Geomorphology 108 (2009) 1–7

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Preface

Climate and long-term human impact on sediment fluxes in watershed systems

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ARTICLE INFO

Article history:
Received 19 August 2008
Accepted 19 August 2008
Available online 5 February 2009

1. River activities as agents of environmental change

During the past decade coordinated programs like IGBP (International Geosphere–Biosphere Programme) successfully promoted research in large-scale oceanic and atmospheric transfers of mass and energy to better understand regional- to global-scale environmental change (e.g., Steffen et al., 2003; Crossland et al., 2005). For many years, the broader scientific community has been focusing on the major drivers of oceanic and atmospheric components of the Earth climate system (greenhouse gas emissions, astronomical, solar, oceanic, volcanic, and system-intrinsic forcings). More recently, this has been supplemented by a growing awareness of the role of regional- to continental-scale land surface change for the climate system (e.g., Wohlfahrt et al., 2004). Thereby, land cover change as triggered by humans plays a key role for land surface change (Redman, 1999; Ruddiman, 2005; Solomon et al., 2007). At the same time more questions arise concerning the consequences of climate and land-surface change for human societies (e.g., Fagan, 2004).

From a historic perspective, the spatial coverage and the intensity of human pressure on the Earth surface seem ever-increasing (Messerli et al., 2002). A growing need for a longer-sustaining governance of available resources of water supply, food production and energy is being felt (Miller and Jacobson, 1992; Amsterdam Declaration, 2001; Reid et al., 2005). As a logical consequence, environmental response to human impact and, vice versa, societal change triggered by environmental impacts have been developing as the overall emerging topic in Earth system sciences (Stern, 2006; Solomon et al., 2007). Thus, society and groups involved in the policies of managing of the Earth resources increasingly address geoscientists for scientific answers that help to mitigate the consequences of global change for the inhabited Earth surface (e.g., Gleick, 2003; Dessler and Parson, 2006; Milly et al., 2008).

Fluvial systems are key elements for operating Earth surface change because they convey most of the global fluxes of water and sediment from land to oceans (e.g., Meybeck and Ragu, 1997). Thereby, geomorphic and sedimentologic analyses of landforms and sediments allow for researching two fundamental facets of land-surface change:

(i) The role of boundary conditions and drivers of the production, temporal storage, transfer, and delivery of water and sediments at various scales of space and time.
(ii) The fluvial fluxes of water and sediment run a significant proportion of the terrestrial biogeochemical cycling of adsorbed carbon, nutrients and pollutants (e.g., Milliman and Meie, 1995; Vörösmarty and Meybeck, 2004).

To develop our understanding of systemic controls and modes of river-borne particulate fluxes and adsorbed biogeochemical compounds, a scholastic group 'LUCIFS' (Land use and climatic impacts on fluvial systems for the period of agriculture) has formed under the umbrella of IGBP-PAGES (Wasson, 1996; Walling, 2003). The LUCIFS agenda pays special attention to quantifiable feedback relationships between climatic fluctuations, land-use practice and the fluvial sedimentary and biogeochemical cycling at larger spatial and longer-term temporal scales. The agreed research protocol favors systems-related methods centering on the sediment budget approach (e.g., Dietrich and Dunne, 1978; Slaymaker et al., 2003) to evaluate basic flux properties and to understand system working. Since modeling has the potential to bridge gaps between empirical records of flux hampering our understanding of system working, modeling strategies form part of the LUCIFS agenda (Wasson, 1996; Lang et al., 2003; Sidorchuk et al., 2003).

Despite the long-recognized potential of geomorphic approaches addressing water and fluvial sediment transport, the current research agenda faces the challenge of understanding changes of sediment flux at larger scales of time and space (cf., James and Marcus, 2006):

(i) Spatio-temporally variable rates of the production and transfer of water and sediment in multi-component systems hamper the

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0169-555X/$ – see front matter
doi:10.1016/j.geomorph.2008.08.018

explanation of the causal interplay of controls, agents and processes that act on watershed-scale sediment cascades.

(ii) The effects of inheritance of form and processes, contingent influences, and threshold values are yet only roughly understood. Any of these intrinsic effects may cause variable spatio-temporal response in a fluvial system and hence induce unique system operation.

(iii) Fragmentary preservation and only partially available datings for suites of individual landforms and sedimentary sequences complicate the reconstruction of high-resolution sediment mass balances. In turn, this challenges to what extent the sediment budget concept may serve to accomplish integrated analysis of watershed systems which evolve along contingent, path-dependent and threshold-driven trajectories.

(iv) To distinguish climatic from human causes of fluvial change appears very intricate because any human impact is imposed on a background of natural variability.

Accordingly there is still much debate how to unequivocally separate direct and indirect drivers of change, and how much of the observed variability can be attributed to intrinsic, anthropogenic, or climatic forcings. To highlight current approaches to the geomorphic issues outlined above, in 2006 45 participants from 14 nations gathered for the second Open LUCIFS Workshop in Muenzenberg (Germany). To bring the participants' communication to the point the workshop focused predominantly on the role of humans for changes in sediment flux. Following a field trip presenting a long-term sediment budget for an agricultural catchment (cf., Houben, 2008), workshop activities centered on paper presentations and discussions. The session program scheduled a whole day for discussing one of these points by small working groups. While the workshop was entitled “Systems-based understanding of long-term man–landscape interactions”, the meeting outline actually emphasized communication about the integration of modern notions of systems-intrinsic factors of sediment propagation and human interference, suitable proxies and methodological approaches to the quantification of past human impact, multi-disciplinary approaches tracking mechanisms of past watershed-scale sediment flux, and enhancing integrated concepts of modeling. In this paper we provide an overview of selected paper contributions and the outcome of the workshop discussion.

2. Long-term human impact and the natural background of watershed sediment flux

Any future changes of regional- to subcontinental-scale fluvial fluxes of sediment are probably affected by direct or indirect human influences. It is reasonable to assume that in the past human pressure on terrestrial geosystems was less severe in many regards. Most likely a dissimilar configuration and interplay of forcings, cascade elements and processes of sediment transfer controlled watershed-scale sediment flux. Two conclusions may be drawn from that. First, there are basic constraints to the direct application of the uniformitarianism principle, and, second, past sediment fluxes of a watershed system are not suitable as a one-to-one analogue for the future (e.g., Oldfield, 2005).

Why then do we consider studying paleodata from landforms and sedimentary records to trace past long-term sediment fluxes? Because the sediment budget approach provides insight into the modes of and conditions for the operation of sediment transfer when viewed against the background of a formal system concept. The accounting of sediment production, transfer and storage along a watershed cascade yields crucial information about the qualitative significance of specific sources, transfer processes and sinks and their variability over a watershed area (e.g., Dietrich and Dunne, 1978; Jordan and Slaymaker, 1991). Temporal changes in the rates of fluxes between watershed components reveal the variability of fluxes over time. Hence, studying paleorecords is a way to learn about the principles and trajectories of sediment flux in watershed cascade systems and how they change over time. By comparing variants of watershed system settings it is possible to single out basic functional relationships between configurational controls and observed responses due to different settings. This includes studying watershed response under different climatic conditions as well as to different degrees of human interference (e.g., Fryirs et al., 2007).

The special issue opens with a paper by Trimble (2009-this volume) which details recent trends in the history of sediment redistribution in the Coon Creek Basin. In fact, it was in seminal contributions by Trimble (1975, 1983) that the concept of a temporally resolved sediment budget was established as fundamental to understanding watershed system response to human disturbances. The papers demonstrated the potential of the budget concept to (i) unraveling how sediment fluxes have evolved since the beginning of European settlement in the Driftless Area in Wisconsin, (ii) appreciating the impact of variable cultivation practice for sediment delivery to down-cascade budget components, (iii) revealing basic properties of watershed-scale system operations, and (iv) relating spatio-temporal changes in rates of input, storage and delivery of watershed components to mechanisms of internal system change. By using records of floodplain sedimentation spanning over 140 years of European settlement, Trimble (1975) has underpinned the significance of temporal storage and its changes for variable system response, thereby exploding the equilibrium myth of sediment production and yield at a point and a time in multiple-component cascading systems. At the same time Trimble created a template for historically oriented budget studies which trace causality by comparison of contemporaneous time series of cause and effect.

Trimble (2009-this volume) reports on renewed unprecedented modifications of sediment reworking along the Coon Creek cascade during recent decades. For example, a basic change toward an overall improved channel and bank stability was caused by further developing riparian vegetation. In addition, quite a number of technical measures have been directly imposed on channel beds to improve fish habitats. On the one hand, Trimble concludes that by now Coon Creek basin may have “lost much of its suitability as a natural laboratory of fluvial processes”. On the other hand, the recent trends in Coon Creek basin can be seen as reflecting a typical development toward a completely human-controlled hydrosystem. Moreover, it may be concluded that the recent development is probably driven by a reappraisal of societal needs in terms of a new balance between acquiescing to the effects of land use and nature conservation.

The sediment budget concept was probably the most influential innovation for the development of Anglo-American geomorphology during the past twenty years (e.g., Slaymaker, 2003). Its adoption to European fluvial landscapes with a longer-running history of human pressure than in America, however, is associated with a variety of methodological challenges. In particular, the fragmentary preservation of sedimentary archives, multiple reworking, difficulties in the construction of accurate chronologies of sediment transfer, and a decrease of information about human activities the further back in time we go challenge the construction of long-term sediment budgets (cf., Houben et al., 2006; Brown et al., 2009-this volume). Nevertheless, European authors increasingly take advantage of the sediment budget concept to trace longer-term human impact on watershed systems (e.g., Preston and Dikau, 2004; Rommens et al., 2005, 2006; Leopold and Völkel, 2007). Verstraeten et al. (2009-this volume) present one of the first temporally resolved budget studies that specify spatio-temporal changes in rates of sediment propagation in the Nethen catchment (Belgium) for the past 2500 years. They provide a detailed overview of sediment production and transfer for different components and different places in the Nethen sediment cascade. From the data it is concluded that historic changes in overall land-use pattern account for the temporally variable pattern of preferential colluvial deposition and later down-cascade alluviation.

Brown et al. (2009-this volume) focus on recent conceptual and methodological advances of the sediment budget concept. The paper is intended as a review paper and deals with traditional approaches to sediment budgeting including methods of quantifying dissolved yield. The authors also discuss the potential of recent technical advances in applications of LiDAR, GIS, geophysical data recording and a variety of approaches to age determination. The paper concludes with an outlook toward a future application of more accurate sediment budgets to increasingly larger spatial scales and even Pleistocene periods because of the above outlined methodological advances.

A subsequent sequence of case studies is particularly dedicated to more traditional approaches of geomorphic analysis that seek to identify controls of observed changes of the formation and degradation of colluvial and alluvial landforms. The sequence starts with a paper by Latocha (2009-this volume) who points out the effects of variable land-use practice on coupling and decoupling hillslope and valley-floor subsystems in the Sudetes Mountains, Poland. The investigation is based on the analysis of human-induced landforms and sedimentary sequences along the hillslopes-to-valley-floor cascade that have evolved over the past 200 years. For this period a suite of archival documents, topographic maps, and aerial photographs are at hand. This allows for allocating the impact of land use on alluvial response and to illustrate modifications of sediment transfer and sedimentation as set by more invariable topographic factors. Also from the Sudetes Mountains but the loess-covered piedmont area, Zygmunt (2009-this volume) reports on the sedimentology and chronology of middle to upper Holocene alluvial fans. Because of the nature of alluvial fan deposition the findings represent aggregated information about variable yield for much larger contributing areas and longer periods of time. The benefits in terms of enlarged spatial coverage and longer time period, however, need to be realized at the expense of spatially and temporally less resolved information. Nevertheless, in an otherwise stable environment fan initiation and progradation can be attributed to human disturbances based on a broader chronological synchroneity of alluvial deposition and larger-scale settlement activities.

Similarly, gullying and gully landforms in European landscapes are often thought of as virtually signifying human-induced changes to formerly stable pristine environments (e.g., Valentin et al., 2005). Panin et al. (2009-this volume) present an extensive synthesis of longer-term Holocene fluvial landscape change as evidenced by gullying and alluvial fan sedimentation onto coupled/decoupled river floodplains in the central Russian Plain. Their synthesis has recourse to a large dataset on the sedimentology, morphology, and chronology of gully sediments and fans. This allows ascribing individual response to place-based factors (lithologic, topographic and geomorphic factors). To substantiate statistically robust phases of increased fluvial activity apart from individual gully evolution, the authors utilize the probability density distribution of a radiocarbon dataset. The data highlight several phases of erosional activity and allow comparison with available time series of paleoclimatic change and settlement activities. Contrasting to the more general perception of gullies as approved indicators of human impact, this analysis by Panin et al. (2009-this volume) conclusively emphasizes the role of climate changes for triggering gullying activity for five millennia in the Russian Plain. Only since the Middle Ages has the role of human impact been that of amplifying gully incision. However, the available information about the hygro-thermal character of paleoclimate change and its effects on the sequence of extreme events is still too thin to deduce which specific change of a climate parameter triggered certain types of alluvial response.

To tackle gaps of data and understanding of the interplay of human activities and environmental response and vice versa, 'geoarcheology' (Butzer, 1973) has developed from some pioneering work (e.g., Butzer, 1960) to a now well established academic subject. The recognition of the benefits of geoarcheologic applications to interdependent problems of human occupation and fluvial processes was reflected by the publication of a textbook on 'Alluvial geoarchaeology' by Brown (1997). Ten years later, the integrative perspective of geoarcheology includes a breadth of methodical opportunities to be explored. In a summarizing treatise Brown (2009-this volume) attempts a holistic view on the history of hillslope-to-valley floor sediment transfer and changes in valley floor alluvial pattern based on integrating recent results from pedogenic, geomorphic, paleoecologic, and sedimentologic and archeologic site microstudies in Midland England. It is illustrated how human-induced colluviation and alluviation vary in space and over time. Particularly for the Late Saxon–Medieval period an intensification of sediment reworking can be noted. The author concludes that social change in the Medieval period was the basic cause for divergent landscape response when compared to preceding periods of agriculture. Innovative land-use factors are seen to introduce a higher spatial connectivity, and increased sediment conveyance was augmented by a period of extremes in climate. It remains, however, an open question how much of enhanced sediment cascading can be attributed to human land-use factors and/or climatic extremes because a lack of detailed and spatially precise land-use and paleoclimate data prevents further analysis.

Schulte et al. (2009-this volume) analyze alluvial fan sedimentation at the outlet of an alpine watershed in the Swiss Alps. Sediment supply to the fan delta is marked by the alpine discharge regime, coarse-grained spectra of river loads and steep river gradients while traditional land-use patterns have negligible effects on sediment production and transfer rates. The responsiveness of this capacity-limited sediment system, therefore, is basically much more sensitive to climate variations. They use a wide range of methods to document sedimentary and geomorphic fan evolution, including sedimentary records, radiocarbon measurements (particularly records of $\delta^{14}C$ anomalies), micromorphology, palynology, and historic maps. The data suggest a correlation of periods of fan activity with global climate proxies, which, in turn, indicate that longer-term periods of increased flood frequency and magnitude were triggered by solar forcing.

The complexity of variable patterns of water and sediment conveyance as influenced by changing climatic and human factors is addressed by Gell et al. (2009-this volume). The authors demonstrate the potential of combining complementary records from different depositional environments such as floodplains and wetlands in the Murray–Darling watershed. The inclusion of lacustrine facies from sixteen wetlands allows the use of a range of available paleoecologic proxies that elucidate qualitative and quantitative changes in water and sediment supply as well as climatic parameters. Apart from using optically stimulated luminescence (OSL), radiocarbon dating, ^{210}Pb decay, and ^{137}Cs activity profiles and magnetic susceptibility measurements to determine sedimentation rates, paleoecologic markers refer to exotic pollen biomarkers and diatom microfossils to characterize changing wetland conditions and linkage to river channels. In this way it can be shown that sedimentation rates significantly accelerated after settlement by European farmers in the 19th century. Environmental and sedimentation change was, however, much divergent for the suite of surveyed wetlands. The study stresses that complex relationships rule wetland response to land use and even small climatic fluctuations. This challenges existing models used to reconstruct and predict the responsive behavior of the Murray–Darling watershed. Here, the significance is earned from the watershed's overall socio-economic importance because it drains one-seventh of the Australian continent thereby containing Australia's most significant agricultural area. The current longer-term drought, its economic consequences and a decreasing availability of water resources challenge watershed management strategies and reveal the need for robust and longer-term (paleo-) data on water and sediment budgets for predictive modeling.

Likewise, the contribution by Hoffmann et al. (2009-this volume) derives its motivation from the debate about current climate change. The authors direct attention to the linkages between fluvial transport and storage and temporal carbon sequestration along watershed cascades. Statistical analysis of total organic carbon contents measured in floodplain sediments forms the basis for estimates of carbon sequestration on valley floors in the Rhine watershed. A conceptual approach to evaluate a long-term Holocene carbon budget is presented that couples carbon sequestration from past to present human-induced sediment flux. This provides valuable information about the spatial and temporal variability of temporal carbon storage through fluvial cycling in order to better appraise relative changes in carbon input to oceans.

The special issue concludes with a paper by Lechterbeck et al. (2009-this volume). Available palynological data are reviewed and evaluated with multivariate statistics to derive a proxy for the intensity of past human impact on vegetation in a long-settled loess landscape in western Germany. The results indicate that from the Bronze Age onwards human impact dominates over the effects of climate in terms of causing vegetation change. Eventually, this approach opens new perspectives for mapping the spatial spread toward a human-controlled vegetation development, testing how variable rates of sediment transfer scale with variable intensities of human impact and integrating measures of human impact into modeling approaches.

3. Conclusions

The contributions assembled in this volume highlight some challenges in understanding changes of sediment flux at larger scales of time and space. Two modes of geomorphic enquiry may be identified. First, a group of case studies that record morpho-sedimentologic sequences to give evidence for past geomorphic change. The interpretation often centers around causal and spatial factors based on observed site-specific geomorphic effects. Second, another group of investigations place sedimentologic–geomorphic studies in a sediment flux framework, which affords a more complex causal explanation of sediment conveyance in a watershed-scale spatio-temporal context. Nevertheless, morphologic and flux characteristics of an Earth surface system are two sides of the same coin: The formation and degradation of landforms by running water can be read as temporary physical imprinting on the land surface by variable fluxes of water and sediment over time and in space. At present the sediment budget concept is a linchpin idea to synthesize findings from various fields of Earth surface change in a coherent geomorphic perspective. The overall recognition of this point is reflected by the growing number of studies which fully adopt the sediment budget approach or in part utilize quantitative estimates to test hypotheses about provenance or rates of change (e.g., Latocha, 2009-this volume; Panin et al., 2009-this volume).

As demonstrated by the papers of this volume, there is still a great methodological potential for the sediment budget framework to significantly contribute to an improved understanding of the mechanisms and causes of environmental change at watershed scales. Some points to be highlighted are concerned with the spatial and temporal resolution of information about fluxes, the assimilation of complementary sources of information, the role of dating, and causal reasoning.

(i) Sediment budget studies may still benefit from incorporating a larger number of field sites that are examined to some detail. While budget studies tend to focus on the allocation and derivation of volumetric bodies, attempts to obtain more detailed information about the variable sedimentary structure of budget entities may fade into the background. Budget analysis would gain advantage in two ways. First, the application of approved methods like facies analysis (e.g., Houben, 2007), digital terrain analysis, shallow geophysics, etc. (e.g., Schrott and Sass, 2008; Brown et al., 2009-this volume) provides valuable lithogenetic and chronostratigraphic information to enhance the spatio-temporal resolution and specify provenance, timing, changes in the rates of deposition, degradation and yield along the watershed cascade. Second, extended information on the latter would further elucidate sub-scale representativity of the findings. Such efforts, however, require more time-consuming field observations or the collection of data by larger working groups (e.g., Trimble, 2009-this volume; Verstraeten et al., 2009-this volume).

(ii) An improved integration of paleoenvironmental information of non-fluvial deposystems is a key to dealing with fragmentary records and data gaps of budget change. Particularly the examination of lacustrine or peat bog environments bears the potential to gain evidence of changing environmental conditions that are not recorded by fluvial deposition but possibly affected contemporaneous fluvial fluxes (e.g., changes in the water balance; Gil García et al., 2007; Gell et al., 2009-this volume).

(iii) Dating control is another key to the reconstruction of budget change and the analysis of causal controls acting on the watershed cascade. The importance of dating justifies the absolute necessity of providing a sufficient number of datings and proper dating procedures concerning accuracy issues and precision as indicated by Brown et al. (2009-this volume).

The prospects outlined above primarily rely on the intensification of practical scientific effort. On the one hand, this brings about rather practical issues that may impede such efforts, e.g. insufficient time periods of examination, increased efforts to coordinate groups from different fields, or limited financial support for less-fashionable topics where progress is gradual and laborious before a broader picture can be drawn. On the other hand, there are more fundamental concerns about how to rationalize causality given the available information content and complexity of interlinkages and drivers acting in multi-component watershed systems. In the following we address limitations inherent the use of the temporal criterion for deducing operational dependencies, and issues that refer to variations of configurational settings, continuously evolving system operations and the specific nature of human control on watershed processes.

(i) At its best, a temporal coincidence or sequence of system events can be a strong indication of a causal relationship, whereby much of the causal interpretation of changes of sediment flux refers to known past to present analogues. At its worst, however, any temporal succession or coincidence of system states alone rarely proves causal relationships in view of scientific epistemology. This may even be aggravated by the incompleteness of independent records of major controls (see below).

(ii) Time-series of climate proxies mostly reflect average(d) conditions, but in many instances geomorphic response is triggered by extreme events as pointed out by Chiverrell et al. (2007).

(iii) The infinite variability of environmental settings in terms of both relevant spatio-temporal scales and constituent system components challenges any attempts to distinguish particular from general system operation when referring to the scientific method (cf., Schumm, 1991).

(iv) At the temporal scale, interdependencies between system components and feedbacks (e.g., process–response relationships) give rise to the continuous generation of qualitatively altered system properties; that is, system evolution. Any consideration of cause and effect or feedback phenomena therefore requires accounting for path dependence. Panin et al. (2009-this volume) apply metadata analysis of chronological data about gully response as a means to distinguish particular gully development from general response to supra-scale influences like climate change or larger settlement activities. Although appropriate data pretreatment may successfully discern local from regional trends (see also Johnstone et al., 2006), it remains, however, debatable if the subsequent causal interpretation of system response referred to static system status and thus neglected the effects of qualitatively modified responsiveness that go along with system evolution.

(v) To reference certain changes in watershed sediment flux to human impact is obstructed by two facets. First, any human impact comes into play on a background of natural variability. Attempts to overcome prevailing uncertainties, again, depend on the availability of better detailed records of human influence and essential parameters of climate change (changes in precipitation, evaporation, temperature). The development of quantitative measures of human impact could develop as a promising a tool (e.g., Zimmermann et al., 2004; Soepboer et al., 2007; Lechterbeck et al., 2009-this volume), and the possibilities of integration into quantitative frameworks of sediment flux need to be explored. Second, possibly the most significant complication arises from the nature of human behavior. The imprints of human activities in the landscape hardly develop linearly over time and in space because autonomous human decision-making defies following strictly rationalized inducements. Accordingly, with an improving resolution of physical records of past colluvial and fluvial change more and more studies arrive at a point where explanation for evidenced changes is reliant upon socially-induced changes of land-use practice rather than simply a critical number of humans. Quite a number of studies assembled in this volume (Brown, 2009-this volume; Gell et al., 2009-this volume; Panin et al., 2009-this volume; Schulte et al., 2009-this volume; Verstraeten et al., 2009-this volume; Zygmunt, 2009-this volume) make it apparent that by now the causal interpretation of watershed processes is limited by the availability of complementary climatic or archeologic records rather than geomorphic analysis. Furthermore, the paper by Trimble (2009-this volume) also exemplifies how societal change of the perception of an intangible asset like nature conservation may impact the operation of sediment conveyance in streams. Thereby, both socially-triggered changes in the conduct of land use and unconformable scaling of human and flux controls add a considerable degree of contingency to the systemic evolution of watershed sediment fluxes (Houben, 2008). Thus, dealing with the social dimension of human impact may provoke some radical doubt whether observable geomorphic effects that are either constituted by human and natural processes and which evolve along with contingent trajectories allow for an appropriate postdiction of the processes and drivers of case-based flux system change.

Approaches to understanding long-term climatic and human impact on sediment fluxes conceptualize a complex systems-based interplay of controls, agents and processes that act alongside contingent, path- and scale-dependent and thresholds-driven trajectories of system evolution. These properties may trigger system operations other than those expected by applying more reductionistic approaches (e.g., Phillips, 2003, 2007). These hypotheses pose grand challenges to the postdictional analysis of causality of system processes. As a corollary to these we may ask: Can we actually single out cause–effect relationships that dominated system response at a time in the past? And even if we could, what would it mean, e.g., for predictive applications? As evolving arrays of configurational, climatic and human controls suggest a basically variable responsiveness in time, shall we develop concepts of probabilistic causation of geomorphic systems operation?

However, it is felt that such thoughts may tend to stray from the analytical starting point while approaching generic meta-analysis of universal laws of earth surface operations (cf., Dearing, 2008). It has been shown that there are still considerable deficiencies in records of sediment redistribution and the effects of changing human and/or climatic controls. From a methodological viewpoint, this inevitably brings about a partially inconsistent definition of system attributes and processes. Accordingly, unexpected system response, without doubt, first needs to be evaluated against the backdrop of a yet partial understanding of complex system operations that happen at a multitude of spatial and temporal scales before drawing wide-ranging conclusions. Given the existing analytical basis, there is the risk of circular argument when field evidence of unexpected response provides the basis for conclusions on system governance at an emergent system level, and, vice versa, emergent properties are used to explain unexpected results about system operations. Accordingly, system phenomena otherwise assumed to signify a non-linear property of system emergence can be explained with linear cause–effect relationships in the light of new evidence from the field and refined concepts of system working (e.g., Phillips, 2006; Houben, 2008).

We may conclude that achieving an appropriate understanding of longer-term operations of watershed sediment fluxes means not referring to suites of templates of straightforward if–then-relationships among a specified variety of settings and system boundary conditions. Instead, dealing with gradual degrees of probability of systemic responsiveness could be a more appropriate methodological equivalent to the operational causality that is achieved in a yet underexplored systems context. On the one hand, this emphasizes the importance of integrating modeling approaches as a tool to test our understanding of complex system operations. On the other hand, improving our understanding of operational causalities in intricate systems requires, first of all, a continually advancing integration of relevant information from the fields of earth surface processes, history, archeology, river engineering, agriculture, sociology, economics, etc., that can contribute to the understanding of long-term watershed sediment flux. A strong plea for more integrative studies can be deduced from that. However, Richards and Clifford (2008) nicely lay out a number of epistemologic pitfalls inherent a simplistic coupling of geomorphic analysis with an overarching, totalizing concept of 'everything-is-linked-to-everything'. Basically, the analysis of long-term sediment flux characteristics probably best benefits from retaining the geomorphic perspective with a strong emphasis on the sediment budget concept. This concept still carries a great methodological potential for further exploring flux characteristics in conjunction with increasing efforts to couple these to spatio-temporal equivalents of time-series of climatic and human-induced forcings.

The LUCIFS strategy draws explicitly on the potential of the sediment budget concept as a conceptual linchpin. Hence, the follow-up open workshop of LUCIFS in 2008 is going to stress the need for retrieving and compiling basic data from the field and comparative analysis of climatic and anthropogenic influences in a wider range of watershed-scale fluxes in order to achieve a better overview of systemic watershed responses. In this way, geomorphic applications can significantly contribute to the understanding of basic facets of land-surface change including 'amorphic' applied issues of resource governance like water supply to human populations, reservoir sedimentation, retention and release of pollutants along riverscapes, and maintenance of freshwater and nutrient supply for coastal ecosystems.

Acknowledgments

Generous financial support by Deutsche Forschungsgemeinschaft (DFG grant 4850/44/06) enabled us to host the second Open LUCIFS Workshop in Muenzenberg and reduce travel costs for a number of participating authors. The PAGES IPO provided additional funds for several participants. Thanks go to Stan Trimble, Anthony Brown, Michel Meybeck, Jean Poesen, and John Wainwright for accepting our invitation to give keynote addresses. Special thanks are due to Richard Dikau for moderating large parts of the workshop. We graciously acknowledge Michael Schmidt for his important part in outlining the scientific workshop program. Our students Jan Voss, Tobias Schrod, Nadine Kleinhenz, Tina Hoppe, and Alexander Nagel helped preparing the field trip sites and provided all on-site arrangements including shuttle services from and to the workshop site. We thank Helga Förster, Martin Döhler, and Michael Schmidt for running the registration and accommodation business in a near-perfect way. The Farmers' Wife Association of Rockenberg is thanked for providing excellent lunch and most welcome refreshments during the field trip. In particularly, we are also grateful to the town councils of Rockenberg and Münzenberg which generously allowed us to host our sessions in historic buildings that fostered the tangibility of the dimensions of past land-use impacts.

This volume was realized thanks to the support by Adrian Harvey, special issue editor of Geomorphology. For all of their voluntary efforts, we are grateful to our external reviewers Jürgen Herget, Nick Preston, Olav Slaymaker, Des Walling, and quite a number of reviewers who wish to remain anonymous.

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