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The human role in changing fluvial systems: Retrospect, inventory and prospect

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Abstract

Historical and modern scientific contexts are provided for the 2006 Binghamton Geomorphology Symposium on the *Human Role in Changing Fluvial Systems.* The 2006 symposium provides a synthesis of research concerned with human impacts on fluvial systems — including hydrologic and geomorphic changes to watersheds — while also commemorating the 50th anniversary of the 1955 *Man's Role in Changing the Face of the Earth Symposium* [Thomas, Jr., W. L. (Ed.), 1956a. *Man's Role in Changing the Face of the Earth*. Univ. Chicago Press, Chicago. 1193 pp]. This paper examines the 1955 symposium from the perspective of human impacts on rivers, reviews current inquiry on anthropogenic interactions in fluvial systems, and anticipates future directions in this field.

Although the 1955 symposium did not have an explicit geomorphic focus, it set the stage for many subsequent anthropogeomorphic studies. The 1955 conference provided guidance to geomorphologists by recommending and practicing interdisciplinary scholarship, through the use of diverse methodologies applied at extensive temporal and geographical scales, and through its insistence on an integrated understanding of human interactions with nature. Since 1956, research on human impacts to fluvial systems has been influenced by fundamental changes in why the research is done, what is studied, how river studies are conducted, and who does the research. Rationales for river research are now driven to a greater degree by institutional needs, environmental regulations, and aquatic restoration. New techniques include a host of dating, spatial imaging, and ground measurement methods that can be coupled with analytical functions and digital models. These new methods have led to a greater understanding of channel change, variations across multiple temporal and spatial scales, and integrated watershed perspectives; all changes that are reflected by the papers in this volume. These new methods also bring a set of technical demands for the training of geomorphologists. The 2006 Binghamton Geomorphology Symposium complements the 1956 symposium by providing a more specific and updated view of river systems coupled with human interactions. The symposium focuses on linkages between human land use, structures, and channel modification with geomorphology, hydrology, and ecology. The emergence of sustainability as a central policy guideline in environmental management should generate greater interest in geomorphic perspectives, especially as they pertain to human activities. The lack of theories of anthropogeomorphic change, however, presents a challenge for the next generation of geomorphologists in this rapidly growing subfield.

Keywords: Human impacts; Fluvial geomorphology; Watersheds; Hydrology; Rivers

1. Introduction

The 2006 Binghamton Geomorphology Symposium has two purposes. The first purpose is to provide a synthesis of research on human impacts on river morphology. The

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majority of papers in this volume, therefore, focus on specific causes of change in rivers or look at cumulative human impacts on rivers at regional to global scales. A second purpose of the symposium is to commemorate the 50th anniversary of the 1955 *Man's Role in Changing the Face of the Earth* conference and its 1956 proceedings volume (Thomas, 1956a), henceforth referred to collectively as *Changing the Earth*. Through the examination of human impacts on fluvial geomorphology, the research papers in this volume carry on the tradition of the 1955 symposium and honor the work of our scholarly predecessors. In addition, several articles explicitly identify some of the links between the 1955 symposium and this 2006 Binghamton conference.

This paper provides historical and conceptual context for the 1955 and 2006 symposiums by summarizing some of the major changes since 1955 and outlining the challenges and opportunities for research concerned with human impacts on fluvial systems as exemplified by papers in this volume. The purpose is not to provide a comprehensive historical review of human impact studies in fluvial geomorphology. This paper does not address the full scope of human impact studies in fluvial systems, especially as they have occurred outside Europe and English-speaking countries. Nor does it attempt to survey the vast literature on human-nature relations and human impact studies. Rather, the purpose of this paper is threefold: (A) to set the stage for later articles in this volume with a retrospective review of the 1956 *Changing the Earth* proceedings and some of its links to the 2006 Binghamton Symposium, (B) to review changes in the research process since 1956 with a focus on why, what, and how human impacts are studied, and (C) to identify prospective directions in this field. This perspective is intended to provide a broad context for many of the key issues raised by papers in this volume.

2. Retrospect: The 1956 *Changing the Earth* proceedings

The 1956 proceedings, *Changing the Earth* (Thomas, 1956a), presented many examples and explanations of human-caused environmental changes, especially in Europe and North America. This novel synthesis of previously disparate findings from many different fields and locations helped motivate and inform two generations of scholars through its recognition of the long-term historical roots and the spatial extent of human impacts to the face of Earth. As important as those proceedings were, however, they did not arise from a vacuum. Substantial work on human impacts preceded the *Changing the Earth* Symposium. This review begins with a brief synopsis of the origins of concern about anthropogenic change in colonial North America, although such concepts can be traced elsewhere to antiquity (Glacken, 1967).

2.1. Precursors to the Changing the Earth Symposium

Precursors to the *Changing the Earth* Symposium in North America can be traced to concerns about destruction of natural resources seen in the writings and paintings of 19th century artists, poets, and scholars such as John James Audubon (1831–39), Susan Fenimore Cooper (1850), Henry David Thoreau (1854), and S.H. Hammond (1857), to name a few of the prominent voices (James, in press). After the Civil War in the United States, concerns over global-scale anthropogenic changes were greatly influenced by *Man and Nature*, George Perkins Marsh's (1864) classic work that documented the breadth of human impacts on natural systems. As the son of a U.S. Congressional Representative and as a paleontologist, diplomat to Turkey and Italy, an architect of the Washington Monument, and scholar of languages, Marsh (Fig. 1) moved in high intellectual and political circles

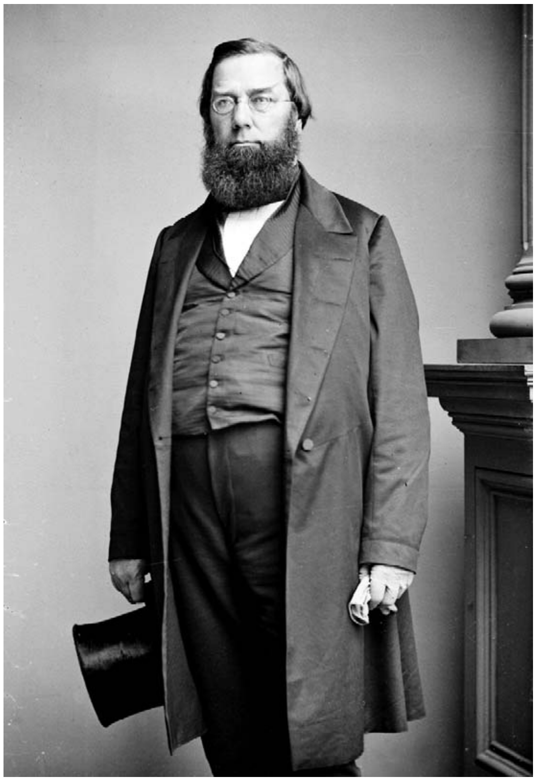

Fig. 1. George P. Marsh, photographed by Mathew B. Brady between 1855 and 1865. Brady-Handy Collection (Library of Congress). [call number: BH8201-4981; reproduction number: LC-BH8201-4981 DLC (b&w film copy neg.)].

(Lowenthal, 1965). His stature increased the effectiveness and dissemination of his ideas, ensuring that *Man and Nature* was widely read and acknowledged as an important work in physical geography. Moreover, Marsh's thesis that humans were causing serious destruction that endangered nature as well as society, resonated with contemporary public sentiment. Marsh's book was the first to integrate the ideas that humans are part of nature but also rely heavily on nature, that the magnitude of human impacts could exceed the ability of nature to recover, and that nature was frail in the face of human exploitation. Prior to Marsh, the common view was that Earth molded human nature and that global resources were abundant. After Marsh, an alternative awareness emerged that humans change a natural world that is composed of finite resources (Lowenthal, 1990). Marsh's work was critical in changing the perception of nature from a fear of the wrath of God to a fear of the wrath of nature (Pisani, 1996). *Man and Nature* has been described as "the fountainhead of the conservation movement" (Mumford, 1931, in Lowenthal, 1965). His writings on natural processes were widely influential on geomorphologists of the late 19th century through the work of explorers such as Hayden, Newberry, Wheeler, and Powell (Vitek and Ritter, 1993).

An extensive review of early 20th century writing on human transformations is given in the original *Changing the Earth* proceedings (Thomas, 1956b). A few key individuals and works, as noted by Thomas, deserve special mention for works that have direct bearing on geomorphic systems discussed in this volume. For example, the Russian, German, and French writings of Alexander Ivanovich Woeikof of Saint Petersburg were widely read in Europe. His writings focused on human-induced soil erosion and sedimentation through the modification of vegetation by grazing, fire, and urbanization (Woeikof, 1901). Neither Marsh nor Woeikof addressed population growth as a cause of change or human impacts outside of the northern and western hemispheres. Nathaniel Southgate Shaler, a Harvard geology professor, took up Marsh's conservation mantle but went further by identifying the link between rapid population growth and resource depletion and damage to pristine natural systems (Shaler, 1905). As a geologist, Shaler was interested also in soil erosion and agricultural practices.

In the late 19th and early 20th centuries in the United States, rapid landscape development and degradation led to a greater recognition of the need for conservation. Strengthening of the conservation movement was characterized by scientific land-management policies brought from Europe by Gifford Pinchot. These policies sought to conserve resources and maintain federal land ownership, in contrast to earlier policies aimed at distributing government lands to private owners (Hays, 1959). Continued population growth and resource consumption coupled with growing alienation of preservationists, however, limited the effectiveness of the conservation movement in curtailing erosive land use, river fragmentation, and other landscape alterations (Fox, 1985). The inability of conservation policies to stop environmental degradation and the ability of humans to alter geomorphology at landscapes scales was made clear by the 1930s Dust Bowl disaster, and the massive dam-building efforts initiated under Roosevelt's New Deal. The shocking potential for humans to radically and almost instantaneously disrupt environmental and geomorphic systems was suddenly demonstrated by the 1945 Hiroshima nuclear bomb, and sustained by subsequent attempts of *Project Plowshare* to harness nuclear explosions for excavating mines, canals, aqueducts, roadways, and harbors during the 1940s and 1950s (Kiersch, 1998; Neal, 1998). Post-World War II public action and scholarly research on human impacts to the Earth thus proceeded during a period of fundamentally changed perceptions of the effectiveness of humans as agents of change.

2.2. The Changing the Earth Symposium and its geomorphic legacy

The combination of rapid environmental degradation, increasing technical potential, and evolving political philosophies created a fertile ground for a symposium on human impacts to Earth. Yet, it still took the efforts of William L. Thomas, Jr., Assistant Director of research at the Wenner–Gren Foundation, to bring the *Changing the Earth* conference to life. The active lead of Thomas and the Wenner–Gren Foundation, which was dedicated to the advancement of anthropology (Fejos, 1956, p. vii), encouraged many of the studies in the proceedings to address the origins of human culture and how cultural history relates to landscape changes over time periods spanning the Holocene. The *Changing the Earth* Symposium, however, was not only about anthropological findings. Thomas asked Carl Sauer to chair the conference and help in its organization, and together they took a broadly geographical approach to its content (Thomas, 1956b). Participants came from diverse origins and eclectic professional backgrounds; the perspectives they brought were equally broad. While the *Changing the Earth* proceedings did not have an explicit geomorphic focus, they provided perspectives that remain relevant to human impact studies in geomorphology to this day.

2.2.1. Geomorphology in the Changing the Earth proceedings

Despite its breadth, the emphasis of the *Changing the Earth* Symposium on human alterations, and its extensive discussion of geomorphically important variables such as climate, land use, vegetation, mining, urbanization and agriculture, surprisingly little direct attention was paid to landform change. Geomorphic issues continually emerged in various guises throughout the proceedings, but only rarely were they the primary focus. The term "geomorphology" is only cited twice in the index for a 1193-page text; once when it is used by Carl Sauer (1956, p. 61) in a list of topics one must know to understand changes in habitability, the other time by Arthur Strahler (1956, p. 621) in explaining how his perspective differs from that of an engineer examining soil erosion and aggradation. "Geomorphogeny" is used as a heading in a critical discussion of Davisian geomorphology (Russell, 1956).

Early concepts of humans as geomorphic agents may have underestimated the geomorphic effectiveness of cultural activities. By the 1920s, however, awareness was sufficient to generate a call from Seuss for the addition of the *noösphere* (<Greek *noös=mind)* to the realms of Earth in addition to the lithosphere, hydrosphere, biosphere, and atmosphere (de Chardin, 1956; Fig. 2). By the year 2000, increasing realization of the geomorphic effectiveness of humans was driving the emergence of a new human-impacts sub-field in geomorphology (e.g., Haff, 2001). It also led to calls for distinguishing the modern period — following the late 1700s — as a new geologic epoch known as the *Anthropocene*, characterized by distinct evidence of human activities preserved in the geologic record (Crutzen and Stoermer, 2000; Crutzen, 2002).

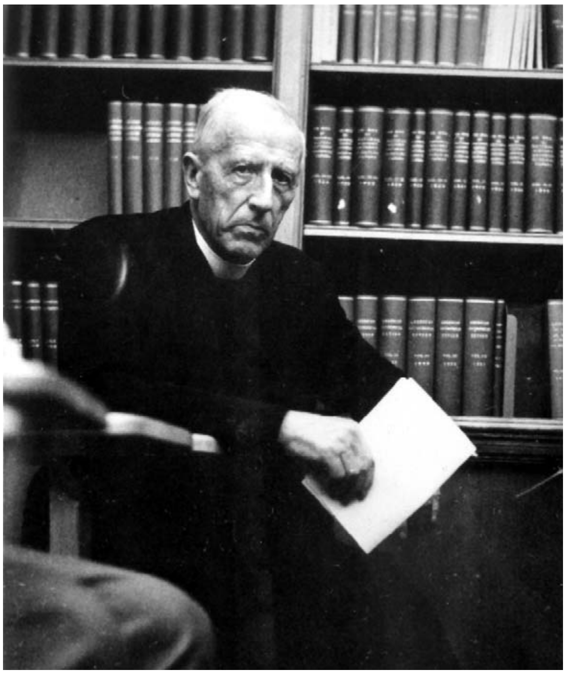

Fig. 2. Pierre Teilhard de Chardin at the Princeton Symposium in 1956. Source: Wenner Gren Foundation. Printed with permission.

The limited attention in the *Changing the Earth* proceedings given to human impacts on river habitats warrants attention because of the key role that rivers play in cultural activities. When rivers were discussed, most of the emphasis was on built structures, such as canals and irrigation works (Klimm, 1956; Sears, 1956; Wittfogel, 1956), on water quantity (Thomas, 1956c), or on factors that affect water quality such as sediment yield (Leopold, 1956) and human waste (Wolman, 1956). The physical habitat and geomorphology of rivers were generally ignored except for brief mention of natural factors such as river capture or changes in channel course that alter river flows and human habitability (Huzayyin, 1956; Russell, 1956). References to human-induced changes in river morphology are mostly in relation to river mouths and deltas (Davis, 1956; Klimm, 1956). Two papers directly addressed surface runoff, sediment, and fluvial changes. Strahler (1956) focused on drainage density and upland river variables by introducing Horton's quantitative hydrology concepts in the context of human impacts. Leopold (1956) focused on the relation between sediment yield and land use, although he could not resist talking about stream channels, making the prescient comment that:

> …man's work directly on river channels has been and probably will continue to be a far more important determinant of future channel conditions than the natural operation of river mechanics in response to man's changes on the watershed. It is probable that long before the effects of the latter can occur, river conditions will have been so altered by dams that [dams] will be the primary factor in controlling river-channel characteristics (Leopold, 1956, p. 646).

The relative importance of watershed-wide land-use impacts and dam impacts on channel morphology can be debated, but Leopold's comment foreshadowed the modern research emphasis on effects of dams on rivers (e.g., Beyer, 2005; Graf, 2006-this volume; Poff et al., 2006-this volume).

Fluvial geomorphology was not completely missing from the *Changing the Earth* Symposium, but it was not an explicit focus of the articles. Many of the chapters referred to the effects of agriculture, forest clearing, urbanization, fire, and other human activities on runoff and soil erosion. The emphasis was usually on the socioeconomic and cultural changes that led to these impacts, however, rather than on downstream implications of the impacts. The emphasis on upland changes rather than riparian impacts reflected a pervasive contemporary bias of the soil-conservation movement towards on-site issues while disregarding off-site effects. Soil conservationists in the United States during the 1930s and 1940s provided numerous examples of soil stewardship, but few instances of concern for downstream impacts (James, in press). This may have reflected a widespread lack of perception of the value of aquatic systems to public and environmental health or of the pervasive nature of riparian and wetland destruction (see Happ, 1944 for an exception). Concern for offsite losses began to build in the 1950s and was a keystone of the environmental movement in the 1960s.

The lack of geomorphology or concern for fluvial systems in the *Changing the Earth* proceedings can be explained, in part, by the tremendous breadth of environmental impacts covered in the symposium. Few areas in the litany of topics addressed in *Changing the Earth* are undeserving of coverage. To the contrary, the list of relevant human impacts is so large that river impacts are subsumed within the vast panoply of human impacts.

If the *Changing the Earth* Symposium did not address geomorphology *per se*, however, why hold a geomorphology symposium that commemorates the *Changing the Earth* contributions? The answer is that the documentation and guidance provided by the *Changing the Earth* conference has been a major impetus to subsequent in-depth environmental scholarship — research that includes studies of human impacts in fluvial geomorphology, the focus of the 2006 Binghamton Symposium. In particular, the *Changing the Earth* proceedings provided an excellent prototype of the broad-scale mixing of natural and societal perspectives needed to develop a compelling synthesis of anthropogenic changes to fluvial systems.

2.2.2. Broad scale approaches and the melding of nature and culture

The *Changing the Earth Symposium* contributed to modern thinking, in part, through its advocacy and demonstration of certain approaches in studying human impacts — methodological perspectives that in some ways needed to be rediscovered in geomorphology. These methods employed broad scales of time and space. By taking the long view (the anthropological view) of human history and impact, the conference foreshadowed modern human-impact approaches in geomorphology, where historical process and contingency play key roles in explaining landscape characteristics, and geomorphic explanation requires more than static equations based on Newtonian physics. Ironically, at the very time of the conference, geomorphology was undergoing a sweeping change in its methodologies by abandoning the historical Davisian approaches in favor of more reductionist approaches that quantified relations between process and form, and examined the role of humans by using these new physical science-based approaches (Goudie, 1995, 2000). These quantitative process studies, however, tended to operate at moderately small scales of time and space to avoid the data needs and non-linearities of longer-term, broader scales (Fig. 3). Moreover, even at local scales, these quantitative studies of processes often sought to eliminate or control for the effects of human agency that could obscure mechanistic process–response relationships.

The *Changing the Earth* Symposium also maintained a broad spatial perspective and emphasized the landscape scale. From a geomorphic viewpoint, the emphasis on landscape scale is most notable in Strahler's (1956) article where he explicitly explains the rationale for the landscape process approach, in part to counter the plot-specific work that process-based scientists with engineering backgrounds had emphasized. The *Changing the Earth* volume also emphasized change through time in specific regions, landscapes, or '*faces*' as they were later referred (Turner et al., 1990). This landscape scale of analysis now dominates much of the human impact work in fluvial geomorphology and is being encouraged by integrated watershed approaches described later.

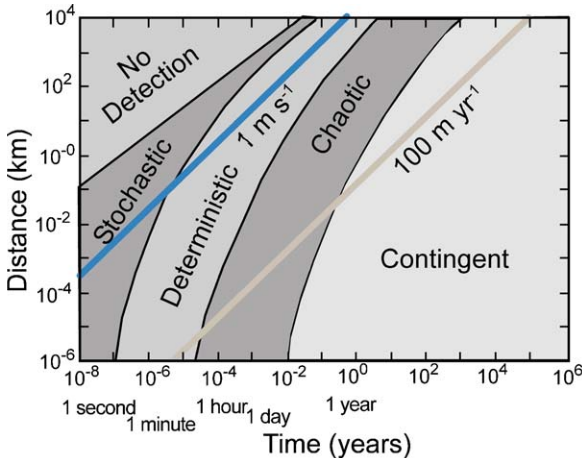

Fig. 3. Four domains of fluvial geomorphic theory postulated by Church (1996) as functions of time and space. The two lines depict approximate rates of water flow (1 m s^{-1}) and sediment transport (100 m $year^{-1}$). The five fields represent a scale dependency of theoretical causality or explanation that is important to considerations of human agency in geomorphic processes. Adapted from Church (1996).

In its documentation of human impacts in many regions of the Earth over several millennia, *Changing the Earth* presaged the modern recognition that finding a truly "natural" fluvial system may be difficult (Graf, 1996), and that humans and nature are inextricably intertwined within the fluvial landscape. This, in turn, reinforced the contingent nature of geomorphology and human agency, where river systems in similar natural environments can vary greatly between different cultural landscapes. Such systems cannot be completely modeled using linear equations of force and resistance to simulate the natural elements in isolation, but are best characterized with an understanding of idiosyncrasies of cultural traits and histories. Glacken (1956, p. 87) describes this modern scientific challenge by emphasizing the importance of considering humans as part of nature:

> If human activities, however, are considered — or defined — as interferences with this balance [of nature], we assume the existence of a nature which is an abstraction, and we neglect the effects of prehistoric and historic cultures on the natural environment. These effects are historical events, and, if not regarded as such, the study of human cultures, with their mass of customs and traditions, and the study of physical environments will go their separate ways, and the gap between the two will be bridged with metaphors.

In a fluvial context, this means that the history of human-river interactions must be known to fully understand consequences to rivers and to humans. Fifty years later, in these proceedings, Gregory (2006-this volume) echoes this same call to contemplate a "*cultural geomorphology*:"

> It is therefore not possible to prescribe a universal approach to managing rivers, but only one which reflects the influence of the particular cultural overlay. Therefore it is now timely for geomorphologists to raise awareness of such cultural distinctions and to consider these when constructing recommendations.

2.2.3. Scholarly purpose

The 1955 conference foreshadowed current trends in geomorphology, such as historically contingent approaches, the intertwining of culture and nature, and analysis at landscape scales. Providing methodological exemplars was not the primary purpose of the proceedings, however, and Thomas (1956b, p. xxii) was very clear in stating that the primary objective was publication of a permanent record accessible to a large audience and available to future scholars. The conference succeeded in this regard, providing expansive and, at times, overwhelming documentation of human transformation of Earth. At a simple inventory level, the conference provided the baseline documentation that was needed to justify making research on human impacts a major priority. The scholarly influence of the symposium, however, went beyond simple inventory. Through its comprehensive documentation and explanation of the true breadth of human impacts on Earth, *Changing the Earth* provided a gathering point; that is, a unified vision of the many and varied types of environmental degradation resulting from population growth, accelerating rates of consumption of resources, and the lack of societal awareness about the consequences of cultural habits. These visions were from many different perspectives and were integrated over broad temporal and spatial scales. Although the volume has been criticized for taking "a tad indifferent" tone that did not push the public to action (Wilson, 2005), this opinion seems unduly harsh. The proceedings were written so that articles could be read by the educated public, but the primary audience was clearly a scholarly one. Its explicit goal was to generate an objective, new scientific synthesis. To criticize it for lacking the rhetorical and emotional appeal of Rachel Carson's (1962) *Silent Spring* is to misconstrue its central purpose.

More than any particular article or new concept, the sense of scientific exploration within the proceedings of *Changing the Earth* has influenced scholars over several generations. Within academia the conference provided an enduring model for the multidisciplinary study of environmental degradation. Global change research and the current branch of geography often referred to as "Nature and Society" were encouraged and influenced by *Changing the Earth* (Kates et al., 1990; p.4). Just as earth science was moving more and more towards specialization with a narrowing focus of professional expertise in individual fields, *Changing the Earth* provided a much-needed synthesis in the opposite direction. By inviting experts from a great diversity of fields, new interdisciplinary ties were forged and a new generation of scholars emerged in the 1960s and 1970s with new perspectives. The work of these scholars and the students they trained ultimately led to this 2006 Binghamton Geomorphology Symposium on *The Human Role in Changing Fluvial Systems.*

3. Changes in research since the *Changing the Earth* Symposium

Much has transpired in human impact studies in fluvial systems since the scholarly environmental perspectives of 1956. More is now known about the history, locations, sequence, and agents of change in fluvial systems. Technologies, methods, theoretical constructs, and the social setting of human impact studies are remarkably different than they were two generations ago. Rather than attempting an encyclopedic review, an overview is provided here of some major changes in geomorphic research since 1956, particularly as they relate to the 2006 Binghamton proceedings (see Walker and Grabau (1993) for a more comprehensive summary of the historical evolution of geomorphic research in the late 20th century). These changes are described in terms of *why* scholars study human impacts in rivers, *what* is being studied over various time periods, *how* data have been collected and analyzed, and *who* has carried out the studies.

3.1. Why study human impacts on fluvial systems?

Many motivations for studying anthropogenic impacts to fluvial systems are similar to the reasons given in 1956 for studying broader environmental impacts. These include documentation, inventory, and explanation of change, as well as a desire to ameliorate the destructive influences of humans on nature. Since that time, however, some new rationales have emerged and some existing ones have evolved and taken on greater import. To a much greater degree than in 1956, rationales for studying human impacts on rivers are now driven by institutional needs, concerns over future environmental change, and a growing desire to restore natural functionality to streams.

3.1.1. Institutional needs and environmental regulations

Discussion of regulation or policy-driven research topics is nearly absent from the 1956 proceedings, although Abel Wolman's (1956) paper addresses the needs of water quality in this context. Other contemporary fluvial research outside the 1956 proceedings was also largely devoid of applied environmental topics, with the exception of flood control, soil erosion, and water quality; topics that were mostly treated from the perspective of protecting human safety and economic well being. Since 1956, however, establishment of a wide array of environmental regulations and a growing awareness of environmental change and degradation have motivated support for a growing amount of environmental monitoring and research. Environmental legislation affecting rivers in the USA range from the National Environmental Policy Act and the Endangered Species Act to the Clean Water Act; similar laws exist in other developed nations. These laws have promoted environmental research and the development of research protocols. They have improved understanding of hydrogeomorphic topics ranging from the establishment of sediment quality standards (Marcus, 1989, 1991), to recommendations for developing geomorphic indicators of stream health (Graf, 2001), to guidelines for stream restoration (Rosgen, 1996).

Because government agencies and funding institutions support much of the modern scholarship on rivers, much of the rationale for modern studies of impact in rivers is related to activities that agencies manage or attempt to influence. These activities are largely in response to accelerating pressures from development, a growing awareness of health effects and environmental degradation, and environmental regulations intended to preserve, conserve, or restore natural systems. In the United States, institutional initiatives for watershed or river studies take the form of requests for proposals (RFPs) from funding agencies, which typically focus on understanding the history and processes of change and predicting future change under different development and mitigation scenarios. Motives for these studies include development of viable strategies to protect and enhance water quality, public health, aquatic ecosystems, individual species, flood-conveyance systems, and water resources. RFP-driven rationales may seek explanation, but are often more concerned with applications of existing knowledge to develop rational river policies, management tools, or engineering solutions to specific problems. In this context, the reasons for studying rivers often take on a more pragmatic, applied perspective than was demonstrated in the 1956 proceedings.

Growing institutional concerns about global to regional change also provide greater incentives for research on environmental impacts than in the past. An increasing number of studies focus on how rivers have responded or are expected to respond to deforestation, agriculture, urbanization, or climate change. The rationale for these studies is typically expressed in terms of trying to understand and predict future response of rivers in order to stabilize and maintain present river environments, or to develop adaptive policies in response to those changes.

3.1.2. Aquatic restoration

Growing awareness of the magnitude of fluvial change has led to an increasing emphasis on understanding ways in which altered fluvial systems can be restored. Recognition of the extreme changes that many fluvial systems have undergone and the consequences of these changes — positive and negative — is a first step in ensuring that policies are implemented based on informed criteria. For example, stream '*restoration*' has become emblematic to many river management programs and is being widely practiced (e.g., Brooks et al., 2006-this volume, provide Australian examples). The general rationale for restoration projects and related research is readily apparent from any inventory of advancing population growth, resource depletion, environmental degradation, and esthetic disfigurement of natural systems. The specific motivations behind "restoration" projects vary dramatically, however, with land ownership, funding agency, and cultural setting. The definition of restoration thus ranges from attempts to return streams to a pre-disturbance state to stabilization projects with structural armoring that may disrupt natural processes and reduce habitat diversity. A common definition of restoration requires that stream channels be returned to a previous condition (NRC, 1992). This criterion calls for explicit historical reconstructions of changes to the fluvial system, a practice that requires geomorphic expertise.

To restore a river on a sustainable basis often requires that the processes controlling channel adjustments be understood at a scale extending well upstream of a specific stream reach and over multi-generational time periods. An understanding is needed, therefore, of the water and sediment loads integrated over the watershed, which has led to a growth in integrated watershed assessment as a tool in river restoration. Integrated approaches, described later, require geomorphic expertise in river processes and should include an assessment of the key contemporary and historic physical, ecological, and social controls on river change. These needs call for geomorphic studies to go beyond physical processes to examine also social aspects of river systems such as economic pressures, land-use policies, and historical development. Strong ties between ecologists and geomorphologists are now emerging (e.g., Malanson, 1993), as exemplified by the 1995 Binghamton Symposium devoted to *Geomorphology and Ecosystems* (Hupp et al., 1995).

3.2. What is studied and when

As with all research disciplines, certain conventional topics in fluvial geomorphology have received close attention while other potential areas of study have gone largely unattended. The *Changing the Earth* proceedings emphasized change through time at specific regions and landscapes, or '*faces*' as they have been referred to. A subsequent conference known as the *Earth Transformed* Symposium (Kates et al., 1990) placed additional emphasis on fluxes of energy and mass, thus framing many of the physical questions raised by the study of anthropogenic changes in terms compatible with mainstream physical science. This section identifies some ways in which the focus of research concerned with human impacts on fluvial systems has changed since the 1950s in response to research on channel changes, scales of observation, integrated watershed analysis, and climate change. This list is by no means comprehensive in terms of factors that have changed since 1956; rather, it highlights notable changes addressed by papers in this volume.

3.2.1. Channel changes

Channel hydraulics and morphology were addressed peripherally in *Changing the Earth*, and largely from a different perspective than that taken by contemporary scholars — although some familiar refrains can be heard. For example, an awareness of human impacts on rivers clearly existed, but many of the implications of these changes were not brought out. Klimm (1956) notes, for instance, that the Grand Canal and other projects on the China plain are of such antiquity that distinguishing between canals and natural channel systems is often impossible, but he does not describe how modified systems differ from natural ones. In contrast, the Leopold (1956) comment noted in Section 2.2.1 presaged the modern documentation of river disruption by dams and indicated an appreciation for the implications of fragmentation. Most radical perhaps was Wittfogel's (1956) advocacy for a theory of *hydraulic civilizations*, which postulated that civilization springs not from urbanization, but from the development and maintenance of irrigation agriculture. The geomorphic implication of Witfogelian theory is that river regulation is not simply a side effect of human occupation, but represents an inherent and prerequisite condition of civilization.

The central role that channel hydraulics and morphology now play in the studies of human impacts on rivers is represented by the 2006 Binghamton Symposium (this volume), which contains an overview of the topic (Gregory, 2006-this volume) as well as articles on impacts of channelization and leveeing (Simon and Rinaldi, 2006-this volume), dams (Graf, 2006-this volume; Poff et al., this volume), agricultural land clearance in the upper Midwest, USA (Knox, 2006-this volume), mining (Macklin et al., 2006-this volume), urbanization (Chin, 2006-this volume; Kang and Marston, 2006-this volume), and alterations of animal populations (Butler, this volume). This list does not include additional potential impacts such as logging, roads, gravel extraction, and a host of other types of resource uses in and around rivers. The discussions of the morphologic changes of channels in most of the articles in this volume reflect the central role that channel change has taken in modern studies of human impacts on rivers.

3.2.2. Scales of observations — time and space

Identifying scales of data and research focus is critical to developing a proper interpretation of anthropogeomorphic impacts. For example, broad landscape-scale changes that have accumulated over a long period of the Holocene and recent local effects of urbanization are both exhibited in the same riverscape. Allocating how much variability is driven by each impact is difficult at best and sometimes impossible, as is exemplified by the controversy over anthropogenic versus climatic drivers of arroyo cutting in the southwestern USA (Cooke and Reeves, 1976). Although time was explicitly addressed in the 1950s human impacts literature, from a theoretical basis and from a practical methodological basis, considerable difficulty was encountered in separating anthropogenic from natural causes and effects across multiple scales.

From a theoretical perspective, Schumm and Lichty's (1965) simple but widely influential paper provided a basis for distinguishing between independent and dependent variables and helped to structure many geomorphic arguments around concepts of space and time. McDowell et al. (1990) refined these arguments and provided an explicit physical basis for scales at which process–response systems operate, ranging from *weather*-related events such as thunderstorms at small scales of space and time up through *tectonic forcing* of glacial epochs at large scales. Most of the human-induced changes described in this volume occur within the second and third classes of this model; that is, *short period variations* and *neoglacial events*. The fourth class of *orbital forcing,* however, is of importance to long-term anthropogeomorphic studies, because the transition from late glacial climatic regimes was a period of great cultural development and prefaced the massive agricultural developments that sprang from the Neolithic. Recognition of multiple drivers and responses operating at various spatial and temporal scales is now well established, and attempts to work across those scales should be a goal of future studies.

From a practical perspective, discussions about multiscalar analysis were severely limited in 1956 by methods that could not adequately characterize the full spectrum of local to macro scales in space, or temporal changes ranging from hours to millennia. As discussed later, new dating, measurement, data storage, data dissemination, and analysis techniques now facilitate analysis at multiple scales.

Not all the theoretical and practical difficulties in separating processes and responses across scales have been resolved (Phillips, 2004). Although the accuracy of measurements has advanced and theory has provided guidance, major obstacles to these analyses remain. For example, distinguishing and understanding changes driven by natural vs. human processes is essential to understanding the relative role of anthropogenic influence. Unfortunately, isolating human influences on fluvial changes is difficult, because of the absence of monitoring in most areas and the difficulty in applying proxy records over large areas or over relatively short time scales at which human-driven change can occur (e.g., Simon and Rinaldi, 2006-this volume). To this day, processes are not monitored in many parts of the world, particularly in remote or developing nations (Marcus et al., 2004; Wohl, 2006-this volume). Difficulties from non-uniformities in global data sets are addressed by Walling (2006-this volume) in analyzing suspended sediment loads at global scales.

Process–response links can also be hard to isolate because of factors such as inheritance of form, polygenetic causalities and equifinality, lagged timing, and threshold responses (McDowell et al., 1990). Geomorphic responses to human activities such as forest clearance may, therefore, be quite different in the same location when considered under different conditions or over different time scales. Moreover, recent work suggests that geomorphic systems are often non-linear (Phillips, 1999). In this case, it may not be possible to reconstruct which variable drove which response. This situation suggests a need for techniques to identify non-linearity and scale dependency in river systems (e.g., Phillips, 2006), so that researchers and managers can determine where and over what periods monitoring is useful for identifying drivers of change and predicting future change. Understanding long- to short-term effects across multiple spatial scales thus remains one of the major challenges to research of human impacts in rivers.

3.2.3. Integrated watershed perspectives

The post-1950s quantitative revolution in geomorphology, coupled with a turn towards using physics to understand river process and response, led to the study of many rivers as objects not tied to the surrounding systems within the watersheds. This detailed study of individual fluvial components in isolation — so important to scientific understanding of causality — can lead to a hydraulic myopia that fails to explain how rivers respond as complex non-linear systems interacting with human activities. Contemporary research on human impacts in fluvial settings thus often needs to step outside of this reductionist box and cross over the traditional boundaries between fluvial geomorphology, aquatic and riparian ecology, river engineering, planning, economics, and related fields. An important development in this regard is the move towards integrated studies of watersheds.

Integrated perspectives have taken hold in key national and international arenas. In North America, holistic river-management is often referred to as an *integrated watershed approach* where 'watershed' is used synonymously with catchment or drainage basin (as opposed to its European use as a drainage divide). At the national level, institutional structures and funding mechanisms have changed dramatically in response to the need for integration, and this has created new research agendas and management policies that emphasize watershed-scale approaches (USEPA, 1993; Naiman and Bilby, 1998; NRC, 1999; Finlayson and Brizga, 2000; Lal, 2000; Downs and Gregory, 2004). The international support for integrating multiple systems to manage global fresh water supplies is displayed in *Agenda 21* of the United Nations Earth Summit in Rio de Janeiro:

> The complex interconnectedness of freshwater systems demands that freshwater management be holistic (taking a catchment management approach) and based on a balanced consideration of the needs of people and the environment. The Mar del Plata Action Plan has already recognised the intrinsic linkage between water resource development projects and their significant physical, chemical, biological, health and socio-economic repercussions (UN, 1992; Section 18.36).

Multi-disciplinary approaches to the study and management of fluvial systems acknowledge the interdependencies between channel morphology, aquatic and riparian ecology, climate, water resources, and numerous other systems that govern the magnitude, frequency, and quality of deliveries of water and sediment. Integrated approaches should also consider changes to upland land-uses that drive the hydrologic and fluvial systems. An important value of the *Changing the Earth* Symposium was its broad coverage of many Earth surface systems. A primary goal of this Binghamton Symposium is to examine human impacts on fluvial systems within this broad context of catchment dynamics.

Many studies in the 1956 proceedings address basin-scale changes that are relevant to hydrologic and fluvial adjustments, including impacts of fire (Sauer, 1956; Stewart, 1956) and technology (Darby, 1956; Heichelheim, 1956; Pfeiffer, 1956). Although these changes in land cover clearly effected fluvial systems, rarely were these changes or watershed processes explicitly linked to river responses in the papers, or even to the runoff and erosion so critical to rivers. In contrast, Strahler (1956) made the watershed approach a central theme of his article. In the modern context, it is now ill-advised to consider major river changes without also considering the basin-wide context. The 2006 Binghamton Proceedings (this volume) merely touches the surface of a vast literature on topics of watershed changes and the linkages to channel change. The effects of urbanization on fluvial systems are addressed by Chin (2006-this volume) and Kang and Marston (2006-this volume). A modern view of historical changes and of current erosion conditions in the Mediterranean region is provided by Hooke (2006-this volume), land cover changes in North America are covered by Knox (2006-this volume) and Poff et al. (2006-this volume), and agricultural impacts on South American rivers are examined by Harden (2006-this volume).

3.2.4. Global change and climate change

Although global climate change has long been an important theme in studies of anthropogenic change, it has only emerged recently as a major topic in the context of human impacts on rivers. The *Changing the Earth* proceedings clearly indicate the scientific perception of climate change in the mid-1950s. The symposium revealed a growing awareness of substantial changes in temperature and precipitation regimes and sea level changes in the recent past, and some papers discussed implications of climate change to ecosystems, water resources, and hydrology. At that time, however, the importance of global-scale changes in atmospheric chemistry, such as greenhouse gases, was not understood, so the dimension of global anthropogenic climate change was completely missing. Thus, while Quaternary climate change was a recurrent theme at the *Changing the Earth* Symposium, it was viewed as an independent variable helping to explain human adjustments (Huzayyin, 1956; Sauer, 1956). To the limited degree that human-induced changes in climate were considered, they were relegated to local surface changes to the water budget and resultant radiation balance (Thornthwaite, 1956), and to urban effects such as the urban heat island (Landsberg, 1956). Ironically, the realization that human-induced CO_2 warming could be significant was first raised in the same year that the *Changing the Earth* proceedings were published (Plass, 1956) and greatly advanced by one of the participants (Landsberg, 1970). Clearly, one of the most fundamental changes over the past fifty years in the understanding of human impacts on rivers is the realization that global scale climate changes can be driven by humans and can be effective agents of change within modern river systems (Goudie, 2006-this volume).

3.3. How research can be conducted

Modern technological innovations have simultaneously complicated and improved the methods by which human impacts on river systems can be studied. Major changes in data collection, analysis, and delivery techniques facilitate anthropogeomorphic research into the multi-scalar, integrated watershed perspectives discussed previously. These changes include advances in dating techniques, mapping techniques, digital simulation, and analytic methods. In addition, advances in the internet — as found throughout the Earth sciences — have greatly expanded the ability of researchers and the public to access data and research results, to collaborate, and to get involved in the development of research agenda, river management, and policy.

Traditional approaches to collection of field data — ranging from coring to erosion pins — have been enhanced by numerous new data collection technologies for field, laboratory, remote sensing, and analytical methods. In the temporal domain, river scholars now have access to dating technologies not even imagined in the 1950s, when dating methods were largely restricted to relative dating derived from stratigraphy or absolute dates derived from dendrochronology, varves, or long-term written records. Although Libby had begun in the late 1940s to experiment with radiocarbon as a means of dating carbon compounds, the reliability of this method was still being tested in 1956. Since the 1950s, however, ^{14}C and a battery of additional isotopes have become extremely important tools for dating late Quaternary stratigraphy, identifying sources of water and sediment, and constraining environmental changes. For example, cosmogenic radionuclides allow dating of erosional surfaces and alluvium over Quaternary time periods (^{36}Cl, ^{26}Al, or ^{10}Be) down to a period of months (^{7}Be). Other isotopes such as ^{210}Pb or ^{137}Cs allow fingerprinting and dating of sedimentary deposits on intermediate historical time scales (Aalto et al., 2003). Additional dating tools, such as thermoluminescence and optically stimulated luminescence (OSL), have expanded the range of dates and applications. A broad suite of modern techniques now enable specification of numerical ages across a wide range of time scales with quantitative measures of uncertainty.

A similar revolution occurred in spatial data collection and processing techniques. Geographic coordinates of field locations can now be quickly measured to sub-meter resolutions, and mapping surveys can easily collect large amounts of data and register them with remote sensing imagery and a variety of feature attributes. A striking feature of *Changing the Earth* was the series of oblique aerial photographs of cultural landscapes in the opening chapter (Gutkind, 2006). To contemporary readers, the vantage provided by oblique aerial views was presumably novel and provided an impressive new synthesis of patterns of human development. In contrast, global and landscape views are now commonplace as remote sensing imagery and visualization tools have proliferated, clarifying the relationship between landforms and cultural features. These capabilities are of particular interest in anthropogenic studies because the scale of human impacts is often too small to be measurable — if detectable — on standard topographic maps.

The advent of computer and spatial data in digital form has powered the development of geographic information systems (GIS) and the proliferation of digital elevation models (DEMs) and digital maps of soils, vegetation, rivers, roads, as well as other information for much of the developed world. These advances have stimulated the development of sophisticated spatially distributed numerical models and automated simulations of physical systems. Entire research initiatives and companies are now devoted to developing algorithms to handle these data sets and digital tools. In rivers, measurements of key hydraulic parameters and habitat characterization can now be acquired with multispectral (Fonstad and Marcus, 2005; Carbonneau et al., in press) and hyperspectral optical imaging devices (Marcus et al., 2003), ground penetrating radar (Costa et al., 2000), and acoustic doppler current profilers (Morlock et al., 2002). Detailed mapping of topography with radar and lidar (Baltsavias, 1999; Cobby et al., 2001), and of land cover with a variety of remote sensing devices that operate across the electromagnetic spectrum (Jensen, 2000) has become standard. Even advances in microscale to subatomic measurements (Tsong, 2006) are gaining attention as geochemical interactions with geomorphic, hydrologic, and biotic processes are increasingly incorporated into the studies of human impacts on rivers (e.g., Macklin et al., 2006-this volume).

Having praised the capabilities of modern spatial technologies, caution should be urged about some consequences. The power of the resultant spatially distributed models and the persuasive nature of visualizations of the output can lead users to believe that the models are real, causing them to bypass the field calibration and validation steps that are essential (Wilson and Gallant, 2000a). In recent years, a substantial effort has been devoted to identifying error propagation in models and digital data sets and how model performances vary in different settings (Choudhry et al., 1998; Wilson and Gallant, 2000b).

Much information is readily available over the internet, where data repositories, online journals, list servers, and email have greatly sped up and facilitated access to data and expertise. Obtaining data, mapping the nature and extent of human and natural features at various scales, and disseminating the results has never been so easy. For example, improvements in the accessibility of global spatial data recently accelerated with the advent of Google Earth™ and other open sources of geographic data. These new techniques hearken a renewed interest in subcontinental-scale geomorphology that has not been in favor since the physiographic studies of the early twentieth century. New emphases on global change, coupled with the need for integrated watershed-scale analyses and the availability of data from other regions, will be likely to stimulate these studies.

3.4. Who does the research — the changing social context

Studies of human impact in fluvial geomorphology have evolved greatly over the last fifty years, partly in response to changes in the social context of the research. These changes apply to human impact studies and also more broadly to Earth sciences. This discussion focuses on institutional changes that have affected how geomorphology is practiced, primarily in the English speaking world. The demographic profile of geomorphologists and the institutional setting of geomorphology outside of the English language settings is beyond the scope of this paper. Interested readers are referred to Walker and Grabau (1993) and Sack (2004) for discussions of these topics.

Most investigators of human impacts in 1956 came from universities, museums, or government agencies focused primarily on monitoring (e.g., the U.S. Geological Survey). These institutions remain crucial to geomorphology as sources of data, funding, expert personnel, and other resources. They have been joined by other groups, however — including additional government agencies, non-governmental organizations, the private sector, and individuals — who now play major roles in driving studies of human impacts on rivers and watersheds. Integrated research approaches have encouraged many of these new institutional players and promoted a substantial broadening of the types of scientists and managers now studying rivers.

Pervasive institutional changes that have arisen from environmental regulations probably are the greatest causes of change in who is doing human impact studies. Two Acts of the U.S. Congress serve as diverse examples of environmental legislation that have substantially changed how fluvial systems are studied and managed in the United States. The 1969 *National Environmental Policy Act* (NEPA, 1969) required all federal agencies to assess the environmental impact of federally funded projects. It also introduced to the decision making process the requirement for public participation in environmental planning (James, in press). As a result, studies of human impacts in rivers in the United States often involve research scientists, environmental consultants, multiple government agencies, and the public. Despite the diversity of inputs from different sectors, these studies must conform to strictly codified guidelines, and have generated few new concepts of river form and function. They have created, however, an entire employment sector for river scientists and, by promoting interest and employment in human impact analysis, they have provided students for universities and generated further research on anthropogenic changes.

The *Clean Water Act* (CWA) is another example of a key set of environmental laws that has affected the study and management of human impacts in rivers in the United States. In the preamble to this lengthy Act, the stated objectives are "…to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (CWA, Title I; *33 UCS 1251*) (Arbuckle, 1993). These goals have not been met in most water bodies and are arguably unattainable in many, but the laws and regulatory procedures that the CWA established are pervasive and deeply intertwined with environmental management practices. Unfortunately, regulatory efforts have focused largely on restoring the chemical integrity of water bodies with little or no attention to the physical condition (Adler et al., 1993). Fluvial geomorphologists and hydrologists have played an important role, however, in recommending physically-based criteria (Marcus, 1989, 1991; Graf, 2001). Furthermore, the CWA has spurred funding initiatives by federal and state agencies to support basic and applied research in river systems. Similar environmental regulatory structures and pressures have emerged in many parts of the world. Collectively, environmental legislation and awareness have stimulated interest in geomorphic studies, broadened the cast of participants in fluvial studies, and increased funding and employment opportunities.

Changes in methodologies have also altered the social context of anthropogeomorphic research. The new methods usually require more resources in the form of sophisticated laboratory facilities, field equipment, imagery, computer resources, and a host of other substantial expenditures. The opportunity for creative projects that can be done on low budgets remains for the truly innovative and resourceful scientist, but, in most cases, a rod and level survey will no longer suffice. An increasing amount of river research is being conducted by teams that include specialists, such as geochemists, hydrologists, pedologists, sedimentologists, surveyors, numerical modelers, and geographic information scientists. Furthermore, this list should be broadened for research teams needed in studies that incorporate cultural and socioeconomic elements.

The need to include the social elements of landscape processes and watershed management in river studies will call for a greater diversity of participants. Otherwise, geomorphologists in the field risk being viewed as outsiders without "standing" in the local cultural contexts of the rivers that are to be preserved or enhanced. Researchers should be cognizant of management and restoration policy and of integrated watershed conditions. Moreover, the modern era of anthropogenic fluvial geomorphology will likely generate research opportunities at a wide range of scales; from local to global spatial scales and over Quaternary to contemporary time frames. Fragmentation and overspecialization in geomorphic training should be avoided and greater emphasis placed on broad integrated training.

The explosion of new data sets, new analytical techniques, and the greater need for specialists has created challenges for non-specialists and those without computer resources (Marcus et al., 2004). Thus, at a time when the emphasis in environmental science and management is often on increased public involvement, and data delivery makes this involvement increasingly possible, the disparities between rich and poor, literate and illiterate, digitally and non-digitally proficient, and specialist and non-specialist have grown. These disparities pose a major obstacle that could undermine many of the positive advances being made (Clark, 1996; Rango and Shalaby, 1998). How geomorphic research is conducted and explained can determine its relevance or threaten its effectiveness for one of the major audiences that should be reached — those who use and live along rivers. For this reason, Marcus et al. (2004) argue that it is increasingly important for geomorphologists and hydrologists to plan educational and outreach components for their research projects, particularly in areas where people are less familiar with scientific approaches and rationales.

4. Prospect: A sustainable future and theories of human impacts

The road ahead holds an increasing need for a deeper understanding of anthropogenic change in fluvial systems. Rates of fluvial change are accelerating in many river basins, public and institutional awareness of the changes has grown, and the need to manage the changes or adapt to them is growing more acute. Studies of human impacts on rivers are rapidly evolving and many changes in research directions may be projected into the future. Rather than trying to catalog these potential incremental changes, the focus here is on two topics of substantive change. The first topic, sustainability, reflects a clear mandate from the global community and many national governments to adjust planning criteria to address longer periods of resource depletion, human needs, and maintenance of habitat. The second topic notes the need for theories that integrate cultural and physical components of river systems to provide a more holistic understanding of the river–human interface.

4.1. Sustainability science

Sustainability refers to the use of resources in ways that can be maintained over multiple generations while minimizing damage to environmental and social systems. The concept was initially introduced in the social sciences, but was later adopted and advanced in the physical sciences and in river science (Kates et al., 2001; Clark and Dickson, 2003). Adoption of sustainability as a policy constraint is generating new research initiatives in human impacts and a reconsideration of the role of government in general. The continued expansion of sustainability as a policy guideline will create a growing demand for geomorphic expertise, because it encourages consideration of long-term environmental changes over a period of centuries. This view is in harmony with concepts of geomorphic time and geomorphic perceptions of landscape change. Moreover, sustainability science provides an important incentive for geomorphologists and social scientists to work together while adopting the integrative, long-term perspectives required by integrated watershed and river basin management.

Although the concept of sustainability is invoked repeatedly in modern environmental research, it is by no means a new concept. Indeed, many participants of the 1955 *Changing the Earth* Symposium recognized the pitfalls of equating human domination over nature with progress (Glacken, 1956) and calls for projecting an environmental ethic into the future were lucid (Sears, 1956). Carl Sauer clearly expressed the need for an environmental ethic of sustainability when he asked:

> Are our newly found powers to transform the world, so successful in the short run of the last years, proper and wise beyond the tenure of those now living? To what end are we committing the world to increasing momentum of change? (Carl Sauer, 1956; p.66).

Sauer goes on to proclaim:

> For the present, living beyond one's means has become civic virtue, increase of 'output' the goal of

Fig. 4. Carl O. Sauer at Princeton conference in 1956. Source: Wenner Gren Foundation. Printed with permission.

> society. The prophets of a new world by material progress may be stopped by economic limits of physical matter… The high moments of history have come not when man was most concerned with the comforts and displays of the flesh but when his spirit was moved to grow in grace. What we need more perhaps is an ethic and aesthetic under which man, practicing the qualities of prudence and moderation, may indeed pass on to posterity a good Earth (Carl Sauer, 1956; p.67).

Sauer (Fig. 4) was a principal in the *Changing the Earth* leadership.

In the lexicon of modern environmentalism these concerns for sustainability could be phrased in terms of a social responsibility to maintain *intergenerational equity*, one of the central tenets of sustainable resource use. Although much modern environmental research is steered towards this end, the failure to alter the overall course of environmental degradation is striking. A new set of motivating questions and rationales are needed that cannot come from the engineering and technical sectors alone, because values are not scientifically testable. These questions will require collaborations between natural scientists, social scientists, philosophers, and ethicists. They will call for new perspectives on natural process–response systems that include changes brought about by human agency. Herein lies a growing challenge to studies of human impacts and to the next generation of geomorphologists who address questions of anthropogenic change.

4.2. Where is theory?

Major progress has been made since 1956 in understanding the location, magnitude, and persistence of human impacts; and these findings have substantially advanced an understanding of the geomorphic human imprint. On the other hand, as a discipline, little effort has been made to tie these studies together into broader overarching statements about what can be known — and equally important what cannot be known — about cause, effect, and prediction in rivers altered by humans. To the degree that theories of river change and stability exist, they are largely based on physical studies that control for, eliminate, or ignore anthropogenic changes, or they may simply treat human influence as another physical or biological process.

To reach the next level of understanding and predictive capability, theories are needed that specifically apply to anthropogenic change. A number of questions can be raised to demonstrate some of the areas of concern (Table 1.1). This list could be extended indefinitely, but the point is that general principles of causality are lacking for this emerging field of anthropogeomorphology and that conceptual models are needed to explain change and provide important

Table 1.1
Questions revealing the need for anthropogeomorphic theories

Scale:
*) Are there spatial or temporal scales at which responses to human pressures change fundamentally?
— If so, at what scales do anthropogenic processes become non-linear, chaotic, or contingent and do these scales differ from natural processes? The importance of time and space to broad theoretical realms implies that fundamental changes to theoretical constructs occur at different scales of time and space (Fig. 3; Church, 1996).

Hydrologic response:
*) Is there a critical proportion of impermeable area of a basin before human impacts on runoff generation generate downstream changes in channel morphology (Kang and Marston, 2006-this volume)? If so, why? Do these thresholds change with climate, topography, or soils?
*) Do anthropogenic increases in runoff, due to agricultural or urban land use, effect extreme flood magnitudes (e.g., ≥50-year recurrence intervals), or do natural soils become so saturated during those events that human changes are ineffective?

Geomorphic responses:
*) Are sediment waves induced by human activities–such as deforestation, agricultural clearance, or mining–inherently different in their character and behavior than those generated naturally by landslides, climate change, or tectonics?
— How does this apply to sediment budgets or to Knox's (1972) biogeomorphic response model?
*) To what extent is channel morphology affected by changes in riparian ecosystems due to vegetation removal or invasion by alien species?

predictive capabilities. The Binghamton 2006 symposium was convened in large part to initiate a dialogue and to spur efforts to identify some incipient theories of anthropogeomorphology, and to point the way to fruitful avenues of theoretical development (e.g., Gregory, 2006-this volume).

4.2.1. Obstacles to theory development

The general lack of theory in anthropogeomorphology reflects, in part, its early stage of development as a distinct field of study. Many studies of human impacts on fluvial systems have been driven by immediate, applied needs and have not focused on identifying theory. Studies concerned with aquatic restoration, stream stabilization, or flood hydrology, for example, have been largely applied and have not often resulted in the development and testing of theories of the human element of systems.

The lack of integrative theory also reflects the emphasis on physical science methods in fluvial geomorphology and hydrology. Only recently has a substantial effort been made to integrate studies of the biological and physical systems. Integrating cultural phenomena into a holistic understanding of river response will be even more difficult. Some barriers arise because scholars in cultural studies often use language that is alien to Earth scientists, engage in protracted social critiques that are not perceived to be germane to natural science concerns, and construct qualitative models that can be seemingly incompatible with quantitative models of natural systems. Individuals who can elucidate both cultures are needed to bridge these differences. This will require institutional support that enables individuals from one field to engage in starting up in another. Whether the resource-constrained research community has the will to take such steps is an important question. It is easy to say "interdisciplinary," but making it happen is another matter, particularly when some aspects of disciplines are so different as to seem antithetical. A concerted effort is needed to overcome differences in methodology, research goals, and conceptual frameworks.

Even within geomorphology and hydrology substantial cultural barriers exist and the nature of discourse often obstructs the development of theory. Some empiricists argue that established theories are detrimental to the operation of science because they can bias methods and observations (Brown, 1996). When studies attempt to extend findings beyond a specific type of impact or outside of the watersheds for which empirical data are available, they often receive harsh criticisms from reviewers who resist making generalizations about systems where local history and context are important. The difficulties faced by authors in making generalizations about anthropogenic impact and river response are real and pervasive. The potential criticism from reviewers can be swift and hard. Yet, theoretical discourse is essential to science and should be encouraged.

Finally, the complexity of geomorphic systems and tremendous local variability can make it hard to identify and define causal relationships and generalizable geomorphic principles, causing scholars to shy away from making overarching statements (Rhoads and Thorn, 1996). This becomes even more of a problem where nonlinear dynamics introduce chaotic response and uncertainty in the trajectories of change (Phillips, 1996). When human activities are included in geomorphic systems, the complexity of the system is often greatly multiplied. Many researchers, therefore, focus on one human cause of change in one watershed or region; e.g., post-agricultural dispersion of sediments throughout a basin. Because scholars often lack the resources needed to extend findings further, inquiry stops. Clearly, a shift in priorities is needed to expand studies to the broader range of multiple human changes and interactions between them.

4.2.2. Use of existing physically-based theories

Despite the obstacles, notable attempts are being made to progress beyond explanations that apply only to local settings. Two avenues have commonly been followed to develop more general theoretical constructs. One approach has been to adopt existing fluvial theories to human-impacted systems. Several theories of runoff and sediment generation, fluvial channel processes, and other landform processes are often applied to understanding human impacts on fluvial systems (e.g., Schumm, 1977). This has been the dominant approach to understanding human impacts to fluvial systems. Although few existing fluvial and hydrologic theories were intended for direct use in studies of human impact, they often may be applied to these changes. For example, the variable source area, complex response, and biogeomorphic response models, as well as the concept of grade and non-linear dynamics are compelling theories that may improve interpretations of fluvial responses to watershed alterations. The question is how to adapt them to incorporate the effects of highly variable human activities.

Another approach to developing anthropogenic theory has been to focus on one component of human impact and develop theory around that particular feature, thus allowing characterization of the impact in physical terms. For example, Graf (2006-this volume) provides a general model for the nature and range of dam impacts by examining stream segments above and below dams in relatively undisturbed settings. In this way, a general theory of dam impacts is developed because the human component can be treated as a change in flow regime.

The direct transfer of physical models to broader conceptualizations of human impact theory is often justifiable, especially where human impacts can be characterized in physical terms. In many settings, however, the human presence is so intertwined in the history and in the landscape, that separation of human impacts from natural changes is impossible. Much of Graf's effort in the example above went toward locating relatively undisturbed river reaches above major dams. Moreover, human activities may result in system response that cannot be subsumed by conventional fluvial theory based on physical science (Urban, 2002; Gregory, 2006-this volume). Research is needed on the extent to which existing theories may be applicable to situations where human impacts are a central factor. This need calls for an examination of elements of anthropogenic fluvial change that are unique and defy categorization by traditional physics, chemistry, or biological parameters.

4.2.3. Anthropogeomorphic theory

For theories of anthropogeomorphology to advance, a change in attitude within geomorphology and hydrology may be needed about the use of terms such as scientific "theories" and "laws." These terms are often held up as paragons of scientific accomplishment, that can only be claimed when the universality of application can match the legendary status of theories by Newton, Einstein, or Bohr. Lofty notions of what theory generation should be may inhibit a scholar's willingness to make generalizations. Whereas such strict and high standards may prevent the trivial from being elevated to the status of the grand, they also promote the promulgation of studies confined to empirical findings and local case studies loaded with idiosyncrasies. Empirical articles making local claims of explanation are far more likely to be published, so the tendency for empiricism is reinforced. In some ways, this can be a good thing, as it encourages research to produce data that can be used to test and develop theories. In actuality, however, few theories have been forthcoming from the data, and greater efforts are needed to extract general principles from applied case studies.

Cultural phenomena need to be explicity addressed by theory. Spatial and historical variations in livelihood strategies, local culture, and politics may tell us more about contemporary floodplain form (e.g., Bravard, 2006), than a model that is based on flood recurrence intervals. The potential for development of theories of fluvial anthropogeomorphology, however, is problematic; it is more easily stated than practiced. The development of such theories should be given a high priority for future work because anticipating future human impacts requires knowledge of how humans interact with natural systems. One obvious statement that can be made in this regard is that geomorphologists should seek collaborations with social scientists, planners, humanist scholars, local residents, and policy makers to establish a broader understanding of the role of humans in these systems. Collaboration alone, however, is not enough. All players must move outside their intellectual comfort zones and willingly adapt their methods, research designs, and vocabulary to accommodate diverse perspectives on what constitutes valid knowledge, understanding, and prediction. If only physically-based findings are produced, only physically-based predictability will be achieved. Anthropogeomorphology calls for new methods of discourse that truly allow culture and nature to be included in theories of human impacts and environmental change in river systems. Thomas (1956b, p. xxxvii) clearly understood this when he stated:

> "The dichotomy of man and nature is thus seen as an intellectual device and as such should not be confused with reality; no longer can man's physical–biological environment be treated, except in theory, as 'natural'."

5. Summary

Studies of the impact of humans on rivers have progressed far since the 1956 *Man's Role* proceedings. The works of pioneers such as Luna Leopold (e.g., 1953, 1956) and Arthur Strahler (e.g., 1952, 1956) were just beginning to guide the growth of a new quantitative, process-oriented approach to river studies. The contrast between research in 1956 and 2006 is thus remarkable in many ways. Human impact studies are now driven to a much greater extent by environmental regulations, institutional needs, and restoration goals, which in turn have led to increased involvement of government regulators, nongovernmental organizations, and consultants in river studies. Methods now include a remarkable array of dating techniques, spatial data acquisition at local to global scales, and computer-based quantitative analysis, mapping and modeling. The evolving social drivers of research and new methods have led to shifts in topics that are studied, with increasing emphasis on channel changes, human agency across multiple scales, and development of approaches to sustainability and integrated management throughout watersheds. Paradigms used to characterize river responses to the impacts of humans are often different, commonly including concepts of nonlinearity, complexity, and thresholds.

Yet at another level, much about human impact research in rivers remains the same. The 1956 *Changing the Earth* proceedings highlighted the need to look at the big picture –to assess human impacts at landscape scales and over century-to-millennial time periods so as to grasp the true scope of human influences on Earth. In articulating this need, the scholars of 1956 made it clear that landscapes are contingent; that they evolve differently under different natural and cultural influences. These themes are echoed in the watershed perspectives, the complex response paradigms, and the historical reconstructions conducted by modern-day river scientists and reflected by articles in this volume. Similarly, the scholars of the *Changing the Earth* Symposium clearly articulated the need for models that bridge the cultural studies–physical science divide. River scholars continue to grapple with this issue, suggesting it may be time to adopt Rhoad's (2004, p. 752) recommendation "…to forget about conceptualizing how an integrative geography should work and get on with the business of trying to make it work."

A common sense of purpose also permeates the literature of 1956 and 2006, although that purpose is often muted in the dry prose of modern scientific writing. Whether it be through explanation of human impacts, calls for new regulatory measures, discussions of new research approaches, or arguments for greater involvement of river scientists in decision making, a clear and deep sense of caring for rivers pervades the articles in this volume and the larger literature on human impacts in rivers. Thus, while many of the particulars of scholarship on human impacts in rivers have changed, the underlying intent remains the same: to enrich our understanding of how humans alter rivers, and to protect and enhance the rivers that we study.

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