CHAPTER ONE

Geomorphic analysis of river systems: an approach to reading the landscape

Introduction

Landscapes have been a source of fascination and inspiration for humans for thousands of years. Sensory responses to landscapes vary markedly from person to person. To many, spiritual associations evoke a sense of belonging, perhaps tinged with nostalgic sentiments. To others, a sense of awe may be accompanied by alienation or innate fear. Artists strive to capture the essence of landscapes through paintings, prose, poetry or other media. Our experiences in life are often fashioned by the landscapes in which we live and play. Relationships and associations vary from place to place and over time. New experiences may generate new understandings, wherein observations are compared with experiences elsewhere. These collective associations not only reflect the bewildering range of landscapes in the natural world, they also reflect the individual consciousness with which we relate to landscapes, and the influences/experience that fashion our way of thinking, whether taught or intuitive. No two landscapes are exactly the same. Each landscape is, in its own way, 'perfect'. Different sets of controls interact in different ways in different settings, bringing about unique outcomes in any particular landscape. Just as importantly, interactions change over time, such that you cannot step in the same river twice (Heraclitus, 535–c. 475 BCE). Sometimes it seems a shame to formalise our understandings of landscapes within the jargonistic language of scientific discourse, but that is what geomorphologists do!

In simple terms, geomorphology is the scientific study of the characteristics, origin and evolution of landscapes. Geomorphic enquiry entails the description and explanation of landscape forms, processes and genesis. Implicitly, therefore, it requires both a generic understanding of the physics and mechanics of process and an appreciation of the dynamic behaviour of landscapes as they evolve through time. The key to effective use of geomorphic knowledge is the capacity to place site-specific insights and relationships in their broader landscape context, framing contemporary process–form linkages in relation to historical imprints. Theoretical and modelling advances are pivotal in the development and testing of our understanding. However, the ultimate test of geomorphological knowledge lies in field interpretation of real-world examples.

This book outlines general principles with which to interpret river character, behaviour and evolution in any given system. Emphasis is placed upon the development of field-based skills with which to read the landscape. Field-based detective-style investigations appraise the relative influence of a multitude of factors that affect landscape-forming processes, resulting patterns of features and evolutionary adjustments. Interactions among these factors change over time. Inevitably, such investigations are undertaken with incomplete information. Information at hand has variable and uncertain accuracy. Some facets of insight may be contradictory. Individual strands of enquiry must be brought together to convey a coherent story. Significant inference may be required, drawing parallels with records elsewhere. Unravelling the inherent complexities that fashion the diversity of the natural world, the assemblages of features that make up any given landscape and the set of historical events that have shaped that place is the essence of geomorphic enquiry. Just as importantly, it is great fun!

Although this book emphasises process–form relationships on valley floors, it is implicitly understood that rivers must be viewed in their landscape and catchment context. Rivers are largely products of their valleys, which, in turn, are created by a range of geologic and climatic controls. Hillslope and other processes exert a primary control upon what happens on valley floors. Sediment delivery from river systems, in turn, exerts a major influence upon coastal-zone processes. Source-to-sink relationships are a function of catchment-scale controls on sediment supply, transport and delivery. Efforts to read the landscape place site-specific observations, measurements and analyses in an appropriate spatial and temporal context. Understanding of this dynamic landscape template provides a coherent platform for a wide range of management applications.

Geomorphic Analysis of River Systems: An Approach to Reading the Landscape, First Edition. Kirstie A. Fryirs and Gary J. Brierley.

How is geomorphology useful?

Geomorphologists have a long tradition of applying their science in environmental management. Geomorphic insights provide a physical platform with which to develop cross-disciplinary practices and applications that build upon an understanding of how the natural world looks and behaves. Landscapes determine the template upon which a range of biophysical processes interacts (Figure 1.1). For example, insights from fluvial geomorphology provide an understanding of physical processes that create, maintain, enhance or destroy riverine habitat (i.e. the physical space that flora and fauna inhabit). Habitat availability in the channel and riparian zone (and floodplain) of a river is a function of the diversity of landforms on the valley floor. Marked differences are evident; for example, along perennial and ephemeral streams or in a gorge relative to a swamp. Distinct vegetation patterns are found on differing channel and floodplain surfaces, reflecting access to water (and inundation frequency), substrate conditions and morphodynamic interactions between flow and vegetation. Vegetation may have a negligible influence upon some rivers; elsewhere, it may be a primary determinant of process–form relationships. Concerns for ecohydraulics and ecohydrology have major implications for the management of flow, sediment and nutrient fluxes. Water chemistry and turbidity are largely a function of catchment lithology, and the nature/amount of sediment that can be readily entrained by a river.

Alterations to the geomorphic structure of rivers have enormous implications for the operation of biophysical fluxes that affect the movement of water, sediment, nutrients, etc. Hence, a geomorphic template provides a basis for 'whole of system' thinking, aiding the development of coherent plans and strategies for environmental management, guiding decision-making for concerns relating to global change, natural resource management, natural hazards or conservation and rehabilitation issues. End users of geomorphological research are typically land or resource managers who address societal concerns for issues such as erosion and sedimentation problems, channel instability, hazard mitigation, pollution and contamination of water and sediments, ecosystem management, water supply and quality, and so on.

Fluvial geomorphologists have long recognised the nested, hierarchical nature of physical processes that structure river systems across various scales (Chapter 2). Geomorphic relationships vary markedly in differing ecoregions, as climatic controls upon ground cover affect runoff and sediment movement through landscapes, among many considerations. Understanding of source-to-sink relationships at the catchment scale provides a critical platform with which to develop and apply management plans and actions. If geomorphologists are to explain complex landscape behaviour and provide appropriate tools for effective management practice, process knowledge must be related to the configuration of landscape components within any given catchment and the changing nature of process linkages over time. Such understandings are required to convey a coherent view of landscape forms, processes and their evolution. These are innately geographic considerations.

Landscapes are linked and dynamic systems. Disturbance responses or management activities at one place and time may have off-site consequences over various timeframes. Although these are typically scale-dependent relationships (small impacts have minimal consequences that are restricted to closer (proximal) areas), this is not always the case (e.g. local disturbance may induce off-site responses that breach threshold conditions). Often, these relationships are predictable. Gravitationally induced flow and sediment flux is the key driver of upstream–downstream linkages in river systems. Sometimes, however, surprising outcomes may occur. For example, headcut activity and bed incision may cut back through valley floor deposits, impacting upon the river upstream. The effectiveness and efficiency of linkages vary markedly from catchment to catchment. Understanding of imprints from past disturbance events, and associated lagged and off-site responses, is critical in the development of proactive planning appli-

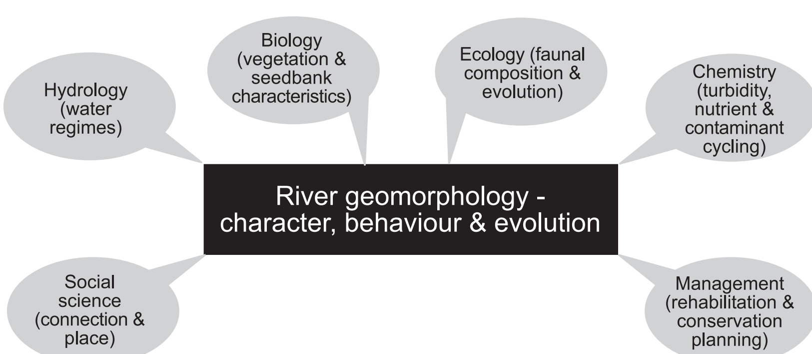

Figure 1.1 Geomorphology as a physical template atop which other interactions occur.

cations. These various considerations underpin visioning exercises that determine 'what is biophysically achievable' in the management of any given catchment.

Geomorphic analysis of river systems: our approach to reading the landscape

Analysis of geomorphic systems cannot be meaningfully formalised using a prescriptive check-list, tick-box set of procedures. Such rigidity belies the inherent diversity of landscapes, and the overwhelming range of factors, process-relationships and controls that combine to generate the pattern of features formed (and reworked) at any given place. This is not to say that all landscapes are necessarily complex; indeed, some may be extremely simple or even near featureless! An open-minded approach to enquiry recognises implicitly the potential for unique outcomes (manifest as assemblages of features and their interactions) in any given setting.

The pattern/configuration of a landscape is derived from its composition (the kinds of elements it contains), its structure (how they are arranged in space) and its behaviour (how it adjusts over time to various impulses for change). Analysis of relationships between landforms can be used to provide insight into the history of formative and reworking events, and the evolutionary history of that system. Ultimately, these space–time interactions can only be unravelled through appraisal of source-to-sink relationships at the catchment scale.

Reading the landscape is an approach by which practitioners use their knowledge and experience to *identify* the assemblage of landforms or features that make up rivers, *develop hypotheses* to *interpret* the processes responsible for those landforms, *determine* how those features have/will adjust and change over time and, finally, place this understanding in its *spatial* and *temporal context*. Successful interpretations draw on existing theory, questioning and testing its relevance to the system under investigation.

All observations and interpretations in geomorphology must be appropriately framed in their spatial and temporal context. This requires appraisal of geologic, climatic and anthropogenic controls upon landscapes at any given locality. Topographic and geologic maps, aerial photographs and satellite images, and Google Earth® provide a simple basis with which to frame analyses in their landscape context, enabling meaningful comparisons with other places. Stark contrasts can be drawn between uplifting terrains at the margins of tectonic plates and relatively stable plate-centre locations, glaciated and non-glaciated landscapes, desert and rainforest areas, or rural and urban streams. Flow–sediment relationships which fashion process–form interactions along valley floors vary markedly in these different settings. It is also important to consider position within a catchment, and the scale of the system under consideration. These insights provide the contextual information within which the approach to reading the landscape is applied.

The constructivist (building block) approach to reading the landscape that is developed in this book assesses how each part of a system relates to its whole in both spatial and temporal terms (Figure 1.2). This 'bottom-up' approach synthesises the behaviour and evolution of landscapes through systematic analysis of fluvial landforms (termed geomorphic units). These features are generated by certain process–form interactions at particular positions in landscapes, and are comprised of differing material properties. Reaches are comprised of differing assemblages of landforms that are formed and reworked under a particular behavioural regime. Catchments are comprised of downstream patterns of reaches that are (dis)connected and through which fluxes of water, sediment and vegetation drive river behaviour, evolution and responses to human disturbance.

Although remotely sensed or modelled data provide critical guidance in our efforts to interpret landscapes, it is contended here that genuine understanding is derived from field-based analyses.

Reading the landscape entails four steps, for which different generic skills are required (Figures 1.3 and 1.4).

1. *Identify individual landforms (geomorphic units) and the process–form relationships that determine their process regime.*
   Landforms (or geomorphic units) are the component parts of a landscape. In general terms, they form under a given set of energy conditions at particular locations in a landscape. They are produced by a particular set of processes that fashion and rework the size and shape of the characteristic form. Geomorphologists have a good understanding of these process–form (morphodynamic) relationships, whereby the process affects the form and vice versa. Individual landforms have certain material and sedimentologic properties with a characteristic geometry and bounding surfaces (i.e. erosional or depositional contacts). Geomorphic units commonly have characteristic vegetation associations reflecting hydrologic and substrate conditions (among many considerations). Combinations of erosive and depositional processes that sculpt, create and rework the feature define the range of behaviour of each particular unit. From this, magnitude–frequency relations of formation and reworking can be inferred. This allows interpretation of the sensitivity/resilience of that feature when it is subjected to disturbance events (i.e. whether the feature will simply have additional

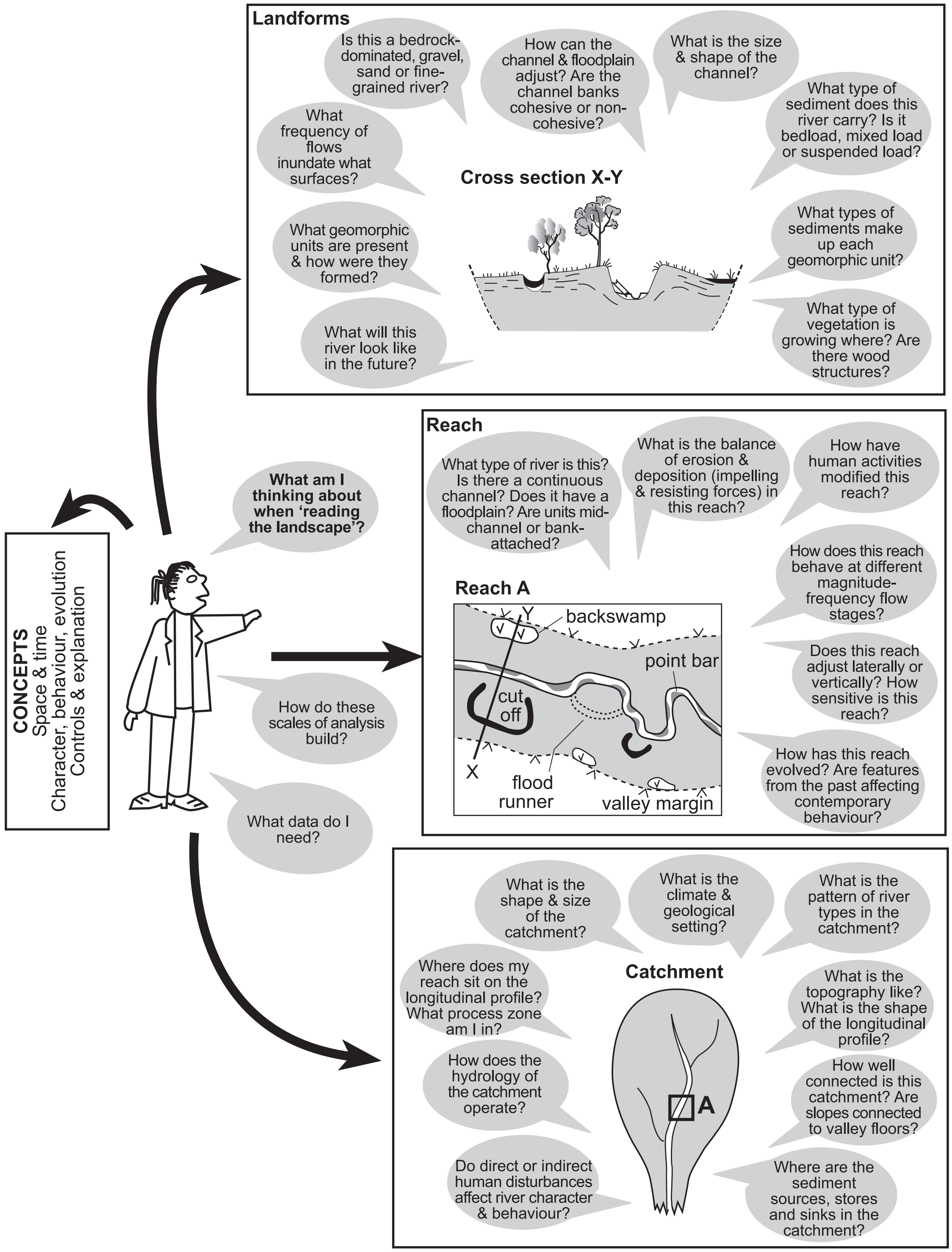

Figure 1.2 Questions you should ask when reading the landscape at the landform, reach and catchment scales.

deposits added to it, whether it will be partially reworked or whether it will be destroyed (eroded and removed)).

2. *Analyse and interpret the package and assemblage of landforms at the reach scale and how they adjust over time.*

Sections of river with a distinct assemblage of geomorphic units that reflect particular combinations of erosional and depositional processes are referred to as a reach. By definition, reaches upstream and downstream are characterised by different packages of landforms. Reading the landscape at the reach scale entails

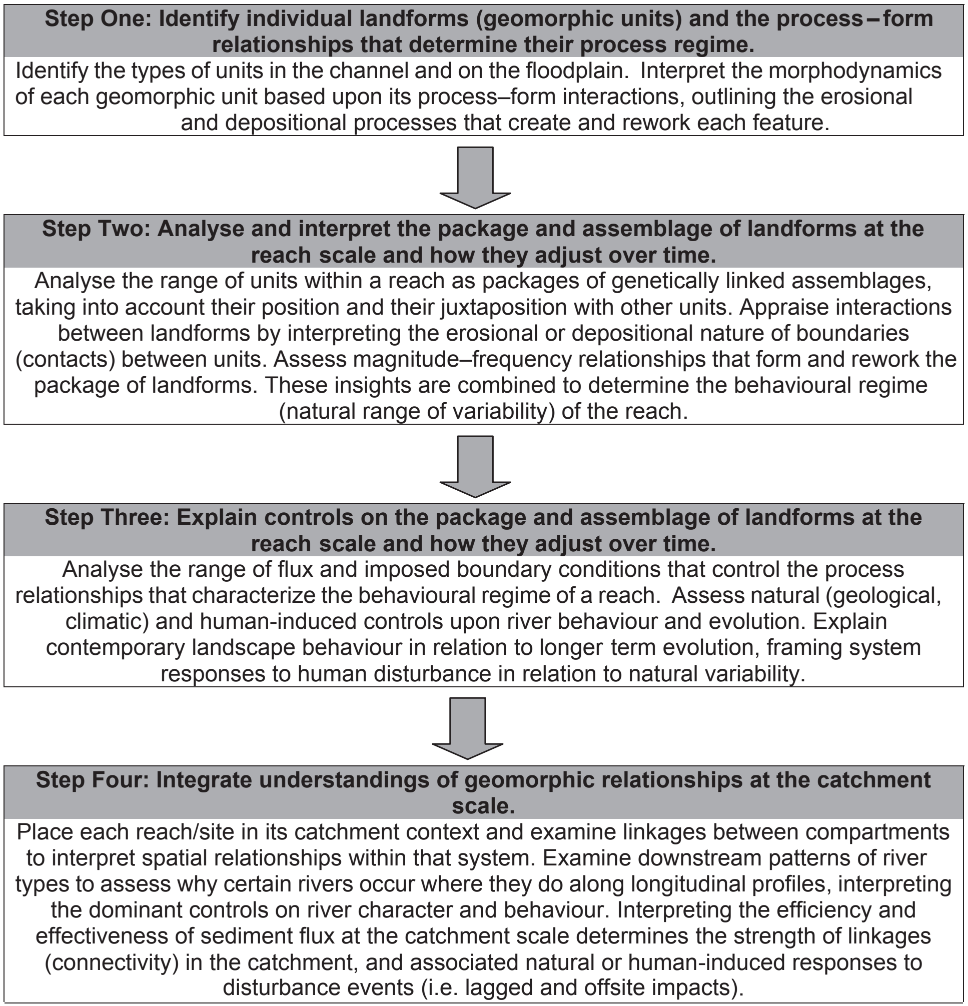

Figure 1.3 An approach to reading the landscape.

assessment of which types of geomorphic units are present (or absent), what types of sediments they are made of, and whether the units are formed and reworked by genetically linked contemporary processes or they reflect former conditions (Figures 1.2 and 1.4). Interpretation of the array of process–form relationships for the range of geomorphic units along a reach, and associated channel–floodplain interactions (if present), is used to determine the character and behaviour of a river. Adjustments around a characteristic state over geomorphic timeframes determine the *range of behaviour* of a river, as systems respond to disturbance events (Chapter 2). Inevitably, the magnitude–frequency domains with which these features are generated and interact may vary from system to system.

Significant insights into landscape history can be gained through analysis of whether adjacent features in a landscape are genetically linked or not (i.e. whether they formed contemporaneously, or whether they formed over differing periods of time). This provides guidance into the evolutionary history of a landscape, highlighting erosional events that rework landscape features (i.e. a temporal discontinuity). For example, terraces are older than adjacent floodplain and channel features, and they were often formed by quite different processes under differing environmental conditions.

3. *Explain controls on the package and assemblage of landforms at the reach scale and how they adjust over time.*

   All landscapes adjust and evolve. Among the many inherent complexities of analysis of landscape systems is determination of the timeframe over which differing features are created and/or reworked and appraisal of the ways in which adjustments to one part of a system affect responses elsewhere in that system. The true value of geomorphic understanding lies in being

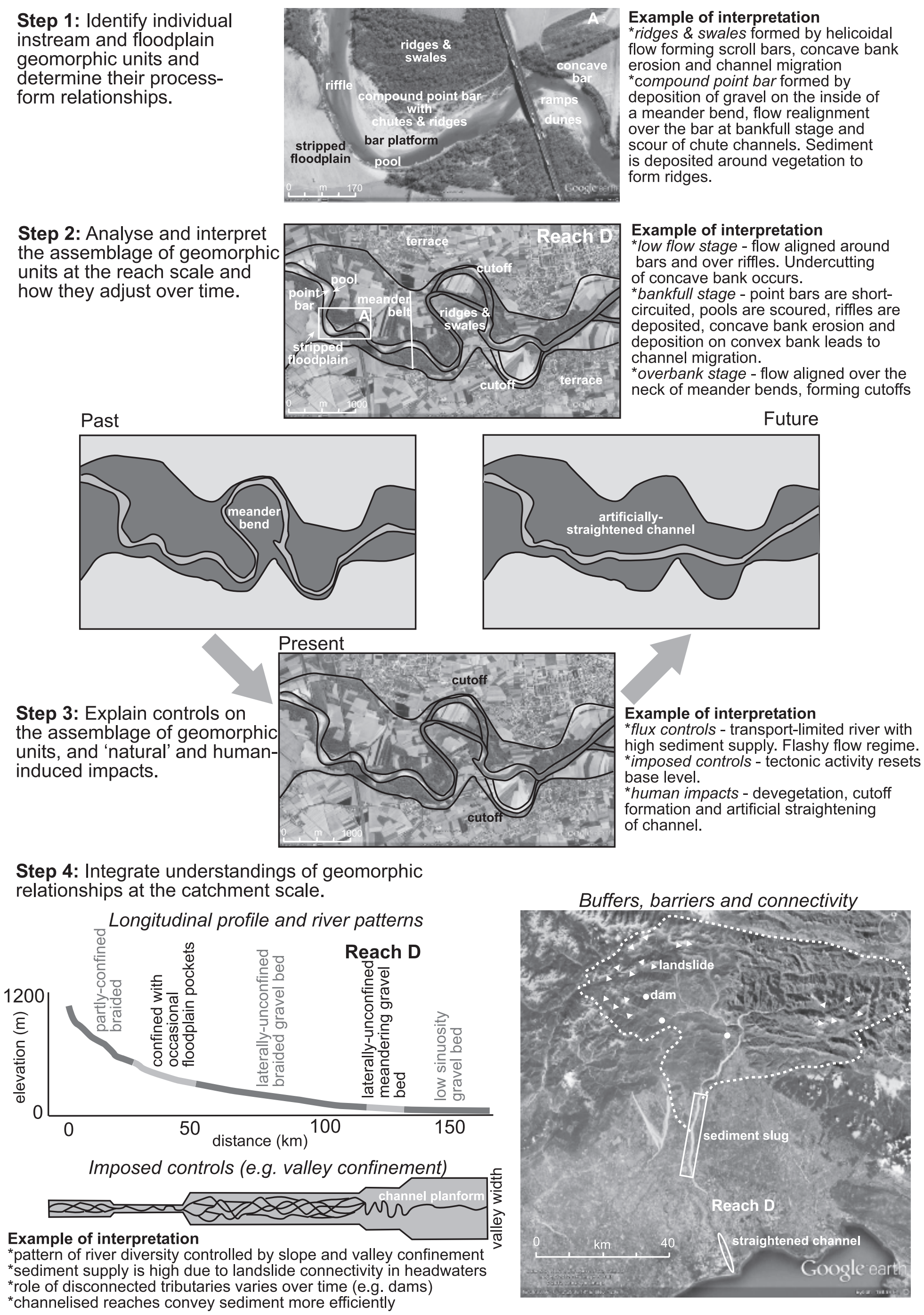

Figure 1.4 An example of how to apply the reading the landscape approach to a real river system (See Colour Plate 1). The example used here is the Tagliamento River in Italy. The approach begins by interpreting process-form relationships for individual, then assemblages of geomorphic units along different reaches of river type. River behaviour is interpreted for a range of flow stages. The role of natural and human induced disturbance on river adjustments over time is considered when analysing river evolution. Finally, each reach is placed in its catchment context, analysing flux and imposed controls on river diversity along longitudinal profiles and how reaches to fit together in a catchment. Interpreting the efficiency of sediment flux at the catchment scale determines the (dis)connectivity of the catchment and associated off-site responses to disturbance. Maps constructed using Google Earth © 2012 images. Based on information in Bertoldi et al. 2009, Gurnell et al. 2000, Surian et al. 2009 and Tockner et al. 2003. The interpretation of river types, river evolution and connectivity are our own.

able to explain the controls that drive process interactions and how they have changed/adjusted over time and interpreting what has triggered these changes/adjustments.

Differing controls upon landscape behaviour operate over variable spatial and temporal scales. By definition, the package of geomorphic units at the reach scale is fashioned by a consistent set of controlling factors. Valley setting (slope and width) is the primary determinant of *imposed boundary conditions* that are set over timeframes of thousands of years or longer (Chapter 2). In contrast, flow and sediment transfer relationships that recurrently adjust over much shorter timeframes set the *flux boundary conditions*. Primary differences in geomorphic setting (and associated behavioural regime) can be attributed to patterns of geologic (imposed) and climatic (flux) controls. Geologic factors such as tectonic setting, lithology and resulting topography affect the erodibility and erosivity of a landscape. Climatic factors influence the nature and rate of process activity (e.g. geomorphic effectiveness of flood events).

Effective integration of process-based insights through appraisals of the ways in which landscape compartments interact and evolve over time provides the basis to explain why certain behavioural adjustments have occurred. Analysis of landscape evolution enables determination of whether the contemporary system adjusts around a characteristic state, adjusts among differing states or has a different evolutionary pathway. These interpretations can be used to relate landscape responses to human disturbance to the *natural range of variability* of a system.

4. *Integrate understandings of geomorphic relationships at the catchment scale.*

Drainage basins are comprised of relatively self-contained, gravitationally induced sets of biophysical relationships. The balance of erosional and depositional processes varies markedly in source, transfer and accumulation zones of a catchment. Erosion is dominant in source zones, deposition is dominant in accumulation zones and an approximate balance of erosional and depositional processes is maintained in transfer zones (Chapter 3). Analysis of source-to-sink relationships at the catchment scale provides the most logical basis to consider the linked nature of spatial and temporal adjustments in landscapes, enabling meaningful interpretation of lagged and off-site responses to disturbance events. The unique configuration and temporal sequence of drivers, disturbances and responses of each landscape, along with the historical imprint, result in system-specific behavioural and evolutionary traits.

Catchment-scale investigations frame analyses of river character, behaviour and evolution in relation to the size and shape of the catchment, the drainage network pattern and density, and topographic relationships (especially relief, longitudinal profile shape and valley morphology) (Figures 1.2 and 1.4). Each site/reach must be viewed in its catchment context, assessing relationships to upstream and downstream considerations. Flow–sediment linkages between reaches and tributary–trunk stream relationships in differing landscape compartments (or process domains) are captured by the term *landscape connectivity* (Chapter 2). In some landscapes, hillslope and valley-floor processes are inherently coupled or connected; elsewhere they are not. Valley floors may be disconnected from adjacent hillslopes, but directly linked to sediment supply from upstream. Analysis of downstream patterns of rivers, and associated implications for flow and sediment flux, determines how adjustments to one feature (or reach) affect adjacent or other forms. The way in which disturbance responses in one part of a catchment affect river adjustments elsewhere within that system is termed a response gradient. Understanding of these catchment-scale considerations provides critical guidance in interpreting the behavioural regime and evolutionary trajectory of a river.

In summary, reading the landscape is an open-ended, interpretative, field-based approach to geomorphic analysis of river systems. Efforts to read the landscape can be summarised as follows: identify features and assess their formative processes, appraise how these features fit together in a landscape (reaches and catchments) and assess how these features adjust and evolve over time. Meaningful *identification* and *description* underpins effective *explanation*, providing a platform with which to make realistic *predictions* about likely future states. Landscape relationships are analysed through appreciation of system dynamics, recognising the variable imprint/memory of influences from the past. Behavioural regimes are differentiated from river changes as landscapes evolve. Human impacts upon rivers are differentiated from natural variability. Chapters 2–9 of this book outline contextual principles and theories with which to ground these analyses, which are explained more fully in Chapters 10–14.

Key messages from this chapter

- Geomorphology is the science concerned with understanding the form of the Earth's surface and the processes by which it is shaped, both at the present day and in the past.

- Rivers are a product of their landscape. As rivers are spatially linked systems, they are best studied at the catchment scale. Catchments synthesise process–form relationships over a range of spatial and temporal scales.
- No two landscapes (and associated river systems) are exactly the same. Reading the landscape presents a grounded basis to examine the character, behaviour and evolution of any given river system.
- Reading the landscape is a thinking and interpretative exercise. Detective-style investigations are required to differentiate among the myriad of factors that affect river character, behaviour and evolution. The approach to reading the landscape outlined in this book has four steps:

1. Identify and interpret landforms and their process–form relationships.
2. Analyse assemblages of landforms at the reach scale to interpret behaviour.
3. Explain controls on process–form interactions at the reach scale and how they adjust over time.
4. Integrate spatial and temporal considerations through catchment-specific investigations to explain patterns of river types and their evolutionary adjustment, framing system responses to human disturbance in relation to the natural variability of the system.