5

Geomorphology in Environmental Management

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'Environmental management' is both a multi-layered social construct, in which environmental managers interact with the environment and each other, and a field of study emphasizing the need for interdisciplinary understanding of human–environment interactions (Wilson and Bryant, 1997). Environmental managers are those

> whose livelihood is primarily dependent on the application of skill in the active and self-conscious, direct or in-direct, manipulation of the environment with the aim of enhancing predictability in a context of social and environmental uncertainty.
> (Wilson and Bryant, 1997: 7)

Thus the goal of environmental management is '...to harmonize and balance the various enterprises which man has imposed on natural environments for his own benefit' (Goudie, 1994: 181). The perception of 'benefit', however, depends on the prevailing management vision and objectives for a particular environmental facet (water, rivers, beaches, deserts, etc.) or location. These variables lead to at least five fundamental dimensions to environmental management: the importance of place, implications of scale, situation in time, the cultural context and political framework (Downs and Gregory, 2004).

These dimensions result in *considerable* scope for social and environmental uncertainty that is largely beyond the realm of this chapter. Instead, we concern ourselves primarily with the 'application of skill' in enhancing the predictability of environmental manipulation from a geomorphological perspective. Geomorphology, as the study of the origins and evolution of Earth's landforms and the processes that shape them, is clearly part of the disciplinary scientific basis of environmental management, and there is a long-standing concern with 'applicable' geomorphology (see Gregory, 1979) that investigates geomorphological processes and resulting landforms under the influence of human activity. Graf (2005) argues that geomorphology has been closely associated with public policy and land-use management in the USA since the late 19th century, especially through Grove Karl Gilberts' studies for the US Geological Survey (Gilbert, 1890, 1914, 1917). While few applicable geomorphology studies occurred through the first half of the 20th century (Cooke and Doornkamp, 1974), geomorphology has both re-connected and increasingly strengthened its association with management applications since that time (Graf, 2005) 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.

Despite an extensive literature on the applicability of geomorphology to problems in environmental management, we find few descriptions of direct geomorphological application. On inspection, the majority of texts regarding 'applied geomorphology' (see Table 5.1) actually involve *applicable* studies rather than the true '…application of geomorphological techniques and analysis to a planning, conservation, resource evaluation, engineering or environmental problem' (Brunsden et al., 1978: 251). Perhaps this phenomenon can be explained because true 'applied geomorphologists' are environmental professionals whose priorities lay primarily with their clients rather than with writing for publication, leaving reports on applied geomorphology mostly to a small cadre of academics who consult part time and whose career success is defined ~~partly~~ by published manuscripts, chapters and books.

Table 5.1 Example texts in 'applied' geomorphology

Authors/Editors	*Year*	*Title*	*Publisher*
Steers, J.A.	1971	*Applied Coastal Geomorphology*	M.I.T. Press, Cambridge, MA
Coates, D.R. (ed)	1971	*Environmental Geomorphology*	State University of New York Publications in Geomorphology, Binghampton
Coates, D.R. (ed)	1972	*Environmental Geomorphology and Landscape Conservation. Volume I. Prior to 1900*	Dowden, Hutchinson & Ross, Stroudsburg
Coates, D.R. (ed)	1973	*Environmental Geomorphology and Landscape Conservation. Volume III. Non-urban regions*	Dowden, Hutchinson & Ross, Stroudsburg
Cooke, R.U. and Doornkamp, J.C.	1974	*Geomorphology in Environmental Management*	Oxford University Press, Oxford
Coates, D.R. (ed)	1976	*Geomorphology and Engineering*	George Allen and Unwin, London
Hails, J.R. (ed)	1977	*Applied Geomorphology: a Perspective of the Contribution of Geomorphology to Interdisciplinary Studies and Environmental Management*	Elsevier Scientific Pub. Co., New York
Dunne, T. and Leopold, L.B.	1978	*Water in Environmental Planning*	W.H. Freeman, San Francisco
Cooke, R.U., Brunsden, D., Doornkamp, J.C. and Jones, D.K.C.	1982	*Urban Geomorphology in Drylands*	Clarendon Press, Oxford
Craig, R.G. and Craft, J.L.	1982	*Applied Geomorphology*	Allen & Unwin, London
Verstappen, H. Th.	1983	*Applied Geomorphology: Geomorphological Surveys for Environmental Development*	Elsevier, Amsterdam
Cooke, R.U.	1984	*Geomorphological Hazards in Los Angeles*	Allen & Unwin, London
Costa, J.E. and Fleischer, P.J. (eds)	1984	*Developments and Applications of Geomorphology*	Springer-Verlag, Berlin
Petts, G.E.	1984	*Impounded Rivers: Perspectives for Ecological Management*	John Wiley and Sons, Chichester
Doornkamp, J.C.	1985	*The Earth Sciences and Planning in the Third World*	Liverpool University Press, Liverpool
Graf, W.L.	1985	*The Colorado River – Instability and Basin Management*	Association of American Geographers, Washington, DC
Fookes, P.G. and Vaughan, P.R	1986	*Handbook of Engineering Geomorphology*	Blackie, Glasgow
Hart, M.G	1986	*Geomorphology, Pure and Applied*	Allen & Unwin, London

Continued

Table 5.1 Cont'd

Authors/Editors	*Year*	*Title*	*Publisher*
Toy, T.J. and Hadley, R.F.	1987	*Geomorphology and Reclamation of Disturbed Lands*	Academic Press, Orlando
Brookes, A.	1988	*Channelized Rivers: Perspectives for Environmental Management*	John Wiley and Sons, Chichester
Hooke, J.M. (ed)	1988	*Geomorphology in Environmental Planning*	John Wiley and Sons, Chichester
Cooke, R.U. and Doornkamp, J.C.	1990	*Geomorphology in Environmental Management: a New Introduction*	Clarendon Press, Oxford
Morisawa, M.	1994	*Geomorphology and Natural Hazards*	Elsevier, Amsterdam
McGregor, D.M and Thompson, D.A. (eds)	1995	*Geomorphology and Land Management in a Changing Environment*	John Wiley and Sons, Chichester
Brookes, A. and Shields Jr, F.D. (eds)	1996	*River Channel Restoration: Guiding Principles for Sustainable Projects*	John Wiley and Sons, Chichester
Bird, E.C.F.	1996	*Beach Management*	John Wiley and Sons, Chichester
Viles, H. and Spencer, T.	1996	*Coastal Problems: Geomorphology, Ecology and Society at the Coast*	Arnold, London
Thorne, C.R., Hey, R.D. and Newson, M.D. (eds)	1997	*Applied Fluvial Geomorphology for River Engineering and Management*	John Wiley and Sons, Chichester
Hooke, J.M.	1998	*Coastal Defence and Earth Science Conservation*	Geological Society, Bath
Giardino, J.R. and Marston, R.A.	1999	*Engineering Geomorphology*	Elsevier, Amsterdam
Oya, M.	2001	*Applied Geomorphology for Mitigation of Natural Hazards*	Kluwer Academic Publishers, Boston
Marchetti, M. and Rivas, V.	2001	*Geomorphology and Environmental Impact Assessment*	A.A. Balkema, Lisse
Allison, R.J. (ed)	2002	*Applied Geomorphology: Theory and Practice*	John Wiley and Sons, Chichester
Kneupfer, P.L.K. and Petersen, J.F. (eds)	2002	*Geomorphology in the Public Eye*	Elsevier, Amsterdam
Downs, P.W. and Gregory, K.J.	2004	*River Channel Management: Towards Sustainable Catchment Hydrosystems*	Arnold, London
Bremer, H. and Dieter Burger, D.	2004	*Karst and Applied Geomorphology: Concepts and Developments*	Gebruder Borntraeger, Berlin
Brierley, G.J. and Fryirs, K.A.	2005	*Geomorphology and River Management: applications of the river styles framework*	Blackwell, Oxford
Fookes, P.G. Lee., E.M. and Milligan, G. (eds)	2005	*Geomorphology for Engineers*	Whittles, Caithness
Anthony, D.J., Harvey, M.D., Laronne, J.B. and Mosley, M.P. (eds)	2006	*Applying Geomorphology to Environmental Management*	Water Resources Publications, Highlands Ranch, CO
James, L.A. and Marcus, W.M. (eds)	2006	*The Human Role in Changing Fluvial Systems*	Elsevier, Amsterdam
Fookes, P.G. Lee., E. M. and Griffith, J.S.	2007	*Engineering Geomorphology: Theory and Practice*	Whittles, Caithness

In this review, we will first consider the evolving role for geomorphology in environmental problem-solving and the ways in which geomorphological services are provided to environmental managers. Three specific roles for geomorphology in environmental management are illustrated, namely applications to natural hazard avoidance and diminution, environmental restoration and conservation, and the sustainable development of natural resources. Evidence from these contributions provides the basis for suggesting some core skills and standards required by applied geomorphologists. Finally, we assess the potential future role for geomorphology in environmental management that and argue that truly successful applications will demand reconceptualizing management problems from a geomorphological perspective, and not simply applying geomorphology within the constraints of traditional management practice.

INCREASING OPPORTUNITY FOR APPLICATION

The substance and style of geomorphology applications in environmental management has evolved over time. Scientifically, the discipline of geomorphology has continued to add technical expertise and tools that allow its applied scientists to better tackle environmental issues. 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-centred solutions. Socially, environmental managers and the public have gradually recognized the relevance of geomorphology in environmental problem-solving, leading to greater numbers of geomorphologists interacting with public policy (Kneupfer and Petersen, 2002). In tandem with a growing public awareness that environmental conditions are important in determining 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 problems.

The evolution of contributions of fluvial and coastal geomorphology to environmental management in the UK 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, we argue 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 now several different drivers promoting geomorphological contributions to environmental management. First and most commonly, geomorphology is 'part of the solution' (Gardiner, 1994; FISRWG, 1998; King et al., 2003) contributing within a multi- and interdisciplinary framework to solve specific environmental problems (Jewitt and Görgens, 2000; Rogers, 2006). For many years, especially in the lowlands, landscapes were imagined to be largely static during the engineering time-frame of a project, and thus geomorphological processes were ignored. However, both research and empiricism have showed the fallacy of this assumption, leading to the progressive integration of geomorphology in management. Now, because environmental management objectives usually 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). Examples are provided later in this chapter.

A second driver is the widely recognized connection between environmental degradation and socio-economic deterioration (Kasperson and Kasperson, 2001), 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 (Alcántara-Ayala, 2002). 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 (Slaymaker, 2009) if it wants to be seen as a key element of global environmental management.

A third driver is more intrinsic and involves a growing effort to support and retain 'geodiversity', the earth science counterpoint to biodiversity. Geodiversity is defined 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 goal involve the restoration and maintenance of physical integrity in environmental systems (e.g. Graf, 2001), for instance in trying to maintain functional river processes and forms even under a modified hydrological regime. At the level of landforms, geodiversity involves the preservation and conservation management of parkland environments (Gordon et al., 1998, 2002) or unique landforms (Downs and Gregory, 1994). In England, this has taken the form of a network of Regionally Important Geological/Geomorphological Sites (RIGS) (see McEwan, 1996) and progress towards a series of Local Geodiversity Action Plans as the mechanism for delivering geoconservation. Thus in contrast to the other drivers, in this application geomorphology may be the solution and endpoint.

In response to these increased demands for geomorphological services, employment opportunities for 'professional' geomorphologists have increased. Whereas geomorphology expertise was once provided almost solely by geomorphologists contracted from academia, there is now a far wider client base (Table 5.2). One result is greater collaborative problem-solving between professional and academic geomorphologists, frequently through academic involvement as 'expert advisors' on projects. A second result, however, is greater ambiguity in defining professionalism in geomorphology. This is a problem of long standing (see Brunsden et al., 1978) and sees the title 'geomorphologist' liberally and sometimes disingenuously applied: we return to this theme later after reviewing a suite of recent contributions of geomorphology in environmental management.

Table 5.2 Client groups for geomorphological services

Client groups for geomorphological services
• Individuals
• Developers
• Various tiers of government: local, state, federal (and tribes in the US)
• Consulting engineers, planners, landscape architects and biologists
• Conservation-focused NGOs and environmental advocacies
• Natural resource managers (energy utilities, irrigation districts, forest managers, resource conservation districts, aggregate miners)
• Reinsurance officers
• Lawyers
• Universities
• International agencies/organizations

Source: Updated from Brunsden, 1996.

GEOMORPHOLOGICAL CONTRIBUTIONS: SERVICES FOR ENVIRONMENTAL MANAGEMENT

Geomorphological application in environmental management arises primarily as proposed changes in land use, development of natural resources, restoration initiatives, and measures to reduce natural hazards are filtered through numerous protective policies and regulations imposed at a local, national or supra-national scale. In the Pacific north-west of the United States, where a maze of state and federal entities each have jurisdiction over some element of a proposed project, Shannon (1998) reports that there are normally 17 tribal, state and federal agencies involved as water passes through a drainage basin, creating multiple opportunities for geomorphology applications with somewhat different objectives.

Many geomorphology services in the USA stem from the 1973 Endangered Species Act and the 1977 Clean Water Act while, in Europe, the 1992 European Union Habitats Directive, the 2000 Water Framework Directive (WFD) and now the 2007 Floods Directive are starting to profoundly influence approaches to environmental management (Clarke et al., 2003; Manariotis and Yannopoulos, 2004; Wharton and Gilvear, 2006). Therefore, the focus and scale of geomorphology services can vary widely, for instance, from helping protect and restore summer breeding habitats of the federally endangered riparian bird, the south-western willow flycatcher (*Empidonax traillii extimus*) (Graf et al., 2002), to a strategic role in the WFD's goal of good 'hydromorphological' quality across all rivers of the member states.

The geomorphological tools applicable to a particular problem will depend on the perceived problem, the management context, available funding and the geomorphological environment of concern, resulting in at least seven categories of geomorphological service including:

1 Project orientation – designed to provide initial insights into the problem or issue;
2 Determination of current site conditions – using desk study, field work, monitoring, and analysis, and usually designed, at least implicitly, to understand the sensitivity to change of the landform;
3 Interpretative analytical investigation of past site conditions – using conceptual models, historic databases and various landform dating techniques to inform probable historical conditions;
4 Prediction of future site conditions – interpretative or using numerical modelling tools applied to predict landform sensitivity to various potential management scenarios;
5 Problem solution and design – almost always as part of a multi-disciplinary team;
6 Post-project appraisal monitoring and evaluation – ideally including implementation, effectiveness and validation monitoring to inform an evaluation of project sustainability;
7 Expert advisory – frequently related to litigation, insurance claims and expert witness testimony.

A list of potential contributions under each type of service is provided in Table 5.3. With the possible exception of expert advisory, project involvement generally implies involvement in more than one service. For example, land-use planning projects frequently require at the least the first four services, and project implementation supports the first five. The sixth service, post-project appraisal, is something of an enigma: while, logically, every project should be evaluated (and thus monitored) as the basis for informing future practice (Downs and Kondolf, 2002), funding is rarely set aside. Assessment of appraisal practice, notably the National River Restoration Science Synthesis in the USA, has revealed a far more ad hoc basis for project appraisal (Bernhardt et al., 2005, 2007). This is particularly unfortunate because a critical requirement of post-project appraisal is a suitable baseline data set (service 2), meaning that land-use planning and engineering projects should integrally involve appraisal design at their outset.

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

Hazard avoidance and diminution: geomorphology services in support of engineering

Perhaps the arena of longest standing interest (see Cooke and Doornkamp, 1974, 1990; Coates, 1976) is the application of geomorphology to the diminution of hazards associated with landscape change, usually related to erosion and sedimentation. More broadly, this reflects geomorphology's technical contribution to reducing the impact of natural disasters (see Alcántara-Ayala, 2002). Such application relates primarily 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 (Doornkamp, 1995). These services have spawned the sub-discipline of 'engineering geomorphology' (e.g., Fookes and Vaughan, 1986; Fookes et al., 2005, 2007); that is, geomorphology applied in assessing the risks to construction associated with surface processes and landform change (Fookes et al., 2007). Examples of the application to river engineering and geotechnical engineering are provided below: numerous other examples are contained in a special issue of *Geomorphology* edited by Giardino and Marston (1999).

River bed and bank protection: geomorphology and river engineering

With increasing settlement and agriculture of floodplain lands has come a need for channel 'stability', a sub-set of channelization (see Brookes, 1988) wherein the river's natural tendency for lateral migration is perceived as a hazard and forcibly resisted by structural reinforcement of river banks to prevent erosion and fix the channel planform. Planned bank 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. However, 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

Table 5.3 Geomorphological services in environmental management

Service	*Environmental management purpose*
Project orientation	Hypothesis generation about probable field conditions
	Development of initial conceptual model of system functioning
Determination of current conditions	Undertake point-in-time (baseline) inventory, as basis for project design and post-project monitoring and evaluation
	Determine likely compliance with regulations
	Determine necessity of additional studies
	Contribute catchment- or network-based studies to river basin and floodplain plans
	Determine opportunities for environmental improvement/restoration
	Identify critical locations: at-risk habitats, extent of current erosion/deposition risk
	Quantify impact of past human activities
	Determine whether apparent risk warrants remedial action
	Early phase advice on whether proposed management approach will succeed
	Initial indication of measurable success criteria
Investigation of past conditions	Indicate significance of evolutionary trajectory of the landform for planned activities
	Indicate whether the proposed development is likely to cause impact
	Guidance on whether proposed restoration will have the desired beneficial impact
	Indicate similarity to historical conditions
	Basis for developing sustainable management options
	Basis for conceptual project design
Prediction of future conditions	Assist in option selection: judge likely success of proposed management actions
	Provide guidelines for necessary project design
Problem solution/design	Advise on sustainable approaches to management solution
	Advise on siting infrastructure (roads, bridges, houses, etc.)
	Contribute bounding parameters to project design
	Impact analysis of likely compliance with environmental regulations
	Risk assessment related to policies for river-basin management, land-use zoning, flood management
	Collaborative contribution as part of project solution team
Post-project monitoring and evaluation	Monitor effectiveness of implemented solution
	Evaluate project success and contribution to knowledge
	Identify unanticipated actions that require remedial attention
	Evaluate efficacy of management method in comparison with others
	Evaluate completion of commitments by project proponents
Expert advisory	Supply analysis for use in legal case
	Provision of expert witness testimony and expert opinion
	Advocacy for client

suite of protective regulations in most countries that amplify the need for far more *strategic* applications that minimize both the environmental impact and the economic cost to taxpayers. These changes have provided numerous opportunities for geomorphology to contribute to river engineering and management (e.g., Thorne et al., 1997; Skidmore et al., 2009).

Breaking with the tradition of always utilizing river bank protection near to floodplain development, geomorphologists are now frequently required to analyse the risk posed to the development by the river's natural evolutionary tendency. Techniques include the use of field reconnaissance surveys (Downs and Thorne, 1996; Thorne, 1998), overlays of historical aerial photographs and large-scale topographic map (Graf, 1984, 2000), and other techniques (Lawler et al., 1997) including procedures for large rivers (Thorne, 2002). Management approaches are then proposed based on the cause, severity, extent, and mode of bank failure in the vicinity of the perceived need (Thorne et al., 1996). Likewise, because research has shown that channel-bed erosion frequently occurs via the upstream migration of an incising knickpoint in channelized rivers (Schumm et al., 1984; Simon, 1989), a regional geomorphological assessment of river bed and bank conditions (Figure 5.1) can determine the most effective site (and minimum requirement) for grade-control structures (see examples in Darby and Simon, 1999) or be used to propose maintenance activities in low-energy river environments prone to sedimentation (Sear et al., 1995; Newson et al., 1997; Landwehr and Rhoads, 2003). 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 (e.g. Chin et al., 2008) show the influence of geomorphology input.

Reducing hillslope and landslide hazards: geomorphology and geotechnical engineering

Slide-prone areas can offer some of the most attractive sites for new development for 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 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 (see Leighton et al., 1984; Linden, 1989), 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. Specific sites or entire regions are assigned a relative

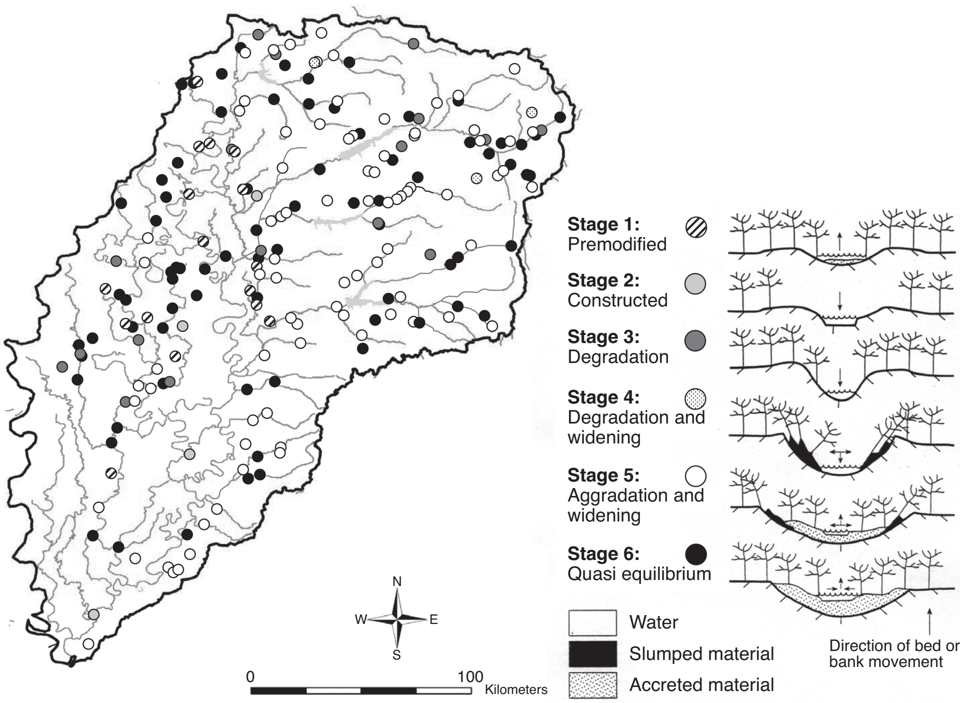

Figure 5.1 Using reconnaissance survey and rapid assessment protocols and to characterize sites in the Yazoo River catchment, Mississippi, according to their stage in river bed and bank erosion (see legend) following the passage of multiple knickpoints (adapted from Simon et al., 2007b)

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), hillslope 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 (e.g., Tubbs, 1974). At its simplest, 'steep slopes' are deemed 'hazardous', and the only geomorphic principle being used is the gross importance of hillslope gradient in driving downslope 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; Chacón et al., 2006; van Westen et al., 2008).

Beyond landslide mapping, a geomorphologist's interpretational skills can be used, for instance, in recognizing the presence of prior landslides which is often one of the best predictors of actual or potential instability (Figure 5.2). Geomorphic features used to identify past landslides commonly include hummocky topography, bent trees, springs and seeps, and arcuate

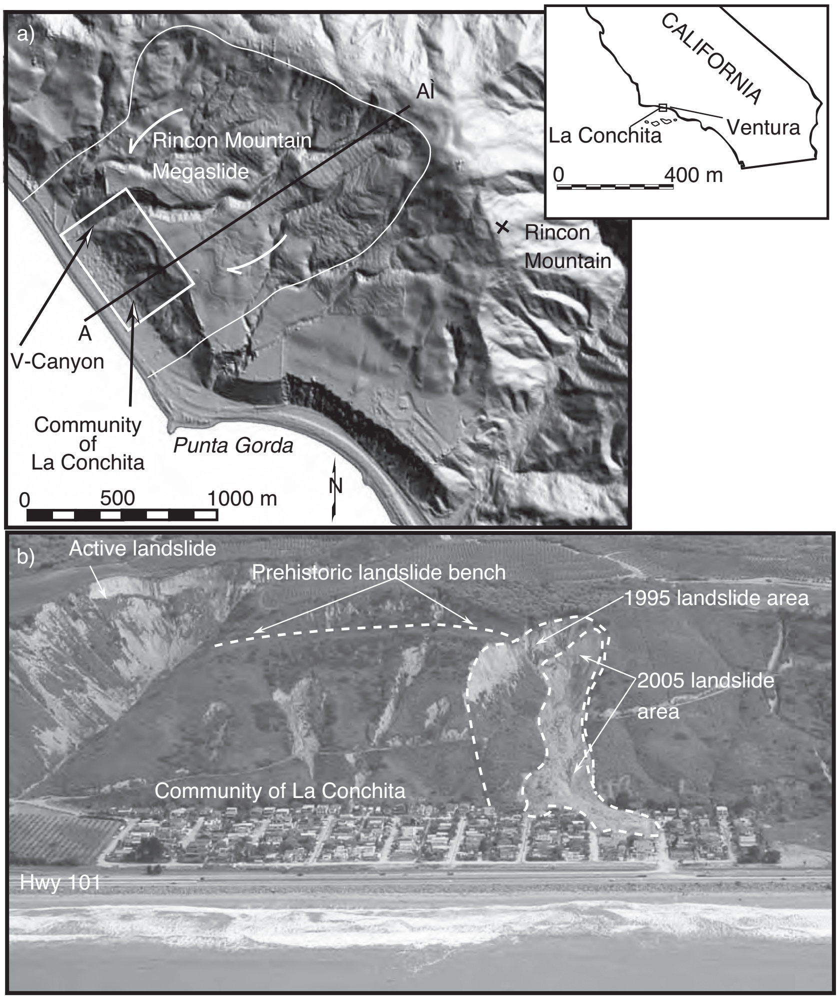

Figure 5.2 Interpretation of LiDAR/aerial imagery to identify multiple ages of landslides above La Conchita, California, including a prehistoric landslide that lay unrecognized during the development of the community of La Conchita (from Gurrola et al., 2010)

scarps (Dunne and Leopold, 1978; Sidle et al., 1985). 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 some 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: geomorphology services in support of natural resources management and land-use planning

A second arena for service is in the sustainable management of natural resources, including agriculture and land-use planning. In this sense, 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 (Clark, 2002). 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. Three examples are provided related to clean water provision, urban planning and the management of large dams.

Assessing fine sediment sources and pathways: geomorphology and clean water protection

Many protective policies for clean water focus on minimizing the deleterious impact of land management activities, and this frequently involves trying to reduce excess fine sediment delivery to potable water supplies or aquatic habitat: more than ten federal laws in the USA allow federal, state and tribal agencies to govern sediment quality (Owens et al., 2005). For aquatic habitat, especially for salmonid species, research has indicated the detrimental impact of too much fine sediment on spawning, rearing and shelter habitat (Bestcha and Jackson, 1979; Sear, 1993; Anderson et al., 1996). Such 'excess' fine sediment is usually derived from land~~-~~surface disturbance caused by agriculture (Collins et al., 1997; Walling et al., 1999), forestry clearance and management (Luce and Wemple, 2001; Owens et al., 2005), or early-phase urban development (Wolman, 1967). Such impacts also leave a significant legacy impact on the channel morphology processes that can affect fine sediment loads for decades to hundreds of years after land-use change (Trimble, 1997; Fitzpatrick and Knox, 2000; Prosser et al., 2001).

The geomorphologist's goal is frequently to identify the likely source and pathways of excess sediment by determining sediment sources or a catchment sediment budget. This information allows regulators to promote best management practices or take punitive actions, as necessary. The approach to defining a sediment budget depends partly on the size of the catchment but usually involves a collation and analysis of available data, catchment modelling and field surveys (Reid and Dunne, 1996; Gregory and Downs, 2008). Various catchment models can be used; one popular approach is to overlay readily available digital information regarding the channel network, geology, hillslope gradients and vegetation data on a digital elevation model to produce a discrete set of landscape units or process domains (Montgomery and Foufoula-Georgiou, 1993; Montgomery, 1999) which, by virtue of their coherence should produce similar unit-area sediment production rates. The resulting map of units subsequently provides a way of organizing field survey to cover a representative range of different units, verifying mapped erosion sources and estimating their dimensions, and estimating the delivery ratio of hillslope material to the channel network (Figure 5.3). Field survey also records channel erosion processes including the dimensions of bank failure and the extent of vertical incision relative to evidence of adjustment from channel morphology, vegetation and structures such as bridges. Data that can help corroborate or constrain rates of sediment yield are extremely useful, for example using dated rates of sedimentation ~~into~~ reservoirs ~~and~~ bays~~,~~ and ~~onto~~ floodplains, dated structures, dendrochronology and 'finger printing' of sediment sources to determine provenance (Oldfield et al., 1979; Walling, 1999; Walling et al., 1999).

Hydromodification and river channel change: geomorphology and urban planning

The geomorphic study of stream channels altered by human disruptions to hydrology has a long history since the first systematic discussion by Leopold (1968). A quarter of a century later, the term 'hydromodification' was coined in the

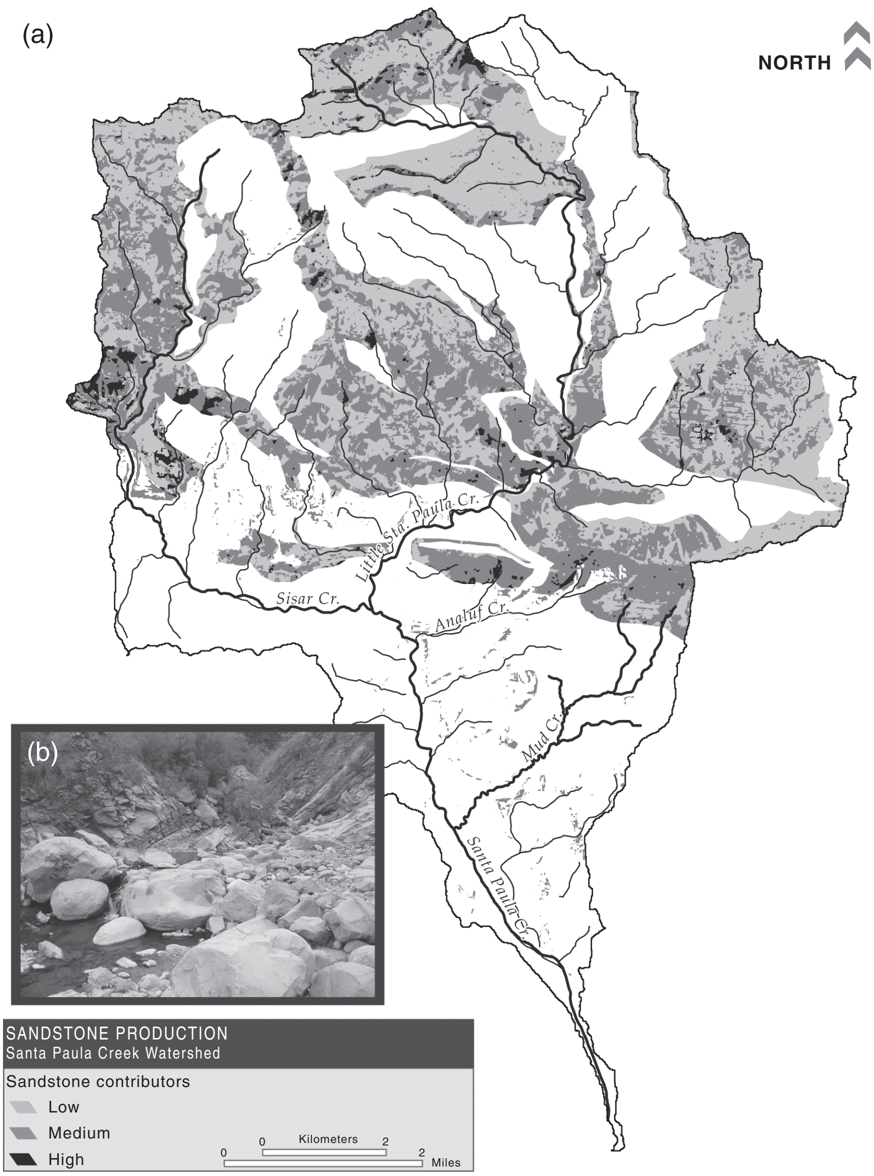

Figure 5.3 (a) Using terrain modelling to explore the sediment source and yield characteristics of a mountainous watershed in southern California. Overlays of geology, land cover and hillslope gradient are used to characterize coarse sediment production for analysing potential influences on salmonid 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

engineering and regulatory literature (Frederick and Dressing, 1993), and in many parts of the USA it is now used as the shorthand term for all manners of land-use change, particularly urbanization, affecting downstream channels.

The dimensions of channels in an urban stream network generally follow the overall pattern of discharge changes across that network, with larger flow peaks resulting in greater channel adjustment. However, the application of geomorphic understanding leads to a more complex interpretation of existing data and suggests that any locally observed correlations between channel size, rate of channel change, and watershed characteristics are likely to be non-universal (Booth and Henshaw, 2001). 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 (Ebisemiju, 1989; Alberti et al., 2007). 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 (e.g. Booth, 1990).

Observed channel stability may reflect true re-establishment of fluvial equilibrium (as anticipated, for example, by Hammer, 1972, Neller, 1988, Ebisemiju, 1989, Henshaw and Booth, 2000), but alternatively it may simply represent the product of flushing all mobile sediment from the system to produce a relatively static, non-alluvial channel (e.g., Tinkler and Parish, 1998). In either case, the re-attainment of 'channel stability' can express the condition of a substantially altered flow regime with negligible physical impacts but potentially catastrophic (and unrecognized) biological consequences (Figure 5.4). This outcome reinforces the need for geomorphologists to be involved in integrated assessments of the urban impacts on river systems (Nilsson et al., 2003).

Water supply impact assessments: geomorphology and the management of large dams

Following the golden age of multi-purpose large dam building in the mid-20th century (Beaumont, 1978), a plethora of research including that from geomorphologists has indicated the deleterious impact of regulated rivers on fluvial ecosystems (Petts, 1984; Ligon et al., 1995, Collier et al., 1996, Graf, 2001). Dam operators are now frequently required to develop revised flow release schedules to minimize further impacts to downstream fluvial ecosystems or, in the case of hydropower dams in the USA regulated by the Federal Energy Regulatory Commission (FERC), to consider impacts on fish and wildlife equally with power generation and flood control before a new licence is issued (see Masonis and Bodi, 1998). Geomorphologists are therefore now providing services to assess 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 re-licensing of hydropower dams in the USA 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. Analyses 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 (Stillwater Sciences et al., 2006). 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' (Reiser et al., 1989) designed to partially restore the flood pulse advantage (Bayley, 1991) by flushing fine sediment, stimulating coarse sediment transport, and facilitating floodplain inundation (Downs et al., 2002). Designing such flow releases to have a sustainable impact is difficult (Kondolf et al., 1993; Kondolf and Wilcock, 1996; Schmidt et al., 2001), 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.

When dam removal is proposed, geomorphologists are generally 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 knickpoint; 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 (see Cui and Wilcox, 2008) (Figure 5.5)

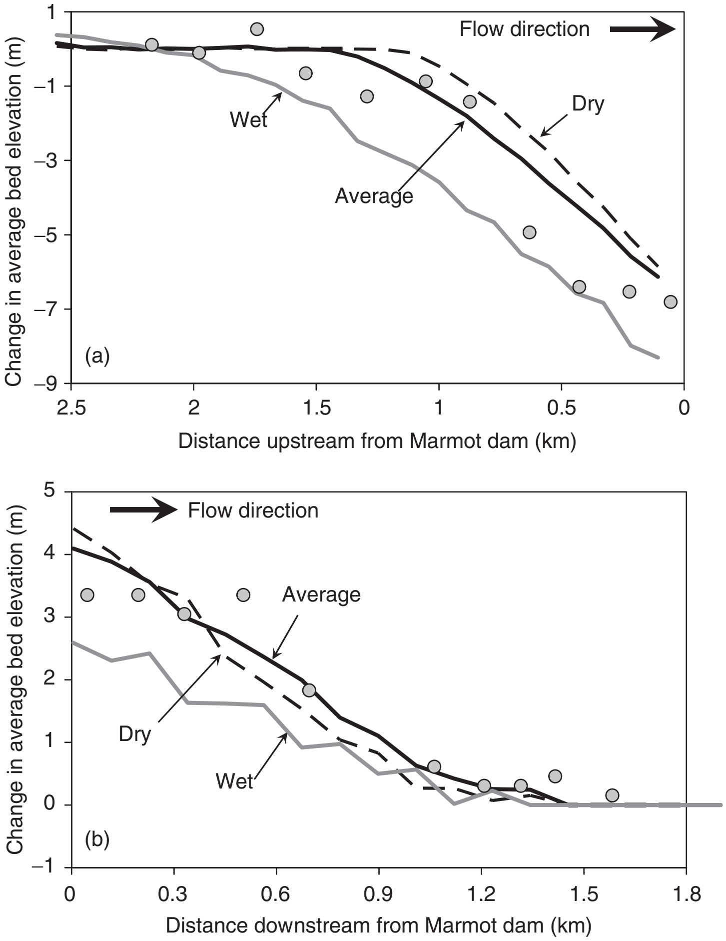

Figure 5.4 Using monumented and reoccupied stations to track channel change over more than a decade of urban-induced flow increases. View is of a restabilized but severely impacted stream channel in western Washington, USA (station PS3 of Booth and Henshaw, 2001)

and the use of scaled (e.g. Bromley and Thorne, 2005) or generic physical models (Cui et al., 2008; Wooster et al., 2008) to provide guidelines for sediment management during dam removal (Randle et al., 2008; Downs et al., 2009).

Environmental restoration and preservation: geomorphology services in support of conservation management and landscape design

A 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' (Jordan et al., 1987), '…the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems' (Jackson et al., 1995, 71), environmental restoration is now a big business with expenditure on river restoration alone estimated at over $1 billion annually since 1990 (Bernhardt et al., 2005). Growing recognition of the importance for ecology of habitat structure and function has greatly increased the visibility and relevance of geomorphology as a contributing discipline. It also marks a sharp departure from geomorphology's role in environmental management as a

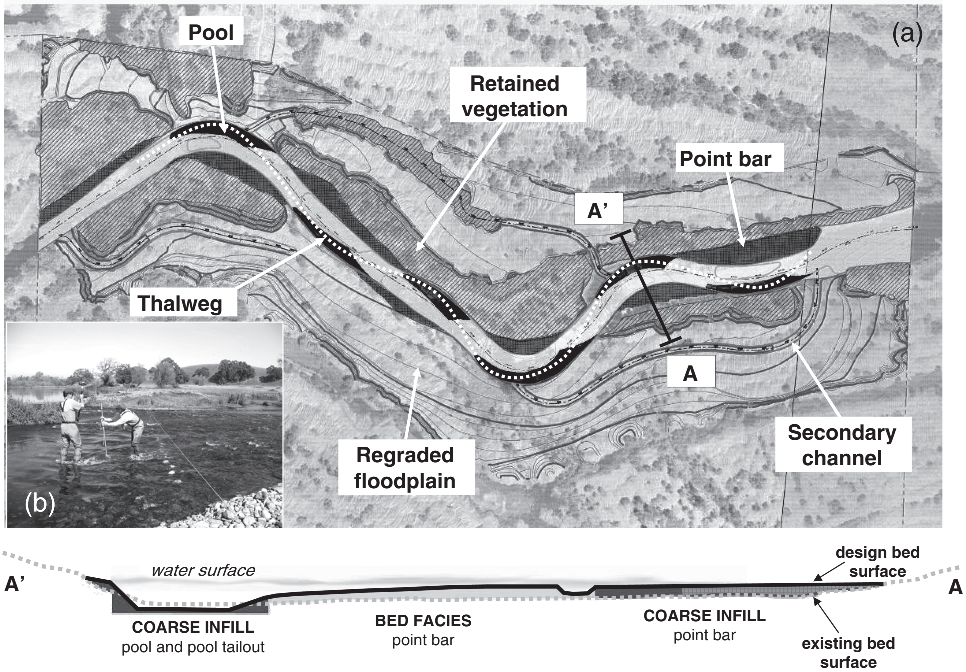

Figure 5.5 Sediment transport modelling used to predict the likely impact of the removal of Marmot Dam (Sandy River, Oregon) for the year following dam removal, under average, wet and dry year scenarios (exceedance probability of peak flow and annual runoff of 50 per cent, 10 per cent and 90 per cent, 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)

discipline helping to reduce or minimize environmental impacts associated with human activity (previous examples) 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. Examples related to river restoration design and parkland planning are provided below.

River restoration assessment and design: geomorphology and restoration ecology

A plethora of quantitative scientific research since the 1970s demonstrated unequivocally both the deleterious impact of human activities on fluvial ecosystems and substantial declines in populations of native aquatic species. This caused a perception shift in river management away from minimizing and mitigating human impacts towards active restoration involving undoing the impact of past actions. A generally acknowledged preference for process-based restoration where possible (NRC, 1992; SRAC, 2000), and increasing understanding of the critical role of hydro-geomorphological processes in maintaining aquatic habitat diversity has served to position geomorphology as a central discipline in river restoration, with geomorphologists frequently providing the functional link between achieving species-based restoration goals and managing on-going risks to floodplain inhabitants related to river flooding and erosion. The geomorphologist's role in river restoration can encompass project orientation including assessing uncertainties inherent to the restoration design (e.g. Wheaton et al., 2008); determining past, present and future conditions for baseline purposes including the use of rapid assessment protocols and baseline data surveys (Downs and Gregory, 2004; Brierley and

Fryirs, 2005), understanding the extent of hydrosystem modification, specifying conceptual models including the recovery potential for the existing channel (Fryirs and Brierley, 2000); project design including relationships between geomorphology and valued flora and biota; and project monitoring and evaluation.

Process-based restoration may involve the geomorphologist in prescribing environmental high flows to restore the ecological benefits related to high-flow events, determining the feasibility of weir or large dam removal (see preceding section for both) or reconnecting floodplains and backwater channels through the removal of embankments (Toth et al., 1998; Buijse et al., 2002). In all cases, a key element is balancing the sediment supply and transport to result in a sustainable design. Where prompted recovery is chosen, the geomorphologist will likely be involved in the siting and design of instream structures constructed of logs or boulders, often to mimic natural channel features (e.g. Lenzi, 2002; Chin et al., 2008), ensuring that they promote the required beneficial processes and are structurally stable (see Hey, 1994; Downs and Thorne, 2000). Where restoration necessitates reconstructing the channel morphology (e.g. reinstating a meandering planform), the geomorphologist should be involved in ensuring the restoration project works in its catchment context (Kondolf and Downs, 1996; Kondolf et al., 2001) and that the design functions with the river's contemporary flow regime and sediment supply (Shields, 1996; Soar and Thorne, 2001). In the case of regulated rivers, this can involve re-scaling the channel (Figure 5.5). Geomorphologists should also help develop a monitoring and evaluation programme to ensure that adequate learning results from the restoration 'experiment' (Downs and Kondolf, 2002; Rhoads et al., 2008; Skinner et al., 2008), ensuring the long-term sustainability of the implemented solution (Gregory and Downs, 2008; Newson and Clark, 2008).

Conservation and recreation provision: geomorphology and parkland planning

Development pressures increasingly make parkland settings a focal point for both conservation and recreation planning, whether the parkland is in a pristine isolated setting or on the urban fringe. There is an inherent tension implicit between conservation and recreational land uses that make it critical to understand the geomorphological sensitivity of the landscape (Brunsden and Thornes, 1979) in addition to its floristic and wildlife values. In urban settings, for instance, river corridors are increasingly viewed by municipalities and regional planners as critical multipurpose open spaces (e.g. Barker, 1997) where there is pressure not only to provide recreational facilities (river access points, trails, etc), but also to provide the urban population accessible exposure to 'natural ecosystems'. At the same time, where habitat for threatened and endangered native species exists in the river corridor there may be regulatory pressure to designate exclusion zones for the public. From the other extreme, many montane habitats support dynamic and fragile habitats where the valued biodiversity is linked closely to geomorphological processes (past and present) that should be understood in developing management plans (Gordon et al., 1998, 2002).

The geomorphologist's role in such situations is to help parameterize the dynamics and sensitivity of the landscape unit so that planners can better understand the processes that maintain and shape the mosaic of habitat patches that form the parkland extent and achieve an acceptable coexistence for the various desired uses. For river corridors, this may involve determining reach-scale channel adjustments in the context of the catchment conditions and so requires an assessment of the evolutionary dynamics of the corridor reach and the likely cumulative effects of other activities within the catchment. Similar to other geomorphological applications, there is an emphasis on understanding current conditions in the context of recent historical changes and projecting such understanding into the future, cognizant of the legacy impacts of natural changes and human impacts in the catchment. Future conditions can be predicted using hydrological models to predict likely changes to channel hydraulic geometry or stream power as an indirect measure of possible erosion threat, and direct monitoring or sediment transport model simulations can determine the potential impact of a sediment pulse moving through a channel network (e.g. Gomez et al., 2009). In other cases, the geomorphologist's knowledge of established conceptual models from prior research may provide the basis for determining likely future conditions. Relating this understanding back to the planning group can assist in determining a riparian buffer zone for preservation purposes, areas at risk of erosion where facilities and structures should be avoided, and the best routes for trails.

SKILLS AND STANDARDS FOR THE EARLY 21ST CENTURY APPLIED GEOMORPHOLOGIST

The examples above suggest that while a wide range of geomorphological capabilities are relevant, applied geomorphological investigations frequently require similar generic skills. These skills derive from the various project services outlined in Table 5.3. First, most projects require the geomorphologist to determine how the landform functions at present, involving not only the specific dynamics of the project site but also its spatial context and regional setting. The practising geomorphologist needs then to discern how the landscape unit functioned during some reference period from the recent historical past, typically before a series of human-related constraints were placed on landscape function (Ebersole et al., 1997) and, third, predict how the landscape unit is likely to function in the future under the same, additional, or fewer constraints. Predicting future conditions, although critical for environmental management, is a relatively new topic for geomorphology and the specific role it should play in geomorphological applications to environmental management is still being debated (e.g., Wilcock et al., 2003; Lancaster and Grant, 2003).

With these three basic analyses complete, a sustainable project solution is likely to involve the geomorphologist in determining how and why changes occurred between past and present conditions. This requires an assessment of the integrated impacts of legacy factors on contemporary geomorphological processes, which can be very challenging (Slaymaker, 2009). Furthermore, the geomorphologist should be capable of contributing as part of the project team to discussions about how the landscape should function in the future (Montgomery et al., 1995). Such discussions must acknowledge management desires and constraints, the impact of legacy factors (including earlier management episodes) and, increasingly, expected landscape response under changes to fundamental drivers such as climate. This process also requires a high level of interdisciplinary appreciation in order to work alongside other scientists and engineers, because project goals are far more likely to be focused on imperilled native species, water quality concerns, or reducing natural hazards than on sustaining geodiversity, *per se*. As a related factor, the applied geomorphologist should understand and be able to communicate how to manipulate site conditions to make the landscape unit function in the preferred way, sustainably and at an acceptable level of risk. This step is increasingly being translated to involve non-structural and well as structural methods of management, and to involve the economic valuation of non-use and recreational management benefits in addition to traditional economic-use valuation (Downs and Gregory, 2004).

Finally, geomorphologists need to be able to design and implement geomorphological monitoring and evaluation so that a significant learning experience can be achieved from the implemented project and so applied to future projects. This step has implications for baseline data collection and so should be considered at the project outset, a hallmark of what is broadly known as 'adaptive management' (Holling, 1978; Ralph and Poole, 2003).

In Table 5.4, the seven generic skills outlined above are subdivided according to a series of techniques that imply technical training. Besides those listed, there are of course other skills, such as clear and concise report and proposal writing capabilities, attention to detail with data collection and analyses, and good interpersonal communication and networking capacity that will also shape an individual's success as a professional. As few geomorphologists are likely to be trained in all of the techniques identified in Table 5.4 (and others no doubt equally essential, but beyond the authors' experience), there is an implication that geomorphological contributions to environmental management will likely occur as part of a team.

The required skills identified in Table 5.4 also reflect a breadth of techniques that are certainly beyond the range of training provided under any one degree course or single training class. Their multiplicity also frames the vexing issue of professionalism, standards and ethics in geomorphology (see Brunsden et al., 1978; Brunsden, 1996; Leopold, 2004). Unlike related disciplines involved with environmental management such as engineering and biology, there are no undergraduate degrees awarded in 'geomorphology' and there is no professional institution that accredits professional geomorphology training. Geomorphologists seeking independent recognition of their skills can aspire only towards accreditation from a neighbouring discipline either by way of an examination that is rigorous but may have only marginal linkage with their daily activities, such as Professional Geologist in the USA as accredited by the American Institute for Professional Geologists or individual state licensing boards; or by peer review that lacks the rigor of examination but may relate more specifically to the skills of the applicant, such as the status of Chartered Geographer (Geomorphology) conferred by the UK's Royal Geographical Society (with the Institute of British Geographers).

The result has been the creation of a new and unregulated market for training 'professional geomorphologists', frequently via unexamined short courses. In particular, training offered by Wildland Hydrology (www.wildlandhydrology.com) has been tremendously popular in the USA with the course's founder, David Rosgen, lauded as the 'river doctor' by *Science* magazine (Malakoff, 2004). While Rosgen has probably

Table 5.4 Core skills and techniques required by the early 21st century applied geomorphologist

Service	*Skills*	*Example methods*
Project orientation	1 Background information assembly	• Assimilation of geology, soils, vegetation, precipitation, population history, land management history, prior geomorphology reports
	2 Terrain modelling using GIS	• Empirical modelling for expected conditions • Development of process domains/landscape units
	3 Development of conceptual models	• Expert interpretation using known site details and accepted process–form linkages in academic literature
Determination of current conditions	4 Mapping and inventorying	• Survey, aerial photographic interpretation • Field reconnaissance using rapid assessment protocols
	5 Baseline data collection	• Collation of existing data records • Collection of additional data to supplement existing records (e.g. transects and cross-sections, grain size determination)
	6 Field interpretation of current morphology and process	• Field reconnaissance using rapid assessment protocols • Expert judgment
	7 Classification and characterization of landscape units	• Application of *a priori* classification hierarchy • Characterization via statistical analysis of attributes
	8 Monitoring of site dynamics	• Repeat measurements (tracer studies, repeat transects/cross-sections) over a designated interval or following large forcing events such as high intensity rainfall, floods, storm surges).
	9 Determine regional sediment flux (also for past conditions)	• Estimate of sediment yield, budget for watershed or coastal zone
Investigation of past conditions	10 Reconstruction of historical data series	• Air photo/map/survey overlay • Reconstruction of sediment flux from historical records • Use of narrative accounts, ground photographs • Vegetation composition and age
	11 Palaeo-environmental reconstruction for pre-historical conditions	• Stratigraphic analysis and interpretation of sedimentary deposits • Geochronology dating methods, e.g. radio carbon, lead 210, 237 • Erosion estimates using short-lived radio nuclides
Prediction of future conditions	12 Sensitivity analysis of potential for change	• According to measured potential for changes related to threshold: e.g. stream power • Interpretation of departure from 'expected' conditions: e.g. using hydraulic geometry comparisons, discriminant bi-variate plots • Positioning of units in expected sequence of change: e.g. channel evolution model • Statistical deterministic or probabilistic analysis • Using hydrological and sediment transport models (see below)

Continued

Table 5.4 Cont'd

Service	*Skills*	*Example methods*
	13 Computer and physical model simulations	• Computer modelling of hillslope stability • Computer modelling of river bank stability • Computer modelling of sediment transport in rivers, and near shore • Modelling of planform change • Physical modelling using scale models or generic experiment in flume
Problem Solution/ design	14 Expert interpretation and integration	• Based on the geomorphologist's experience and mental models, project perception • Ability to determine and contextualize the historical legacy on contemporary geomorphological processes
	15 Contribution to project objectives for sustainable/minimum maintenance/ impact	• Contribution via problem-solving forum of technical specialists, government agency representatives, other stakeholders
	16 Project siting	• Interpretation or risk analyses to determine minimum conflict point or maximum benefit between natural process and project requirements
	17 Project design	• Use of empirical and numerical models to propose process-based dimensions suitable to contemporary forcing mechanisms • Experience with implementation methods and techniques • Design of adaptive monitoring and evaluation programmes, experience in hypotheses setting
	18 Project implementation oversight	• In assistance to project engineer
Post-project monitoring and evaluation	19 Determination of measurable success criteria	• Expert knowledge of geomorphological system relationships (analytical references)
	20 Development of monitoring and evaluation plan	• Identification of primary variables, methods, locations and frequency of monitoring • Suggestions for suitable analyses
	21 Adaptive management response to outcomes of post-project appraisal	• Ability to interpret evaluation in context of implemented project to determine success and next steps
Expert advisory	22 Data provision	• Analytical expertise to provide data for open use or to bolster case
	23 Cross-examination capability	• Expert knowledge of specific geomorphological system and related systems to answer questions in deposition and in court

done more to popularize the discipline of fluvial geomorphology than anyone, many academic geomorphologists have concerns with the adequacy of the course content in its applied context (Juracek and Fitzpatrick, 2003; Simon et al., 2007a; Roper et al., 2008), and argue that the courses lack the rigor of academic geomorphology training and have no examination to identify the proficiency of the taker. This debate is of more than academic interest because, in some parts of the USA, it is now implied, if not explicitly stated, that geomorphology professionals *must* have extensive training in wildland hydrology classes, effectively usurping university training as the basis for defining professional geomorphology status, at least for fluvial geomorphology. Belatedly, several universities are responding with Certificate Programs in river and stream restoration (e.g. University of Minnesota, Portland State University, and North Carolina State University).

FUTURES: APPLIED GEOMORPHOLOGY RE-CAST

While the lack of a 'professional geomorphologist' accreditation is a clear weakness and probable hindrance to geomorphology's future role in environmental management, we suggest that the most important issue for geomorphologists to consider is the *way* in which geomorphology contributes to problem solving. Because, historically, engineers have been charged with solving environmental management issues and have achieved this largely through implementing structural solutions, applied geomorphologists have commonly adopted this prevailing paradigm by finding site-based remedies to an undesirable problem, and using structural solutions to achieve an immediate fix using short-term funding. Such 'engineering geomorphology' has undoubtedly heightened the problem-solving emphasis of geomorphology but does not reflect a true geomorphological approach to environmental management, being more limited and narrowly focused than might reasonably be derived from geomorphology's academic heritage. Several illustrations are provided below of overarching issues that would help re-cast applied geomorphology to the benefit of both geomorphology and environmental management. Other issues and a selection of inherent strengths and exciting opportunities that geomorphologists could, or should, bring to environmental problem-solving are outlined in Table 5.5.

Regional-scale approaches and longer-term planning horizons to offset cumulative impacts

Geomorphologists have long argued that site-based, structural approaches to environmental management should be discarded in favour of seeing environmental management in a broader landscape context (e.g. the catchment, littoral cell) and in terms of cause-and-effect linkages (Sear, 1994; Hooke et al., 1996; Kondolf and Downs, 1996). While a movement towards catchment-based approaches began several decades ago with integrated river basin management plans, cause-and-effect-based solutions are less frequently adopted, especially over long-term planning horizons. This is at odds with geomorphological research that frequently points to decades-to-centuries legacy effects (e.g. for the movement of disturbed sediments through a watershed), and

Table 5.5 Prospects for geomorphology in environmental management: strengths, weaknesses, opportunities, threats

Strengths	*Weaknesses*
• Directly concerned with the surface of the earth • Directly concerned with regional (e.g. catchment) functions that are the basis for maintaining healthy ecosystems and valued native biological populations • Long history of studying the role of human impact in system functioning • Well positioned to integrate biology, engineering and planning into practical solutions • Well positioned to practice design and management with nature to achieve truly sustainable designs	• Poor representation at policy levels • Poor representation on funding bodies to ensure adequate research funds • Lack of standard methods • Lack of routine monitoring of geomorphic systems • Viewed as a sub-set of engineering, especially in more quiescent landscapes • Lack of a professional group and professional accreditation
Opportunities	*Threats*
• 'Ecosystem services' a natural processes-based spin on conservation and management • Well placed to integrate human activities as part of a process–form–habitat–biota–culture link • New dating techniques for process rates that work well within timeframes of human occupation • New forms of digital data and processing (e.g. LiDAR and terrain modelling) as the basis for better approaches to cumulative impacts • Improved predictive models as the basis for strong representation under conditions of global change	• Geomorphology practised by others with little or insufficient training, and so lacking in broad areas of necessary skills (Table 5.4) • Perception of simplistic geomorphological descriptions of system functioning (e.g. the 'bankfull' paradigm) that do not apply in all cases

which suggest that geomorphology approaches to environmental problem-solving should be based on the same time frame to avoid costly management errors involved with over-engineered and wrongly positioned structures (Gregory and Downs, 2008). Three challenges for geomorphology research are to improve our analytical approaches for setting contemporary processes of landscape change into the context of historical legacy factors (which, inherently requires reconciliation of process geomorphology studies with historical approaches; Slaymaker, 2009), to better predict the impacts of cumulative effects at a project site, especially into the future (Reid, 1998) and, not least, to re-cast public perception of landscape change.

Acknowledging environmental management in terms of uncertainty, risk and probability

Long-term, larger spatial scale approaches to environmental management challenge geomorphologists to cast their predictions probabilistically, so that risk analyses are possible. Deterministic, reductionist approaches to geomorphological science needs to be allied to probabilistic outcomes to allow this potential to be tapped. This 'uncertainty' challenge is also not unique to geomorphology but applies generally across the environmental sciences and into civil engineering (e.g. Johnson and Rinaldi, 1998; Brookes et al., 1998). It implies the use, as suggested frequently, of adaptive environmental assessment and management (Holling, 1978) approaches that are risk-tolerant rather than risk-adverse (Clark, 2002), and that maximize the chance of surprise discoveries (McLain and Lee, 1996) as a function of 'learning by doing' (Haney and Power, 1996). It also implies a change towards using a series of moderate interventions with moderate risk as the basis for environmental management, rather than society's current preference for one large intervention that frequently represents a huge risk (Cairns, 2002).

Providing the scientific basis for an ecosystem service-based approach

Another significant opportunity for geomorphology in the coming decades will result from efforts worldwide to redefine environmental management in terms of the services to humans provided by functioning ecosystems. A groundswell of support has developed for considering the economic advantages of functioning ecosystems as part of environmental problem-solving, motivated in part by a stark appraisal of the extent of degradation and unsustainable use of ecosystem services by authors of the Millennium Ecosystem Assessment (MEA, 2005). Geomorphology is ideally based to exploit a paradigm of environmental management based on 'What do you want your landscape to do for you?' rather than 'this activity is forbidden'. In this regard, ecosystem services can be seen as moving the popular concept of 'design with nature' (McHarg, 1969) towards an overall and more pluralistic concept of 'management with nature' (Downs and Gregory, 2004). Critically, however, this will require reconceptualizing human agency and geomorphological systems to consider human influence not *on* the environment, but *within* it through a combined approach that encompasses sociocultural and biophysical processes (Urban, 2002). This might entail, for example, applied geomorphologists adopting socially based concepts such as 'ecohealth', which sees human health as a primary outcome of effective ecosystem management (Parkes et al., 2008).

Applying regional-scale, risk-based, ecosystem services-oriented approaches to environmental management would significantly enhance the potential for geomorphology application. It would also require that geomorphologists are well-represented in policy formulation, so that the discipline is not just relevant to the problem-solving milieu but central to how environmental managers define both their 'problems' and 'solutions'. Such development will require (1) educational outreach by academic and professional geomorphologists to non-geomorphology audiences and (2) employment of geomorphologists in government, non-governmental, and consulting organizations to reinforce relevance. Within geomorphology, practitioners and academics need to foster a better symbiosis between basic and applied research that facilitates the application of cutting-edge skills to the interdisciplinary, value-laden questions of environmental management. In particular, there is the need for (3) better dissemination to practitioners of basic and applicable geomorphology research, and (4) a steady supply of new 'tools' that increase the technical capabilities of professional geomorphologists (adapted from Gregory et al., 2008: Table 3).

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 mangers 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. This approach also implies funding environmental management to be far less construction-oriented, and so far more amendable to geomorphological approaches based on adaptive management.

Undoubtedly, thankfully, applied geomorphology has made great strides since the first edition of Cooke and Doornkamp's *Geomorphology in Environmental Management* was published in 1974. The future seems to offer enormous opportunity for continuing to expand the role of geomorphology in environmental problem-solving, particularly if geomorphologists can embrace temporal and spatial scales of problem solving more closely allied to geomorphology's scientific origins, and better integrate concerns for environmental conservation and social justice to gain improved understanding of the mutual vulnerability and dependence of society and landscape (Slaymaker, 2009). The challenges, however, are technical, conceptual and ethical, and perhaps most perceptively summarized by a non-geomorphologist in the advice memorably given by Uncle Ben to Peter Parker in the ~~film *Spiderman*: 'Remember, with great power comes great responsibility'.~~ All three ~~challenges~~ must be considered equally in advancing the role of geomorphology in environmental management.

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