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Geomorphology and Society

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Geomorphology and Society

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Preface

The International Geographical Union (IGU) now has more than 40 “commissions”, groups of researchers who focus on a particular theme or subdiscipline of geography. Landscapes and landforms have long been objects of study for physical geographers, and an IGU commission dealing with such matters, under various guises (Geomorphological Response to Environmental Change, Geomorphological Challenges in the Twenty-First Century), has been long been active. The science of geomorphology has been through several transformations, if not revolutions, since its formal inception in the second half of the nineteenth century (Chorley et al. 1964). These include an early twentieth-century focus on “cycles of erosion” (Davis and Penck), the quantitative and systems approaches of the 1960s onward, and a concern with processes and applied geomorphology in the latter part of the twentieth century. Arguably, another transformation is under way, with the growing recognition of the nature and scale of the human impact on Earth that has led to an increasing need to examine the relationship between people and the Earth’s physical environment. Analysis of the reciprocal impacts of people on geomorphology and of geomorphology on people represents an important thrust (not new, as such, but certainly rejuvenated) in the discipline.

Jamie Woodward’s rather alarming evaluation[1] of the declining use of the word “geomorphology” in scholarly books published in English suggests that a new direction for geomorphology is clearly necessary. The IGU’s mission is to foster the diversity of geography and to respond to new developments and iniatives, while at the same time securing its traditional roots. The geomorphic challenges commission, following several years of strong activities in the late 1990s and early 2000s appeared to be in need of some fresh ideas. And so it was, in 2012, that a proposal was put to the IGU General Assembly, at its Congress in Cologne,

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[1] Is geomorphology sleepwalking into oblivion? Earth Surface Processes and Landforms (2014).

Germany, to establish a new commission entitled Geomorphology and Society. The proposal was approved and an initial steering committee, under Professor Alcantara-Ayala as interim chair began its work. The original mission of the commission was stated as follows:

> The aim of the Commission shall be to contribute to strengthening collaborative work among scientific geomorphology networks to advance knowledge and to fostering capacity building for young researchers. Particularly, the Commission will be focused on developing applied geomorphology for the benefit of society.
>
> 1) To promote international collaboration in geomorphology within the IGU community.
> 2) To strengthen scientific cooperation with the International Association of Geomorphologists (IAG) and other international bodies related to the geomorphology field.
> 3) To support applied geomorphology research for building gateways with policy makers and societal engagement.
> 4) To stimulate the interaction among young scientists and the consolidation of leading working teams in different aspects of geomorphology.
> 5) To strengthen the scientific discussion between the numerical, experimental and field observation geomorphologists.
> 6) To foster the exchange of information and the dissemination of geomorphology.
> 7) Holding special sessions of the Commission within the IGU Congress and Conferences, as well as in other academic forums.

The inaugural meeting of the commission took place at the National Taiwan University in Taipei in September 2014. The main theme of the symposium was stated as “Earth Surface Processes in a Dynamic Environment”, with a clear emphasis on the way in which society impacts, and is impacted by, geomorphology. Earth surface processes, climatic change and land-use change are critical issues globally. Regional differences give rise to a diverse array of impacts and scenarios, requiring different approaches for more effective management solutions. The meeting provided a platform for dissemination of research findings of various geomorphologic issues and promoted meaningful discussion among scholars to develop collaboration in the future. A selection of the papers presented at that meeting comprises this volume on geomorphology and society.

We thank Irasema Alcantara-Ayala for the idea and the energy that she put in to getting the commission off the ground and R.B. Singh for suggesting that we try to publish the papers from the symposium. We wish to acknowledge the participants of that inaugural meeting for giving the IGU commission such a positive beginning. The National Taiwan University provided the venue for the sessions for the papers, and we also thank the Ministry of Science and Technology, Global Change Research Center, Department of Geography as well as the Tourist Bureau for their help during the field excursion.

Furthermore, we pay tribute to the team of referees who helped to develop the various chapters of this volume into something more coherent and scientifically sound, including Yazidhi Bamutaze, John Boardman, John Compton, Frank Eckardt, Gerry Garland, Andrew Goudie, Stefan Grab, Trevor Hill, Than van

Hoang, Peter Holmes, Jasper Knight, Olaf Slaymaker, Dieter Soyez, Tom Spencer, and Xiaoping Yang. We of course take full editorial responsibility for any errors that remain and are hopeful that the volume makes a positive contribution to emerging research on geomorphology and society.

Cape Town, South Africa Michael E. Meadows
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Chapter 1
Geomorphology and Society: An Introduction

Michael E. Meadows and Jiun-Chuan Lin

1.1 Introduction

A recent special section of the high-profile science journal *Nature* makes a strong case for the integration of social science into natural science research (for a commentary on this, see Viseu 2015). Of course, Geographers have long realised the importance of a holistic approach to the understanding of processes and problems associated with the interface of people and the environment. Grappling with the idea of developing a clearer picture of how the various factors of the physical environment interact with – and are both affected by and in turn affect – the social, political, economic and even cultural elements of populations is not a new idea. Indeed, George Perkins Marsh laid some of the foundations for this kind of thinking as long ago as the mid-nineteenth century (Marsh 1864). However, it is only recently that the sheer scale of human impact on global environments, arguably best exemplified by the record levels of atmospheric carbon dioxide and the impacts that these have had on global temperatures (IPCC 2013), has been realised. Clearly, as the *Nature* special issue argues '..we have to bring people with different kinds of skills and expertise together. No one has everything that is needed' (Nature 2015, p. 309) and that scientists must indeed '. . .work together to save the world' (Nature 2015, p. 305). This is not, however, a simple question of bolting social science expertise onto funded research projects; rather we must attempt to really integrate the social and natural sciences in a way that is not

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'deeply asymmetrical' as it currently appears to be (Viseu 2015, p. 291). As Kondolf and Piégay (2011, p. 114) have noted '. . .most models of human interactions with natural systems tend to treat the two as separate systems that interact in specific ways, such as return interval of flooding, in many cases the two are directly coupled'.

The need to meaningfully integrate sometimes disparate ways of thinking in order to explore complex environmental problems was at the heart of the establishment of the International Geographical Union (IGU) Commission on Geomorphology and Society, ratified by the IGU General Assembly in Cologne in 2012. The recognition of the dependence of global society on geomorphological processes, the threats that these processes represent as geohazards, and the impacts of humans on landforms and the processes that form them all act as motivation in our efforts to better comprehend the complex set of relationships that these elements entail. The inaugural conference of the new commission was held at the Taiwan National University in Taipei in September 2014 and attracted the participation of geomorphologists, both academic researchers and practitioners, from many different countries. The presentations at that conference form the basis of the current volume, which is aimed at illustrating the imperative of understanding the relationship between geomorphological processes, operating at different spatial and temporal scales, and society. While some of the contributions deal with the impact of geomorphic processes on people, others focus more on how people impact on geomorphology; still others offer a perspective that integrates both elements in suggesting more effective ways of mitigating geohazards in the future.

1.2 A Brief Outline of the Contributions

The nature and scale of human impact on environments in general has led to increasing use of the term 'Anthropocene' as the label for our current geological epoch. Of course, the International Commission on Stratigraphy of the International Union of Geological Sciences had not, at the time of writing, decided whether or not to formally ratify the use of the term as a formal stratigraphic unit. Irrespective of a formal decision to accept (or not) the term as a geological unit, there is a lively debate as to exactly when the Anthropocene actually commenced. In the opening chapter of the book, Meadows argues that, whether we like it or not, the term is here to stay and that, even if only as a pop-culture label, it is symbolic of the sheer magnitude of the accumulated impacts of society on the environment in general and, in the context of this volume, geomorphology in particular. Meadows goes on to suggest that a perspective on the Quaternary offers a foundation to understand baseline earth system conditions against which we can better evaluate the nature and scale of human impact on geomorphology now and in the future.

Soyez chooses a very particular anthropogenic impact to focus on, one that appears to have been rather neglected, if not ignored, by geomorphologists. He outlines various issues associated with the extraction of sand and gravel materials, principally for construction work. Population growth and increasing urbanisation have resulted in an exponential rise in the extraction of sand and gravel resources globally, much of which is not adequately monitored and, in an alarming number of instances, is even illegal. The deleterious environmental effects of this kind of mining are diverse and, since many of these are quite obviously geomorphological, it is interesting that civil society actors, rather than geomorphologists, currently play the dominant role in highlighting the issue and the threats that it poses to sustainability. There is no doubt that the diverse problems associated with aggregate extraction pose challenges (and offer opportunities) that demand research at the interface of human and physical geography.

Taiwan provided a most suitable locational context for the inaugural conference of the IGU Commission on Geomorphology and Society. In his chapter, Lin introduces us to the extraordinary combination of physical environmental and societal factors that yield such dynamic geomorphological conditions in this small sub-tropical island. A combination of earthquakes – the island sits on the northwestern margin of the Philippine tectonic plate – steep togography, high relief, frequent summer and early autumn typhoons together with high urban population densities is a concoction that all too can induce catastrophe. The geomorphic conditions manifest as frequent landslides, river channel dynamics and coastal changes that demand detailed technical knowledge to be combined with a deeper understanding of societal response if such catastrophe is to be avoided in future. In this sense, Taiwan represents an ideal 'laboratory' for the study of geomorphology and society.

Indeed, several other chapters develop case studies that demonstrate the need for closer cooperation between geomophologists, politicians, planners and county and municipal decision-makers in the country. Jen and co-authors document the landslides and debris flows initiated by one of the largest typhoons in Taiwan's recent history, Typhoon Morakot, which brought record rainfall to the country in 2009 and initiated excessive mass movement that had significant impacts on the population. The chapter explores the use of a GIS-based mapping technique to identify areas of landslide concentration (hotspots) as a step in the direction of preventing future problems arising from events of similar nature and magnitude. Shen then examines the need for systematic and accurate land development controls in regard to flood mitigation. She demonstrates, using examples from four selected river reaches in the country, that the delineation of so-called historical fluvial territories (i.e. the geomorphologically active parts of the river floodplain historically prone to inundation during flood events) is an important element of avoiding future disasters related to flooding. Su's chapter explores a slightly different element of the geomorphology and society interface, although the motivation to introduce a solar energy plant to a low-lying part of coastal Taiwan lay in the devastation caused by Typhoon Morakot. She presents a political economy approach to understanding why and how the decision to establish the plant was taken. The various parties include national, regional and local policy-makers as well as individual landowners –all acting out against a background of changes in policy in the face of land subsidence caused principally by tectonic activity.

Japan is, of course, a country that is also associated with high levels of tectonic activity and high relief and so clearly offers pertinent examples of the need to understand landscape morphodynamics with a view to geohazard mitigation. Hayakawa and co-authors utilise very high resolution laser-scanning to produce a recent time series of a mega-landslide, the Ohya-kuzure mass movement feature in central Japan, and in so doing reveal the spatial and temporal pattern of sediment production that provides information vital to the mitigation of possible future sediment-related risks to communities in downstream areas. The chapter by Le et al. presents yet another effective methodology for documenting landslide impacts, this time based on a case study from central Vietnam. The mapping technique employs available aerial photography and reveals that a landslide typology based on morphology can be a useful tool as a preliminary step in determining the susceptibility of populations in different localities. The mass movement theme is further developed by Keiler and Fuchs who, in taking the European Alps region as an example, focus more on the societal/behavioural issues that need to be addressed if a more robust understanding of future geohazard risk is to be obtained. The combination of vulnerability and exposure, along with their connections with mountain geomorphology, emerge as key considerations.

Two of the chapters present cases related to lakes, one describing how land use change and geo-engineering has impacted on sedimentation, the other outlining the impacts of hydroclimate dynamics on lake levels and their subsequent effects on people. Nagao and colleagues describe a situation in central Japan in which changes in the drainage system arising from land reclamation efforts aimed at facilitating food production significantly altered deposition, particularly in relation to increased organic matter inputs. Although this is less obviously a ‘geomorphological’ perspective, it does illustrate how human actions, often aimed at increasing productivity of the land, can have unintended consequences for sediment supply in vulnerable low-lying lakes and wetlands. In the central Rift Valley of Kenya, a series of lakes which are of vital importance to livelihoods of the local population are shown by Obando and her co-workers to be very sensitive to hydroclimate dynamics. More particularly, rainfall in the catchments of these four lakes has, since 2010–2011, been well above the long-term mean, most likely associated with El Niño conditions. This has significantly increased lake levels and applied considerable stress to several aspects of the natural environment such that local communities have been severely impacted as a consequence. Of course the trend in rainfall amount and distribution is a key element of soil erosion and needs to be carefully accounted for in modelling soil loss. Sumner et al. review our understanding of the issue of rainfall erosivity and its importance for accelerated soil erosion risk assessment. They note that, in the case of Mauritius (incidentally another small subtropical island), where cyclonic rainfall events (these would be called ‘typhoons’ in Asia) would usually be thought as most significant in the context of soil loss are supplemented by rainfall from winter cold fronts and can also be very important drivers of increased erosion.

The last two chapters of the book deal with coastal geomorphology, a sub-category of the discipline that classically illustrates the interdependency of landforms and people. Coastal morphodynamics are very strongly impacted by both the direct (e.g. coastal development) and indirect (e.g. sea level caused by anthropogenic climate change) effects of people. Regnauld and colleagues use an example from western Brittany to illustrate that even major human-induced geomorphic impacts (in this case the almost complete removal of a coastal gravel bar for construction during the second world war) can be effectively managed in a way that enables natural environmental processes to recover. This involved a complex series of management (and mismanagement) interventions over time but has culminated in a situation whereby the coastal barrier and marsh system is now an important and valuable site of conservation. The need to integrate our understanding of sediment systems in relation to estuaries and coasts is the focus of the study by French et al. for a part of the Suffolk coast of England. They employ a new coastal mapping approach that captures not only the natural dynamics of the system under varying environmental conditions (including sea level rise of course) in a robust way, but also accounts for the multiplicity of human responses that interact with the predicted shoreline changes. The authors document an innovative participatory approach that can be applied to a more complete understanding of the challenges of living at the coast and, in this way, provide an excellent example of what it means really to integrate geomorphology and society.

1.3 Prospective

Geomorphology is a complex science that requires multiple levels of understanding of a wide array of features and processes operating at a range of spatial and temporal scales. The individual and unique nature of the geomorphology of the earth's surface led Schumm (1991) to employ the term 'singularity' in relation to landforms. His argument in essence is that that the sensitivity of landforms to external forcing (including human activity) varies to some degree between apparently similar systems and even within the same system under the same conditions. Phillips (2015) has even gone as far as to suggest that geomorphology is 'badass' in that its processes, illustrated in his case by the meandering of a section of the Kentucky river, is individualistic, non-conformist in a way that makes their understanding additionally difficult (but also more interesting). The various chapters in this volume illustrate that the challenges of resolving geomorphological processes are in themselves substantial but that, as soon as the societal element is introduced, the complexity and challenge escalates further. Thus, integrating geomorphology and society is no trivial exercise, but the efforts to do so are all the more important in these times of rapid change in environmental processes and, indeed, in global society at large. That these contributions are brought together in the form of a book, rather than as a special issue of a specialised journal, is all the more important given Woodward's (2015) quite alarming observation that the use of the term 'geomorphology' in monograph titles has dramatically declined in the last few years. We hope that this volume will in some small way help to communicate the importance of our discipline to a broader community of scientists and social scientists.

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Chapter 2
Geomorphology in the Anthropocene: Perspectives from the Past, Pointers for the Future?

Michael E. Meadows

Abstract The term Anthropocene has been introduced to highlight the fact humans have, directly or indirectly – accidentally or intentionally – profoundly transformed the earth system. There is much debate as to whether the magnitude and extent of such change is geologically distinctive and, accordingly, warrants formal designation as a new epoch although, irrespective of this, the magnitude of change is undoubtedly significant. In order to put the Anthropocene into perspective, the chapter briefly reviews various systemic and cumulative drivers of geomorphic change before going on to explore the time-transgressive impacts of humans on virtually all environments of the earth. This is followed by a consideration of three instructive case studies of how the deleterious effects of growing numbers of people using increasingly sophisticated technologies are expressed geomorphologically across a range of environments. The problems of accelerated soil erosion, the impact of large dams and the nature and extent of artificial ground are used to highlight the important role that geomorphology plays in understanding the burgeoning footprint of humanity on earth systems. The Quaternary record offers a foundational understanding of baseline conditions of earth system processes and responses and facilitates increased confidence in evaluating the magnitude of past and future global climate change and its diverse effects. A quarter of a century on from the first IPCC report, the degree to which the strength of its statements, and the confidence with which they are made, is rooted in a better understanding of longer-term past changes should not be underestimated. The fact that geomorphology may still be a 'Cinderella' in relation to studies of environmental change is ongoing cause for concern and, if we are to illuminate the range of options available to mitigate and adapt to future change, we need systematically to incorporate a stronger geomorphological perspective into global change science; the Anthropocene represents an appropriate platform from which to inject that perspective.

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2.1 Introduction: The Anthropocene

The term 'Anthropocene' was introduced to the world of science at the turn of the new millennium (Crutzen and Stoermer 2000) and it is now very widely employed, although not without controversy, to describe the current geological age. There are now three academic journals using the word in their titles (*Anthropocene*, *Elementa – Science of the Anthropocene* and *Anthropocene Review*) and it is clear that, notwithstanding heated debate around its definition, Anthropocene as a label is here to stay. The term was originally proposed to highlight the increasing impact of humans on the environment to the point of their dominance over other 'natural' processes. Thus, anthropogenic activities were considered global in their extent and so potent in their effects that geologists of the future would be able to examine the sedimentary record and see a marked shift from a dynamic world dominated by natural processes to an even more dynamic one characterised by processes directly affected by people. Hence, in the future it would be possible to look back and see in the geological record where the Holocene ended and the Anthropocene began. In essence, this led to the concept of 'a geology of mankind' (Crutzen 2002).

Although the idea of human impact is not new, since George Perkins Marsh wrote the first systematic account of how people transformed the earth surface through deforestation and the like 150 years ago (Marsh 1864), it is the idea that human effects now outweigh natural changes that has prompted the need to consider the naming of a new geological epoch. While much of the debate has focused on what criteria should or could be used to identify the Anthropocene (see Steffen et al. 2011; Ruddiman 2013) and, accordingly, how and when should its starting point be defined (Smith and Zeder 2013; Foley et al. 2013), this chapter rather focuses on the nature and scale of impact in relation to geomorphological processes and landforms in particular. It is not my intention here to enter the debate as to whether or not use of the term is valid or, if so, when the epoch actually began. As Braje and Erlandson (2013, p. 116) put it '. . .Designating a starting point for the Anthropocene may be less important than understanding the cultural processes that contributed to human domination of Earth's natural systems' and in any case, formal ratification is in the hands of the International Union of Geological Sciences (IUGS) through a working group of its International Commission on Stratigraphy (and see Waters et al. 2014). Indeed, rather than arguing about the precise identification of an Anthropocene 'beginning', Butzer (2015) suggests that a more flexible, time-transgressive approach would more fruitfully stimulate study of human disturbance of the global environment. It is, nevertheless, important to understand the environmental processes by which human impacts were manifested and that geomorphologists need to play their part in elucidating these. The aim here, therefore, is to use the idea of the Anthropocene as a lens through which geomorphologists can develop research which contributes more directly to a better understanding of the relationship between society and landforms and the processes that shape them. Brown et al. (2013) suggest that there could well be a 'geomorphological case' for the Anthropocene and Lewin and Macklin (2013) have already assessed the possible value of a formally defined Anthropocene for geomorphologists. Whether we recognise the Anthropocene or not, further exploration is still needed of the nature and magnitude of societal impact on geomorphic processes in a variety of geographical contexts and at a range of scales. Only through such studies can we begin to understand and address the resultant problems and seek the means to a more sustainable future.

To begin this discussion, it is first necessary to consider the different 'drivers' of geomorphic change and to explore their relative importance in shaping landforms. Following a brief consideration of the magnitude of human impact on the earth's system, the chapter moves to an exploration of several key case studies illustrating the nature and scale of human modification of landscapes. In considering the use of evidence from the late Quaternary, the relatively recent geological past, the scale of human-induced change can perhaps be benchmarked. Finally, there is contemplation of how prospective environments may develop and how geomorphologists can usefully contribute to current thinking about a more sustainable future.

2.2 Drivers of Geomorphic Change

In relation to global environmental change, Slaymaker et al. (2009) recognise two major forms of 'driver' in geomorphology, sets of processes that have shaped, and continue to shape, the landforms around us. These are the so-called 'systemic' and 'cumulative' drivers of change. Paramount among the systemic drivers are those related to the hydroclimate and its relationship to surface runoff. The hydrological cycle is obviously sensitive to change in global climate but the geomorphic effects are strongly scale-dependent and not necessarily easily accounted for. Runoff is influenced by such processes as land use change, which is spatially discontinuous and complex. Land use change can have net positive effects on runoff volume, for example when forest is replaced by agriculture with much lower biomass and land cover (Muñoz-Villers and McDonnell 2013), but can equally restrict runoff volumes in situations where the change results in increased biomass and evapotranspiration, such as when Mediterranean-type shrublands are invaded by alien trees (le Maitre et al. 1996) or through afforestation (Iroumé and Palacios 2013). Substantial geomorphic impacts are produced by other common human interventions, such as the construction of impoundments which in some cases stop even major rivers from running to the sea altogether (Biemans et al. 2011). Therefore, in so far as people can manipulate the hydrological cycle and climate, intentionally or otherwise, such processes are an important means by which society affects geomorphology.

The second major systemic driver according to Slaymaker et al. (2009) is sea level change. Through the global effects of anthropogenic climate change, sea level is rising mainly through the combined influence of increased runoff due to ice sheet melt-out and thermal expansion of the ocean itself as a result of higher temperatures. There are obvious implications here for coastal geomorphology, with impacts likely on estuaries, coastal marshes and dunes, beaches, cliffs, deltas and coral reefs that can all be considered, indirectly at least, geomorphological consequences of human-induced climate change.

Topographic relief and human activity are classified as cumulative drivers of the earth system by Slaymaker et al. (2009). Except perhaps at the local scale, topographic relief, despite its marked importance for denudation, is essentially a longer-term, if dynamic, influence on geomorphology and is not considered further here. But human activity as a cumulative driver, over and above the secondary effects wrought through climate change and associated effects on the hydrological cycle and sea level, is patently an essential focus in the context of this chapter in particular and the book in general. In regard to this, Slaymaker et al. (2009) divide the important factors into direct and indirect. Indirect factors include the essential social and economic features of the human society, for example population growth, cultural practices, trade and industry. These are obviously highly complex issues and spatially extremely dynamic although the authors point to the growth of the world's population, especially in the second half of the twentieth century, as perhaps the most potent indirect driver in this category. The world's people are increasingly urbanised and increasingly concentrated at or rather near the coast or regions otherwise prone to flooding (Jongman et al. 2012) with implications for the location of geomorphic impacts.

2.3 Time-Transgressive Human Impacts on the Earth System

The debate around use of the term Anthropocene has in part centred on the difficulty of establishing when it actually commenced. This a common kind of problem in stratigraphy, where one geological time unit ends and another begins is always a cause for deliberation and sometimes a source of dispute, but the case for the Anthropocene is especially challenging because substantial impact of humans on the earth system has been spatially uneven and time-transgressive. Human modification of the earth has arguably been significant for more than 8000 years (Ellis 2011) with major land use changes a characteristic of the Neolithic 'revolution'. Mass extinction of mega-fauna, a process in which humans certainly played their part through hunting, occurred even earlier. But the scale of transformation was not of a similar magnitude everywhere in these earlier phases of impact and the 'palaeoanthropocene' (Foley et al. 2013) is equally difficult to pin down. Ruddiman (2013) makes the point that the first major human impact on atmospheric greenhouse gas concentrations occurred in the mid-Holocene as a result of land use changes, more especially deforestation, and that it was at this point that the atmospheric condition of the current interglacial began to diverge from the pattern typical of other interglacials of the late Quaternary. However, many others argue that the most profoundly global human impacts have occurred since industrialisation of the global economy and especially in the post second world war period increasingly referred to as the ‘Great Acceleration’ (Costanza et al. 2007) because of the directional trends observed in so many diverse parameters related to human activity and the parallel trends in features of the earth system.

The geomorphological implications of such dramatic changes are important as landscapes have become transformed through the combined effects of agriculture, forestry, mining, water storage and diversion and urbanisation as well as the indirect consequences of changing climate and sea level. Land use change is perhaps the most obvious direct form of human intervention with immediate geomorphic consequences. To put this into context, Ellis (2011) has modelled the degree of transformation across global biomes and arrived at the conclusion that people had already converted substantial proportions of the earth’s terrestrial biomes into what he terms ‘anthromes’ (see Ellis et al. 2010) by the year 1750. Hooke et al. (2012) review the scale of land transformation and suggest that rather more than 50 % of the earth’s terrestrial surface had been modified by the year 2007 (Table 2.1). Human appropriation of global net primary productivity has doubled in the last century and now more than 25 % of every gram of carbon fixed through photosynthesis is directed to human use (Kraussman et al. 2013). Of course, this human ‘footprint’ is spatially irregular and regions within the tropical and temperate woodland biomes have been especially impacted along with vast areas of the Middle East and the Indian subcontinent (Kareiva et al. 2007). Such statistics prompted Ellen Wohl (2013) to lament that, in effect, ‘wilderness is dead’.

2.4 Human Impact on Geomorphology

Some examples of geomorphic changes that have accompanied the monumental dimensions of this scale of modification are apt here (Table 2.1). Syvitski et al.’s (2005) analysis suggests that, while accelerated soil erosion has increased sediment transport by rivers globally by 2.3×10^9 t a^{-1}, this has been accompanied by substantial reductions in sediment flux to the oceans (by 1.4×10^9 t a^{-1}) because of sediment storage in reservoirs. Indeed, reservoirs around the world now store more than 100 billion metric tons of sediment (Syvitski et al. 2005). Globally, large impoundments retain more than 2.3 Gt of sediment annually, resulting in sediment starvation of deltas which, combined with the extraction of water, oil and gas, results in a situation whereby deltas are sinking at four times the rate of sea-level rise (Syvitski 2012). More than 50 % of Earth’s ice-free land area has been directly modified by human actions involving moving earth or changing sediment fluxes (Hooke et al. 2012).

Table 2.1 Land area modified by human action (Hooke et al. 2012)

Activity	Area involved 10^6 km^2	% of earth's land surface
Human modified land		
Cropland (mostly cultivated or ploughed land)	16.7 ± 2.4	12.8 ± 1.8
Permanent meadows and pastures	33.5 ± 5.7	25.8 ± 4.3
Land area modified by deposition of eroded sediment	5.3 ± 2.0	4.1 ± 1.5
Land area modified by logging	2.4 ± 1.2	1.8 ± 0.9
Plantation forestry area	2.7	2.1
Sub-total agriculture and forestry	**60.6 ± 6.5**	**46.6 ± 5.0**
Urban areas (including urban roads)	3.7 ± 1.0	2.8 ± 0.8
Rural housing and commercial developments	4.2 ± 1.4	3.2 ± 1.1
Highways and roads in rural areas	0.5 ± 0.1	0.4 ± 0.1
Reservoirs	0.2 ± 0.1	0.2 ± 0.1
Railways	0.03	0.02
Mining and quarrying	0.4 + 0.4/−0.1	0.3 + 0.3/−0.1
Sub-total human infrastructure	**9.0 ± 1.7**	**53.5 ± 5.1**
Total land area modified by humans	**69.6** ± **6.7**	**53.5** ± **5.1**
Natural lands (mostly)		
Forest area (natural, if not necessarily virgin)	36.2 ± 2.9	27.8 ± 2.2
Other land (mainly high mountains, tundra, deserts etc.	24.3	18.7
Total natural land area	**60.5**	**46.5**
Total land area (excluding ice sheets)	130.1	100.0

Table 2.2 Human actions that modify geomorphic systems (After Syvitski and Kettner 2011)

Deforestation and its associated role in soil erosion, slope failure and downstream sedimentation,
Farm-animal grazing leading to gully development and soil erosion,
Agriculture, including tillage, terracing, irrigation systems and subsurface
Water extraction, leading, respectively, to increased soil erosion, creep, siltation and subsidence,
Mining and its associated role in river channel and hill slope alteration, slope instabilities and subsidence,
Transportation systems, including gully development, soil erosion and riverbed scouring,
Waterway re-plumbing, including reservoirs and dams, diversions, channel levees, channel deepening, discharge focusing and ultimately coastline erosion,
Coastal management through groynes, jetties, seawalls, breakwaters and harbours, leading to unnatural coastal erosion or sedimentation, wetland, mangrove and dune alterations,
Warfare that magnifies many of the above activities for a duration that extends beyond the period of combat, and
Global climate warming and its impact on coastal inundation, precipitation intensity, including the intensity of cyclones, desertification and an accelerated hydrological cycle

A diverse range of human actions is known to modify geomorphology (Table 2.2). Some of these impacts warrant exploring in greater detail as they are symbolic of the scale, magnitude and complexity of geomorphic challenges imposed by humans and point geomorphologists in the direction of where to focus their efforts. The three examples chosen here to elaborate on this are: (a) accelerated soil erosion; (b) the impacts of large dams; and (c) the growth in artificial ground.

2.4.1 Accelerated Soil Erosion

Dotterweich (2013) recently reviewed global evidence of the long-term history of soil erosion in humid and semi-humid landscapes and records; the earliest available historical documents describing soil erosion are from Greece and China from about 2500 years ago and the process is widespread in many types of environments. The initiation of accelerated rates of soil loss is most often land use change, in particular the clearance of forest in woodland in environments that support such vegetation but it is also prevalent in semi-arid regions as well, albeit not always confined to soil erosion by water because wind too is a potent geomorphic force. In order to assess the degree to which agriculture and other activities have resulted in increased soil loss and sediment delivery, it is instructive to consider how the process of natural erosion operated in the 'pre-human' era. Wilkinson and McElroy (2007) have engaged in such an exercise for the contiguous United States and compared the estimated spatial distribution and magnitude of long-term 'natural' soil erosion with those of the latter part of the twentieth century as measured, or modelled to be more precise, on cropland. The resulting maps are strikingly akin to mirror images of each other in that the denudation rates have highest values in the western half of the country whereas the cropland map shows elevated rates in the central and eastern states. Beyond the contrast in the spatial distribution of denudation, the magnitude is also markedly different; rates of erosion on agricultural land are estimated at an average of 600 m Gyear^{-1} and, in some places exceeding 2000 m Gyear^{-1} in comparison with values below 15 m Gyear^{-1} or less in equivalent areas prior to the land use change (Wilkinson and McElroy 2007). The analysis indicates an acceleration directly due to human modification of more than an order of magnitude and leads the authors to the conclusion '…that farming practices are the most important processes of erosion acting on the surface of modern Earth' (p. 150). Wilkinson and McElroy (2007) go on to argue that, combined with the accelerated erosion of the sediment itself, subsequent deposition of the material of floodplains '…is the most important geomorphic process…currently shaping the landscape of Earth (p. 140)'. The significance of this surpasses even the effect of continental glaciation during the Quaternary or the modern rates of erosion by glacio-fluvial processes.

In semi-arid and arid environments (Goudie and Middleton 2006), but also under agricultural land use in sub-humid or even humid regions (Borrelli et al. 2014; Biemans et al. 2014), accelerated soil loss due to wind erosion is a significant geomorphic force. Globally, large volumes of mineral dust enter the atmosphere and an increasing proportion of these aerosols emanate from areas that have been significantly impacted by humans. Undoubtedly the rate of erosion of fine particles is significantly increased where vegetation cover is reduced in grazing and croplands. Furthermore, increased temperatures and reduced soil moisture due to anthropogenic climate change is likely to exacerbate the problem. For example, conditions that resulted in the North American ‘Dust Bowl’ in the 1930s were certainly amplified by agricultural mismanagement (Cook et al. 2009) and evidence suggests that such conditions are more likely to occur again as a result of climate change (Seager et al. 2007).

Soil erosion is, of course, not necessarily an irreversible environmental problem and there are many cases of degraded land being rehabilitated. Accelerated erosion that occurred in the wheat farming regions of the Cape Town (South Africa) hinterland in the 1930s was addressed through investment in soil conservation works and farmer education; gullies were reclaimed, contours constructed and the land once again became productive (Meadows 2003). It is becoming increasingly clear that soil conservation efforts need to address more than the basic biophysical processes and that solutions founded on an enabling policy environment that integrates the land-user perspective are much more likely to be effective (Dumanski 2015).

2.4.2 Geomorphic Impacts of Dams

Large dams have diverse effects on a range of geomorphological characteristics that have been widely reported, especially in the downstream direction. Graf (2006) analyses above and below impoundment reaches of 72 large North American rivers and documents impacts that amount to a ‘shrunken and geomorphologically simpler’ downstream environment (p. 336). Regulated reaches have significantly less active flood plain areas and greater inactive flood plain areas. The cumulative effect of reservoir management and irrigation extractions leads to a mean annual decrease in global discharge of almost 1000 km^3 (Biemans et al. 2011; Gerten 2011) and, although this represents only about 2 % of discharge, there are seasonal fluctuations resulting in periodically more substantial effects and many rivers where the hydrological impact is of geomorphic significance.

Rather than reduction in discharge per se, geomorphologically it is the impact of impoundments on river sediment load that is of most importance. This is exacerbated by the fact that the number of dams, both small and large, has grown exponentially in the last century or so, both in the developed and developing world. There were no dams in North America in the year 1800, although there has been extremely rapid increase in construction across the region since then; indeed, humans ‘. . .have engineered how most water and sediment are discharged into the coastal ocean’ (Syvitski and Kettner 2011, p. 957) and the global influence on sediment flux is considerable. Gupta et al. (2012) review the situation in southeast Asia where there are now 250 mega-dams and tens of thousands of smaller impoundments that have decreased sediment flux in the order of 20–90 %. In some rivers, sediment flux has been so interrupted by impoundments that only negligible amounts of sediment now reach the coast from their catchments, for example the Ebro in Spain (Walling 2006). In the case of the Three Gorges Dam, the world's largest, 1.8 Gt of sediment were trapped within the first decade following its construction and there were some periods when more than 90 % of the upstream sediment load was deposited; sediment thickness already exceeds 60 m in places (Yang et al. 2014).

There are numerous detailed examples in the literature of the potential geomorphological and hydrological implications of sediment starvation downstream of reservoirs. Petts and Gurnell (2005) note the changes in channel form that dams invoke and the knock-on impacts of this for irrigation ecology of riparian vegetation. For south-east Asia, one large-scale outcome, among many others, is the marked reduction in the extent of some of the largest deltas in the continent (Gupta et al. 2012). All five of the major rivers that drain into the East Pacific Ocean have experienced dramatic reductions in sediment delivery to the sea (Wang et al. 2014). Delta shrinkage is predicted to accelerate in the future; Syvitski et al. (2009) have estimated that, globally, delta surface area vulnerable to flooding could increase by 50 % under projected sea-level rise estimates due to losses in aggradation and other processes (Syvitski et al. 2009). There are obvious implications of this for the large populations living or obtaining their livelihoods on deltas. Downstream channel incision is also an important issue resulting from clearwater erosion due to sediment trapping by the impoundments. The balance of erosion or sedimentation in rivers is complex and dynamic with a number of controlling factors, but there is little doubt that sediment retention in impoundments can dramatically alter the equilibrium.

2.4.3 Excavation and the Creation of Artificial Ground

The magnitude of rock and soil material moved around the surface of the earth by humans in mining or construction, for example, is a geomorphic effect of humans that manifests as landforms. Ever since the first people began to excavate stone to make implements or discard waste material in 'middens', there has been direct and intentional human modification of the actual land surface of the earth. Price et al. (2011) report the scale of this to be enormous, with almost 60Gt of excavated material annually translocated, sometimes long distances from its source, and that this is almost three times the amount transported by the world's rivers. This represents deliberate modification arising from the creation of made ground, worked ground or infilled ground resulting from a range of activities including mining, construction, industry, ore-processing, solid waste generation, transport infrastructure development and land reclamation. Of course inadvertent movement of material also occurs due to processes of accelerated soil erosion (see above) and this also needs to be taken into consideration when assessing the magnitude of human effects on landforms.

Table 2.3 Summary of artificial ground in a selected regions of Great Britain based on 1: 50,000 scale geological map sheet areas and the maximum coverage of artificial ground shown by BGS DiGMapGB10 10,000 maps (After Price et al. 2011)

UK location	Sample area (km^2)	Mapped artificial ground area (km^2)	% artificial ground in sample area	Principal sources of artificial ground
Manchester city (large industrial conurbation)	559	99	17.8	Subsurface and open cast mineral extraction, textiles and engineering, industrial development, canals, construction and demolition
London area (large urban and peri-urban conurbation with multiple industrial centres)	2196	181	8.2	Dockland development, open cast mineral extraction, commercial development, construction and demolition
Midland Valley, Scotland (rural with multiple urban and industrial centres)	2297	185	6.2	Coastal industrial development, opencast and subsurface mineral extraction, metal processing

These effects are indeed so prominent that there is now a formal proposal to recognise so-called anthropostratigraphic and technostratigraphic units of classification for Holocene deposits (Howard 2014). Peloggia et al. (2014) have suggested the use of the term ‘geotechnogenic ground’. Ford et al. (2014) also argue for the need for a separate classification scheme for such sediments and Lewin (2013) has even gone as far as to suggest that some landscape elements, for example, modern floodplains, have in effect been ‘genetically modified’. There are practical difficulties in accurately assessing the distribution of such artificial landforms and associated sediments, either because the excavation or the resultant landforms are often obscured by the very activity that creates them, although Jordan et al. (2014) have developed a possible methodology and applied it to a case study of the Norfolk coast.

Some examples from Britain are helpful in revealing the scale of this process, at least for the industrialised world. In some cities, for example, Manchester, artificial ground occupies as much as 18 % of the urban area, although this may be an underestimate (Burke et al. 2009 after Price et al. 2011) and includes colliery spoil, infilled gravel and brick pits, industrial waste and reclaimed river valleys (Table 2.3). Such assessments have benefitted from the use of remotely sensed spatial data (aerial photographs, satellite imagery, digital elevation models) which increasingly allow time-series to be mapped, especially if used in conjunction with other documentary sources. Made ground in Salford, which may exceed 10 m in thickness, includes material, mainly colliery spoil and furnace waste, used to infill the former course of the River Irwell and deposited next to the Manchester Ship Canal (Price et al. 2011) during the late nineteenth century. The identification and mapping of artificial ground is but one further means by which we may judge the nature and magnitude of the human geomorphic footprint. As with anthropogenic soils, such deposits may yet represent the 'golden spike' of the Anthropocene (Certini and Scalenghe 2011).

2.5 Perspectives from the Past: The Quaternary Benchmark

In deliberating as to whether or not the term Anthropocene should be formalised, one of the key issues is to assess the degree and extent to which human activities have come to dominate global earth system processes. In other words, have humans transformed global environmental processes in such a way as to deflect the natural course of events in some clearly identifiable way? In reality, such a question is unanswerable without recourse to evidence from the past, for if we do not know what is the longer-term 'pulse' of the earth system, i.e. what indeed is the 'natural course of events', we cannot begin to evaluate the magnitude of human impact. This is not a novel idea of course, since geomorphologists have long recognised that understanding landforms and the processes that shape them cannot be comprehensive if it is based only on 'snapshots' of the contemporary situation or recent past. As Meadows (2012) argues, reliable reconstructions of palaoenvironments are essential to our meeting the environmental challenges of the future. The recently published Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5) (IPCC 2013) fully accepts this and, for the first time, contains a chapter dedicated to the use of palaeoclimate archives, in particular from the Quaternary, as a benchmark of earth system sensitivity. 'This offers a foundational understanding of baseline conditions of climate and on other components of the earth system and allows increased confidence in evaluation of the magnitude of past and future global climate changes' (Meadows 2014, p. 1). In other words, to quote Winston Churchill: 'The farther back you can look, the farther forward you are likely to see'.

However, this is not simply a matter of applying reconstructions of the Quaternary past to predict the future. Knowledge of the way environments changed, even in the geologically recent past, cannot be a kind of 'plug and play' to foresee how landscapes will respond, for example, to a given range of predicted climate parameters. Knight and Harrison (2013) have, however, gone as far as to argue that earth scientists may need to abandon the concept of uniformitarianism altogether as it pertains to the Anthropocene and that '…traditional systems' properties such as equilibrium and equifinality are increasingly irrelevant (p. 5). This is certainly a provocative view and to accept it uncritically would be to ignore a great deal of evidence about the sensitivity of the earth to wide range of perturbations beyond those invoked by human activity. There are in fact several ways in which developing robust analyses of past environmental changes can provide a valuable perspective that may lead to more effective management of the environmental challenges of the future, although this requires continued improvement both in methodologies and in the way in which data are provided (McCarroll 2010; Meadows 2014).

Are reconstructions of the Quaternary past helpful in evolving scenarios of future responses of the earth to climate change and does that have geomorphological relevance? The fifth assessment report of the IPCC (AR5; IPCC 2013) adopts reconstructions of past climate as benchmarks which can be used to train climate models. Put crudely, complex ocean-atmosphere models need to be able adequately to reconstruct known climates of the past otherwise we can hardly expect them to be able to accurately predict climates of the future. Climate models are required that generate credible scenarios of the future, making available data of relevance to geomorphic processes at a range of different spatial scales. This can best be done through identifying how landforms and the processes that shaped them responded to changes in the past and indicates the degree to which geomorphology is sensitive to the dynamics of climate and other variables, including human activity.

In essence, the past is a reference or archive against which to quantify the anthropogenic effect. Benito-Garzón et al. (2013), for example, have computed long-term climate anomalies between the mid-Holocene and IPCC-generated future climate scenarios to provide a comparative perspective on the magnitude of differences in climate across time. This is then applied to a model of biome changes but it could just as easily be adapted to deal with key geomorphological parameters such as sediment flux. In reality, landscape sensitivity can only really be properly assessed by examining the response to perturbations of the past.

Ecologists utilise the concept of a ‘historical range of variability’ and this is also applicable to assessing the geomorphic response to what may be considered the ‘natural’ amplitude and frequency of environmental dynamics (Wohl and Rathburn 2013). The degree to which human activities might result in exceeding historical thresholds of equilibrium represents yet another possible palaeoenvironmental line of inquiry for geomorphologists interested in applying their minds to issues of more practical significance, such as the susceptibility of channels to incision (Florsheim et al. 2013).

Arguments have been made for utilising past environmental analogues, in particular the identification of periods of time when the earth’s climate was as warm, or warmer than today. What transpired geomorphologically during those times? Obviously at a rudimentary level this is far too simplistic, not least because past boundary conditions are usually very different from the modern and, as is evident throughout this volume, the impact of humans on the global environment is so profound that any information about, say, past rates of soil erosion in response to warmer temperatures may be meaningless. Indeed, ‘. . .no interval during the last 650,000 years is extreme enough to be an indicator of late twenty-first century climate’ (Haywood et al. 2009, p. 5). Surprisingly, then, the search for analogues is ‘not over yet’ (Meadows 2012, p. 542). One especially promising candidate for a ‘palaeoanalogue’ is is the so-called Palaeocene-Eocene Thermal Maximum (PETM) event (Bowen and Zachos 2010). Enormous amounts of carbon were released into the earth’s atmosphere around this time (c 55 Ma) over a relatively short period (perhaps 20 ka) and, indeed, the effects were long-lasting, as has been