

GEOMORPHOLOGY IN ENVIRONMENTAL MANAGEMENT AND SOCIETAL DEVELOPMENT

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She is a genius of sadness, immersing herself in it, separating its numerous strands, appreciating its subtle nuances. She is a prism through which sadness could be divided into its infinite spectrum. She is a victim of flash floods occurred with maximum ferocity on 17 kilometer long stretch between Gaurikund and Kedarnath (Uttarakhand).

Abstract: *Landscapes is intimately concerned to the echo system. The change of landscape is a continuous process which decipher template on which life functions and dictate human activities which exist in a particular place. Such as steep landscape tend to demarcate human and agricultural development; costal landscapes supports wet land nursery habitats crucial to the world's marine life and also sustain myriad human industrial, agricultural, and economic activities around major population centers. The function of Biological influences on human actions clearly affects landscape-forming processes, helping steer landscape change. Wetland vegetation plays decisive role in determining how coastal morphology and ecosystems respond to sea-level rise and land-use changes alter the feedbacks between biological and physical processes in particular environments. In mountainous regions, vegetation dictates the shape of the whole landscape; very effectively humans efforts may alter vegetation cover for spatial effect of land use.*

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The stiffness of the surface and rigid ground changes, perfectly affects humans. The central theme of the study of earth science is the Geomorphology which is very scientific and emerging subject of earth surface. It stands in the center of study of the Earth's surface, where strong couplings link human dynamics, biology, biochemistry, geochemistry, geology, hydrology, geomorphology and atmospheric dynamics, including climate change. It is now pursuing to address the feedbacks between geomorphology and these connected disciplines.

Adaptive environmental management on a changing globe requires rapid advancements in the understanding of Earth-surface dynamics; understanding these dynamics will allow influencing the habitats in a purposeful manner. In this study it is asserted novel investigative approaches being applied at the fast-expanding frontiers of Earth science address the principal challenges presently facing the Geomorphologists and expect the future of Earth science.

Keyword: Geomorphology, Environmental management, societal development, Hazards,

Geomorphology, as a science, has moved beyond description to yield explanations and predictions of landform change, but as a relatively young discipline marked by rapid development from different origins, it is perhaps not surprising that the subject has been characterized by multiple, often competing, methods and perspectives. These dimensions result in *considerable* scope for social and environmental uncertainty. Instead, it is concerned basically with the 'application of skill' in extending the predictability of environmental manipulation from a Geomorphological appearance. Geomorphology, as the study of the origins and evolution of Earth's landforms and the processes that shape them, is obviously part of the disciplinary scientific basis of environmental management, and there is a long-standing concern with 'applicable' Geomorphology (Gregory, 1979) that investigates Geomorphological processes and resulting landforms under the influence of human activity. Graf (2005) finds that geomorphology has been closely associated with public policy and land use management. In the 1st half of 20th century, Grove Karl Gilberts' and other Geomorphologists studied for the US Geological Survey (Gilbert, 1890, 1914, 1917). While few applicable geomorphology studies happened through the first half of the 20th century. Geomorphology has both re-united and increasingly strengthened its association with management applications since that time through process-based studies beginning with Horton (1945) and chapters by Leopold (Leopold, 1956) and Strahler (Strahler, 1956) in the seminal publication *Man's Role in Changing the Face of the Earth* (Thomas, 1956). By the century's end, Graf (1996: 443) contended that:

Geomorphology as a natural science is returning to its roots of a close association with environmental resource management and public policy..... there is a new emphasis on application of established theory to address issues of social concern.

In this article, it will be first considered that the evolving role for geomorphology in environmental problem-solving and the ways in which Geomorphological services are provided to environmental managers and societies. Four specific roles for geomorphology in environmental management and societal development are exhibited, namely applications to natural hazard avoidance and reduction, environmental restoration and conservation, the sustainable development of natural resources. Evidence from these findings provides the basis for suggesting some core skills and standards required by applied Geomorphologists. Finally, it is assessed that the potential role of geomorphology in societal development that argue truly successful applications will demand re-conceptualizing management problems and development

from a geomorphological perspective, and not simply applying geomorphology within the constraints of traditional management practice.

Geomorphological application in environmental management.

The process and style of Geomorphological association in environmental management has extended for a long period. Scientifically, the geomorphology has continued to provide technical expertise and tools that allow its applied scientists to better deal environmental problems. Notable in this regard has been the greater availability of predictive tools, frequently stemming from GIS-based terrain modelling, with which to evaluate alternative management scenarios, thus increasing the visibility and transparency of geomorphology-centered solutions. Socially, environmental managers and the public have gradually recognized the relevance of geomorphology in problem-solving, leading to greater numbers of Geomorphologists interacting with public policy. In tandem with a growing public awareness that environmental situations are important in deciding human quality-of-life (since at least Rachel Carson's 1962 book *Silent Spring*), scientific studies of the impacts of humans on ecosystem processes have increasingly highlighted their Geomorphological underpinnings. Consequently, Geomorphologists have been asked to tackle an ever-broadening variety of environmental management and development problems.

The existence and supports of fluvial and coastal geomorphology to environmental management in India is illustrative. Original engineering solutions based on dominating and controlling nature had no place for geomorphology, but a subsequent shift from 'hard' to 'soft' engineering solutions ushered in what Hooke (1999) calls the 'first phase' of geomorphology application, based on the recognition that landforms change naturally during the lifespan of an engineering project and that projects disrupting natural geomorphic processes were frequently causing deleterious effects elsewhere. A second phase occurred once strategic Geomorphological questions were asked during early project planning phases, where local Geomorphological baseline information was collected and utilized to answer specific landform questions ahead of implementation, and where Geomorphologists were actively involved in the project design and ultimately its appraisal. Hooke's predicted third phase (which, a decade later, it is argued that is now the present emphasizes our understanding the conditions governing geomorphological variability, instability and equilibrium, and the widespread use of enhanced modelling and remote data to predict the effects and the risks of different management scenarios.

There are many drivers encouraging Geomorphological contributions to environmental management. Generally, geomorphology is 'part of the solution' (Gardiner, 1994; King et al., 2003) associated with a multi interdisciplinary framework to solve specific environmental problems. For a long time, especially in the lowlands, landscapes were imagined to be largely static during the engineering time-frame of a project, and thus Geomorphological processes were neglected. Both research and empiricism have expressed the fallacy of this presumption, leading to the progressive integration of geomorphology in management. Significant to the environmental management objectives generally involve either reducing the risk posed to the built environment

by landform change, minimizing the impact of floods or mass movements, or restoring charismatic native aquatic and terrestrial species, geomorphology is frequently a tool in the service of end-points in engineering, land-use planning, and biology respectively.

A second driver is the deeply accepted relation among environmental degradation and socio-economic deterioration, with the most vulnerable communities existing in areas of high environmental sensitivity and low social resilience (Fraser et al., 2003). Included in this category are contributions in reducing the impact of natural disasters, a topic which demands an understanding of the coupled nature of human and natural disaster vulnerability. Geomorphology has become implicitly recognized as a strategic component of environmental and social justice related to sustainability and global change. Understanding the mutual vulnerability and dependence of society and landscape may be one of the most demanding challenges to geomorphology if it wants to be seen as a key element of global environmental management.

A third driver is much essential and consists a growing effort to support and retain 'geo-diversity', the earth science alternative to biodiversity. Geo-diversity is explained as 'the natural range diversity of geological (rocks, minerals, fossils), geomorphological landform, processes and soil features. It includes their assemblages, relationships, properties, interpretations and systems' (Gray, 2004: 8). At a process level, Geomorphological contributions to this aim involve the restoration and maintenance of physical integrity in environmental systems in trying to maintain functional river processes and forms even under a modified hydrological regime. At the level of landforms, geo-diversity involves the preservation and conservation management of parkland environments or unique landforms. In India, this has taken the form of a network of important Geological/Geomorphological Sites and progress towards a series of Local Geo-diversity Action Plans as the mechanism for delivering geo-conservation. Thus in contrast to the other drivers, in this application geomorphology may be the solution and endpoint.

As narration of the range of services geomorphology can provide to environmental management, it provide a series of examples below organized according to three reasonably distinct management requirements, namely: hazard avoidance and reduction, sustainable development of natural resources, and environmental restoration and preservation. They are drawn from recently published journal articles and book chapters and personal experiences in fluvial and hillslope Geomorphology.

Hazard avoidance and reduction:

It is a fact that the arena of deepest standing interest (see Cooke and Doornkamp, 1974, 1990; Coates (1976) is the application of geomorphology to the reduction of hazards related with landscape change (Fig:1) generally related to erosion and sedimentation. Intensively, this projects geomorphology's technical contribution to reducing the impact of natural disasters. Similar application relates basically to site-specific geomorphology studies in the service of river, coastal, geotechnical and agricultural engineering, but it can also include risk assessment services to the insurance industry. These services have spawned the sub-discipline of 'engineering

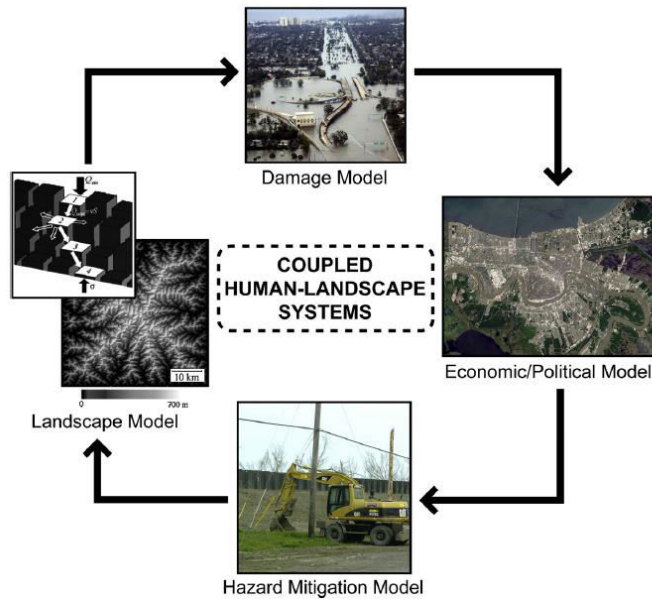


Figure 1. A schematic of coupled human-landscape systems, using New Orleans, Louisiana, as an example, A numerical (cellular) landscape model might include processes dominated by water, sediment, or biological transformation; landscapes impact humans through natural-disaster events, captured in a damage model that simulates floods by wiping out discrete zones of human infrastructure; human dynamics are represented by an economic- or political-processes model (perhaps agent-based), that results in decisions to develop or change human infrastructure, which in turn links back to the landscape through an economically driven hazard-mitigation model that represents human choices to modify the landscape in ways that will moderate future damage (adapted from [Werner and McNamara, 2007](#)).

geomorphology' (Fookes et al., 2005, 2007); that is, geomorphology applied in assessing the risks to construction associated with surface processes and landform change. Instances of the application to river engineering and geotechnical engineering are provided below:

River bed and terrain protection:

Significance of increasing settlement, tourism and agriculture of floodplain lands has come a need for channel 'stability', a sub-set of channelization wherein the river's natural tendency for meandering and lateral migration is perceived as a hazard and forcibly resisted by structural reinforcement of river banks to prevent erosion and fix the channel planform. River bank planning and protection frequently involves symptomatic and piecemeal application of rip-rap, gabion baskets, concrete walls and sheet steel piling.

Likewise, erosion of the channel bed has frequently been arrested by concrete or structural grade controls which, together with bank protection, can result in a fully immobile channel (such type of construction is being constructed in Uttarakhand for protection of land slide at the bank of rivers). Such schemes are invariably detrimental to instream habitat for native aquatic species, have high failure rates, and have frequently exacerbated channel erosion problems downstream or upstream requiring additional protection measures that are also environmentally deleterious. As a consequence, there are now a suite of protective regulations in most countries that amplify the need for more *strategic* applications that minimize both the

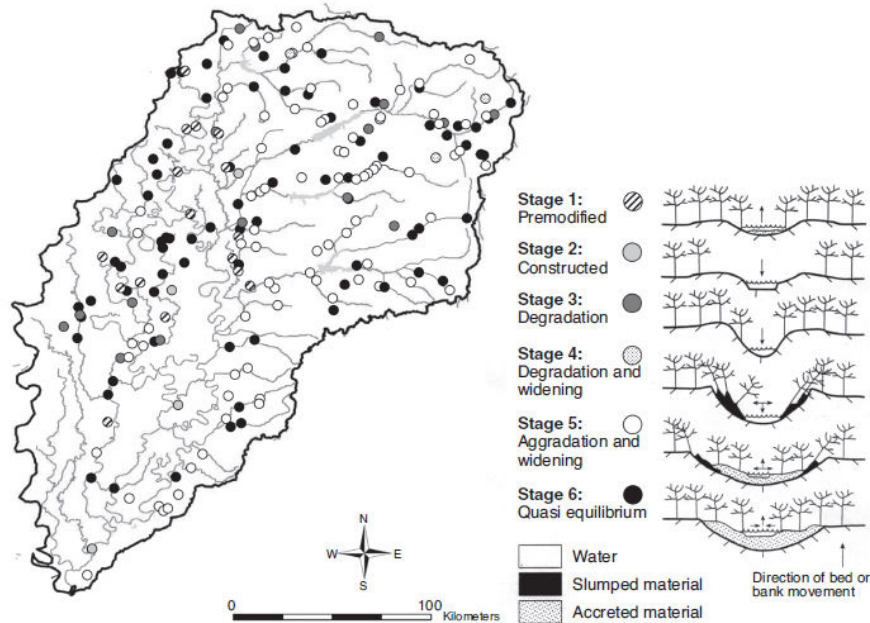


Figure .2 Using reconnaissance survey and rapid assessment protocols and to Characterize sites in the Yazoo River catchment, Mississippi, according to their stage in river bed and bank erosion (see legend) following the passage of multiple knickpoints (adapted from Simon et al., 2007b)

environmental impact and the economic cost to taxpayers. These changes have provided numerous opportunities for geomorphology to contribute to river engineering and management

Breaking with the tradition of always utilizing river bank protection near to terrain and floodplain development, Geomorphologists are now frequently required to analyze and study the risk posed to the development by the river's natural evolutionary tendency. Techniques include the use of field reconnaissance surveys, overlays of historical aerial photographs and large-scale topographic map and other techniques including procedures for large rivers. Management approaches are then proposed based on the cause, severity, extent, and mode of bank failure in the vicinity of the perceived need. Likewise, because research has shown that channel bed erosion frequently occurs via the upstream migration of an incising knickpoint in channelized rivers, a regional Geomorphological assessment of river bed and bank conditions (Fig: 2) can determine the most effective site (and minimum requirement) for grade-control structures or be used to propose maintenance activities in low-energy river environments prone to sedimentation. Again strategic approaches such as use of multiple low structures to manage a large knickpoint by mimicking step-pool channel morphology to provide better habitat characteristics show the influence of geomorphology input.

Minimising hillslope and landslide hazards:

Mountainous and Slide-prone regions always offer and attract some of the most attractive locations for new development for so many reasons, ranging from the economic value associated with views from the hillside to the simple fact of being some of the last remaining undeveloped land in areas of otherwise dense population. The value of geomorphology in reducing the risk of

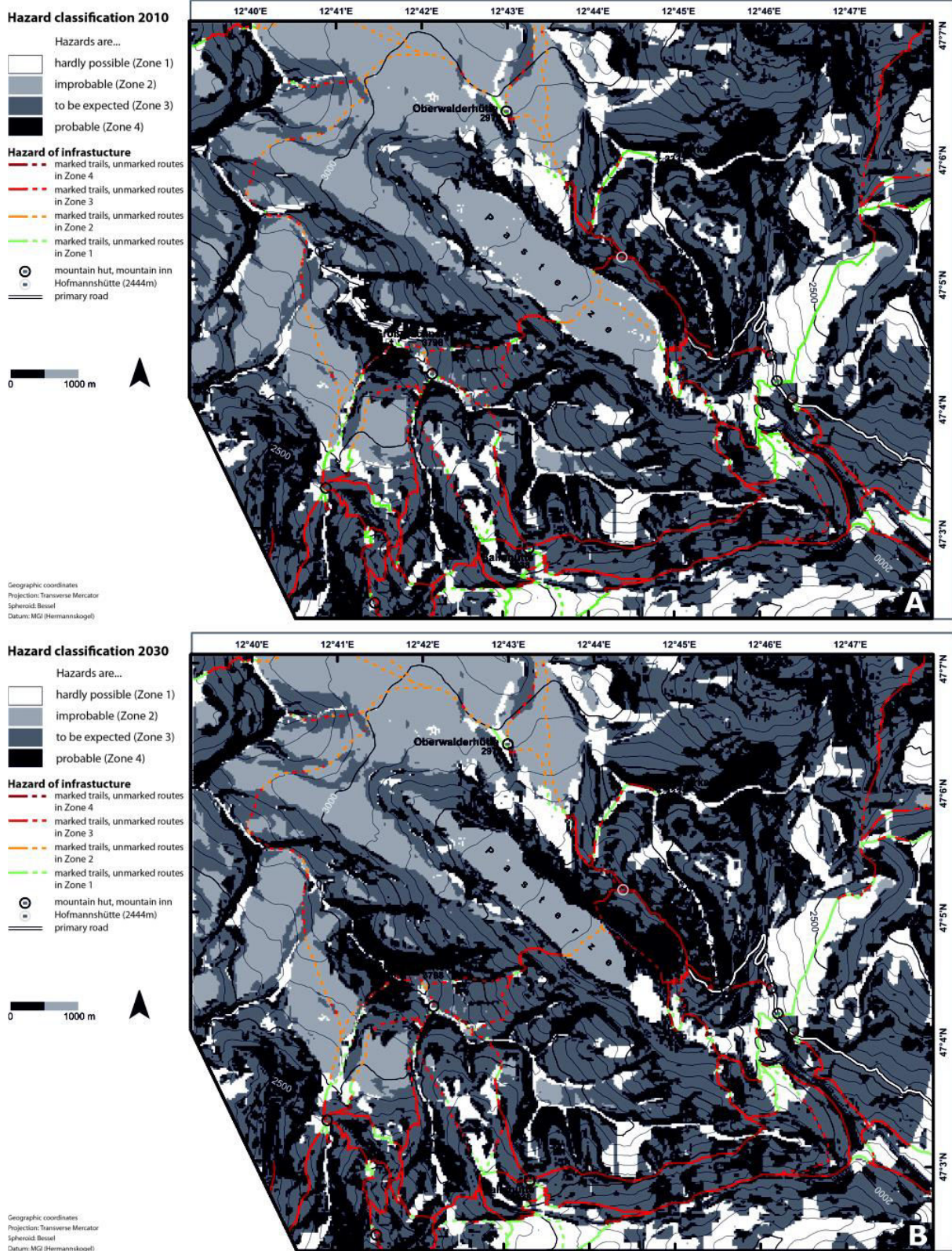


Figure 3: The hazard classification map prepared with the help of Geotechnological tools for the year 2010 and 2030 for Alpine region. The landslide vulnerability maps clearly reveal result that in 2010, a current situation and a future scenario in 2030 to be suitable for planning purpose by the local stake holders (Katharina Kern et al- 2012)

landslides has almost always been recognized for many decades, but the importance of that role relative to other hazard-mitigation strategies continues to vary through history and by locality. Spectacular examples of previously unrecognized landslides demonstrate the cost of ignorance, although the human response to instabilities once recognized can range from complete avoidance to massive hillslope reconstruction. Geomorphology input often consists of landslide hazard mapping as the basis for minimizing slope instability risk in populated areas. (Fig:3) Specific sites or entire regions are assigned a relative hazard rating, based typically on one or more of the factors understood to determine stability past landslides, slope angle, surficial and underlying geologic material(s), hill slope hydrology, vegetation, prior engineering works, active geomorphic process (such as wave action at the base of a slope). The choice of 'relevant' factors and the assignment of hazard levels are based on some combination of local (empirical) knowledge and geomorphic principles. At its simplest, 'steep slopes' are deemed 'hazardous', and the only geomorphic principle being used is the gross importance of hill slope gradient in driving down slope processes. More recent and increasingly sophisticated approaches continue to make use of basic topographic information but now include high-resolution data, additional types of information on slope conditions and material properties, and predictive techniques adapted from the field of artificial intelligence (Ayalew and Yamagishi, 2005; van Westen et al., 2008).



Figure .4 Interpretation of LiDAR/aerial imagery to recognize multiple ages of landslides above La Conchita, California, including a prehistoric landslide that lay unrecognized during the development of the community of La Conchita (from Gurrola et al., 2010)

Apart from the landslide mapping, a Geomorphologist's interpretational skills can be used, for instance, in recognizing the presence of prior and future landslides which is often one of the best predictors of actual or potential instability (Fig:4). Geomorphic features used to identify past landslides commonly include hummocky topography, bent trees, springs and seeps, and

arcuate scarps. This approach can be combined with more rigorous, mechanistic modelling of driving and resisting forces in a soil or rock mass in critical areas identified by the Geomorphologist. In many cases such analyses are devoid of additional geomorphic input, which may be justifiable insofar as the land mass often behaves as predicted by engineering analysis. In many cases, however, the heterogeneity of hillslope deposits, the presence of groundwater or surface water, and the varied influences of human infrastructure and human activities require an integrative analysis which geomorphology is well-suited to implement.

Sustainable development of natural resources:

A second and most essential arena for service is in the sustainable management of natural resources, including agriculture and land-use planning. In this criterion, sustainable management can be defined in relation to the preservation or enhancement of the total stock of natural capital, zero or minimum net negative impact of management operations, and zero or minimum requirement for ongoing management intervention to uphold system values. Relative to engineering geomorphology, this arena has been less clearly articulated as a focus area for geomorphology in environmental management, but services generally relate to the assessment of Geomorphological impacts to assist in the development of plans for habitat conservation, soil conservation, urban development, water supply, water quality, forest management, river basin management or beach management. Two examples are provided related to, urban planning and the management of large dams.

Geomorphology and urban planning

The geomorphic study of stream channels changed by human disruptions to hydrology has a long history discussed by Leopold (1968). A quarter of a century later, the term 'hydromodification' was coined in the Engineering and regulatory literature, and it is now used as the shorthand term for all manners of land-use change, particularly urbanization, affecting downstream channels

Geomorphologists should be aware that local channel gradient and the pattern of gradient changes across a channel network are particularly important factors but are rarely incorporated into case-study analyses, so a geomorphic perspective is needed to determine, for example, whether the measurements were taken in reaches that are more or less susceptible to change (Montgomery and Buffington, 1997). The location of urban development relative to the channel network is also important: developments that concentrate urban effects in only a few areas tend to have less impact on the channel network as a whole than equivalent development spread across the watershed. Flow increases introduced at one point in the channel network may be far more effective at eroding sediment than at another, because of the spatial variability of watershed soils and the distribution of alluvial and bedrock (or other non-alluvial) reaches.

The channel stability may reflect true re-establishment of fluvial equilibrium but subsequently it may simply represent the product of flushing all mobile sediment from the system to produce a relatively static, non-alluvial channel (Fig:5). In both cases, the re-attainment of

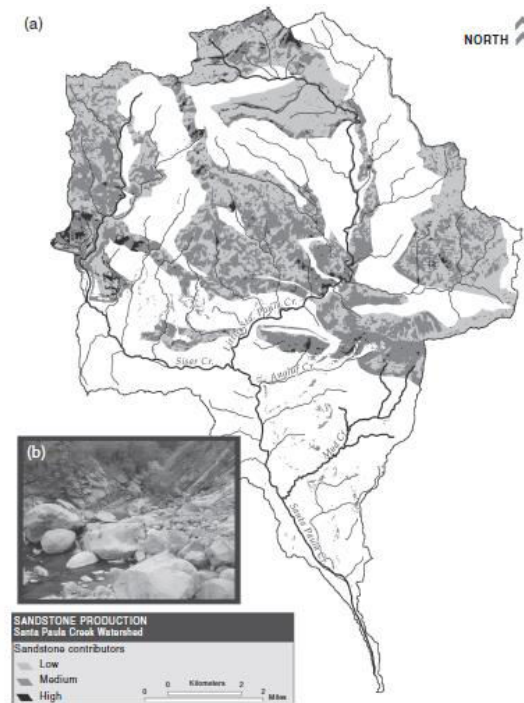


Figure 5. (a) Using terrain modelling to explore the sediment source and yield characteristics of a mountainous watershed in southern California. Overlays of geology, land cover and hillslope gradient are used to characterize coarse sediment production for analysing potential influences on salmonid habitat. While many habitat concerns focus on excess fine sediment production, in this watershed coarse sediment derived largely from sandstone sources (inset photograph (b) provides both the overarching structure for fish habitat and natural barriers to fish passage and so is critical (Downs and Booth, 2011)

'channel stability' can express the condition of a substantially changed flow regime with very less physical impacts but potentially catastrophic biological results. This result reinforces the need for geomorphologists to be involved in integrated assessments of the urban impacts on river systems.

Geomorphology and the management of large dams

The magnitude of golden age concern with the golden age of multi-purpose large dam building in the middle of last century, a plethora of research including that from Geomorphologists has indicated the deleterious impact of regulated rivers on fluvial ecosystems. Dam operators are now skilled and frequently required to develop revised flow release schedules to minimize further impacts to downstream fluvial ecosystems, to consider impacts on fish and wildlife equally with power generation and flood control. Geomorphologists are now capable to provide services to estimate the future downstream impacts of large dams modify flow release schedules or evaluate the potential impacts of dam removal.

Geomorphological studies in relation to the hydropower dams generally occurs as an integral part of a suite of studies that also encompass water quality, aquatic species, special-status plants and wildlife, recreation, aesthetics and cultural resources. Observations consider the character and changes to hydrology and sediment supply dynamics caused by the dam's operation, the morphological condition of the downstream channel and the characteristics of downstream transport and storage of sediment and large wood. Where operational changes are

proposed, they frequently involve altering the flow release schedule to better suit the downstream ecology. Increasingly this involves the prescription of 'flushing flows' designed to partially restore the flood pulse advantage by flushing fine sediment, stimulating coarse sediment transport, and facilitating floodplain inundation. Designing such flow releases to have a sustainable impact is difficult, primarily because promoting sediment transport in regulated rivers may result in further channel incision and bed armouring. Geomorphologists may therefore need also to design a programme of coarse sediment augmentation to parallel the prescribed high-flow releases.

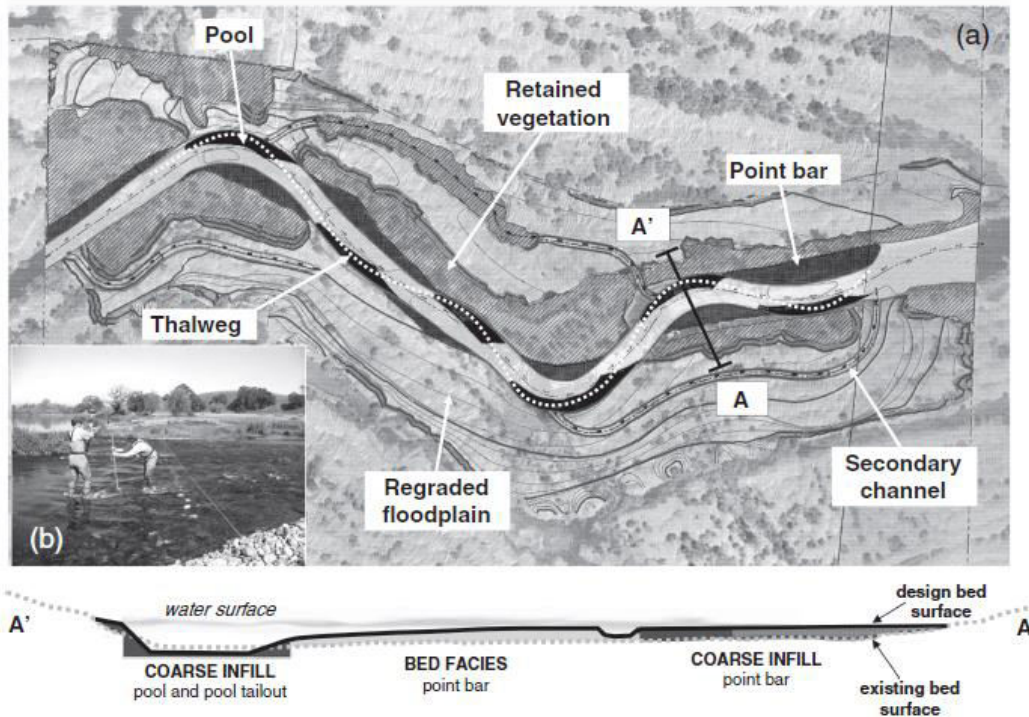


Figure 6 Sediment transport modelling used to predict the likely impact of the removal of Marmot Dam (Sandy River, Oregon) for the year following dam removal, under average, wet and dry year scenarios (exceedance probability of peak flow and annual runoff of 50 per cent, 10 per cent and 90 per cent, respectively). The 14-m high dam was removed in July 2007 and the cofferdam breached in October 2007. Plots show predictions from (a) the former reservoir area and (b) the depositional wedge immediately downstream of Marmot Dam. Data points are from post-project surveys undertaken 1 year later: 2008 had an annual runoff exceedance probability of approximately 29 per cent (adapted from Downs et al., 2009)

Whenever dam removal is proposed, Geomorphologists are normally involved in assessing the dynamics of sediment re-distribution that follows the removal of the dam. Concerns usually exist for the upstream dynamics of the resulting knick-point; the rate of fluvial sediment excavation and likely channel morphology within the former reservoir site; and the ecological impact of sediment released downstream (Pizzuto, 2002; Doyle et al., 2003). Emphasis on predicting future conditions under a variety of dam-removal scenarios has resulted in the development of sediment transport models that can accommodate pulsed sediment supply (Fig:6)

and the use of scaled or generic physical models to provide guidelines for sediment management during dam removal (Randle et al., 2008; Downs et al., 2009).

Environmental restoration and preservation:

The significance of third service area relates to conservation management practices and landscape design, including planning for restoration, preservation, and recreation. Stemming from the concept of 'restoration ecology', '...the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems', environmental restoration is now a big business with expenditure on river restoration. Growing recognition of the importance for ecology of habitat structure and function has greatly increased the visibility and concern of geomorphology as a contributing discipline. It also marks a sharp departure from geomorphology's role in environmental management as a discipline helping to reduce or minimize environmental impacts associated with human activity towards applications directly involved with environmental reconstruction and repair, translating biological objectives into implementation practicalities and elevating the geomorphologist's need for numerical simulation modelling.(Fig:7)

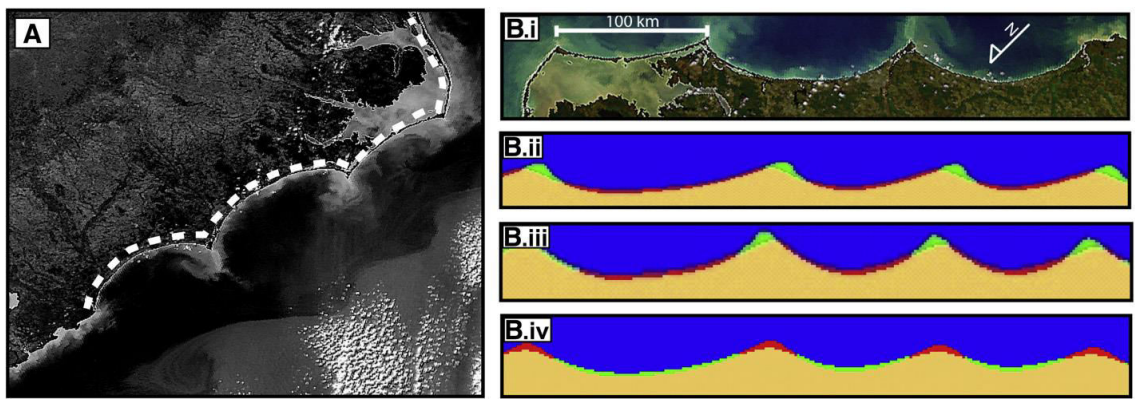


Figure. 7. (A) Satellite image of the sandy, cuspate Carolina Cape system (highlighted by the white dotted line); cape tips are ~100 km apart. The spatial regularity of the cuspate pattern was for decades assumed to be the result of peculiarities in the underlying geology, the classic argument of “template forcing.” Recent numerical modeling work, however, grounded in complexity theory, has shown that the capes could be self-organized, emergent features formed from fluxes of alongshore sediment transport, obviating the need to invoke a specific forcing template to explain their formation. (B) An extension of the same shoreline modeling examines how the coast might change under various hypothetical climate change scenarios; the numerical model is not a direct representation of the Carolina cape system (B.i) nor intended to be, but is nevertheless analogous to it as an exploratory tool and illustrative of the large-scale, long-term processes driving changes in the landscape. The model output, in planview, shows that (B.ii) if stronger storms send larger waves from the left(NE), the cape tips will grow(shown in green) and shift to the right (SW) and the embayments will erode landward (shown in red); (B.iii) if more or larger storm waves arrive from the right (SW), the cape tips will grow and shift to the left (NE); and (B.iv) if stronger winds tend to direct waves straight onshore (to the NW), the cape tips will erode landward and the embayments will accrete seaward (adapted from Ashton et al., 2001; Slott et al., 2006).

Geomorphology in societal development

Humans evolved in the context of geomorphic processes, and their survival and prosperity depended in no small measure on their understanding of these processes, the threats posed to their

survival and implications for food production. Human settlements are often vulnerable to geomorphic hazards by virtue of their location in the path of geomorphic processes such as flooding- landslides or debris flows. In the next level of interaction, human settlement alters geomorphic processes, such as exacerbating the severity of flooding by reducing infiltration and increasing storm water runoff (for a given unit of precipitation), increasing erosion and sediment yields through land clearance, triggering mass movements by altering drainage patterns or undercutting the toes of slopes and inducing seismic activity through crustal loading under large reservoirs. Moreover by managing or regulating geomorphic processes, humans have altered their environments, often simplifying natural systems to improve conditions for human survival, such as increasing habitat for game or enhancing water availability for agriculture.

It cannot be discussed about geomorphology and society without considering human perception and perceived opposition between nature and culture. Human perception of Geomorphological processes underlies the choice of management actions, but differs among cultures. Sometimes processes are viewed negatively and humans fight against them, whereas in other contexts, they are considered beneficial. Increasingly, the discourse is shifting from an attitude of 'development against nature' to one of 'live with nature'. So long as the scale of human intervention does not undermine the geomorphic processes (and the biodiversity and resources they support), humans benefit from the healthy functioning of geomorphic processes. For example, fluvial corridors that have not incised can improve downstream water quality through the self-operation of nitrates that occurs in a floodplain forest well-connected to the groundwater (Naiman et al. 2005). The scientific community has an increasingly important role to play in providing 'reality checks' and innovative solutions to advance these societal goals.

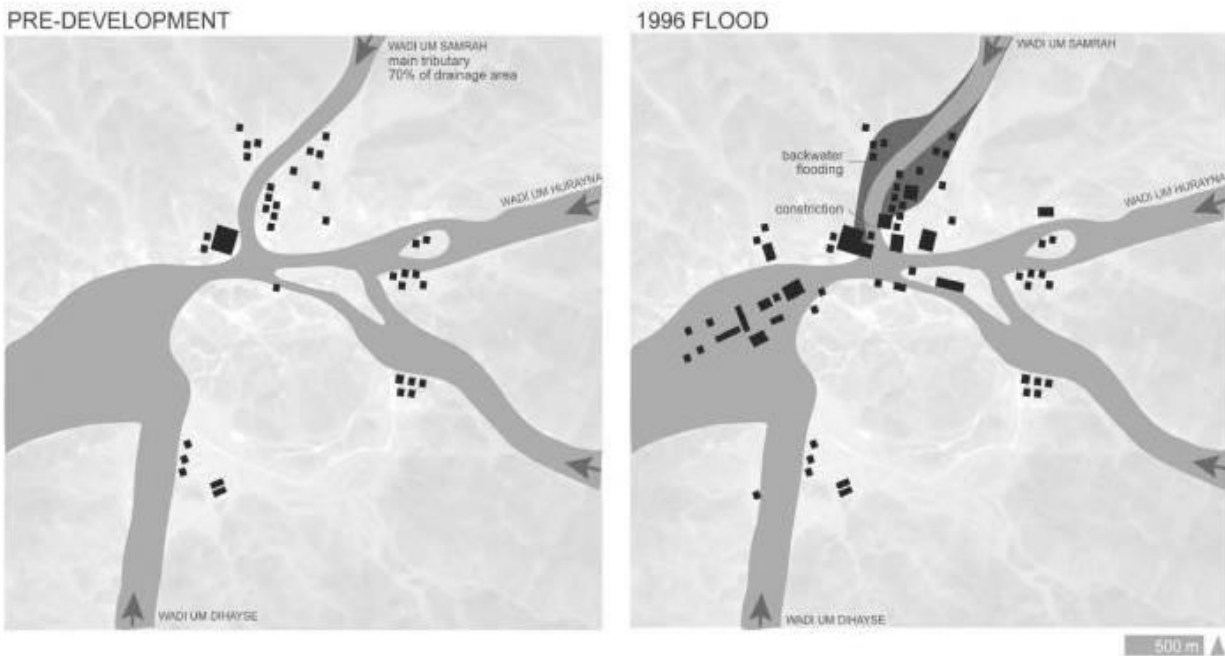


Figure 8. Development in floor of flash-flood prone wadi floor. El Sheik El-Shazli, Red Sea Governate, Egypt, showing increased flood levels upstream resulting from construction infloodway. (From Gohar and Kondolf, 2007)

Settlements in relation to geomorphic processes

When considering interactions between human settlement and geomorphic processes, it can be identified two levels of interaction. First, human settlements as affected by natural geomorphic processes; and second, human modifications to geomorphic processes and rates. The first level of interaction is illustrated by the Malangaon village of Maharashtra destroyed by the landslide or the floodplain settlement inundated by large floods in between Gaurikund and Kedarnath . Here humans have placed themselves in the way of geomorphic processes that would have occurred whether the humans were there or not. If the processes were sufficiently frequent, we often find that indigenous settlements were placed out of harm's way. For example, the local Ababda tribesmen living in the valley floor near the shrine of Sheik El Shazli. in the Red Sea Range of Egypt, located their dwellings just above the level reached by periodic flash floods in the Wadi Urn Smarah, while recent settlers have built structures in the path of flash floods and debris flows, which in turn have backed up floodwaters and caused flooding of structures previously above floods (Fig:8) . Medieval settlements in river valleys near Stuttgart, Germany, were optimally placed with respect to several resources and hazards. These primarily agricultural communities located their villages on bedrock where possible, so as not to displace prime agricultural land, here windblown loess and floodplain silts forming fertile loams. Village sites also had a spring or surface water source, and were located above the level of floods. It was only in the 19th century that floodplains, heretofore reserved for agriculture, became extensively occupied by dwellings, resulting in loss of arable land and creation of flood hazards. Historically, human settlements have typically been located along rivers, to take advantage of water supply, navigation and mill power where high ground was available nearby, it would traditionally be preferred for settlement, but in some cases the advantages of the location outweighed the disadvantages of periodic flooding, and cities were developed where there was nothing but low floodplain. However, even subtle differences in topography of floodplains were recognised and exploited by early settlers. Natural levees along large meandering rivers constitute a good example. Along the Sacramento River, early settlements, such as Colusa, were restricted to the natural level. Likewise, in New Orleans, merits, such as Colusa, were restricted to the natural level. Likewise, in New Orleans, the older neighborhoods of the French Quarter and Garden District were built on the natural levee of the Mississippi, which was not only higher, but also conveniently adjacent to the channel, for docking, etc. Along the Mekong River in Cambodia, settlements and permanent agriculture (e.g. fruit trees) are located on natural levees, with back-swamp areas used for annual crops. In Bangladesh, artificial flood-control levees have typically failed to control floods, but ironically serve as 'high ground' onto which residents take refuge during inundations The collapse of the Bronze Age Harappan, one of the earliest urban civilizations, remains an enigma. Urbanism flourished in the western region of the Indo-Gangetic Plain for approximately 600 y, but since approximately 3,900 y ago, the total settled area and settlement sizes declined, many sites were abandoned, and a significant shift in site numbers and density towards the east is recorded. It is reported that morphologic and chronologic evidence indicating that fluvial landscapes in Harappan territory became remarkably stable during the late

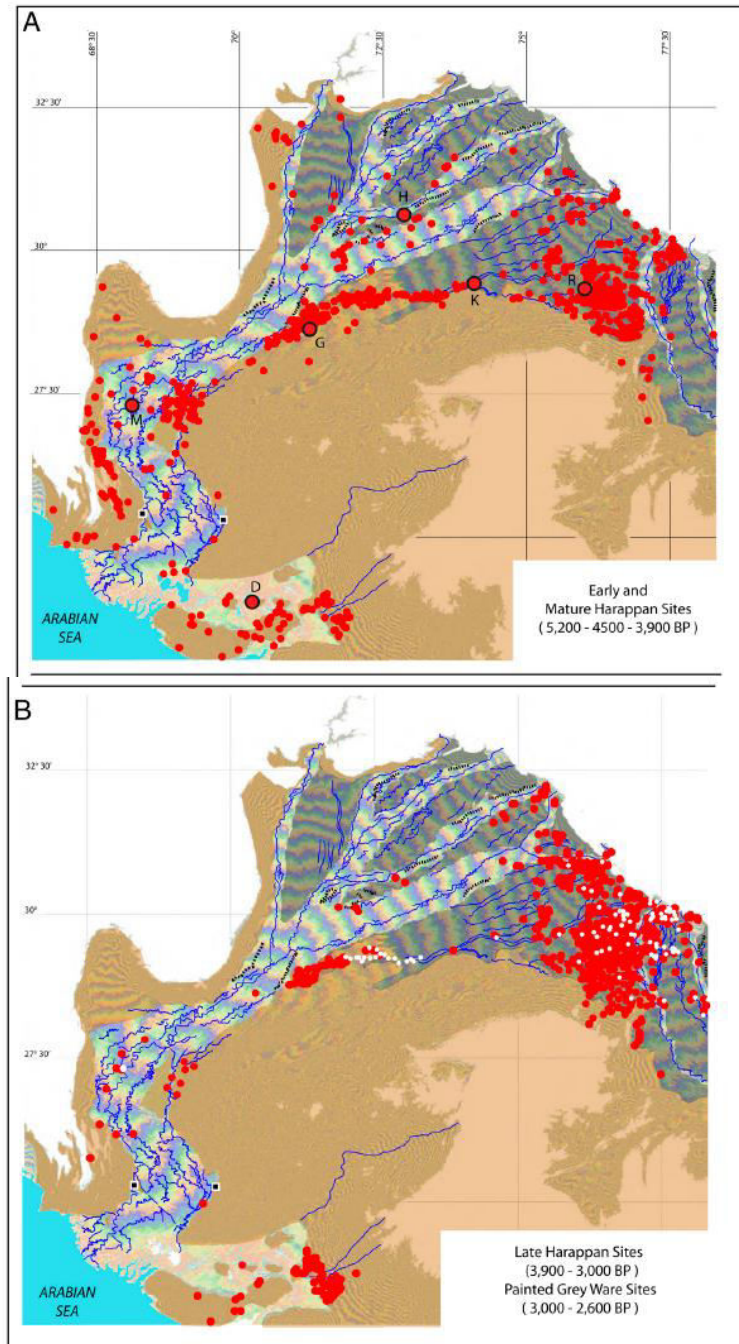


Figure. 9. Settlements on morphological units of the western Indo-Gangetic plain . (A) Early and Mature Harappan sites, with names of some major urban centers: D = Dholavira; M = Mohenjo-Daro; G = Ganweriwala; H = Harappa; K = Kalibangan; R = Rakhigarhi. (B) Late Harappan (red) and Painted Gray Ware (white) sites. (Liviu Giosan et al,2011)

Holocene as aridification intensified in the region after approximately 5,000 BP. Upstream on the alluvial plain, the large Himalayan Rivers in Punjab stopped incising, while downstream, sedimentation slowed on the distinctive mega-fluvial ridge, which the Indus built in Sindh. This fluvial quiescence suggests a gradual decrease in flood intensity that probably stimulated intensive agriculture initially and encouraged urbanization around 4,500 BP. However, further

decline in monsoon precipitation led to conditions adverse to both inundation- and rain-based farming. Contrary to earlier assumptions that a large glacier-fed Himalayan river, identified by some with the mythical Sarasvati, watered the Harappan heartland on the interfluvium between the Indus and Ganges basins, we show that only monsoonal-fed rivers were active there during the Holocene. As the monsoon weakened, monsoonal rivers gradually dried or became seasonal, affecting habitability along their courses. Hydroclimatic stress increased the vulnerability of agricultural production supporting Harappan urbanism, leading to settlement downsizing, diversification of crops, and a drastic increase in settlements in the moister monsoon regions of the upper Punjab, Haryana, and Uttar Pradesh.(Fig:9)

Where no high ground is available, societies have often taken refuge from floods by migrating from flood-prone areas during the wet season or building structures above the anticipated flood levels. In the Mekong River Delta, dwellings built on frequently inundated floodplains are commonly built on stilts, such that the living spaces remain above flood waters during the prolonged inundation of the wet season, and the houses are accessed by small boats. In Dadun, a 'water village' of the Pearl River Delta in China, the flood of 1962 inspired many residents to build second and third stories on their houses in anticipation of future floods. The next level of interaction of humans with geomorphic processes involves human activity changing the nature or rate of the geomorphic process. As described by Downs and Gregory (2004) with respect to river use, the magnitude and extent of human alterations has increased over time, from hydraulic civilizations such as Egypt to the massive dam construction of the 20th century. Examples include deforestation and road construction increasing erosion rates and triggering landslides by removing protective vegetation cover, decreasing slope strength, altering infiltration and drainage patterns and undercutting the toes of slopes. Land-use changes can increase runoff from a given rainfall, resulting in higher peak flows, which in turn leads to channel incision and destabilization. These are all natural geomorphic processes (soil erosion, mass wasting, infiltration and runoff, flood flows, overbank flooding), but they are altered (often intensified) by human-induced changes.

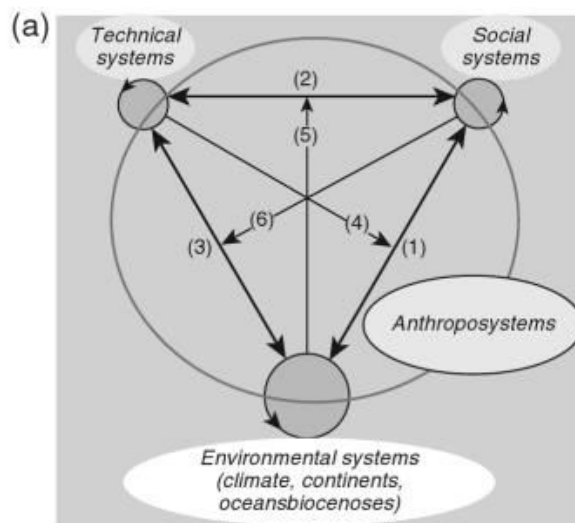
Human effects on geomorphic processes

Human actions have a wide range of effects on geomorphic processes. Anthropogenic increases in erosion may involve either increased strength of the geomorphic process acting on the landscape (e.g. increased flood heights and velocities) or reduced strength of the soil, hillslope or river bank being acted upon (e.g. by de-vegetation, toe undercutting).

At the extreme are human activities that directly alter the landscape, such as massive grading for subdivisions, open-cast mining, highway construction and dredging for harbors. Certainly, one of the most striking illustrations of such large-scale landscape modification, with profound ecological implications, is the 'mountaintop removal' practice of coal mining, in which the tops of mountains are literally removed and dumped in intervening valleys, obliterating the pre-existing topography, disrupting (and typically contaminating) surface runoff and groundwater flow (Palmer et al., 2010). More pervasively, human activities change the rate of geomorphic

processes that lead to effects downstream, such as changes in vegetation cover resulting in increases or decreases in infiltration or erosion rates. The Sierra Nevada range in California is illustrative. Mining (for gold in the 19th century and for construction aggregate in the 20th century) directly modified large areas of the landscape. Hydraulic mining for gold literally washed away mountains and delivered over 1.3B m³ of sediment to rivers in the Central Valley of California, causing a five-fold increase in sediment loads over the period 1860-1885 over their pre-disturbance value (Gilbert. 1917). Dam construction in the 20th century reduced the yield of sediment from mountains to the Valley down to about 20 per cent of its pre-disturbance level, and mining of sand and gravel from channels and floodplains resulted in an annual deficit of about 40 M m³.

Examining the movement of coarse sediment through the river network from eroding uplands to the coast is illustrative. River-derived sediment nourishes beaches, which protect coastal cliffs from wave erosion. Where dams trap sediment, preventing its transport to the coast, and where downstream of the dams, sand and gravel has been removed from the river channel for construction aggregate (e.g. northern Italy, southern California, Japan), the coastal sediment deficit has resulted in sand-starved beaches that have narrowed or disappeared, accelerating erosion of coastal cliffs. Ironically, one purpose of many of the dams on these coastal rivers was to protect house son floodplains adjacent to the river from damage from floods, but the end result has been to damage or destroy houses built on coastal cliffs, whose erosion has been accelerated. Elsewhere, eroding coastlines are protected by boulders, concrete jacks or concrete rubble. In the Ministry of Works in Japan, some scientists joke that humans do what was formerly the river's job: instead of allowing the river to carry its sand to the coast, humans remove the sand from the channel to make concrete, which is removed from the system for the life of a structure, but ultimately winds up along the coast as rubble to protect against coastal erosion.



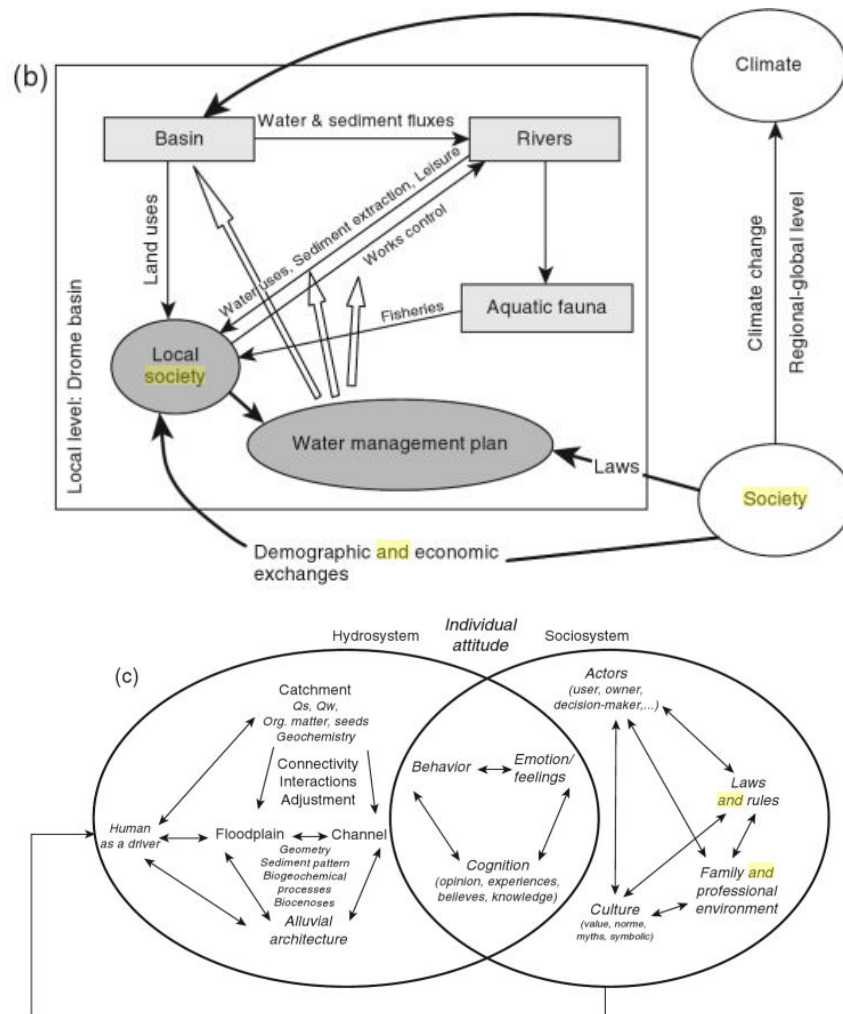


Figure 10 From a physically based conceptual approach to the 'anthroposystem'. (a) The 'anthroposystem' as defined by Leveque et al. (2000), a complex system where the 'environmental' components (physics, chemistry, biology) interact with the social and the technical components. Interactions are not only considered as human pressures on environment but also as technical developments and social reactions to the environment, its characters and evolution. Modified from Leveque et al., 2000. (b) Example of the conceptual framework of natural and anthropic factors influencing the fluvial dynamics of the Drome River, France (Pont et al., 2009). (c) Perception of the river by an individual strongly depends on his social environment and his own characters (e.g. feeling, knowledge, experience). (Adapted from Le Lay and Piegay, 2007)

In these examples, it is seen that human effects as most often changing the rate and magnitude, and sometimes the direction, but not the essential nature of geomorphic processes. In addition, we often see that site-specific reactive management can often set off a vicious cycle, in which actions sometimes the direction, but not the essential nature of geomorphic processes. In addition, we often see that site-specific reactive management can often set off a vicious cycle, in which actions taken to "fight nature" conceived in a simple cause-consequence context have unintended consequences downstream (both in space and time). As geomorphic systems consist of spatially nested cascading sub-systems (hillslope => river => coast) (Picgay and Schumm, 2003). Channel rectification to improve drainage for agriculture concentrates flow in-channel and typically induces bed incision.

Society and perception

Many perception studies have shown that landscape features perceived as natural are more positively appreciated by respondents than those that appear to be artificial, built by humans. Nevertheless, the perception of nature varies among our largely urbanized population, as a function of individual attitudes depending on socio-cultural settings, and economic development (Fig:10) . Moreover, even if there is some consensus in perceptions of nature, many examples illustrate culturally varied reactions such as preferences for single-thread meandering channels or against wood in rivers.

Conclusion

This review has focused on issues surrounding the Geomorphologist's application of skill to environmental problem-solving. Despite applied geomorphology's long but largely unrepresented history within the geomorphology discipline, escalating environmental awareness and better technical expertise have brought increasing opportunities to contribute to environmental management. Most frequently, Geomorphologists are part of a project team seeking to navigate a suite of protective policies and regulations in projects focused on hazard avoidance and diminution, the sustainable development of natural resources, or environmental restoration and preservation. Multiple service areas, with their attendant need for technical analyses, have opened new venues for Geomorphological training beyond the traditional basis in academia.

Despite potential threats to the meaningful application of geomorphology to environmental management, this promise can translate into tremendous opportunities, especially if Geomorphologists demonstrate to environmental managers the value of regional and long-term approaches cast in terms of uncertainty, risk, and probability of outcome. Realizing these opportunities requires Geomorphologists to re-cast 'applied geomorphology' wherein the goal for environmental management that is not the control or manipulation of the natural environment, but rather the maximizing of ecosystem services. An approach to environmental management based on ecosystem services would seek to maximize beneficial outcomes rather than simply to minimize the infringement of regulations, making it inherently more integrated with natural processes and landscape evolution rather than preoccupied with perceived risk and static morphology. With societal demand for improved ecosystem health, there is a recognized need to look at a larger scale, and to manage river basins rather than focusing on a short "problem reach. As the field of river restoration evolved in India, many of the early efforts were attempts to create habitat, stabilize channels with structures and/or create idealized meandering forms based on simplified ideas drawn from geomorphic research.

REFERENCES

- Ashton, A., Murray, A.B., Arnould, O., 2001. Formation of shoreline features by large-scale instabilities induced by high-angle waves. *Nature* 414, 296-300.
- Amoros, C. and Petts, G.E. (1993) *Hydrosystemes fluviaux*. Masson, Paris, p. 300.

- Anderson, M.K. (2005) *Tending the Wild: Native American Knowledge and Management of California Natural Resources*. University of California Press, Berkeley, p. 555.
- Asakawa S., Yoshida K. and Yabe K. (2004) Perceptions of urban stream corridors within the greenway system of Booth D.B. (1990) Stream channel incision following drainage basin urbanization. *Water Resources Bulletin* 26: 407-18.
- Brunsdon D., Doornkamp J.C. and Jones D.K.C. (1978) Applied geomorphology: A British view, in Embleton C., Brunsdon D. and Jones D.K.C. (eds), *Geomorphology: Present Problems and Future Prospects*. Oxford: Oxford University Press, pp. 251-62.
- Clark M.J. (2002) Dealing with uncertainty: adaptive approaches to sustainable river management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 12: 347-63.
- Coates D.R. (ed.) (1976) *Geomorphology and Engineering*. London: George Allen and Unwin.
- Cooke R.U. and Doornkamp J.C. (1974) *Geomorphology in Environmental Management*. Oxford: Oxford University Press.
- Downs P.W. and Gregory K.J. (2004) *River Channel Management: Towards Sustainable Catchment Hydrosystems*. London: Arnold.
- Downs P.W., Cui Y., Wooster J.K., Dusterhoff S.R., Booth D.B., Dietrich W.E., et al. (2009) Managing reservoir sediment release in dam removal projects: a approach informed by physical and numerical modelling of non-cohesive sediment. *International Journal of River Basin Management* 7: 1-20.
- Doyle M.W., Stanley E.H. and Harbor J.M. (2003) Channel adjustments following two dam removals in Wisconsin. *Water Resources Research* 39: 1011. doi:10.1029/2002WR001714.
- Fraser E.D.G., Mabee W. and Slaymaker O. (2003) Mutual vulnerability, mutual dependence: the reflexive nature of human society and the environment. *Global Environmental Change* 13: 137-44.
- Gardiner J.L. (1994) Sustainable development for river catchments. *Journal of the Institution of Water and Environmental Management* 8: 308-19.
- Gilbert G.K. (1890) *Lake Bonneville*, Monograph 1, United States Geological Survey. Washington, DC: US Government Printing Office, p. 438.
- Gilbert G.K. (1914) *Transportation of Debris by Running Water*, Professional Paper 86, United States Geological Survey. Washington, DC: US Government Printing Office.
- Gilbert G.K. (1917) *Hydraulic Mining Debris by Running Water*, Professional Paper 105, United States Geological Survey. Washington, DC: US Government Printing Office.
- Graf W.L. (1996) Geomorphology and policy for restoration of impounded American rivers: what is 'natural'? in Rhoads B.L. and Thorn C.E. (eds), *The Scientific Nature of Geomorphology*. New York: John Wiley and Sons, pp. 443-73.
- Graf W.L. (2001) Damage control: restoring the physical integrity of America's rivers. *Annals of the Association of American Geographers* 91: 1-27.
- Graf W.L. (2005) Geomorphology and American dams: The scientific, social, and economic context. *Geomorphology* 71: 3-26
- Gray J.M. (2004) *Geodiversity: Valuing and Conserving Abiotic Nature*. Chichester: John Wiley and Sons.
- Gregory K.J. (1979) Hydrogeomorphology: how applied should we become? *Progress in Physical Geography* 3: 84-101.
- Gregory K.J. and Downs P.W. (2008) The sustainability of restored rivers: catchment-scale perspectives on long term response, in Darby S.E. and Sear D.A. (eds), *River Restoration: Managing the Uncertainty in Restoring Physical Habitat*. Chichester: John Wiley and Sons, pp. 253-86.
- Haney A. and Power R.L. (1996) Adaptive management for sound ecosystem management. *Environmental Management* 20: 879-86.
- Holling C.S. (ed.) (1978) *Adaptive Environmental Assessment and Management*, International Institute for Applied Systems, Analysis 3. New York: John Wiley and Sons.
- Hooke J.M. (1999) Decades of change: contributions of geomorphology to fluvial and coastal engineering and management. *Geomorphology* 31: 373-89.
- Hooke J.M., Bray M.J. and Carter D.J. (1996) Coastal groups, littoral cells, policies and plans in the UK. *Area* 27: 358-67.
- Horton R.E. (1945) Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. *Bulletin of the Geological Society of America* 263: 303-12.
- King J., Brown C. and Sabet H. (2003) A scenario-based holistic approach to environmental flow assessments for rivers. *River Research and Applications* 19: 619-39.
- Katharina kern, Gerhard Karl LIEB1), Gernot SEIER1) & Andreas kellerer-pirklbauer (2012) Modelling geomorphological hazards to assess the vulnerability of alpine infrastructure: The example of the Großglockner-Pasterze area, Austria *Austrian Journal of Earth Sciences*
- Kondolf G.M. and Downs P.W. (1996) Catchment approach to planning channel restoration, in Brookes A. and Shields Jr. F.D. (eds), *River Channel Restoration: Guiding Principles for Sustainable Projects*. Chichester: John Wiley and Sons pp. 129-48.
- Lancaster S.T. and Grant G.E. (2003) You want me to predict what?, in Wilcock PR and Iverson R.M. (eds), *Prediction in Geomorphology*, Geophysical Monograph 135. Washington, DC: American Geophysical Union, pp. 41-5
- Liviu Giosana, Peter D. Clift, Mark G. Macklin, Dorian Q. Fuller, Stefan Constantinescu, Julie A. Durcan, Thomas Stevensf, Geoff A. T. Duller, Ali R. Tabrezg, Kavita Gangal, Ronojoy Adhikari, Anwar Alizai Florin Filipe, Sam Van Laningham, and James P. M. Syvitski (2012) Fluvial landscapes of the Harappan civilization E1688–E1694 | PNAS | Published online
- Leopold L.B. (1956) Land use and sediment yield, in Thomas WL (ed.), *Man's Role in Changing the Face of the Earth*.

- Chicago: University of Chicago Press, pp. 639-47.
- Leopold L.B. (1968) *Hydrology for Urban Land Planning - a Guidebook on the Hydrologic Effects of Urban Land Use*, Circular 554. Washington, DC: United States Geological Survey.
- McEwen L. (1996) Student involvement with the regionally important geomorphological site (RIGS) scheme: An Opportunity to learn geomorphology and gain transferable skills. *Journal of Geography in Higher Education* 20: 367-78.
- Montgomery D.R. and Buffington J.R. (1997) Channel-reach morphology in mountain drainage basins. *Geological Society of America Bulletin* 109: 596-611.
- Montgomery D.R., Grant G.E. and Sullivan K. (1995) Watershed analysis as a framework for implementing ecosystem management. *Water Resources Bulletin* 31: 369-85.
- Parker G. (1990) Surface-based bedload transport relation for gravel rivers. *Journal of Hydraulic Research* 28:417-36.
- Parkes M.J., Morrison K.E., Bunch M.J. and Venema H.D. (2008) *Ecohealth and Watersheds: Ecosystem Approaches to Re-integrate Water Resources Management with Health and Well-being*, Publication series No. 2. Winnipeg: Network for Ecosystem Sustainability and Health and the International Institute for Sustainable Development.
- Pizzuto J. (2002) Effects of dam removal on river form and process. *Bioscience* 52: 683-91.
- Ralph S.C. and Poole G.C. (2003) Putting monitoring first: designing accountable ecosystem restoration and management plans, in Montgomery D.R., Bolton S. and Booth D.B. (eds), *Restoration of Puget Sound Rivers*. Seattle, WA: University of Washington Press.
- Randle T.J., Greimann B.P. and Bountry J.A. (2008) Guidelines for Assessing dam removal impacts, in *EOS Transactions of the American Geophysical Union*, Fall Meeting 2008, abstract H41I-02.
- Sear D.A. (1993) Fine sediment infiltration into gravel spawning beds within a regulated river experiencing floods: ecological implications for salmonids. *Regulated Rivers: Research and Management* 8: 373-90
- Slaymaker O. (2009) The future of geomorphology. *Geography Compass* 3: 329-49.
- Strahler A.N. (1956) The nature of induced erosion and aggradation, in W.L. Thomas (ed.), *Man's Role in Changing the Face of the Earth*. Chicago: University of Chicago Press, pp. 621-38.
- Thomas W.L. (ed.) (1956) *Man's Role in Changing the Face of the Earth*. Chicago: University of Chicago Press
- Wilcock P.R., Schmidt J.C., Wolman M.G., Dietrich W.E., Dominick D., Doyle M.W., et al. (2003) When models meet managers: examples from geomorphology, in Wilcock P.R. and Iverson R.M. (eds), *Prediction in Geomorphology*, Geophysical Monograph 135. Washington, DC: American Geophysical Union, pp. 27-40.