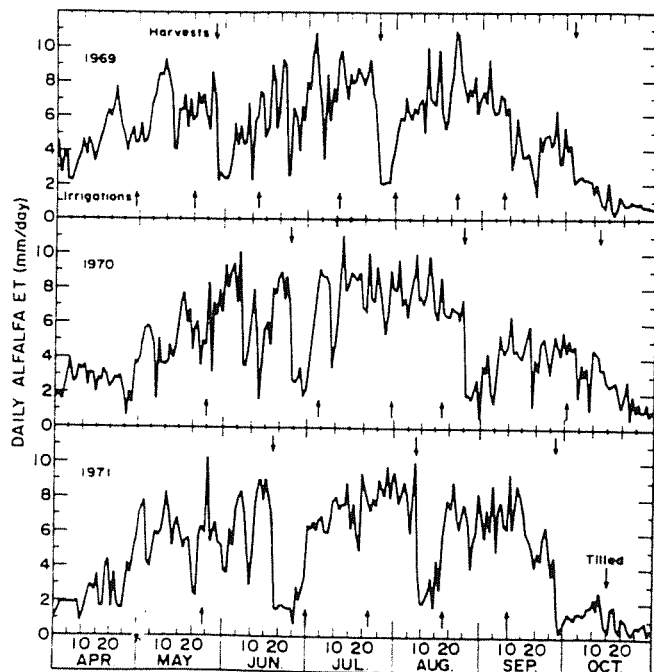


Fig. 1. Daily alfalfa ET measured with weighing lysimeter no. 1 for three growing seasons, with harvest and irrigation dates indicated, Kimberly, ID.

Forage Sampling

The alfalfa was harvested three times per season, as is typical for the area. Lysimeter forage was manually harvested within a day or two of when the adjoining fields were harvested, usually by swathing and baling. Forage samples were removed and oven dried to determine dry matter yield. Yields were adjusted to 120 g kg^{-1} water content (mass/mass) for consistency. Field yields were determined from commercial scale weights of total harvested forage, or from bale counts and sample bale-weights, which were obtained from weighing at least 10 bales selected at random across the field.

RESULTS AND DISCUSSION

Daily Evaporation

Values of ET_d obtained with Lys. 1 are shown in Fig. 1 for the 3 yr of measurement. Data obtained with Lys. 2 for 4 yr are shown in Fig. 2. Harvest and irrigation dates are designated. Data are shown for a 214-d period because spring growth begins in late March or early April, depending on general weather conditions, and ceases by November. There is no live aboveground growth at Kimberly during the winter. The gradual increase in ET_d in April and early May (Fig. 1 and 2) was due to the growth of the crop and the general increase in evaporative demand. The crop usually did not reach the condition of "effective-full-cover" [at least 30 cm in height as described by Wright and Jensen (1972)] until mid-May. Frosty periods occasionally retarded ET_d rates until about that time. During the spring of 1969 weather was warmer than

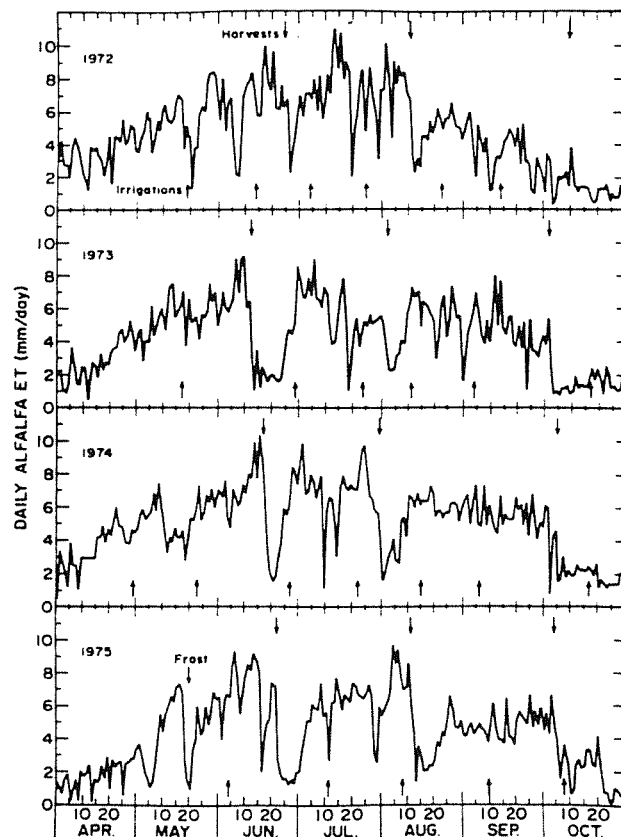


Fig. 2. Daily alfalfa ET measured with weighing lysimeter no. 2 for four growing seasons, with harvest and irrigation dates indicated, Kimberly, ID.

normal, so early crop development was more advanced than for the other 6 yr. This resulted in generally higher ET during that period.

Daily ET exceeded 10 mm d^{-1} a few days each season, except in 1973 and 1975. The pronounced variation of ET_d (Fig. 1 and 2) was due primarily to changes in daily weather. This correspondence can be seen in Fig. 3 where daily Class A pan evaporation (E_{pan}) and ET_d are graphed for 30 d when crop conditions assured potential ET rates. The daily patterns were mostly similar except on a few days, such as 26 June and 6 July, when ET_d exceeded E_{pan} . The mean ratio of ET_d to E_{pan} for the 31 d plotted was 0.932 ($SE = 0.118$).

At harvest ET_d was reduced to 25% or less of pre-harvest rates for several days until regrowth began (Fig. 1 and 2). Depending on soil moisture and stand conditions, after 14 to 21 d ET_d returned to pre-harvest rates. Once regrowth began after the first and second harvests, ET_d sometimes increased to near maximum rates in just 5 to 7 d. The delay in recovery of ET following the first harvest in 1973 and 1975 was due to suboptimal available soil water in the lysimeter. Delay in removing the harvested hay from the field delayed post-harvest irrigation, and water was not hauled to the lysimeter in those two cases. Regrowth following third harvests was generally slower at the end of the growing season.

Daily ET was reduced much less after the harvest of a first-year stand than for older stands, as can be seen by comparing the results for 1972 with those of the other years (Fig. 2). This result agreed with field observations in that, after harvest the stubble of the young stands still contained some leaves, and new shoots appeared more quickly than for older stands.

Seasonal Evaporation

Total alfalfa ET, derived from summations of ET_d , and corresponding pan evaporation data are listed in Table 1 for each month of the 214-d growing season and the 7-yr period of study. The mean ($\bar{x}$) and the coefficient of variation (CV) are listed for each month

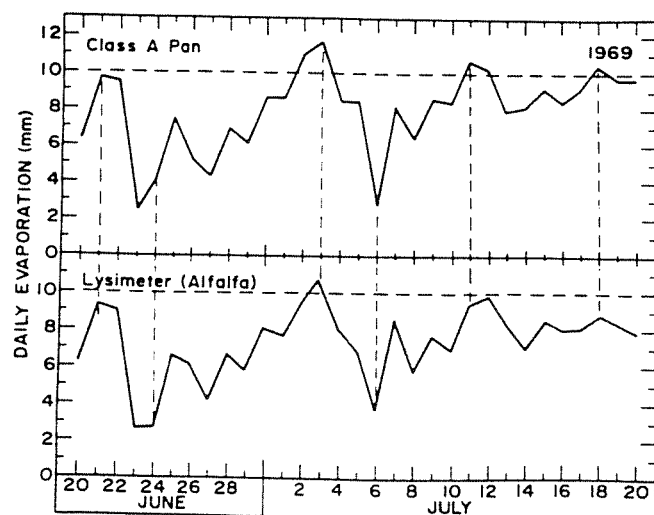


Fig. 3. Comparison of daily Class A pan evaporation and alfalfa ET for a 31-d period when crop cover assured maximum ET.

and seasonal period. Seasonal totals are included for both the April through September and April through October periods, since complete pan evaporation data were not available for October of 1973, 1974, and 1975. Seasonal totals of alfalfa ET and pan evaporation are shown as a percentage of the respective 7-yr means to provide a relative yearly index of alfalfa ET in comparison with general weather conditions, as represented by pan evaporation. The two highest ET years, 1969 and 1974, correspond to the two highest pan years, while 1975 is lowest for both. The seasonal CV for alfalfa ET is greater than the CV for pan evaporation because of greater variation in ET early and late in the season and the effects of harvest.

The data of Table 1 show that ET relative to pan evaporation was proportionately higher for Lys. 1 than for Lys. 2. This difference between the two lysimeters was partly due to the drier soil conditions of Lys. 2, during short periods in 1973 and 1975 (Fig. 2), but also seemed due to differences in growth of the two crops. The alfalfa stands were established with different lots of seed, supposedly of the same variety. How-

Table 1. Summary of alfalfa ET by month and season obtained from summations of daily ET, corresponding Class A pan evaporation, respective monthly means ($\bar{x}$) and coefficients of variation (CV), and seasonal totals as a percentage of the 7-yr mean. Alfalfa ET was measured with two weighing lysimeters during 7 yr at Kimberly, ID.

	Lys. 1			Lys. 2			Lys. 1 and 2	
	1969	1970	1971	1972	1973	1974	1975	$\bar{x}$ CV
Alfalfa-ET								
	mm						%	
Apr.	136	80	75	105	83	105	51	90.7 30.2
May	194	167	182	171	171	166	135	169.4 10.7
June	168	178	142	186	138	186	163	166.0 11.8
July	211	233	232	222	175	211	177	208.7 11.4
Aug.	223	197	188	179	155	165	160	181.0 13.3
Sept.	150	125	172	105	140	169	143	143.3 16.3
Oct.	45	80	35	44	50	71	75	57.1 31.2
Σ (Apr.-Sept.)	1083	980	991	968	861	1001	829	959.0 9.0
Σ (Apr.-Oct.)	1128	1060	1025	1012	912	1073	904	1016.3 8.2
Percentage of 7-yr mean								
Apr.-Sept.	113	102	103	101	90	104	86	100 9.10
Pan evaporation								
	mm						%	
Apr.	200	153	149	156	150	184	110	157.4 18.2
May	262	208	221	223	261	227	194	228.0 11.1
June	213	218	225	226	244	294	243	237.6 11.6
July	278	267	265	282	240	257	252	263.0 5.6
Aug.	273	256	250	241	215	239	216	241.4 8.7
Sept.	181	162	181	139	145	213	181	171.7 14.7
Oct.	91	114	94	80	-M-	-M-	-M-	94.8 15.0
Σ (Apr.-Sept.)	1408	1265	1292	1267	1254	1414	1195	1299.3 6.3
Σ (Apr.-Oct.)	1499	1379	1386	1347	--	--	--	1402.8 4.7
Percentage of 7-yr mean								
Apr.-Sept.	108	97	99	98	97	109	92	100 6.3
Ratio of ET to pan evaporation								
Apr.-Sept.	0.77	0.78	0.77	0.76	0.69	0.71	0.69	0.738 5.44

Table 2. Summary of alfalfa harvest dates, length of corresponding growing periods, and lysimeter forage yield with means ($\bar{x}$) and coefficients of variation (CV) for 7 yr at Kimberly, ID.

Harvest	Lys. 1			Lys. 2				Lys. 1 and 2	
	1969	1970	1971	1972	1973	1974	1975	$\bar{x}$	CV
Harvest date									
1st	28 May	24 June	18 June	26 June	12 June	17 June	22 June	17 June	-
2nd	24 July	25 Aug.	8 Aug.	11 Aug.	2 Aug.	30 July	11 Aug.	7 Aug.	-
3rd	3 Oct.	12 Oct.	27 Sept.	11 Oct.	2 Oct.	5 Oct.	4 Oct.	5 Oct.	-
Length of growing period									
	d								%
1st†	58	85	79	87	73	78	83	77.6	12.6
2nd	57	62	51	46	51	43	50	51.4	6.4
3rd	71	48	50	61	61	67	54	58.9	8.6
Total	186	195	180	194	185	188	187	187.9	5.2
Lysimeter forage yield (120 g kg ⁻¹ water content)									
	Mg/ha								%
1st	6.08	8.57	9.62	6.39	6.52	8.03	8.22	7.63	17.4
2nd	6.06	6.32	5.86	5.51	5.38	5.36	5.51	5.71	6.5
3rd	5.77	2.19	4.75	2.84	3.54	4.27	-M-	3.89	33.2
Total	17.91	17.08	20.23	14.74	15.44	17.66	-	17.18	11.4

† Note: First period assumed to begin 1 April each year.

ever, the crop on Lys. 2 was less upright, had finer stems, and was more prone to lodge than that on Lys. 1. Such variations in plant morphology have been noted between strains of given alfalfa varieties (Lowe et al., 1972). The Lys. 2 site also had less topsoil and more of the highly calcareous subsoil mixed in the surface-soil layer because of previous land leveling than did the Lys. 1 site. This may have contributed to less vigorous growth. Differences in forage yield relative to ET will be discussed in a later section.

The mean ratio of ET to pan evaporation, sometimes called a pan factor, was 0.74 for the entire 214-d, 7-yr period. The mean for Lys. 1 alone was 0.77,

and for Lys. 2 alone, 0.73, excluding the 2 yr when Lys. 2 was drier than desired for short periods.

Harvest Period Evaporation and Yield

The dates of harvest, the corresponding length of the respective growing periods, and the lysimeter forage yields are summarized in Table 2. The first growth period was assumed to begin on 1 April each year. The harvest dates were generally typical of local farms, except for the second harvest in 1970 that was delayed until late August (Fig. 1) to accommodate some associated research. The total growing period contributing to the three harvests, averaging about 188 d, was less than the April through October period of 214 d, as used in Table 1. Forage growth after the third harvest was not harvested for yield analysis. The forage sample for the third-growth period of 1975 was inadvertently discarded before dry weights were obtained.

Total and mean daily ET and total pan evaporation are listed by growth period in Table 3. Mean daily ET was calculated from the sum of ET_d for the respective period and the length of the period as listed in Table 2. The mass of the dry matter removed from the lysimeter surface at harvest was small compared to the mass of the water transpired. The average dry matter removed per harvest was 511 g m⁻² (Table 2), which was equivalent to an ET of a 0.511-mm water depth equivalent or about 0.16% of mean ET_d (Table 3).

The joint variation of ET_d and E_{pan} by growth period is shown in Fig. 4 for each of the 21 periods included in Table 2. Points are distinguished by lysimeter and growth period. The linear correlation equation relating ET_d to E_{pan} is shown in Fig. 4. Excluding the one 1973 point changed the slope (b), intercept (a), and correlation (r) coefficients to 0.772, -11, and 0.95, respectively, where ET_d and E_{pan} are in millimeters. The linear correlation equation indicated in Fig. 4 did not include the five points plotted for the fourth growth period, from third harvest until 1 No-

Table 3. Summary of total and mean daily alfalfa ET by harvest period, corresponding Class A pan evaporation, and respective means ($\bar{x}$) and coefficients of variation (CV) for 7 yr at Kimberly, ID.

Harvest	Lys. 1			Lys. 2				Lys. 1 and 2	
	1969	1970	1971	1972	1973	1974	1975	$\bar{x}$	CV
Total alfalfa ET per harvest									
	mm								%
1st	323	410	376	444	338	396	335	374.4	12.0
2nd	367	434	322	325	240	269	274	318.7	20.8
3rd	401	182	289	221	293	358	242	283.7	27.1
Total	1091	1025	987	990	870	1023	851	976.7	8.9
Mean daily ET per harvest									
	mm d ⁻¹								%
1st	5.6	4.8	4.8	5.1	4.6	5.1	4.0	4.9	9.6
2nd	6.4	7.0	6.3	7.1	4.7	6.3	5.5	6.2	13.6
3rd	5.7	3.8	5.8	3.6	4.8	5.3	4.5	4.8	17.9
Seasonal mean	5.9	5.3	5.5	5.1	4.7	5.4	4.6	5.2	8.9
Pan evaporation									
	mm								%
1st	434	530	491	567	510	567	491	512.9	9.2
2nd	456	531	440	414	401	385	392	431.3	11.8
3rd	533	264	352	318	365	467	334	376.1	24.6
Total	1423	1325	1283	1299	1275	1419	1217	1320.1	5.8

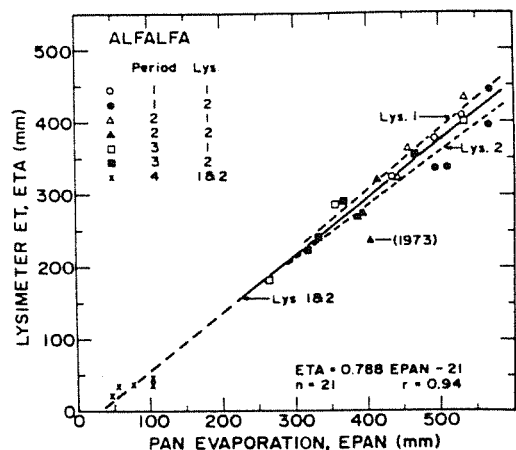


Fig. 4. Joint variation over a 7-yr period of total lysimeter ET and pan evaporation by harvest period for two lysimeter sites and three harvests per growing season. Period 4 was from third harvest until 1 Nov.

vember, since complete data were not available for that period. It can be seen, however, that these points were clustered closely about the indicated linear relationship.

The best-fit linear correlations for Lys. 1 and Lys. 2, considered individually, are also plotted in Fig. 4. The b , a , and r coefficients for Lys. 1 alone ($n=9$) were: 0.892, -26, and 0.98; for Lys. 2 alone ($n=12$) they were: 0.734, -7, and 0.92; and for Lys. 2 excluding the one 1973 point: 0.712, 6, and 0.94; where ET_d and $Epan$ are in millimeters. A negative intercept coefficient was expected since $Epan$ is not affected by the amount of crop cover.

The joint variation of lysimeter ET and forage yield is shown in Fig. 5, with points distinguished by lysimeter and harvest. There was less association between ET and yield than there was between ET and pan evaporation, indicating that crop growth was not as closely coupled to the climatic factors as was evaporation. The one 1973 point was again on the outer limit of the cluster of points, but in this relationship it showed a higher water-use efficiency (WUE) than most of the other points, i.e., there was less ET per unit of forage produced. This occurred because ET was suppressed immediately following harvest until irrigation and then regrowth was very rapid (Fig. 2). The indicated 1972 first-harvest point represented a lower WUE. The alfalfa early in that growth period was still in the small seedling stage; thus, evaporation from the soil was proportionally higher and crop production lower than for an established crop. Twenty points were included in the correlation analysis because the forage yield for the third-harvest of 1975 was not available.

The lines for the linear correlations obtained considering the ET and yield data for Lys. 1 and Lys. 2 individually are also included in Fig. 5. The relationship of these two lines to the combined line is similar to the pattern of Fig. 4. The b , a , and r coefficients for the linear correlation equation for Lys. 1 alone ($n=9$) were: 27.5, 176, and 0.76; and for Lys. 2 alone ($n=11$) they were: 24.5, 180, and 0.60, respectively.

Excluding the first-growth period of 1972 and the

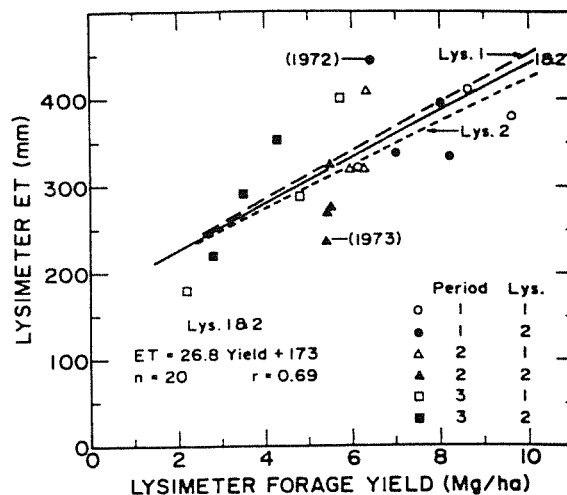


Fig. 5. Joint variation over a 7-yr period of total lysimeter ET and lysimeter forage yield (120 g kg^{-1} water content) by harvest period for two lysimeter sites and three harvests per growing season.

second-growth period of 1973 (Fig. 5), the linear correlation equation between lysimeter ET and lysimeter yield (Y_l), for Lys. 1 and Lys. 2 combined ($n=18$), was:

$$ET = 25.4 Y_l + 180; r = 0.74, \quad [1]$$

and between Y_l and ET it was:

$$Y_l = 0.0216 ET - 1.24; r = 0.74, \quad [2]$$

where yield is in megagrams per hectare (120 g kg^{-1} water content) and ET is in millimeters. The overall mean ET to produce 1 Mg ha^{-1} was 56.9 mm , giving a corresponding WUE of $17.6 \text{ kg ha}^{-1} \text{ mm}^{-1}$.

For 17 harvests when field yield data were available, the mean yields per harvest for the field and lysimeter were 5.75 ($SE=0.42$) and 6.05 ($SE=0.43$) Mg ha^{-1} , respectively, giving a ratio of mean field to mean lysimeter yield of 0.95. The linear correlation of the association between field yield (Y_f) and Y_l was:

$$Y_f = 0.968 Y_l - 0.029; r = 0.99, \quad [3]$$

where yield is in megagrams per hectare (120 g kg^{-1} moisture). Field yields were slightly below lysimeter yields, probably because of the inclusion of lower producing areas of the field in the field yield and the effects of machine harvesting on regrowth. Regrowth in the field was also delayed under windrows because of shading and the concentration of insects. Regrowth between windrows sustained some damage during baling and bale pick up. Nonetheless, agreement between field and lysimeter yields (Eq. [3]) was considered adequate for the lysimeter ET-yield relationships (Eq. [1] and Eq. [2]; Fig. 5) to be representative of field water use. Thus the seasonal field water use would be expected to have been about 5% less than that of the lysimeter.

Field yields obtained in this study were generally comparable with those obtained on well-managed farms of the area but above county averages. The published Twin Falls County average for 1978 was about 11.4 Mg ha^{-1} (USDA Economics, Statistics and Cooperative Service, 1980), which was about 40% less

than the mean lysimeter yield (Table 3). The county-wide yield included several large areas where there is a shortage of irrigation water most years and alfalfa production is given a low priority relative to other crops.

The seasonal water use by alfalfa in southern Idaho estimated with the SCS-BC method (USDA-Soil Conservation Service, 1967) by Sutter and Corey (1970) was 646 mm. The three-crop mean ET of 977 mm obtained in this study (Table 3) was thus nearly 50% greater than that previous estimate. The intent of Sutter and Corey (1970) was to provide estimates for alfalfa representative of conditions when crop growth is not limited by lack of water at any time during the growing season and growth is mainly dependent on climatic conditions. However, as concluded by Sammis et al. (1982), it seems that the estimates are more applicable to average county-wide conditions than to conditions of negligible moisture stress. Application of the SCS-BC method for high producing alfalfa in irrigated areas could lead to a serious underestimation of alfalfa water use.

Another possible cause of the lower estimates is that alfalfa crop coefficients for the SCS-BC method were derived from the results of water use based on soil sampling data. Crop water use obtained by soil sampling methods could be less than that obtained with weighing lysimeters, because a period of several days is often allowed after an irrigation before the soil-water content is measured. While this may avoid errors due to the drainage of excess water from the soil profile, it also misses the higher daily ET that may occur immediately after an irrigation (Fig. 1 and 2). With soil sampling methods, deep measurements have sometimes been omitted, and it is often difficult to account for water extraction from the deeper layers of the root zone because of the relatively small changes in water contents with time. It is also difficult to assess the lateral or vertical movement of water into the root zone from adjacent wet soil or from deep water tables. These errors are avoided with an adequately irrigated lysimeter.

While the 1.2-m depth of the lysimeters of this study was less than the rooting depth of the alfalfa in the surrounding fields, the depth should have been sufficient to avoid rooting depth problems (McIlroy and Angus, 1963; Tanner, 1967). Sufficiently high soil-water contents were maintained (except in a few cases) so that measured ET was usually the maximum possible for the given climatic and crop conditions. The data of Fig. 3 establish that lysimetrically measured alfalfa ET closely followed pan evaporation, which would not have occurred if rooting depth were a problem. Errors due to limited rooting depth would be in the direction of reduced plant growth and ET; however, lysimeter yields were generally greater than field yields.

Soil sampling methods also often miss relatively low ET rates during early and late portions of the growing season, rainy periods, or from harvest until major regrowth. Water-content measurements often have not been initiated until about mid-May, at the beginning of the frost-free period (Bauder et al., 1978; Retta and Hanks, 1980). The lysimeter data of this study (Fig. 1 and 2; Table 1) show a total ET from 1 April until

mid-May of about 100 mm, and from mid-September until 1 November of about 75 mm, for a total of 175 mm occurring before and after the frost-free period, or 17% of the April through October total. Whereas soil-sampling methods permit spatial sampling throughout a field, the results from a single lysimeter are effectively an average for a surface area that is equivalent to several soil sampling sites.

CONCLUSIONS

Alfalfa ET, as measured with weighing lysimeters, was highly variable on a daily basis in response to general weather conditions. Daily ET exceeded 10 mm d^{-1} for a few days in most seasons. Forage harvest reduced ET to less than 25% of pre-harvest levels for about a week. Another 1 to 2 wk elapsed before regrowth was sufficient to return ET to potential rates. Thus, improved irrigation management practices such as irrigation scheduling will in many cases require accurate estimates of daily ET.

Seasonal ET averaged 1016 mm. The mean ratio of seasonal alfalfa ET to Class A pan evaporation was 0.74 for April through September. The ratio of alfalfa ET to pan evaporation averaged 0.93 when alfalfa was in a full-cover state. Total monthly and growth-period ET were linearly related to corresponding total pan evaporation. Total ET per growth period was also linearly related to forage yield, even for well-irrigated conditions, but to a lesser degree than was the relationship to pan evaporation. Lysimeter forage yields averaged about 5% greater than surrounding field yields. Average ET per unit of forage produced was 581 $m^3 Mg^{-1}$ (120 $g kg^{-1}$ water content) for an overall WUE of 17.2 $kg ha^{-1} mm^{-1}$.

Seasonal water-use values obtained in this study were about 50% greater than previously reported water-use estimates for southern Idaho based on the SCS modified Blaney-Criddle method. Thus, a greater portion of irrigation water diverted to amply irrigated, high-producing alfalfa fields of the region is lost to the atmosphere by evaporation than has often been considered to be the case. This has an impact on estimates of drainage, ground-water recharge, and irrigation efficiencies for the region. Accurate assessments of irrigation water requirements for high-producing alfalfa under the arid conditions of southern Idaho will require changes in the crop factors used in the SCS-BC method or use of other more accurate methods.

ACKNOWLEDGMENT

The author gratefully acknowledges the assistance of John L. Stevens and James E. Chapman in conducting the field experiments and analyzing data.

REFERENCES

- Bauder, J.W., A. Bauer, J.M. Ramirez, and D.K. Cassel. 1978. Alfalfa water use and production on dryland and irrigated sandy loam. *Agron. J.* 70:95-99.
- Daigger, L.A., L.S. Axthelton, and C.L. Ashburn. 1970. Consumptive use of water by alfalfa in western Nebraska. *Agron. J.* 62:507-508.
- Erie, L.J., O.F. French, and K. Harris. 1965. Consumptive use of

- water by crops in Arizona. Univ. of Arizona Agric. Exp. Stn., Tech. Bull. 169.
- Jensen, M.E., J.L. Wright, and B.J. Pratt. 1971. Estimating soil moisture depletion from climate, crop, soil data. *Trans. ASAE* 14:954-959.
- Lowe, C.C., V.L. Marble, and M.D. Rumbaugh. 1972. Adaptation, varieties, and usage. p. 391-413. *In* C.H. Hanson (ed.) *Alfalfa science and technology*. ASA, Madison, WI.
- McIlroy, I.C., and D.E. Angus. 1963. The Aspendale multiple weighed lysimeter installation. Div. of Meteorol. Physics Tech. Paper 14. CSIRO, Melbourne, Australia.
- Pruitt, W.O. 1966. Empirical methods of estimating evapotranspiration using primarily evaporation pans. p. 57-61. *In* *Evaporation and its role in water resources management*. ASAE, St. Joseph, MI.
- Retta, A., and R.J. Hanks. 1980. Corn and alfalfa production as influenced by limited irrigation. *Irrig. Sci.* 1:135-147.
- Ritchie, J.T., and E. Burnett. 1968. A precision weighing lysimeter for row crop water use studies. *Agron. J.* 60:545-549.
- Sammis, T.W. 1981. Yield of alfalfa and cotton as influenced by irrigation. *Agron. J.* 73:323-329.
- _____, E.J. Gregory, and C.E. Kallsen. 1982. Estimating evapotranspiration with water production functions or the Blaney-Cridle method. *Trans. ASAE* 25:1656-1661.
- Sutter, R.J., and G.L. Corey. 1970. Consumptive irrigation requirements for crops in Idaho. Univ. of Idaho Bull. 516.
- Tanner, C.B. 1967. Measurement of evapotranspiration. p. 573-574. *In* R.M. Hagan et al. (ed.) *Irrigation of agricultural lands*. ASA, Madison, WI.
- University of Idaho. 1972. Idaho fertilizer guide—irrigated alfalfa. Univ. of Idaho Coop. Ext. Serv.
- USDA Economics, Statistics and Cooperative Service. 1980. Idaho agricultural statistics. 1980. Idaho Crop and Livestock Reporting Service, Boise, ID.
- USDA Soil Conservation Service. 1967. Irrigation water requirements. Eng. Div. Tech. Release 21 (revised 1970). U.S. Gov. Print. Office, Washington, DC.
- Van Bavel, C.H.M. 1967. Changes in canopy resistance to water loss from alfalfa induced by soil water depletion. *Agric. Meteorol.* 4:165-176.
- Wright, J.L., and M.E. Jensen. 1972. Peak water requirements of crops in southern Idaho. *J. Irrig. Drain. Div. Am. Soc. Civ. Eng.* 98(2):193-201.
- _____, and _____. 1978. Development and evaluation of evapotranspiration models for irrigation scheduling. *Trans. ASAE* 21:88-96.

Alfalfa Yield vs ET

