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2002 RAY K. LINSLEY AWARD

The American Institute of Hydrology (AIH) established this award in 1986 to honor the first Vice President of AIH. Ray K Linsley - one of the truly great leaders in the hydrological sciences. The award is presented annually, on the recommendation of the AIH Awards Committee, for a major contribution to the field of surface water hydrology. The first Ray K Linsley Award was presented to Peter 0. Wolf at the AIH International Conference on Advances in Ground-Water Hydrology in Tampa, Florida on November 17, 1988.

Citation: *Stephen J. (Steve) Burges*

It is an honor and privilege to introduce the recipient of the 2002 Ray K. Linsley Jr. Award, Professor Emeritus, David H. Pilgrim, School of Civil Engineering, the University of New South Wales, Australia.

Dr. Pilgrim earned his B.E. degree in Civil Engineering with first class honors and the University Medal, the highest recognition for a baccalaureate graduate, in 1953. He earned his Ph.D. in 1967 and his higher doctorate, D.Sc., in 1984, all from the University of New South Wales. He is an Honorary Fellow of the Institution of Engineers, Australia and a Chartered Professional Engineer.

Dave was born in Sydney on December 2, 1931. He worked as a design engineer for the Irrigation Commission of New South Wales from 1953 to 1958 when he joined the staff of the University of New South Wales in Sydney. He rose through the academic ranks to become Professor in 1987 and Professor Emeritus in 1993. He has been exceptionally active in retirement, consulting and devoting considerable time to charitable activities

He has been recognized formally on many occasions by the Institution of Engineers Australia. He has twice received their prestigious Warren Medal (1982 and 1986), the Engineering Excellence Award for "Australian Rainfall and Runoff" (State Award 1989, and National Award 1990), was the 1991 Munro Orator, elected Honorary Fellow (1991) and Emeritus Member of the Civil College (1998). He was the 1988 Unwin Lecturer of the Institution of Civil Engineers, London.

I first met Dave and his wife Devona in January 1968 when they came to Stanford on a sabbatical leave. I had been at Stanford for one academic quarter and was then working with Bob Street on my MS degree. Ray Linsley was my doctoral advisor. It is my good fortune to have known Dave and Devona for thirty-four years and to have had opportunities to visit them over the years with my wife, Sylvia.

In 1961, Penman posed the significant and still only partially answered question: "Where does the rain go?" Dave Pilgrim's interest in hydrology began with a similar set of questions that predated Penman's question. While working as a design engineer in the 1950's Dave had to estimate the lateral inflow into a major water supply canal cut through rock and clay. The complete lack of credible information needed to estimate those inputs reliably caused him to undertake his first major line of hydrologic research: From whence in a catchment comes the water that enters the channel system? Dave undertook pioneering work in tracer studies to answer some of these questions. The key findings of those experiments are given in two 1966 papers in the Journal of Hydrology. He followed up on this work in two key papers in Water Resources Research in 1976 and 1977 in which he explored the issues of travel time and nonlinear transport dynamics of flow in a small catchment. His results provided key underpinnings for the development of the theories of the geomorphic unit hydrograph in the late 1970s and early 1980s. His third major enquiry along these lines addressed the relative contributions of surface and subsurface flow. This work resulted in three seminal papers, two in Journal of Hydrology in 1978 with Dale Huff and Tim Steel, and one in Water Resources Research in 1979. The approach that Dave and his colleagues developed has been used by many others to determine the flow paths of highly nonlinear subsurface water movement to channels.

Dr. Pilgrim's theoretical work followed his experimental work in logical sequence: It would be unproductive to model rainfall-runoff transfers until the flow paths were relatively well understood. His early work on modeling rainfall-runoff and non-uniqueness of model parameters is reported in papers in Tom Chapman and Frank Dunnin's 1975 book "Prediction in Catchment Hydrology" and in Water Resources Research with Johnson in 1976. This path breaking work is still fresh today.

While most work on rainfall-runoff modeling has been reported for humid environments, Dave Pilgrim and his colleagues have tried to describe the complex hydrologic response of arid environments to rainfall. The essence of this work is described in two key papers. The first was with Ian Cordery and Dave Doran in 1979 in IAHS. The second was with Tom Chapman and Dave Doran in Hydrologic Sciences Journal in 1988. He and his colleagues have pointed out clearly that much research is needed to address and answer some of the hydrologic problems of climatically important arid areas.

A long standing problem in hydrology is to determine scaling laws by which information obtained from manageable experiments (at relatively small scale -- on the order of a few square kilometers or smaller) might be transferred to larger catchments. This linkage has remained elusive and our attempts and need for such linkages were described eloquently by the 1998 Linsley Award winner, Professor Jim Dooge in his famous 1986 Water Resources Research paper "Looking for Hydrologic Laws". Jim summarized Dave's work: "*Pilgrim's meticulous enquiry and penchant for exploring phenomena in many and varied catchments provide clues for some of our failures to determine 'Hydrologic Laws' of the catchment*". Such issues are described lucidly and documented in two papers. The first is Dave's 1982 Journal of Hydrology paper with Cordery and Baron "Effects of Catchment Size on Runoff Relationships". His 1983 Journal of Hydrology paper "Some Problems in Transferring Hydrologic Relationships Between Small and Large Drainage Basins and Between Regions" is essential reading for those who hope to further our understanding of catchment dynamics.

Scientific hydrologists provide the leadership for the professional hydrologic engineering community in Australia. Consequently, a large fraction of Dr. Pilgrim's work has been directed towards improving the understanding of flood hydrology and developing design methodologies for estimating flood risk and mitigating flood damage. His 1986 Water Resources Research Paper "Bridging the Gap Between Flood Research and Design Practice" remains essential reading.

Dr. Pilgrim's contributions to flood hydrology span almost 40 years. The culmination of much of this enquiry is contained in his book, the 1987 and 2001 editions of "Australian Rainfall and Runoff", the design guide for flood hydrology practice in Australia.

His contributions, "for service to science, particularly hydrology", were recognized in 1988 by his being made a "Member of the Order of Australia".

David Pilgrim is a scientific and practicing hydrologist of the first rank whose scholarship is firmly rooted in fundamentals. In his work has always sought to tie research to practice. He and Ray Linsley had much in common. Ray was committed to advancing hydrologic science and improving the practice of hydrologic engineering through education, research, and leadership of the profession. Dave and Ray were colleagues and co-workers in 1968. It is more than fitting that their names be linked with the prestigious AIH Ray K. Linsley Award. By making this award, the American Institute of Hydrology honors itself and the most distinguished academic and practicing hydrologist from Australia.

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R.K. LINSLEY AWARD

Response: David H. Pilgrim

SOME ISSUES IN FLOOD ESTIMATION

Ray K Linsley was a great and pioneering hydrologist and practical engineer, and it is a great honour to be associated with his name in receiving this award. My introduction to hydrology was as an engineering student at The University of New South Wales, Australia, taking the first final-year elective to be offered in Australia in this subject, and studying the three ground-breaking texts that had been published three years earlier in 1949 by Linsley, Kohler and Paulhus (affectionately known as "LKP"), Wisler and Brater, and Johnstone and Cross. These three books provided the seedbed for the growth of recognition of hydrology as a discipline in its own right, and a great incentive for the four students in that first elective. I think that it is safe to say that we derived the first unit hydrographs and storm loss rates in Australia. Ray spent some time with us at The University of New South Wales in 1963 and I had the great pleasure of spending most of 1968 at Stanford with him. Professor Linsley was much more than an ivory-tower academic. As well as having a keen interest in the science of hydrology, he was an astute engineer with a great practical experience and emphasis – qualities that I have always greatly admired.

My Career Highlight – "Australian Rainfall and Runoff"

My invitation from Dr Singh suggested that the occasion would give the opportunity to reminisce about the past and to suggest challenges for the future. In my 40 years as a faculty member, my research interests covered a wide field including the investigation of runoff processes over a range of geographical and climatological regions and including radioisotope tracing studies, hydrological modeling, flood estimation and the promotion of flood plain management. If I had to nominate the highlight of my career, without doubt it would be the leading of the five-year project to produce the third edition of "Australian Rainfall and Runoff", the guide to all flood estimation in Australia for The Institution of Engineers Australia (1987). While this might appear somewhat parochial and not of international significance, and very "applied", it gives a great deal of satisfaction to see one's research efforts over many years come to fruition in incorporation in generally accepted national guidelines. "Australian Rainfall and Runoff" (AR&R) is probably unique in providing authoritative guidelines for flood estimation for a nation, particularly as large and diverse geographically as Australia, and having the *imprimatur* of the national professional body. The UK Flood Studies Report is the only other guide that I know of that approaches this. "Australian Rainfall and Runoff" is really a misnomer and that its subtitle "A Guide to Flood Estimation" more closely describes its contents, but the title has become so firmly entrenched that correcting it would hardly be possible.

With the unique status of AR&R and the fact that expenditures on works sized by design floods represent approximately 0.4% of Australia's gross domestic product, I would like to briefly describe its history, organization, and the approaches adopted in its development. The first edition published in 1958 was developed by a technical committee of The Institution of Engineers Australia and was a manual of practice or handbook with specific directions given to designers. It attempted to put before the profession the new techniques that had been published nearly ten years before. Looking back, it was a simple document but represented a huge step forward for hydrology in Australia. The further development of techniques led to the second edition published in 1977, largely due to the efforts of Dr Allan Pattison who undertook his PhD study at Stanford under Professor Linsley. This was prepared by an editorial committee with relatively little interaction with the profession, and provided a collection of procedures without specific instructions on applications in particular circumstances, based on the assumption that design should be carried out by "engineering hydrologists" with considerable hydrological knowledge. In response to the expressed needs of the profession, the 1987 edition adopted the approach that firm guidance and specific design information should be given where possible. It was recognized that although not necessarily desirable, much design is carried out by persons whose main expertise is not in hydrology, and who require as firm guidance as possible. This even applies to the estimation of extreme floods for small dams and urban detention basins and channels. However the document falls short of being a prescriptive code of practice, and designers have the liberty, and even duty, to keep abreast of developments and to use other and newer procedures where circumstances warrant. It was recognized in preparing the revision that any document published by the Institution as the relevant professional body will inevitably be regarded as authoritative, and any departure from its recommendations, no matter how justified, throws additional responsibility on the designer. The 1987 edition occupies 374 pages plus a second A1 (60 x 42 cm) volume containing 108 maps and diagrams of design rainfall and other information. It was recently re-published in 2001 both in hard copy and electronic forms, the only change being an updating of extreme flood estimation.

Features of the organization were:

- a cohesive design and editorial team based at The University of New South Wales;
- involvement of the national Bureau of Meteorology, who met the design team's requirements and carried out intensity-frequency analyses of all available rainfall data for durations from 6 minutes to 72 hours;
- a review panel consisting of a wide range of users representing not only academic and water authority interests, but also the great majority of non-specialist users, and also representing different regions of the nation;
- at the beginning of the project, a comprehensive national survey was carried out of design methods and data in use at the time;
- incorporation of the maximum possible interaction with the profession including a series of workshops conducted around the nation in the latter stages of preparation to provide information on the proposed contents and procedures, to obtain feedback and local data and information, an important aspect of encouraging "ownership" of the final document;
- the project encouraged the analysis of a wide range of observed data in most regions of Australia and the development of regional design information.

With regards to the points noted above, it has always seemed to me that it is rather surprising and sad that there is often so little interaction between researchers who seek to provide improved design techniques and the practitioners who apply them in the real world. This criticism certainly did not apply to Ray Linsley.

Two foundational and related principles adopted were that where possible, recommended methods and design information should be based on observed data, and specific design information should be provided for different regions. Analysis of recorded data for rural watersheds clearly demonstrated that the one set of design information could not apply to the whole of Australia, as had been assumed in the past. Probably the most spectacular example is given by two formulae for time of concentration derived from minimum observed times of hydrograph rise from small to medium sized basins:

$t_c\,(\text{hrs}) = 0.76\ A^{0.38}$ for south eastern Australia

$t_c\,(\text{hrs}) = 2.31\ A^{0.54}$ for south west Western Australia.

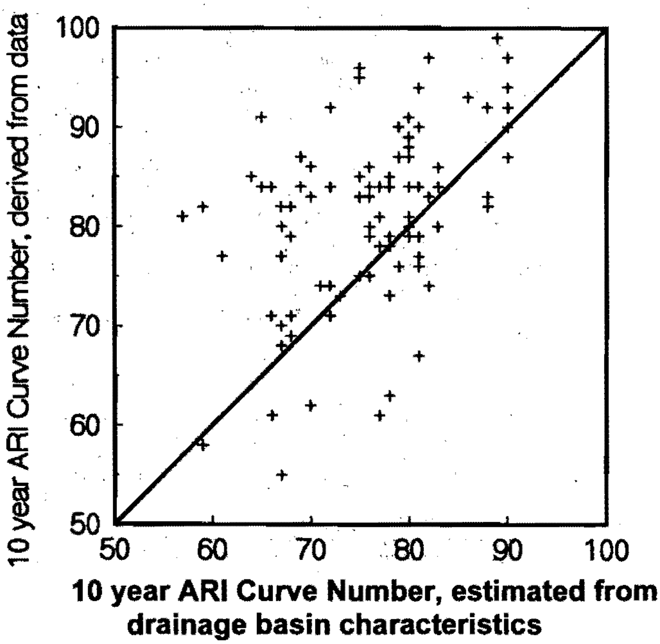
These two formulae were derived independently from observed data from 96 and 27 drainage basins respectively, and in both cases no variables tested other than area A (km^2) were statistically significant. The latter formula gives answers 2.1 to 7.4 times greater than the former for areas of 0.1 to 250 km^2 respectively, resulting from the different hydrological characteristics and runoff processes operating in the regions.

Some Problems in Developing and Use of Design Flood Procedures

Following from the above discussion, there are several problems that I have raised in the past (Pilgrim, 1986) that I believe are still not widely recognized.

Design Floods and Floods Resulting from Actual Storms

While the same mathematical model may be used for both types of problems, there are important differences in the two approaches. That design is generally of a probabilistic nature and simulating an actual flood is a deterministic problem is fairly obvious, but the implications of this are frequently not recognized in practice. Design methods are often developed from factors which are assumed to affect flood discharges and testing of a method is generally undertaken by its ability to reproduce some historical floods, whereas it should really be tested by its ability to reproduce a value from a flood frequency curve. Similar considerations apply to the estimation of parameters in fitting a model to a given watershed. These problems are illustrated by the testing of the U.S. Soil Conservation Service Method by Hoesein et al (1989) on 139 drainage basins in two regions in eastern Australia. For 96 basins in south-east Queensland and an Average Recurrence Interval of 10 years, the figure below shows values of the parameter CN estimated by the SCS procedure considering the variables thought to affect flood runoff compared with values derived probabilistically from frequency curves of observed floods and design rainfalls.



The values showed a wide and random scatter. Similar results have been found for the runoff coefficient in the Rational Method (Pilgrim, 1989). These studies also illustrate the importance of the derivation of design values from observed data.

Economic Importance of Small Drainage Basins

Studies in Australia indicate that approximately 70% of average annual expenditure on works sized by flood estimates occurs on small to medium sized rural and urban drainage basins. It seems that similar considerations would apply to other developed countries. The individual works are generally small and require relatively simple design procedures. However the overall costs demand that greater attention be paid to the development of accurate procedures based on observed data, despite the fact that this might not seem to be attractive or intellectually stimulating to many researchers.

Some Problems with Computer Models

While computer models are essential tools in all research and teaching operations and in every design office, they also have their downsides. In teaching graduate classes over many years to students who mainly worked in design offices using models, I found that the great majority confessed to having only vague ideas of the underlying hydrological principles before these were covered in class. This problem is compounded by the widely held belief that commonly used models give reliable results that "must be right". I remember sitting through a paper presented at a conference by a bright PhD student with a competent supervisor that reported the finding that computer modeling had proved that only partial area runoff occurred in major runoff events on an urban drainage basin that my university gaged. I did not believe this finding, so the next time that a major storm occurred, I made it my business to walk throughout the basin during the heavy rainfall. I can assure you that 100% of the drainage basin contributed surface runoff to the outlet. Despite the cherished beliefs of most model developers (and I am one of them), we need to remember and to teach our students that models by definition are at best simplifications of the real world, and that they are only as good as the assumptions that are built into them.

A further problem relates to the widespread practice of basing research, especially for PhDs, on the development and application of computer models rather than field-based studies. Sitting at a computer in an office is more convenient and comfortable. Results are more predictable as they are not as subject to the vagaries of the weather and field conditions. They also are less costly and are frequently regarded as more prestigious. However our analytical abilities have far outpaced our knowledge of physical processes during floods. This concentration on computer models has led to a flood of papers but very little improvement in practical flood estimation.

Field Experience

The above discussion reflects my experience that being in charge of a gaging network operated by my university contributed greatly to both my research and also teaching in hydrology. This network covered two groups of rural drainage basins of different physical characteristics, in addition to urban basins and a network in the arid zone. I know from observation the different runoff processes in each area, some quite different from the standard text-book types. While not everybody can have the luxury of easy access to a gaging network, I have always encouraged my students to get into the field during heavy rainfall and observe what is happening. Getting one's hands dirty and feet wet can bring hydrology to life and create a critical attitude to methods adopted in practice, and help to avoid the uncritical adoption of model results as discussed above.

Data Banks

Most data today are stored in computer banks. Access to data for research or analysis is simple and rapid, and provides the only practicable means of handling the large volumes of data that are often involved. However the user is removed from the source of the information and analysis can become the mere manipulation of a set of figures without the analyst getting the "feel" of the data. There is the increased temptation to use mathematical or statistical techniques without the careful consideration of the hydrological context and knowledge. Also, while most authorities check the data on entry into the bank, it has been my experience that errors can and do occur. In developing design procedures at my university, it was common practice to spend up to half the allotted time on checking the data, generally leading to considerable improvements in its accuracy and the discovery of relevant information that was not recorded in the data bank. This was done in the belief that no amount of sophisticated analysis can compensate for poor data.

The Need for Increased Data Collection

The discussion above leads to the concern over the worldwide trend of reduction of data collection networks, based largely on short-term financial constraints. This concern has been expressed, for example, by the World Meteorological Organization and the US Geological Survey as well as in Australia. For stream gaging networks, the reduction has also received some support from the premise that we have sufficient information to allow the estimation of values at discontinued stations from a much smaller number of long-term stations. However there is growing evidence of dissimilar runoff characteristics of drainage basins within regions with apparently similar climatological, physical and soils characteristics. This particularly applies to flood values, as illustrated by the discussion of the SCS method above. The reasons are not understood and probably will remain so without much further research and data collection. In addition, the debate about the long-term characteristics of yield and flood frequency curves depends largely on assumptions based on relatively short records. Cordery (2002) has given a comprehensive review of the need for increased data collection in an Australian context, but much applies universally. He has shown that streamflow data collection has a long-term benefit-cost ratio of at least nine. Of course, the need for increased hydrological data collection goes far beyond streamflow information, and includes a range of water quality, groundwater, micro flora and fauna and other ecological data. These needs require considerable long-term financing. The problem is that this is not recognized by politicians whose horizons of financial interest are often of a short-term nature. There is a great need for a program of political lobbying by the professional bodies on this topic.

Some Challenges for the Future

I will conclude with a few challenges in the field of flood estimation that I have also raised in the past (Pilgrim, 1986) but that are still relevant today:

- Guidelines for the choice between flood frequency analysis and design based on a design rainfall. To a large extent in current practice, this is based on the subjective preference or bias of the analyst. Both are probabilistic estimates. Recommendations for Australian conditions are included in AR&R.
- Design probabilities for complete systems. Bridges and culverts are generally designed as individual structures. However they are often components in a series of waterway crossings on a transport route, either a highway or a railroad, and the flooding of any one will close the route, possibly with serious economic consequences. For a valid analysis, the whole system requires consideration.
- Floods between the 1% probability event and the Probable Maximum Flood (PMF). With the growing use of risk management, these values are of critical importance and are receiving increasing attention.
- Guidelines to assist the selection of design probabilities. These are selected for the great majority of practical flood estimates from standard arbitrary values based on experience or legislation. More widespread analysis of typical situations could identify the factors affecting the most efficient design levels and their sensitivity, at least on a regional basis.
- The effects of urbanization. This problem is compounded by the probable lack of transposability resulting from the great variations in types of urbanization and physical processes in different regions.
- Losses to runoff in design storms. While the estimation of losses from rainfall in the deterministic modelling of runoff from actual storms attempts to take account of soil and cover types and conditions, there is considerable evidence that these factors do not have as great an effect in the probabilistic estimation of design floods.

Possibly the greatest challenges facing us are effective communication between researchers and practical designers, especially for those of us who are academics training our future hydrologists, and more importantly between the hydrological community and the politicians and their policy advisors who hold the purse strings. These are skills at which Ray K Linsley excelled. Following in his footsteps would be the best way to honor his name.

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