Semiarid hillslopes on the Walnut Gulch Experimental Watershed in southeastern Arizona

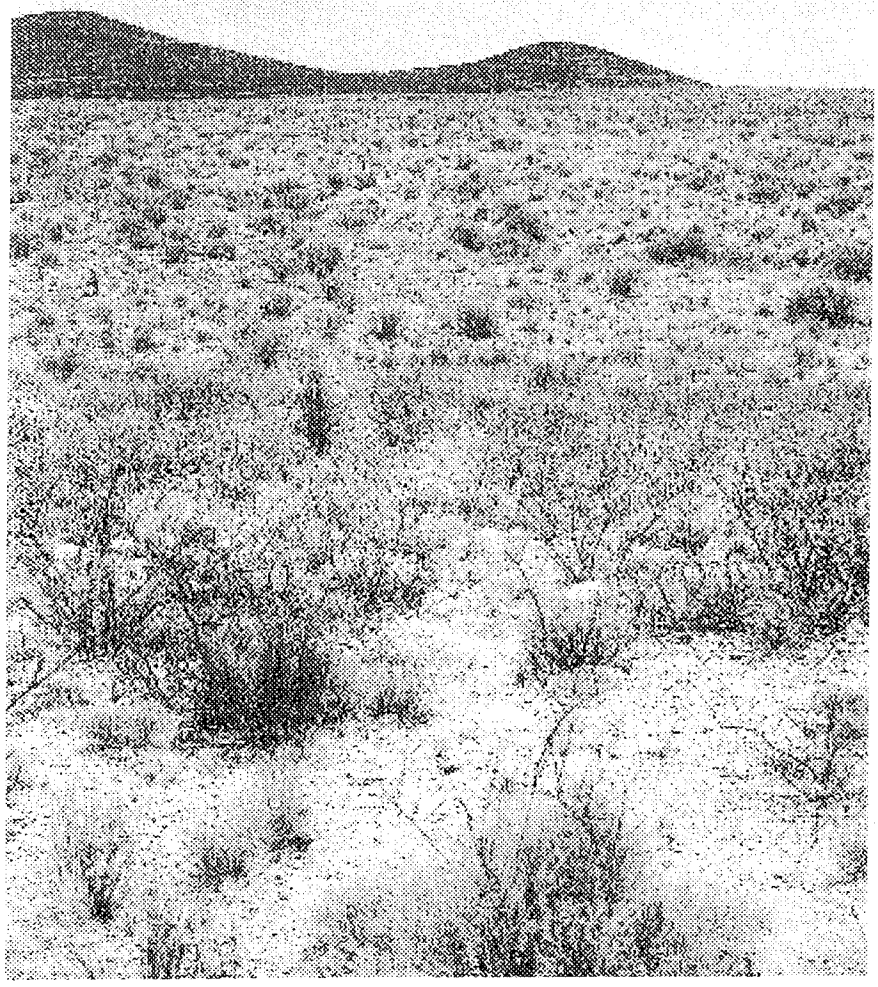
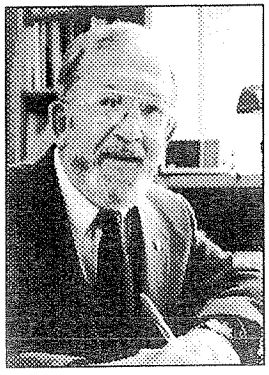


PHOTO COURTESY OF R. SIMONTON

Water research and management in semiarid environments

D.C. Goodrich and J.R. Simanton



Dr. Kenneth G. Renard

Arid and semiarid environments cover more than one-third of the world's land surface (Branson et al. 1981). Sound water and soil management in these areas is crucial because those resources are particularly sensitive to climate variability and anthropogenic effects. An international symposium, *Water Research and Management in Semiarid Environments*, was convened to focus on these issues. The goals of the symposium were to evaluate the collective knowledge of arid and semiarid hydrologic and erosion processes by reflecting upon past accomplishments, the state-of-the-science, and research trends for the 21st century. In addition, the symposium was a vehicle to honor Dr. Kenneth G. Renard for his accomplishments leading to a better understanding of the water and soil resources of arid and semiarid environments and their management, as well as his contributions to the establishment of the renowned Walnut Gulch Experimental Watershed (see front cover).

The symposium

The symposium was held November 1-3, 1994, in Tucson, Arizona, USA. Participants included nationally and internationally known experts on water and soil conservation research in arid and semiarid regions. Formal oral presentations, poster sessions, panel discussions, and water and soil resource conservation computer-model demonstrations were held over a two-day period culminating with a field day at the Walnut Gulch Experimental Watershed. Major categories of topics discussed at the symposium included spatial and temporal characteristics of precipitation and infiltration; modeling of hydrologic processes in arid and semiarid regions; the importance of watershed research; sediment transport and delivery, and soil erosion prediction models such as the Revised Universal Soil Loss Equation (RUSLE) and WEPP (Water Erosion Prediction Project). A selected group of research papers addressing these topics are compiled in this special issue of the *Journal of Soil and Water Conservation*.

The career

Dr. Kenneth G. Renard's distinguished 38-year career with the United States Department of Agriculture's (USDA) Agricultural Research Service (ARS) began in 1957 at Madison, Wisconsin. In 1959 he was assigned to the Walnut Gulch Experimental Watershed in Tombstone, Arizona, where he pioneered watershed-engineering research in arid and semiarid areas. He was also a leader in development, design, and construction of unique instrumentation for measuring runoff in sediment-laden ephemeral streams (Smith et al. 1982; Renard et al. 1986). Dr. Renard, Research Leader of the Southwest Watershed Research Center in Tucson, Arizona (1968-1987), provided major inputs to formulating research at the Center and was instrumental in directing the program to the stature it enjoys today. Under his leadership, initial efforts to inventory and instrument hydrologic and erosion processes have advanced to the current emphases on water quantity, water quality, and global change in the hydrologic cycle.

Dr. Renard has made important contributions to the understanding and management of water and soil resources of arid and semiarid environments including studies of precipitation, infiltration, evaporation, runoff, groundwater, and erosion and sedimentation (Renard 1970; 1986; Renard et al. 1990; Renard et al. 1993). In addition, he has participated actively on national research teams resulting in the

Reprinted from the *Journal of Soil and Water Conservation*
September-October 1995, Volume 50 Number 5

EPIC (Erosion Productivity Impact Calculator; Williams et al. 1983), and SPUR (Simulation of Production and Utilization of Rangelands; Renard et al. 1983) models, and, most recently, led the effort to revise the Universal Soil Loss Equation (RUSLE; Renard et al. 1991; 1994) together with a computer program and documentation. Dr. Renard is recognized nationally and internationally as an expert in erosion, sediment-transport, and delivery processes. He has been an invited participant in water resource and erosion projects through the United Nations and in several foreign countries. During his career, Dr. Renard has been active in many professional societies including the Soil and Water Conservation Society, the American Society of Civil Engineers, and the American Society of Agricultural Engineers. Dr. Renard has also had notable impact on the careers of numerous scientists and land managers both directly, through collaboration, encouragement and training, and indirectly, through development of the Walnut Gulch Experimental Watershed.

The watershed

Perhaps the foremost contribution of Dr. Renard's career to arid/semiarid environmental science was the establishment, development, and instrumentation of the USDA-ARS Walnut Gulch Experimental Watershed [150 km^2 (58 mi^2)]. The watershed, in southeastern Arizona (31° 43′N, 110° 41′W) just north of the transition between the Chihuahuan and Sonoran Deserts encompasses the historic town of Tombstone. It is assumed to be representative of 60 million hectares of brush- and grass-covered rangeland of the semiarid Southwest (see Renard et al. 1993, for a detailed watershed description). It was selected as a primary research facility by the USDA in the mid 1950s as part of a national effort to establish highly instrumented watersheds of approximately 100-400 km^2 (38–154 mi^2) in the primary hydroclimatic regions of the country. The initial mission was to quantify the influence of upland conservation on downslope water supply (Kelly and Glymph 1965; Goodrich et al. 1994).

Rainfall and runoff instrumentation on the Walnut Gulch Experimental Watershed was initially installed in 1954 and was expanded in the 1960s, under the guidance of Ken Renard. The network now includes 85 recording raingages and 11 Walnut Gulch Supercritical flumes on main drainages (Osborn et al. 1979; Gwinn 1970; Smith et al. 1982—see lower right cover photo). Runoff from 10 small [< 40 ha (< 99 ac)] watersheds is measured using various gaging structures and sediment discharge is monitored by automatic pump samplers and sediment traps above weirs and a total-load automatic traversing slot (Renard et al. 1986) on supercritical flow flumes. In addition, regular soil moisture and energy flux measurements are being made at grass and desert shrub dominated sites within the watershed. Largely due to the diligent efforts and leadership of Ken Renard, the Walnut Gulch Experimental Watershed is an exceptional outdoor laboratory, as no other semiarid watershed in the world has comparable hydrologic instrumentation in time and space.

The extensive hydrologic network, data- and knowledge-bases that have arisen from the vision of Dr. Renard and the Southwest Watershed Research Center have had far-reaching impacts on the development of semiarid water management technology and society. It is estimated that well over 300 publications are based at least in part on data and research conducted at the Walnut Gulch Experimental Watershed.

A partial listing of some of the major impacts resulting from efforts conducted at the Walnut Gulch Experimental Watershed includes the following:

1) Quantification of spatial and temporal variability of precipitation and development of design storm characteristics employed for design and construction throughout the Southwest (Renard and Osborn 1966; Osborn and Hickok 1968; Osborn and Lane 1969; Osborn et al. 1972; Smith and Schreiber 1974; Osborn et al. 1979; Osborn 1983; Frasier et al. 1984; Woolhiser and Osborn 1985; Simanton and Renard 1986; Osborn and Renard 1988);

2) Development of instrumentation and techniques in measurement of ephemeral streamflow and sediment yield (Osborn et al. 1963; Hickok and Ree 1965; Gwinn 1970; Smith et al. 1982; Renard et al. 1986);

3) Quantifying the role of stream channel transmission losses in the water balance of semiarid watersheds (Keppel and Renard 1962; Osborn and Renard 1973; Renard and Laursen 1975; Lane 1982; Lane 1983);

4) Development of flood-frequency relations for ephemeral streams employed for design and construction throughout the Southwest (Boughton and Shirley 1983; Boughton and Renard 1984; Reich and Renard 1981);

5) Quantifying the impact of ephemeral streams on sedimentation and groundwater recharge (Lane 1982a; Osterkamp et al. 1983; Renard et al 1964; Wallace and Renard 1967);

6) Investigating the consequences of possible climate change on soil, water, and plant resource utilization in arid areas (Frasier et al. 1987; Cox et al. 1988; Frasier 1989; Lane et al. 1994);

7) Using experimental watersheds and rainfall simulation experiments to establish the databases necessary for natural resource model development (Renard 1986; Simanton and Renard 1986; Lane and Nearing 1989; Woolhiser et al. 1990; Simanton et al. 1991; Renard et al. 1991);

8) The historical data and knowledge base, as well as the instrumentation and research infrastructures have made Walnut Gulch an ideal lo-

cation to conduct large-scale, multi-disciplinary research; included are studies of the water and energy balance using remotely sensed and conventional ground based data (Kustas et al. 1991; Kustas and Goodrich 1994; Moran et al. 1994; Nichols 1994); and,

9) Incorporation of natural resource models into decision support systems to offer alternative management practices for efficient and sustainable use of water and soil resources in arid/semiarid environments (Yakowitz et al. 1992; Renard et al. 1993).

The future

Based on discussions from the Symposium, research and management regarding water use in arid and semiarid areas will likely focus on improved efficiency and conservation. Population increases and the corresponding demand for food, fiber, and amenities of life will require technology development that increases water resources in water-deficient areas and insures environmental protection and enhancement. Rapid advances in computer technology and associated modeling capability will allow us to explore additional and more complex management alternatives for the use of arid and semiarid areas. Multi-objective decision making, geographic information systems, digital elevation databases, expert systems, remote sensing, and other new and improving electronic technologies are innovative tools for natural resource management. At the same time, intensifying land use, climate change, and other stresses on natural resources pose new challenges. Our analytical capabilities are advancing more rapidly than our ability to collect data with which to test hypotheses and refine our knowledge of natural resources. The National Research Council (1991) report "Opportunities in the Hydrologic Sciences" noted the data-poor nature of the hydrologic sciences, the growing "schism between data collectors and analysts" as well as the erosion in long-term data collection programs. Therefore experimental watershed research and long-term data acquisition for model development and validation are essential to advance our science and enable new technology to be applied to arid and semiarid areas with confidence.

The special issue of the *Journal*

The sequence of papers in this special issue of the *Journal* begins with several commentaries and a feature article related to semiarid hydrology and water management and a discussion on the importance of experimental watersheds. The first group of technical articles deals with basin characterization using remote sensing methods. The next set of articles relates to research on various phases of the hydrologic cycle moving from precipitation to infiltration to runoff generation and water harvesting. The next large grouping of papers deals with erosion and sedimentation. This group includes papers on erosion prediction models, soil factors affecting erosion and several studies of sediment transport on alluvial fans, tepetates, and in large channels. The special issue ends with a technical note on the availability of data from a large collection of watersheds and finally, summary and closing remarks by Dr. Renard are presented.

Several general concerns and themes were apparent in a large percentage of the presentations and papers included herein. A noted concern related to the "scale" problem in which research and data collection are often carried out over a limited range of time and spatial scales and resulting methods based on that research are applied outside the range of scales utilized. A related issue was the measurement of natural variability in time and space of a variety of climatic and watershed characteristics and its treatment in models and resource management methods.

REFERENCES CITED

Boughton, W.C., and E.D. Shirley. 1983. Fitting procedures for the Log-Boughton distribution. Journal of Hydraulic Engineering, ASCE 109(HY4):579–589.

Boughton, W.C., and K.G. Renard. 1984. Flood frequency characteristics of some Arizona watersheds. Water Resources Bulletin, AGU 20(5):761–769.

Branson, F.A., G.F. Gifford, K.G. Renard, and R.F. Hadley. 1981. Rangeland hydrology, Range Science Series No. 1, Second Edition. Society for Range Management. Kendall/Hunt Publishing Co., Dubuque, Iowa. 645pp.

Cox, J.R., M.H. Martin-R, F.A. Ibarra, J.H. Fourie, N.F.G. Rethman, and D.G. Wilcox. 1988. The influence of climate and soils on the distribution of four African grasses. Journal of Range Management 41(2):127–139.

Frasier, G.W., D.A. Woolhiser, and J.R. Cox. 1984. Emergence and seedling survival of two warm-season grasses as influenced by the time of precipitation: A greenhouse study. Journal of Range Management 37(1):7–11.

Frasier, G.W., J.R. Cox, and D.A. Woolhiser. 1987. Wet-dry cycle effects on warm-season grass seedling establishment. Journal of Range Management 40(1):2–6.

Frasier, G.W. 1989. Characterization of seed germination and seedling survival during the initial wet-dry periods following planting. Journal of Range Management 42(4):299–303.

Goodrich, D.C., P.J. Starks, R.R. Schnabel, and D.D. Bosch. 1994. Effective use of USDA-ARS experimental watersheds. C.W. Richardson, A. Rango, L.B. Owens, and L.J. Lane (eds.), ARS Conference on Hydrology, Denver, Colorado, September 1993, USDA-Agricultural Research Service, Pub. 1994-5, pp. 35–46.

Gwinn, W.R. 1970. Calibration of Walnut Gulch supercritical flumes. Journal Hydraulics Division, ASCE 98(HY8):1681–1689.

Hickok, R.B., and W.O. Ree. 1965. Instrumentation of experimental watersheds. Symposium on Representative and Experimental Areas, Budapest, Hungary, IASH 66:286–298.

Kelly, L.L., and L.M. Glymph. 1965. Experimental watersheds and hydrologic research. Symposium on Representative and Experimental Areas, Budapest, Hungary, IASH 66:5–11.

Keppel, R.V., and K.G. Renard. 1962. Transmission losses in ephemeral stream beds. Journal Hydraulics Division, ASCE 88(HY3):59–68.

Kustas, W.P., D.C. Goodrich, Moran, et al. 1991. An interdisciplinary field study of the energy and water fluxes in the atmosphere-biosphere system over semiarid

rangelands: Description and some preliminary results. Bulletin of the American Meteorological Society 12(11):1683–1706.

Kustas, W.P., and D.C. Goodrich, D.C. 1994. Preface to the special section on MONSOON '90. Water Resources Research 30(5):1211–1225.

Lane, L.J. 1982. A distributed model for small semiarid watersheds. Journal Hydraulics Division, ASCE 108(HY10):1114–1131.

Lane, L.J. 1982a. Relationships between morphology of small streams and sediment yield. Journal Hydraulics Division, ASCE 108(HY11):1328–1365.

Lane, L.J. 1983. Chapter 19: Transmission losses. In: SCS National Engineering Handbook, U.S. Government Printing Office, Washington, DC, pp. 19-1–19-21.

Lane, L.J., and M.A. Nearing (eds.). 1989. USDA-Water erosion prediction project: Hillslope profile model documentation. NSERL Report No. 2. USDA-ARS National Soil Erosion Research Laboratory, Purdue University, West Lafayette, Indiana.

Lane, L.J., M.H. Nichols, and H.B. Osborn. 1994. Time series analysis of global change data. Environmental Pollution 83:63–68.

Moran, M.S., D.C. Goodrich, and W.P. Kustas. 1994. Integration of remote sensing and hydrologic modeling through multi-disciplinary semiarid field campaigns: MONSOON'90, Walnut Gulch'92, and SALSA-MEX. Sixth ISPRS International Symposium on Physical Measurements and Signatures in Remote Sensing, Val d'Isere, France, pp. 981–991, Jan. 17–21.

National Research Council, Opportunities in the Hydrologic Sciences, National Academy Press, 348p. 1991.

Nichols, M.H., L.J. Lane, H.M Arias, and C. Watts. 1994. Comparative modeling of large watershed responses between Walnut Gulch, Arizona, USA, and Matape, Sonora, Mexico. Proceeding of a Symposium on Variability in Stream Erosion and Sediment Transport, Canberra, Australia, IAHS, pp. 351–358.

Osborn, H.B. 1983. Timing and duration of high rainfall rates in the southwestern United States. Water Resources Research, AGU 19(4):1036–1042.

Osborn, H.B., R.V. Keppel, and K.G. Renard. 1963. Field performance of large critical depth flumes for measuring runoff from semi-arid rangelands. USDA-ARS 41-69, 14p.

Osborn, H.B., and R.B. Hickok. 1968. Variability of rainfall affecting runoff from a semiarid rangeland watershed. Water Resources Research, AGU 4(1):199–203.

Osborn, H.B., and L.J. Lane. 1969. Prediction-runoff relation for very small semiarid rangeland watersheds. Water Resources Research, AGU 5(2):419–425.

Osborn, H.B., L.J. Lane, and J.F. Hundley. 1972. Optimum gaging of thunderstorm rainfall in southeastern Arizona. Water Resources Research, AGU 8(1):259–265.

Osborn, H.B., and K.G. Renard. 1973. Management of ephemeral stream channels. Journal Irrigation and Drainage Division, ASCE 99(IR3):207–214.

Osborn, H.B., K.G. Renard, and J.R. Simanton. 1979. Dense networks to measure convective rainfall in the southwestern United States. Water Resources Research, AGU 15(6):1701–1711.

Osborn, H.B., and K.G. Renard. 1988. Rainfall intensities for southeastern Arizona. Journal Irrigation and Drainage Division, ASCE 114(ID1):195–199.

Osterkamp, W.R., L.J. Lane, and G.R. Foster. 1983. An analytical treatment of channel-morphology relations. U.S. Geological Survey Professional Paper 1288, U.S. Department of Interior, 21 p.

Reich, B.M., and K.G. Renard. 1981. Application of advances in flood frequency analysis. AWRA Water Resources Bulletin 17(1):67–74.

Renard, K.G. 1970. The hydrology of semiarid rangeland watersheds. ARS 41-162, USDA-ARS, Washington, DC, 26 pp.

Renard, K.G. 1986. Rainfall simulators and USDA erosion research: History, perspectives, and future. L.J. Lane (ed.), Erosion on Rangelands: Emerging Technology and Database. Proceedings Rainfall Simulator Workshop, January 14-15 1985. Society for Range Management, Denver, CO, pp. 3–6.

Renard, K.G., R.V. Keppel, J.J Hickey, and D.E. Wallace. 1964. Performance of local aquifers as influenced by stream transmission losses and riparian vegetation. Transactions of ASAE 7(4):471–474.

Renard, K.G., and H.B. Osborn. 1966. Rainfall intensity comparisons from adjacent 6-hour and 24-hour recording rain gages. Water Resources Research, AGU 2(1):145–146.

Renard, K.G., and E.M. Laursen. 1975. A dynamic behavior model of an ephemeral stream. Journal Hydraulics Division, ASCE 101(HY5):511–528.

Renard, K.G., E.D. Shirley, J.R. Williams, and A.D. Nicks. 1983. SPUR hydrology component: Upland phases. USDA-ARS Miscellaneous Publication No. 1431, pp. 17–44.

Renard, K.G., J.R. Simanton, and C.E. Fancher. 1986. Small watershed automatic water quality sampler. Proceedings 4th Federal Interagency Sedimentation Conference, Las Vegas, Nevada, March 1986, Vol. I, pp. 1-51–1-58.

Renard, K.G., J.C. Willis, and D.A. Farrell. 1990. Major sedimentation (erosion) issues and ongoing research and developments at the USDA-ARS. Proc. ASCE International Symposium, Hydraulics/Hydrology of Arid Lands, Hydraulics and Irrigation and Drainage Divisions, San Diego, California, pp. 1060–1065.

Renard, K.G., G.R. Foster, G.A. Weesies, and J.P. Porter. 1991. RUSLE-Revised universal soil loss equation. Journal of Soil and Water Conservation 46(1):30–33.

Renard, K.G., L.J. Lane, J.R. Simanton, W.E. Emmerich, J.J. Stone, M.A. Weltz, D.C. Goodrich, and D.S. Yakowitz. 1993. Agricultural impacts in an arid environment: Walnut Gulch case study. Hydrological Science and Technology 9(1-4):145–190.

Renard, K.G., J.M. Laflen, G.R. Foster, and D.K. McCool. 1994. RUSLE revisited: Status, questions, answers and the future. Journal of Soil and Water Conservation 49(3):213–220.

Simanton, J.R., and K.G. Renard. 1986. Time related changes in rangeland erosion. L.J. Lane (ed.), Erosion on Rangelands: Emerging Technology and Database. Proceedings Rainfall Simulator Workshop, January 14-15 1985. Society for Range Management, Denver, CO, pp. 18–22.

Simanton, J.R., M.A. Weltz, and H.D. Larsen. 1991. Rangeland experiments to parameterize the Water Erosion Prediction Project: Vegetation canopy effects. Journal of Range Management 44(3):276–281.

Smith, R.E., and H.A. Schreiber. 1974. Point processes of seasonal thunderstorm rainfall: 2. Rainfall depth probabilities. Water Resources Research, AGU 10(3):418–423.

Smith, R.E., D.L Chery Jr., K.G. Renard, and W.R. Gwinn. 1982. Supercritical flow flumes for measuring sediment-laden flow. USDA-ARS Technical Bulletin No. 1655. 70 p.

Wallace, D.E., and K.G. Renard. 1967. Contribution to regional water table from transmission losses of ephemeral streambeds. Trans. ASAE 10(6):786–789, 792.

Williams, J.R., K.G. Renard, and P.T. Dyke. 1983. EPIC-A new method for assessing erosion's effect on soil production. Journal of Soil and Water Conservation 38(5):381–383.

Woolhiser, D.A., and H.B. Osborn. 1985. A stochastic model of dimensionless thunderstorm rainfall. Water Resources Research, AGU 21(4):511–522.

Woolhiser, D.A., R.E. Smith, and D.C. Goodrich,. 1990. KINEROS-A kinematic runoff and erosion model; documentation and user manual. USDA-ARS, Pub. ARS-77, 130 pp.

Yakowitz, D.S., L.J. Lane, J.J. Stone, P. Heilman, R.J. Reddy, and B. Imam. 1992. Evaluating land management effects on water quality using multi objective analysis within a decision support system. Proceedings of the American Water Resources Association 1st International Conference on Ground Water Ecology, Tampa, Florida, April 1992.

D.C. Goodrich and J.R. Simanton are with the USDA-Agricultural Research Service, Tucson, Arizona 85719. *This special issue would not have been possible without the dedicated effort of a large number of reviewers who provided thorough evaluations of the submitted manuscripts. Our sincere thanks are extended to all of the reviewers. The staff of the* Journal of Soil and Water Conservation *is gratefully acknowledged for the excellent advice and assistance in preparation of this special issue. In addition, all the Symposium participants deserve special thanks for making it a success and honoring Dr. Kenneth G. Renard.*