Changing landscapes: five decades of applied geomorphology

J. M. Hooke

Department of Geography and Planning, School of Environmental Sciences,

University of Liverpool, Roxby Building, Liverpool, L69 7ZT, UK

Tel: 44 (0)151 794 2873

Email: janet.hooke@liverpool.ac.uk

Abstract

Much geomorphological research has potential to be applied but this paper examines the extent and nature of actual applications to environmental management. It reviews how this work has expanded and changed and reflects on the stimuli, types of involvement, and attitudes. These aspects, and how geomorphology can be applied effectively, are exemplified by developments in coastal and river management in the UK, highlighting the contributions made by geomorphology to sustainable strategies. Applied geomorphology has been recognised as a topic and component within geomorphology throughout the last 50 yr, contributing about 10% of published research papers in the subject. Major increase in direct involvement with environmental policy and practice came in the 1980s and 1990s but it has been followed by enormous expansion since then, including employment of professional geomorphologists in all stages and scales of projects, from provision of specific solutions, to design and initiation of projects, through to national policy development. Major stimuli to this increase in application encompassed the evident failure and detrimental effects of earlier approaches using hard engineering, changes in environmental awareness and attitudes of the public, and increased threat of climate change and incidence of major storms and natural disasters. These led to developments in approaches that 'work with nature', implementation of demonstration projects in river restoration, managed coastal retreat and now Natural Flood Management, and the explicit need for geomorphological assessment of water bodies following EU legislation. These have all lead to the present situation where applied geomorphology is 'booming', with high demand for geomorphologists. Evidence is provided that geomorphologists have contributed significantly to this change in thinking and are now very actively involved in developing and applying means of using their understanding and skills to implement more sustainable management, to the benefit of the environment and society.

Keywords: applied geomorphology; sustainable environmental management; coastal management, river channel management; working with nature.

1. Introduction

Applied geomorphology has always been important in the Binghamton Geomorphology Symposia (BGS), especially in the early days, with influential key volumes of papers produced on the subject. This review provides a perspective and analysis of how the subject area has developed, particularly examining it from the UK and European viewpoint, and focusing on management of dynamic environments, notably coasts and rivers, since challenges posed by such environments are dominant there and widespread elsewhere in the world. Some major developments in approaches have been made in the UK and this also builds on the author's inside experience of the trajectory of applied geomorphology, and the stimuli and barriers to application. It complements the paper by Keller (2019) addressing other kinds of problems and the differing milieu in the USA environment of California. This review includes discussion of motivations and frameworks for application, and the keys to effective applications, based on publications, involvement in projects and policy development, and on interviews with current practising professional geomorphologists as well as other academics. It will mainly consider actual applications, where geomorphology has contributed to delivering beneficial outcomes in the physical management of the environment, rather than the abundant research that has potential for application. The paper is divided into four sections: (1) A quantitative and qualitative analysis of published work in this sphere and review of how the practice has changed and of prospects identified by earlier authors; (2) Reflections on the progression and present state of applied geomorphology in relation to the stimuli, type of involvement, and attitudes; (3) Case studies of influential applications and changes in approach associated with geomorphology; (4) Discussion on future opportunities and challenges.

2. Publications on applied geomorphology

2.1 Quantitative and qualitative analysis

To provide some trajectory of extent and scope of publications on Applied Geomorphology, bibliographic searches were undertaken of key terms in both WoS (Web of Science) and Scopus in mid-August 2018. Searches were initially on *'applied geomorphology'* in title or abstract or keywords, then, within those publications, on various topic areas and on *managem*ent, *policy, practice and planning*. Searches were also made on '*geomorphology*' then *'applied'* within that *(Table 1*). Scopus generally gives 3-4 times the number of papers of WoS (given below). Neither search engine includes unpublished grey literature, such as reports and project or policy documents (as exemplified in Section 4), which are arguably where most of the actual applications are documented, with much applied work not reported in academic or research publications. Only the full term 'geomorphology' has been used. It is recognised that applied geomorphology has also been called by other terms such as environmental geomorphology and engineering geomorphology. Thus, it is likely that the search results are a major underestimate of the amount and range of activity. Nevertheless, the analysis provides some indication of the trajectory and type of work that links research or academia and application. The literature presented in books is considered subsequently.

The searches produced 9208 (1447) papers with the term *applied within geomorphology* publications and 2706 when *applied geomorphology* was searched. In line with geomorphology, and indeed research publications in most spheres, the numbers have increased exponentially over the period from about 1985 (Fig. 1). Papers in applied geomorphology can be seen largely to parallel expansion in total number of papers published on geomorphology but with slight lag in early 2000s, high variability in the last 10 yr and recent high increase. Throughout the last 50yr, about 10% of geomorphology papers are labelled as applied geomorphology. '*Applied*' in the title of papers is spread throughout the decades.

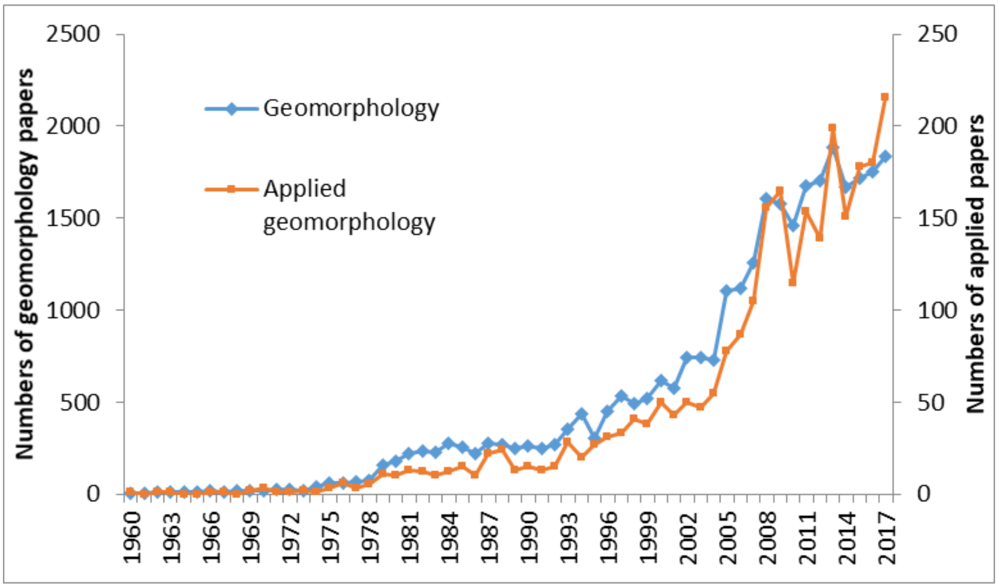


Fig. 1 Numbers of papers published each year in geomorphology and applied geomorphology (as listed in SCOPUS).

In summaries of keywords used, Scopus reports reveal that *techniques* terms come out very highly (DEM, surveying, Remote Sensing, GIS), but *landforms* is also high, followed by topics of *fluvial* and *rivers*. From searches on topics in applied geomorphology, *landform, sediment* and *erosion* come out very high as do *coast, fluvial, catchment* and *ecology* but *river* tops the scoring. *Landslide* appears much less and about the same as *tectonic*. *Classification, indicators and mapping* all appear high. *Coastal* aspects do not appear prominently in searches within geomorphology or applied geomorphology but if search is on coast then sub-terms associated with application, many more papers appear: management (9628), policy (2058), practice (2423) and planning (3140). The journal *Geomorphology* contains the most papers labelled applied geomorphology, followed by *Earth Surface Processes and Landforms*. In terms of countries producing the publications the USA is highest with 569, then China with 273, closely followed by the UK with 271, then Italy, France, Spain and Germany.

Table 1 Numbers of papers with terms appearing within title, abstract or keywords over the period 1960 to 2018 (August)

Topic	**Within geomorphology**	**Within applied geomorphology**

	Scopus	WoS	Scopus	WoS
Geomorphology	31741	14072		
Applied	9208	1447	2706	1446
Management	10057	1630	1199	267
Policy	1715	174	228	33
Practice	3119	352	394	50
Planning	3903	745	529	141
Design	3744	653	509	118
Restoration	2962	600	320	80
Conservation	5527	566	626	91
Engineering	12352	555	1475	88
Hazard	5340	845	618	142

Table 1 indicates numbers of papers using terms that are associated with application such as *management, policy, practice*, both within geomorphology and within applied geomorphology papers. Use of *management* as a term tends to be wide in scope and often about potential rather than actual application. *Management* includes many ecologically orientated papers. Papers appearing under *policy* are rather different from those in *management* and much more applied, covering many different topics. *Practice* also covers varied fields. *Planning* is more prevalent than *practice* or *policy* and, as expected, includes much on mapping, indices, GIS, habitats, zoning and geodiversity. Searches on *geomorphology* then *management* are dominated by *fluvial* authors, though *coast* has more papers - 4728 v 3862. Within *policy*, the terms *land use* and *climate change* begin to appear fairly high in keywords. *Practice* is similar but *landslides* appear higher. Overall, it is also apparent that authors generally do not use the term 'applied geomorphology' in their indexing of research papers, confirmed by Plater (personal communication), an Editor of the journal *Geomorphology*. This perhaps reflects reluctance to attach to a 'poorly regarded' part of geomorphology and the tension with research until recently (see Section 3), or that it was not identified as a separate part of geomorphology or the main aim of the academic papers. Of course, most authors now tend to justify their research by indicating the relevance to real-world problems.

Assessing wider publications, not just these quantitative search data, several major books published in the early phases of the subject (Table 2a) were very influential and provide useful indicators of the topics and approaches. Several major reviews also give a valuable perspective on issues and views about application at their time (Table 2b). As in most research spheres, books have generally declined as an outlet, but some collective Special Issues of journals still appear. Much of the applied work produced as unpublished grey literature is now increasingly available on websites of organisations sponsoring the work. The prefaces or introductions to volumes of collected papers are a rich source of commentary on the state of the subject at the time and are used here to reflect on the trajectory. Within BGS, applied geomorphology was a major early topic and Sawyer et al. (2014), in their review of BGS, cite Giardino et al. (1999) as identifying that the 1970, 1976, 1980, 1984 (Tectonic), and 1997 symposia looked at real-world problems (Table 3). They reported that these applied geomorphology BGS volumes have had more citations than ones on other topics; of individual articles, those on hazards are cited most.

Within these books and collected sets of papers in applied geomorphology, certain themes and areas of application have long been prominent and continue to be major spheres of activity including: *role of human impacts, natural hazards, resource use, planning of development and infrastructure*. From very early on, a major type of work and set of skills has been terrain and zone mapping, but always influenced by and moving with technology. Capabilities within that sphere have been transformed recently with advances in remote sensing and GIS and development of technology such as LiDAR, drones and digital photogrammetric techniques. This is now an enormous field in its own right and enabling major expansion of application of geomorphology whilst retaining, or arguably regaining, a primacy for mapping. Explicit analysis of landforms has declined, though scenic evaluation is now an increasing component in conservation of landscapes. Weathering has long been a theme but now biogeomorphology is a major focus and ecogeomorphology has also become prominent. Soil erosion and land degradation do not feature prominently in these analyses but geomorphology has made major contributions to this field, as exemplified in the volume on Soil Erosion in Europe (Boardman and Poesen, 2006), and can be regarded as inherently applied though also highly interdisciplinary. The emphasis and approaches have varied over time and obviously in different environments across the globe. Keller et al.'s (2019) paper reflects the importance of tectonic, earthquake and upland processes dominant in California whereas this paper reflects the active environments of the UK, coasts and rivers. Elsewhere, for example in Italy and Japan, landslides are major topics.

Other very influential books but more specialised, exemplifying or guiding applications in specific spheres, include Dunne and Leopold's (1978) text with worked examples that encompasses both hydrology and geomorphology. In the hazards field, Cooke's (1984) seminal monograph on geomorphological hazards in Los Angeles, related to slope and fluvial processes and sediment problems, emphasised the complexity of the hazards and the challenges in prediction. Around the same date was Douglas's (1983) book *The Urban Environment* in which he examined many aspects and considered how problems and hazards could be mitigated. In Alcántara-Ayala and Goudie's (2010) volume on Geomorphological Hazards and Disaster Prevention, exemplifying progress in the field, the whole second part is devoted to applications of geomorphological knowledge and takes up aspects that include use of GIS, how risks and vulnerability are assessed and analysed, the challenges arising from global climate change, the interaction of hazards and sustainability of societies, and how geomorphological knowledge can help in disaster prevention. These have long been major themes in applied geomorphology and are arguably becoming even more important and with increasingly significant contributions being made. The chapters emphasise that geomorphological hazards and disaster prevention cannot be understood from the geomorphology alone but must consider the cultural and societal interactions.

Table 2a Major Books and Special Issues on applied geomorphology

Authors	Date	Type	Title
Tricart	1963	Authored book	L'Epiderme De la Terre: Esquisse d'une geomorphologie appliquee
Coates	1971	Edited, BGS 1	Environmental Geomorphology
Coates	1972	Edited, 3 vols	Environmental Geomorphology & Landscape Conservation
Cooke and Doornkamp	1974	Authored book	Geomorphology in Environmental Management
Coates	1976	Edited, BGS 7	Geomorphology and Engineering
Hails	1977	Edited book	Applied Geomorphology
Craig and Craft	1982	Edited book, BGS 11	Applied Geomorphology
Verstappen	1983	Authored book	Applied Geomorphology
Costa and Fleisher	1984	Edited book	Developments and Applications in Geomorphology
Hart	1986	Edited book	Geomorphology: Pure and Applied
Hooke	1988	Edited book	Geomorphology in Environmental Planning
Cooke and Doornkamp	1990, 2nd edition	Authored book	Geomorphology in Environmental Management
McGregorand & Thompson	1995	Edited book	Geomorphology and Land Management in a Changing Environment
Thorne	1995	Special Issue	Geomorphology At Work
Giardino et al	1999	Special Issue, BGS 28 1997	Changing the Face of the Earth – Engineering Geomorphology
Allison	2002	Edited book	Applied Geomorphology
Kneupfer and Petersen	2002	Special Issue, BGS 30	Geomorphology in the Public Eye

Table 2b Previous reviews and assessments of applied geomorphology.

Authors	Date	Title	Publication
Brunsden et al.	1978	Applied Geomorphology: A British View.	In Embleton et al.
Coates	1984	Geomorphology and Public Policy	In Costa and Fleisher
Hooke	1986	Applicable and applied geomorphology of rivers	*Geography 71*, 1-13
Hooke	1988	Introduction: frameworks for interaction. Conclusion: the Way Ahead	In Hooke
Sherman	1989	Geomorphology: praxis and theory	In Kunzer

Griffiths and Hearn	1990	Engineering geomorphology: A UK perspective	*Bull. Intl. Assoc. Engg Geology, 42*, 39-44
Jones	1995	Environmental Change, Geomorphological change and Sustainability	In McGregor and Thompson
Wolman	1995	Play: The handmaiden of work	In Thorne, Special Issue, *Geomorphology*
Brunsden	1998	Geomorphology in Environmental Management: An Appreciation	*East Midland Geogr, 21*, 63-77
Hooke	1999	Decades of change: contributions of geomorphology to fluvial and coastal engineering and management.	In Giardino et al., Special Issue, *Geomorphology*
Brunsden	2002	Geomorphological roulette for engineers and planners: Some insights into an old game	*Quart. J. Engg. Geol & Hydrogeol 35*, 101-42
Kondolf et al.	2003	Integrating Geomorphological Tools in Ecological and Management Studies.	In Kondolf and Piégay
Church	2010	The Trajectory of Geomorphology	*Prog Phys Geog* 34, 265-286

Table 3. Binghamton Symposia focused primarily on applied geomorphology (From Sawyer et al., 2014)

Topic	Organizers	Location	Year
1. Environmental geomorphology	D.R. Coates	Binghamton, NY	1970
7. Geomorphology & engineering	D.R. Coates	Binghamton, NY	1976
11. Applied geomorphology	R.G. Craig & J.L. Craft	Kent, OH	1980
28. Changing the face of the earth: engineering geomorphology	J.R. Giardino, R.A. Marston & M. Morisawa	Bologna, Italy	1997

2.2 Trajectory of applied geomorphology - general trends and phases

The themes emerging from the searches and the contents of the books and reviews can be used to analyse the trajectory of published work in this field and the nature of commentaries and perspective at that time. Geomorphological research on human impacts and interactions dates back to at least the middle of the nineteenth century and continues to be a major driver of applied geomorphology, especially as human pressures and scale of environmental impact and of development increase (James and Marcus, 2006). Many of the early seminal papers were brought together in Coates' (1972) three volume work on *Environmental Geomorphology and Conservation* and these papers are reflective of the early issues and approaches in understanding human impacts; they demonstrate the potential and provide the building blocks for applications. However, early direct application is evident as, for example, in Gilbert's (1917) seminal work on the impact of hydraulic gold mining in California that led to policy changes.

Tricart's book in 1963 on Applied Geomorphology (Tricart, 1963), according to Ahnert (1963 p630), was written mainly "to convince those who study, plan, or build the works of man {sic} in the landscape of the necessity to include morphological processes in their considerations if they want to understand their subject". Thornbury (1954) included an applied chapter in his textbook and many examples of mapping, terrain analysis and resource analysis can be found prior to 1970. Examples of applied geomorphology increase from then onwards, particularly with the rise in process understanding and measurements, a major factor in the rise of applied geomorphology. The Binghamton Symposia and publications helped lead development and the book published by Cooke and Doornkamp in 1974 contributed to raising the profile and demonstrating the potential amongst academics. Cooke and Doornkamp (1974, p.1) state that awareness of geomorphology in environmental management was 2growing rapidly after a very slow start2. By 1977, Hails (1977) could cite new developments such as postgraduate courses in Environmental Studies, work in government research labs, and expansion of consulting firms. He identified that interdisciplinary research was developing but questioned whether the potential would be realised. In 1978, (in a paper arising from a 1976 Conference overviewing Geomorphology) Brunsden et al. (1978) documented that in the 1975 BGRG bibliographic research register in Britain, 15.5% (65) of entries mention applied geomorphology. They reckon probably 5% claim to practise it but the figures conceal employment and range of work, including involvement in decision-making in the previous 10 yr.

Craig and Craft's (1982) volume was designed to show geomorphology as it is (and can be) applied to current problems facing people of the world. The focus was on areas where problems and humans interact; for example, there are four coastal papers. Verstappen's (1983) book *Applied Geomorphology* was about mapping techniques, continuing a long tradition, but highlighting developments in remote sensing. Still by 1986, Hart (1986, p. xvi) could say "with a few exceptions, applied geomorphology is a fairly new development". By 1986, Hooke could scope 'Applicable and applied geomorphology of rivers', identifying possible contributions on flood effects, bank erosion, locations and characteristics of river instability, and prediction of human interference effects, but these were still mainly potential not actual applications. Hooke (1988) discusses how applied geomorphology had advanced and brings together papers that get nearer to specific policies and practices. In 1990, Cooke and Doornkamp produced a second edition of their book with more on application than applicability. They considered that environmental consciousness had increased due to yet more environmental catastrophes and degradation. This was highlighted by Jones (1995) who addressed the Challenges of Global Environmental Change. During the 1980s in Britain, under political influence of commercialisation, a company, Geomorphological Services Ltd (GSL), was established to undertake applied geomorphology contracts. By the mid-1990s a big expansion of engineering geomorphology had occurred but Jones considered it was declining and analyses the reasons. He characterised the phases of development (largely in UK) as follows:

- 1960s – exasperation and aspiration – applicability, not application; debate about involvement; technocentrism at its zenith.

- 1970s - birth of applied geomorphology; sudden involvement with engineering; development of a product, market and catalyst; end of 1970s was a coming-of-age.
- 1980s – dramatic expansion and diversification; greater participation in consultancy and contract work; reports for Government.
- 1990s - demise of engineering geomorphology; demand was insufficient to sustain GSL.

He did highlight the importance of usable products, giving the example of the analysis of the Ventnor (Isle of Wight, UK) landslides, which included involvement with the public through production of a leaflet and operating a shop for information and advice (Fig. 2). He predicted that in the future the lack of coherence in applied geomorphology would lead to its demise because of its diversity but application would be absorbed and become part of the ethos of geomorphology. Arguably, the latter has occurred.

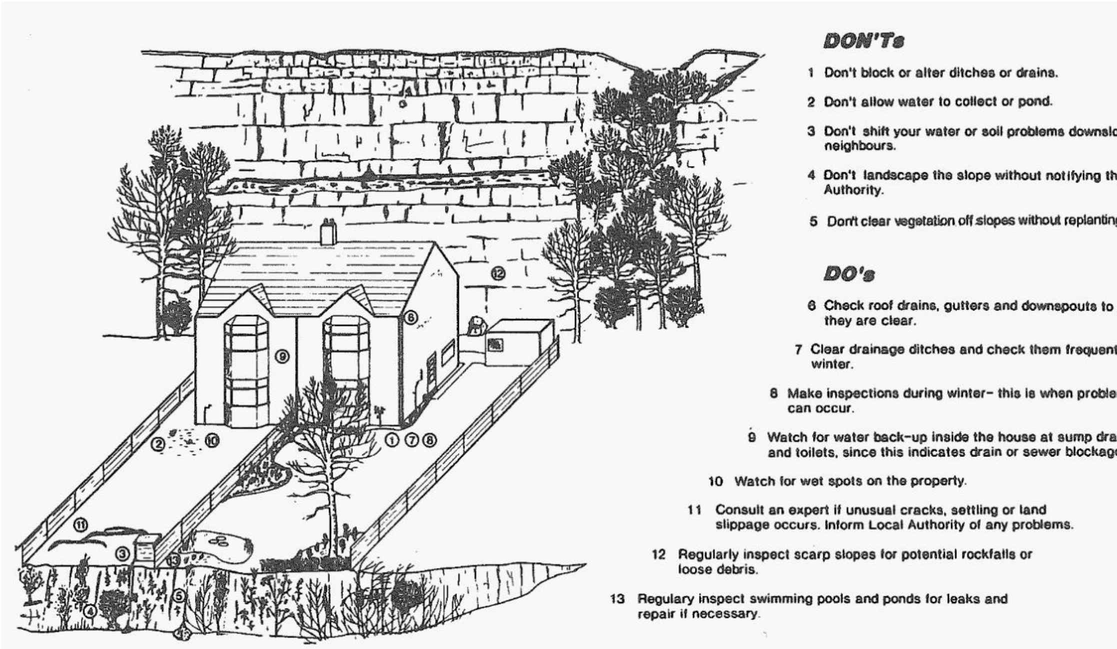


Fig. 2 Advice to residents of a landslide-prone area, Ventnor, Isle of Wight, UK, regarding good and bad maintenance procedures (after Geomorphological Services Ltd., 1991; Lee et al., 1991). Source: Jones (1995)

However, Engineering Geomorphology was still of sufficient prominence that it was the subject of the 1997 BGS (Giardino et al., 1999) and the Editors stated that the future for engineering geomorphology was bright, highlighting opportunities from developing technology and need to become involved in policy formulation. Within that Special Issue Hooke (1999) considered that the past decade had been very exciting in fluvial and coastal management and that a change in attitude was evident. She gave examples of this real involvement (see Section 4). Brunsden (1998) also reviewed applied geomorphology over the previous 30 yr (ie., 1968-1998) and discusses sustainable use, by then coming on to the agenda. He indicates the sometimes hostile attitudes of other professions and that the "Long battle to gain acceptance may not be over" (p. 68). He documents the growth of professionalism. Likewise, in 2002 Brunsden reviewed the whole topic of applied geomorphology and what it involves; he itemises what geomorphologists have to offer and highlights the advantages of physical geography training. By 2010, Church (2010, p. 269), reviewing geomorphology over the period 1960s-90s said:

> "The period did claim a signal practical achievement. The Newtonian focus and the appropriation of engineering methods of observation and analysis brought geomorphology to the attention of engineers and land managers at a time when there was also increasing concern for the quality of land management and environmental engineering. For the first time, a substantial portion of geomorphology became applied geomorphology..... this movement began to knit geomorphology into a wider community of environmental scientists and managers, it increased the confidence of geomorphologists in the value of the discipline, it imported many technical methods of investigation into the discipline, and it contributed to the increasing sophistication of geomorphological investigations."

During the 1990s the need for application and the wish for geomorphology to be used led to several books aiming to give guidance or exemplifying how geomorphology could be applied, some of it based on direct application experience (e.g. Thorne et al. (1997) (which became a government manual, Sear et al., 2003); Thorne (1998) in the fluvial field, and Viles and Spencer (1995) and Bird (1996) in the coastal sphere). During the 2000s applied work boomed, particularly with change in attitude and a move towards 'working with nature' that gave increasing scope and need for geomorphology, and with the increased examples of effective application. Such an approach had come into coastal management in the 1990s in the UK (see Section 4.1), and been advocated in fluvial management from the mid-1980s (Brookes, 1985b), gaining impetus with development of river restoration in the 1990s. Development of frameworks for geomorphological assessment became important, for example in the fluvial field, with early work by Rosgen (1994) and later the suggestions of River Styles by Brierley and Fryirs (Brierley et al., 2002; Brierley and Fryirs, 2005; Brierley et al., 2011). Further compilations of papers illustrating applied geomorphology in this period include the books edited by McGregor and Thompson (1995) and Allison (2002). Kneupfer and Petersen (2002) also published a Special Issue on Geomorphology in the Public Eye as the 30th Binghamton Symposium, focusing on policy interaction, education and communication. Orme (2013) reviews the long-history of intersection of geomorphology with environmental management and highlights the value and need for geomorphologists to contribute to meeting environmental challenges and pressures of development, exemplifying the benefits of their contributions.

It can be seen from this review that certain themes have long been prominent and sustained and that the techniques and tools available have long played an important role. Views on the health, degree and future development applied geomorphology can be seen to have varied over time. Geomorphology as a whole, of course, burgeoned after the development of the systematic, quantitative and process geomorphology advances, mainly in the 1960s, and much of this was potentially applicable. Geomorphology had incorporated much engineering understanding on principles, particularly of hydraulics and sediment transport, but for some time or in certain settings applied geomorphology was very much seen as adjunct of engineering , partly because that was the only way in. With the continued perspective to now, arguably geomorphology should be seen to be complementary to engineering with geomorphology developing its own distinctive holistic approach, informed by analysis of whole systems and of dynamics and an ethos of using natural principles, and employing its own array of tools as well as those assimilated from other fields. The physical geography inheritance of geomorphology in the UK is very apparent in these approaches and indeed in development of professional employment now, and differs from the background and training in some other countries such as the USA. The present situation, at least in UK, is that many more academics than formerly are directly involved in applying geomorphology, in spheres of strategy, policy, and practices as well as direct site / specific problems. The situation professionally has been transformed, with geomorphologists employed within private consulting companies. Within the regulatory authority, the Environment Agency in England, the number of geomorphologists has risen from one in 1986 to a block set of nine appointments in 2010 when the need for explicit geomorphology was recognised, and now 35 geomorphologists employed with that remit. The reasons for these developments, the motivations and barriers, and the nature of involvement are discussed below. The present state of applied geomorphology, the keys to effective application and the benefits of application are discussed.

3. Applying geomorphology

3.1 Motivations and stimuli

Hooke (1999) identified a number of stimuli to applied geomorphology at that time and why it had developed so much in the 1980s and 1990s. These can be compared with the present situation and the extent to which they have continued, been renewed or additional motivations have become apparent. Of the reasons for development of applied geomorphology that Hooke (1999) identified in 1999, the problems of hard engineering solutions, of problem-specific approaches, increase in environmental awareness, influence of catastrophes and events, and continued development and urbanisation pressures have still been major stimuli in the last 20yr. Climate change under global warming has become a major motivator and environmental attitudes have changed towards working with nature. Major policy and framework changes, partly arising from some of the former pressures, creation of demonstration projects to show approaches can be possible and effective, and, in UK universities, pressures and assessments that promote application have become major stimuli in the last two decades. Based on direct involvement, the commentaries in publications and on the views of current professional geomorphologists, the stimuli over the past five decades are summarised in Table 4.

As seen, major growth in applied geomorphology came in the 1980s and 1990s. A major reason for this was the increasing realisation and evidence that **past actions and approaches** to environmental management were **not working** and that they were having **detrimental consequences** that were propagating in time and space (Fig. 3) *(*Brookes et al., 1983; Brookes, 1985a; Brookes and Gregory, 1988 ; Hooke, 1999). It took some time from the height of the trends in controlling nature, such as channelizing rivers, and building sea walls, for these consequences to become evident, though even recent solutions were shown not to work in some cases (Leeks et al., 1988). It is one of the reasons for the gradual rejection of engineering fixes, in specific locations, and the change to present attitudes of 'working with nature' becoming much more widespread. This is exemplified by the case study below on coastal management on the south coast of England, where the motivation to seek alternative approaches was the loss of material and narrowing of beaches, the undermining of existing hard defences and the realisation that the uncoordinated action in one location was affecting another along the coast (Hooke, 1999). On rivers, there was increasing realisation that piecemeal actions were inadequate and that the whole system needed to be understood. Brookes and Gregory (1988) showed how one river management authority in England was developing an alternative, holistic approach by 1988. This movement towards alternative approaches was helped by development of the concept of **sustainability** and its increasing currency to its present centrality in environmental management. However, it arguably still failed to become a central explicit part of the frameworks for many years. The value and necessity of recognising local contingencies and landscape history, a primary skill of geomorphologists, is now appreciated much more by environmental mangers. The professional geomorphologists say that much of their current work or suggested solutions entail looking up and downstream in channel systems and catchments and investigating the background to understand the functioning and characteristics.

Fig. 3 Examples of structural failures and narrowed beaches in the 1980s on south coast of England.

Another motivation was the **increasing concern about human impacts**. This was not new as shown in many early publications dating right back to the mid-nineteenth century (Coates, 1972; Brunsden, 1998; James and Marcus, 2006) but the scale was becoming such that managers and the public had growing awareness and concern. Arguably, the developments in geomorphology itself, with the increase in understanding of processes, dynamics, variability, and time and spatial scales, enabled researchers to envisage and model the implications and for them to begin to give answers to some of the questions being asked; this capability has been continually increasing.

Wider concerns and frameworks played a role. Many reviews attribute the rise in environmental applications and the changes in attitude to increasing concern about ecology and conservation, some attributing it to the **ecological movement**s and increased awareness. Both Hooke (1999) and Walker et al. (2007) do not think this was so much of direct impact on geomorphology, though it altered the milieu. It has been in the more recent phases that the ecological and biodiversity concerns have really been a primary motivation and a major plank of frameworks and policies, e.g., the development and implementation of the **WFD (Water Framework Directive)** legislation in Europe. The change in awareness and attitude is now leading to is an increasing acceptance of, and desire to, implement 'working with nature'. By the late 1980s and early 1990s the growing awareness of the possibility and issues of climate change due to **global warming** did gain ascendancy and was a stimulus to consideration of new scenarios. This has continued to accelerate, facilitated by the increased sophistication of modelling of likely scenarios. However, Lane (2013) argued there has been a lack of engagement of the scale required and activities represented by Naylor et al. (2017) are part of attempts to remedy that.

Catastrophes and disasters have always been a major motivation or stimulus for changes in environmental policy, legislation or practice. In the work on coastal management on the English south coast the major coastal floods of 1989, combined with the increasing discussion of sea-level rise, became a strong motivator for further action and different kinds of solutions (Bray and Hooke, 1997a). The incidence of several major floods in the last decade or so in Britain has been a major stimulus to much more work on flood management and to an ongoing change in attitudes by decision-makers and the public as to how to deal with flood risk. Recent failures of newly designed flood defences being overtopped by large margins has engendered further questioning of approaches, climate change impacts and future scenarios. The 2007 floods in UK led directly to the Pitt review (2008) that advocated 'Working with Natural Processes' (WWNP) but the real impetus came after the 2012-13 floods and more since. This is now leading to enormous amount of work on NFM (Natural Flood Management) and actual implementation (see Section 3.2).

Specific developments have arguably facilitated and accelerated application in various spheres. Key to changing the attitudes of other professions and the public has been the opportunity to implement **demonstration projects** of new/ alternative approaches. This notably happened with river restoration in the UK in the 1990s. Much discussion was taking place but it was only after the construction of the River Cole scheme in a rural area in Wiltshire, southern England, and the River Skerne scheme in an urban area in Darlington, northern England, (Brookes, 1995; River Restoration Centre) that the whole movement took off. Likewise, demonstration of managed retreat on the coast has led people to realise that it can work and have environmental benefits and a major scheme has now been implemented on the south coast of England, at Medmerry, where it had long been advocated (Environment Agency, 2015). These demonstrations have led to more projects and a boom in schemes designed along geomorphological principles as the number of demonstrably 'successful' projects where geomorphology has provided a sustainable solution (and often cheaper), restored habitat and/or added value are completed. Increased experience is also facilitating greater success in projects in achieving such goals.

Some of these developments in attitude and approach then application have led to major **policy changes**. These in turn have stimulated much work. Environmental Impact Assessment (EIA) arguably did this early on, though there is little evidence that much geomorphology was actually incorporated. Recent legislation is strengthening EIA requirements for geomorphology. A specific development that has required and enabled much fluvial geomorphological engagement has been the passing of the **Water Framework Directive** (WFD) by the European Union in 2000. This was primarily ecologically motivated, with the degradation of European rivers so evident, and the major classification is on ecological health of water bodies, but it entails hydromorphological assessment. Much applied work has been entailed in developing indices and means of assessment (e.g., MImAS used by the authority in Scotland) (Sepa, 2018). Assessing compliance with WFD of any new schemes or modification on rivers or coasts is now a major source of work for professionals.

For academic researchers, applications of geomorphology can occur in two directions, one of which is because of a personal motivation to apply results or to see societal good and practical outcomes from research. The choice of research and pathway may be dictated by this or application may be motivated by obtaining results of research and then realising the potential to apply them. Contact with and persuasion of relevant decision-makers can then be a challenge. The other direction comes from the environmental managers who have a problem, perceive a need and have an awareness that a geomorphologist can help. Personal motivation of researchers to help society and see practical outcomes is much more widespread now than in former days of universities as 'ivory towers'. However, there is now an external stimulus in the UK; the lack of academic research being applied in most disciplines was the reason why it has become a formal requirement and motivation in the Research Assessment Framework of Universities in the UK and for all grant proposals to demonstrate interaction with users by a Pathways to Impact plan. Research that is applied such that it influences policy or practice is now highly regarded and rewarded. In some cases, therefore, involvement with application is now because funders and universities demand it.

Table 4 Stimuli to applied geomorphology over past decades in UK

Period	**Stimulus**	**Who to**	**Type of work**
1970s	Process geomorphology	Researchers	Process dynamics and effects
1980s	Commercialisation	Researchers Consultants	Engineering geomorphology
	Engineering failures, e.g., sea wall collapse	Environmental managers	Engineering geomorphology
	Detrimental effects, e.g., channelisation, beach narrowing	Environmental managers	Alternatives to channelisation and piecemeal coastal and river protection Holistic approaches
	Floods	Environmental managers	Solutions, options and designs
1990s	Climate change, sea-level rise Increased environmental awareness	All Public	Sustainable approaches River restoration, managed retreat
2000s	WFD Ecological concerns	Regulatory authorities	Methods of hydromorphic assessment
	Floods - 2000, 2007, 2009	Policy makers	Risk management strategies
	Catchment management		Holistic approaches
2010s	REF Impacts Research Funding	Academics	Policy and practice influence
	Floods - 2013, 2015	Environmental managers, communities	NFM
	Successful geomorphological applications	Decision-makers	Restoration, sustainability

	WFD	Professionals, statutory authorities	WFD compliance of works
All periods	Personal motivation	Academics Community groups	Societal benefit Improved environment

3.2 Nature of involvement and components of effective application

Questions arise regarding how geomorphologists are involved or can become involved in applying their knowledge and expertise and the role they play in teams/ projects/ organisations in addressing environmental problems and management. They can be involved in various types of work, e.g., policy, practice, problem solving, regulation compliance, and design. Involvement ranges from researchers and specialists being called in to help solve a specific problem to overall advice and development of policy, or to full-time employment of professional geomorphologists in various levels of activity; this itself has evolved over time.

In terms of types of work, Brunsden et al. (1978) identified two groups of applied work: (1) Problem solving and data analysis; (2) Problem identification and….data collection. They considered the first to be more like research; the second involved being able to 'read the landscape', a theme that Brierley et al. (2013) and Fryirs and Brierley (2013) have later advocated. Brunsden et al. (1978) identified various abilities arising particularly from geographical geomorphology in Britain and they recognised it would need consultants and employees in organisations. Coates (1984) considered that geomorphology can contribute to public policy in understanding how human actions will feedback changes into other natural system components. He identified two classes of public policy: those needed for the public good, and those formulated in response to damaging events. The avenues for involvement in public policy include publications, government work, industry, consultancy, and special interest groups. Four types of work in which geomorphology can interface with policies were identified by Hooke (1988): cataloguing and inventories, assessment of effects of activities; prediction of effects of proposed activities; development of policies and alternative strategies. Jones (1995) assessed the potential for geomorphological involvement in the four stages of policy evolution: problem identification and strategy specification, policy formulation, policy implementation, and policy evaluation, echoing Coates' (1984) phases of decision-making of perception, planning, implementation and management.

To become closely involved in application, then the geomorphologist/researcher needs to deliver usable products to the decision-maker/environmental manager, co-design solutions that can help to solve their environmental or practical problems, or provide tools for managing an aspect affected by dynamic geomorphology. Those usable products may be information or understanding about past changes, processes and dynamics, especially in relation to a small-scale, specific problems or localities. It may be a model or a methodology that allows for prediction. It may be a typology or framework that can have wide application and acts as an operational tool, such as development of indices. It could be direct cooperation in design of an actual solution, e.g., of new channels. A major component of professional work now is assessing viability and longevity of schemes.

One of the challenges to involvement and the delivery of effective solutions is the nature of geomorphology itself. Long ago, Hails (1977) stressed the need to be objective and questioned whether the potential would be realised. Verstappen's (1983) focus was factual and functional information that is required about landforms, geomorphological processes, morphogenetic situations, and environmental context. Coates (1984) advised that application requires a clear strategy and to recognise constraints. Brunsden (2002), in an engineering-orientated discussion particularly related to slope instability, considered that major contributions are in the spheres of process mechanisms, rates and dynamic equilibria, and in measurement and modelling, and that we can offer rigorous quantitative service to clients. As shown by Brunsden (2002) and very much a component of current work, is the need for a combination of scientific, quantitative analysis and 'expert judgment' and interpretation of landforms, evidence and relations. Kemble (2018 p. 33), a professional geomorphologist in a consulting company, states that "geomorphology requires available scientific knowledge but also needs the application of that knowledge through the 'art' of informed professional judgement. A crucial part of this 'art' is understanding the environment in which the problem or issue lies, and trying to select/adapt tools that can be applied". Other professional geomorphologists concur that geomorphology can provide a key spatial and temporal context that could be overlooked by a more traditional (engineering) approach. Science underpins the geomorphological work but needs to be made more accessible. Professional geomorphologists find that field observations and provision of empirical evidence are key to convincing other professionals of the understanding provided by geomorphology.

The complexity of the environment leads to variability and uncertainties and geomorphologists need to educate clients/ users in uncertainties (e.g., Sear et al., 2007; Darby and Sear, 2008) and the inherent nature of the environment and its dynamics. Hooke (1999) argued that theoretical developments have helped in dealing with complexity but need to be applied more; that is still the case though it is increasing slowly. Many projects entail prediction of future changes and that is very challenging geomorphologically, though some research projects have taken steps to do this, for example, FutureCoast (n.d), iCoast (n.d.) and ARCoES (n.d.) and currently Bluecoast (n.d.) in relation to coastal dynamics and morphological change.

Comparing the current situation with past ideas of how applied geomorphology would develop it is interesting to see that Coates (1984) voiced future concerns on lack of coherence, source of geomorphological advice, and marketing of potential expertise, those doubts still voiced by Jones (1995) 10 yr later. However, Thorne (1995) reflected that the papers at the conference and in the Special Issue on Geomorphology at Work were making clear the value of a geomorphologist as a member or, under the right circumstances, leader of a project team including other professionals such as engineers, planners, managers and natural scientists. He opined they were also demonstrating the important contribution made by geomorphological analyses in defining problems and selecting appropriate solutions and management approaches. He considered the 'market' for the employment of professional geomorphologists and the application of geomorphology in a wide variety of contexts had never been stronger. It is thus interesting to see that we have now arrived at that situation, though it has perhaps taken longer than anticipated. The development of holistic approaches to environmental problems is much more accepted now and means that most projects involve multidisciplinary teams (though Craig and Craft (1982) thought team efforts were characteristic and required for projects even back in 1980).

In the present situation, and particularly considering the role of professional geomorphologists now employed quite widely in consulting companies and regulatory authorities, two major types of work are apparent (de Smeth, personal communication): First, assessment of compliance of proposed works with legislation and regulations (particularly the WFD in Europe), or advice and contribution to sustainable design of infrastructure and flood defence schemes. Their experience is that they are often involved late in the process (though this is changing) as it is presumed by the project leaders that it is a tick box exercise for proposals already made. The geomorphologists have found that, increasingly, they have to help in redesign to make schemes more sustainable and environmentally acceptable (Maas, personal communication). Second, work that the geomorphologists themselves initiate and lead, mostly of smaller scale and involving environmental trusts, conservation bodies, and NGOs. Such work can entail audits and field surveys, conceptual models, outline and detailed design, and modelling. Kemble (2018) considers the nature of the work has grown over the past decade, and is not just about assessment but now is in providing design input. Much of the work in all spheres concerns understanding and managing sediment, not just computation of the mechanics of transport (commonly an engineering responsibility) but the sources and dynamics of input, the variable transmission in space and time, and the zones and timescales of storage.

Aspects of attitude amongst two groups of people are relevant to how geomorphology has been and is able to be applied; these are the attitude of professionals in other disciplines and of academics, and the public attitudes and general milieu relating to environmental awareness and attitudes of how the environment and particularly risk should be managed. The first affects how and to what degree geomorphologists can be involved in applied projects. The second affects the acceptability of solutions of the kinds advocated or proposed by geomorphologists and will be discussed in Section 4. Both of these have changed markedly over the last 50 yr and have facilitated the advance and expansion of applied geomorphology.

Problems of attitudes and lack of awareness amongst other disciplines and decision-makers were apparent from early on as identified by Brunsden et al. (1978). Griffiths and Hearn (1990) considered that the subject had not received universal acceptance by civil engineers because it was seen as too academic and not directly applicable to engineering design. Almost all the work and skills on offer were perceived as in geomorphological mapping and this posed limitations. Jones (1995) highlighted the resistance of engineers but Klotz's (2003, p. 1675) view of fluvial geomorphology, as an outsider, was that "While this scientific discipline was relatively unknown as an applied science until recent years, recent application of the science to restoration designs shows a great deal of promise for effective stream channel management." Even now, those employed report that their value often still has to be demonstrated to convince other professionals, who very often act as the 'gate-keepers'. The current professional geomorphologists think that ignorance of geomorphology is still widespread. Respect and attitude is improving and awareness of value is increasing but it is a 'young service and needs trust'.

Associated with this, a matter for recurrent comment in publications has been that of professionalism and professional status. Brunsden et al. (1978) and Brookes (1995) called for some professional status to be developed. It was partly this impetus that led to the creation of Chartered Geographer (Geomorph) status within the RGS (Royal Geographical Society), since most geomorphologists in Britain are trained through the physical geography route. This has resulted in a small trickle of applications each year but increasing very recently. Professionalism is still an issue and the British Society for Geomorphology (BSG) has just established a Sub-Committee for Professional Geomorphologists. Some of the original issues in establishing a professional qualification concerned the kinds of skills and attributes needed to be recognised for a professional geomorphologist.

There are questions of who undertakes the geomorphology. Pressure exists for development of tools and procedures that can be widely applied. One problem is that some of the tools developed tend, inevitably, to be rather simplified, and indeed may be designed for use by non- geomorphologists, and that has inherent dangers of misrepresentation or misinterpretation if used by non-experts. In spite of pressures to develop guidelines and methods for wider use, some fierce opposition to the use of 'cookbook' approaches is evident and Kondolf et al. (2003) cite application of Rosgen's (1994) approach to classification and his framework for river management having failed in places. Other approaches and applications may purport to do geomorphology but have not been developed by specialists, including, for example, design of new 'natural' river channels.

Another barrier to application for a long time was the attitude in academic circles that applied work is low-level, not research and not valued. Brunsden (1998 p. 68) reckoned that “Old suspicions and prejudices against applied research were being ‘swept away’ by practitioners". Many consider this change of attitude within academic circles to have come much later, but the "taint has now gone from applied work” (Plater personal communication 2018) and has altered completely in Britain under the formal research evaluation. Experience with consultancy where the client has come to the researcher for help, though, has shown that the product requested must be delivered and a project not used as an excuse for the academic’s own research agenda. From the 1990s onwards, in the UK at least, government and agencies turned increasingly to consulting companies, partly because of the volume and demands of the work (and partly because of failure to meet deadlines or deliver required products), with academics called in as advisors or parts of teams. The involvement of academics nowadays is often in tackling difficult problems and trouble-shooting at specific locations. However, increasingly, projects are co-designed by academics and organisations, encouraged by the need for connection with users through research funding mechanisms.

A related long-standing issue over involvement of geomorphology, certainly of concern to academics, is the reciprocal relationship between research and application. In the early days, this was a cause for debate. Thornes (1978, p. xiv) cites Walker (1978) who considered that applied coastal research aimed at solving specific problems “will almost certainly lead to reduction in production of fundamental discoveries, discoveries that actually make applied research meaningful”. Thornes, however, concludes that geomorphologists are destined to play a larger role in solving problems of direct relevance to the prevailing social and economic climate. Wolman (1995, p. 585) considered that analysis of the impact of anthropogenic activities in the context of natural processes requires continuous reciprocal exchange between research and application. “Apologies are not needed for choices of orientation, but only for destructive separation”. Thorne (1995) is of the opinion that studies in the volume on Geomorphology at Work fundamentally demonstrate the unbreakable thread that runs between ‘blue skies’ research, strategic research and practical applications in geomorphology. Brunsden (1998, p.64) argued that, “far from stifling theoretical development… the practice of the subject had provided real opportunity for fundamental research”. The recent research projects in the UK on coastal dynamics cited earlier are an example of that feedback. Research in the UK is now required to show how it will feed through to delivery of beneficial societal outcomes.

4. Case studies

The following case studies track some aspects of the development of coastal and river channel management in England and illustrate some of the points made earlier about the influences and the ingredients and milieu needed, as well as demonstrating the way geomorphology has contributed to more sustainable management of these dynamic environments.

4.1. Coastal management in the UK: Shoreline Management Plans, SCOPAC and the Sediment Transport Study.

In the late 1980s coastal management authorities (which were largely the Local Government Authorities) on the south coast of England were becoming increasingly worried about the narrowing of beaches and lack of sediment on them. They became aware that the actions by each authority, largely in the form of hard engineering, were having effects on the neighbouring authorities, particularly in supply of sediment. They also had examples of engineering failures within their own areas (Fig. 3). In 1986 The Standing Conference on Problems Associated with the Coastline (SCOPAC) came together as a network of the responsible local authorities and other key organisations that share an interest in the sustainable management of the shoreline of central southern England (SCOPAC, n.d.). They formed SCOPAC, which subsequently became very influential nationally, to help resolve a number of issues (https://www.scopac.org.uk/aboutus.html) concerning governance frameworks, and how to deal with the complexities of the coast.

From the outset, research had a primary role; SCOPAC's role has been "to assist members in developing a co-ordinated and sustainable approach to coastal risk management by commissioning research and sharing information" (SCOPAC, n.d.). The need was to understand more fully what was happening on the coasts, why the beaches were depleted of sediment and whether there were alternative approaches to management that avoided some of the problems. They became vaguely aware of the concept of sediment cells, the idea there may be sediment circulation compartments on the coast. They approached the geomorphologists at Portsmouth University to explore how this could be investigated and, with only a modest research budget that precluded large-scale original work and a realisation that much information already existed, they asked them to bring together all those data and knowledge relating to sediment on the coast. The geomorphologists, Bray, Carter and Hooke, designed a bibliographic database to compile all the literature and evidence about all sediment processes and fluxes on the central south coast of England. The compilation of the bibliographic material entailed searching and locating not only the published academic research but the grey literature, all the reports and even historical documents, held by organisations, even involving personal visits to offices to procure documents. This database is still being kept updated and is an invaluable source to all those involved in coastal management on the south coast and beyond (SCOPAC, 2012).

The SCOPAC database was originally compiled and assembled during 1989 and comprised 2160 items (Carter et al., 1989; SCOPAC 2012 Database User Guide). Substantial revisions were made in 1992, 1995 and 1998, by which time the number of entries exceeded 3800. For the 1998 edition, it was converted to Microsoft ACCESS, providing a wealth of advanced search facilities and future upgrading options. The 2002 version included almost 5000 separate entries, and the 2012 version 6.0, currently in use and compiled by some of the original team of geomorphologists, identified an additional 700 new entries (New Forest District Council, 2017). The database comprises a searchable archive of sources, searchable by author, topic and/or area. It provides reference details, searchable keywords, abstract and details of where original material is held. The database encompasses all aspects of sediment transport and sediment budgets on the coast, including long-term and short-term coastal changes, and the effects of dredging and reclamation. It can be searched on any 'field' or 'part-field' of the information and displayed in various ways (Fig. 4).

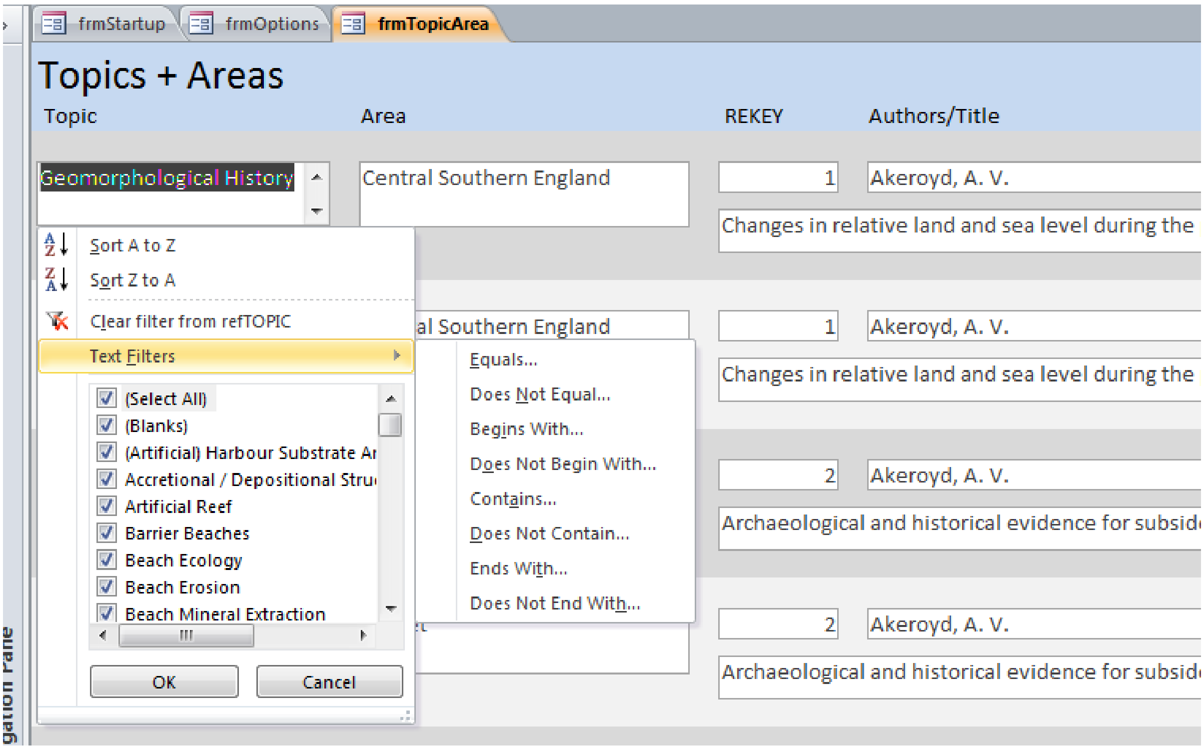


Fig.4 Example interface of online SCOPAC Sediment Transport Study database

Once the original bibliographic database was compiled, assimilated, and indexed for keywords, it was apparent that much information and data already existed so the geomorphologists were commissioned to analyse all these data with a view to identifying sources, processes, transfers and stores of sediment, and the possible cells on this coastal area. A very detailed, five volume Sediment Transport Study (STS) report was produced (Bray et al., 1991), which included maps (e.g., Fig. 5) in which all these elements were identified. Compartments or cells were indeed evident, with distinct pathways, separated by boundaries, and the research classified the types of divisions (boundaries) and compartments, the sources and processes within each (Bray et al., 1995; Hooke et al., 1996). Again, the STS has been kept updated (Bray et al., 2004; New Forest District Council, 2017); and is a very important current source of information and understanding of the coastal processes and sediment budget. In 2002 the STS became fully interactive and can be interrogated online (SCOPAC Sediment Transport Study, n.d.*)*. The SCOPAC Sediment Transport Study area now spans the coastline between Start Point, Devon and Beachy Head, East Sussex and is broken down into 27 sediment units (Fig. 6).

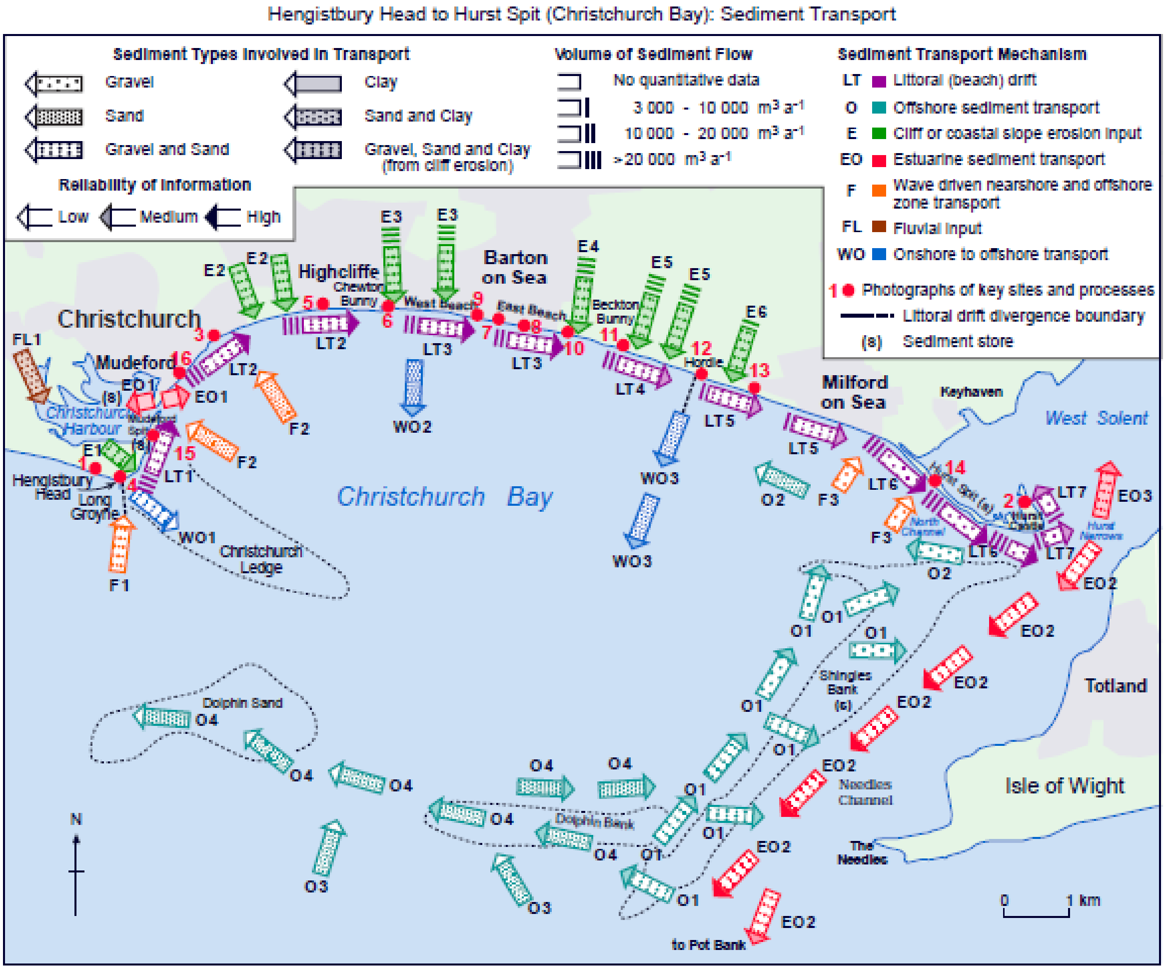


Fig.5 Example of map of one area of SCOPAC Sediment Transport Study, Christchurch Bay, on the south coast of England, showing details of sediment sources, sediment transport pathways, mechanisms and type, and sediment volumes.

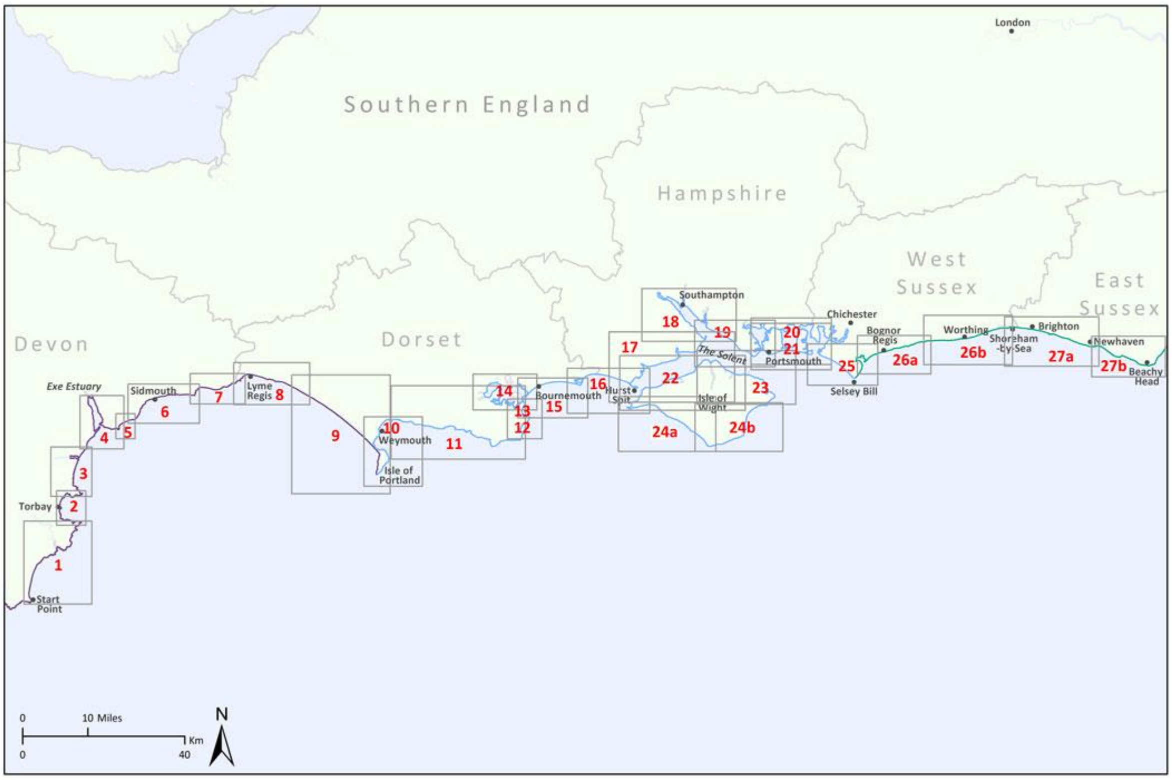


Fig. 6 Division of central south coast of England into sediment cells and compartments (SCOPAC Sediment Transport Study).

SCOPAC recognised that these cells could form the basis for much more coherent management within cells and identification of where an action would not affect neighbouring cells so much between boundaries. Meanwhile, a national study for the relevant government ministry also was done (Motyka and Brampton, 1993). Government was pressed for more coordinated action and management on the coast. They set up the Parliamentary Rossi Committee (1992), which in 1992 recommended:

"that the government consider how best to establish, resource and empower regional coastal zone management groups based on natural coast cells as the linchpin of integrated protection and planning of the coastal zone."

This gave a primacy for researching and understanding the geomorphology of the whole coastline nationally. In 1993, the relevant Government Minister declared:

"….Science and experience has shown that natural river and coastal processes should only be disrupted by the construction of defence works where life or important man-made assets are at risk. The policy henceforth is to '**work with nature**. " (MAFF, 1993).

This meant that the authorities needed to understand nature and that this applied to both rivers and coasts. This was a very big step forward in which geomorphologists, working in concert with the public authorities, had been very influential.

The way in which this was then tackled on the coast was that Coastal Groups, comprising the neighbouring local authorities, were formed for all parts of the coast in England and Wales, and they were then required to construct Shoreline Management Plans (SMPs), which remain the basis for coastal management to the present (MAFF, 1994; Hooke and Bray, 1995; Shoreline Management Plans, no date).   These plans were to form the basis for sustainable management into the future, with timescales up to 100yr. The contents and structure of SMPs and the management options can be seen in Table 5.

The performance and outcomes of the first round of SMPs were then evaluated (Bray et al., 2000) and what emerged was that, although members of SCOPAC were fully appreciating all the arguments and information about the coastal processes and dynamics, in the end some of the planning decisions on developments were not sustainable, but rather followed local interests of protection. For example, the STS showed that most of the sediment in this region comes from cliff erosion, not rivers, (Bray et al., 1995; Hooke et al., 1996) and thus any further cliff protection would exacerbate the lack of beach sediment, yet such decisions were still taken (Hooke and Bray, 1995).

One of the outcomes of the STS and the SMPs was that the gaps in understanding and in data emerged. This led subsequently to two large national research projects, modelling the possible future evolution of the coast, Futurecoast (n.d.) and subsequently iCoasst (n.d.). Regionally, the gaps in the STS also gave rise to pure research projects on cliff erosion (Bray and Hooke, 1997b; Rendel Geotechnics, 1997) and Shingle Transport (Cooper et al., 1996; Defra/ EA, 1999). A review of SCOPAC and its needs (Hooke et al., 1998) also identified the pressing requirement for much more data and monitoring and this led to the establishment of the Channel Coast Observatory (n.d.) and subsequently Coastal Observatories around the coast of England and Wales. A geomorphologist (Cope, PhD supervised by Hooke and Bray) is now the Chair of the SCOPAC Research Committee. This case study thus represents 30 yr of sustained involvement and influence of geomorphology directly in management of a major and dynamic part of the English coastline. It is an example of how geomorphologists interacted closely with decision-makers, leading to development of approaches and understanding that were used in practice, and it influenced major national policy that continues to result in more sustainable and environmentally beneficial strategies of management.

Table 5 Shoreline Management Plans (SMPs)

Source: https://www.scopac.org.uk/smps.html

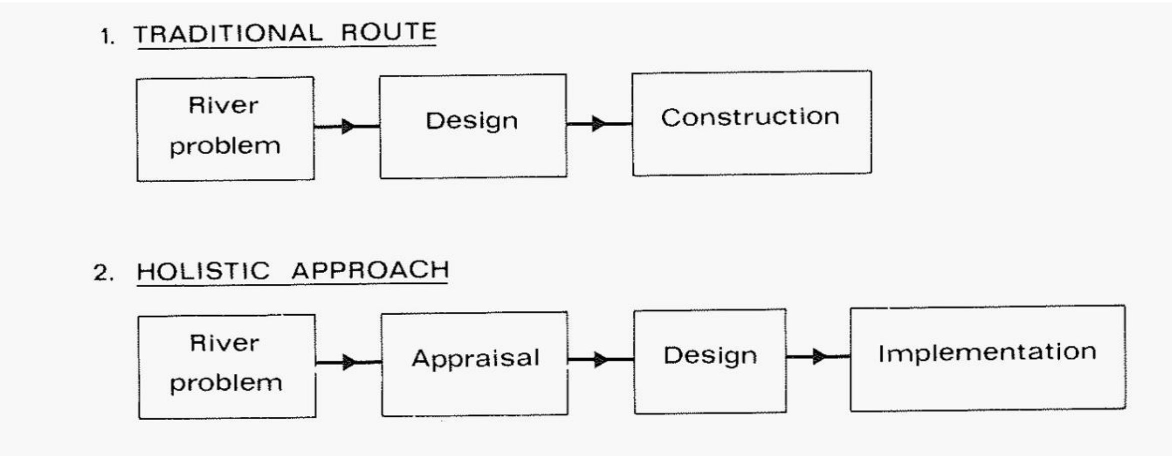
In 1994 the Coastal Groups and local authorities of England & Wales were encouraged by Government to adopt the concept of Shoreline Management Plans (SMPs), with a view to providing a more strategic and sustainable approach to coastal defence. The first SMPs (SMP1) were completed by 2000; SMP2 is the first review of those documents. SMPs divide the 6,000 mile shoreline of England & Wales into a series of cells and sub cells defined by coastal type and processes such as the movement of beach and seabed sediment (sand, shingle, etc) within and between them.
Following broad-brush assessments of the coastal flooding and erosion risks, and taking account of existing defences, people and the developed, historic and natural environments, and adjacent coastal areas, SMPs identify one of four shoreline management policies for sections of coastline (or Policy Units) within a sub-cell.
Shoreline Management Policy options: ▪ **Hold the Line** - maintaining the existing line of defence as it is or changing the standard of protection ▪ **Managed Realignment** - allowing the shoreline to retreat or advance in a controlled or managed way, either because that is the best approach for a particular stretch of coast, or because the benefits of protection are clearly out of scale with the financial costs. ▪ **No Active Intervention** (do nothing) means that no investment will be made in coastal defences or other operations other than for safety purposes ▪ **Advance the Line** - involves the building of new defences on the seaward side of existing defences
The chosen policy must be technically feasible, environmentally acceptable and economically sustainable.
A shoreline management policy is applied per Policy Unit for the short (0-20 years), medium (20-50 years) and long term (50-100 years).
Within these timeframes the SMPs will also include an action plan that prioritises what work is needed to manage coastal processes into the future. This in turn will form the basis for deciding and, subject to available funding, putting in place specific flood and erosion risk management schemes, coastal erosion monitoring and further research on how to best adapt to change.
Consequently the SMPs provide a 'route map' assisting local authorities to formulate planning strategies and control future development of the shoreline. In addition, the final plans aid government to determine future national funding requirements for flood and coastal erosion risk management.

4.2 Application of fluvial geomorphology in river and catchment management in UK

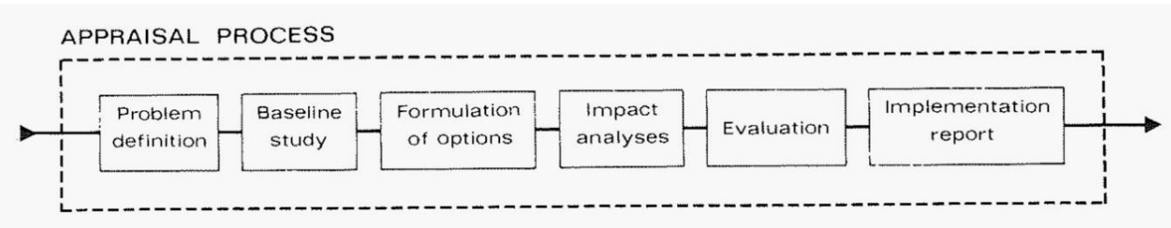
During the 1980s the potential and the need for application of fluvial geomorphology to river management was growing (e.g., Hooke, 1986; Brookes and Gregory, 1988), partly due to our increasing understanding of processes, partly due to our awareness of the dynamics of rivers on management timescales of decades and centuries, even in environments such as lowland Britain (e.g., Hooke, 1977, Hooke and Redmond, 1989), and partly due to the evident failure and problems created by hard engineering solutions, especially highlighted by Brookes' work on channelisation

(Brookes, 1985a, b; Leeks et al., 1988). What was becoming increasingly apparent was the need for evaluation of whole reaches and systems to understand and tackle problems, not just site-specific analysis and fixes. It was apparent that the piecemeal approach was not sustainable and had the domino effect of encouraging further hard protection, as on the coast, with detrimental effects geomorphologically and ecologically.

The statutory authority responsible for river management in England (and formerly Wales as well) is the Environment Agency (EA) (with its predecessor the National Rivers Authority). Brookes joined the Authority in the mid-1980s and began to try to influence a rethinking of strategies and methods for channel management, particularly adopting 'softer' engineering and alternative approaches (Brookes, 1988; Brookes and Gregory, 1988). The Authority commissioned several studies from geomorphologists in universities to undertake research into methods that could be applied (Brookes, 1995). During this period, a small group in the Thames Region of the Authority developed a more holistic approach in which alternative strategies and methods of management of a problem had to be considered (Fig. 7). This culminated in guidance published as 'River Projects and Conservation - A Manual for Holistic Appraisal (Gardiner, 1991). However, Brookes was the sole geomorphologist in the national authority for many years and strongly advocated appointments of many more geomorphologists and the integration of geomorphology in river management (Brookes 1995). This did not come to fruition until many years later. Three main stimuli have arguably led to the present situation where there are 35 explicitly recognised geomorphologists within the authority (EA) in England plus much wider developments in application and approach.



Approaches to channel management



Stages in appraisal process

Fig. 7 Alternative approaches to channel management and stages in the appraisal process in the holistic approach (from Brookes and Gregory, 1988)

The first of these is the movement that began to take place in the early 1990s of the implementation of the idea of river restoration. This was already happening in the US (Keller, 1975), provoked by a range of concerns of which a primary one was ecological, and by 1990 some was taking place in Europe (Brookes, 1990). Several studies and publications were produced during the 1990s trying to compile and disseminate geomorphological knowledge so that it gained wider application (e.g., Thorne et al., 1997) and several methods and tools for geomorphological evaluation of rivers were developed, including Fluvial Audits (Sear et al., 1995), but it was difficult to convince a still overwhelmingly engineering dominated management structure that river restoration was practically feasible and would be effective and non-problematic (i.e., not increasing flooding or erosion). It was the construction of the restoration projects on the **River Skerne in Darlington** (County Durham), the **River Cole at Coleshill in Wiltshire** and the River Brede in Denmark as demonstrations under an EU LIFE project that were able to convince others of the feasibility and value of such projects. This led to the establishment of the River Restoration Centre (RRC, n.d.), which has provided guidance and information ever since and has been a massive beneficial influence on the progression of river restoration in the UK. They now have 4895 implemented projects registered on their National River Restoration Inventory (RRC Factsheets, 2018), with a steady rise in number 2000-2012, followed by a decline but still >900,000 m of channel restored in the last five years (Fig. 8). A Manual of River Restoration Techniques (RRC, 2014), first issued in 1997, now provides detailed examples of innovative and best-practice river restoration techniques, and includes 64 case examples across the UK that can be downloaded**,** as well as updates on how these techniques have worked (https://www.therrc.co.uk/manual-river-restoration-techniques).

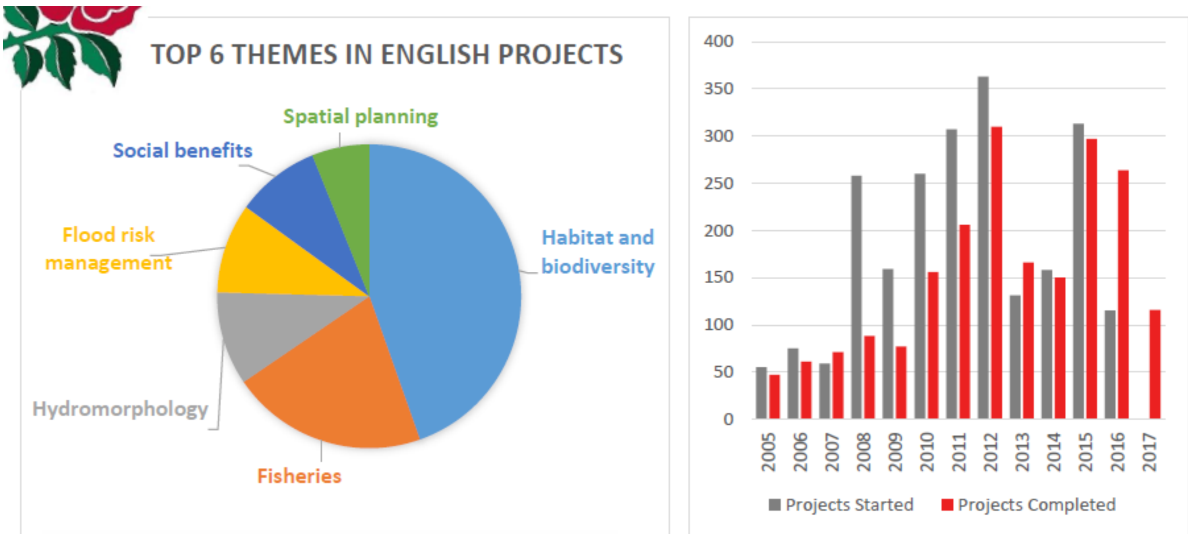


Fig. 8 Themes in English river restoration projects and numbers of projects in the period 2005-2017 (from National River Restoration Inventory Factsheet English projects (RRC factsheets, 2018)).

River restoration schemes are constructed for a range of purposes (Fig. 8), often multiple purposes, and are multidisciplinary, instigated by a range of organisations from statutory to community and voluntary. The involvement of geomorphology may still not be straightforward or automatic as evidenced by personal experience on the River Alt restoration in Liverpool (Rawlinson et al., 2017). This was a project in which a formerly culverted section of stream in an urban area was daylighted by construction of a completely new course through a brownfield site. It was mainly for amenity, ecological and regeneration purposes. Quite late in the project, Hooke was called in to provide fluvial geomorphological advice. She helped to redesign the morphology of the channel to be much narrower than the original design (within constraints imposed by the site and the basic course already decided). Opportunity for creation of fluvial features in this very low gradient channel was limited. She also advised on the gravel material of the channel bed and both the morphology and the gravel have proved remarkably stable. This site is now a major community asset, with high biodiversity within an urban area (Rawlinson et al., 2017; Alt Meadows, 2018) (Fig. 9).

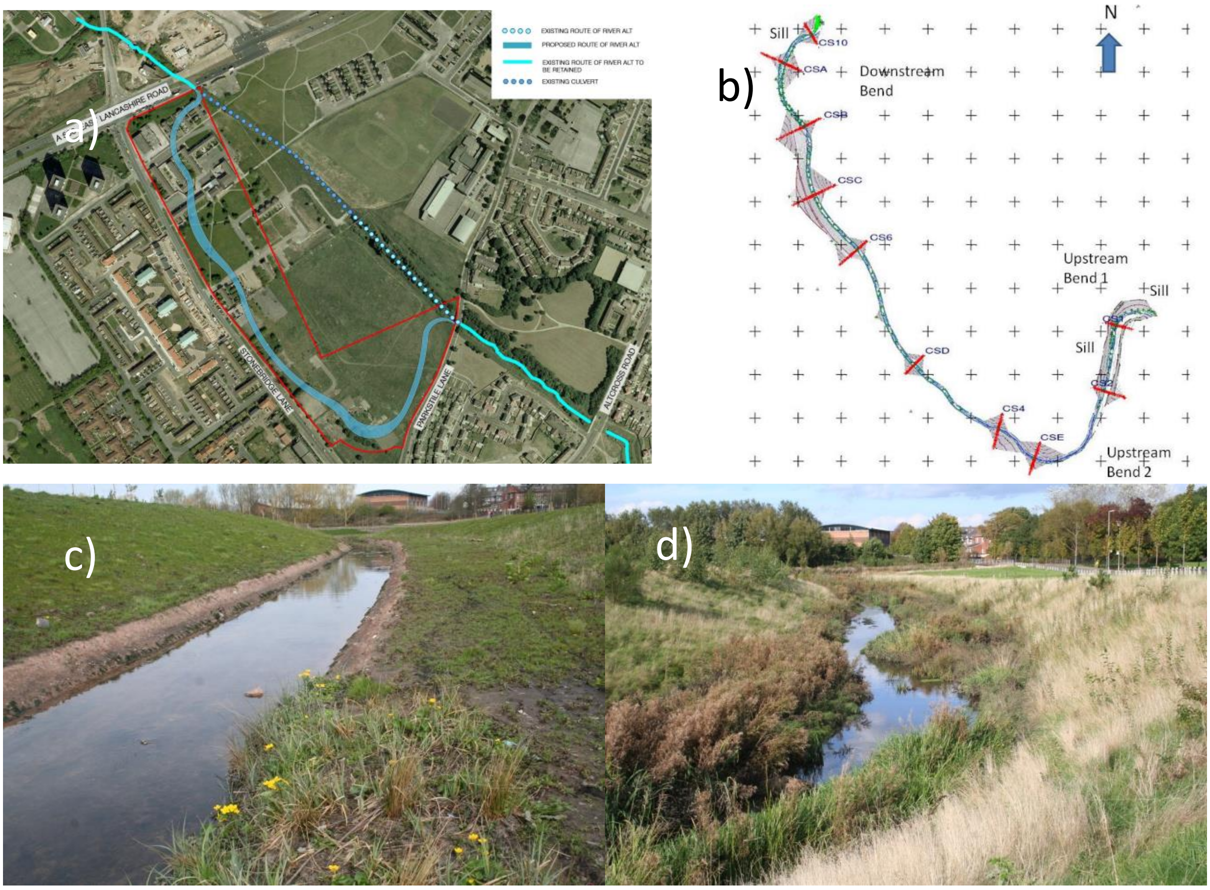


Fig. 9 River Alt Restoration (Alt Meadows): (a) original proposal showing culverted course and proposed new channel (Cass Foundation);(b) new channel course with cross-sections used for design and monitoring; (c) upper part of new course in April, 2015, soon after construction; (d) upper part of new course in June 2018 (Photos: Hooke).

The second large impetus to the increase in direct use of geomorphology in river management has been the EU Water Framework Directive (WFD). Although primarily established to increase the ecological quality of water bodies, the WFD entails three evaluation components of which one is hydromorphology. The WFD posed major challenges for the hydromorphology element, the assessment of what is natural (Newson and Large, 2002) and the identification of methods that could be used for the evaluation. It was quickly found that no standardised tools were available and this has led to much work across Europe on development of techniques and methods (Walker et al., 2007). One, MImAS, was developed in Scotland, mainly by geomorphologists (Sepa, 2018). The hydromorphological work has been ongoing as a major EU project, RESTORE, and is producing publications on methods developed and their application (e.g., Belletti et al., 2018). Some of this work has entailed river classifications (England and Gurnell, 2016) but categories still vary and are different from others in UK and those adopted elsewhere in the world, partly due to the differing physical environments but partly, as Tadaki et al. (2014) point out, influenced by the politics and societal values in which they are generated and feeding back into those and the environmental outcomes. The implementation of WFD led to the appointment of nine geomorphologists to the Environment Agency in England in 2010. Assessing compliance of existing river reaches and of proposed new schemes and infrastructure works is now a major part of the remit of the geomorphologists employed in the statutory authorities and by consulting companies across Europe.

The third important and recurring impetus to the application of geomorphology to rivers, as in other spheres, is the occurrence of natural disasters and impacts of events, primarily flooding but also erosion, as is also the case on coasts. This has contributed significantly to the change in attitude in how rivers should be managed that is ongoing but increasingly evident and accepted in the UK, as in some other parts of the world. Of course, one of the major reasons why rivers were originally modified was to reduce or prevent flooding, damage and danger. However, as outlined above, it became increasingly evident in the late twentieth century that some previous engineering works were having long-term impacts, were having detrimental effects that were propagated upstream and downstream, and that the engineering structures themselves could fail or not solve the problems. The raised ecological awareness and concern for the environment and biodiversity has also heightened the interest in developing alternatives that are more sustainable and ecologically beneficial. The predicted scenarios of climate change arising from global warming have added to this, with increasing urgency as more extreme events occur. In the UK, as elsewhere, the incidence of floods has varied over decades and a period of floods in the 1960s provoked research that led to development of flood estimation techniques through the Flood Studies Report (Natural Environment Research Council, 1975). Flood frequency was mostly somewhat less in the 1970s -90s but then a series of large floods, affecting different parts of the UK, has stimulated various investigations. These events have included the 2000-01 floods, 2007 floods in the English Midlands that took authorities and communities by surprise, the 2012-13 floods in which issues in the lowlands of the Somerset Levels over dredging gained much publicity and controversy, and the massive floods in NW England (Cumbria) in 2015-16) following a succession of storms named Desmond, Eva and Frank.

Particularly important in terms of changing thinking and influencing policy were the 2007 events which gave rise to the Pitt Review (2008). Although the ideas of 'design with nature' and 'working with nature' had been around a long time (McHarg, 1969; Downs and Gregory, 2004) and even supposedly adopted as Government policy in 1993 (see Section 4.1), it had still not been widely implemented in specific flood prevention schemes, though many river restoration schemes were designed with the purpose or had to make sure they decreased flood risk. The Pitt Review's

Recommendation 27 was that: [The Agencies]... ”should work with partners to establish a programme through Catchment Flood Management Plans and Shoreline Management Plans to achieve greater working with natural processes”. By 2013, impetus to try to implement these kinds of approaches more coherently was building. They ultimately resulted in a series of national projects on Working with Natural Processes, largely advocated by geomorphologists, with a range of reports and data published in 2017 (Environment Agency, 2017). These embraced techniques such as River restoration, Floodplain restoration, Leaky barriers, Offline storage areas, Soil and land management, Headwater drainage, Woodlands planting in Run-off pathway and various other positions. These are now collectively called Natural Flood Management (NFM) techniques and NFM is now a major sphere of activity for both fluvial professionals and researchers. The move towards implementation or testing these techniques was given added impetus by the floods in 2015-16, particularly in Cumbria, because the highest daily rainfall ever recorded in England occurred and some of the river levels reached were massively higher than anything on record (e.g., Fig. 10), and some exceeded new flood defence schemes.

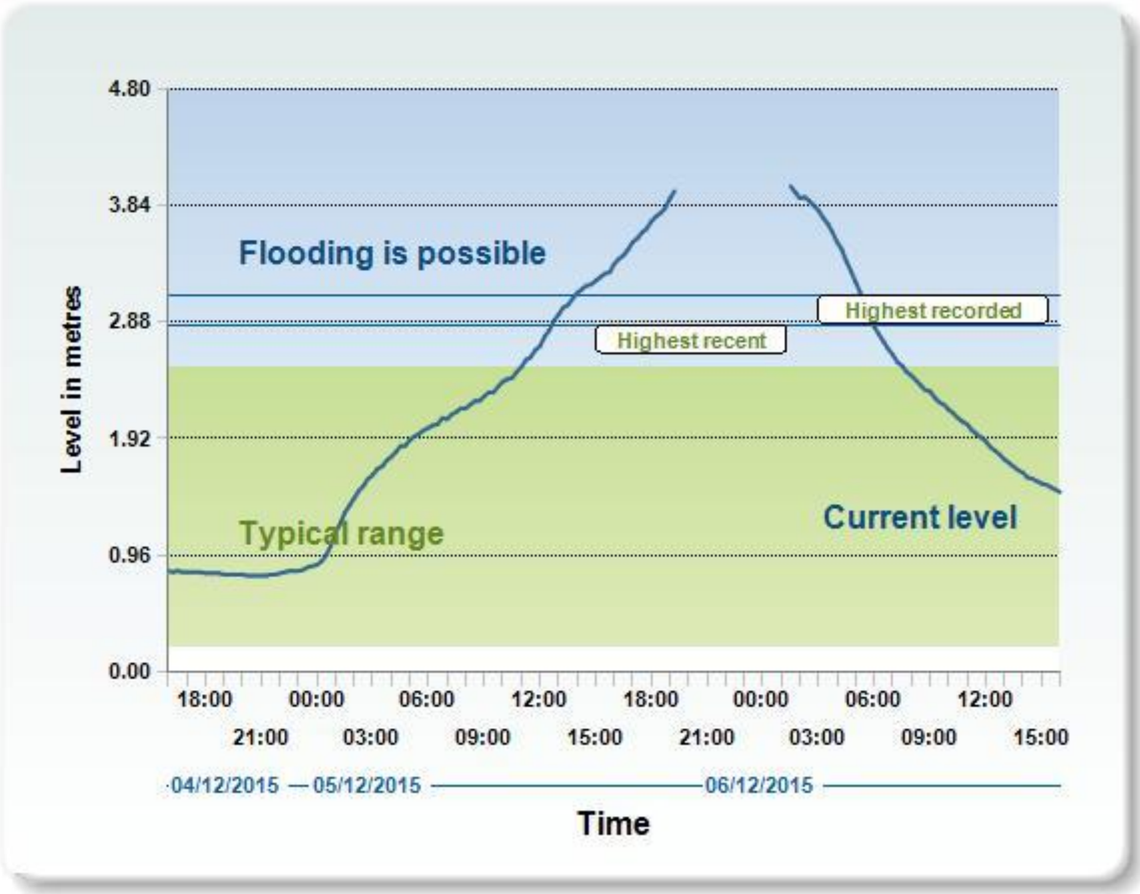


Fig.10 Real-time download of river levels at Environment Agency gauge on River Kent at Sedgewick, Cumbria, NW England, 4-6 December, 2015 (from flood-warning-information.service.gov.uk/river-and-sea-levels). The highest recorded is for the period since 1968 and occurred in 2005.

Many small NFM schemes and some larger ones had already been implemented (Environment Agency, 2017), and the number was accelerating rapidly. Most of these were either woody debris dams in headwaters or levée removal in downstream channels (e.g., Fig. 11). As with river restoration, the instigation and results of three demonstration projects, in which geomorphologists have played a major part, have been instrumental. The three projects are: (1) From Source to Sea (National Trust, Holnicote, Somerset); (2) Making Space for Water (Moors for the Future Partnership, 2016, Peak District); (3) Slowing the Flow at Pickering (Forest Research, North Yorkshire) (Moors for the Future Partnership, 2016). In 2017 the Government awarded £15M nationally for further implementation. Accompanying this big rise in interest and implementation of NFM, the Natural Environment Research Council (NERC) has funded three large research projects to investigate the effects of these measures and quantify the extent to which they are effective. This is an example of applied work leading back into research. Much is still unknown about how many of these small structures and measures are needed, what the optimal locations are and what their long-term effects and lifetimes will be. Work by Mcparland and Hooke is currently investigating effects of NFM on sediment flux and storage and thus flood retention capacity of structures (Mcparland and Hooke, 2019) (Fig. 11). The public and communities are now becoming much more accepting of these kinds of approaches. However, much still remains in gaining public confidence and in finding suitable locations and landowners for implementation. Like river restoration though, the demonstration of these approaches is leading to growing awareness and conviction of their value. Together, these examples show that the application of geomorphology has to go hand-in-hand with the social and policy context. The Environment Agency have now brought together a summary of all their activity and the evidence about managing flood and coastal erosion risks in England between 2011 and March 2017 and made it available to the public (Environment Agency, 2018).

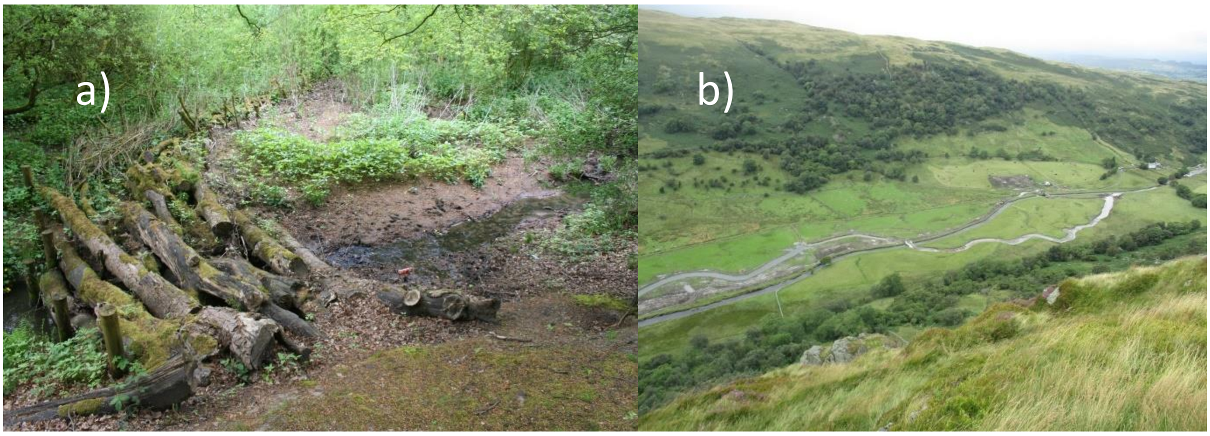


Fig.11 Examples of Natural Flood Management: (a) Woody debris dam on Black Brook, St Helens, Merseyside, UK, where Mcparland and Hooke (2019) are studying the sediment effects of such structures (Photo Hooke); (b) Swindale, Cumbria, where levées have been removed and a new sinuous channel created (Photo Lee Schofield RSPB) (from Natural England, 2016)

5. Future opportunities and challenges

Major opportunities are arising now because of the convergence of several of the major developments reviewed, including greater geomorphological knowledge, greater awareness and respect from other disciplines and professionals, technological developments allowing us to collect the required data, greater enthusiasm or pressure (motivation) to become involved in application right through to outcome, and the increased public desire to enhance the environment.

Significant challenges remain. Geomorphology is not an exact science and does not necessarily produce definitive outcomes. This is not because of weak science but because of the complexity and variability of the environment. It therefore requires potential users of geomorphology to be educated in this and to incorporate approaches, practices or designs that allow for the uncertainty and variability. Many of the professional geomorphologists say that they still have to use 'professional judgement', which is hard to explain to the end-user. It is important to show as much of the evidence and line of reasoning as possible.

A major problem but one that is gradually changing and related to the above nature of the environment and the 'solutions' we can provide is that the public tend to want certainty and protection. However, increasingly they also want a natural environment, with high ecological quality, biodiversity and amenity. Public awareness of destruction and harm to environment by human actions has grown enormously, increasing environmental consciousness of the public and demand for improvements/good stewardship from all levels of politics (local councils up). However, there is still a lack of understanding of the approaches and the types of solution recommended by geomorphologists that are alternatives to 'conventional' hard solutions. The public still need convincing to trust 'softer' solutions; demonstration and test schemes for new approaches are highly beneficial. This happened early on with river restoration and also with some early managed retreat and is now being done with NFM. Geomorphologists are now becoming involved in design of schemes and ‘solutions’ to environmental problems that we consider will be more sustainable, though we must take care with our new paradigm that we are not just replacing one with another (Brierley and Hooke, 2015). Conflict or tensions can arise between the societal or collective abstract needs, public gain or environmental wishes versus personal concerns for security and private loss or risk, as illustrated by the SCOPAC case study; political frameworks are required to resolve those. Attitudes as to what is desirable and acceptable are changing rapidly at present in Britain, partly because of large storms and realisation that 'hard’ flood defences may not work. Increasing evidence of climate change is also having an influence. A current big push in the UK and elsewhere is also the natural environment as a contribution to wellbeing and health (e.g., ECRR n.d.; IUCN n.d.).

One of the essential components of effective application and involvement of geomorphology is clear communication to non-technical and technical audiences to build on very limited understanding of natural dynamics, Good communication is needed across disciplines (engineers, ecologists, geotechnics, landscape, hydraulic modellers) and with regulators. It is also needed in wider public engagement, which is increasingly necessary in order to have schemes, modifications and restorations accepted, and because some actions are being implemented by local groups. Communication is one of the real challenges and barriers to application of geomorphology. Jeffries (personal communication) has argued that, unlike ecology, we have no icon (such as fish); landscape processes and dynamics are difficult to explain. We need a catalyst to make geomorphology of value to the public. More education is needed to continue to move general understanding away from one of control to an appreciation of natural dynamics.

In spite of all the progress and optimism conveyed in this paper, professional resistance and lack of understanding are still encountered. It is still very important for geomorphologists to increase and improve communication about our subject, what we can do and what we are suggesting, and to write in understandable language for the users. That entails knowing the audience. Even having convinced managers and much of the wider public on the need for geomorphological approaches to problems, final decisions will often still be dependent on short-term political thinking and may be constrained by lack of integrated management frameworks. Geomorphologists need to try to influence thinking at all levels.

Since much conservation and restoration work is ecologically motivated, an essential component and platform for increased geomorphological work is to convince ecologists and environmental managers that geomorphology is the key to healthy and sustainable ecology, that suitable geomorphological attributes (e.g., substrate, morphology) are essential for maintaining, enhancing or creating habitat. Many conservation organisations are geared to wildlife protection rather than landscape for its own sake but even for wildlife they have insufficient expertise or low awareness of the need for the geomorphological understanding.

Also, in terms of public appreciation, the appetite for more knowledge and information about the landscape, features, processes, and how they can change may be underestimated. At many 'natural' locations visitors see the large-scale landscape features first and then the butterflies and birds (if they are lucky). Yet, information on geomorphological features is usually lacking. There are numerous examples of major sites in many parts of the world where the attractive feature is the landscape or landforms and yet no information on these, is provided. Several of us have campaigned over past decades to try to improve this situation but progress is very slow. This wider education would increase awareness more generally and therefore enlarge the scope and receptiveness to geomorphological involvement and solutions to environment problems or enhanced management.

Kemble (2018) identified specific challenges in delivering geomorphology as a professional in a consulting company: tight programmes and budgets, continued omission of geomorphology as a discipline early in the life of a project, lack of numbers of experienced/skilled geomorphologists, and the need for training and awareness of the next generation of [water] managers. Others agree that geomorphology is highly specialised so it is difficult to recruit the right skills. There are also challenges around managing risk, both in relation to clients/users, for example in relation to erosion, as to what is inherent in the environment, and in relation to corporate liabilities. Kemble (2018) identifies the following guiding principles for effective contribution of geomorphology:

- Be in at the start of a project
- Keep relevant - do not simply apply a typology
- Do a desk study and site visit
- Explain processes for making decisions
- Develop understanding to support use of 'professional judgement'.

A major barrier to answering questions was formerly the difficulty of obtaining relevant and suitable scale data. This problem is rapidly decreasing with technological advances but to answer current or future questions more effectively we should encourage environmental authorities and organisations to implement monitoring, especially of sediment flux and morphological change. This is becoming more feasible and easier with the technological developments such as UAVs (drones) and SfM (Structure from Motion) and would make available the more frequent and longer-term records that are badly needed for geomorphological analysis. Such developments are already happening with some coastal monitoring, allowing us to measure in detail the effects of individual storms and longer-term cumulative changes.

Overall, all the evidence is of rapid expansion of application of geomorphology in real-world problems and of a growing appreciation of the value of geomorphological contributions and approaches. In the words of some of the professional geomorphologists (personal communications): "Geomorphology overall is getting stronger and making a difference", " Geomorphology is seeing a Renaissance - it is booming and riding the waves", "Users and clients are coming to us [geomorphologists] now". Research and academic geomorphologists are now making the connection between potentially applicable understanding and results, and actual application of their expertise and research to specific problems of varying scale. The future is very bright with the increased acceptance and appreciation, the increased capabilities from both science and technology, and the increased proof that geomorphologists can make a difference in helping to manage the environment more sustainably and even enhance it. The expansion has now provided many employment opportunities for geomorphologists, but such that recruitment of suitable specialists is proving difficult. It is essential that we continue to train geomorphologists in universities and give students and young researchers opportunities for direct experience with companies and user organisations.

6. Conclusions

The title of this paper is a play on words: it is about active, dynamic physical environments such as coasts and rivers that change in morphology over decadal timescales; it is about the changing milieu and frameworks in which geomorphology has been applied over the past five decades; and it is about how geomorphologists have contributed to changing the approach to environmental management and the actual physical condition of parts of the landscape. This paper has reviewed the developments in applied geomorphology over the past 50 yr and analysed the stimuli to development and expansion, highlighting the contributions made, particularly in river and coastal management. Applied geomorphology has been recognised as a topic and component within geomorphology throughout the last 50yr, contributing about 10% of published research papers in the subject. Much geomorphological research has the potential to be applied but actual application of geomorphology leading through to policy, practice or planning outcomes that contribute to sustainable environmental management began to increase in the 1970s and 1980s, mainly through Engineering Geomorphology. It was then transformed during the 1980s and 1990s by participation in development of coastal management strategies and in more holistic approaches to river management. River restoration burgeoned in the UK and Europe from the late 1990s onwards, especially after completion of demonstration schemes. Direct involvement in a range of facets of tackling environmental problems has expanded enormously since then such that now professional geomorphologists are widely employed in consulting companies and statutory authorities. In the UK and Europe the passing of EU legislation, designed to improve ecological and environmental quality of water bodies and requiring geomorphological assessment, was a major stimulus. The incidence of natural disasters has always been influential in environmental policy and practice but the recent occurrence of major river and coastal floods has contributed to an accelerating change in thinking on how dynamic and active environments should be managed. Natural Flood Management, as part of Working with Natural Processes, is now being actively pursued as a policy in Britain. Overall, arguably the greatest contribution of applied geomorphology has been to help transform thinking from one of controlling nature by hard structures to one of 'working with nature' that requires and uses understanding of geomorphological processes, morphology and dynamics to provide sustainable solutions to problems of human impact and human interaction with the environment. Increased awareness and appreciation of the need for and value of the contribution of geomorphology in how this can be implemented and achieved means that geomorphologists are in demand and has created a need for increased training and education in geomorphology. The future for the subject is very bright.

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