

Review of River Restoration Motives and Objectives

by Joseph M. Wheaton

©2005

Note:

This condensed review of common river restoration motives and objectives is a culmination of unpublished excerpts and omissions from my PhD literature review and a book chapter. Although, the level of detail provided below was deemed unnecessary for the abovementioned manuscripts, it is recognized that this material may indeed be helpful to others doing similar reviews. As such, I am providing this unedited document via my web site. I reserve the copyrights to all figures, tables and intellectual property contained herein (unless otherwise noted). If you wish to cite ideas or works mentioned in this document, I encourage you to pull the original papers (full bibliography provided). Alternatively you will eventually be able to cite Wheaton *et al.* (In Review) or if you would like to cite this unpublished document, the following will suffice:

Wheaton JM. 2005. Review of River Restoration Motives and Objectives. Unpublished Review, Southampton, U.K., 12 pp.

Motives for River Restoration: Why is it Done?

Nine common types of motives for river restoration are briefly reviewed. Motives represent more generalized aims than formalized and specific restoration objectives. Considerable overlap exists between types of restoration motives. This is partly because river restoration projects frequently attempt to address multiple objectives simultaneously. As an example, the Skjern River Restoration Project in Denmark was intended to concurrently a) restore meandering and natural dynamics; b) improve conditions for flora and fauna; c) ensure high water quality in the river system and the Fjord; and d) improve the basis for outdoor leisure (Riber, 2000). Hence the 'types' of restoration motives outlined below provide some common and convenient headings, but should not be used as a strict classification for project types. These motives include ecosystem restoration, habitat restoration, flood control, floodplain reconnection, bank protection, sediment management, water quality, aesthetics and recreation. Comparison of these overlapping motives suggests that they may be arranged hierarchically. For example, floodplain reconnection is a type of flood control and habitat restoration and water quality restoration are types of ecosystem restoration. However, because water quality restoration could also be viewed as sediment management and/or aesthetic restoration, a hierarchal organization becomes complex and less meaningful. It is precisely these reasons that broad generalizations about river restoration are difficult to make.

Ecosystem Restoration

Ecosystem restoration is motivated by the degraded states of present day ecosystems. River restoration is only one aspect of ecosystem restoration programmes, which might also include preservation of existing in-tact areas, re-establishing connectivity between key habitats and landuse changes (Frissell et al., 1993). Ecosystem restoration is sometimes touted as superior to other types of restoration under a veil of pseudo-scientific claims of 'holism' and 'sustainability' (Fitzsimmons, 1996). In concept ecosystem restoration shows promise, but practice and policy are struggling with a steep learning curve. In the 1990s alone, the CALFED Bay-Delta Program and Anadromous Fish Restoration Program of the US Fish and Wildlife Service spent US\$ 394 and 284 million respectively on parallel ecosystem restoration projects for the Sacramento-San Joaquin River System, California (Kondolf, 2000). Despite the influx of cash into Calfed, Kondolf (2000) argues that the more or less

equitable allocation of these funds has led to piecemeal, small-scale projects spread over a 160,000 km² catchment with questionable ecosystem-wide benefits. He goes on to suggest that it may be wiser to focus efforts more intensely on intact sub-catchments. The CALFED project is the second largest ecosystem restoration program in the world, behind the Florida Everglades Restoration Program (with a USD 12 to 15 billion price tag). Whereas catchments make for easily definable management units, ecosystem boundaries are rather vague (Ricklefs, 1987). Fitzsimmons (1996) argues that spatial boundaries of ecosystems are nothing more than a mental construct that grew out of a loose scientific conceptual paradigm never intended to be a basis for resource management and land use planning. As such, catchments may be more reasonable manage units to base ecosystem restoration around. Montgomery et al. (1995) recommend a framework of watershed analysis that establishes linkages between physical and biological resources at a landscape scale, which can be used to prioritize ecosystem restoration programmes (Figure 1). Ecological restoration may also incorporate concepts of indicator or keystone species (Willson and Halupka, 1995). Doing so allows ecosystem restoration to focus on those species whose needs are similar to and reflect the needs of a broader group of species. Willson and Halupka (1995) suggest that the abundance of salmonids, for example, is an indicator of ecosystem health in both aquatic and terrestrial ecosystems. A more pessimistic view of the dominance of fisheries in ecosystem restoration efforts might be concluded from economic benefits alone. Omerod (2003) argues, 'By any measure, fishes are among the world's most important natural resources. Annual exploitation from wild populations exceeds 90 million tonnes, and fish supply over 15% of global protein needs as part of total annual trade exceeding \$US 55 billion.'

Habitat Restoration

Habitat restoration is based on the assumption that if adequate physical habitat is available to support flora and/or fauna, ecosystems, than healthy populations should follow. In other words, habitat restoration is undertaken when habitat quality and/or availability is identified as a factor limiting productivity (Everest and Sedell, 1984). Habitat restoration can be intended to benefit entire ecosystems or limited to specific species and even specific lifestages (e.g. spawning or rearing for fish). Recognition of the importance of physical habitat and its dependence on hydrogeomorphic processes is well established (Maddock, 1999; Smith et al., 2001). Recent techniques for assessment and classification of physical habitat have underscored the interconnectivity of processes responsible for creating and maintaining physical habitat across multiple spatial and temporal scales (Maddock, 1999; Newson *et al.*, 1998; Thomson *et al.*, 2001). Efforts to improve instream habitats for salmonids date back to the 1930s when the USDA Forest service started undertaking 'stream improvement' with the intent of increasing salmonid production (Everest and Sedell, 1984). In-channel habitat restoration is most frequently done for fish and to a lesser extent macroinvertebrates and other fauna (Muotka et al., 2002). Riparian habitat restoration efforts extend out of the channel and both flora and fauna. Brooks *et al.* (1996) divide the most common forms of habitat enhancement into instream structures, modification of substrate and devices which provide cover; and speculate that instream structures intended to modify the flow are probably the most widely used. Wheaton *et al.* (2004b) segregated spawning habitat rehabilitation into similar subdivisions: hydraulic structures, spawning bed enhancement and gravel augmentation.

Habitat restoration of specific species is sometimes criticized in comparison to broader ecosystem approaches (Brookes *et al.*, 1996). In a fairly comprehensive review of habitat management for salmonids, Hendry *et al.* (2003) divide management activities into three separate but interrelated areas: water quality, water quantity and physical structure. Wheaton *et al.* (2004a; 2004b) note that habitat enhancement is generally focused on improving physical structure, but may be ineffective in the long-term if water quality and quantity are not actively addressed as well. Gore (1985) suggests that restoration of benthic macroinvertebrates should be a precursor to restoring habitat for fish as they constitute much

of the food supply for fish. Streams channelised for timber floating in Finland are now being restored to increase substrate heterogeneity, which is hoped to increase leaf litter retention, support higher abundances of detritivorous invertebrates and in turn support healthier salmonid communities (Laasonen et al., 1998). In the same Finnish streams, Muotka et al. (2002) addressed the long-term recovery of benthic macroinvertebrates in relationship to 'single-goal' (i.e. salmonid habitat) restorations. They noted that although stream communities have high resilience to disturbances, habitat restoration is an exceptional type of disturbance that in the first years following restoration produces erratic and unpredictable responses in macroinvertebrate communities. They concluded that benthic macroinvertebrates show high potential for long-term recovery to habitat restoration, but that it was premature to conclude whether benthic biodiversity increases persist. The National Research Council (1992) cautioned that habitat restoration for specific species may be at the expense of other species such as beaver. However, Wheaton et al. (2004b) argue that recovery of socially and economically important fish is a political and funding reality for agencies, practitioners and river managers and is now commonly required for dam re-licensing (e.g. FERC 1998). Further, Shields *et al.* (In Press) contend that ecological recovery may be triggered by simply increasing availability of limiting instream habitat features.

Flood Control

Increasingly flood control projects are intended to dually function as restoration projects (Brookes and Shields, 1996). Traditional flood control efforts based on modern hydraulic theory were invariably intended to provide flood protection through increased channel capacity and conveyance ability (Mount, 1995). In Europe, embankments for flood control purposes were being employed as early as the 11th century and widespread manipulation of major rivers was apparent by the 17th century (Petts, 1998). Past flood control schemes have frequently failed to provide promised flood control as compounding effects of urbanization, encroachment into the floodplain, climate change and poor landuse policies have grown (Ganoulis, 2003; Jungwirth *et al.*, 2002). For example, flood control levees have been shown to actually increase flood stages in many rivers (Mount, 1995; Sparks, 1995). Popular examples of flood control projects intended to meet restoration motives are floodplain reconnection and levee modification. The most typical levee modifications include levee breaching (e.g. Cosumnes River, CA Florsheim and Mount, 2002), set back levees (Fischer, 1994) and levee removal in conjunction with land retirement. Whereas channelised rivers typically have homogenized, trapezoidal channels with large levees, set back levees can be smaller and allow multi-stage channels with greater floodplain connectivity (Mount, 1995) On the Napa River, California, for example, local residents voted against three proposals by the U.S. Army Corps of Engineers for traditional flood control projects in favour of a "Living River Strategy." Over 263 hectares of floodplain and tidal marsh along a tidally influenced reach of the Napa River are now reconnected due to a combination of levee removals, set-back levees and a multi-stage channel (Neary et al., 2001). (Bravard *et al.*, 1999; Fischer, 1994) In a comprehensive review of the status and dismal expected future trends of floodplains, Tockner and Stanford (2002) argue that floodplains are 'natural flood control structures and they should be used that way.'

Floodplain Reconnection

Floodplain reconnection is starting to be undertaken on its own geomorphic and ecological merits as opposed to solely under the umbrella of a flood control effort (Gilvear and Winterbottom, 1998; Holmes, 1998). Through chanelisation, straightening, levee construction, land reclamation and anthropogenic-induced channel incision, many rivers are now disconnected from their floodplains (Buijse *et al.*, 2002; Tockner and Stanford, 2002). Hydrologic and geomorphic connectivity between inchannel and floodplain habitats has been shown to be critical to maintaining biodiversity, productivity, attenuating flood waves,

reducing nutrient loads, improving water quality, trapping sediment on the floodplain and promoting higher groundwater recharge rates (Holmes, 1998). In particular, the presence of a flood disturbance regime leads to variably aged floodplain patches (measured both in terms of sediment residence time and vegetation age) and dynamic renewal of organic and inorganic matter to the floodplain environment (Hughes, 1997; Richards et al., 2002). Floodplain reconnection generally is achieved by physical reconnection (e.g. levee removal, channel realignment, raise channel bed or lower adjacent floodplain surface) and/or flow regime adjustments to induce inundation of the floodplain (e.g. modified flow release schedule, pulse flows or dam removal). Compared to other restoration motives, floodplain reconnection has been less common; due in part to more complicated land ownership, flooding implications and regulatory requirements induced by the geographic extent of floodplains (Brookes, 1999). However, large scale floodplain reconnection projects are now underway in Europe (Petts, 1998), the UK (Holmes, 1998), the US and elsewhere (Buijse *et al.*, 2002).

Bank Protection

Bank protection is mentioned here loosely as a form of restoration because practitioners are increasingly calling such projects river restoration (e.g. Johnson and Brown, 2001). The basic idea behind bank protection is to protect stream banks by controlling or eliminating bank erosion. The reality is most bank protection projects are still intended to protect property, roads and structural improvements that have encroached into the floodplain beyond or dangerously close to these eroding banks (Kondolf, 1996). Bravard et al. (1999) astutely point out that although river engineers have opted for 'softer' alternatives to riprap, they have not truly adopted a geomorphic engineering approach. They go on to say that the 'natural' geomorphic processes of bank erosion and sediment transport are still seen as problematic by many engineers and something which needs to be controlled and stabilized. Localized hard bank protection efforts often transfer bank stability problems downstream to the next bend (Kondolf, 1996). Especially in incised river systems, bank erosion can be accelerated well beyond natural rates (Shields et al., 1995a). For example, in certain parts of the Midwestern United States, bank material constitutes as much as 80% of the total sediment eroded from incising channel and can have significant ecological impacts (Shields et al., 1995b; Simon et al., 2000). However, Simon and Darby (2002) note that restoration efforts should address the causes of incision (i.e. processes) often at larger scales than the symptoms such as bank erosion. Irregardless, when excessive bank erosion leads to habitat degradation, bank protection is sometimes seen as a solution. One of the ironic and frequent misapplications of bank protection is in channels 'restored' to a meandering planform. Meandering rivers, by definition, erode their outside banks, deposit sediment on point bars and migrate within their floodplains (Knighton, 1998). Yet, practitioners insist on keeping their projects in place and employ the use of 'natural bank revetments' on outside meander bends (e.g. Rosgen, 1996). A restoration project on Whitmarsh Run, Maryland used extensive riprap to prevent channel migration and bank erosion, but the project subsequently failed due to aggradation and the inability of the reach to transfer sediment delivered from upstream (Soar and Thorne, 2001).

Sediment Management

Sediment management has long been a consideration in river engineering, and more recently river restoration. Fluvial geomorphology is the study of the sources, fluxes and storage of sediments (Newson and Sear, 1993). Engineering and geomorphic perspectives on sediment management fundamentally differ in the time-scales they consider these fluxes over (Annable, 1999; Sear et al., 2003). Fluvial geomorphologists have argued convincingly that the short temporal and spatial scales that river engineering tends to focus on are inadequate for most sediment management applications including river restoration (Newson, 2002; Sear, 1994). Brooks and Brierley (2004) point out that restoration proposals often presume that problems associated with anthropogenic-induced channel aggradation and degradation are reversible.

They argue that the geomorphic recovery potential is constrained by substantial time lags and non-linearities in channel response and the sometimes permanent alteration of some sources of sediment. Sear (1996) separates sediment management responses into source control, trapping and reach-scale restoration designs that reinstate morphologies that encourage selective deposition (trapping) or throughput (routing). Table 1 summarizes some of the more common sediment management techniques (Sear et al., 2003). Various technical documents review these treatments from both engineering (e.g. Hoey et al., 1998), fisheries (NOAA, 2003) and geomorphic perspectives (Clark et al., 1997; Sear et al., 2003). Although sediment management is not always an explicit restoration motive, basic considerations of the sediment system should be considered in all river restoration projects (Sear, 1994).

Water Quality

Particularly in urban and large lowland rivers, water quality motives for restoration are paramount (Ellis, 1996?). In developed nations, point-sources of pollution (e.g. sewage and industrial discharges) have largely been harnessed; whereas non-point sources (e.g. urban and agricultural runoff) remain major problems (USEPA, 1989). Using salmonids as an example, Hendry et al. (2003) summarize the water quality requirements as:

- ‘Well oxygenated water with natural nutrient content and temperature range, typically of upland or spring origin.’
- ‘Suitably buffered water to prevent sustained variations in pH outside of the normal range.’
- ‘Water devoid of significant chemical contaminants.’
- ‘A naturally low silt/fines content within the normal sediment matrix.’

Although water quality requirements will vary from organism to organism, these provide a basic reference point for conceptualization. Actually managing rivers for water quality is difficult due in part to uncertainties in both water quality standards and measurements (Mujumdar and Sasikumar, 2002). In the United States, the Environmental Protection Agency accounts for uncertainty in assessment through requiring applying a somewhat arbitrary margin of safety (MOS) to estimates of total maximum daily load (TMDL). Reckhow (2003) argues that the EPA should abandon the use of MOS in favour of a more detailed uncertainty analysis of TMDL. Buffer strips have been shown to be quite effective at reducing sediment and nutrient loads (Jorgensen et al., 2000). Herricks (1996) outlines further detailed water quality considerations for river restoration projects.

Aesthetic & Recreation

Aesthetics and recreation motives for restoration are not central themes in the scientific restoration literature as they are rather subjective societal values. However, restoration projects that provide aesthetic and recreational benefits, may be central to achieving stakeholder support (Pfadenhauer, 2001) and have been undertaken throughout the world (Brookes and Sear, 1996). From a political perspective, providing aesthetic and recreational improvements may mean the difference between a project being funded or rejected, regardless of its scientific merits. One could argue that the magnitude of public support for river restoration in the United States is due to a rapidly growing sport-fishing industry and the values people place on fish (Fedler and Ditton, 2000). Perhaps the most important aspects of incorporating aesthetic and recreation motives into a restoration project are stakeholder involvement in the decision making process and educational outreach to explain how such motives can merge with more technical objectives of restoration proposals (Boon, 1998; Boshard *et al.*, 2002; Pfadenhauer, 2001; Rhoads *et al.*, 1999). Lane (In Press) argue that incorporating societal goals is crucial to the restoration process but that comprises should be expected. An adequate understanding and expectation of the hydrogeomorphic and ecological response to restoration activities is critical to communicating how aesthetics and recreational benefits may change through time. For example, although a riffle restoration project may provide easy access for children and fisherman to a river (RRC, 2002), it may be necessary to

restrict access during critical lifestages for fish (i.e. spawning and incubation). Similarly if a project is to provide perceived aesthetic improvements, some consideration of the dynamic nature of the forms providing the aesthetic improvements should be communicated.

From Restoration Motives to Objectives

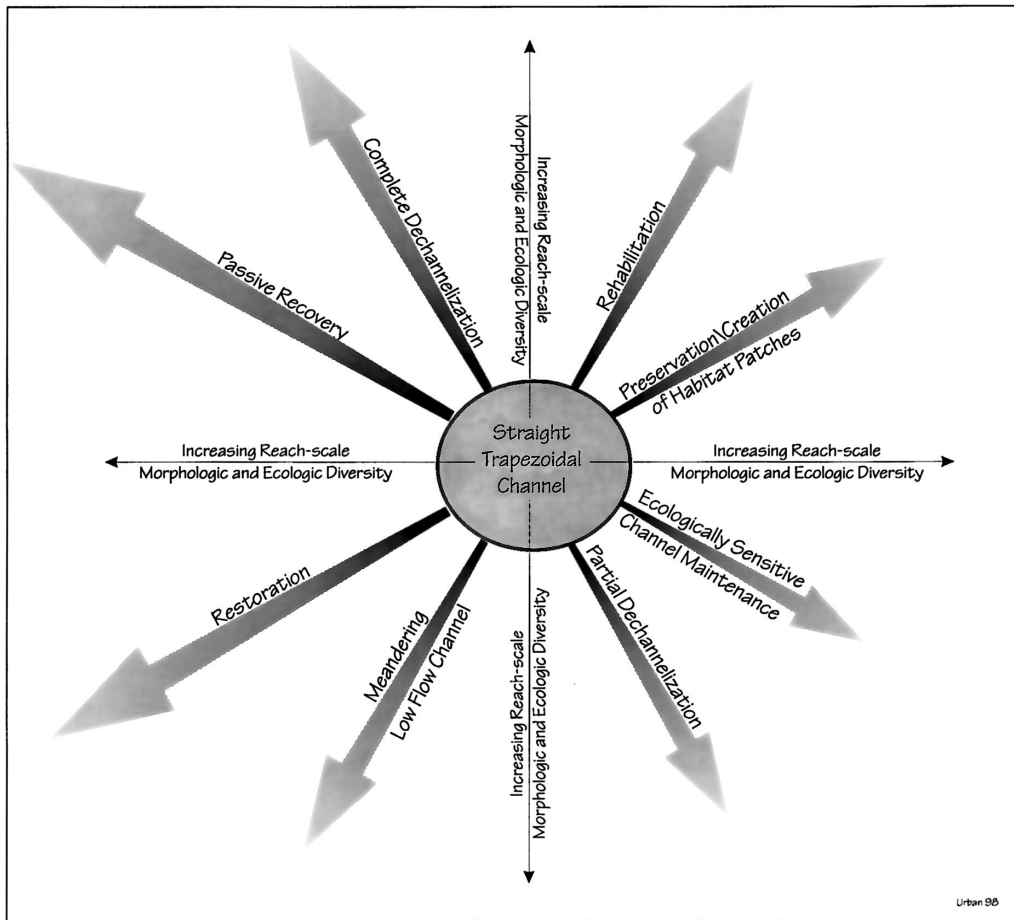
Once the motives for restoration are established, restoration aims fall into place but more specific objectives require careful consideration. Many have argued that difficulties in assessing restoration success arise from inadequate, vague and unclear restoration objectives (Jungwirth et al., 2002). That is, the motives for river restoration may provide good enough detail for some generalized aims; but they are insufficient as detailed restoration objectives. Further, the expectations from funding agencies of individual restoration projects are often lofty and unrealistic. For example, in a recent request for proposals to fund community-based river restoration projects by American Rivers and the National Oceanic and Atmospheric Association¹ applicants are asked to demonstrate that their project:

1. 'will successfully restore anadromous fish habitat, access to existing anadromous fish habitat, or natural riverine functions;'
2. 'is the correct approach, based on ecological, social, economic, and engineering considerations;'
3. 'will minimize any identifiable short- or long-term negative impacts to the river system as a result of the project;'
4. 'has had community involvement in project decision making and may have community involvement in the implementation;'
5. 'will have the potential for public outreach and education.'

Although, requirements four and five are reasonable and attainable, requirements one through three are prime examples of the unrealistic expectations placed on river restoration and failure to recognize the importance of uncertainty. These are reasonable aims, but no practitioner, without lying, can claim with absolute certainty that they 'will successfully restore' or 'will minimize *any* identifiable... negative impacts.' The problem with requiring an applicant to make such bold statements is that it asserts a level of confidence in restoration simply not warranted by current science or practise and creates expectations restoration is unlikely to achieve. Subtly rewording such requirements to account for uncertainty could help recast river restoration to the public in a more modest tone.

Phillip Williams (p. comm.) asserts that rigour in restoration planning should start with development of an explicit conceptual model of how the river system functions (Figure 2). Such a conceptual model should identify both the historical context and the present day limitations. Wheaton et al. (2004b) argue 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. Restoration objectives should then be formed based on an understanding of how the conceptual model interacts and responds to various societal motives (NRC, 1992). Based on the specific objectives, a measurable set of indicators and target levels are 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 upto this decision, the interpretations and decision whether or not to proceed with restoration is ultimately a political one (Alario and Brun, 2001).

¹ Applications and information available from American Rivers on the web: at <http://www.amrivers.org> or details at: <http://www.amrivers.org/index.php?module=HyperContent&func=display&cid=797>.



Urban 98

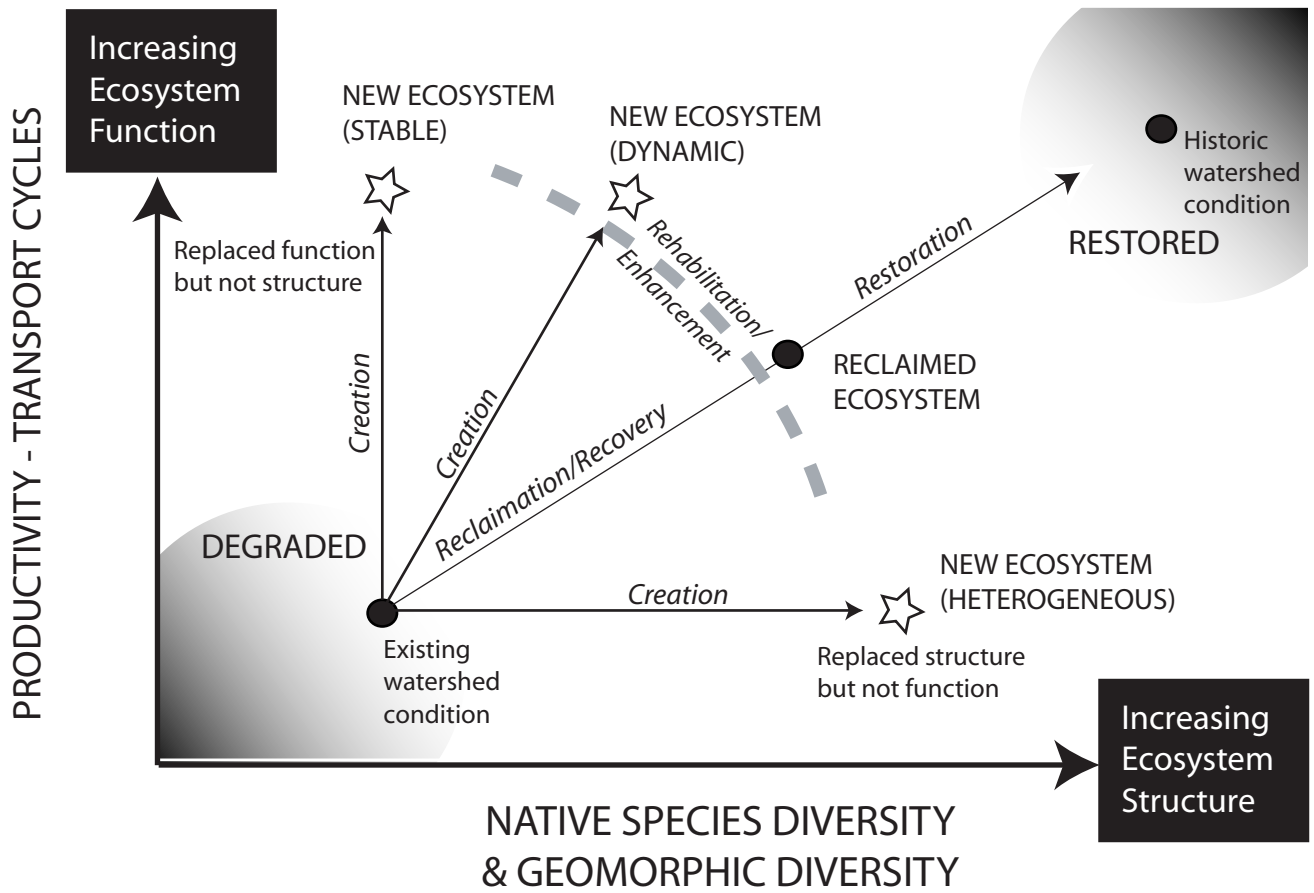
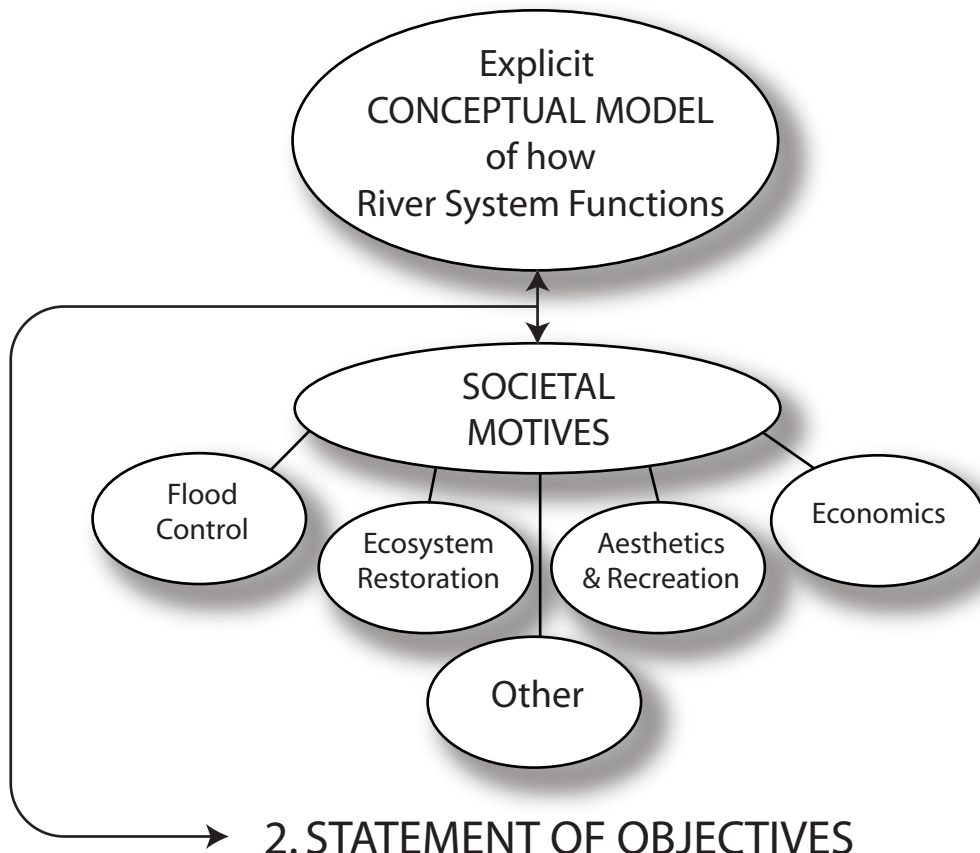


Figure 1- Conceptualizations of Ecosystem Restoration and related activities. Adapted from from NAP (2002) and Stockwell (2000).

1. DEVELOPMENT OF CONCEPTUAL MODEL



2. STATEMENT OF OBJECTIVES

3. SELECT MEASURABLE SET OF INDICATORS

Some will be quantitative, some will be qualitative.

4. SELECT TARGET LEVELS FOR INDICATORS

5. PREDICTIONS & COMPARISONS

Before proceeding with intervention, need to be able to show potential impacts of intervention versus inaction.

Figure 2- Steps to promote rigor in pre-restoration intervention. (Ideas are those of Philip Williams (personal communication)).

Procedure:	Description
Erosion Control	Construction or reinstatement of measures to prevent bed scour and/or bank erosion where flood defence or land drainage assets are threatened.
Gravel Trap	Construction or cleaning out of structure designed to catch the coarse fraction of the sediment load and prevent sediment transfer to a flood control project downstream.
Re-alignment	Relocating and straightening the channel to increase conveyance capacity and/or facilitate development of the floodplain. Usually accompanied by re-grading and re-sectioning.
Re-grade	Large-scale (often grant-aided capital works) modification of channel slope and long-profile based on regime theory or 1-dimensional hydraulic modelling (e.g. HEC-RAS).
Re-section	Imposing or returning channel cross-section to design configuration, including re-profiling bed and banks. Usually based on regime theory or 1-dimensional hydraulic modelling.
Dredge	Removal of sediment that has accumulated in the channel to a degree that is considered (by Environment Agency staff and local stakeholders) to compromise flood defence or land drainage functions of the channel.
De-silt	Removal of sediment (usually silt) that has accumulated in the channel within the last three years (often performed in conjunction with aquatic weed clearance).
Shoal removal	Removal of individual shoals (usually formed by gravel) where these are considered to compromise the flood control function of the channel.

Table 1- Engineering and Maintenance procedures adopted for sediment management (reproduced from Sear et al. 2003)

References

- Alario M and Brun M. 2001. Uncertainty and Controversy in the Science and Ethics of Environmental Policy Making. *Theory and Science*. 2(1): Available on the web: <http://theoryandscience.icaap.org/content/vol002.001/02alariobrun.html>.
- Annable WK. 1999. On the Design of Natural Channels: Decisions, Direction and Design, The Second International Conference on Natural Channel Systems Niagara Falls, Ontario, Canada, pp. 29.
- Boon PJ. 1998. River restoration in five dimensions. *Aquatic Conservation-Marine and Freshwater Ecosystems*. 8(1): 257-264.
- Boshard M, Romaine M and Ade K. 2002. The Paradigm Shift: A Discussion Paper on Designing a Collaborative Community Transboundary Ecosystem-based Aquatics Plan for the Okanagan Portion of the Columbia River Watershed, Towards Ecosystem-Based Management: Breaking Down the Barriers in the Columbia River Basin and Beyond Spokane, WA.
- Bravard JP, Landon N, Peiry JL and Piegay H. 1999. Principles of engineering geomorphology for managing channel erosion and bedload transport, examples from French rivers. *Geomorphology*. 31(1-4): 291-311.
- Brookes A. 1999. 17. Floodplain Restoration and Rehabilitation. In: Anderson MG, Walling DE and Bates PD (Eds), *Floodplain Processes*. John Wiley and Sons, pp. 553-576.
- Brookes A, Knight SS and Shields FD. 1996. 4. Habitat Enhancement. In: Brookes A and Shields FD (Eds), *River Channel Restoration: Guiding Principles for Sustainable Projects*. John Wiley and Sons: Chichester, UK, pp. 103-126.
- Brookes A and Sear D. 1996. 3. Geomorphological Principles for Restoring Channels. In: Brookes A and Shields FD (Eds), *River Channel Restoration: Guiding Principles for Sustainable Projects*. John Wiley and Sons: Chichester, UK, pp. 75-101.
- Brookes A and Shields FD. 1996. *River Channel Restoration: Guiding Principles for Sustainable Projects*. John Wiley and Sons: Chichester, UK, 433 pp.
- Brooks AP and Brierley GJ. 2004. Framing realistic river rehabilitation targets in light of altered sediment supply and transport relationships: lessons from East Gippsland, Australia. *Geomorphology*. 58(1-4): 107-123.
- Buijse AD *et al.* 2002. Restoration strategies for river floodplains along large lowland rivers in Europe. *Freshwater Biol.* 47(4): 889-907.
- Clark MJ, Newson MD, Sear D and Thorne CR. 1997. *Geomorphological Approaches to River Management*. R D Project 661, Environment Agency, Southampton, UK.
- Doyle MW, Harbor JM, Rich CF and Spacie A. 2000. Examining the effects of urbanization on streams using indicators of geomorphic stability. *Physical Geography*. 21(2): 155-181.
- Ellis JB. 1996?? *Urban Watercourses: Ecological Sustainability and Restoration*, Natural Environmental Research Council, Swindon, UK, 10 pp.
- Everest FH and Sedell JR. 1984. Evaluating Effectiveness of Stream Enhancement Projects. In: Hassler TJ (Editor), Pacific Northwest Stream Habitat Management Workshop: American Fisheries Society. AFS: Humboldt State University, CA, pp. 156-164.
- Fedler AJ and Ditton RB. 2000. Developing a national outreach strategy for recreational fishing and boating. *Fisheries*. 25(1): 22-28.
- Fischer KJ. 1994. Chapter 6: Fluvial Geomorphology and Flood Control Strategies: Sacramento River, California. In: Schumm SA (Ed), *W.B.R.* ASCE Press: New York, pp. 115-139.
- Fitzsimmons AK. 1996. Sound Policy or Smoke and Mirrors: Does Ecosystem Management Make Sense? *Water Resources Bulletin*. 32(2): 217-227.
- Florsheim JL and Mount JF. 2002. Restoration of floodplain topography by sand-splay complex formation in response to intentional levee breaches, Lower Cosumnes River, California. *Geomorphology*. 44(1-2): 67-94.
- Frissell CA, Liss WJ and Bayles D. 1993. An Integrated, Biophysical Strategy for Ecological Restoration of Large Watersheds. *Changing Roles in Water Resources Management and Policy: American Water Resources Association*. 29(3).
- Ganoulis J. 2003. Risk-based floodplain management: A case study from Greece. *International Journal of River Basin Management*. 1(1): 41-47.
- Gilvear DJ and Winterbottom SJ. 1998. Chapter 8: Changes in channel morphology, floodplain land use and flood damage on the rivers Tay and Tummel over the last 250 years: Implications for floodplain management. In: ? (Ed), *United Kingdom Floodplains*. Westbury Publishing: Westbury, UK, pp. 94-112.
- Gore JA. 1985. Mechanisms of colonization and habitat enhancement for benthic macroinvertebrates in restored river channels. In: Gore JA and Petts G (Eds), *Alternatives in Regulated River Management*. CRC Press: Boca Raton, FL.
- Hendry K, Cragg-Hine D, Grady MO, Sambrook H and Stephen A. 2003. Management of habitat for rehabilitation and enhancement of salmonid stocks. *Fisheries Research*. 62(2003): 171-192.
- Herricks EE. 1996. 7. Water Quality Issues in River Channel Restoration. In: Brookes A and Shields FD (Eds), *River Channel Restoration: Guiding Principles for Sustainable Projects*. John Wiley and Sons: Chichester, UK, pp. 75-101.
- Hoey TB, Smart DWJ, Pender G and Leys K. 1998. *Engineering methods for Scottish gravel bed rivers*, Scottish Natural Heritage, Glasgow, 121 pp.
- Holmes NTH. 1998. Chapter 22: Floodplain restoration. In: ? (Ed), *United Kingdom Floodplains*. Westbury Publishing: Westbury, UK, pp. 29-41.
- Hughes FMR. 1997. Floodplain biogeomorphology. *Progress in Physical Geography*. 21(4): 501-529.
- Johnson PA and Brown ER. 2001. Incorporating Uncertainty in the Design of Stream Channel Modifications. *Journal of the American Water Resources Association*. 37(5): 1225-1236.
- Jorgensen EE, Canfield TJ and Kutz FW. 2000. Restored riparian buffers as tools for ecosystem restoration in the MAIA; Processes, endpoints, and measures of success for water, soil, flora, and fauna. *Environmental Monitoring and Assessment*. 63(1): 199-210.
- Jungwirth M, Muhar S and Schmutz S. 2002. Re-establishing and assessing ecological integrity in riverine landscapes. *Freshwater Biology*. 47(4): 867-887.
- Knighton D. 1998. *Fluvial forms and processes : a new perspective*. Arnold: London ; New York.
- Kondolf GM. 1996. A cross section of stream channel restoration. *Journal of Soil and Water Conservation*. 51(2): 119-125.

- Kondolf GM. 2000. Historical Changes to the San Francisco Bay-Delta Watershed: Implications for Ecosystem Restoration. In: Nijland HJ and Cals MJR (Eds), *River Restoration in Europe: Practical Applications-Conference on River Restoration: Proceedings*. ECRR: Wageningen, The Netherlands, pp. 327-338.
- Laasonen P, Muotka T and Kivijärvi I. 1998. Recovery of macroinvertebrate communities from stream habitat restoration. *Aquatic Conservation-Marine and Freshwater Ecosystems*. **8**: 101-113.
- Levy JK, Hipel KW and Kilgour DM. 2000. Using environmental indicators to quantify the robustness of policy alternatives to uncertainty*1. *Ecological Modelling*. **130**(1-3): 79-86.
- Maddock I. 1999. The importance of physical habitat assessment for evaluating river health. *Freshwater Biology*. **41**: 373-391.
- McDonald A, Lane SN, Chalk EA and Haycock NE. In Press. Rivers of dreams: on the gulf between theoretical and practical aspects of an upland river restoration. *Transactions of the Institute of British Geographers*.
- Merkle A and Kaupenjohann M. 2000. Derivation of ecosystemic effect indicators -- method. *Ecological Modelling*. **130**(1-3): 39-46.
- Montgomery DR, Grant GE and Sullivan K. 1995. Watershed Analysis as a Framework for Implementing Ecosystem Management. *Water Resources Bulletin*. **31**(3): 369-386.
- Mount JF. 1995. *California Rivers and Streams: The conflict between Fluvial Process and Land Use*. University of California Press: Berkeley, CA.
- Mujumdar PP and Sasikumar K. 2002. A fuzzy risk approach for seasonal water quality management of a river system. *Water Resources Research*. **38**(1): 1004-1013.
- Muotka T, Paavola R, Haapala A, Novimkee M and Laasonen P. 2002. Long-term recovery of stream habitat structure and benthic invertebrate communities from in-stream restoration. *Biological Conservation*. **105**(2): 243-253.
- Nearly VS, Wright SA and Bereciartua P. 2001. Case Study: Sediment Transport in Proposed Geomorphic Channel for Napa River. *Journal of Hydraulic Engineering*. **127**(11): 901-910.
- Newson MD. 2002. Geomorphological concepts and tools for sustainable river ecosystem management. *Aquatic Conservation-Marine and Freshwater Ecosystems*. **12**(4): 365-379.
- Newson MD, Clark MJ, Sear DA and Brookes A. 1998. The geomorphological basis for classifying rivers. *Aquatic Conservation-Marine and Freshwater Ecosystems*. **8**(4): 415-430.
- Newson MD and Sear DA. 1993. River conservation, river dynamics, river maintenance: contradictions? In: White S, Green J and Macklin MG (Eds), *Conserving our Landscape, Joint Nature Conservancy*, pp. 139-146.
- NOAA. 2003. *Sediment Removal from Freshwater Salmonid Habitat*, NOAA Fisheries- Southwest Region, 98 pp.
- NRC. 1992. *Restoration of aquatic ecosystems: science, technology, and public policy*. National Academy Press: Washington DC, 552 pp.
- Ormerod SJ. 2003. Current issues with fish and fisheries: editor's overview and introduction. *J Appl Ecology*. **40**(2): 204-213.
- Petts G. 1998. Chapter 4: Floodplains rivers and their restoration: A European perspective. In: ? (Ed), *United Kingdom Floodplains*. Westbury Publishing: Westbury, UK, pp. 29-41.
- Pfadenhauer J. 2001. Some Remarks on the Socio-Cultural Background of Restoration Ecology. *Restoration Ecology*. **9**(2): 220-229.
- Reckhow KH. 2003. On the Need for Uncertainty Assessment in TMDL Modeling and Implementation. *Journal of Water Resources Planning and Management-Asce*. **129**(4): 245-246.
- Rhoads BL, Wilson D, Urban M and Herricks EE. 1999. Interaction between scientists and nonscientists in community-based watershed management: Emergence of the concept of stream naturalization. *Environmental Management*. **24**(3): 297-308.
- Riber HH. 2000. The Skjern River Restoration Project. In: Cals MJR (Ed), *River Restoration in Europe: Practical Applications-Conference on River Restoration: Proceedings*: Wageningen, The Netherlands, pp. 209-213.
- Richards K, Brasington J and Hughes F. 2002. Geomorphic dynamics of floodplains: ecological implications and a potential modelling strategy. *Freshwater Biology*. **47**(4): 559-579.
- Ricklefs RE. 1987. Structure in Ecology. *Science*. **236**(April 10): 206-207.
- Rosgen D. 1996. *Applied River Morphology*. Wildland Hydrology: Pagosa Springs, CO.
- RRC. 2002. *Manual of River Restoration Techniques*, The River Restoration Centre, Silsoe, UK.
- Sear D. 1996. The Sediment System and Channel Stability. In: Brookes A and Shields FD (Eds), *River Channel Restoration: Guiding Principles for Sustainable Projects*. John Wiley and Sons: Chichester, UK, pp. 149-177.
- Sear D, Newson CL and Thorne CR. 2003. *Guidebook of Applied Fluvial Geomorphology*. R and D Technical Report FD1914, DEFRA: Flood Management Division, London, UK, 253 pp.
- Sear DA. 1994. River Restoration and Geomorphology. *Aquatic Conservation-Marine and Freshwater Ecosystems*. **4**(2): 169-177.
- Shields FD. In Press. Stream ecosystem restoration: Is watershed treatment effective without instream habitat rehabilitation?
- Shields FD, Knight SS and Cooper CM. 1995a. Rehabilitation of Watersheds with Incising Channels. *Water Resources Bulletin*. **31**(6).
- Shields FD, Knight SS and Cooper CM. 1995b. Use of the index of biotic integrity to assess physical habitat degradation in warmwater streams. *Hydrobiologia*. **312**: 191-208.
- Simon A, Curini A, Darby SE and Langendoen EJ. 2000. Bank and near-bank processes in an incised channel. *Geomorphology*. **35**(3-4): 193-217.
- Simon A and Darby SE. 2002. Effectiveness of grade-control structures in reducing erosion along incised river channels: the case of Hotophia Creek, Mississippi. *Geomorphology*. **42**(3-4): 229-254.
- Smeets E and Weterings R. 1999. *Environmental Indicators: Typology and overview*. Technical Report No 25, European Environment Agency, Copenhagen, Denmark, 19 pp.
- Smith BPG, Hannah DM, Gurnell AM and Petts GE. 2001. A hydrogeomorphological context for ecological research on alpine glacial rivers. *Freshwater Biology*. **46**(12): 1579-1596.
- Soar PJ and Thorne CR. 2001. *Channel Restoration Design for Meandering Rivers*. ERDC/CHL CR-01-1, U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS, 437 pp.
- Sparks RE. 1995. Need for Ecosystem Management of Large Rivers and Their Floodplains. *Bioscience*. **45**(3): 168-182.
- Thomson JR, Taylor MP, Fryirs KA and Brierley GJ. 2001. A geomorphological framework for river characterization and habitat assessment. *Aquatic Conservation-Marine and Freshwater Ecosystems*. **11**(5): 373-389.
- Tockner K and Stanford JA. 2002. Riverine flood plains: present state and future trends. *Environmental Conservation*. **29**(3): 308-330.

- USEPA. 1989. *Nonpoint sources: agenda for the future*. WH-556, U.S. Environmental Protection Agency: Office of Water, Washington D.C., 31 pp.
- Wheaton JM, Darby SE and Sear D. In Review. Chapter Three: Scope of Uncertainty in River Restoration. In: Darby SE and Sear D (Eds), *Uncertainties in River Restoration*. John Wiley and Sons: Chichester, U.K.
- Wheaton JM, Pasternack GB and Merz JE. 2004a. Spawning Habitat Rehabilitation - II. Using Hypothesis Testing and Development in Design, Mokelumne River, California, U.S.A. *International Journal of River Basin Management*. **2**(1): 21-37.
- Wheaton JM, Pasternack GB and Merz JE. 2004b. Spawning Habitat Rehabilitation - I. Conceptual Approach and Methods. *International Journal of River Basin Management*. **2**(1): 3-20.
- Willson MF and Halupka KC. 1995. Anadromous Fish as Keystone Species in Vertebrate Communities. *Conservation Biology*. **9**(3): 489-497.