Neogeomorphology, Prediction, and the Anthropic Landscape

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ABSTRACT

The surface of the earth is undergoing profound changes due to human impact. By some measures the level of human impact is comparable to the effects of major classical geomorphic processes such as fluvial sediment transport. Human-driven landscape change is occurring rapidly, and it affects the public directly. Anthropic landscape change has no geologic precedent and may represent an irreversible transition to a new and novel landscape with which we have no experience. For these reasons prediction of future landscape trajectories will be of increasing importance. The remarkable circumstance of being alive at, and cognizant of, the opening of a new geologic epoch – the Anthropocene – offers unique opportunities to the geomorphology community. These opportunities include exposure to new and challenging intellectual problems, the exciting prospect that geomorphology can contribute centrally to the debate over the likely future of the earth’s surface, an increased level of public visibility, influence and support, and a chance to attract a larger number of the best students to an expanded geomorphology. Beyond a consideration of the physical landscape response to a given human impact, the new geomorphology must anticipate what form that impact might take. This branch of geomorphology is called here neogeomorphology. Neogeomorphology operates partly on the basis of knowledge of the physical forces that drive landscape change, as studied in classical geomorphology and geology, but also incorporates elements of economics and other social sciences that help define the larger context that conditions the role of the physical forces. The combination of physical and social forces that drive landscape change represents the Anthropic Force. Neogeomorphology is the study of the Anthropic Force and its present and likely future effects on the landscape. Unique properties associated with the Anthropic Force include consciousness, intention and anticipation. These properties support the occurrence of entirely novel geomorphic phenomena, such as landscape engineering and management, i.e., intentional influences on the evolution of the earth’s surface. The occurrence of short time-scale phenomena induced by anthropic landscape change, the direct effects of this change on society, and the ability to anticipate and intentionally influence the future trajectory of the global landscape, combine to underscore the importance of prediction in neogeomorphology.
Introduction

Today the surface of the earth is undergoing a profound transformation as the result of human activity. Alterations of river flows, changes in soil stratigraphy, chemistry and structure, modification of the earth’s topography, retreat of coastlines, wholesale transformation of vegetative, ecological and hydrological systems, introduction of novel materials into and onto the earth’s surface, changes in climate and the subsequent responses of the earth’s surface to that change, all these changes indicate that the dominion of Nature over the earth’s surface is being challenged by the emergence of what can be called the Anthropic Force – the combined effects, direct and indirect, of the activities of human beings.

As geomorphologists we have choices on how to respond to this state of affairs. We can continue to focus primarily on the pristine terrain that has always attracted us – where Nature remains more (or less) in control – and to try to decipher her handiwork. Or we can decide to devote a larger fraction of our time and effort to an intellectual engagement with the Anthropic Force – to try to determine its principles, to attempt to understand its mechanisms and effects, and to try to anticipate what it implies for the future. The branch of geomorphology that attempts to identify the principles of landscape change as driven by the Anthropic Force, and to predict or influence that change, is distinct from classical geomorphology. Here this endeavor is called neogeomorphology, emphasizing its focus on modern (and by extension future) earth surface phenomena.

One compelling reason for an increased level of study of anthropically driven earth surface processes is the emergence of new opportunities for study, research and support which attention to these processes will bring. There is no agreed upon framework for analyzing the effects of human beings on the earth’s surface, although much valuable information has been accumulated and discussed [e.g., Goudie, 2000; Slaymaker, 2000]. While classical research areas such as fluvial geomorphology are characterized by recognized principles (such as the concept of grade), a comparable set of principles framing the general nature and effects of anthropic impact has not been developed. We need to investigate more fully the fundamental nature of the transformation that is unfolding around us, of which we are a part, and which affects us directly. It is likely that the Anthropic Force, expressed through the complex effects of human plans and actions, has many secrets to reveal. The younger members of our profession will undoubtedly be the most alert and responsive to the so far undercapitalized opportunities that will arise from an attempt to fully understand the unfolding anthropic landscape.

Relative importance of anthropic impact

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1 “Nature” is defined here as that part of the world that functions relatively independently of human activity.
One obvious question is how important is human activity as a geomorphic force? Roger Hooke has provided us with one measure of the relative effectiveness of classical versus anthropic geomorphic processes using the weight of permanently\(^2\) displaced soil and rock [Hooke, 1994]. Important classical geomorphic processes include fluvial, glacial, periglacial, aeolian, hillslope, littoral and tectonic processes. Anthropic geomorphic processes would include the effects of agriculture, highway building, housing construction, mining, military impacts, and so on. Table I shows some of the rates for global human impact in gigatons per year as estimated by Hooke. Agricultural erosion is the dominant anthropic effect by this measure, although activities such as road building are also substantial.

<table>
<thead>
<tr>
<th>Table I, after Hooke [1994]</th>
<th>Process</th>
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<td>Rivers - meandering</td>
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<td>Rivers - long distance transport</td>
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<td>Tectonics (= river transport)</td>
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<td>Glaciers</td>
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<td>Slope processes</td>
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<td>Wave action</td>
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<td>Aeolian</td>
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<td><strong>Total Classical</strong></td>
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<td>Human</td>
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<td>Housing starts(^*)</td>
<td>3</td>
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<td>Mining</td>
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<td>Highway construction(^*)</td>
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<td>Agricultural erosion</td>
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<td><strong>Total Human</strong></td>
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\(^*\) GNP scaling to global values from US data.

These numbers suggest that the anthropic impact of humans today exceeds the largest natural mover of sediment – the world’s rivers. Hooke [2000] also shows that, by the same measure, the rate of human impact has been a rapidly increasing function of time, with a spike in the last century caused by the combined effects of population increase and increasing availability of technology (e.g., bulldozers).

**Prediction in an anthropic world**

Recognized products of scientific inquiry include improvements in our understanding of natural phenomena and the development of explanations for the behavior of natural systems. Predictions are also a valuable product of science. However, in geomorphology, most professional work, and certainly most academic work, is aimed

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\(^2\) These estimates do not include sediment displacements such as those driven by oscillatory wave motion or plowing, disturbances that create only minor “back and forth” changes in land surface topography.
at generating better understanding and improved explanations, rather than at generating predictions. This is partly due to the long time-scales of many geomorphic processes and the difficulty inherent in forecasting [Haff, 1996] the behavior of large, open systems such as those studied by geomorphologists. However, given that the intensity of human impact is large, that such impact affects us, and that we have no clear roadmap at present on what anthropic modification of the landscape implies for our future, prediction of the state of the earth’s surface is likely to assume increasing importance.

This is especially true where surface changes occur rapidly and affect large numbers of human beings, prediction is increasingly important. For example, the narrow strip of land represented by the beach or by barrier islands and spits is one of the most dynamic geologic environments. In addition it is often highly developed and entirely altered by humans [Nordstrom, 2001]. Dams, groins, jetties and channel dredging have, to varying degrees impacted on the supply of sand to the shoreline virtually everywhere. Seawalls have destroyed miles of upper beaches. Dune destruction is widespread on developed islands. In other cases, artificial dunes have been built where none were before and have completely changed the nature of islands, e.g., the relative importance of overwash versus wind in supplying sand to the island. Major neogeomorphic tasks on beaches include prediction of lifespan (cost) of nourished beaches, impact of shoreline engineering on future shoreline position and impact of the sea level rise on natural and artificial beaches.

Anthropic activity is like the weather. It happens every day. It is widespread (global). It is constantly changing, and it affects us personally. The phenomena of weather are in the purview of meteorology, a science perched on the cusp of practice and theory. The “practice” part is prediction, but meteorology also has a more theoretical, abstract side. The practical requirements of prediction in no way detract from the importance and mystery of the “fundamental” part of the science. After all, it was in the context of meteorological prediction that dynamical chaos was discovered [Lorenz, 1993].

**Prediction and public support**

The rapid evolution of the landscape under human impact is dramatically increasing the market value of prediction. The question of the longevity of a beach replenished by pumping of offshore sand at a cost of $1.5M per mile [Jehl, 2001] focuses the attention of the public. Neither geomorphology nor any other science is supported because of its ability to provide explanation and understanding. Explanation and understanding per se have only a modest public value, similar to the value of museums and symphony orchestras, providing insight and pleasure to a curious and interested constituency, but providing no tangible product of value to society. This is why these institutions are frequently in precarious financial circumstances. In science, the intrinsic value of understanding is mainly a personal value appreciated by the individual scientists. But prediction, or more generally, our ability to anticipate, influence, react to, or capitalize upon the future, does have public value. At a minimum, it is the value of the reduction of costs associated with sources of potential natural and man-made hazards,
like steep slopes and dams. The anticipation of future anthropic transformation of the land surface, for example its effects on soils and wetlands, may have an even higher value in terms of the dollar worth of the “natural services” [Daily, 1997] of these landscape elements.

Traditionally, geomorphology, and much of the rest of geology, has looked to the past, often the distant past, with the aim of reconstructing the earth’s history. This is one reason why the geological sciences enjoy only modest public support: geological understanding is seen to lie further from prediction (i.e., from future utility) than does understanding in sciences like physics and chemistry. Knowledge about the past acquires public value to the extent it (ultimately) leads to information useful in the future. In a world with accelerating anthropic impact on the landscape, the past is not far from the future. Time is compressed. The distance between understanding and prediction is shortened. The public has a sense of this recent past, and (sometimes) realizes that the future may be different. Therefore it is likely that not only will the ability to predict in geomorphology acquire increasing value, but it will be increasingly demanded by the public. The rise of the Anthropic Force as a dominant factor in landscape change thus offers significant opportunities to our science for generating increased support, visibility and influence, as well as for addressing new and exciting scientific problems.

**Characteristics of anthropic impact**

*The susceptible layer.* Although anthropic impact is intense, as indicated by Hooke’s analysis, it affects directly only a thin layer of the earth’s surface. Most earth material that is displaced through human activity is displaced by agriculture and lies within a decimeter or so of the surface. Although most agricultural disturbances generally do not create large topographic perturbations of the earth’s surface, plowing, fertilization, and changes in type of plant cover effect major changes in composition and structure of what for human well-being is the most important element of the landscape — the uppermost soil layers. Many other human disturbances such as road building also involve thin surface layers. The top decimeter of the earth’s land area, here called the *susceptible layer*, represents a volume of about $1.5 \cdot 10^{14} \text{m}^2$ (total land area) x 0.1 m = $1.5 \cdot 10^{13} \text{m}^3$, or, calculated at a density of $2 \text{tm}^{-3}$, a mass of about $3 \cdot 10^4 \text{Gt}$ (gigatons). According to Hooke [1994], the net volume of soil and rock moved annually by human activity today, including effects of mining, construction, and soil erosion from cultivated land (but not from plowing per se) is about 100 Gt $\text{y}^{-1}$. If cropland is 10% of the earth’s land surface [Vitousek, 1997] and has a turnover frequency to a depth of 0.1 m of once every two years, then an additional $7.5 \cdot 10^{11} \text{m}^3$ or 1500 Gt $\text{y}^{-1}$ is disturbed each year, equivalent to a global continental soil layer 5 mm thick. Non-agricultural human disturbance (30 Gt $\text{y}^{-1}$) affects an global-equivalent soil layer 0.1 mm thick. These numbers may be compared with the volume or thickness of earth material involved in the landforms and processes of classical geomorphology. These include features as large as major mountain ranges and basins. A generous estimate of the thickness of continental material affected
by or affecting classical geomorphic processes is the average thickness of continental crust above sea level, about 840 m. Total continental volume (height times lateral dimensions) is appropriately assigned to the realm of classical geomorphology because this volume helps determine such things as the long profile of rivers and river discharges, distribution of climate, and so on. The susceptible layer represents only $10^{-2} m/840m$ or 0.001% of the volume of material involved in setting the stage for classical geomorphology. “Thick” features such as the Andes or the Colorado Plateau are immune to human influence as far as their gross morphology is concerned. However, the volumetrically trivial but accessible and easily transformed susceptible layer is crucial for sustaining civilization and life. Its function and future represent a central focus of study for neogeomorphology.

**Anthropic impact and soils.** The susceptible layer overlaps the upper, most biologically active part of the soil profile (not by chance, since plow depths are determined by the need to maximize biologic activity). An important aspect of anthropic impact on landscape is thus its impact on the world’s soils, and the response of soil systems to such impact. The economic value of soils for direct human economic production through construction (most of which rests on the earth’s surface) and agriculture, and its more fundamental value in sustaining most of the terrestrial biosphere, together with the fact that soils are globally being subjected to large changes in distribution (erosion and excavation), structure (plowing and construction) and chemistry (fertilizers and pollution), puts a high premium on prediction of the future state of the world’s soils. Most such prediction, and indeed most work on soils in general, is done by agronomists, not geomorphologists. In its broader view, geomorphology has much to say about the future of soils that will not be said by the agronomy community, which is focused strongly on agriculture per se, and less on the larger scale consequences of massive soil transformation. Some flavor of the conflicting viewpoints and conclusions of agronomy and geomorphology can be found in the recent exchanges between Trimble, Pimentel and others [Trimble and Crosson, 2000; Pimentel and Skidmore, 1999; Nearing et al, 2000].

The quantitative treatment of soil dynamics in a geomorphic context is highly underdeveloped compared to the treatment of the dynamics of bodies of air and water, a fact due to the lack of a general dynamical equation for soils. Much of the effort at prediction in hydrology and atmospheric science is based upon the knowledge and use of these equations. A fundamental equation, like the Navier-Stokes equation for fluids, does not exist for soils, either in practice or, probably, in principle. However, there is little doubt that a more geophysical approach to soil formation, to the development of soil horizons, and to soil transport are areas of prime opportunity for geophysically oriented geomorphologists. Efforts to raise our treatment of the pedosphere to the level of our treatment of the hydrosphere and the atmosphere are likely to greatly increase our understanding of, and our predictive ability regarding, the dynamical behavior of soils.

**Short time-scales: Direct disturbance.** A characteristic of human impact is the injection of short time-scales into landscape dynamics. These time-scales are of (at least) five types. The first reflects directly the operation of the disturbing agency, and thus by
definition creates changes characterized by human time-scales. When a field is plowed, the movement of soil by the plow is under the control of the farmer. This motion reflects the time-scale on which he operates his machinery (and many shorter time-scales at the level of the individual soil particle). Construction, mining and other engineering activities also produce changes in the landscape with time-scales in the range of minutes to years.

**Social forces.** Economic or social time-scales, such as those reflected by business cycles, and time-scales for development or diffusion of technology, migration of populations and so on are longer than direct physical disturbance time-scales, but are nonetheless short compared with many classical geomorphic time-scales.

**Climatic and seasonal.** Just as rivers increase their flows in response to the melting of mountain snow, human landscape disturbance is overprinted with rhythms determined by seasonal and climatic time-scales. Fields are plowed in the spring and lie dormant in the winter. The arrival of drought driven by changes in climate directly affects the ability of the farmer to plant, promotes the transmigration of people, and affects the pattern of their displacement, all leading to geologically short time-scales for impact on and modification of the land surface.

**Landscape response.** The fourth type of fast time-scale due to human impact is associated with the “natural” response time of the landscape to impact, once humans have created a disturbance. Stripping of vegetation from a hillslope may be done in one or a few days by directed human action, but the now-denuded hill responds to the removal of vegetation on a time-scale determined by its own dynamics, which, in the simplest case, is independent of the human disturbance time-scale. The hillslope erodes at a rate that depends on factors such as slope, rainfall frequency and intensity, and soil characteristics. Likewise agricultural soils are transformed directly by the plow, but then respond on a longer time-scale to fluvial and wind erosion and to pedogenic processes. Erosion-response time-scales (days to decades) of disturbed terrain tend to be shorter than many other nature-driven time-scales, such as the time for formation of the soil profile in the first place (centuries to millennia [Hall et al, 1982]), because many soil systems exist presently in a mechanically metastable state. Vegetation promotes weathering and soil formation, and is largely responsible for holding soil in place on hillslopes. Human activity serves to destabilize these marginally stable surfaces.

**Indirect disturbance.** Indirect effects of human activity may also introduce relatively short time-scales into the landscape system. A warming climate is expected to generate a greater frequency of extreme events, such as floods, droughts and storms [Easterling et al, 2001] (see, however, Lins and Slack [1999]). Large-scale changes in erosion patterns and intensity may result from either vegetative responses to changes in temperature and moisture availability, or from intense downpours where soil infiltration capacities are overwhelmed. Synergistic effects on erosion arising from the interplay of vegetation, fire, disease, and other climate sensitive processes are easily imagined. Climate change, with effective time-scales on the order of decades and longer, is probably the most important of the indirect effects of human activity.
Predictability and rapid change. The appearance of new short time-scales is a reflection of the fact that the surface of the earth is undergoing rapid change. Periods of rapid transition in most dynamical systems are nearly always more complicated, less easily understood, and less predictable than the more stable (if still complex) epochs that bracket the transition. Emergent features of complex systems that are readily identifiable under times of nearly steady forcing are harder to identify and their behavior is less easy to understand under a regime of rapid change. Examples of systems undergoing rapid change and loss of predictability during a transition might include wind and water ripples subject to drastic changes in flow conditions, replacement of an old forest or grassland with suburban sprawl or a shopping mall, terrestrial and marine biota during the immediate aftermath of an oil spill or an asteroid impact, re-establishment of soils following destruction of old soil horizons, and so on. Following the period of rapid change, identification of appropriate variables again becomes easier with, respectively, the emergence of regular wavelengths and orientation of bedforms, the appearance of patterns in the arrangement of streets, the re-establishment of a recognizable network of relationships between species, in which the distribution and abundance of animals and plants is determined (relatively) more by inter-organism interactions than by the immediate struggle against a suddenly more hostile physical environment, or, finally, where illuviation, eluviation and chemical transformations eventually re-establish recognizable soil profiles. Anthropic change represents a rapid transition in natural landscape systems with a transition time that is comparable to human time-scales, but short compared to many geomorphic and climatic time-scales. Increased uncertainty and reduced predictability in landscape behavior and function can therefore be expected to characterize our own and, at least, the next few succeeding generations. This represents a major challenge to neogeomorphology, one that suggests fundamental questions that need to be asked about the behavior of complex systems.

The built layer. Another characteristic of anthropic impact also characterized by short times-scales is the generation of a built layer. Human activity typically superimposes on the earth’s surface a layer of artificial composition and structure. The built layer include highways, buildings and other surficial expressions of industrialization and urbanization, as well as a shallowly buried network of pipes, tunnels and cables. The spectral characteristics of the exposed part of the built layer, such as increased reflectance from flat surfaces, form the basis for monitoring urban change through time via satellite observations [e.g., Stefanov and Christensen, 2001]. Growth of the built layer is correlated with geomorphic variables. For example, spatial evolution of urban sprawl in the United States occurs preferentially at the expense of soils having higher than average agricultural value [Imhoff et al, 1999]. Identifying the forces that tend to attract sprawl and other anthropic effects to specific geomorphic features [Wear and Bolstad, 1998] and assessing the subsequent impact on the landscape is an important problem associated with the presence of the Anthropic Force.

Anthropic impact – a unique geological event

The Silurian geomorphologist. One way to make predictions is to observe the past and then extrapolate into the future. The past is a key to the future. A characteristic of
anthropic change however is that it has no geological record. Anthropic modification of landscape is a new and unique phenomenon. An analogy can be made with the emergence of vascular plants in the Silurian. About 400 million years ago the landscape was characterized by thin or absent soils, chemical weathering rates were low, wind was a more important agent of transport and erosion than it is now, and streams and rivers tended to be shallow and braided. This pre-vegetation land surface was radically transformed by the emergence of land plants. Plants modified the same kind of thin uppermost geomorphic layer that humans are in the process of reconstructing today. Weathering was promoted by biologically influenced chemical reactions at the rock surface and the resulting soil was held in place by plant root structure. Large-scale regional climate changes were induced by plant transpiration processes and albedo changes. Aeolian processes decreased in importance as plant cover increased. Vegetative stabilization of material in stream banks promoted the transformation of braided river courses to meandering channels. The changes induced by land vegetation were global. They were also essentially irreversible. The land surface never went back, except locally, to its pre-Silurian “natural” condition. As land plants began to emerge on the previously “pristine” land surface, a Silurian geomorphologist might have searched the geologic record for some clue as to what this new phenomenon might portend. What did it imply for the future course of the surface of the earth? He would have found no answer. (In the Silurian up until about the 1970’s all geologists were male). Perhaps he could be forgiven for thinking that the plants and their effects were an aberration, and that the pre-Silurian landscape was the natural standard to which the state of the earth’s surface might soon return. He would have been wrong. Today we stand on the brink of a change to the earth’s surface that may be as profound and long lasting as the impact of land vegetation. Because of the short time-scales involved, and the fact that what will happen will affect us directly in many ways, it is in our interest to engage the study of these changes in a head-on way. For the field of geomorphology this is all the more true, given that the landscape is “our” part of the whole earth system. The rate and intensity of human impact, and the potential for continuing global change in ways never seen before have suggested to some [Crutzen and Stoermer, 2000] that we have entered a new geological epoch – the Anthropocene. The short time-scales of impending change in the Anthropocene can be expected to greatly enhance the need for geomorphological prediction.

**Prediction of landscape change**

*Response of landscape to disturbance.* Predictions associated with anthropically driven landscape change can be divided into two groups. One of these concerns predictions of how landscapes, once disturbed in a given way, will respond. What will be the hydrologic and erosive response to an artificial but dense network of roadways, or the effect on slope stability of change or removal of vegetative cover? Initial conditions of the system may be set in part by human activity, but classical geomorphic processes are largely responsible for subsequent landscape evolution.

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3 Some recent work [Kenny and Knauth, 2001] suggests that Precambrian land surfaces may have supported substantial phytomass.
Anticipation of disturbance. However, such predictions are only part of the problem of assessing how landscape will change under the force of human impact. In addition to the problem of predicting the response to a given type of impact at a given place and time is the problem of anticipating what those impacts will be, where they are likely to occur, and with what frequency. Without an accounting of the Anthropic Force, geomorphologists will be driven into a kind of defensive or reactive stance, rushing to assess disturbances resulting from human action, but blind to the forces that are the fundamental cause of those disturbances. Thus a glacial geomorphologist interested in land patterns caused by glaciation needs to understand not only the direct effects of glacial ice in creating drumlins, eskers and other landforms, but he or she must also have some knowledge of the dynamics of glacier ice per se. It is necessary to understand the driving system, even though it may be the landscape that is the ultimate target of interest. Likewise, to understand and then be able to predict what is happening to the surface of the earth today requires knowledge of the behavior of the driving system, i.e., of the behavior of human populations in relation to their use and modification of the earth. It is necessary to understand the dynamics of the Anthropic Force.

The Anthropic Force

The Anthropic Force has its own peculiarities that separate it in kind as well as in degree from the “natural” forces of classical geomorphic change. The most obvious observation perhaps is that the Anthropic Force is not entirely analyzable in terms of physics. The constraints on what humans can do to the surface of the earth are constraints of physics in only the most general sense (e.g., mass and energy conservation). For the most part, humans can do whatever they want to the landscape as long as they can pay for it and can generate sufficient societal or political support. For example surface water “naturally” flows downhill, but water flowing in the Colorado River Aqueduct to Los Angeles flows uphill as necessary to overcome topographic barriers.

Economics and sociology, as well as demography, are entry points to understanding the Anthropic Force. Physics and the principles of geology and geomorphology are also important, but are not the sole determining factors in landscape function. From this point of view it is again clear that models of the Anthropic Force will not be wholly physically based. However, the work of physicists, mathematicians, computer scientists and others on rule-based models of complex systems [e.g., Murray and Paola, 1997; Werner, 1999] is likely to be directly relevant. Complex systems theory [e.g., Bar Yam, 1997] provides the mathematical framework to analyze the human component of anthropic landscape change.

Is it the task of geomorphology to inquire into issues of economics, demographics and human social behavior, or is the proper arena of geomorphology restricted to physical processes alone? My answer would be that it is not a question of abstractly dividing knowledge into spheres of influence. It is a question of what is happening to the system that geomorphologists study – the earth’s surface. If as a community geomorphology does not actively engage the profound changes implies by growing human impact, then other disciplines such as geography and ecology will. Indeed, they are already doing so.
By virtue of the importance and immediacy of anthropically driven landscape change, it would be prudent to exercise caution before ceding the study of the Anthropic Force to other disciplines, or ignoring circumstances that could, unattended, lead to a situation where we would need to be informed by others about fundamental issues affecting our own field.

**Examples of research directions in neogeomorphology**

_Slope and cost._ Topographic slope plays a critical role in human impact on the landscape. If one had to ask what was the most important classical geomorphic variable beyond proximity to oceans or major rivers [Cohen and Small, 1998; Small et al, 2000; Sachs et al 2001] affecting human impact on the landscape the answer might be “slope”. Any casual inspection of a map showing both topography and culture is likely to confirm this observation. Most agriculture is confined to low slope terrain. Buildings, roads, and other forms of civil engineering infrastructure spread out from nucleation points along directions of low topographic slope, a fact well known to urban planners, real estate developers, and geographers. Models of urbanization and landscape change make explicit use of the effect of slope (and other topographic variables) in prediction of land use change [Clarke and Gaydos, 1998; Wear and Bolstad, 1998]. A slope factor is incorporated into a rule that limits the spread of urbanization on to steeper slopes. The slope rule plus other rules reflecting assumed dynamics of human population change are then used in cellular automata models [Batty and Xie, 1994, White and Engelen, 1993; Fagan et al, 2001] to predict future patterns of land use change such as urbanization [Clarke and Gaydos, 1998]. Such models can be calibrated against historical data bases of urban expansion. The reason that slope is important is mostly an economic one – it is more expensive to build and maintain structures on sloping terrain than on level surfaces. Many other geomorphic properties like vegetative cover, soil type and thickness, creep rate and slope stability co-vary with hillslope gradient, and are thus also connected to economic considerations and probability of land transformation. Only the most preliminary studies have been made of global correlations of geographic, climatic and geologic variables with population and economic productivity (and hence anthropic impact). At the intersection of geomorphology, demography and economics lie many opportunities for neogeomorphic research. Prediction, including human influence on future landscape evolution, will be an important product of such research.

_Roads and low-order streams._ The construction of dams and their influence on the hydrologic behavior of rivers is well studied. Less well studied are the effects of human activity on low-order channels [Marsh and Marsh, 1995]. Existing first order streams are especially likely to be dammed, deflected, filled in, diverted though culverts, or confined to artificial drainage ways. New low-order streams are created by road and roof gutters, footpaths, dirt roads, and other constructed linear depressions. Because road densities over large areas can approach or exceed natural stream densities, it is clear that the deflection of normal overland flow by highway berms and the collection of runoff from impervious paved surfaces represents a huge impact on stream geometry and, very likely, on stream function. Increased erosion due to concentration of flow on a land surface that is otherwise unadjusted to the new hydrologic regime is readily observable,
especially in arid climates. Significant biologic consequences of this geomorphic reconfiguration of stream channels are also expected since much chemical processing (e.g., control of nitrogen export by periphyton) occurs in the first few hundred meters of stream length [Peterson, et al, 2001]. Geomorphic stream-ordering schemes [e.g., Strahler, 1957] provide a useful way to spatially organize ecologic function [Naiman, 1983], and might prove similarly useful for organizing the effect of anthropic impact on the streamscape.

**IPAT.** One possible way to relate human factors such as cost to actual landscape change is encapsulated in the IPAT equation of Ehrlich and Holdren, \( I = PAT \) [Ehrlich and Holdren, 1971; Ehrlich and Ehrlich, 1990]. Here \( I \) is environmental or geomorphic impact, \( P \) is population, \( A \) is affluence per capita, and \( T \) is a technology factor. Thus an increase in population is associated with an increasing intensity of landuse. This impact is amplified by resources per capita consumed by the population, i.e., by their affluence or wealth, and by the technical means available for changing landscape. For example, the transition from ox and wooden plow to tractor represents a significant increase in the technology factor \( T \) and consequent ability to transform the landscape. The cost of preparing, using, or maintaining land appears in the affluence factor \( A \). Construction of buildings or other structures on steep slopes is accompanied by an increase in cost of excavation and access, and may require implementation of slope-stability measures. In an agricultural setting steeper slopes require greater investment of resources to maintain productivity in the face of potential increases in soil erosion. If \( A \) is small, then the costs cannot be afforded, and the resulting impact (measured say by amount of erosion or percent of area cleared for planting) may be small\(^4\).

The argument made here is not that geomorphologists should focus on providing advice to farmers or civil engineers, but that the geomorphology community should direct greater attention to abstracting and unifying the processes that attend human impact on the landscape. This can be done by identifying and clarifying the principles that underlie the action of the Anthropic Force. As an example, the connection of a geomorphic variable like slope to economic variables such as cost suggests one way in which concepts of classical geomorphology can be connected to variables that are primarily human rather than physical. The correlation between population or GNP density and elevation and proximity to bodies of water represents another broad connection between physiography and human activity [Cohen and Small, 1998; Small et al, 2000; Sachs et al 2001].

**Engineering and the managed landscape**

**Intention, design and feedback.** Prediction in neogeomorphology is destined to play a larger role than it has done historically in classical geomorphology. The short time-scales of human-induced landscape change and the fact that landscape change impinges directly upon human beings through its connection to food, water, health and

\(^4\) In historical times where land was cheap or free, as in the southern Piedmont of the United States in the 19\(^{th}\) century [Trimble, 1974], the affluence factor was relatively ineffective at limiting cultivation and consequent catastrophic erosion on steep slopes.
much of the basic physical infrastructure of society underline the importance of prediction. Another factor is the role of human intention. To the extent that human impact on the earth’s surface is caused by identifiable activities of human beings, earth-surface changes can be influenced or controlled by human behavior. The human-influenced geomorphic system is subject to a feedback loop involving human action and reaction that by definition is lacking for classical geomorphologic landscapes. The existence of this feedback loop provides the possibility for a conscious influence on the evolution of the earth’s surface. Prediction of the path of evolution of the anthropic landscape thus involves elements of intent and design, both of which are lacking in classical geomorphology. Intent and design are also hallmarks of engineered systems. Engineering is the way in which part of the natural world is reconstituted into a form that is amenable to control and whose function accords with our intentions. This is accomplished through a series of steps that run from conception to design to fabrication to maintenance of the final product. Successful design and maintenance rely strongly on the existence of a feedback loop to ensure that function matches intent. Engineered systems that are highly predictable can be built because of the presence of this feedback loop. All successful engineered systems contain such loops.

Feedback requires monitoring, i.e., it is necessary to collect the information that will be fed back. Determination of system initial conditions is the first step in constructing the feedback loop. The surveillance of the earth by satellites, planes, data loggers and a large and increasing number of human eyes provides an increasing rate of data input. One can predict that with the falling cost and proliferation of microelectronic devices (cameras, sensors, etc.) and the growing sophistication and diversity of earth observing satellites, surveillance of the earth’s surface will steadily increase. As more information is collected it is likely to appear that the perceived landscape trajectory (in the multi-dimensional space of topographical, hydrological, ecological and anthropic variables) is not optimal for whatever goal or purpose motivate the observer, so that some changes in system parameter(s) will be made. There seems no question, given (i) the magnitude and rate of human impact on the landscape, (ii) the potential effects for good and ill of that impact on human populations, (iii) our growing ability to rapidly gather earth surface data, and (iv) the human impulse to control, influence or modify that which affects us, that the surface of the earth will increasingly be treated as an engineered system. As such, prediction will play a key role – since the whole point of engineering is to construct systems that behave in the future in a manner in accord with our intentions.

**Geoengineering.** Can nature be engineered at the global scale? The term “geoengineering” is used to refer to wholesale modification of earth system function, especially climate [Keith, 2000; Schneider, 2001]. Examples of geoengineering projects that have been suggested include enhancement of oceanic productivity via iron-fertilization in order to increase carbon flux to the deep ocean [Keith, 2000] and damming the Congo (Zaire) River to create inland “seas” in the Zaire and Chad basins [Rusin and Flit, 1960]. The advisability of attempting to engineer the earth in this way has been strongly criticized [e.g., Schneider, 2001]. However, geoengineering, and the corresponding response of the earth surface to geoengineering, is a proper subject of
study for neogeomorphology in view of the finite possibility that drastic measures might, for better or worse, be undertaken in the future [Keith, 2001].

Landscape design and alternative futures. Geoengineering aside, the earth’s surface is continually being (re)designed at a more incremental level. Conception and execution of plans for modifying existing landscapes or creating new ones lie in the purview of landscape design. Landscape design is usually practiced at the local level, where small scale projects – malls, parks, city centers, research complexes and so on – are “landscaped” as per the desires of the property owner. There are also examples of regional scale landscape design, for which a range of scenarios for possible future landscapes are created. These scenarios suggest actions that might be taken to drive landscape function and appearance in a desired direction. The Harvard School of Design studio focusing on so-called “alternative futures” for the Camp Pendleton Marine Corps base in southern California [Steinitz, 1997] is one example. Agricultural fields represent another example of landscape design. “Alternative futures” as a way of visualizing and thus helping to bring into existence the actual future is likely to become an increasingly important tool. A corresponding methodology using “storylines” and “scenarios” is being used to analyze future climate trends [IPCC, 2001; Schneider, 2001].

It is not possible to say presently whether our attempts at engineering or managing the earth’s landscape will or will not be successful. Only time will tell. Humans are very successful engineers. However, there are many differences between an attempt to consciously control the evolution of the surface of the earth, and, for example, to control the transmission of electricity through a network of wires. In the case of power transmission, wires, towers, footings, insulators and a myriad other system components are conceived of, designed, fabricated, and tested before the overall system is finally synthesized from its parts. Each part is also typically built with a factor of safety to guard against uncertainty in design and component quality as well as against fluctuations in external forcing. This is a tried and true approach to building a system with good predictability. But the scale and complexity of the landscape define a system that differs from the above examples of engineered systems in fundamental ways. The landscape comes preconstructed. It was not initially designed by us, its materials are preassembled, and it is much more of an open system than most engineered systems. The landscape system also comes with no factor of safety – a fundamental component of all predictable engineered systems. Engineered systems tend to be simple rather than complex, because otherwise we wouldn’t be able to understand them and make them do our bidding. Engineered systems that are complex, such as the Internet or the United States power grid, are only partially under our control [e.g., Strogatz, 2001], and their behavior is not always predictable. Nonetheless imperfect predictability and loss of some control can result in useful, or even essential, engineered products.

Engineering versus management; the preservation of “natural” degrees of freedom. It may well be that nature cannot be controlled at the global scale. But its behavior can be influenced. A rational pattern of anthropic forcing that attempts to direct the behavior of a natural system in a way consistent with human goals is management. Management is a restricted form of engineering (“soft” engineering) in which an attempt
is made to allow large chunks of the managed system to operate without wholesale transformation of their internal degrees of freedom. Successful engineering-management will require that classical processes of Nature continue to play a large role in landscape function. As the Anthropocene was opening, most of the complexity associated with the earth’s surface was “natural”. It still is, in the sense that most of the degrees of freedom underlying earth surface processes are determined at some level by pre-Anthropocene materials, networks and hierarchies. But the pre-anthropic system has been disturbed, displaced, chopped up into subunits, and subject to new boundary conditions and driving forces. The environmental changes and stresses of today are the results of the two spheres of Nature and Man adjusting to each other as a consequence of these interactions and disturbances. It is to our advantage to preserve large chunks of the original complexity of Nature, since these chunks provide many under-valued but nonetheless priceless (i.e., irreplaceable and essential) services. A desirable managed landscape would include much of the natural world, but would be a mixture of human and natural components and effects (the “countryside” described by Daily [2001]). The most important part of the natural world to retain is the network of relations that defines natural complexity. A fundamental question is to what extent can the web of complexity that is Nature be modified and disaggregated without catastrophic loss of function and value. This is the central question addressed for example in studies of the effects of habitat fragmentation [e.g., Saunders et al, 1991]. The same question applies to the landscape. To what extent can the “natural” functions of landscape – hydrological, pedological, and geomorphological, as well as biological and ecological – be preserved, and their function predicted, in the presence of anthropic forcing?

If one were required to design a landscape that maintained many of the essential functions of the natural landscape, but was modified to meet human requirements of agriculture, transportation, housing and the like – a landscape that must continue to function appropriately under conditions of a changing climate – what are the general principles that would govern one’s design? Civil engineers know how to answer some of these questions, some of the time, at the small scale, but no one knows how to answer them at the large scale. A general problem posed by an anthropic world is to understand how complex systems are likely to react to external forcings, partitionings and addition and removal of degrees of freedom, and how to direct that response in a desired direction. This is also a central outstanding problem for the analysis of complex systems in general, an observation that underlines the fundamental and abstract nature of the basic questions facing neogeomorphology.

Conclusions

For the most part anthropically driven earth surface processes today lie outside the main focus of geomorphology – the natural surface of the earth. It is up to the geomorphic community to decide whether or not to bring anthropic processes and their effects on the landscape more fully into the sphere of geomorphology. If we do not embrace these new opportunities, other disciplines will. There are many reasons to think carefully before declining this challenge. The discovery of new processes and relationships in any system is an entryway to new research opportunities. The emergence of a new geologic force
during our tenure as earth scientists is, probabilistically considered, a fantastically unlikely event, and presents us with an unprecedented and exciting challenge to understand what is happening to us and our planet and to assess the likely course of landscape evolution in the future. Anthropic impact as a physical phenomenon is at least as rich in its complexity, and as important in its implications for the human condition, as most natural geomorphic and geologic processes. The most fundamental principles of neogeomorphology have yet to be enunciated. A young researcher coming into the field of geomorphology today has open to him or her a new universe of possibilities for research ideas and for influence on the future of the field. New research opportunities will surely represent every bit the intellectual challenge as opportunities in any other area of the geosciences. New approaches and challenges will appeal to many students who might not otherwise consider geomorphology as a discipline of study. Neogeomorphology will provide new career opportunities. Because neogeomorphology deals with that part of the geosphere that, on human time scales, affects us most directly and critically, a vigorous effort by our community in neogeomorphology can lead to an increase in public support for geomorphology as a whole. For reasons discussed above, prediction will play a important role in the anticipated growth of this branch of geomorphology. In general it can be expected that geomorphology as a whole will be elevated to a new level of visibility and influence to the extent it is willing and able to more fully incorporate the full suite of anthropic effects on the landscape into the basic set of processes that it studies.
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References


W. L. Stefanov, and P. R. Christensen, Classification of global urban centers using ASTER data: preliminary results from the urban environmental monitoring program, American Geophysical Union abstract, Spring Meeting, Boston (2001).


