Available online at www.sciencedirect.com

SCIENCE DIRECT®

Geomorphology 72 (2005) 238–249

GEOMORPHOLOGY

www.elsevier.com/locate/geomorph

The most-cited works in *Geomorphology*

Martin W. Doyle *, Jason P. Julian

Department of Geography, University of North Carolina, Chapel Hill, NC 27599-3220, USA

Received 22 December 2004; received in revised form 11 April 2005; accepted 29 April 2005
Available online 21 July 2005

Abstract

We conducted a review and analysis of the references cited in articles published (1995–2004) in the journal *Geomorphology* and also solicited comments from the authors of the most-cited works on their major influences. Of the 31,696 unique works cited in the journal, only 22 were referenced at least 20 times, with the vast majority (92%) cited only once or twice. We divided the citations into the 10 most-cited books (i.e., complete volumes) and 10 most-cited papers (i.e., journal articles, book chapters, reports). A total of 23 different researchers were responsible for the 20 works, with one (Wolman) being an author or co-author of a quarter of them. Seven of the ten most-cited papers were based on work in the USGS in the mid-twentieth century, indicating a particularly fruitful time of geomorphic research and a particularly important cohort of scientists. Based on our citation analysis and author commentaries, we suggest that classic works in geomorphology are most likely to be those that provide useful knowledge and those that incorporate interdisciplinary perspectives.

Keywords: Citation analysis; History of geomorphology; Bibliometric

Contents

* Corresponding author.
E-mail address: mwdoyle@email.unc.edu (M.W. Doyle).

0169-555X/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.geomorph.2005.04.016

1. Introduction

A scientific discipline can be investigated by examining those works that its constituents deem most important, and by the importance of these works to other disciplines. Works that maintain their importance over long periods of time indicate key contributions by substantial scholars or the dominance of a paradigm within the discipline. Further, if key works in a discipline are only highly regarded within that discipline and cited rarely in other disciplines, then this may indicate that scientists have a research agenda that is of little interest to the outside community.

Literature citation reviews provide an objective view of a discipline by quantifying the works most important to that discipline (Dorn, 2002). For instance, a recent literature citation review (Resh and Kobzina, 2003) revealed that the most-cited paper in stream ecology was a relatively recent article (Vannote et al., 1980) that instigated a new research paradigm rather than more classic earlier works (e.g., Odum, 1969) that actually inspired many of the most-cited works in stream ecology. Some journals "revisit" classic papers (e.g., *Progress in Physical Geography*) in order to synthesize information that led to their composition. Perspective articles written by recognized leaders in the field offer insight into the inspirations and developments that led to their classic works (Wolman, 1995; Leopold, 2004). Such articles, and the recent loss of several prominent geomorphologists like Strahler (see Schumm, 2004) and Chorley (see Haggett, 2002), piqued our curiosity about what are the "classics" in geomorphology and perhaps as importantly, what led to their development.

Here we examine the classics of the discipline of geomorphology through a citation analysis. Citation analyses provide metrics of the relative impact of different works, but also provide historical contexts for key works in the discipline (Haschenburber and Souch, 2004). Rather than subjectively deciding what the most important contributions to geomorphology are, a database was compiled of all references cited in articles published in the journal *Geomorphology* over the last 10 yr. The dataset was analyzed to elucidate trends in the discipline of geomorphology, particularly concerning what current researchers consider important. Finally, brief descriptions of the studies are presented from the authors' perspectives.

2. Methods

There are several avenues for evaluating contributions of scientific publications to a discipline. Some evaluations select specific articles to represent a research theme, and then examine the background that led to the authoring of those specific articles and the impact of those articles on the entire discipline (Haschenburber and Souch, 2004). Alternatively, citation frequencies of scientific articles are used for evaluation in a range of disciplines (Resh and Kobzina, 2003; Leimu and Koricheva, 2005), including geomorphology (Dorn, 2002).

To systematically and objectively review the literature cited in the discipline, we used the journal *Geomorphology*, because it specializes in the discipline, as opposed to similar but broader journals (e.g., *Geology*, *Water Resources Research*). Additionally, *Geomorphology* provides a greater number of articles than comparable discipline specific journals (e.g. *Earth Surface Processes and Landforms*), and thus a more extensive reference list database from which to draw. Limitations or biases from using *Geomorphology* are discussed below. Other citation analyses have used keyword searches to search multiple journals, but the keyword approach does not tend to capture books or monograph citations, and is inherently limited and potentially biased by the keywords chosen by the investigator (Dorn, 2002).

Data collection began with the issue published in February 1995 (volume 11, issue 3) and ended with August 2004 (volume 61, issue 4); special issues of the journal were included. This range was chosen because it represented the bulk of publications in *Geomorphology*, and also it represented those articles with digital references which could be easily downloaded. The reference lists from each article were downloaded into a database; and because of inconsistencies in reference styles, were thoroughly reviewed in order to accurately determine the frequency of each unique reference (e.g., ensured Leopold et al., 1964 was counted as the same reference as Leopold, Wolman, and Miller, 1964). Multiple editions of a book were combined into one citation, even though the book may have been updated between editions (e.g., Knighton, 1984, 1998).

The *Geomorphology* citation database was used to find the most-cited works, with our main focus on works cited at least 20 times. Based on this ranked list, the citations were divided into the 10 most-cited, complete volumes (e.g., textbooks) and the 10 most-cited, specific studies (e.g., journal articles, book chapters, technical reports). For these 20 works, the ISI Citation Index (Web of Science) was used to quantify the number of times they were cited in the science literature in general for the same period of 1995–2004. This procedure provided a measure of the relative importance of the work to the broader scientific community. Multiple spellings of the authors' names and multiple years were used to ensure that possible citation mistakes were accounted for in building this latter database.

Finally, we contacted the authors of the most-cited articles and asked them to provide some commentary on what led to their classic work. For two of the papers, we relied on previously published reviews of the papers, and for one we relied on correspondence with one of the author's colleagues.

3. Results

A total of 45,201 citations (appearance in an article's reference list) were listed in *Geomorphology* between 1995 and 2004. These represented 31,696 unique works. For example, Leopold et al. (1964) is cited by numerous papers in *Geomorphology*, and thus contributes multiple times to the total citations, but contributes only once to the total number of unique works. Of the unique works, 29,162 were cited only once (79.6%) or twice (12.4%) in the journal over the 10-yr period (Fig. 1). Only 22 works (0.07%) were cited at least 20 times by other articles in the journal (Fig. 1). The 10 most-cited complete volumes are hereafter referred to as the "classic books" (Table 1) and the 10 most-cited specific studies are referred to as the "classic papers" (Table 2).

Books tended to be cited slightly more often than papers. The earliest classic in the list was Bagnold (1941) and the most recent was Selby (1993). Of the classic papers, two were USGS Professional Papers (Leopold and Maddock, 1953; Wolman and Leopold, 1957), one was a Binghamton Symposium Proceedings volume (Schumm, 1973), one was a technical report

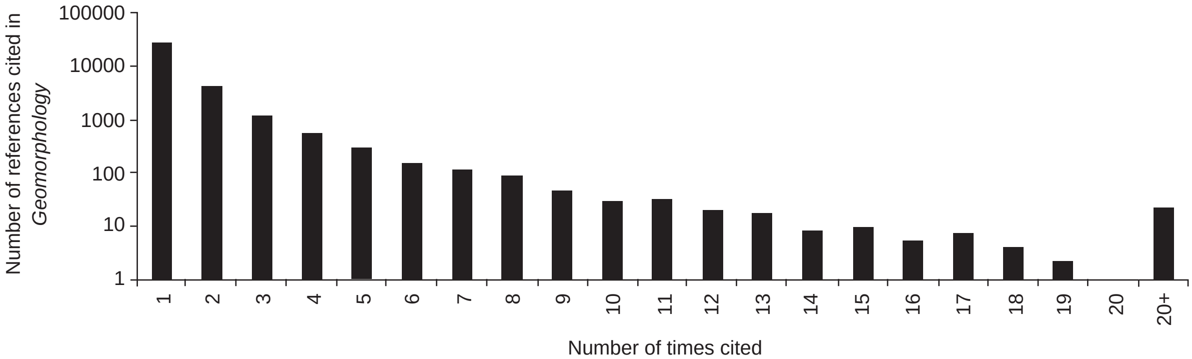

Fig. 1. Frequency distribution of citations in *Geomorphology* over a 10-yr period (1995–2004).

Table 1
Citations for complete volumes

Number of times cited		Work
Geomorphology	ISI citation index	
48	661	Schumm (1977). The fluvial system
42	1242	Bagnold (1941). The physics of blown sand and desert dunes
39	1277	Leopold et al. (1964). Fluvial processes in geomorphology
38	257	Bull (1991). Geomorphic response to climatic change
33	287	Knigton (1984). Fluvial forms and processes[a]
31	366	Carson and Kirkby (1972). Hillslope form and process
27	671	Birkeland (1984). Soils and geomorphology[b]
27	192	Pye and Tsoar (1990). Aeolian sand and sand dunes
27	134	Selby (1993). Hillslope materials and processes
22	268	Greeley and Iversen (1985). Wind as a geological process

[a] Combined with 1998 edition.
[b] Combined with 1999 edition.

(Varnes, 1978), and the remainder were from peer-reviewed journals.

Fluvial geomorphology dominated the classic works: three of the books and nine of the papers concerned fluvial forms or processes. Aeolian (three books) and hillslope (two books, one paper) processes were well represented in the classics, followed by soils (one book) and general geomorphology (one book).

A total of 23 individuals were authors or co-authors of the 20 classics. Of the 23 authors, four individuals were responsible for multiple classics: Leopold, Miller, Schumm, and Wolman. These four scholars were responsible for 8 of the 20 most-cited works in geomorphology. In particular, Wolman was a co-author of the third most-cited book and the author of four classic papers, thus contributing to 25% of the classics in *Geomorphology*.

While the 20 classics were cited <50 times each in *Geomorphology*, all were cited at least 100 times in the ISI database, with six being cited more than 500 times (Tables 1 and 2). Leopold et al. (1964), cited 1277 times, was the most popular in the broader literature, with Bagnold (1941) second with 1242 citations. Horton (1945), cited 773 times, was the most popular classic article in the broader literature.

4. Discussion

4.1. Database analysis

This citation analysis indicated the rarity of frequently cited works. Of the 31,696 unique works cited in *Geomorphology*, only 22 were cited at least 20 times in the selected 10-yr period. Most works (92%) were cited only once or twice, which is similar

Table 2
Citations for individual papers or reports

Number of times cited		Work
Geomorphology	ISI citation index	
30	280	Varnes (1978). Slope movement types and processes
27	773	Horton (1945). Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology
26	349	Wolman (1954). A method of sampling coarse river-bed material
26	184	Wolman and Gerson (1978). Relative scales of time and effectiveness of climate in watershed geomorphology
25	211	Keller and Swanson (1979). Effects of large organic material on channel form and fluvial process
25	100	Nanson and Croke (1992). A genetic classification of floodplains
22	503	Leopold and Maddock (1953). The hydraulic geometry of stream channels and some physiographic implications
22	345	Wolman and Miller (1960). Magnitude and frequency of forces in geomorphic processes
22	185	Wolman and Leopold (1957). River flood plains: some observations on their formation
22	132	Schumm (1973). Geomorphic thresholds and complex response of drainage basins

to citation analyses in other disciplines (Resh and Kobzina, 2003). While citation frequency is not a direct measure of a work's quality, works cited repeatedly obviously are key contributions in one form or another.

Previous citation analyses of geomorphology have indicated different results from those we found. Dorn (2002) also derived a "top ten" cited geomorphic papers, but only one paper (Wolman and Gerson, 1978) is common between his list and our list. However, Dorn used a keyword-based search, drawing a larger range of journals with papers that cited works with these keywords, which likely explains the lack of overlap between his study and the present study. In another citation analysis, Haschenburber and Souch (2004) used only papers appearing in the journal the *Annals of the Association of American Geographers*. They examined citation characteristics of particular papers appearing in this journal that represented significant works within specific research themes over the past century. While there was no overlap between their examined works and our classics, one of their papers (Marston, 1982) is very similar in theme and approach to Keller and Swanson (1979), as both focus on the role of woody debris in structuring channel morphology. In comparison to both of these previous citation analyses in the discipline of geomorphology, the present study took a completely objective approach to building the citation database, rather than relying on selected keywords or selected works that represented specific themes. While our approach provides objectivity, these other approaches offer additional insights that our approach lacks.

One of the most impressive features of the classics list is the role of only a few people in authoring or coauthoring many of the works. In particular, Wolman stands out as a significant source, authoring 40% of the classic papers. Wolman's contribution to the discipline extends beyond his writings, as he has been a mentor for many current geomorphologists (see Costa et al., 1995). In addition, many of the careers of the classics authors overlapped while serving with the U.S. Geological Survey (USGS) in the 1950s and 1960s. We revisit this aspect of the classics below.

Examining the most-cited works gives an indication of the relative importance of specific subfields and themes within geomorphology. Fluvial geomorphology dominates the classics in *Geomorphology*, comprising three of the books and nine of the papers. Based on his citation analysis of multiple journals using a geomorphic-based keyword search, Dorn (2002) also found fluvial geomorphology to be the dominant subfield for geomorphic citations in an array of journals (i.e., *Earth Surface Processes and Landforms, Water Resources Research, Geological Society of America Bulletin, Geology, Nature*). These results indicate that: (i) *Geomorphology* is biased toward fluvial-based research, (ii) most geomorphic research being conducted is in fluvial systems, or (iii) the earliest work in geomorphology was in river environments and so the established fundamental concepts in the discipline became associated with river studies. It is likely a combination of the three. First, while *Geomorphology* is the most appropriate journal for this review, authors in some subfields may be more inclined to publish in topic-specific journals (e.g., glacial geomorphology in *Annals of Glaciology*). Second, notably, more special issues of *Geomorphology* have been dedicated to fluvial forms and processes than to any other topic, indicating a distinct interest of readers and/or contributors on the topic of fluvial geomorphology as well as indicating a potential larger contemporary fluvial research basis than other subdisciplines. This would bias the citation database towards fluvially based studies. Finally, many fundamental concepts of geomorphology were derived from fluvial-based research. Horton's (1945) work on fluvial systems, for example, was critical in instigating the more general paradigm shift from descriptive to quantitative research in geomorphology, and thus remains heavily cited across a range of subfields of geomorphology. Three other cornerstone concepts of geomorphology were also derived from the early work of fluvial geomorphologists: thresholds in geomorphology (Schumm, 1973), frequency-magnitude of geomorphic events (Wolman and Miller, 1960) and disturbance-response in geomorphic systems (Wolman and Gerson, 1978).

In addition to subfields, emerging themes are also important in the classic works. One of the most-cited articles focused on woody debris in rivers, and this topic has only emerged more recently in the research community. The frequency with which the research of Keller and Swanson (1979) has been cited illustrates not only the rapidly expanding interest of wood in streams in contemporary research but also how important and foresightful their relatively early work on the subject was. The most recent classic paper is the work of Nanson and Croke (1992) on floodplain classification published only 3 yr before the end of the study period. Given the expanding research and industry in preserving/rehabilitating river corridors and the utility of a classification system, this work is expected to continue to rise in popularity.

Within geomorphology, the "types" of works that are well-cited are worth examining. The classic papers consisted of four groups: classifications, landform observations, general concepts, and methods. Two papers provided easily used and conceptualized classifications, one for landslides (Varnes, 1978) and the other for floodplains (Nanson and Croke, 1992). Landform observations (Horton, 1945; Leopold and Maddock, 1953; Wolman and Leopold, 1957; Keller and Swanson, 1979) are studies based primarily on observation, quantitative description, and interpretation that attempt to explain the dominant processes shaping these landforms. Many subsequent studies over the past few decades are attempts to provide the theoretical process-basis for the forms initially quantified in these studies, like the theoretical explanation of Julien and Wargadalam (1995) for hydraulic geometry relations. Three papers (Wolman and Miller, 1960; Schumm, 1973; Wolman and Gerson, 1978) are more theoretical than the others, providing a conceptual basis for processes that may not have been quantified or observed easily or for processes that could not be directly observed because of the long timescales over which they occurred. Finally, only one methods paper (Wolman, 1954) was in the classics list. The generality and ease of the "Wolman pebble count" method have set this work as a widely cited reference for most fluvial geomorphic field-based studies. No theoretical modeling studies were in the classics.

Clifford (1996) notes that the identity of academic disciplines is often established through good examples of research that develop applications, rather than more theoretical or abstract works. This citation analysis reflects this trend in that most of the classic papers are those that simply describe or classify landscape forms and those that elucidate large-scale trends in earth surface features, offering simple, first-order explanations. This trend is further reflected in the fact that classifications are among the most-cited works in geomorphology as they tend to provide particularly useful and practical knowledge when based on geomorphic processes (Varnes, 1978; Nanson and Croke, 1992). As geomorphology's role in real-world applications increases (Rhoads and Thorn, 1996), first-order explanations and process-based classifications will likely become increasingly important.

This citation review also illustrates the potential for certain works to transcend disciplinary boundaries. In particular, the works by Bagnold (1941) and Leopold et al. (1964) were cited broadly across the general science literature, including geology, planetary science, fluid mechanics, snow engineering, and marine sciences, to name but a few. Leopold et al. (1964) offered one of the earliest process-based texts on fluvial geomorphology and thus is frequently cited in the geomorphology, engineering, and stream ecology literature. Other classic works have been frequently cited in other disciplines. For instance, the river continuum concept (Vannote et al., 1980), which is essentially an ecological application of the ideas of Leopold and Maddock (1953), is the most-cited paper in stream ecology (Resh and Kobzina, 2003); and thus, Leopold and Maddock (1953) is frequently cited in both geomorphology and ecology.

There was also consistency in the length of the classic papers. Setting aside Wolman's (1954) brief introduction of the pebble count (five journal pages), and Horton's (1945) thorough coverage of watershed morphology (95 journal pages), the remainder of the most-cited papers were 16–30 pages in length, with an average of 21 pages. While it is impossible to tell whether length is directly related to quality, this does suggest that high impact papers may require greater length to develop, which is contrary to the short length articles many journals currently prefer.

There are certainly some biases which must be acknowledged as part of this analysis. The first, as alluded to earlier, was the choice of using *Geomorphology* rather than other journals. The choice of this journal certainly biased the results against some subfields of geomorphology, but it is inclusive of the breadth of the discipline and so provides the best avenue for this analysis. There is also an issue of potential temporal bias in the analysis in that by using 1995–2004, older works would tend to be more heavily cited than more recent works. However, it should be noted that two of the classic books (Bull, 1991; Selby, 1993) and one of the classic articles (Nanson and Croke, 1992) were published within just a few years of the end of the study period, illustrating that relatively new papers were also likely to be highly cited. A similar citation analysis in the future, however, would likely have greater influence by newer papers.

4.2. Author commentaries

Common among many of the author commentaries (see Appendix) was the presence of the U.S. Geological Survey as a guiding force in the mid-twentieth century. Someone from the USGS authored all but three of the classic papers (Horton, 1945; Keller and Swanson, 1979; Nanson and Croke, 1992), mostly during the 1950s and 1960s. This time was an unusual opportunity because of the changing research paradigm in geomorphology from a historically based descriptive science to the emerging process-based quantitative science that remains today (see Sack, 1992). Indeed, some have said that modern quantitative fluvial geomorphology began with Horton's (1945) work (Chorley, 1995), which set the stage for the subsequent studies by Leopold, Wolman, and others. Within the USGS, this era provided an optimal research environment in its granting of a large degree of intellectual freedom to pursue general science. This intellectual freedom, exceptional cohort of scientists, and vibrant time within the discipline of geomorphology resulted in novel, important research and the development of a new generation of scientists.

In addition, the role of engineering appeared in the authors' commentaries quite often. First, Horton was employed as a waterways and hydraulic engineer for almost 30 yr, and thus brought a somewhat unique perspective to geomorphology, working outside of the descriptive basis, Davisian paradigm that had dominated geomorphology for first half of the twentieth century. For Leopold, his approach to geomorphology was influenced by his undergraduate training in civil engineering and time spent with the "great engineer" Thomas Maddock, Jr. (Leopold, 2004). This new engineering approach to geomorphology was an emerging theme of Wolman and Varnes as well. Given that geomorphology was in the midst of taking on an increased quantitative perspective of processes, it is not surprising that engineering played a crucial role in these works.

Finally, the classic articles represent some contributions made early in authors' careers (most often with the USGS as described above) and others made later in their careers, with these latter contributions often being follow-up concepts or studies of topics initially pursued early in their career. For example, the principle theme of Wolman and Gerson (1978) was an adaptation of the geomorphic effectiveness concept initially introduced by Wolman and Miller (1960). Varnes' (1978) classic work on landslide classification was an expansion of his 1958 work. Additionally, genetic classification of floodplains by Nanson and Croke (1992) was based on Nanson's doctoral work 15 yr earlier, and Schumm's classic article on thresholds was the result of his reviewing and synthesizing over 20 yr of experience of field geomorphology in semi-arid regions.

4.3. Prospects for future classics

Speculating on what could contribute to the authoring of a future classic work is difficult, although there are some commonalities in the classics from this citation analysis and some ideas from science in general (Kuhn, 1962). First, we concur with Clifford (1996) that classic works within a discipline are usually those that are intuitive to a broad group within the discipline and those that provide useful knowledge, and the classic articles in our analysis certainly support this. Future classics will likely depend upon an emerging technology that allows for novel types of observations. Whereas topographic maps, plane-tables, and stream gauges contributed to the current classics, remote sensing of earth and planetary surficial forms, geographic information systems, and emerging geochronology methods (Muzikar et al., 2003) are likely to be the tools used for future classics.

Second, as engineering contributed to the current classics, articles incorporating novel insights from another discipline are likely to emerge as future classics, particularly if those studies are conducted by someone outside the field. Horton's work was minimally influenced by the dominant paradigm of geomorphology at the time, enabling him to approach the subject from a conceptual perspective unlike that of his contemporaries. His engineering approach to geomorphology brought novel techniques, notably mathematical treatments, which allowed substantial developments in future geomorphic studies. Additionally, Maddock's engineering perspective facilitated the development of hydraulic geometry, one of the fundamental empirical laws of geomorphology. Further, the fruition of Keller's research was made possible by his fortuitous collaboration with Swanson, someone more familiar with forest ecology dynamics, thus drawing on additional, outside perspectives. While the discipline of geomorphology is often criticized for its lack of unity, disobedience of "normal science," dependence on other scientific disciplines, and its attempt to be both a descriptive and applied science (Rhoads and Thorn, 1996), these characteristics have been found to be the essential ingredients for classic works. We believe that this diversity and nonconformity will be the impetus for future classics in geomorphology.

Acknowledgments

We are extremely grateful to the authors of the classic papers for taking the time to write comments on their works. We also thank Jon Harbor, Rebecca Manners, and two anonymous reviewers for preliminary reviews of this manuscript.

Appendix A. Comments from authors of classic papers

A.1. Varnes

David J. Varnes (April 6, 1919–February 3, 2002) had a remarkable career that spanned more than 60 yr. In 1948, he became a charter member of the newly organized Engineering Geology Branch of the U.S. Geological Survey (USGS). Here blossomed a lifelong interest in relating geology and geomorphology to engineering problems, with much of his work directly involving the study of landslides. As the direct predecessor to his oft-cited 1978 paper, David produced a definitive work on landslide classification that was published in the 1958 Highway Research Board text, *Landslides and Engineering Practice*. He followed this with a more complete landslide classification in his 1978 TRB paper. His last major effort in this regard was the paper (co-authored with D.M. Cruden), "Landslide Types and Processes," in the 1996 TRB book, *Landslides: Investigation and Mitigation*. These three works set the worldwide standard for landslide classification. Concurrently with his efforts in landslide classification, David carried out research that applied engineering–geologic mapping to landslide-hazard zonation through a commission of the International Association of Engineering Geologists (IAEG). This work resulted in an outstanding UNESCO publication on landslide-hazard zonation, which the French Government recognized with the 1985 award Chevalier dans L'ordre des Palmes Academics.

In 1995, David retired from the USGS, culminating his distinguished 53-yr career with the agency. However, he retained his USGS office as a Scientist Emeritus, and until his death he continued to work on creep-to-failure phenomena in earthquakes and landslides. (Robert L. Schuster, U.S. Geological Survey, October 2004).

A.2. Horton

Note: this commentary was drawn from an extensive review by Chorley (1995).

Robert E. Horton (1875–1945) published his seminal work on drainage basin morphology just weeks before his death. For almost 30 yr, Horton was employed as a waterways and hydraulic engineer, but then subsequently concentrated on consultancy and directing his own Horton Hydrologic Laboratory for the 19 yr before his death.

Horton's geomorphology was fundamentally unique because of his obvious innocence of contemporary geomorphology, namely the dominant paradigm of descriptive geomorphology. His approach to geomorphology was wholly original and owed little to previous geomorphologists. Much of Horton's impact lay in his ability to provide a physical basis for a process-response view of landform development, and many have hailed his work as the basis on which contemporary fluvial geomorphology is based.

Horton's work was influenced by two scholars, Howard Meyerhoff and Alfred Lane, the former being a relentless anti-Davisian and the latter being an expert on the transport of fluvial sediment loads and channel stability. Beyond their influence, he draws heavily on concepts from engineering (e.g., stream order from German engineers), as well as quantitative predictions using mathematics (e.g., soil erosion using the DuBoys formula). Like Gilbert, his conceptual predecessor almost 50 years earlier, Horton possessed an engineering type of approach to geomorphology based on the idea that landscape evolution accrues as the result of local quantifiable forces operating on local materials of quantifiable resistance leading eventually to a timeless equilibrium state being achieved. This mathematical approach resonated strongly with many young geomorphologists (e.g. Strahler, Leopold, Wolman) and set the tendency of much of geomorphology in the second half of the twentieth century to concentrate on smaller scales of space and time, and on the specific effects of measurable processes.

A.3. Wolman

Many of the papers [in the classics list] date from the 50s and 60s. I was at the time the lucky participant with some extraordinary mentors and colleagues such as Luna Leopold, Walter Langbein, Tom Maddock, John Miller, John Hack, Stan Schumm, Dick Hadley, and others at the USGS. Whether it be among a number of things, such as the partly new quantitative orientation in geomorphology, the emphasis on process, the marriage with hydrology, or a remarkable group of individuals, it was a lively time in geomorphology, a time also of expanding research support and university appointments. It was the setting then, and the energy and productivity of colleagues that stimulated thinking and publication.

The "floodplain" paper, for example, grew out of a succession of papers on the hydraulic geometry initiated with the publication by Leopold and Maddock (1953). Both the "magnitude and frequency" paper and later "relative scales," I think have their origin in attempts to explain how and why there is any order in the fluvial system. (I think there is but a new kind, or emphasis upon, catastrophism or big events has much interest today.) In some ways the question of "equilibrium" or adjustment also relates to Schumm's "thresholds".

The popularity of "sampling coarse river bed material" arises, as you know, because it is a simple method of measuring a property of rivers of much interest to hydraulicians, geomorphologists, and ecologists of many kinds. Wentworth in particular, and many others, pointed out that a bulk sample of coarse gravel to be representative of the distribution of sizes had to be enormous. Without a dredge or backhoe, such samples were impossible to get. Because many of us were interested in surface roughness or the size of the larger particles, the grid sample seemed reasonable. I wrote the paper, the possible legitimacy of the notion came from Rosiwal analysis (Jarai et al., 1997) used to measure mineral amounts by a grid placed over a slide of a thin section of rock under a petrographic microscope. (M. Gordon "Reds" Wolman, Johns Hopkins University, November 2004).

A.4. Keller

I first recognized the importance of large woody debris while doing PhD work on pools and riffles in Wildcat Creek near Lafayette, Indiana in 1971. I observed that the debris formed a jam that backed up water at high flow. The backwater caused a chute to form across a bend, facilitating a meander cutoff. I nearly forgot this until starting as a new Assistant Professor at the University of North Carolina at Charlotte. I was looking at Mallard Creek near the university for a site to study pools and riffles. The floodplain was forested, and I was complaining to myself that I couldn't find a "natural" site without large woody debris interfering with the morphology I was looking for. Then it happened — I heard a large groan followed by a loud cracking. I walked around a bend just in time to see a large tree fall into the stream with a great splash! I suddenly had the a-ha–this is "natural"–these streams with forested floodplains and lots of trees on the banks are greatly modified by large woody debris that enters the active channel! Then in 1973, I moved to the University of California, Santa Barbara, and started work in the redwood forest of northwestern California where the woody debris that ends up in streams is truly gigantic. I contacted Fred Swanson, who was working for a US Forest Service Research Laboratory at Oregon State University, and suggested we write a paper on the role of large woody debris on stream channel form and process. Fred had been working for several years on large woody debris in streams of the Oregon Coast Ranges. We had a great collaboration at just the right time for the emerging field of forest geomorphology. (Ed Keller, University of California — Santa Barbara, November 2004).

A.5. Nanson

Floodplains remain an integral part of fluvial research for they allow us to combine our understanding of hydraulics, hydrology, sedimentology, and geomorphology. I first studied them on the Beatton River in northern British Columbia and as part of my doctoral comprehensive exams at Simon Fraser University. My thesis supervisor Ted Hickin, who also became my early mentor and good friend, suggested I prepare a review on the various ways floodplains form. It was not a particularly large task then because in the 1970s there was only one widely accepted floodplain formation model: that of channel migration with floodplains forming essentially by lateral point-bar accretion (Mackin, 1936). Both as an undergraduate and graduate student, I was greatly in awe of the paper by Wolman and Leopold (1957) that so beautifully described and illustrated the lateral migration model and so cogently argued why such processes produced floodplains in equilibrium with current bankfull flow conditions. I still see it as one of the truly seminal papers in geomorphology, remarkable for both its simplicity and its insight; and I note with great satisfaction that it is included as one of the 10 most-cited papers that are the focus of this article.

The opportunity to write this paper came when Jacky Croke arrived at the University of Wollongong with an Australian–European Awards Program scholarship from Ireland. She was preparing her PhD thesis for University College Dublin on the small stream of Glenmalure in County Wicklow and in the process was discovering that the specific lateral-accretion model could not explain all she was finding. Bringing this frustration with her, as well as a detailed grasp of the recent literature, together we fashioned a paper that attempted to encompass all the ideas and observations on floodplain formation that we could find at the time. Faced with a difficulty that is so often a problem in geomorphology, that of trying to classify something that is essentially a continuum of changing processes and forms, we opted for a "genetic" approach. As geomorphologists, we were interested as much in process as we were in form, and we were keen to find and explain the linkages between them. We focused on process and developed a classification based on the related properties of stream power and sediment character. They appeared to discriminate the common types of floodplain form and sedimentology. After Jacky returned to Dublin, the writing continued back and forth by letter and fax; and in September 1989, we gave an early version of our ideas at a specialist meeting on floodplains in Gottingen, Germany, associated with the Second International Geomorphological Congress. The paper was finally published in a special issue of *Geomorphology* titled "Floodplain Evolution" edited by Bob Brakenridge and Juergen Hagedorn. Worth noting is that most of the papers in that volume cite the one that was such an inspiration to us, the classic by Wolman and Leopold (1957). (Gerald Nanson, University of Wollongong, November 2004).

A.6. Leopold

Note: Leopold declined commenting on his work. We have thus drawn upon a previously published review of their work by Clifford (1996):

"The paper was part of a wide-ranging investigation of water utilization problems in the southwest USA. It was written during a formative and expansionary phase of the USGS, and the authors were free to explore concepts and to engage in speculation, to an extent which would not be permissible now. Partly as a result, the report was as much a strategic document aimed at changing the philosophy and practice of an academic discipline as it was a technical contribution to the literature on water resources. . . . At that time, the central problem with nonengineering treatments of river dynamics was the identification and significance of grade. To geographers working in a Davisian framework, grade was the product of deductive reasoning and demanded no proof, but numerous attempts were still made to recognize its occurrence. Such efforts were frequently contradictory, and often achieved only by association with other assumed 'stages' of landscape development. Engineering methods provided something of an alternative, and the influence of engineering and individual engineers is one of the most striking aspects of the paper."

"It is difficult to overestimate the influence of this classic work. Its radicalism was to challenge an evolutionary historical approach to landform systems, and to establish a research agenda and methodology based upon quantitative descriptions as a prelude to subsequent rational analysis. ... It was, in essence, a practical approach to geomorphology, founded upon the availability of simple environmental data. It posed significant questions, and offered some of the answers, even if, scientifically, these were correct only to the first order. Most importantly, along with Horton's paper on streams and drainage basins (1945), it established both the means and the rationale for a working relationship among geomorphologists, hydrologists, and engineers, which is regarded now as both essential and normal. ... Contemporary fluvial geomorphology owes this paper and its authors a great debt, and this debt will continue for a very long time to come."

A.7. Schumm

I'm really surprised that after almost 30 yr, *The Fluvial System* is still being frequently cited and that the "thresholds" paper is also. Concerning the thresholds paper, Marie Morisawa invited me to participate in the 4th Binghamton Geomorphology Symposium and I decided to review my 20 yr experience in interpreting the erosional evolution of semiarid landforms. I had been annoyed by attempts to relate every minor erosional or depositional fluctuation to climate change. Experimental work at CSU provided support for the idea that some landforms were sensitive and ready for change (geomorphic thresholds) and when the change occurred (incision, deposition), it would not be straightforward (complex response).

Much of the above was a result of my 13 yr with the USGS, which enabled me to see the geology and landforms of much of the western US. Terrace correlations seemed to be a major problem, especially when what was assessed to be a 1000-yr-old terrace contained barbed wire, rubber boots, and a stove lid. It was a fun time working with Dick Hadley and dealing with cranky ranchers in the west.

The Fluvial System was the result of an invitation to present a short course on things fluvial to South Africa economic geologists. The Economic Geology Research Unit at the University of Witwatersrand presented 5-day short courses on a variety of topics of interest to geologists. They were particularly interested in fluvial processes and fluvial deposits because much of their gold and diamonds are found in paleoplacers. I was asked to prepare notes for distribution. The end result was a manuscript that eventually became the book. It's amusing to note that prior to the short course, the ERGU was burgled and several copies of the "notes" were stolen. Apparently, someone thought that I would reveal how to find more gold and diamonds — a bad assumption. (Stan Schumm, MEI, Inc., November 2004).

References

Bagnold, R.A., 1941. The Physics of Blown Sand and Desert Dunes. Chapman and Hall, London. 265 pp.

Birkeland, P.W., 1984. Soils and Geomorphology. Oxford Univ. Press, Oxford, UK. 372 pp.

Bull, W.B., 1991. Geomorphic Responses to Climate Change. Oxford Univ. Press, New York. 326 pp.

Carson, M.A., Kirkby, M.J., 1972. Hillslope Form and Process. Cambridge Univ. Press, London. 475 pp.

Chorley, R.J., 1995. Classics in physical geography revisited: Horton (1945). Prog. Phys. Geogr. 19 (4), 533–554.

Clifford, N.F., 1996. Classics in physical geography revisited: Leopold and Maddock (1953). Prog. Phys. Geogr. 20 (1), 81–87.

Costa, J.E., Miller, A.J., Potter, K.W., Wilcock, P.R., 1995. Natural and anthropogenic influences in fluvial Geomorphology. Geophysical Monograph, vol. 89. American Geophysical Union, Washington, DC. 239 pp.

Dorn, R.I., 2002. Analysis of geomorphology citations in the last quarter of the 20th century. Earth Surf. Processes Landf. 27, 667–672.

Greeley, R., Iversen, J.I., 1985. Wind as a Geological Process on Earth, Mars, Venus, and Titan. Cambridge Univ. Press, Cambridge, UK. 333 pp.

Haggett, P., 2002. Richard John Chorley 1927–2002 — obituary. Trans. Inst. Br. Geogr. 27 (4), 522–525.

Haschenburber, J.K., Souch, C., 2004. Contributions to the understanding of geomorphic landscapes published in the Annals. Ann. Assoc. Am. Geogr. 94, 771–793.

Horton, R.E., 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Bull. Geol. Soc. Am. 56, 275–370.

Jarai, A., Kozak, M., Rozsa, P., 1997. Comparison of the methods of rock-microscopic grain-size determination and quantitative analysis. Math. Geol. 29 (8), 977–991.

Julien, P.Y., Wargadalam, J., 1995. Alluvial channel geometry: theory and applications. J. Hydraul. Eng. 121, 312–325.

Keller, E.A., Swanson, F.J., 1979. Effects of large organic material on channel form and fluvial processes. Earth Surf. Processes 4, 361–380.

Knighton, A.D., 1984. Fluvial Forms and Processes. Edward Arnold, London. 218 pp.

Knighton, A.D., 1998. Fluvial Forms and Processes: A New Perspective. Edward Arnold, New York. 383 pp.

Kuhn, T.S., 1962. The Structure of Scientific Revolutions. Univ. of Chicago Press, Chicago. 212 pp.

Leimu, R., Koricheva, J., 2005. What determines the citation frequency of ecological papers? Trends Ecol. Evol. 20, 28–32.
Leopold, L.B., 2004. Geomorphology: a sliver off the corpus of science. Annu. Rev. Earth Planet. Sci. 32, 1–12.
Leopold, L.B., Maddock Jr., T., 1953. The hydraulic geometry of stream channels and some physiographic implications. USGS Professional Paper, vol. 252. Washington, DC, 57 pp.
Leopold, L.B., Wolman, M.G., Miller, J.P., 1964. Fluvial Processes in Geomorphology. W.H. Freeman and Co., San Francisco, CA. 522 pp.
Mackin, J.H., 1936. Erosional history of the big horn basin, Wyoming. Bull. Geol. Soc. Am. 48, 813–894.
Marston, R.A., 1982. The geomorphic significance of log steps in forest streams. Ann. Assoc. Am. Geogr. 72, 99–108.
Muzikar, P., Elmore, D., Granger, D.E., 2003. Accelerator mass spectrometry in geologic research. Geol. Soc. Am. Bull. 115 (6), 643–654.
Nanson, G.C., Croke, J.C., 1992. A genetic classification of floodplains. Geomorphology 4, 459–486.
Odum, E.P., 1969. Strategy of ecosystem development. Science 164, 262–270.
Pye, K., Tsoar, H., 1990. Aeolian Sand and Sand Dunes. Unwin Hyman, London. 396 pp.
Resh, V.H., Kobzina, N.G., 2003. A perspective on the key citations in freshwater benthic science, and the studies that influenced them. J. N. Am. Benthol. Soc. 22 (3), 341–351.
Rhoads, B.L., Thorn, C.E. (Eds.), 1996. The Scientific Nature of Geomorphology. Wiley and Sons, Chichester, UK. 481 pp.
Sack, D., 1992. New wine in old bottles: the historiography of a paradigm change. Geomorphology 5, 251–263.
Schumm, S.A., 1973. Geomorphic thresholds and complex response of drainage systems. In: Morisawa, M. (Ed.), Fluvial Geomorphology. New York State Univ. Pub. Geomorph, Binghamton, pp. 299–310.
Schumm, S.A., 1977. The Fluvial System. Wiley, New York. 338 pp.
Schumm, S.A., 2004. Arthur Newell Strahler (1918–2002) — in memoriam. Ann. Assoc. Am. Geogr. 94 (3), 671–673.
Selby, M.J., 1993. Hillslope Materials and Processes. Oxford Univ. Press, New York. 451 pp.
Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., Cushing, C.E., 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37, 130–137.
Varnes, D.J., 1978. Slope movement types and processes. In: Schuster, R.L., Krizek, R.J. (Eds.), Landslides: Analysis and Control. Special Report, Transp. Res. Board, Nat. Acad. Sci., vol. 176. National Academy of Sciences, Washington, DC, pp. 11–33.
Wolman, M.G., 1954. A method of sampling coarse river-bed-material. Trans. Am. Geophys. Union 35, 951–956.
Wolman, M.G., 1995. Play: the handmaiden of work. Earth Surf. Processes Landf. 20 (7), 585–591.
Wolman, M.G., Leopold, L.B., 1957. River flood-plains: some observations on their formation. USGS Professional Paper 282-C, 87–107.
Wolman, M.G., Miller, J.P., 1960. Magnitude and frequency of forces in geomorphic processes. J. Geol. 68, 54–74.
Wolman, M.G., Gerson, R., 1978. Relative scales of time and effectiveness of climate in watershed geomorphology. Earth Surf. Processes 3, 189–208.