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The Scope of Uncertainties in River Restoration

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3.1 INTRODUCTION

The science and practice of river restoration are both still very much in their adolescence (Palmer et al., 1997). Yet, both have been graced with funding and support from a diverse range of interest groups (Malakoff, 2004). One of the premises of this book is that if funding is to continue to be allocated to river restoration, it will have to be shown that river restoration is ‘working’ (see Preface; Wissmar and Bisson, 2003c). Definitions of ‘working’ (often equated with success) are understandably subjective and vulnerable to uncertainties in the river restoration process, societal values, the fluvial system and ecosystem response to restoration management activities. Davis and Slobodkin (2004) argued that defining restoration goals and objectives is rightfully a value-based activity, as opposed to scientific activity. Each activity is inherently uncertain. Paradoxically, the uncertainties influencing river restoration projects are rarely recognised or quantified, much less reported to stakeholders or the public (Walters, 1997).

The topic of uncertainty in river restoration is riddled with complexity and confusion. Indeed, uncertainty manifests itself in many ways, as established in Chapters 1 and 2. Lemons and Victor (see Chapter 1) have already illustrated how deep the value-laden dimensions of uncertainty lies, not just in decision making, but in scientific research as well. Graf (see Chapter 2) expanded on this theme, citing uncertainties from theories, the research itself, communication and biases among investigators. He concluded that the research can either ‘ignore the uncertainty and hope that it is not debilitating for the project at hand, or accept the uncertainty and use it as a feature of the research.’ In this chapter the rich topic of uncertainty is presented in a broader, more generic context. This foundation is intended to help separate the sources and types of uncertainties that the various authors in this book present, and meanwhile unravel some of the ambiguities surrounding uncertainty in river restoration.

As cautioned earlier, potentially significant uncertainties are rarely recognised, much less explicitly dealt with in river restoration. Hence, a lexicon and typology for uncertainty is outlined firstly in this chapter. This is done to dispel the notion of a certain world with certain outcomes within the broader scope of types and sources of uncertainty. A return specifically to river restoration then follows to identify types of uncertainties using the above-mentioned typology. The tremendous diversity of river restoration in the context of uncertainties arising from restoration motives, notions and approaches are considered. A case will be made that a basic strategy for dealing with uncertainty is needed by the river restoration community to allow both the community and individual investigators or practitioners to:

- explore the potential significance (both in terms of unforeseen consequences and welcome surprises) or insignificance of uncertainties;
- effectively communicate uncertainties;
- eventually make adaptive, but transparent, decisions in the face of uncertainty.
Finally, it will be argued that amongst the various strategies for dealing with uncertainty, the only strategy that might provide these aims is one of embracing uncertainty.

### 3.1.1 The Status Quo in River Restoration

The rapid rise and international popularity of river restoration is both encouraging and worrisome (Kondolf, 1996). Although sparse examples dating back to the 1930s exist\(^1\), river restoration has primarily developed on the coat tails of the environmental awareness movement of the late 1970s (Graf, 1996; Sear, 1994). It is encouraging that so much enthusiasm exists to restore rivers. Yet, it is interesting to note the societal choices between some mix of reactive restoration efforts in response to damage already done, as opposed to pro-active conservation actions to prevent further damage (Boon, 1998). The international popularity of river restoration is evident in the restoration literature (e.g. restoration in 21 different countries reported in Nijland and Cals, 2000), restoration databases (e.g. the United Kingdom River Restoration Centre (RRC), United States Environmental Protection Agency (EPA))\(^2\) and an International River Restoration Survey\(^3\) launched by Wheaton et al. (2004c) with respondents from 34 different countries. In Denmark alone, 1068 restoration projects had been completed by Danish regional authorities by 1998 (Hansen and Iversen, 1998); whereas in the United States, Malakoff (2004) reported that by 2004 more than $US10 billion had been spent on a total of more than 30,000 projects. The popularity of river restoration is apparent in international, national, regional and local public policy that actively promotes, requires and, in some cases, funds river restoration efforts (Jungwirth et al., 2002). However, their effectiveness is constrained by limited funds and scope to deal with closely related land use issues and other socio-political goals (Tockner and Stanford, 2002).

Despite the popularity of river restoration in the developed nations of the world, the global decline of the physical and ecological integrity of rivers is difficult to overstate (Jungwirth et al., 2002; Vitousek et al., 1997). Indeed, most restoration efforts still pale into significance relative to expanding anthropogenic impacts on riverine landscapes (Tockner and Stanford, 2002). Even in parts of the world where numerous river restoration efforts are already underway (i.e. Europe, North America and Australia), wetlands are actively being drained and filled, rivers are still diverted and regulated, urban growth is encroaching into floodplains and headwaters, while we continue to permanently alter basin hydrology and fragment habitats (Collins et al., 2000; Moss, 2004; Mount, 1995). These problems pose even larger threats in the developing nations of the world (Marmulla, 2001). Over 250 new major dams become operational worldwide annually and 75 are planned for the Amazon Basin alone (Robinson et al., 2002). It seems logical that preservation should be easier to achieve than restoration (Frissell et al., 1993), but there seems to be excessive confidence in the ability to restore (Stewardson and Rutherford, see Chapter 5), sometimes reducing restoration to a mitigation measure justifying planned impacts or maintaining the status quo. Both conservation and restoration are based on the transformation of uncertain science and uncertain notions of what is natural, ecosystem integrity and physical integrity into societal goals (Graf, 2001; Lemons and Victor, see Chapter 1). Additionally, the good intentions of restoration projects may lead to unintended but often foreseeable consequences. Even if society is willing to make difficult socio-political decisions to support preservation and restoration of rivers, there is no guarantee of desired outcomes following.

Given the dynamism of rivers, it seems obvious that the outcomes of restoration projects are uncertain. However, the restoration community seems hesitant to admit that the goals and science that restoration are founded upon are uncertain too (Stewardson and Rutherford, see Chapter 5). Aside from indirect references to uncertainty in adaptive management programs, the river management community has largely brushed uncertainties aside (Clark, 2002; Wissmar and Bisson, 2003c). It is unclear whether this is a conscious or passive decision, though individual decisions to ignore uncertainty can be plausibly attributed to one or more of the following:

- ignorance of uncertainty and/or its significance;
- the hope that uncertainty is insignificant;
- an acknowledgement of uncertainty, but not knowing how to deal with it;
- being misinformed about uncertainty, leading to the assumption that it is insignificant;
- being knowledgeable about uncertainty, but having established its insignificance.

\(^1\) The United States Department of Agriculture Forest Service started undertaking ‘stream improvement’ in the 1930s with the intent of increasing salmonid production (Everest and Sedell, 1984).

\(^2\) RRC Database includes over 750 projects within the United Kingdom: http://www.therrc.co.uk; the USEPA River Corridor and Wetland Restoration Database includes over 600 projects throughout the United States: http://yosemite.epa.gov/water/restorat.nsf/rpd-2a.htm.

\(^3\) Complete real time results, background information and forthcoming interpretations are available on the web: http://www.geog.soton.ac.uk/users/WheatonJ/RestorationSurvey_Cover.asp.
Newson and Clark (see Chapter 14) attribute the river manager’s current treatment of uncertainty to a ‘risk-averse’ management culture that prefers to entrench itself in ‘rituals of verification’ aimed at minimising liability (Power, 1999). Uncertainty is also frequently misunderstood by the general public (Pollack, 2003; Riebeek, 2002) as something negative and undesirable (Newson and Clark, see Chapter 14). A widespread misconception that science embodies certain knowledge persists in the reports of the mainstream media and views of the general public (Clark, 2002; Riebeek, 2002). Such misconceptions fuel expectations that science-based approaches to river restoration will yield positive outcomes. Ironically, people confront uncertainties everyday without hostility and choose to routinely make decisions about the future (Pollack, 2003).

Restoration science and the restoration literature are not much further along than practitioners and decision makers. Wissmar and Bisson (2003b) asserted that ‘a better understanding of variability and uncertainty is critical to the successful implementation of restoration programs for aquatic and riparian systems.’ Yet, buried within a rich literature on restoration are only occasional passing mentions of uncertainty (Brookes and Shields, 1996) and a handful of explicit treatments (Johnson and Brown, 2001; Johnson et al., 2002; Johnson and Rinaldi, 1997; Johnson and Rinaldi, 1998; Wissmar and Bisson, 2003c). These studies understandably tend to focus on a specific type of uncertainty that might be reasonably articulated within a specified page limit, so a more holistic treatment of uncertainty is necessary (Newson and Clark, see Chapter 14; Van Asselt, 2000). Restoration is established as one important component of environmental management. It would be a shame to lose what public support already exists for restoration if political scrutiny recasts unrealistic expectations of river restoration as a ‘failure’, as opposed to the inadequate consideration of uncertainty they truly stem from.

3.2 WHAT DO WE MEAN BY UNCERTAINTY?

3.2.1 A Lexicon of Uncertainty

In the simplest sense, uncertainty is a lack of sureness about something or someone (Merriam-Webster, 1994). However, uncertainty can be more than simply a lack of knowledge. It persists even in areas where knowledge is extensive; and knowledge does not necessarily equate to truth or certainty (Van Asselt and Rotmans, 2002). There are at least 24 potential synonyms for the noun uncertainty and 27 synonyms for the adjective uncertain (Table 3.1). There are a number of concepts related to and influenced by uncertainty, but which differ from uncertainty itself. A selection of these concepts is considered briefly below.

**Accuracy:** Accuracy refers to correctness or freedom from error. In measurement, accuracy refers to how close an individual measurement is to the ‘true’ or ‘correct’ value (Brown et al., 1994). The classic accuracy analogy is the location of darts on a dart board – the closer the darts are to the intended position (bull’s-eye) the more accurate. If one can be certain about both the ‘true’ value (e.g. the position of the bull’s-eye) and the value of the individual measurement (e.g. the position of the dart), then the accuracy is actually a certainty. In practice, accuracy statements are uncertain because ‘true’ values are often assumed and measurements have limited precision.

| Table 3.1 Potential synonyms of the noun ‘Uncertainty’ and the adjective ‘Uncertain’ |
|----------------------------------|----------------------------------|
| Synonyms of Uncertainty          | Synonyms of Uncertain            |
| Ambiguity                        | Ambiguous                        |
| Capriciousness                   | Capricious                        |
| Chance                           | Probabilistic                     |
| Danger                           | Dangerous                         |
| Disbelief                        | Disbelieving                      |
| Equivocation                     | Equivocal                         |
| Doubt                            | Doubtful                          |
| Expectation                      | Erratic                           |
| Future condition                 |                                   |
| Hesitation                       | Hesitant                          |
| Ignorance                        | Ignorant                          |
| Improbability                    | Improbable                        |
| Indecision                       | Indecisive                        |
| Indeterminacy                    | Indeterminant                     |
| Insecurity                       | Insecure                          |
| Irresolution                     |                                   |
| Obscurity                        | Obscure                           |
| Surprise                         | Surprising                        |
| Unintelligibility                | Unintelligible                    |
| Vacillation                      | Vacillating                       |
| Vagueness                        | Vague                             |
| Uns sureness                     | Undecided                         |
| Unpredictability                 | Unpredictable                     |
Confidence: Confidence (e.g. in a statement, hypothesis, measurement, feeling or notion) relates to the degree of belief or level of certainty. Confidence levels, for example, describe the probability that a given population parameter estimate falls within a designated continuous statistical confidence interval.

Divergence: Divergence describes a situation when similar causes produce dissimilar effects (Schumm, 1991). Divergence relates to uncertainty in situations where problems of cause and process are under consideration.

Error: Error is the difference between a measured or calculated value and a ‘true’ value. In every day conversation, an error is a mistake. In science, error is the metric by which accuracy is reported and is not a synonym for uncertainty (Ellison et al., 2000). A ‘true’ value is certain by definition. If the error between the ‘true’ value and a measured or calculated value is known there is no uncertainty in principle. However, in practice ‘true’ values are often not known and instead are assumed to be so, while the measured or calculated value may be uncertain. Hence error becomes representative of uncertainty. Once errors are calculated, it can be helpful to consider whether the error is systematic or random. Systematic errors stem from consistent mistakes and are often constant or predictable, affecting the mean of a sample (i.e. bias, Trochim, 2000). Systematic errors can potentially be constrained as their source is identifiable. By contrast, random errors influence the variability of a sample (not the mean) and are generally unpredictable or unconstrainable (Trochim, 2000).

Exactness: Exactness is really a synonym for accuracy. However, it is worth pointing out that exactness has quite a different meaning to exact. Exact statements or exact numbers, in principle, have no uncertainty about them. They are statements of truth. By contrast, exactness is a relative measurement assigned to inexact statements or values (i.e. those with some uncertainty).

Expectation: Expectation has to do with anticipation of probable or certain events. Uncertainty fundamentally relates to expectations. When uncertainties are unknown, not fully considered or ignored, the degree that expectations may be Unrealistic will generally increase.

Equifinality: Equifinality (also referred to as convergence), arises when different processes and causes produce similar effects (Schumm, 1991). In a modelling context, Beven (1996a; 1996b) suggests that ‘the consequences of equifinality are uncertainty in inference and prediction.’ In a social context, a potentially limitless range of possibilities may lead to a single event, such as the election or defeat of a politician.

Precision: Precision is a measure of how closely individual measurements or calculations match one another (Brown et al., 1994). Recalling the dart board analogy from accuracy, a precisely thrown set of darts will cluster around one another, but may be nowhere near the bull’s-eye. In measurement, the precision of an instrument refers to the finest scalar unit the instrument can resolve. Precision is related to uncertainty in that it defines a detection threshold, below which differences can not be discerned.

Repeatability: Repeatability can be viewed as either the ability to reproduce the same measurement, result or calculation or the variability in repeated measurements, results or calculations. Uncertainty can simply limit repeatability or increase variability.

Risk: Risk is a measure of likelihood that an undesirable event or hazard will occur (Merriam-Webster, 1994). Ward (1998) credited Knight (1921) for making the important clarification between risk and the type of uncertainty for which there exists ‘no valid basis of any kind for classifying instances’:

‘He used the term “risk” for situations in which an individual may not know the outcome of an event, but can form realistic expectations of the probabilities of the various possible outcomes based either on mathematical calculations or the history of previous occurrences.’

Newson and Clark (see Chapter 14) contrast risk (with ‘known’ impacts and probabilities) with uncertainty (with ‘known’ impacts but ‘unknown’ probabilities) and ignorance (with ‘unknown’ impacts and probabilities).

It is worth noting that uncertainty itself and all the related concepts outlined above are described in terms of their ‘degree’. That is, none of these concepts are simple Aristotelian two-valued logic concepts (e.g. true–false). Each concept is measured along a continuum of values with end-members of total uncertainty (complete irreducible ignorance) and absolute certainty. Probabilistic uncertainty is an example of a quantification of uncertainty, yet not all uncertainty is quantifiable. To quantify uncertainty it is necessary to estimate the degree of our limited knowledge. Yet, if a condition of irreducible ignorance is considered as one extreme of uncertainty, it is difficult at best to estimate the degree of something we do not even know exists. Within this broad view of uncertainty, uncertainty might also be considered along a continuum that reflects our ability to quantify it (Figure 3.1).

In summary, when someone mentions uncertainty casually, it is difficult to discern whether they are referring to
limited knowledge, a lack of knowledge altogether, or one of the above-mentioned concepts that are influenced by uncertainty. Moreover, the lexicon provided here contains concepts that are highly inter-related and easily confused. Similar to vague, pseudo-scientific buzzwords and catch-all phrases like holistic and integrated, the term ‘uncertainty’ alone evidently has little meaning until its details are unravelled.

### 3.2.2 A Typology for Uncertainty

Since uncertainty is so hard to define, a classification of uncertainty is often used (Van Asselt and Rotmans, 2002). The utility of any typology or classification is ultimately dependent on its application (Kondolf, 1995b; Lewin, 2001). Rotmans and van Asselt (2001) astutely pointed out ‘there is not one overall typology that satisfactorily covers all sorts of uncertainties, but that there are many possible typologies’. In the context of this review, a typology was sought which considered sources of uncertainty and did not unnecessarily ignore any type of uncertainty. The existing van Asselt (2000) typology was chosen over others because of its generic and inclusive consideration of uncertainty. The typology was first introduced in detail in van Asselt (2000) and concisely reviewed in Rotmans and van Asselt (2001) and van Asselt and Rotmans (2002).

At the highest level, two sources of uncertainty exist: uncertainty due to variability and uncertainty due to limited knowledge (Figure 3.2). Van Asselt and Rotmans (2002) presented uncertainty due to variability first as these uncertainties ultimately combine to contribute to uncertainty due to limited knowledge. Environmental management is concerned with the management of inherently variable natural and managed systems. Knowledge about natural change and variability in ecosystems, fluvial systems and hydrologic systems is incomplete and hence contributes to uncertainty due to limited knowledge (Wissmar and Bisson, 2003a). Five distinct subclasses of uncertainty due to variability are proposed: inherent natural randomness, value diversity (socio-political), behavioural diversity, societal randomness and technological surprise. Inherent natural randomness is attributed to ‘the nonlinear, chaotic and unpredictable nature of natural processes’. The natural variability of river systems should be a fundamental consideration in integrated river basin management and restoration; it is reviewed thoroughly in Wissmar and Bisson (2003c). Value diversity, behavioural diversity and societal randomness each contribute to uncertainties in environmental management, particularly through stakeholder negotiations, public support, project funding, policy making and individual perspectives. Technological surprises result from new breakthroughs, which may provide unforeseen benefits and/or bring unforeseen consequences.

Van Asselt and Rotmans (2002) separated seven types of uncertainty due to limited knowledge. Unlike uncertainties due to variability, these are thought to map out along a continuum that reflects the relative degree of uncertainty. At the highest degree of uncertainty are four ‘structural uncertainties’ (van Asselt and Rotmans, 2002):

- **Irreducible ignorance**: ‘We cannot know.’
- **Indeterminacy**: ‘We will never know.’
- **Reducible ignorance**: ‘We do not know what we do not know.’
- **Conflicting evidence**: Knowledge is not fact but interpretation, and interpretations frequently contradict and challenge each other. ‘We don’t know what we know.’
Van Asselt and Rotmans (2002) then proposed a transition into ‘unreliability’ uncertainties of a relatively lesser degree:

**Practically immeasurable:** A lack of data or information is always a reality in studying natural systems. Not only are many natural phenomena incredibly difficult or impossible to measure, all are fundamentally limited by problems of temporal and spatial resolution, up-scaling and averaging (Kavvas, 1999). ‘We know what we don’t know’ (Van Asselt and Rotmans, 2002).

**Lack of Observations and Measurements:** Although in principle this is easy to identify and augment, in practice this is always a factor. Borrowing from van Asselt and Rotmans (2002): ‘could have, should have, would have, but didn’t.’

**Inexactness:** Related to lack of precision, lack of accuracy, measurement and calculation errors. Under Klir and Yuan’s (1995) typology, these are considered ‘fuzziness’ or vagueness.

The van Asselt (2000) typology is both more general and detailed than other typologies such as Klir and Yuan (1995). However, all provide a reasonable means to deal with the first step to understanding uncertainty. Namely, they allow a systematic identification of sources and types of uncertainties that could work in either individual river restoration projects or international policy making on water and environmental management (see also Chapters 1 and 2). In practice, it is recognised that the semantics of uncertainty will always be interpreted differently in different professional contexts (Newson and Clark, see Chapter 14). However, within the context of this chapter, the van Asselt (2000) typology and associated meanings will be used consistently.

### 3.2.3 How do Knowledge and Uncertainty Relate?

The positivist view (Van Asselt and Rotmans, 2002) contends that as knowledge increases, uncertainty decreases. Brookes et al. (1998) made the more restrictive but contradictory generalisation that ‘as knowledge relating to rivers and their floodplains increases, uncertainty is increased rather than decreased.’ So, which is it? In reality, there is no unique relationship between uncertainty and knowledge (Van Asselt and Rotmans, 2002), nor is uncertainty a fixed quantity that will always be reduced by scientific research (Jamieson, 1996). It is a highly contextual relationship dependent on the type of uncertainty (i.e. uncertainty due to lack of knowledge versus variability) and the specific circumstances under consideration. A few...
examples of potential relationships between knowledge and uncertainty using the nomenclature of the van Asslet typology are illustrated in Figure 3.3. Having established the basic terminology of uncertainty, it is possible to discuss the sources of uncertainty within river restoration.

### 3.3 REVISITING RIVER RESTORATION AND UNCERTAINTY

It is difficult to generalise about the importance of uncertainty simply because restoration activities and the restoration community itself are so diverse. The stakeholders who

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**Figure 3.3** Some potential relationships between knowledge and uncertainty through time (Contrary to the argument of the positivist, no unique inverse relationship between uncertainty and knowledge exists.)
initiate river restoration projects include private individuals, non-governmental organisations (NGOs), governmental organisations and various collaborative combinations of the above. The restoration community is also comprised of practitioners, decision makers and scientists. No attempt is made here to list ‘all’ the uncertainties encountered throughout the restoration process as the daunting list would never be comprehensive, and is entirely perspective and project specific. For example, there is little consensus over the meaning of the term ‘river restoration’ with at least 30 different authors proposing different definitions (Lemons and Victor, see Chapter 1; NAP, 2002; Newson, 2002; Sear, 1994; Stockwell, 2000). Similar to Shields et al. (2003), ‘river restoration’ in this book is used as a catch-all term for a variety of management responses and activities used to address perceived problems with rivers (Kondolf, 1996). As a starting point, a generic decision process, which most restoration projects loosely follow, highlighting some of the common sources of uncertainty is mapped out in Table 3.2.

### 3.3.1 Motives for Restoration

Once river restoration projects gain momentum, it is easy to lose sight of why they were originally envisioned (Stewardson and Rutherfurd, see Chapter 5). Here, the motives for restoration are considered to represent more generalised aims than formalised and specific restoration objectives and activities (i.e. the ‘why’ instead of the ‘what’). Eight common types of motives for river restoration (still others exist) are listed below:

1. Ecosystem Restoration
2. Habitat Restoration
3. Flood Control/Defence
4. Floodplain Reconnection
5. Property and Infrastructure Protection (bank stability)
6. Sediment Management
7. Water Quality
8. Aesthetic and Recreational.

Considerable overlap exists between many of the above. For example, floodplain reconnection can be a type of flood control. Habitat restoration and water quality restoration are sometimes considered forms of ecosystem restoration. In another example, water quality restoration could be viewed by some as sediment management or by others as aesthetic or recreational restoration. Thus, a hierarchical organisation of restoration motives would be highly subjective and dependent on individual values and perspectives. This in itself is not necessarily problematic. However, it represents a form of communication uncertainty arising out of value diversity which is often taken for granted. Once the motives (why to do it) for restoration are established, restoration aims fall into place, but more specific objectives (what and how to do it) require careful consideration.

### Table 3.2 Sources of uncertainty in an environmental management decision process structure (Adapted from Chapman & Ward (2002))

<table>
<thead>
<tr>
<th>Stage in Decision Process</th>
<th>Uncertainty About</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor the environment and current operations within the organisation</td>
<td>Completeness, veracity and accuracy of information received, meaning of information, interpretation of implications</td>
</tr>
<tr>
<td>Recognise an issue</td>
<td>Significance of issue, urgency, need for action</td>
</tr>
<tr>
<td>Scope the Decision</td>
<td>Appropriate frame of reference, scope of relevant organisation activities, who is involved, who should be involved, extent of separation from other decision issues</td>
</tr>
<tr>
<td>Determine the performance criteria</td>
<td>Relevant performance criteria, whose criteria, appropriate metrics, appropriate priorities and trade offs between different criteria</td>
</tr>
<tr>
<td>Identify alternative courses of action†</td>
<td>Nature of alternatives available (scope, timing, logistics involved), what is possible, level of detail required, time available to identify alternatives</td>
</tr>
<tr>
<td>Predict the outcomes of courses of action†</td>
<td>Consequences, nature of influencing factors, size of influencing factors, effects and interactions between influencing factors (variability and timing), nature and significance of assumptions made</td>
</tr>
<tr>
<td>Choose a course of action</td>
<td>How to weigh and compare predicted outcomes</td>
</tr>
<tr>
<td>Implement the chosen alternative*</td>
<td>How alternatives will work in practice</td>
</tr>
<tr>
<td>Monitor and review performance‡</td>
<td>What to monitor, how often to monitor, when to take further action</td>
</tr>
</tbody>
</table>

† = Most decision support systems only provide input at these levels; * = The precautionary principle is implemented here; ‡ = Adaptive management starts here and feeds back through the process as necessary.
Many have argued that uncertainty in assessing restoration success arises from inadequate, vague and unclear restoration objectives (Jungwirth et al., 2002; Kondolf, 1995a; Skinner et al., see Chapter 10). Motives may serve well as aims (not necessarily to be achieved by an individual project) but they are insufficient to act as detailed project objectives, which in principle should be achievable. Using restoration motives carelessly as objectives produces unrealistic expectations. For example, in a recent request for proposals to fund community-based river restoration projects by American Rivers and the National Oceanic and Atmospheric Association, applicants were asked to demonstrate that their project: will successfully restore anadromous fish habitat, access to existing anadromous fish habitat, or natural riverine functions; is the correct approach, based on ecological, social, economic, and engineering considerations; will minimise any identifiable short or long term negative impacts to the river system as a result of the project . . .

The problem with requiring an applicant to make such bold statements about individual projects is that it asserts a level of confidence in restoration simply not warranted by current science or practice and creates unrealistic expectations4 (Stewardson and Rutherford, see Chapter 5). Subtly rewording such requirements to account for uncertainty could help recast river restoration in a tone commensurate with our abilities and uncertainties. Interestingly, these objectives are consistent with Clark’s (2002) critical synopsis of Predictive Management as opposed to adaptive management as the current model in river management.

The restoration community has burdened itself with the idea that restoration objectives should be scientifically based (Davis and Slobodkin, 2004). While science surely has an important role in restoration, Davis and Slobodkin (2004) argued that determining restoration objectives is fundamentally a value-based and subjective process. Nothing is seen as inherently wrong with this reality, so long as it is transparently recognised. From an uncertainty perspective, this means that restoration objectives are therefore sources of uncertainty due to variability; namely value diversity, behavioural diversity and societal randomness. For example, the fate of 81 000 hectares of forest land allocated for ecosystem restoration around the city of Chicago, Illinois has pitted two ‘environmental’ groups against each other based on their contrasting notions of ‘what is natural’. The divergent environmental views are essentially split between preservationists, who wish to preserve the forest land planted in the 1800s, and restorationists, who want to restore the pre-settlement (1830s) prairie and savannah (Alario and Brün, 2001). Both evoke emotional arguments, which can be supported on scientific grounds. ‘Which is right?’ is the wrong question to ask of science. Alario and Brün (2001) concluded that the appropriate arena to decide such an issue is a political decision making process.

3.3.2 Notions that Drive Restoration

Underlying motives for river restoration and the eventual specific techniques tried to achieve them are some very basic, yet highly uncertain notions. Since these basic notions are rarely questioned, it is important to highlight how they introduce uncertainty. Notions are also known as ‘Liertbilds’ – or target visions – and have gained widespread acceptance in the restoration literature (Hughes, 1995; Jungwirth et al., 2002; Kern, 1992). Notions, such as those in Table 3.3, that drive restoration strategies are frequently based on societal values and beliefs, or on popular, but by no means certain, scientific paradigms (Davis and Slobodkin, 2004; McDonald et al., 2004; Rhoads et al., 1999).

Falkenmark and Folke (2002) argued that sustainable catchment management must be based on ethical principles. They suggest that management based on scientific principles alone is primarily concerned with ‘doing the thing right’, whereas notions that drive restoration strategies are actually driven by ‘doing the right thing.’ It is a presumption that good ethical practice generally translates into good biological practice (Pister, 2001). Hence notions are vague ideas, perhaps based on scientific knowledge, but primarily supported by ethical beliefs and societal values. The restoration literature is rarely explicit in distinguishing the notions it advocates from the science used to support it. Phillip Williams (personal communication) asserts that ‘rigour’ in restoration planning should start with the development of an explicit conceptual model transparently describing our notions of how the river system functions5. Such a conceptual model should identify both the historical context and the present day limitations (i.e. uncertainties). Wheaton et al. (2004a) argued that numerous conceptual models in the scientific literature already exist and can be borrowed or modified to formulate a site or basin specific conceptual model as the basis for restoration. Yet, Stewardson and Rutherford (see Chapter 5) describe three levels in restoration from which

4This is fundamentally a communication uncertainty resulting from socio-political value diversity (see Figure 3.1).

5In principle, the process of ‘rigour’ in restoration planning still follows the generic environmental management decision process of Table 3.2. In essence what Phillip Williams, a seasoned practitioner, describes is an informal Decision Support System (DSS).
epistemological uncertainties emerge: the validity of the conceptual model; whether the proposed intervention results in the planned geomorphic change; and whether the change is sustainable. They then caution that the validity of the conceptual model is the source of the ‘most uncertainty.’ Returning to Phillip William’s concept of rigour in planning, he argues restoration objectives should be based on an understanding of how the conceptual model interacts and responds to various societal motives (NRC, 1992). Based on specific objectives, a measurable set of indicators and target levels can be selected (Doyle et al., 2000; Levy et al., 2000; Merkle and Kaupenjohann, 2000; Smeets and Weterings, 1999). Finally, a comparison of predicted indicator responses to restoration intervention versus inaction should be used to decide whether restoration is appropriate. Although available science may be used to inform the steps leading up to this decision (Lemons and Victor, see Chapter 1), the decision whether

| Table 3.3 Common motives that guide notions and drive river restoration efforts |
|---------------------------------|---------------------------------|
| Notion                          | Example(s)                      |
| What is Natural?                |                                 |
| Nature is in Equilibrium        | ‘the equilibrium between sediment supply and available transport capacity.’ (Soar & Thorne 2001); ‘landforms can be considered as either a stage in a cycle of erosion or as a system in dynamic equilibrium.’ (Schummm & Lichfty 1965). |
| Nature is in flux               | ‘Restored ecosystems are those in which the rates and types of disturbance do not exceed the capacity of the system to respond to them.’ (Hruby 2003). |
| Nature Constant                 | ‘confidence on global stability; there are no limitations to development’ (Levy et al. 2000). |
| Nature Balanced                 | ‘the environment is forgiving of most shocks, but large perturbations can knock ecological variables into new regions of the landscape.’ (Levy et al. 2000). |
| Nature Ephemeral                | ‘the environment can not safely tolerate human modifications’ (Levy et al. 2000). |
| Nature Resilient                | ‘ecosystems are adaptive, evolutionary, and self organising . . . ecological systems often thrive under conditions of high variability’ (Levy et al. 2000). |
| Physical Integrity              |                                 |
| Physical Integrity              | ‘Physical Integrity for rivers refers to a set of active fluvial processes and landforms wherein channel, floodplains, sediments, and overall spatial configuration maintain a dynamic equilibrium, with adjustments not exceeding limits of change defined by societal values. Rivers possess physical integrity when their processes and forms maintain active connections with each other in the present hydrologic regime.’ (Graf 2001). |
| Alluvial River Attributes       | Several commonly known concepts that govern how alluvial channels work have been compiled into a set of ‘attributes’ for alluvial river integrity (Trush et al. 2000). |
| Ecological Integrity            | Ecological Integrity ‘maintenance of all internal and external processes and attributes interacting with the environment in such a way that the biotic community corresponds to the natural state of the type-specific aquatic habitat, according to the principles of self-regulation, resilience and resistance.’ (Angermeier & Karr 1994). |
| High Biodiversity = Ecological Integrity | Natural systems foster biodiversity and artificial systems are homogenized and dominated by invasive species (Ward et al. 2002, Lister 1998). |
| Morphological Diversity = Biological Diversity | Newson (2002) did not dispute the abundance of evidence supporting the linkages between channel dynamics and biodiversity, but criticises the lack of direct collaboration between geomorphologists and ecologists to substantiate the links in river management: ‘the mantra “morphological diversity = biodiversity” currently remains an act of faith.’ |
| What is Sustainable?            |                                 |
| Sustainability                  | According to Cairns (2003), the notion of sustainability is based on ‘the assumption that humankind has the right to alter the planet so that human life can inhabit Earth indefinitely.’ |
| Geomorphic Sustainability       | ‘sustainability encompasses the notion of self-regulation of spontaneous functions (e.g. sediment deposition, colonisation and succession of vegetation) with minimal intervention and no adverse impact on the future aquatic environment whilst maintaining the functions of the channel demanded by society (flood control, navigation etc.).’ (Sear 1996). |
or not to proceed is ultimately a political one (Alario and Brun, 2001).

### 3.3.3 Approaches to Restoration

Generally, river restoration projects consist of three components: planning, implementation and evaluation. The diversity of approaches available to implement these components rather appropriately reflects the varied types (motives) of restoration projects and physiographic settings they are applied in. Thus, historical and spatial contingencies are contributing to uncertainties due to natural variability (Phillips, 2001). Indeed, a plethora of restoration approaches and strategies has been formalised in both the peer-reviewed and grey literature (Wheaton et al., 2004a). Examples range from generalised approaches for stream restoration (e.g. FISRWG, 1998; Jungwirth et al., 2002; Koehn et al., 2001; NRC, 1992; RRC, 2002) to more specific strategies incorporating: fluvial geomorphology (e.g. Brookes and Sear, 1996; Gilvear, 1999; Kondolf, 2000; Sear, 1994), ecosystem theory (e.g. Richards et al., 2002; Stanford et al., 1996), hydraulic engineering (e.g. Shields, 1996) and detailed design procedures (Miller et al., 2001; Shields et al., 2003; Wheaton et al., 2004b). Most of the approaches have parallels in structure and ideology (Wheaton et al., 2004a).

Popular labels used to describe restoration approaches include holistic, science-based, integrated and multidisciplinary (Hildén, 2000; Jungwirth et al., 2002; Wissmar and Bisson, 2003a). Since most approaches purport or aim to be all of these (Wheaton et al., 2004a), and the converse of each is perceived as negative, there is little value in discriminating approaches on these grounds. However, their components (i.e. planning, implementation and monitoring) can be differentiated using three descriptive metrics: the scale of restoration; form based versus process based; and active versus passive. These metrics can provide insight into the types of uncertainties encountered and expectations placed on restoration projects during planning, implementation and monitoring.

Since the late 1990s, approaches almost unanimously call for catchment scale planning in restoration6. However, confusion arises over whether this means: restore the entire catchment; use watershed assessments to nest reach scale restoration in a catchment context (e.g. Bohn and Kershner, 2002; Brookes and Shields, 1996; Walker et al., 2002) or undertake a range of management and restoration activities across various spatial scales but nested within a catchment context (e.g. Frissell et al., 1993; Roni et al., 2002). Ecosystem degradation has often taken place over many decades or centuries and extends across landscape, catchment and regional scales (Palmer et al., 1997). However, restoring an entire catchment is rarely viable (Brookes and Shields, 1996). Even those who call for ecological restoration of the entire catchment (e.g. Frissell et al., 1993) actually advocate achieving this through a range of targeted activities at various spatial and temporal scales.

Most of the restoration literature also points towards a consensus that a ‘process-based’ approach is superior to a ‘form-based’ one (Wheaton et al., 2004a). Much of the form versus process debate simplifies down to the difficulty and/or appropriateness in selecting an analogue or reference condition. The frequently referenced ‘Lietbilds’ or target visions (Kern, 1992) and the popular Rosgen approach to restoration (Malakoff, 2004; Rosgen, 1996) both rely heavily on analogues. Jungwirth et al. (2002) suggest that at least three methods for selecting analogue or reference conditions exist:

- Select an existing reference site with ‘desirable’ conditions (location substitution).
- Select a historical reference condition for the site of interest on the basis of historical analysis (time for space substitution).
- Create a reference condition on the basis of theoretical models (either conceptual or mathematical).

In referring to these analogue conditions, is the desired form or the desired process then mimicked? This seems to be the point of departure for opinions within the restoration literature. Some argue that any mimicking of reference conditions is a form-based approach (McDonald et al., 2004). Others suggest that as long as ample consideration of sustaining processes and desired functions is made, the use of analogue conditions can be process based (Palmer et al., 1997; Wheaton et al., 2004a). Although exact interpretations are themselves uncertain and will continue to spur debate over semantics (conflicting evidence uncertainties), most concur that consideration of sustaining processes is fundamental (Wheaton et al., 2004c).

Fundamental methodological disagreements arise in the restoration literature with respect to passive versus active approaches to river restoration (Edmonds et al., 2003; Wissmar and Beschta, 1998). Here, active approaches are referred to as those which involve direct structural modification to the river, its floodplain or infrastructure therein (e.g. channel realignment, levee removal, instream habitat structures). By contrast, passive approaches are those that ‘rely on the river to do the work’ (e.g. flow augmentation, runoff substitution).

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6 See also Table 3.1.
River Restoration: Managing the Uncertainty in Restoring Physical Habitat

change in landuse, managing nonpoint sources of pollution, buffer strips) (Wissmar and Beschta, 1998). Using a ‘process-based’ approach can make intuitive sense for passive approaches to restoration. For example, providing flow releases from a reservoir to mimic a natural hydrograph and encourage mobilisation and reorganisation of sediments, may restore the processes that ‘allow the river to do the work’ (Stanford et al., 1996; Trush et al., 2000). However, active approaches are considered favourable when natural or passive recovery may take an unacceptably long time (Montgomery and Bolton, 2003). The choice of a passive versus active approach will depend very much on the specific social, political, economic and environmental contingencies of individual river basins (Wissmar et al., 2003), as well as the extent to which initial conditions matter (Phillips, 2002). Wheaton et al. (2004b) suggested that in some spawning habitat rehabilitation contexts, it may be appropriate to employ passive approaches like gravel augmentation in conjunction with active approaches like spawning bed enhancement to kickstart recovery. Ultimately, all these choices are fuelled by an uncertain conceptual understanding of the system and logical ideas about how best to proceed with restoration. Given these inherent uncertainties, adaptive management is well suited to allow practitioners and decision makers to make a decision in the face of uncertainty, and to adjust that decision as time and new challenges unfold (Clark, 2002; Lister, 1998).

3.4 PHILOSOPHIES OF UNCERTAINTY

So, is all this uncertainty bad? By this point, it should be clear that uncertainty in river restoration is ubiquitous. However, different segments of society view uncertainty in very different ways, depending on the context (Lemons and Victor, see Chapter 1). As already mentioned, ordinary people are quite comfortable with the uncertainties of life in an intuitive and nonexplicit sense (Anderson et al., 2003; Pollack, 2003). However, uncertainty in policy and science, especially as reported in the media (Riebeek, 2002), are very different contexts. The choice of what to do about uncertainty is a philosophical question. Five potential philosophical treatments of uncertainty are proposed in Figure 3.4. Each of these philosophies is reviewed in the remaining sections and linked to current attitudes within different segments of the river restoration community.

3.4.1 Ignore Uncertainty

It has already been argued here that the restoration community has tended to passively ignore uncertainty and possible explanations as to why this may be the case proposed. For example, managers, policy and decision makers are fearful of admitting uncertainties, as this may be seen as a sign of weakness (Clark, 2002; Levy et al., 2000). Now that public support exists for river restoration, so too does the expectation that the problems restoration addresses are well understood. Indeed, these problems are reasonably well understood, but numerous uncertainties remain. Aside from basic, and potentially reducible,
communication uncertainties the significance of the vast majority of uncertainties associated with restoration are simply not known. Admittedly, specific examples of uncertainties in restoration may indeed be insignificant. However, to assume insignificance on both ethical and technical grounds without first establishing it might ultimately backfire on the restoration community.

3.4.2 Eliminate Uncertainty

The positivist view of the world has fuelled much scientific progress on the notion that uncertainty is bad, absolute knowledge is good, and it is necessary to strive to eliminate uncertainty (Klir and Yuan, 1995; Priddy, 1999; Van Asselt and Rotmans, 2002). This fosters an unnecessarily narrow view of uncertainty as subsumed entirely within the realm of science. Van Asselt and Rotmans (2002) argued this view grew out of the ‘Enlightenment Period’ or ‘Age of Reason’ of the 17th and 18th centuries where science was to be ‘the provider of certainty.’ Further to this endeavour, many scientists assumed that unique causal laws exist for all natural phenomena and ignored the possibilities of indeterminacy and equifinality (Wilson, 2001). Many physical scientists still subscribe to a ‘positivist’ view (Harman, 1998), implicitly associating uncertainty with an inability to quantify the environment, rather than acknowledging a limited understanding about the environment itself (Klir and Yuan, 1995).

Whether specific types of uncertainty can be eliminated depends on an individual’s interpretation of semantics. Under the holistic view of uncertainty advocated in this chapter uncertainty cannot be completely eliminated. Pollack (2003) suggests that ‘uncertainty is always with us and can never be fully eliminated’. Other authors (e.g. Knight, 1921) suggest that some types of uncertainty can be transformed into related concepts (e.g. error, expectation, reliability, risk) with the help of mathematical constructs and knowledge gained from historical inference. Through this transformation, uncertainty of a specific type (i.e. uncertainty for which a valid basis for classification exists) in a sense might be ‘eliminated.’ Such a transformation represents an improved understanding of uncertainty but does not truly ‘eliminate’ it.

With technological progress has come the expectation of greater predictive power. Priddy (1999) suggested, ‘the strictest standard of truth in science is that of predictability.’ Although intuitively no one expects prediction to be completely free of uncertainty, the notion that uncertainty can be eliminated is latent in the mainstream media (Riebeek, 2002). Pollack (2003) argues that scientists are accustomed to dealing with uncertainty explicitly, but the general public’s familiarity with uncertainty is implicit and often confused. Jamieson (1996) suggests that, particularly with respect to decisions about increased environmental protections, the ‘rhetorical role of uncertainty claims’ are used to suggest no action should be taken until uncertainty is eliminated. Hence, it is concluded that attempts to eliminate uncertainty are misleading and founded on ignorance of the principles of uncertainty.

3.4.3 Reduce Uncertainty

A more pragmatic view of uncertainty seeks to reduce, rather than eliminate, those specific elements that are perceived as problematic (Klir and Yuan, 1995). This approach to uncertainty is represented diagrammatically in Figure 3.4. Notice that with regards to reducing uncertainty, the key questions are, in order: can it be quantified, is it significant and can it be constrained? So long as the answer is ‘yes’ to all these questions, uncertainty might be reduced. However, if the opposite is true, uncertainty is simply ignored. To move beyond uncertainty as an ambiguous buzzword that will forever plague scientists and decision makers, a broader view of uncertainty as information is appropriate (Newson and Clark, see Chapter 14).

3.4.4 Cope with Uncertainty

Coping or living with uncertainty represents a more proactive view of dealing with uncertainty than elimination or reduction. This approach recognises that, regardless of the significance of uncertainty and our ability/inability to quantify or constrain it, we are always forced to cope with it. Especially within the hydrologic and atmospheric modelling literature, uncertainty is actively recognised and specific methods to cope with it are continually being proposed (e.g. Beven, 1996a; Beven, 1996b; Osiddle et al., 2003; Werritty, 2002).

3.4.5 Embrace Uncertainty

Despite the advantages of efforts to cope with or reduce uncertainty over eliminating it, all the preceding still fundamentally view uncertainty as negative. Several authors have departed from this view towards a more progressive view of embracing uncertainty (Johnson and Brown, 2001; Newson and Clark, see Chapter 14). One of the earlier proponents of this view appears to be Holling (1978), who argued:

‘while efforts to reduce uncertainty are admirable . . . if not accompanied by an equal effort to design for uncertainty and obtain benefits from the unexpected, the best of predictive models will only lead to larger
problems arising more quickly and more often’ (in: Levy et al., 2000).

K hilar and Yuan (1995) considered uncertainty in modelling as ‘an important commodity . . . , which can be traded for gains in the other essential characteristics of models.’ Others have suggested that recognising that not all uncertainty is bad will be increasingly important to decision makers who are forced to make decisions in the face of uncertainty (Clark and Richards, 2002; Pollack, 2003). Especially in long term policy analysis (the next 20–100 years) decision makers are faced with what Lempert et al. (2003) referred to as ‘deep uncertainty.’ Johnson and Brown (2001) argued that incorporating uncertainty into restoration design allows practitioners to consider multiple causes and hypothesised fixes; thereby reducing the potential for project failure. It has been argued here that uncertainty is not necessarily bad, but ignorance of it can foster unrealistic expectations. Chapman and Ward (2002) argued that uncertainty is not just as a risk, but also an opportunity. Uncertainty due to natural variability, in say flow regime, can be a particularly good thing, for example by promoting habitat heterogeneity and biodiversity (Clifford et al., see Chapter 7; Montgomery and Bolton, 2003).

In Figure 3.5, the notions of embracing uncertainty are synthesised in the context of the van Asselt (2000) typology. This approach embraces uncertainty as information and its potential for helping avoid risks, or embracing unforeseen opportunities. Notice that the uncertainties are not treated uniformly, but instead are segregated by source (i.e. due to limited knowledge or due to variability) and type. Anderson et al. (2003) note that environmental management problems are so diverse that a single approach is unlikely to be appropriate for all. Thus, Chamberlin’s (1890) idea of multiple working hypotheses is emerging in environmental management through advocating pluralistic approaches (e.g. Lempert et al., 2003; Van Asselt and Rotmans, 2002).

The embracing uncertainty framework proposed here emphasises this point by structuring a range of questions and possible management decisions based on the specific uncertainties at hand. In the spirit of ‘sustainable uncertainty’ as proposed by Newson and Clark (see Chapter 14), this is not at all a rigid framework but instead a loose and adaptive guide built around an uncertainty typology. Unlike the four other philosophical treatments of uncertainty, this allows the restoration scientist, practitioner or decision maker to:

• explore the potential significance (both in terms of unforeseen consequences and welcome surprises) or insignificance of uncertainties;
• effectively communicate uncertainties;
• eventually make adaptive, but transparent, decisions in the face of uncertainty.

3.5 CONCLUSION

In this chapter a very broad picture of uncertainty in river restoration and environmental management has been painted. This was done to unravel the ambiguities around the notion of ‘certainty’ in restoration and recast uncertainty as useful information. In fact, the arguments and evidence presented challenge the view of scientific deterministic ‘certainty’ and societal beliefs that certainty is necessary in restoration. A typology for discriminating uncertainty was reviewed that can be used to separate uncertainties that can lead to unforeseen and undesirable consequences from uncertainties that lead to potentially welcome surprises. Many of the uncertainties surrounding restoration motives, notions and approaches are most seriously manifested as communication uncertainties. That is, instead of being expressed simply as uncertainties due to limited knowledge, they are ignored and miscommunicated through the restoration process in a manner that prevents transparent decision making. The significance of the plethora of other uncertainties alluded to is largely situation-specific and, to date, unexplored.

Five philosophical strategies for dealing with uncertainty ranging from the status quo of ignoring uncertainty to the advocated embracing uncertainty were reviewed. Traditional scientific research has focused on a narrow class of uncertainties and adopted ‘eliminate’ and ‘reduce’ uncertainty philosophies. It is argued that it is unethical to assume that uncertainty is insignificant. There is an increasing recognition in environmental management that ethical and social dimensions are the primary drivers, with scientific and technical dimensions playing a secondary role (Falkenmark and Folke, 2002; Lister, 1998). Thus, an emerging challenge which the restoration community is faced with is combining these dimensions to ‘do the right thing right.’ Out of the decision making arena has emerged the pragmatic view of coping with uncertainty. However, from the suggestions and examples in the more general environmental management literature, it is concluded that embracing uncertainty could also help transcend the scientific research and decision making boundaries in river restoration.

8 Recall the development of notions in Section 3.3.2, and the distinction of Falkenmark and Folke (2002) between technical concerns (e.g. ‘doing the thing right’) and ethical concerns (e.g. ‘doing the right thing’).
Figure 3.5 Framework for embracing uncertainty in the decision making process (This framework relies on the Van Asselt (2000) typology of uncertainty.)
REFERENCES


