



## AVON ŌTĀKARO NETWORK

# Floodplain restoration principles for the Avon Ōtākaro Red Zone

Case studies and recommendations

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ERO Report 1

Floodplain restoration principles for the Avon-Ōtākaro Red Zone. Case studies and recommendations.

ERO Report 2

Restoration opportunities assessment for the Avon-Ōtākaro Red Zone using a local knowledge approach.

ERO Report 3

Integrated assessment frameworks for evaluating large scale river corridor restoration.

Copies of the reports are publicly available on the Avon Ōtākaro Network website.

Front cover: Lake Kate Sheppard in the lower Avon Ōtākaro river corridor.

Photo credit: Shane Orchard



# Floodplain restoration principles for the Avon Ōtākaro Red Zone

## Case studies and recommendations

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A project funded by the Tindall Foundation



in collaboration with  
Avon Ōtākaro Forest Park and Greening the Red Zone

**AVON-OTAKARO  
FOREST PARK**



## LIST OF ABBREVIATIONS

AOFP	Avon Ōtākaro Forest Park
AORZ	Avon-Ōtākaro Red Zone
AvON	Avon Ōtākaro Network
CBD	Central Business District
DEM	Digital Elevation Model
DOC	Department of Conservation
DRB	Danube River Basin
DSE	Department of Sustainability and Environment
ERO	Ecological Regeneration Options
EU	European Union
EWA	Environmental Water Allocation
GI	Green Infrastructure
GIS	Geographic Information System
GtRZ	Greening the Red Zone
ICPDR	International Commission for the Protection of the Danube River
KRRP	Kissimmee River Restoration Project
LiDAR	Light Detecting and Ranging
LVD	Lyttelton Vertical Datum 1937
MfE	Ministry for the Environment
MHWS	Mean High Water Springs
MDB	Murray-Darling Basin
MDBC	Murray-Darling Basin Commission
NIWA	National Institute of Water & Atmospheric Research
NZCPS	New Zealand Coastal Policy Statement 2010
UNEP/GPA	United Nations Environment Programme (UNEP) Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA)
VEAC	Victorian Environmental Assessment Council
WWF	World Wide Fund for Nature

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## 1. Introduction

### Why are floodplains important?

Floodplains are an integral part of river systems created and maintained by fluctuating water levels and flows (Junk et al., 1989; Ward et al., 1999). Interactions between the hydrological aspects and the landscape typically support a rich range of ecosystems associated with a complex mosaic of riparian landforms and biological communities (Jungwirth et al., 2002; Ward et al., 2002). Key physical drivers structuring these ecosystems include the dynamic characteristics of climate, periodic flooding, and associated natural disturbance effects (White et al., 2007). They may occur in all geographical areas and at many points along the river corridor continuum (Tockner et al., 2000).

The many different biological communities found in floodplain landscapes include a wide range of aquatic and semi-aquatic wetland communities and periodically flooded forest types, all reliant to some degree on their connection to the river. In these dynamic environments, interactions between physico-chemical and biological processes operate at many different spatio-temporal scales with the natural disturbance aspects ensuring regular turnover (Tockner et al., 1999). Hydrological connectivity facilitates exchanges of materials and energy in addition to providing dispersal pathways for biota (Phelps et al., 2015; Thorp et al., 2006). Interplay between the dynamic and connective aspects fosters a continual evolution of ecotones that promotes a high diversity of ecological niches. In turn this supports high levels of biodiversity (Amoros & Bornette, 2002; Ward et al., 2002). In New Zealand as with elsewhere, floodplains provide habitat for many iconic and threatened species, some of which depend on these systems for critical components of their life cycle (DOC & MfE, 2000; UNEP/GPA, 2006). In addition, they support many societal values and uses including a wide range of commercial, cultural and recreational activities.

Across the world many floodplains have been degraded by human activities and continue to be lost under pressures from multiple stressors (Tockner et al., 2010; Wohl, 2011). However, the primary causes relate to hydrological alterations because of the many interests in rivers. These include their use for navigational purposes, energy generation, and as a source of water for agriculture (Benke et al., 2000; Nilsson et al., 2005; Tockner & Stanford, 2002). In combination with their disposition towards periodic flooding and its potential impacts on human activities, this has resulted in the regulation of many rivers through engineering designed to control characteristics of water levels, direction, and flows (Hauer & Lorang, 2004; Kuiper et al., 2014; Nilsson et al., 2000).

These alterations often promote the expansion of human settlement and intensive land uses in floodplain landscapes that were previously untenable due to natural river dynamics (Jungwirth et al., 2002). Even where remnant floodplain ecosystems may be found, the disruption of the frequency, magnitude, and timing of flow events and their associated natural disturbance regime are key factors leading to the degradation of floodplain ecosystems worldwide (Ward & Stanford, 1995). As a result floodplain ecosystems continue to be a highly threatened ecosystem type and are typically high priorities for conservation (Arthington et al., 2010; Poff et al., 2007; Tockner & Stanford, 2002). In New Zealand, this same pattern has emerged due to anthropogenic pressures on floodplains and other lowland ecosystems (DOC & MfE, 2000). In addition, they are areas of high importance to the traditional lifeways of Māori due to the many cultural values they support (Beatty, 1920). These values include rangatiratanga, manaakitanga, and mahinga kai (Tau et al., 1990; Jolly et al., 2013).

### Introduction to the Avon-Ōtākaro Red Zone

The sequence of strong earthquakes experienced in Canterbury during 2010 - 2011 caused widespread damage and included four earthquakes exceeding magnitude  $M_w$  6.0, all on previously unrecognised faults (Beavan et al., 2012). Surface deformation effects included liquefaction, lateral



spread, subsidence, cliff and bank collapse, rockfall and alterations to hydrological regimes (Allen et al., 2014; Quigley et al., 2016). Following the Canterbury earthquakes many thousands of homes were acquired by the government for demolition on the basis that the land was too badly damaged to be economically remediated for immediate residential redevelopment. A large tract of the land acquired, some 535 ha, runs eastward from the Christchurch CBD along the banks of the Ōtākaro / Avon River (Figure 1-1). This 'red zoned' area is known by various names including the 'Residential Red Zone' and Avon-Ōtākaro Red Zone (AORZ) as used here. Future uses of this land provide the context for this report.

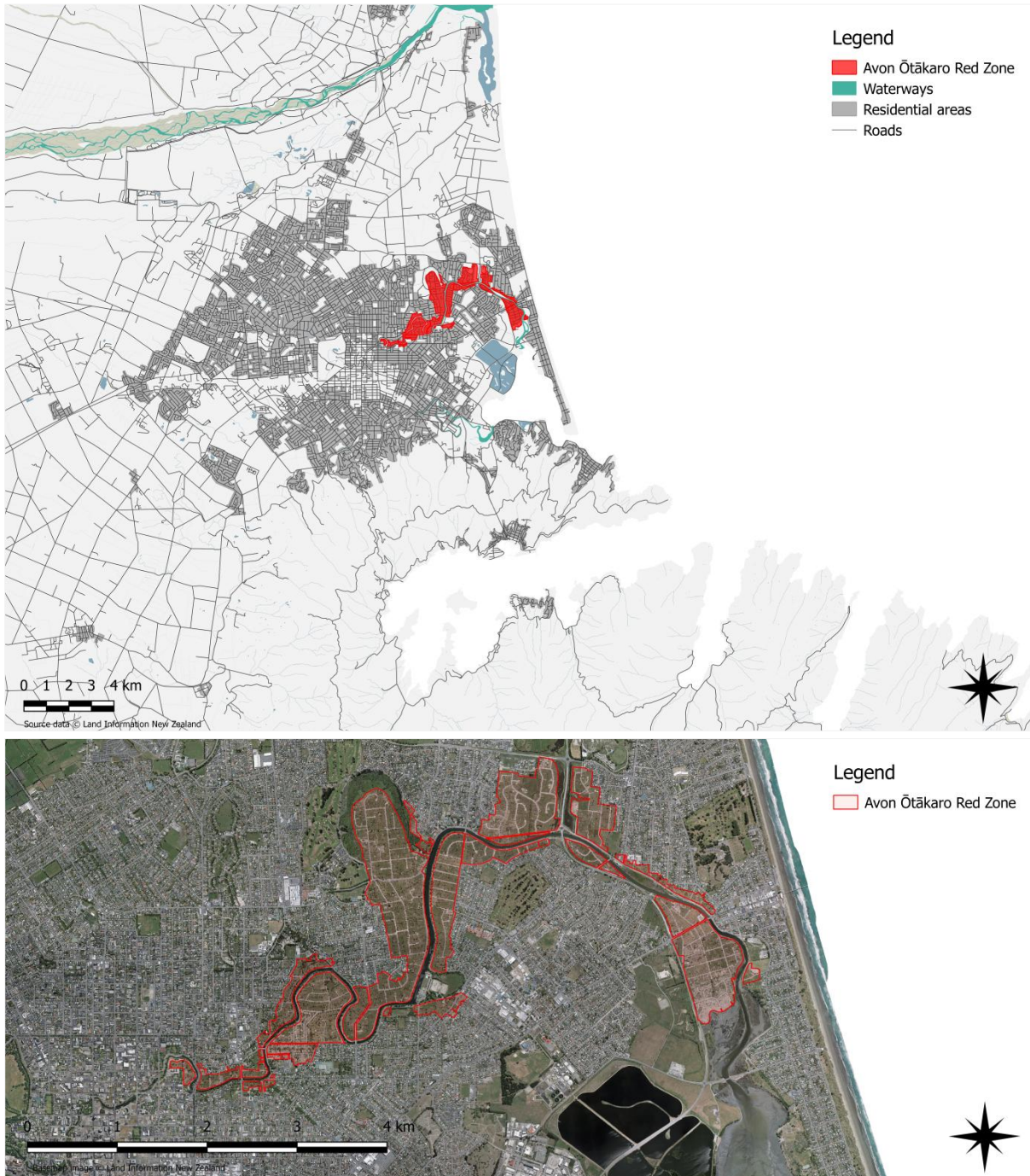
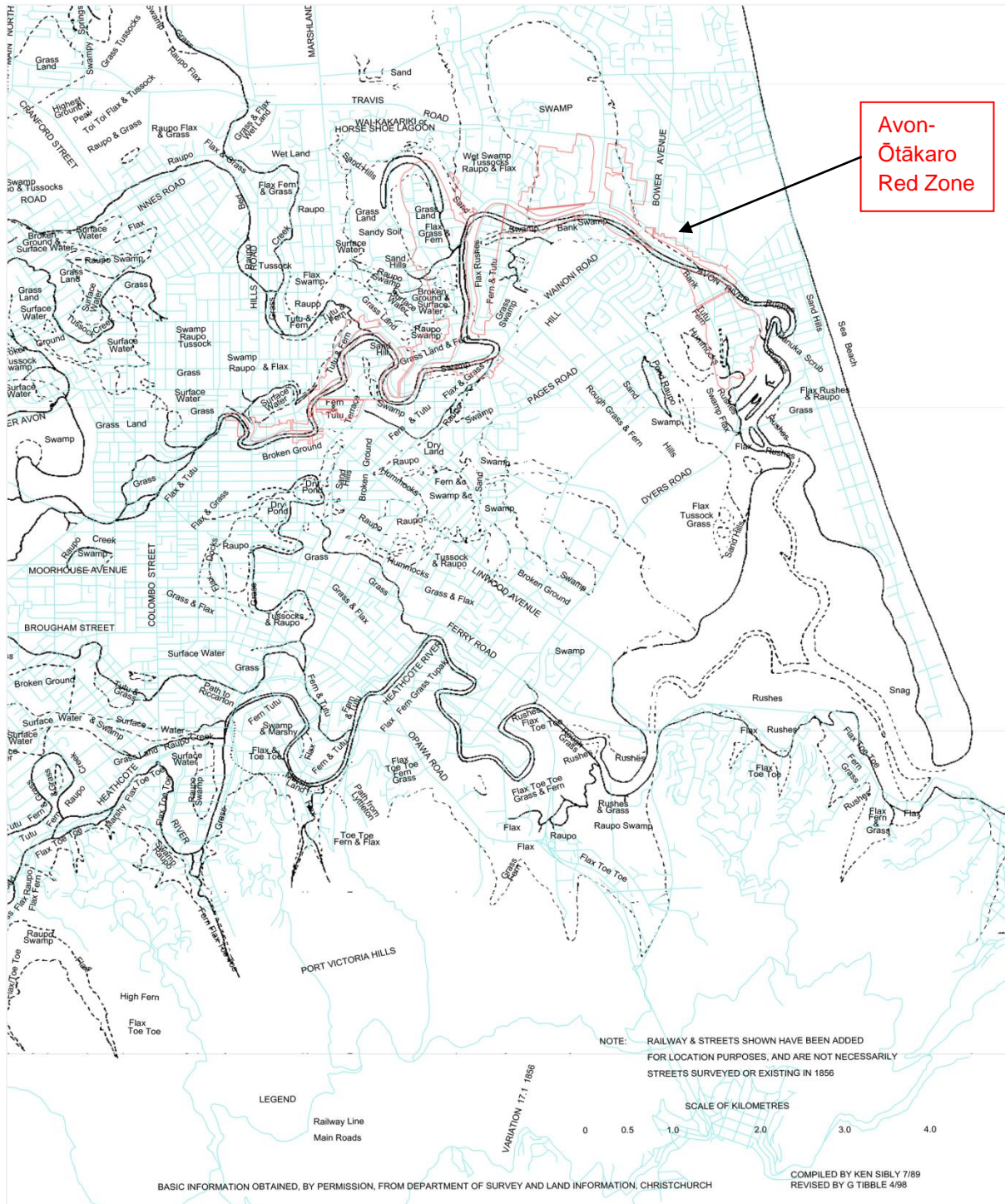


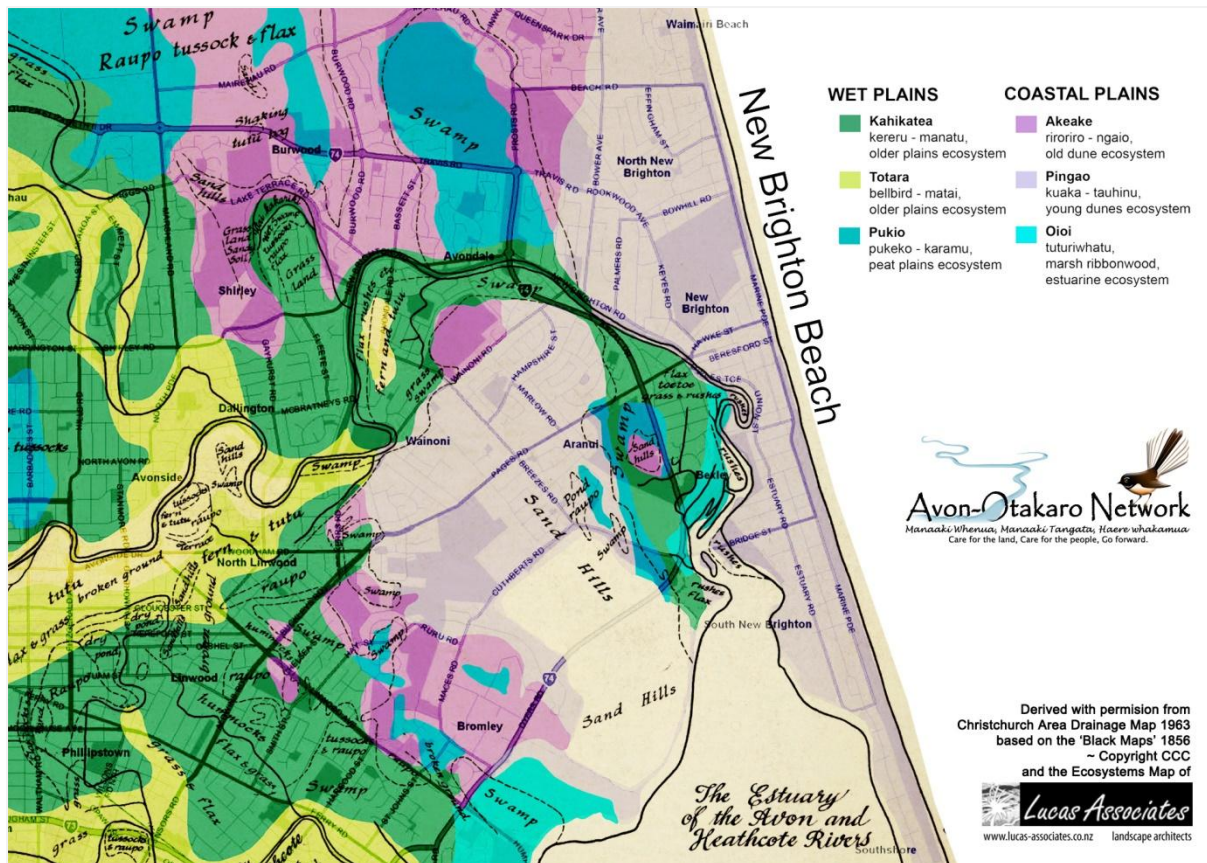
Figure 1-1. Two views of the Avon-Ōtākaro Red Zone.



Historically, the area now occupied by the AORZ was part of an extensive network of riparian floodplain wetlands supporting a rich mosaic of indigenous ecosystems. The pre-European distribution of ecosystems was relatively well documented in the Black Maps of 1856 (Figure 1-2). In addition, a description of historically occurring ecosystems together with their characteristic species assemblages was prepared by Lucas et al. (1997) based on land systems (Figure 1-3).



**Figure 1-2.** Excerpt from the 1856 Black Maps with the approximate position of the AORZ shown as an overlay. Note changes in the position of waterways channels (in black) in relation to the position of modern day roads (in blue). (Black Map courtesy of Christchurch City Council).



**Figure 1-3.** Ecosystems of the lower Ōtākaro / Avon River catchment based on the 'Black Maps' and 'Indigenous ecosystems of Ōtautahi Christchurch' (Lucas et al., 1997; Lucas Associates, 2011).

This historical information highlights the underlying floodplain landforms that characterise the majority of the AORZ area. This information also provides a potential baseline for assessing the impacts of land-use change on the previous pattern of indigenous ecosystems. However, the underlying land and waterscape has now been altered by the earthquakes. Consequently, these information sources are best regarded as descriptions of reference systems that could be potentially re-created in the future. They cannot be directly used to ascertain the potential distribution of restored ecosystems, or to identify those that could be restored, without additional information on current biophysical conditions. Alongside the consideration of ecological regeneration in the AORZ, there is also a need to understand the effects of removing or re-engineering past modifications. Fortunately, there are a growing number of river restoration projects that have addressed similar contexts worldwide. These provide opportunities to test re-assembly hypotheses and improve the basic understanding of river re-engineering proposals and their likely effects.

### Earthquake recovery and regeneration planning

Formal planning for the regeneration of the AORZ area is being led by Regenerate Christchurch, an entity established under the Greater Christchurch Regeneration Act 2016. Regenerate Christchurch has a range of functions including to “develop visions, strategies, and Regeneration Plans” and “provide independent advice on regeneration activities to the Council and the Minister”. Key components of the planning process to date include preparation of an 'Outline for the Ōtākaro / Avon River Corridor Regeneration Plan' (Regeneration Plan), and completion of initial community engagement activities including public visioning workshops to establish community needs and values. A single Regeneration Plan will be developed for the whole of the AORZ and some adjacent lands



representing a total area of 602 ha. It will include areas occupied by waterways and their margins (Regenerate Christchurch, 2017). The planning process is expected to result in a clear vision for the area, a spatial plan identifying the location of future land uses and activities to achieve the vision, and identification of key actions required for its implementation within a temporal plan.

## Background and objectives of the study

The Avon Ōtākaro Network (AvON) is one of many community-based organisations that has formed since the Canterbury earthquakes. Since 2011, AvON has been working towards the creation of a multiple-purpose river park as an outcome of the earthquake recovery process. The vision of the organisation is “to promote the future use of the Ōtākaro/Avon River and the surrounding red zone lands as an ecological and recreational reserve for the community”.

The specific aims of the group as found in the AvON Charter are:

- to establish a community-driven, science-informed living memorial to rejuvenate and nurture the long-term environmental, economic, community and spiritual wellbeing of the eastern suburbs and greater Christchurch.
- to create a place of hope and inspiration for the people of Christchurch by restoring health and vitality to our river and its lands (Avon Ōtākaro Network, 2013).

Alongside the work of AvON many other community groups have developed projects or proposals for land uses in the AORZ. Collectively these initiatives have mobilised a high level of interest in the future of the area. A prominent aspect of AvON’s role has been to facilitate networking between the various proposals to explore the potential for synergies and encourage integration. Although many current land-use proposals are compatible with ecological restoration to some extent, very few are focussed towards restoration of a natural river corridor from the CBD to the sea despite this being a cornerstone of the AvON vision. Exceptions include the proposals developed by Avon Ōtākaro Forest Park (A-OFP) and Greening the Red Zone (GtRZ). Following commencement of the formal planning process by Regenerate Christchurch an important information gap was identified by AvON, A-OFP, and GtRZ, that is relevant to identifying and assessing the full range of options and opportunities for future uses of the AORZ. The information sought was specification of the ecological restoration outcomes that could potentially be created together with how they might be implemented. These may include opportunities to address legacy degradation issues, develop highly cost-effective land-uses, or create novel ecologically engineered environments with high societal benefits, and combinations thereof.

To help address the wider opportunities for river corridor restoration in the regeneration planning process, the Ecological Regeneration Options (ERO) project has been developed in collaboration with the above groups. The purpose of the project is to inform Regenerate Christchurch and other groups involved in planning for future uses of the AORZ. Therefore, potential audiences include Regenerate Christchurch in the context of their integrated business case assessments, proposal proponents in embedding restoration principles and synergies within their designs, and the wider community of interests in the opportunity presented by the AORZ. A key aspect is to encourage and facilitate comparisons between restoration opportunities and other land-use proposals. Better knowledge of these opportunities is expected to be useful for the identification of trade-offs and beneficial co-uses of the land and other natural resources. This information may be incorporated into many of the developing proposals for regeneration of the AORZ and will assist the integration of green, blue, and built infrastructure opportunities in both time and space.

This study is the first of three in the ERO series. The purpose of this report is to provide: (a) an overview of the floodplain characteristics of the AORZ, including consideration of potential inundation effects under sea level rise, (b) a review of international experience in large scale floodplain

restoration relevant to the AORZ, (c) a synthesis of key principles for the identification of floodplain restoration opportunities in the AORZ.

## 2. Methods

This study has been conducted in two parts. Firstly a coarse level analysis of current surface elevations and hydrology in the AORZ, including post-quake changes, was conducted to characterise the study area for subsequent interpretation against floodplain management and river restoration literature. The methods used literature review and document analysis of recent technical studies in the post-quake literature and GIS-based analysis of available datasets using overlay techniques. Data sources are cited in the relevant figures.

Secondly an extensive literature review of international experience in floodplain restoration was conducted to identify principles relevant to the AORZ context. Based on the review findings, three examples were chosen for preparation of case studies. The first two case studies were chosen on the basis of similar historical degradation patterns, adjacent land uses, and river regulation context. These cases are the lower Danube and Kissimmee Rivers. The third case, the Murray River in Victoria, was chosen for its relevance to innovative environmental assessment approaches in support of flood plain restoration and planning. Transferable principles were identified through case-case comparison and used to inform recommendations for floodplain restoration approaches that could be applied in the AORZ.

## 3. Post-quake characteristics of the Avon-Ōtākaro Red Zone

### Earthquake effects on surface elevations and hydrology

The Canterbury earthquake sequence is one of the best documented tectonic events in New Zealand history (Quigley et al., 2016). LiDAR data was acquired after each of the major earthquakes. Together with other remote sensing and field studies a detailed picture of land movements may be derived. Compared to pre-earthquake ground levels, the dominant trend in the AORZ is subsidence, together with lateral movement especially in the vicinity of waterway channels (Allen et al., 2014). Subsidence predominates across all of the major areas within the AORZ (Figure 3-1) despite some variability (Table 3-1) with the average subsidence across in the entire AORZ being 0.48 m based on a 5 m DEM. A difference map (Figure 3-2) illustrates the wider pattern in the context of adjacent lands. Note that the effects of a 5.7  $M_w$  quake in February 2012 are not accounted for in these data.

**Table 3-1.** Summary of pre-2010 to post-2011 ground surface subsidence in the AORZ.

AORZ areas	Area (ha)	Elevation change (m)		
		min	max	mean
Avon Loop	3.67373	-1.2391	0.0607	-0.5247
Linwood	12.72408	-1.8935	0.8501	-0.3917
Richmond	16.26356	-1.6400	0.5913	-0.5219
Avonside	48.96481	-1.5441	0.4875	-0.5517
Dallington	131.8225	-1.7252	0.9879	-0.5395
Wainoni	8.897279	-1.3211	0.5069	-0.4241
Avondale	48.84491	-1.5411	0.0860	-0.5852
Burwood	55.25861	-2.5357	1.9030	-0.2509
New Brighton	42.03767	-1.7656	0.5706	-0.5194
Bexley	68.06241	-3.2755	1.0990	-0.4913

<sup>†</sup> negative values are subsidence and positive values uplift relative to pre-earthquake ground elevations.

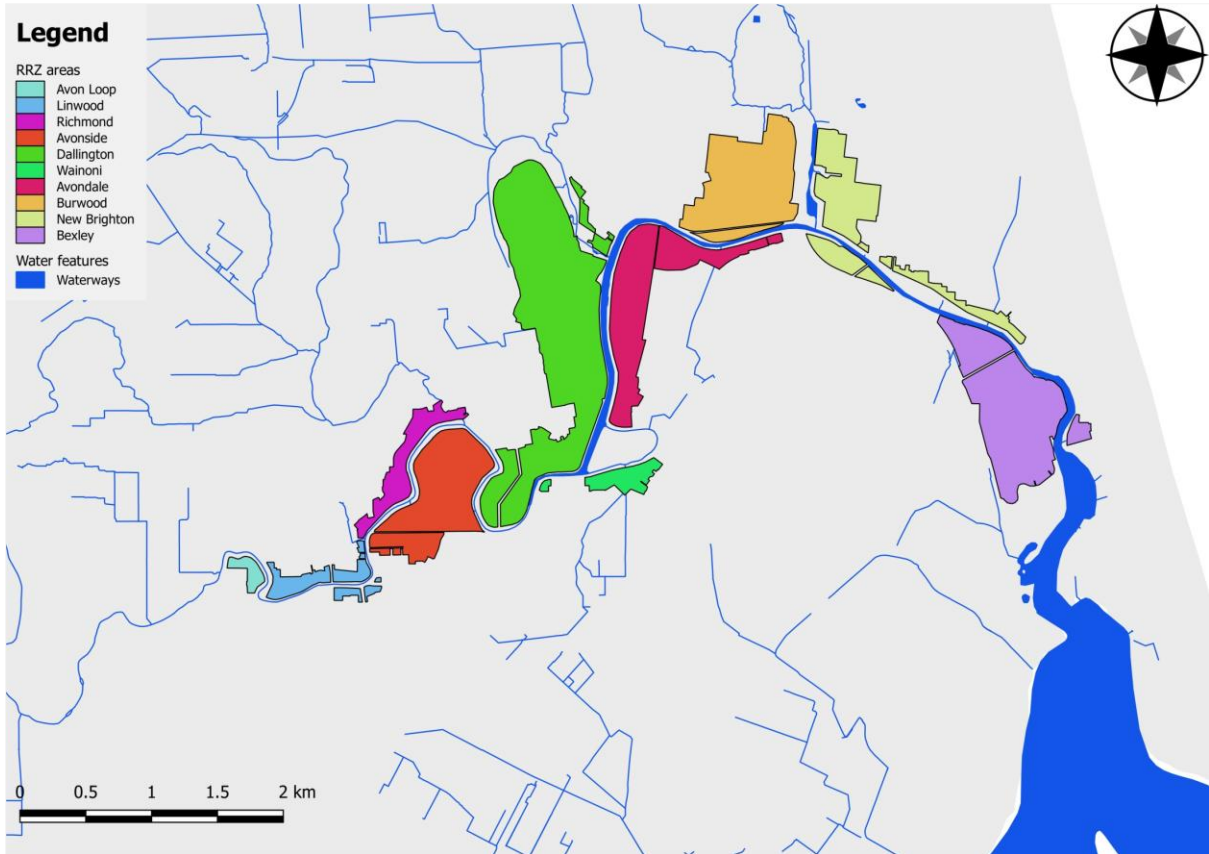


Figure 3-1. Major areas for regeneration within in the AORZ.

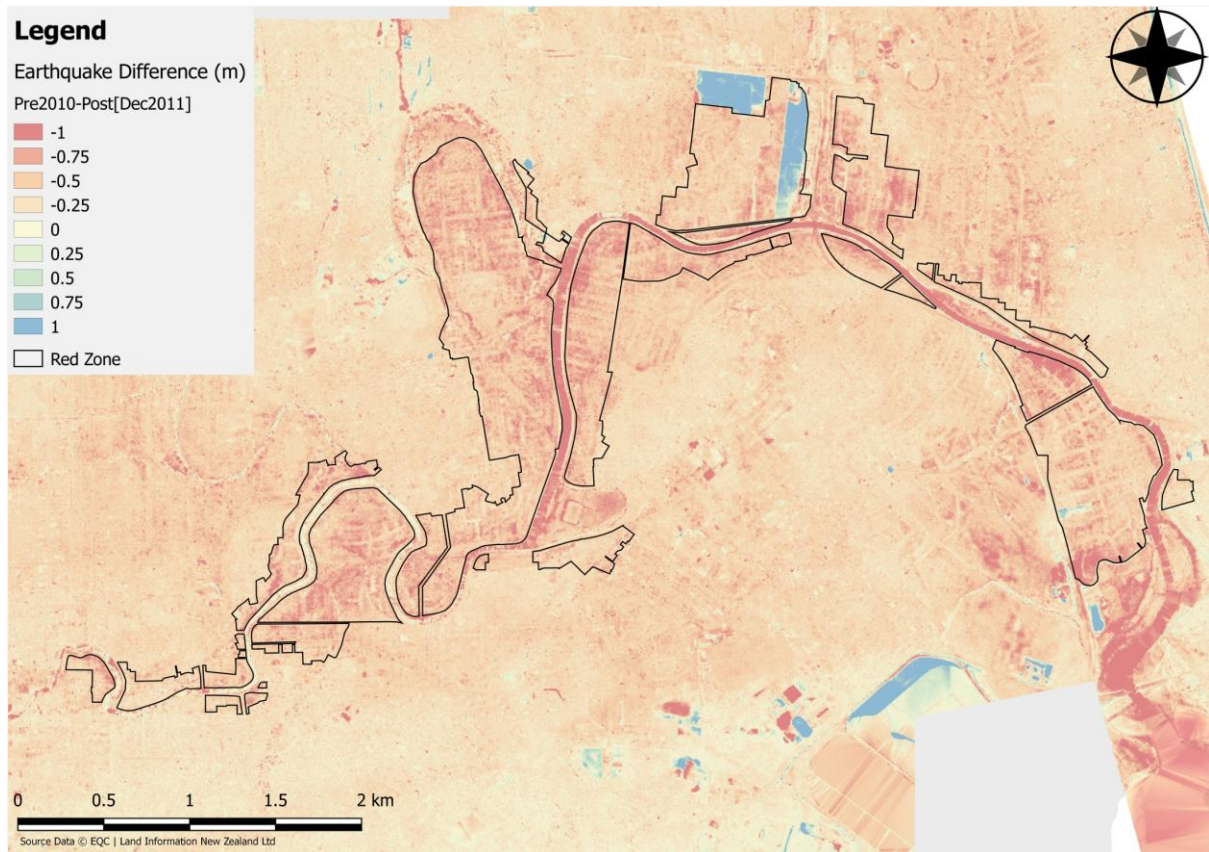
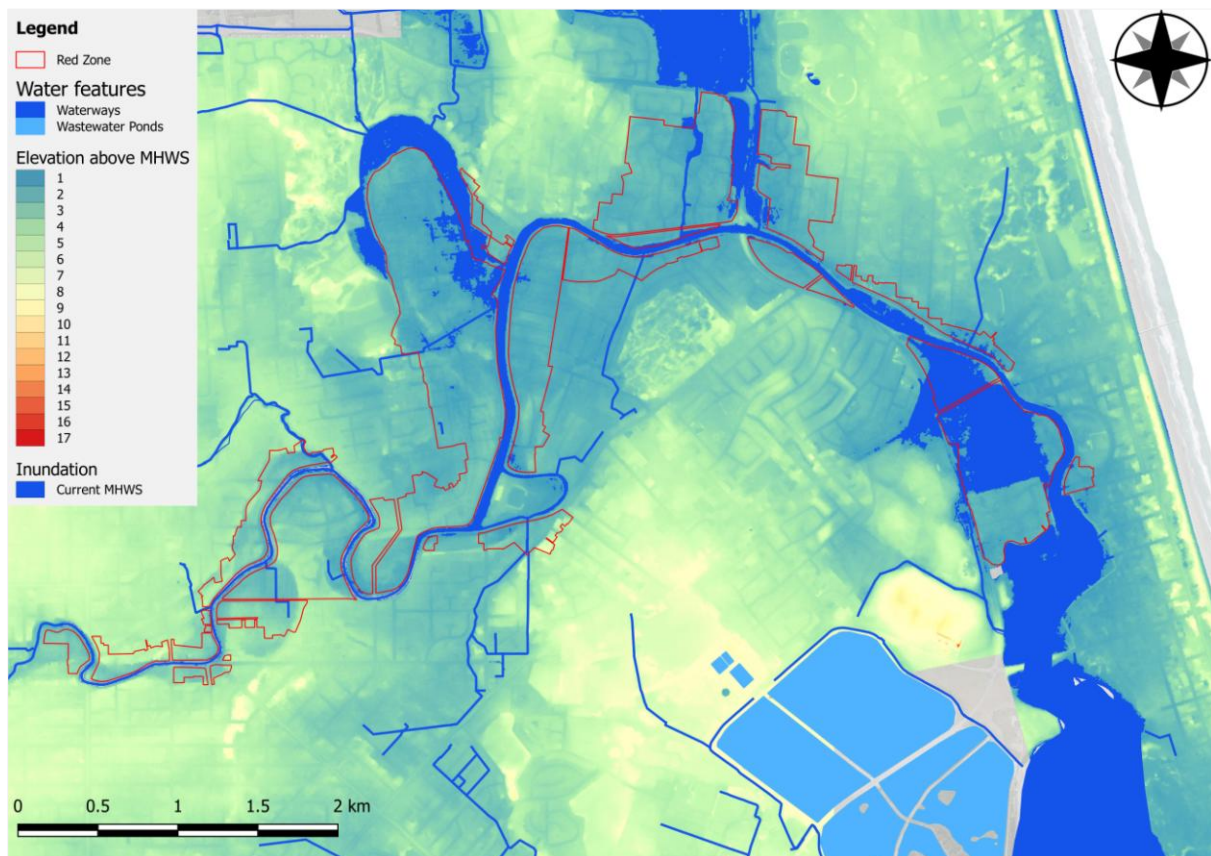


Figure 3-2. Elevation difference map showing pre-2010 to post-2011 ground level changes derived from LiDAR data.



A consequence of land subsidence in the lower Ōtākaro / Avon is greater exposure to flooding including coastal inundation and the potential effects of sea level rise. Particularly in the downstream reaches of the river corridor, this has resulted in heightened connectivity to the sea. For comparison the inundation extent of a 1.15 m LVD event on ground surface elevations derived from 2012 LiDAR data illustrates that a substantial area of the AORZ in Bexley is exposed to tidal inundation if water control structures were removed (Figure 3-3). Additionally, much of the AORZ is exposed to inundation within a 100 year planning horizon based on an expectation of 1 m sea level rise (Figure 3-4). Under the NZCPS decisions on new infrastructure require climate change considerations to be addressed for at least a 100 year planning horizon. Despite that investments in ecological restoration are nature-based entities, they represent 'green infrastructure' that also requires a sound business case (Cohen-Shacham et al., 2016). Future-proofing of the expected benefits of ecological restoration must therefore be secured by design. This may be accomplished through a combination of attention to the targeted restoration objectives, and the design of implementation strategies to address ecological succession and resilience to climate change.



**Figure 3-3.** Inundation extent at MHWS as simulated by a 1.15 m LVD event on ground surface elevations derived from 2012 LiDAR. The underlying DEM has been re-scaled to show elevation above 1.15 m LVD in the adjacent areas.



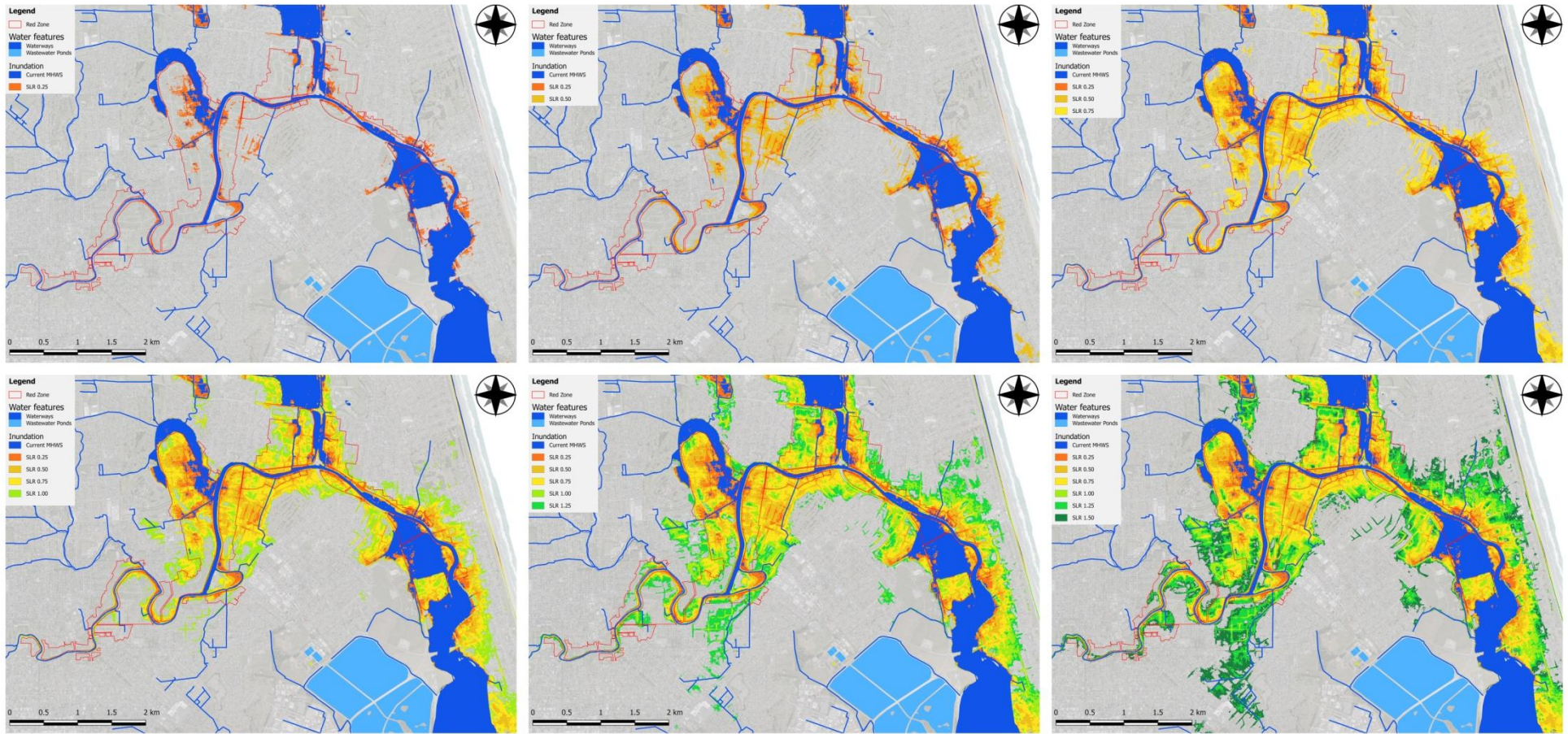


Figure 3-4. Sea level rise scenarios simulated in 0.25 m increments relative to an elevation of 1.15 m LVD as used in Figure 2-3. Available from <http://bit.ly/2oe0d7R>

## Implications for ecological restoration and regeneration planning

In general, the earthquake impacts were more severe in the vicinity of the estuary and waterways and included changes to ground levels and bathymetry (Allen et al., 2014; Measures et al., 2011). Post-quake studies have shown further more subtle changes in a variety of drivers important to ecological structure and function. These include substrates (Cochrane et al., 2014; Zeldis et al., 2011), river bank and channel profiles (Allen et al., 2014, Orchard & Hickford, 2016) and alterations to the salinity regimes of the lower rivers (Orchard, 2016a; Orchard & Measures, 2016). The magnitude of these effects has been sufficient to drive long-term ecological changes in the distribution of species and habitats. Examples include rapid responses in the distribution of glasswort (*Sarcocornia quinqueflora*) and other saltmarsh species (Cochrane et al., 2014), and spawning sites for īnanga (*Galaxias maculatus*) (Orchard, 2016b; Orchard & Hickford, 2016). The full extent of these effects remains poorly understood yet is fundamentally important to the current ecology and ongoing successional processes in the AORZ.



**Plate 1.** A recent view of the lower Ōtākaro / Avon River near Anzac Bridge. Photo: Shane Orchard.



## 4. The bigger picture – creating room for rivers

A central theme of floodplain restoration concerns release from, or reversal of, the effects of human land use encroachment on riparian ecosystems and waterways. Many of these have been completed in the context of river regulation (Nilsson et al., 2000), often accompanied by various forms of drainage schemes on floodplain land to assist the development of settlements and intensive human land uses.

Examining the historical pattern of human land use encroachment with regards to the naturally occurring ecosystems of the AORZ is an essential starting point for restoration planning. The combination of earthquake impacts and land acquisition via Red Zoning creates a unique opportunity to reverse undesirable aspects of previous land use decisions. However, the literature contains many examples of human land-use encroachments similar to those that have historically affected the waterways and floodplains of the lower Ōtākaro / Avon River, and there are examples of restoration initiatives in some of these contexts. One of the best examples is found in the lower Danube where floodplain restoration initiatives have been in place for several years and include studies that have reported on the ecological outcomes of attempts to reverse land use encroachment.

### Case Study 1

#### Ecological restoration of the lower Danube floodplain



##### Overview

Floodplain restoration in the Danube River Basin (DRB) recognises the cumulative loss of natural river features and associated habitat degradation and loss of indigenous species. In many parts of the DRB the goal of floodplain restoration is to reverse these long term degradation trends to achieve restoration outcomes that include the recovery of river dynamics, natural ecosystems, and ecological functions (ICPDR, 2009). However, the river system and floodplain remains characterised by a high degree of interest in intensive land uses. Many of the restoration initiatives have involved re-imagining the concept of sustainable floodplain management by identifying alternatives to the historical development pattern, thereby addressing the many competing demands. The DRB is the world's most international river basin, spanning 19 countries (Figure 4-1). In most reaches, river dynamics have become heavily impacted by human land use encroachments and direct engineering of the waterways and their margins (Figure 4-2). A recent assessment of floodplain extent and condition found that the morphological floodplain area (delineated by post-glacial lower terraces) was 26,524 km<sup>2</sup>, or 3.3% of the total DRB. Active floodplains, being those currently located within flood protection dikes, cover 8452 km<sup>2</sup> equating to a 68% loss after accounting for the in-stream water surface area of 1724 km<sup>2</sup>. Including the main tributaries in the assessment raises the total loss to around 80% of the original floodplain areas (Schwarz, 2010). Other impacts include the modification of 1,100 km of natural river banks (Schwarz, 2010, 2013)

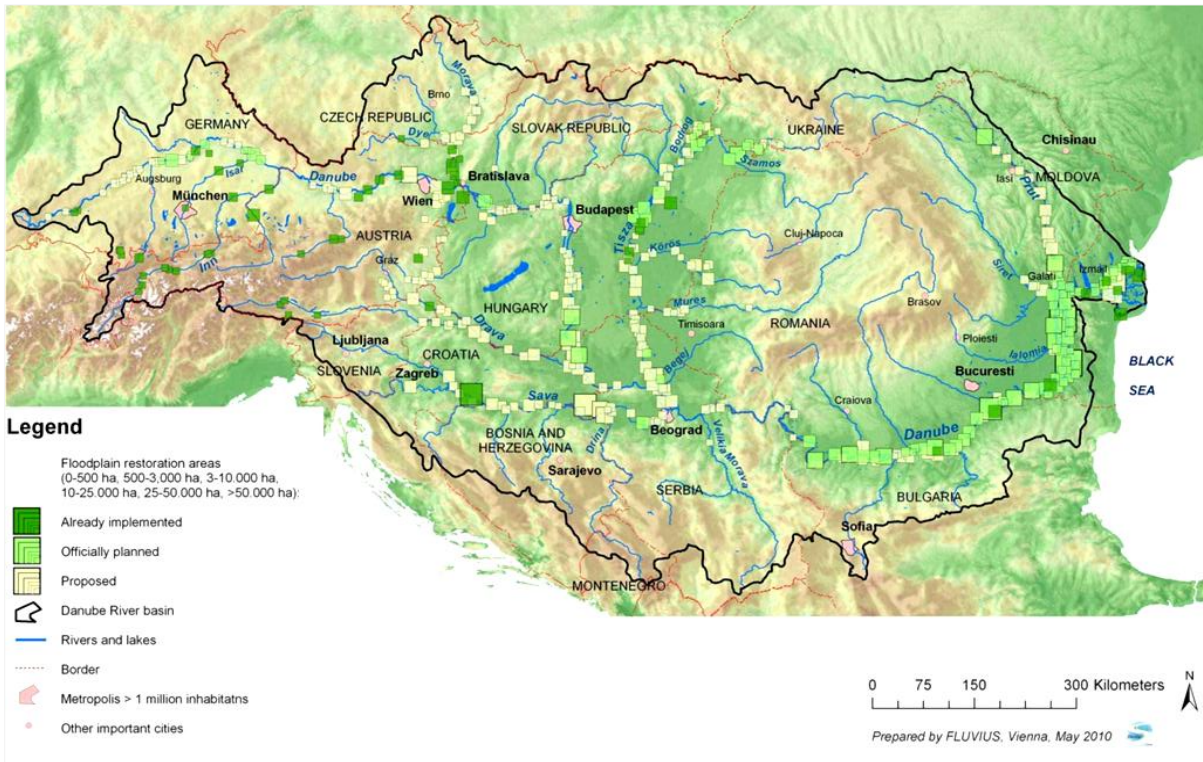


Figure 4-1. Floodplain restoration areas in the Danube River Basin (Schwarz, 2010),

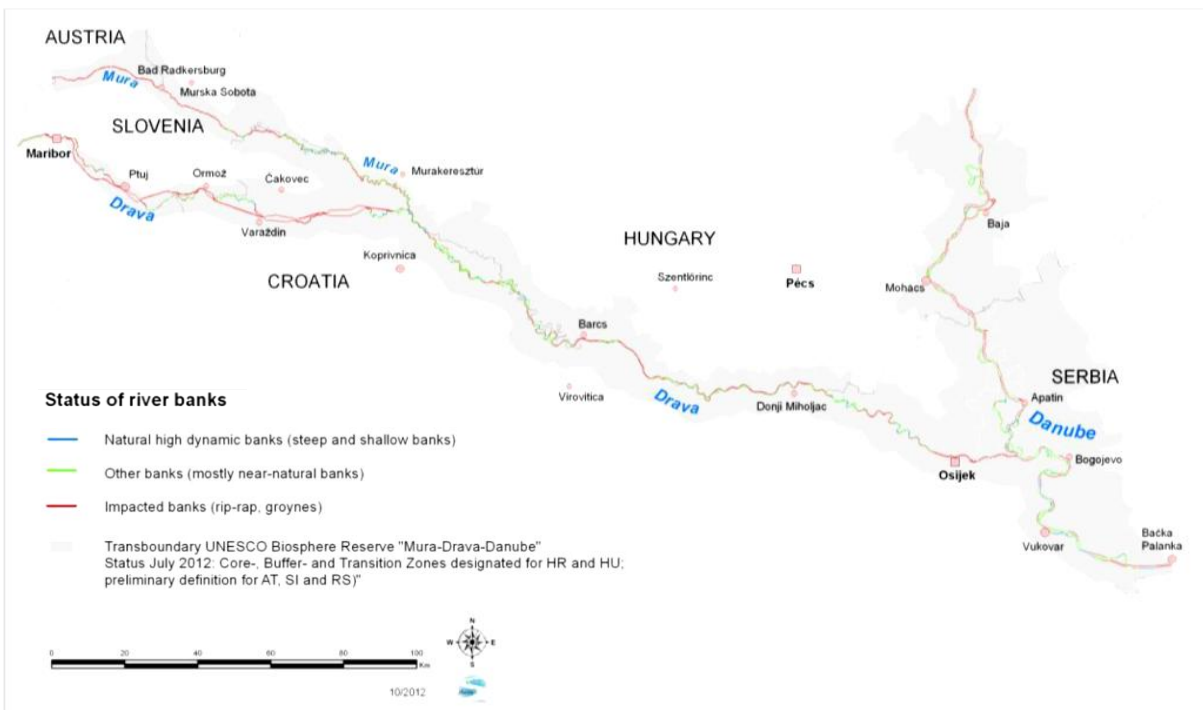


Figure 4-2. Example of the status of river banks in a section of the Danube River Basin (adapted from Schwarz, 2013).

Key activities that have contributed to ecological degradation include the channelization of waterways for navigation, building of flood defences, hydropower developments, and extractions of gravel and sand (ICPDR, 2008). As is common across Europe, flood protection works have been a major contributor to the loss of floodplain areas due to the traditional approach of building defences to confine water within the river channel (Hohensinner & Drescher, 2008). This has resulted in a progression of engineering works that have disconnected floodplain areas from river systems, accompanied in many areas by agricultural expansion and in others by urbanisation (Habersack et al., 2014). Signing of the Danube River Protection Convention in 1994 marked a step-change for river management. This established the International Commission for the Protection of the Danube River (ICPDR) for the purposes of facilitating a more sustainable approach to river management that addresses the competing water uses (ICPDR, 2009). In addition, a series of severe floods across Europe around the turn of the century forced a re-think in approaches to flood risk that resulted in heightened awareness of the role of floodplains in flood management (Barredo, 2007; European Commission, 2013). Together with increased attention to biodiversity targets these developments have set the scene for a concerted focus on floodplain restoration across the basin that has grown steadily over the years.

Early initiatives began in the 1990s (Schiemer et al., 1999; WWF 2000; 2002) and were assisted by low economic returns from agricultural polders (low-lying land enclosed by dikes) together with improved recognition of restored floodplains as a cost effective land-use alternative (Staras, 2001). Since then, studies in the DRB have reported a range of benefits associated with floodplain restoration, including reduced flood risks in the immediate catchments of restoration projects and downstream (e.g. Schober et al., 2015). The contemporary policy framework has also become more supportive of an integrated approach to river management in which ecological objectives are recognised. The three primary influences are the EU Habitats Directive, Water Framework Directive, and Floods Directive (Council of the European Communities, 1992; 2000; 2007). Considerable policy progress was made in the context of the current EU Floods Directive (Council of the European Communities, 2007) that includes attention to the avoidance of further ecological degradation. This demonstrates better alignment with integrated river basin management principles in comparison to the earlier philosophy (Habersack et al., 2015). In addition to these governance aspects, increased public awareness of the degradation of floodplains has been, and remains, an important factor driving the development of new approaches to river management in the DRB (Sommerwerk et al., 2010).

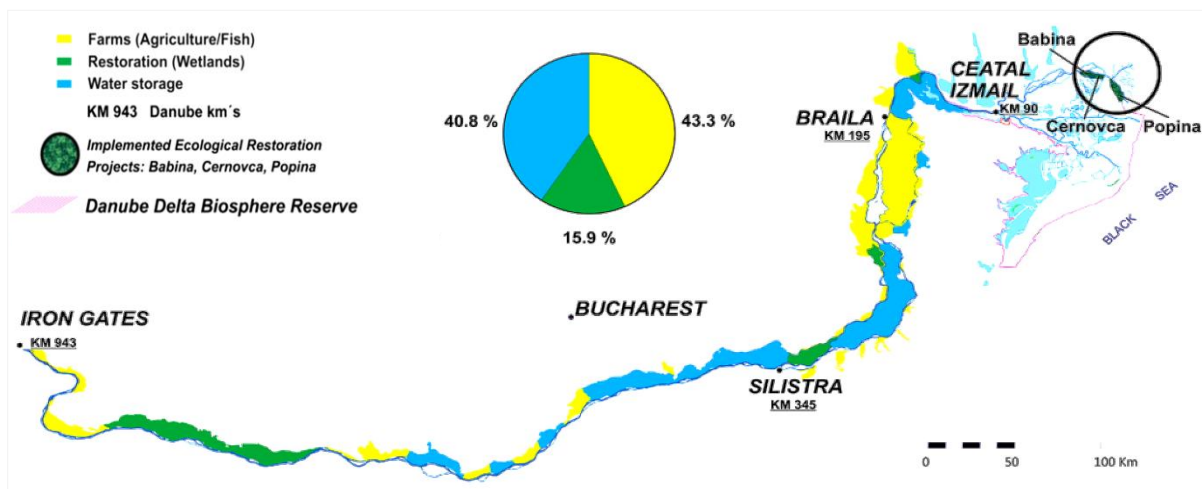
### Floodplain restoration in the lower Danube

The remainder of this case study focuses on the lower Danube where land use patterns and restoration initiatives include many aspects relevant to regeneration activities in the lower Ōtākaro / Avon River corridor. In particular, this part of the DRB is characterised by extensive channelization and river-bank engineering (Buijse et al., 2002). Many disconnected floodplains have been converted into agricultural areas and ponds for aquaculture, and systems of man-made channels are a commonly found for drainage (Staras, 2001). From a societal standpoint, conversion of the Lower Danube floodplains can be observed to have favoured a select few river uses at the expense of other user groups (Nichersu, 2006). Activities that have historically sought to restrict the natural flooding dynamics of floodplains include navigation, agriculture, and residential development (Moss, 2008).

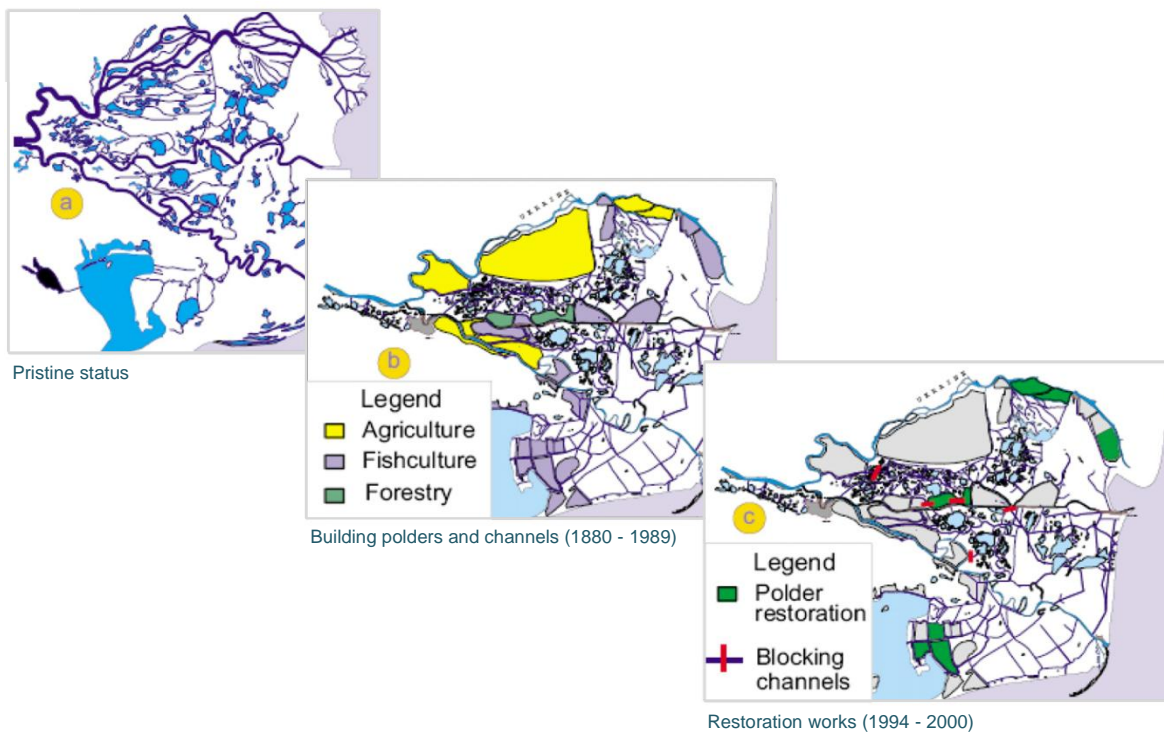
The consequences of these alterations have been the subject of many studies. Commercial fisheries reliant on the floodplain habitat have collapsed (Staras, 2001) providing an example similar to the loss of resources contributing to mahinga kai in the Ōtākaro / Avon River and wider Ihutai catchment (Pauling et al., 2007; Lang et al., 2012). Despite this, some areas experience increased water levels on flood peaks versus historical river states illustrating that flood risk management remains an issue (Schober et al., 2015). Human impacts have had a drastic effect on many aspects of floodplain ecology. Many of the effects on biota can be traced back to the curtailment of riverine dynamics, in most places associated with land use conversion. As a result, habitats characteristic of floodplain ecosystems are no longer regenerated by fluvial processes, leading to a cascade of effects on habitat

structure that may occur even when other aspects of the competing land uses do not pose a direct threat to biodiversity (Naiman, 1988).

A key step in facilitating a new river management approach in the lower Danube was establishment of an innovative project, the Ecological and Economical Resizing of Lower Danube Floodplain (REELD) (Covasnianu et al., 2010). REELD activities have included prioritising the restoration of selected areas to enhance habitat values, and evaluating opportunities for mixed-use polder concepts elsewhere that combine cultivation and water retention functions (Covasnianu et al. 2010). In general, REELD has been successful in resolving conflicting socio-economic demands for the use of the river and floodplains, as evidenced by a growing number of restored areas (Figure 4-3). Key restoration measures have included reconnecting areas cut off by embankments and the reinstatement of meanders that had been bypassed by engineered channels (Staras, 2001). Practical actions have included the blocking of man-made channels for drainage as well as the reconnection of polders through planned breaches of dikes (Figure 4-4).



**Figure 4-3.** Farmed floodplain areas and sites undergoing restoration in the Lower Danube including floodplains reverted to wetlands (green), and floodplains with restored water storage function (blue) (Hein et al., 2016).



**Figure 4-4.** Key phases in the history of ecological restoration in the Danube Delta (Adapted from Staras, 2001).



The results of these measures have typically been rapid recovery of floodplain structure and function (Zöckler, 2000). For example reconnected polders have increased spawning habitat availability for several fish species (Navodaru et al., 2005) and other benefits have included improved retention of nutrients and suspended solids (Schneider, 2002; Suciú et al., 2002).

### Challenges

Some of the challenges for the achievement and maintenance of restoration objectives in the lower Danube include invasive species and climate change (Hulea et al., 2009). Invasive species are a particular consideration in floodplain re-connection works since these may introduce undesirable exotic species into areas that were formerly protected by the absence of connectivity (Havel et al., 2015). The significance of these effects relates to the specific biodiversity and circumstances of the floodplain areas in question (Flanagan et al., 2015). Particular concerns in the AORZ could include improved access for predatory species or creation of invasion pathways for plant pests.

Climate change creates another set of considerations that interacts with species distribution and connectivity aspects, both unwanted and desirable (Mauser et al., 2012; ICPDR, 2013). As is the case in the Danube, lower Ōtākaro / Avon River corridor is exposed to sea level rise. This has the potential to exert widespread impacts due to the low-lying topography of considerable area within the AORZ. Many of the potential effects are interdependent leading to a complex set of considerations for attempts to engineer the system towards a targeted end state, or indeed, define which state is the most desirable (Flanagan et al., 2015). For example, Hein et al. (2016) considered that disconnected floodplain remnants of the lower Danube could exhibit amplified warming effects under climate change placing their biota at greater relative risk. Re-connection of water bodies could moderate warming effects though carries with it invasive species considerations as discussed above.

The many different combinations of stressors indicate that floodplain conservation and restoration will need ongoing attention and an adaptive approach. In the lower Danube, this is being addressed by a package of measures that include the recognition of impacts, and strategies designed to enhance the adaptive capacity of ecosystems under likely climate change scenarios (ICPDR, 2013). In general, floodplain re-connection offers several benefits that include buffering the effects of hydrological and thermal extremes and improved habitat connectivity for mobile species (Schiemer et al., 2007). However, incremental alterations to hydrological and thermal regimes remain likely effects of climatic change and are certain to influence the outcomes of floodplain restoration measures (Vaughan et al., 2009). The early detection of these changes is a key activity for restoration planning and longer term adaptation to climate change (ICPDR, 2013). Additional considerations include the need to address potential interactions between discrete restoration projects and sites as these evolve over time (Sommerwerk et al., 2010). This can be achieved through evaluation approaches that capture the outcomes of restoration at different spatio-temporal scales relevant to the system as a whole.

### Conclusions

The lower Danube case shows strong similarities in the land use patterns that have contributed to historical degradation of riverine wetlands in Ōtautahi Christchurch. Regeneration activities in the AORZ include opportunities to reverse legacies of previous land use development and reinstate more natural floodplain dynamics as well as improving resilience to new threats such as sea level rise. Restoration efforts in the lower Danube have tackled similar legacy issues albeit without the impetus provided by a large scale disturbance and government land acquisition response. However, the need to address the economic implications of alternative future land uses and the cost effectiveness of re-development strategies are aspects in common.

The long history of restoration projects in the Danube provide examples to learn from, and numerous principles that may be useful in the design of restoration strategies for the AORZ.

Key aspects to highlight include:

- Establishment of a strategic oversight organisation (in this case REELD) was useful to achieve the finer-scale planning needed and achieve stakeholder buy-in as necessary steps prior to the implementation of restoration treatments.
- Evaluation and prioritisation assessments have been used extensively to progressively identify opportunities and consider their impacts and alternatives. Cost-effectiveness was a consideration for restoration options assessment. This accounted for the cost to implement any particular change from the status quo versus its benefits and alternatives. Benefits have been assessed primarily against the policy objectives found in three high level directives addressing water, habitats, and flood risk.
- Enlargement of the active floodplain area has contributed to reduced flood risk in terms of lowering peak water heights in the immediate catchment and also downstream during flood events.
- Restored floodplain areas were found to retain suspended matter and nutrients thus improving eutrophic conditions in downstream water bodies. Thereby the floodplain acted as a filter in comparison to a previous drainage configuration characterised by constructed drains that discharged high nutrient and sediment loads into the natural waterways effectively bypassing any filtration or other interception function. An analogous situation exists in the AORZ and in other nearby catchments (e.g. the Ashley and Waimakariri) was observed to be exacerbated by earthquake induced ground level subsidence leading to increased run-off of polluted water into existing drains, accompanied in some cases by the construction of new drains creating further point source discharges.
- The creation of high value habitat to address conservation priorities, and mixed-use concepts elsewhere were features of the broad-scale restoration strategy applied to the former floodplain areas.
- A re-engineered hydrological regime was found to be a strong driver of change mostly associated with improved ecological outcomes. Natural habitats typically recovering quickly in response to floodplain reconnection. Increased hydrological connectivity improved habitat availability for many aquatic species such as fish. Moreover, this presented a highly cost effective technique for ecological restoration in many cases requiring only the alteration or removal of former defences.
- Reconnection of meanders and lentic water bodies was used extensively to improve habitat and ecological connectivity. This caused some negative effects on species adapted to conditions on floodplain remnants. Invasive species benefitting from improved connectivity are another consideration.
- Reinstatement of natural erosion dynamics and lateral (bank) erosion in particular, are critical aspects of natural floodplain function being essential for the self-maintenance of the full range of dynamic riparian habitats.

## 5. Adaptive management

Overcoming the challenges posed by the complexities of eco-hydrological relationships and the societal demands on rivers are core issues for successful approaches to floodplain restoration and management (Schiemer et al., 2007). One of the best frameworks for overcoming these challenges in a practical manner is through the implementation of an adaptive approach (Ball, 2008; Folke et al., 2005; Norton, 2005). The core concept involves an iterative process whereby complexities may be addressed sequentially in both the societal and ecological dimensions of the system. This approach provides opportunities to resolve the many difficult decisions regarding priorities, reference states, techniques, and trade-offs that are typical of river restoration (Nilsson et al., 2007). Key benefits include the opportunity to incorporate successive cycles of learning and application to refine the overall trajectory of a project towards optimal outcomes as these become more obvious over time (Pahl-Wostl, 2006). These learning opportunities may be applied within a programme of scientific investigations designed to explore the likely responses to alternative strategies at various scales, or as an aspect of social learning and motivational work with the wider community, and many combinations thereof.

One of the prominent international examples of this approach to river restoration is the Kissimmee River Restoration Project in central Florida. The project aims to restore the ecological integrity of a degraded river corridor that resulted from channelization for flood control purposes in the 1960s. The project area includes 70 km of river channel and approximately 11,000 ha of floodplain wetland. Although this is some 20 times the size of the AORZ regeneration project there are many similarities. A particular feature is the adaptive management approach taken, supported by a series of outcome evaluations. After several years of implementation these provide useful information on the success of the restoration strategies used.

## Case Study 2

### Kissimmee River Restoration Project

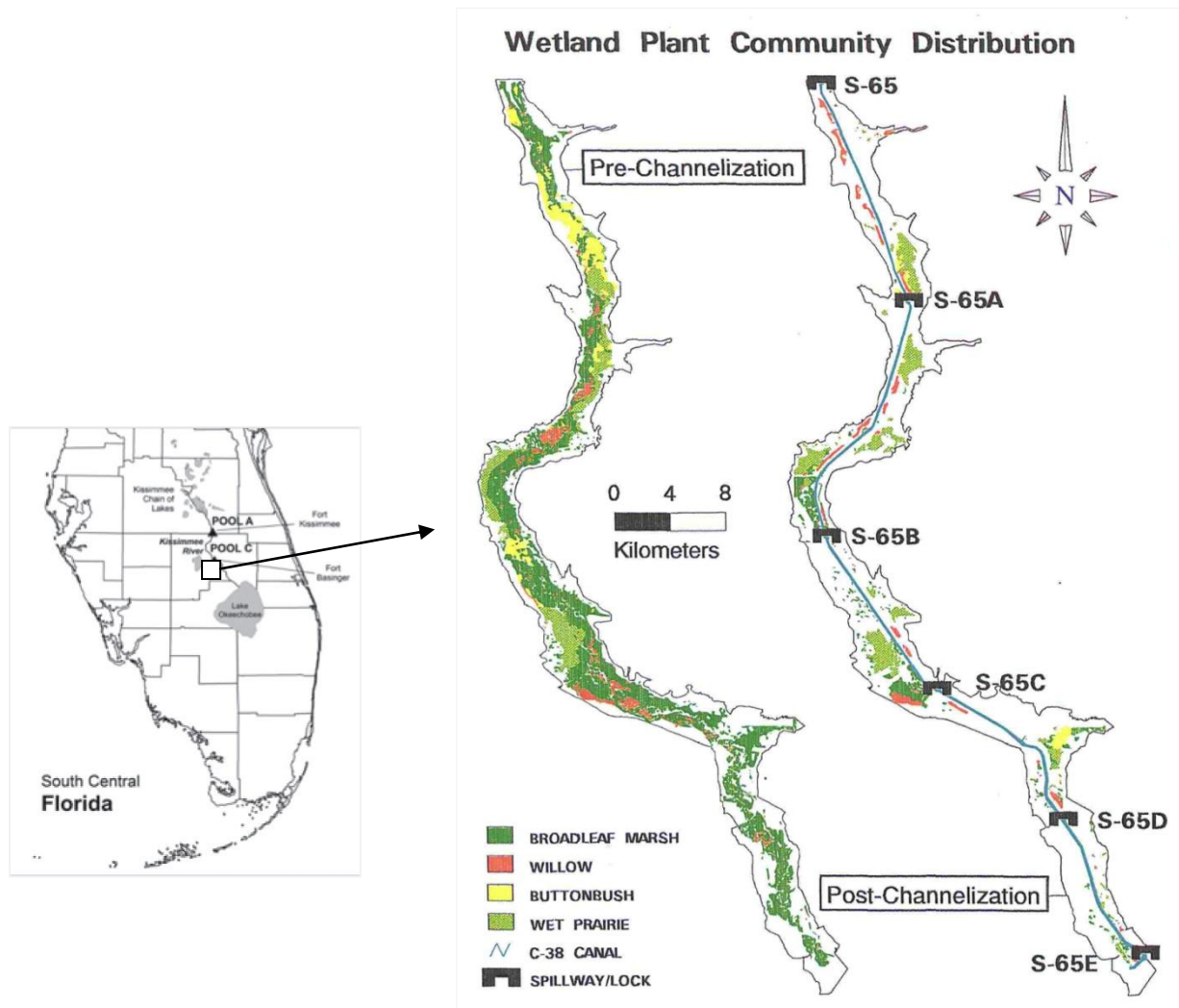


#### Overview

The Kissimmee River runs between Lake Kissimmee and Lake Okeechobee in central Florida. The historic river ecosystem was characterised by a meandering somewhat braided channel situated within an extensive riparian floodplain (Toth et al., 1995). Under a flood control programme, the river channel was dewatered and replaced with a 9 m deep, 100 m wide excavated canal (U.S. Army Corps of Engineers, 1956). Accompanying this, a series of embankments were created and the floodplain water table lowered by drainage channels over a large area of the river corridor. This work was completed in 1971 and caused the loss of a large area of the former floodplain ecosystem (Figure 5-1).

Over time, the negative impacts of the channelization project began to attract political attention (Loftin et al., 1990) with a particular focus on the degradation of waterfowl habitat in addition to other historic aquatic and wetland values of the area (Bousquin et al., 2005). This led to calls for restoration of the former ecological structure and function resulting in federal authorisation for the Kissimmee River restoration project in 1992 (Dahm et al., 1995; Toth et al., 1995). Re-engineering of the river channel commenced in 1999 and has progressed through several stages. Key aspects of the wider restoration strategy include acquiring land in the catchment adjoining the river, re-establishing historic discharge

patterns, and reinstatement of more natural river channels (Bousquin et al., 2005; Toth, 2015). All of these restoration treatments are applicable at various scales within the AORZ.



**Figure 5-1.** Location of the Kissimmee River restoration project in central Florida showing the pre-channelisation (natural) and post-channelisation (degraded) distributions of dominant wetland plant communities (Toth et al., 1995).

Prior to channelization and floodplain drainage, the hydrology of the Kissimmee River was characterised by prolonged overbank flooding (Toth et al., 1998). This was likely a major driver of ecosystem structure and function a mosaic of aquatic, riparian and ephemeral habitats that supported a rich biota of wetland plant species, fish, and water birds (Warne et al., 2000). This example is especially relevant to the current opportunity presented by the AORZ due to similarities in the historical ecosystem types that were found in the area prior to modification (Tau et al., 1990). The restoration of these ecosystems and the cultural values they support remains of high importance to Ngāi Tahu (Jolly et al., 2013; Lang et al., 2012). An additional activity at Kissimmee was back-filling of sections of the drainage canal which has no direct comparison in the AORZ. However, remediation of these filled surfaces, and others formed by spoil deposits from the original canal excavation, bear similarities to the filled and compacted ground conditions that are present across a large proportion of the AORZ as a result of previous residential land uses and land clearance following the earthquakes.

Implementation of the Kissimmee project has involved four major phases of re-engineering to remove water control structures, backfill old canals and reconnect natural waterways channel and floodplains

(Bousquin et al., 2005). Other important steps have included land acquisition, a new headwaters regulation regime, and a restoration evaluation programme providing a feedback loop guiding implementation of the other steps (Figure 5-2).

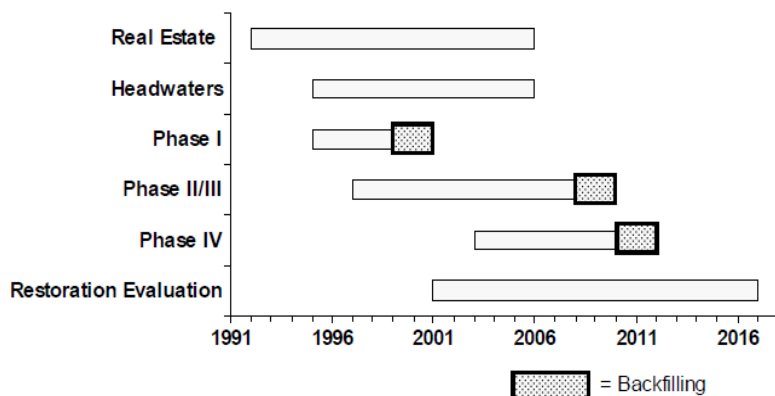


Figure 5-2. Major steps and timelines of the Kissimmee River Restoration Project (Bousquin et al., 2005).

### Key aspects of the Kissimmee project

#### *Ecological integrity objective*

From the outset, the Kissimmee River restoration identified the concept of “ecological integrity” as the overarching goal for restoration planning. This created an opportunity to shift away from more commonplace restoration examples that single out particular species or desired functions for attention, in favour of a more ecosystem-based approach (Dahm et al., 1995). In practice this was reflected in restoration objectives for a self-sustaining system and a focus on resilience to future events. The inclusion of resilience as a goal has similarly been recognised by Regenerate Christchurch in the Outline for the Ōtākaro/Avon River Corridor Regeneration Plan (Regenerate Christchurch, 2017). As with the Kissimmee case, inclusion of the concepts of resilience and sustainability in high level planning documents is important to guide and enable the possibility of managing for resilience in the more detailed design and implementation phases.

#### *Opportunistic socio-ecological context*

In the Kissimmee River case, the development of a restoration project and accompanying social buy-in for implementation was achieved in a context where the negative effects of past modifications were reversible. For example, over much of the project area land development patterns had not advanced to the stage where land acquisition for restoration was difficult or prohibitive. The socio-ecological context also assisted the development of an adaptive approach, due to the lack of competing interests that may have introduced uncertainty over whether a large scale and long term restoration project would eventuate. The AORZ may offer a similar socio-ecological context albeit generated by a different set of historical events. The acquisition of a large tract of contiguous land offers similar opportunities to consider ecosystem-level restoration objectives consistent with an integrated whole-of-system approach to river corridor restoration. This creates a unique opportunity since antecedent societal conditions often present challenges in the restoration of channelized river systems. Factors such as complex resource allocation arrangements and land tenures are commonplace and often prohibitive (Arthington et al., 2010).

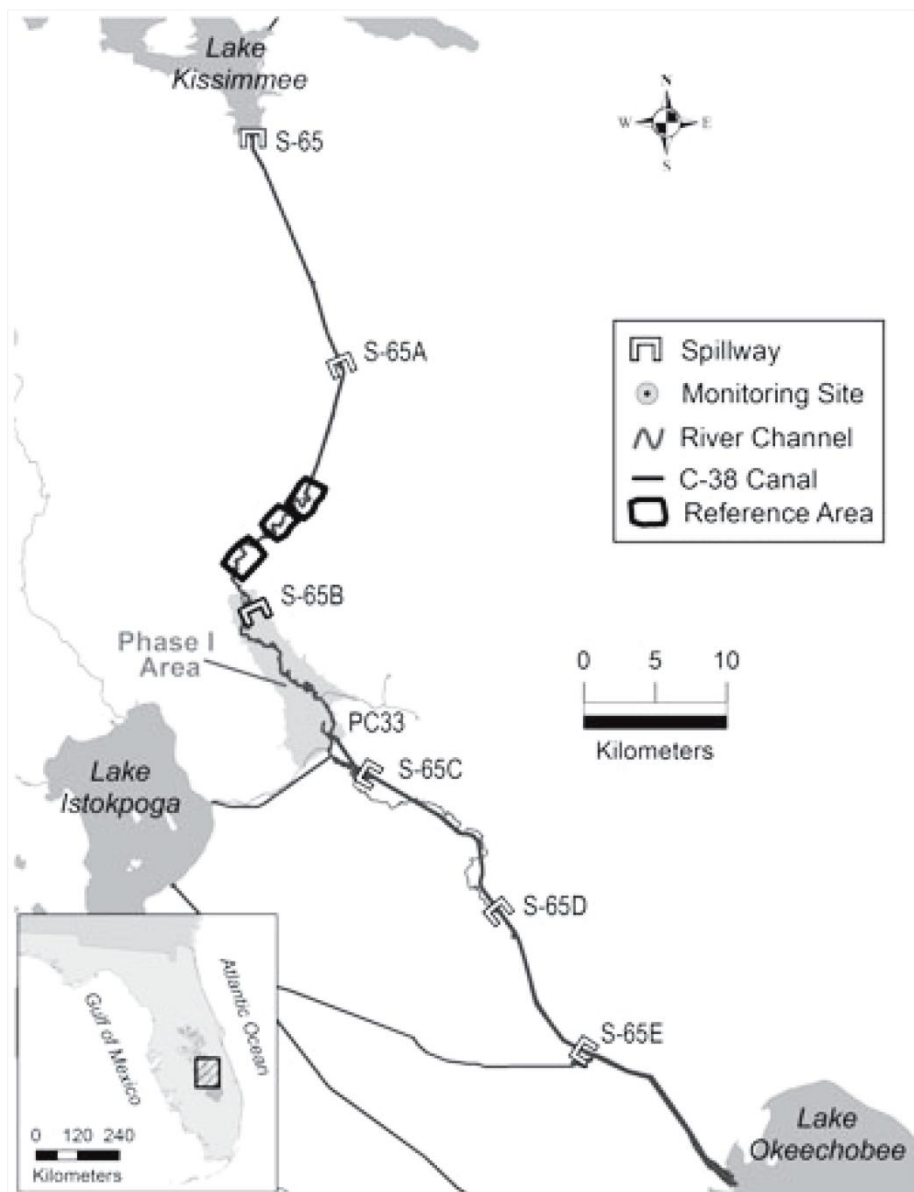
#### *Adaptive management philosophy*

The approach developed for the Kissimmee identified adaptive management as a core process that would direct restoration planning activities (U.S. Army Corps of Engineers, 1991). Although commitment to large scale re-engineering components was secured early on, the exact implementation of these was the subject of considerable experimentation. This approach was the

cornerstone of a strategy to maximise the eventual benefits despite that their accurate quantification was initially unknown. Given the unprecedented scale and cost (approx. USD\$620 million) of the restoration initiative (Bousquin, 2008) this philosophy is highlighted as a critical component that eventually contributed to the level of success.

#### *Information acquisition using pilot projects*

Demonstration and pilot projects were used to overcome technical questions and produce information on the expectation restoration trajectories of key components of the ecosystem (Figure 5-3). Examples included backfilling demonstration areas monitored for five years to identify technical issues regarding soil stability (Anderson, 2014). Social elements were also included to identify the changing public perceptions for the project and its potential future benefits (Koebel & Bousquin, 2014). The results of the demonstration projects were documented in a symposium volume (Loftin et al., 1990), technical bulletin (Toth, 1991), and several peer-reviewed papers.



**Figure 5-3.** Map of the Kissimmee River from Anderson (2014) showing the locations of the reconnected river channel in the Phase I of the restoration project water control structures, and reference areas where the demonstration study was conducted. Note that the control structure S-65B was removed as part of the restoration project.



A similar approach could be useful in the AORZ to evaluate impacts of embankment reconfiguration at smaller scales to inform the prediction of restoration trajectories at larger scales, for example as part of a staged approach. Several studies have shown highly dynamic effects including rapid channel widening and downstream sedimentation associated with the release and recovery of previously retained river channels (e.g. Thomas et al., 2015) and incised river channels more generally (e.g. Beechie et al., 2008). Pilot studies could be a useful approach to assess and manage these effects.

Other studies at Kissimmee sought to relate small scale river dynamic manipulations to the overarching project objective of ecologic integrity (Toth et al, 1998). The findings are likely transferable with regard to this objective. The key conclusion that emerged was the reinstatement of natural hydrologic regimes as a central strategy for restoring floodplain ecological integrity (Anderson, 2005). Consequently, this became the central restoration objective. Remaining practical considerations included the definition of appropriate reference conditions and acquisition baseline measurements against which restoration predictions could be made to support more detailed planning, and outcomes assessed to gauge progress (Bousquin et al., 2005).

#### *Re-establishing dynamic components of the environment*

Acceptance of a shifting and highly dynamic biodiversity pattern in time and space is a central issue for wetland restoration (Zedler, 1988) and a necessary aspect for ecological integrity and self-maintenance as restoration objectives. At Kissimmee ecological integrity has been promoted primarily through restoration of floodplain structure and function. Although predictions of expected responses have also received consideration (e.g. as summarised in Anderson et al., 2005) and they have generally not driven the restoration strategy (Toth et al., 1995). Core restoration activities have included re-establishing spatial and temporal diversity in river corridor habitats through attention to aspects such as channel morphology, deposition dynamics, and discharge variability, many of which have inter-related effects. At larger scales the expected biotic outcomes include reinstatement of a mosaic of habitat conditions. At the finer scale the resultant species assemblages have not always met *a priori* species dominance predictions (e.g. Toth, 2016).

The identification of hydrologic components including variability is an innovative aspect of the restoration approach differing markedly from criteria based on a deterministic optimum. Implications include the need for continual re-evaluation to inform a restoration strategy that is designed for adaptive re-adjustment (Suding, 2011). Although expert and local knowledge has been employed extensively in the development of expectations for restoration trajectories, assembly rules have been found to be of limited use past the initial phases of restoration (Toth & van der Valk, 2012). Vegetation studies (e.g. Toth, 2015; 2016) have shown that continuing dynamics are often the source of confounding factors for the attainment of long term goals. Examples include both new and legacy effects and their interaction over the successional timeframe important to key ecosystem components.

#### *Monitoring & evaluation process*

Throughout the Kissimmee project, feedback from the ecosystem and the human users has driven adaptation of the process. The core evaluation model made use of a GIS-based hierarchical habitat classification scheme and accompanying bio-physical data. This accommodates a multidisciplinary approach that includes monitoring of many aspects (e.g. hydrology, substrates, chemistry, flora and fauna). The need for comprehensive monitoring to evaluate the success of the restoration project was identified early in project development and documented within the final Integrated Feasibility Report (IFR) for the project (U. S. Army Corps of Engineers, 1991).

Development of the evaluation programme has itself produced an exemplar for other projects in the USA and further afield (Bernhardt et al., 2005). As is the case in the AORZ, opportunities for benefits spanned both land and water environments. Conceptual models of restoration benefits linked to monitoring programmes designed to detect them were developed for many components of the project site and adjacent area (e.g. nearby communities). These included aspects of the vegetation, avifauna,

fish, and invertebrates, as well as the health of the overall ecosystem (Dahm et al. 1995). The initial evaluation framework was documented (Anderson & Dugger, 1998) as were the processes used to develop expectations for specific restoration actions (Toth & Anderson, 1998) supporting opportunities for re-evaluation and learning in both the societal and biophysical aspects of the project.

Biophysical aspects of the monitoring and evaluation effort was organised around four major topics: ecological, hydraulic, sedimentation, and stability (U. S. Army Corps of Engineers, 1991). The ecological components included specific attention to water quality, habitat, threatened and endangered species, birds, fish and fisheries as part of comprehensive approach to support the restoration objectives (Table 5-1). Before-after-control-impact (BACI) analyses (Stewart-Oaten et al., 1992; Underwood, 1992) have been used to assess many of the evaluation questions (Bousquin et al., 2005). This approach considers the restoration treatment as the impact and evaluates the response against a similar area that has not been treated (the control). The experimental and staged approach to the restoration has specifically set aside control areas to enable this type of study and the results used to inform future stages.

**Table 5-1.** Components of the baselines studies and ongoing monitoring programme for the Kissimmee River Restoration Project (from Bousquin et al., 2005).

Baseline Study	Ecology/Fish and Wildlife					Hydraulics	Sediment	Stability
	Birds	Fish/ Fisheries	Habitat	Water Quality	Threatened/ Endangered Species			
Hydrology			X			X		
Geomorphology			X				X	X
Water Quality			X	X				
Dissolved Oxygen			X	X				
River Channel Vegetation			X					
Vegetation Classification			X					
Vegetation Mapping			X					
Floodplain Vegetation			X					X
Algae			X					X
Invertebrates								X
Fish		X						X
Reptiles and Amphibians								X
Birds	X				X			

### Vegetation responses

In 1998, a network of sampling locations was established to evaluate restoration responses of wetland plant communities compared to reference sites outside of the restoration area (Toth, 2005). Another study used daily stage data to calculate hydroperiods and inundation depths at the study sites for comparison to historic floodplain dynamics (Toth & van der Valk, 2012). The results showed that the dechannelisation programme had re-established a flood-pulse regime that was comparable to historical patterns. Results from vegetation monitoring showed that rapid vegetation change had occurred following reinstatement of a more natural flooding regime, as expected. The major changes included the elimination of pasture grasses and facultative shrubs that were intolerant of the inundation regimes. However the predicted dominance of historically occurring (indigenous) wetland vegetation did not eventuate due to the spread of relatively new exotic species in the area (Toth, 2010; Toth & van der Valk, 2012).

A study based on species turnover rates (Toth, 2015) related these changes to invasibility aspects of the restored system versus the modified pre-restoration state. This highlighted that increased opportunities for invasion are fundamentally important to the restoration process following a 'working

with nature' type approach that depends on the extant seed bank for recolonisation of the hydrologically restored areas (Arnold et al., 2009). Since the same invasibility may offer opportunities to exotic species (Lonsdale, 1999), trials to quantify the likely effects are useful to inform the best strategies and investments that may be needed to ensure success. Potential issues include the availability of local seed sources (Markwith et al., 2014) and opportunities for exotic species to establish an alternative stable state (Holling, 1973) or long-term transient state (Fukami & Nakajima, 2011) that are counterproductive to restoration objectives (Toth 2016a; 2016b).

In other instances exotic species have been shown to assist the attainment of conservation objectives (Ewel & Putz, 2004; Schlaepfer et al., 2011). Risk assessment that addresses the specific restoration context provides a practical basis to address these important decisions. On sites that are already highly modified the human element is a key consideration in developing a philosophy on exotics and is strongly influenced by the objectives for indigenous species that are identified as being important.

## Conclusions

Many aspects of the Kissimmee Restoration Project are relevant to the regeneration potential of the AORZ. Of particular note is the substantial opportunity to apply the 'working with nature' approach. In the context of New Zealand's largest floodplain regeneration project to date this approach could improve cost-effectiveness if successful strategies can be identified in comparison to intensive treatments such as planting. In addition, the adaptive approach exemplified at Kissimmee provides a practical means to address knowledge gaps. These are likely to arise due to ecological succession processes whilst it is also important to manage for resilience to climate change. In combination, these are important aspects for managing risks to the expected benefits and to enable readjustment of objectives and investments as required.

Perhaps to a greater degree than any comparable project Kissimmee exemplifies the benefits of implementing action through experimentation and learning. A feature of the project has been the use of small scale studies to optimise the design of specific restoration treatments within an overall strategy. As in the Danube example, these treatments explored the potential gains offered by hydrologic restoration alongside other investments. However, additional innovative components include the use of whole-system conceptual models to guide the project, including the development of its experimental aspects, from the very beginning. This same opportunity is available to the AORZ.

Tangible results of this conceptual focus have included widespread buy-in for a focus on whole-system outcomes that accommodate multiple desirable objectives and are self-maintaining over time. This foundation is important since it enables a focus on integration across the many sources of potential benefits. In turn, the implementation of this strategy has required attention to trade-offs where they occur despite that the theoretical basis centres on the assumption that a more natural floodplain structure and function will support the greatest range of resources and values (Toth et al., 1995). To address this, the project has invested heavily in an ecosystem-based monitoring and evaluation programme to support restoration planning and adaptive decision making with a specific focus on establishing the outcomes that have, and could be achieved. This represents a comprehensive approach to dealing with uncertainty and decision making, whilst also providing evidence to confirm successes or otherwise at each step of the way.

The inclusion of local knowledge, for example in the recognition of historical patterns and considerations around reference states, is an additional strength of the project. Alongside this, the recruitment and retainment of a core multi-disciplinary team of people invested in the project is a defining feature that has helped facilitate the adaptive management approach. Governance and leadership have also been important aspects. Interagency coordination was a key focus from the outset and has helped to gain consensus on priorities and objectives, together with the measurement criteria to be used to gauge success and the approach required for implementation.

## 6. Environmental water allocation for floodplain restoration

Learning from the Kissimmee River project and elsewhere suggests that an experimental, adaptive approach to large scale river restoration can be successful. In that example, water control structures were progressively removed and channel configurations re-engineered in phases to create a staged approach coupled to an extensive monitoring and evaluation programme. A different though complementary approach involves planned watering of the floodplain whilst the existing water control infrastructure remains in place. All of these approaches can be related to the wider topic of environmental water allocation (EWA).

Within the AORZ the planned watering approach could be used to kick-start restoration of selected sites as pilot projects or as part of a wider adaptive programme. In particular, there are practical opportunities for diversion of flood flows to selected sites using existing stormwater network infrastructure. Such projects could be combined with the daylighting of sections of the current network, the creation of constructed wetlands to receive flows as part of a treatment train prior to discharge, and combinations of these integrated within a staged approach to reconnecting and restoring the hydrology of former floodplain areas. Examples of environmental water allocation elsewhere in Ōtautahi Christchurch include a recent Christchurch City Council proposal to create an urban forest in Woolston. The 2.75 hectare project will involve lowering ground levels at the site by up to a metre and diversion of stormwater from a nearby drain to create suitable hydrological conditions for the establishment of floodplain forest species.

In more heavily regulated river and estuarine systems, decisions on allocation of water to the environment require strategic planning to address competing resource demands, which may include flood protection demands, thereby ensuring the best range of outcomes. Worldwide, there has been increasing interest in EWA approaches to sustain floodplain and wetland values (Arthington et al., 2010). A prerequisite for this planning is comprehensive information on the flood-dependency of natural values. Although, floodplain plant communities are known to be structured by characteristics of the inundation regime predicting the ecological effects of hydrologic alterations is difficult (Olden & Naiman, 2010; Zelder & Callaway, 1999). There remain few examples where the specific flood pulse requirements of natural occurring vegetation have been established (Paillex et al., 2009; Toth & van der Valk, 2012). This topic will only become more important for lowland floodplain restoration strategies in New Zealand, and elsewhere, due to increasing human pressures on these systems coupled with the challenges posed by climate change. The following case study illustrates recent progress in this under-researched topic. The example comes from a Victorian government initiative that recognised the need for improved information on effects of flood pulse regimes on the natural values of the Murray River catchment (Ballinger & Mac Nally, 2006).

### Case Study 3

#### Murray River floodplain restoration



##### The Living Murray project

The Living Murray is a large scale river restoration programme established in 2004 with a focus on addressing negative effects of historic river regulation. In the lower Murray-Darling Basin (MDB) overbank flooding can only occur in extremely large flood events due to extensive river engineering. Much of this is designed to harvest flows for agriculture with water being diverted to irrigation storage

schemes. Overbank flooding occurs only when these are full (VEAC, 2006). This regulates peak water levels in downstream reaches with the effect of reducing the frequency and size of flood events experienced by most of the floodplain (DSE, 2008).

VEAC (2006) highlighted the long-term environmental impact that insufficient flooding is having on the survival of riverine forests and wetlands. Riverine flood events are critical for conservation of the region's biodiversity due to aspects that include maintaining ecological connectivity between otherwise fragmented habitat patches (Ballinger & Mac Nally, 2006). This connectivity is an important determinant on the geographic range of many plants and animals (VEAC, 2008b). Recently, the reduction in flooding has been exacerbated by continuing drought, and it is likely that the situation may worsen under climate change due to reduced rainfall and increased evapo-transpiration resulting in reduced runoff (DSE, 2008). Several studies have indicated that floodplain dewatering is having adverse effects on biodiversity including riparian forest habitats characterised by River Red Gum (*Eucalyptus camaldulensis*) and Black Box (*E. largiflorens*) (Cunningham et al. 2007; MDBC, 2003; VEAC, 2008a). It has also contributed to the development of acid sulphate soils (McCarthy et al., 2006) and has reduced opportunities for water-based recreation (VEAC, 2008b). Despite this, water allocations for environmental purposes were, until recently, restricted to a very limited number of floodplain sites, generally being 'icon sites' identified for particular conservation objectives (Leslie & Ward, 2002).

### Barmah-Millewa EWA initiative

In 2005 a Victorian government initiative began investigations into River Red Gum forests and associated ecosystems in the lower Murray-Darling Basin (MDB) with a focus on the impact of insufficient flooding on riverine forests and wetlands (VEAC, 2006). At the time, EWA initiatives were already being explored at the Ramsar-listed River Redgum (*Eucalyptus camaldulensis*) forests at Barmah-Millewa (Figure 6-1), one of the six icon sites for conservation (King et al., 2010). Historically, this floodplain area supported a diverse range of fish and other aquatic species that provided a major food source for the local aboriginal community (King, 2005) as did the lower Ōtākaro / Avon River for local Māori communities (Tau et al., 1990).

A series of EWA initiatives have been conducted at Barmah-Millewa following an experimental approach. This sought to generate information on ecosystem responses to inform the potential use of EWA at other sites under the Living Murray initiative, as well as achieve specific objectives at Barmah-Millewa. These target objectives included improving vegetation health, enhancing spawning and recruitment of native fish and frogs, and improving habitat for water birds (King et al., 2010). A large floodplain watering event was completed in the 2005-2006 summer, resulting in Australia's largest EWA initiative to date with the allocation of 513GL to the Barmah-Millewa floodplain. The bulk of the release made between October and December 2005 providing medium level flooding across over half of the floodplain area (King et al., 2010). Hypothesis driven studies were designed to test responses in relation to key ecological objectives and also to guide design of the inundation regime for the release. Significant results included evidence in support of several of the hypothesised ecological outcomes. These included enhanced vegetation growth, and stimulation of a major water bird breeding event (King et al., 2007; 2010).

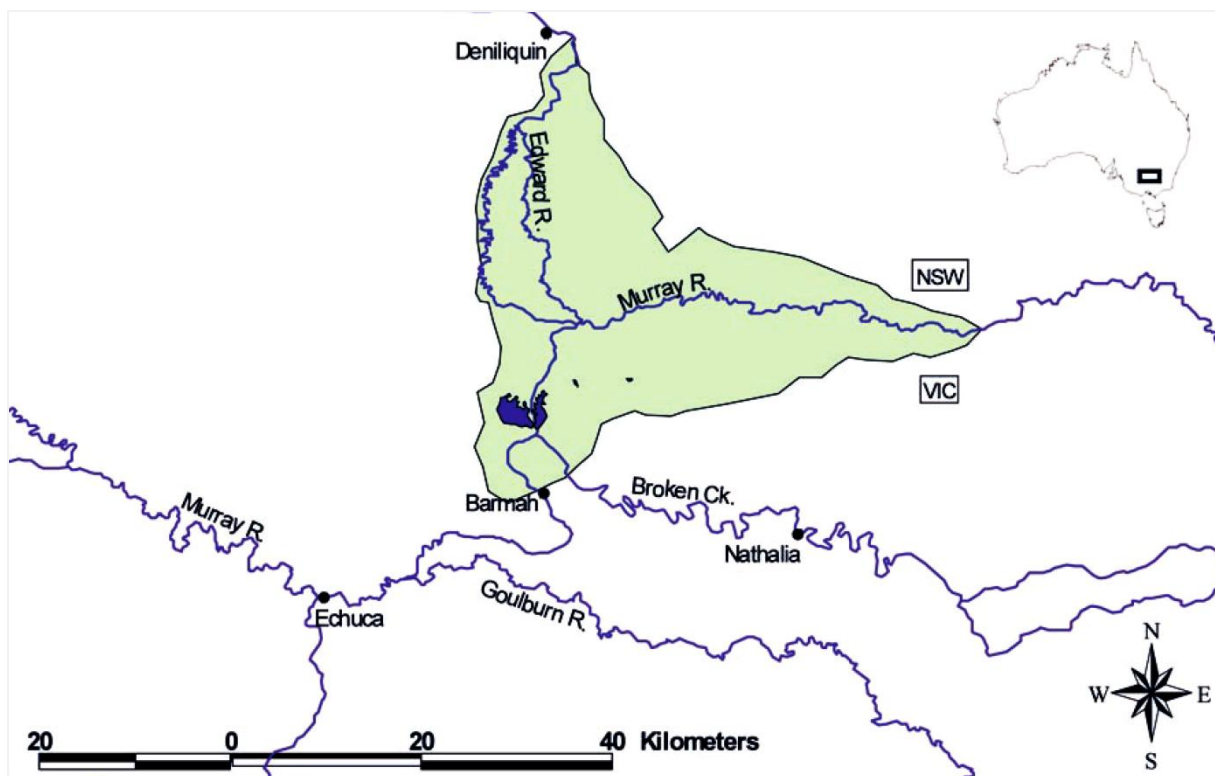


Figure 6-1. Location of the Barmah-Millewa forest in the Murray River catchment (King et al., 2007).

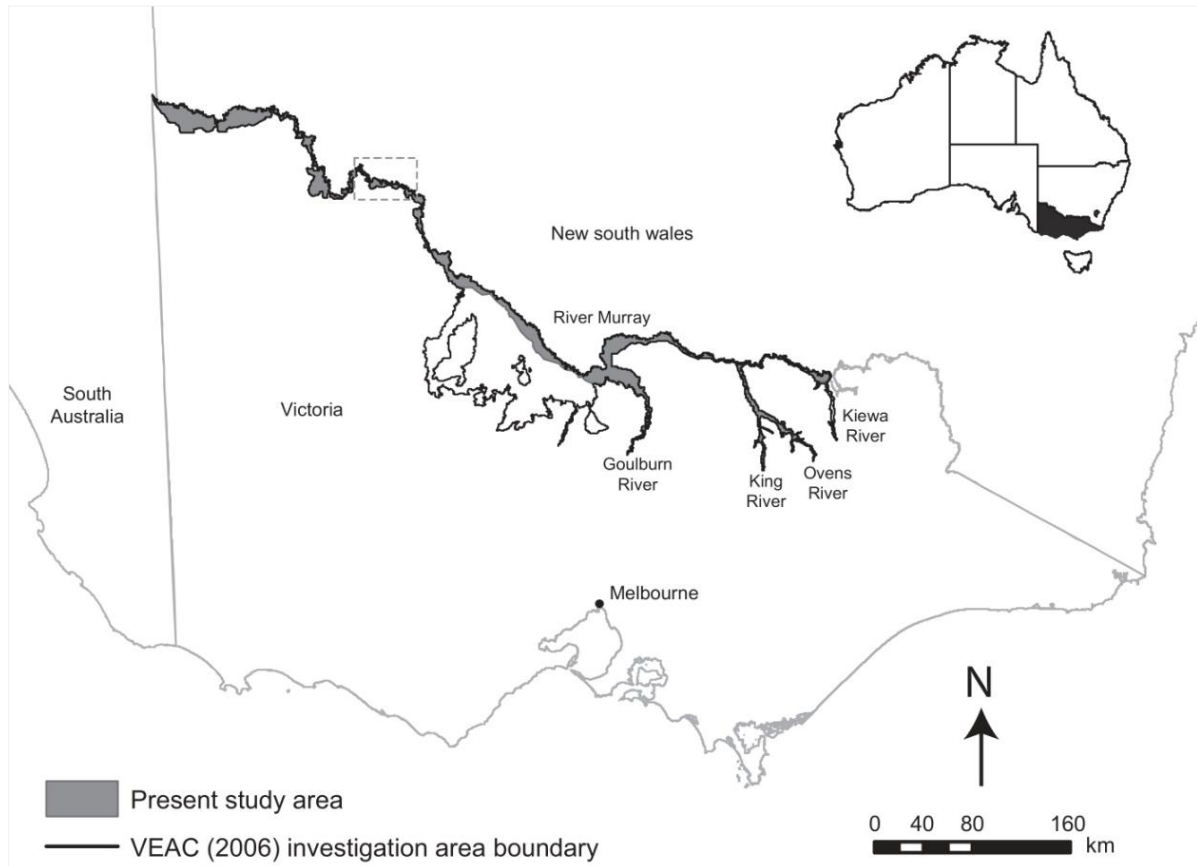
One of the knowledge gaps addressed was the effects of various water management arrangements on the spawning and recruitment of native fish species. To investigate these effects, the 2005 initiative was designed to support a three year study of effects on four key species (King et al., 2007; 2009). Two years of pre-EWA data were collected during which hydrological conditions were similar, and the third year of the experiment coincided with the period of floodplain inundation. The study showed increases in spawning activity occurred for two of the four species in response to the EWA, and despite some variability, evidence of enhanced recruitment for all species (King et al., 2009; 2010). Although knowledge gaps remain, these results demonstrate the potential for EWA to enhance fish spawning and recruitment. Less successful outcomes were also recorded including a large numbers of native fish being trapped in drying pools following the inundation period (Jones & Stuart, 2008). Other undesirable effects included increased spawning, recruitment and dispersal of exotic fish (Macdonald & Crook, 2006; Stuart & Jones, 2006) and increased spread of an exotic waterweed (King et al., 2010). As with the initiatives at Kissimmee, the learning gained from the experimental approach taken has helped raise awareness of the information gaps and complexities to be addressed in planning for future river restoration projects using hydrologic techniques.

### Establishing the flooding requirements of natural floodplain values

Globally, the habitat requirements of fish and birds have been commonly used as a guide for establishing inundation objectives in river and floodplain restoration projects (Miller et al., 2004; Welcomme, 2008; Turnhout et al., 2012; Twedt, & Best, 2004). Similarly, indicators based on fish and fisheries responses are often used as indicators for evaluation (Jungwirth et al., 2000; Lasne et al., 2007; Schiemer, 2000). There has been much less attention to establishing the inundation requirements of a wide range of species and habitats as is required to support more integrated approaches to floodplain management through simultaneously considering a range of natural values. An example is a study conducted by the Victorian Environmental Assessment Council (VEAC) in connection with restoration of the Murray River (VEAC, 2006, 2008a; 2008b). Its objectives were to support management decisions, particularly involving EWA, beyond a focus on the 'icon sites' to include the full extent of river's floodplain ecosystems.

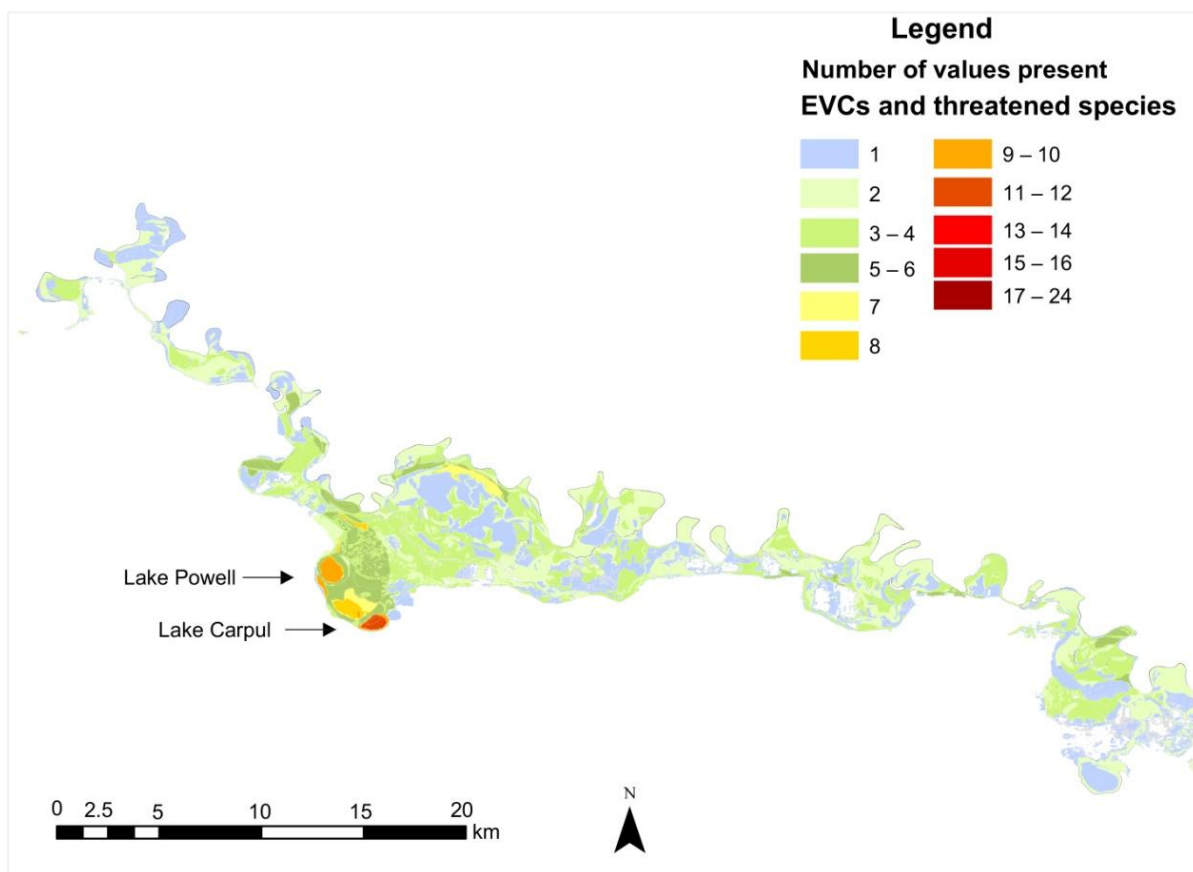


The analysis was applied to a large proportion of the Murray River and major tributary floodplain areas in Victoria (Figure 6-2). The study considered a broad range of natural values relevant to conservation planning and river management by using habitat units based on ecological vegetation classes (EVCs). These were identified and mapped using a classification system that considered a combination of floristic, life form and ecological characteristics (Peake et al., 2011; VEAC, 2008b).



**Figure 6-2.** Location of the study area for the VEAC flood-dependent natural values study. The area covered represents a contiguous length of the floodplain ecosystem on the Victorian side of the Murray River. The inset is the Robinvale area case study areas shown in Figure 6-3 (Peake et al., 2011).

Outputs included identifying the location and extent of vegetation communities that are at least partly dependent on flooding and therefore require attention in water management arrangements particularly in connection with river regulation (Figure 6-3). A range of scenarios were produced for these areas to illustrate options for management across multiple values. To support impact assessments, restoration planning and other decision making contexts the study provided estimates of inundation requirements for each natural value for components such as flooding frequency, maximum period without flooding and minimum duration of each flooding event before significant deterioration occurred (Peake et al., 2011).



**Figure 6-3.** An example of flood-dependent natural values mapped on the Victorian side of the River Murray in the Robinvale area (VEAC, 2008b).

Overall this study represents a practical approach to bringing together information on multiple values to support the development of an integrated management approach. Although it was applied to a much larger area than required for regeneration planning in the AORZ the underlying philosophy and range of natural values considered are highly relevant. The use of GIS-based data visualisation techniques are a strength of the approach used in the Victorian study. The spatial data can be used for scenario modelling to compare the outcomes of different EWA opportunities and potentially other restoration techniques across the entire project area, producing a useful tool for identifying trade-offs and optimising promising strategies. Spatially explicit scenarios may also be readily visualised for the public providing a platform to support community engagement and public input to the scenario generation and evaluation process. A similar approach offers a potentially useful decision support tool to support conservation planning and adaptive management in the Ōtautahi Christchurch context.

## Conclusions

The allocation of water to and across the riparian margins of waterway channels is a fundamental issue for floodplain management, particularly where these areas are subject to human impacts. In this context, allocation is defined in a whole-system sense with particular focus on the distribution of water across the catchment and deviations from the natural pattern. Such deviations can exert differential effects in different parts of the catchment and may include altered hydrological gradients and flood pulse characteristics of riparian and floodplain areas. Human modification may originate by many means including via abstraction of in-stream flows, impoundment of water in dams, floodplain dewatering through the use of embankments, or lowering of groundwater levels using incised drainage channels (Tockner et al, 2008).

In the AORZ context, in-stream abstraction is not generally an issue (with the exception of the potential effects of alpine river abstraction on spring flows) and impoundment is restricted to

stormwater detention facilities designed to lower flood risk, primarily in upstream reaches. However, floodplain dewatering through embankments and artificial drainage are prominent features of the AORZ. For conservation and restoration activities the significance of water allocation does not so much revolve around a single preferred hydrologic configuration given that regeneration of the AORZ may include a variety of land-uses. Continued use of hard defences and/or engineered drainage patterns may be desired for some AORZ land-uses together with the need to address flood risk in adjacent residential areas. However it is a useful concept to explore in the context of hydrologic restoration. As shown in the Kissimmee case, restoration of a more natural hydrologic regime can be adopted as a core objective. The Murray River case shows how the same concept may be adapted and applied within a highly regulated allocation context.

A potential approach to environmental water allocation within the AORZ involves commitment to a staged progression of hydrologic changes once decisions on the range of land uses and role of existing defences have been made. Re-engineering of drainage and flood defence arrangements can then be planned to drive desirable changes in riverine and floodplain ecology through effects on both water level and salinity regimes.

There are at least two major knowledge gaps that will require attention. These are:

- (a) Impacts of drainage and flood defence decisions on hydrodynamics within the AORZ, together with evaluation of the ecological effects on restoration opportunities and objectives. Key topics include establishing the likely eco-physiological effects on desirable habitats, possible alternatives, spatial patterns, and successional trends.
- (b) Re-evaluation of the longer term sustainability of potential restoration strategies. In keeping with current climate change adaptation policy this assessment requires consideration of at least a 100 year planning horizon with sea level rise being an obvious physical driver that will exert widespread effects. In practice this is amenable to an iterative process whereby various hydrologic scenarios could be evaluated for resilience over time following the recommended guidelines for the assessment of climate risk.

## 7. Floodplain restoration principles

Several strong themes can be identified from the literature reviewed and cross-case comparisons presented in this study. Many of these are relevant to regeneration planning in the AORZ and could usefully inform the development of an innovative, integrated, and forward thinking approach.

Key transferable principles that could be applied are:

- The regeneration of more natural hydrological regimes is a core potential strategy that may underpin the attainment of other benefits through influences on ecological structure and function. A re-engineered hydrological regime is a strong driver of change often associated with improved ecological outcomes.
- The attainment of a self-maintaining system is promoted by restoring natural hydrodynamic regimes, together with associated disturbance, erosion, and deposition processes. Reinstatement of natural erosion dynamics and lateral (bank) erosion in particular, are critical aspects of natural floodplain function being essential for the self-maintenance of the full range of dynamic riparian habitats. This requires a degree of tolerance of channel migration.
- A fundamental step for restoration planning is an assessment of floodplain reconnection potential with regards to existing channel configurations and former floodplain remnants (such as ox-bows). Reconnection of meanders and lentic water bodies has been used extensively to improve habitat and ecological connectivity. This has caused some negative effects on

species adapted to conditions on floodplain remnants and invasive species benefitting from improved connectivity are an additional consideration. However, natural habitats typically recover quickly in response to floodplain reconnection. Increased hydrological connectivity offers improved habitat availability for many aquatic species such as fish. Moreover, this presents a highly cost effective technique for ecological restoration in many cases requiring only the alteration or removal of former flood defences.

- Environmental water allocation is a useful concept to explore in the context of hydrologic restoration. The concept may be applied in the sense of periodic restoration of lost hydrological connections or as a component of a staged approach to floodplain reconnection associated with the progressive retreat of flood defences and other forms of drainage. In each case, optimisation of the environmental allocation is assisted by establishing the likely ecological responses to hydrological manipulation in target areas, together with associated effects on natural values and key habitats.
- A focus on high value habitat to address conservation priorities, and on mixed-use concepts elsewhere provides a potential framework for restoration planning. A systematic and spatially explicit assessment of the flood-dependency of natural values is a useful decision tool that supports trade-off assessment when allocating or restricting natural flows.
- An adaptive management approach provides a practical means to address knowledge gaps and predictive challenges such as those arising from complex relationships, ecological succession and the future effects of climate change. Assessment of restoration potential also requires attention to societal aspects such as competing uses. These aspects may be supported by an iterative and adaptive approach with a focus on identifying opportunities and issues as they arise using the best available information.
- Evaluation and prioritisation assessments are beneficial throughout the adaptive management cycle to progressively identify opportunities and consider their impacts and alternatives across multiple values. Whole-system conceptual models can be useful to guide project development and identify information requirements and implementation options.
- Investment in a comprehensive monitoring and evaluation programme supports restoration planning, innovation, and adaptive decision making with a specific focus on establishing the outcomes that have, and could be achieved. This also helps reduce risks associated with uncertainty and change.
- Small scale pilot studies and demonstrations offer opportunities for innovation and experimentation. These may help inform the design of larger scale initiatives and provide opportunities for community engagement, participation, and learning.
- Recruitment and retainment of a multi-disciplinary science team provides practical support for an adaptive management approach centred on iterative cycles of design, implementation and learning. The inclusion of local and traditional knowledge and practical know-how are important elements. Science outreach, communication, and participatory opportunities are additional aspects that support the cross-sector and cross-disciplinary integration needed.
- Governance and leadership are important aspects. Attention to interagency coordination and strategic oversight functions help to achieve stakeholder buy-in, gain agreement on priorities and objectives, establish suitable measurement and reporting criteria, and identify opportunities for implementation.



## 8. Key conclusions

There are internationally proven strategies available for hydrological and ecological restoration in the AORZ. These approaches are consistent with a city-to-sea philosophy for river corridor regeneration that accommodates ongoing dynamics including ecological succession, climate change, and resilience to sea level rise.

Due to the difficulty of producing accurate *a priori* predictions of complex eco-hydrological relationships and expectations for restoration and successional change, an adaptive management approach is recommended.

A feature of prominent and successful river corridor restoration projects has been the assembly of a core science and information management team able to support and guide the development and implementation of an adaptive management approach. Local and traditional knowledge, practitioner know-how, and technical expertise in ecosystem-based management and the restoration ecology of key taxa are some of the recommended knowledge and skill sets for inclusion. Attention to governance, outreach, science communication, and citizen science activities are additional dimensions that can support the successful implementation of adaptive management in practice.

Comparative evaluation of restoration options can occur at many different points within an adaptive management cycle to facilitate decision-making. These assessments may help refine or select a short list of options at strategic decision points before committing resources to greater levels of detail. These aspects may be readily included in the proposed Integrated Assessment activities and Better Business Case evaluations being developed to support the regeneration planning process for the AORZ.

An adaptive approach can accommodate experimental trials, pilots and innovative demonstrations at small scales to inform the design and planning of larger scale initiatives.

Close proximity to the central city provides many opportunities for community engagement, education, and experiential activities to feature prominently in the development, design, and implementation of restoration strategies. These have been shown to be the source of beneficial outcomes in other successful projects, including through the socialisation of restoration objectives, and by encouraging participation, buy-in, and ownership of the new management paradigms that may be implemented.

The *process* of developing and implementing an adaptive management strategy could be a significant source of benefits in relation to overall project objectives. Attention to, and development of this process is an important component of identifying specifications for ecological restoration in the AORZ, consistent with a socio-ecological systems approach to managing common-pool natural resources. The objective of developing and implementing optimum restoration and regeneration activities lies at the centre of this process and is dependent on it. To address this further, information on the potential opportunities and benefits offered by innovative restoration processes were among the topics addressed at the ERO workshop (Orchard et al., 2017).

Ecological restoration activities in the AORZ offer an unprecedented opportunity to address national priorities including the remediation of legacy effects on lowland biodiversity and associated cultural values. Through attention to design and integration between compatible activities and co-uses ecological restoration can be achieved alongside, or incorporated within other beneficial land use options.

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## 10. References

- Allen, J., Davis, C., Giovinazzi, S., Hart, D. E., Cochrane, T., Deam, B., De Pascale, G., Hicks, M., Holland, D., Hughes, M., Johnson, L., Ko, S. Y., Measures, R., Quigley, M., Rix, G., Siembieda, W., Stark, N., Teasley, R., Wotherspoon, L., & van Ballegooy, S. (2014). Geotechnical & flooding reconnaissance of the 2014 March flood event post 2010–2011 Canterbury earthquake sequence, New Zealand. Report No. GEER035.
- Amoros, C., & Bornette, G. (2002). Connectivity and biocomplexity in waterbodies of riverine floodplains. *Freshwater Biology*, 47(4), 761–776. doi:10.1046/j.1365-2427.2002.00905.x
- Anderson, D. H. (2014). Geomorphic responses to interim hydrology following Phase I of the Kissimmee River Restoration Project, Florida. *Restoration Ecology*, 22(3), 367–375. doi:10.1111/rec.12061
- Anderson, D. H., Bousquin, S. G., Williams, G. E., & Colangelo, D. J. editors. (2005). Defining success: expectations for restoration of the Kissimmee River. South Florida Water Management District, West Palm Beach, FL, USA. Retrieved 10 April 2017 from [https://www.sfwmd.gov/sites/default/files/documents/krr\\_volii\\_expectations.pdf](https://www.sfwmd.gov/sites/default/files/documents/krr_volii_expectations.pdf)
- Anderson, D. H., & Dugger, B. D. (1998). A conceptual framework for evaluating restoration success. *Transactions of the North American Wildlife and Natural Resource Conference* 63:111–121.
- Arnold, G. v. d. V., Toth, L. A., Gibney, E. B., Mason, D. H., & Wetzell, P. R. (2009). Potential propagule sources for reestablishing vegetation on the floodplain of the Kissimmee River, Florida, USA. *Wetlands*, 29(3), 976–987. doi:10.1672/08-156.1
- Arthington, A. H., Naiman, R. J., McClain, M. E., & Nilsson, C. (2010). Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities. *Freshwater Biology*, 55(1), 1. doi:10.1111/j.1365-2427.2009.02340.x
- Avon Ōtākaro Network (2013). Avon Ōtākaro Network Charter, updated July 2013. Avon Ōtākaro Network, Christchurch, N.Z. Retrieved 10 April 2017 from <http://www.avonotakaronetwork.co.nz/f/40db45a5b17a77f.pdf>
- Ball, T. (2008). Management approaches to floodplain restoration and stakeholder engagement in the UK: a survey. *Ecohydrology & Hydrobiology*, 8(2-4), 273–280. doi:10.2478/v10104-009-0021-0
- Ballinger, A. & Mac Nally, R. (2006) The landscape context of flooding in the Murray-Darling basin. *Advances in Ecological Research*, 39, 85–105.
- Barredo, J. I. (2007). Major flood disasters in Europe: 1950–2005. *Natural Hazards*, 42(1), 125–148. doi:10.1007/s11069-006-9065-2
- Beattie, J. H. (1920). Traditional Lifeways of the Southern Māori. The Otago University Museum Ethnological Project 1920. (Edited by Atholl Anderson). Otago University Press, Dunedin, N.Z.
- Beavan, J., Motagh, M., Fielding, E. J., Donnelly, N., & Collett, D. (2012). Fault slip models of the 2010–2011 Canterbury, New Zealand, earthquakes from geodetic data and observations of postseismic ground deformation. *New Zealand Journal of Geology and Geophysics*, 55(3), 207–221. doi:10.1080/00288306.2012.697472
- Beechie, T. J., Pollock, M. M., & Baker, S. (2008). Channel incision, evolution and potential recovery in the Walla Walla and Tucannon River basins, northwestern USA. *Earth Surface Processes and Landforms*, 33(5), 784–800. doi:10.1002/esp.1578
- Beechie, T. J., Sear, D. A., Olden, J. D., Pess, G. R., Buffington, J. M., Moir, H., . . . Pollock, M. M. (2010). Process-based principles for restoring river ecosystems. *Bioscience*, 60(3), 209–222. doi:10.1525/bio.2010.60.3.7
- Beesley, L., King, A. J., Gawne, B., Koehn, J. D., Price, A., Nielsen, D., . . . Meredith, S. N. (2014). Optimising environmental watering of floodplain wetlands for fish. *Freshwater Biology*, 59(10), 2024–2037. doi:10.1111/fwb.12404
- Benke, A. C., Chaubey, I., Ward, G. M., & Dunn, E. L. (2000). Flood Pulse Dynamics of an Unregulated River Floodplain in the Southeastern U.S. Coastal Plain. *Ecology*, 81(10), 2730–2741. doi:10.1890/0012-9658(2000)081[2730:FPDOAU]2.0.CO;2
- Bernhardt, E. S., Palmer, M. A., Allan, J. D., Alexander, G., Barnas, K., Brooks, S., . . . Sudduth, E. (2005). Synthesizing US river restoration efforts. *Science*, 308(5722), 636–637. doi:10.1126/science.1109769
- Bousquin, S. (2015). Kissimmee River Restoration Project Fact Sheet. South Florida Water Management District, FL, USA.
- Bousquin, S. G., Anderson, D. H., Colangelo, D. J., & G. E. Williams, G. E. (2005). Establishing a baseline: pre-restoration studies of the channelized Kissimmee River. South Florida Water Management District, West Palm Beach, Florida, USA.

- Buijse, A. D., Coops, H., Staras, M., Jans, L. H., Van Geest, G. J., Grift, R. E., . . . Roozen, F. C. J. M. (2002). Restoration strategies for river floodplains along large lowland rivers in Europe. *Freshwater Biology*, 47(4), 889-907. doi:10.1046/j.1365-2427.2002.00915.x
- Cochran, U. A., Reid, C. M., Clark, K. J., Litchfield, N. J., Marsden, I., & Ries, W. (2014). The Avon-Heathcote Estuary as a recorder of coseismic vertical deformation. GNS Science Consultancy report 2014/128. 50pp.
- Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (eds.) (2016). Nature-based Solutions to address global societal challenges. Gland, Switzerland: IUCN. xiii + 97pp.
- Council of the European Communities (1992). Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Official Journal of the European Communities L206*, 7-50.
- Council of the European Communities (2000). Council Directive 2000/60/EC of 23 October 2000 establishing a framework for community action in the field of water policy. *Official Journal of the European Communities L327*, 1-72.
- Council of the European Communities (2007). Council directive 2007/60/EC of 23 October 2007 on the assessment and management of flood risks. *Official Journal of the European Union L288*, 27-34.
- Covasianu, A., Tudose, O. G., Cazacu, M. M., Nichersu, I., Memier, M., & Balin, I. (2010). R.E.E.L.D. (Economical and Ecological Reconstruction of the Danube Flood Plain) Campaign: airborne LIDAR data and GIS technique outputs. European Geosciences Union, General Assembly 2010, Vienna, Austria, 02.-07. May 2010.
- Cunningham S. C., Griffioen, P., White M., & Mac Nally, R.. (2011). Mapping the condition of River Red Gum (*Eucalyptus camaldulensis* Dehnh.) and Black Box (*Eucalyptus largiflorens* F.Muell.) stands in The Living Murray Icon Sites. Stand Condition Report 2010. Murray-Darling Basin Authority, Canberra. 47pp.
- Dahm, C. N., Cummins, K. W., Valett, H. M., & Coleman, R. L. (1995). An ecosystem view of the restoration of the Kissimmee River. *Restoration Ecology*, 3(3), 225-238. doi:10.1111/j.1526-100X.1995.tb00172.x
- DeBruyne, R. L., & Roseman, E. F. (2015). The renaissance of North American large rivers: synthesis of the special section. *Restoration Ecology*, 23(2), 139-142. doi:10.1111/rec.12192
- DOC & MfE (2007). Statement of national priorities for protecting rare and threatened biodiversity on private land. Retrieved 10 April 2017 from <https://www.biodiversity.govt.nz/land/guidance/index.html>
- DSE (2008). Sustainable Water Strategy Northern Region Discussion Paper. Department of Sustainability and Environment, Melbourne.
- European Commission (2013). Green Infrastructure (GI) - enhancing Europe's natural capital. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels, 6.5.2013.
- Ewel, J. J., & Putz, F. E. (2004). A place for alien species in ecosystem restoration. *Frontiers in Ecology and the Environment*, 2(7), 354-360. doi:10.1890/1540-9295(2004)002[0354:APFAS]2.0.CO;2
- Flanagan, N. E., Richardson, C. J., & Ho, M. (2015). Connecting differential responses of native and invasive riparian plants to climate change and environmental alteration. *Ecological Applications*, 25(3), 753-767. doi:10.1890/14-0767.1
- Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, 30(1), 441-473. doi:10.1146/annurev.energy.30.050504.144511
- Fukami, T., & Nakajima, M. (2011). Community assembly: alternative stable states or alternative transient states? *Ecology Letters*, 14(10), 973-984. doi:10.1111/j.1461-0248.2011.01663.x
- Habersack, H., Haspel, D., & Kondolf, M. (2014). Large rivers in the anthropocene: insights and tools for understanding climatic, land use, and reservoir influences. *Water Resources Research*, 50(5), 3641-3646. doi:10.1002/2013WR014731
- Habersack, H., Schober, B., & Hauer, C. (2015). Floodplain evaluation matrix (FEM): An interdisciplinary method for evaluating river floodplains in the context of integrated flood risk management. *Natural Hazards*, 75(S1), 5-32. doi:10.1007/s11069-013-0842-4
- Hauer, F. R., & Lorang, M. S. (2004). River regulation, decline of ecological resources, and potential for restoration in a semi-arid lands river in the western USA. *Aquatic Sciences*, 66(4), 388-401. doi:10.1007/s00027-004-0724-7
- Havel, J. E., Kovalenko, K. E., Thomaz, S. M., Amalfitano, S., & Kats, L. B. (2015). Aquatic invasive species: challenges for the future. *Hydrobiologia*, 750(1), 147-170. doi:10.1007/s10750-014-2166-0
- Hein, T., Blaschke, A. P., Haidvogel, G., Hohensinner, S., Kucera-Hirzinger, V., Preiner, S., . . . Zsuffa, I. (2006). Optimised management strategies for the Biosphere reserve Lobau, Austria - based on a multi criteria decision support system. *Ecohydrology & Hydrobiology*, 6(1-4), 25-36. doi:10.1016/S1642-3593(06)70123-9
- Hohensinner, S., & Drescher, A. (2008). Historical change of European floodplains: the Danube River in Austria. In: Klimo, E., Hager, H., Matic, S., Anic, I., Kulhavý, J. (Eds.), *The Floodplain Forests of temperate zone of Europe*, Lesnická práce, Prague.



- Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, 4(1), 1-23. doi:10.1146/annurev.es.04.110173.000245
- Hulea, O., Ebert, S., & Strobel, D. (2009). Floodplain restoration along the Lower Danube: A climate change adaptation case study. *IOP Conference Series: Earth and Environmental Science*, 6(40), 402002. doi:10.1088/1755-1307/6/40/402002
- ICPDR (2008). Development of Inland Navigation and Environmental Protection in the Danube River Basin. International Commission for the Protection of the Danube River, Vienna.
- ICPDR (2009). Danube River Basin Management Plan (DRBMP) according to EU Water Framework Directive (WFD). International Commission for the Protection of the Danube River, Vienna.
- ICPDR (2013). Climate Adaptation Strategy for the Danube River Basin. International Commission for the Protection of the Danube River, Vienna.
- Jolly, D. & Ngā Papatipu Rūnanga Working Group (2013). Mahaanui Iwi Management Plan 2013. Ōtautahi Christchurch: Mahaanui Kurataiao Ltd. 391pp.
- Jones M. J., & Stuart I. G. (2008). Regulated floodplains – a trap for unwary fish. *Fisheries Management and Ecology*, 15, 71–79.
- Junk, W. J., Bayley, P. B., & Sparks, R. E. (1989). The floodpulse concept in river-floodplain systems. In D. P. Dodge, editor. Proceedings of the International Large River Symposium. Canadian Special Publication of Fisheries and Aquatic Sciences, Ottawa, Ontario, Canada. pp110-127.
- Jungwirth, M., Muhar, S., & Schmutz, S. (2000). Fundamentals of fish ecological integrity and their relation to the extended serial discontinuity concept. *Hydrobiologia*, 422, 85-97. doi:10.1023/A:1017045527233
- King A. J. (2005) Fish in the Barmah-Millewa Forest – history, status and management challenges. *Proceedings of the Royal Society of Victoria*, 11, 117–126.
- King, A. J., Tonkin, Z., & Mahoney, J. (2007). Assessing the effectiveness of environmental flows on fish recruitment in Barmah-Millewa Forest. Report prepared for the Murray-Darling Basin Commission (now Murray-Darling Basin Authority). Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment. MDBA Publication No. 17/09. 102pp.
- King, A. J., Tonkin, Z., & Mahoney, J. (2009). Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia. *River Research and Applications*, 25(10), 1205-1218. doi:10.1002/rra.1209
- King, A. J., Ward, K. A., O'Connor, P., Green, D., Tonkin, Z., & Mahoney, J. (2010). Adaptive management of an environmental watering event to enhance native fish spawning and recruitment: Environmental flow management for native fish breeding. *Freshwater Biology*, 55(1), 17-31. doi:10.1111/j.1365-2427.2009.02178.x
- Koebel, J. W., & Bousquin, S. G. (2014). The Kissimmee River Restoration Project and Evaluation Program, Florida, U.S.A. *Restoration Ecology*, 22(3), 345-352. doi:10.1111/rec.12063
- Kuiper, J. J., Janse, J. H., Teurlincx, S., Verhoeven, J. T. A., & Alkemade, R. (2014). The impact of river regulation on the biodiversity intactness of floodplain wetlands. *Wetlands Ecology and Management*, 22(6), 647-658. doi:10.1007/s11273-014-9360-8
- Lang, M., Orchard, S., Falwasser, T., Rupene, M., Williams, C., Tirikatene-Nash, N., & Couch, R. (2012). State of the Takiwā 2012 -Te Āhuatanga o Te Ihutai. Cultural Health Assessment of the Avon-Heathcote Estuary and its Catchment. Christchurch, N.Z., Mahaanui Kurataiao Ltd.
- Lasne, E., Bergerot, B., Lek, S., & Laffaille, P. (2007). Fish zonation and indicator species for the evaluation of the ecological status of rivers: example of the Loire basin (France). *River Research and Applications*, 23(8), 877-890. doi:10.1002/rra.1030
- Leslie, D. & Ward, K. A. (2002). Murray River environmental flows 2000-2001. *Ecological Management & Restoration*, 3, 221-223.
- Loftin, M. K., Toth, L. A. & Obeysekera, J. T. B. (1990). Proceedings of the Kissimmee River Restoration Symposium. South Florida Water Management District, West Palm Beach, Florida, USA.
- Lonsdale, W. M. (1999). Global patterns of plant invasions and the concept of invasibility. *Ecology*, 80(5), 1522-1536. doi:10.1890/0012-9658(1999)080[1522:GPOPIA]2.0.CO;2
- Lucas, D., Meurk, C. D., Head, J., & Lynn, I. (1997). Indigenous ecosystems of Ōtautahi Christchurch (Sets 1-4). Christchurch-Ōtautahi Agenda 21 Forum.
- Lucas Associates (2011). Christchurch Ōtautahi Indigenous Ecosystems. Updated 2011. Lucas Associates Ltd., Christchurch, N.Z. Retrieved 10 April 2017 from <http://lucas-associates.co.nz/christchurch-banks-peninsula/christchurch-ecosystems/>
- McCarthy B., Conallin A., D'Santos P., & Baldwin D. (2006). Acidification, salinization and fish kills at an inland wetland in south-eastern Australia following partial drying. *Ecological Management and Restoration*, 7, 221–223.

- Macdonald J. I., & Crook D. A. (2006). Contribution of the Barmah-Millewa Floodplain Lakes to carp populations in the Mid-Murray River, 2005 / 06. Report to Murray- Darling Basin Commission. Arthur Rylah Institute for Environmental Research, Victoria, Australia.
- Markwith, S. H., Mezza, G., Kennard, S. N., & Bousquin, S. G. (2014). Intra-floodplain seed dispersal limitation and wetland community restoration. *Ecological Restoration*, 32(3), 249-259. doi:10.3368/er.32.3.249
- Mauser, W., Prasch, M., Koch, F., & Weidinger, R., (2012). Danube Study – Climate Change Adaptation: Study to provide a common and basin-wide understanding towards the development of a Climate Change adaptation strategy in the Danube River Basin. Final report. Ludwig-Maximilians-Universität, Munich, Germany. 174pp.
- MDBC (2003) Preliminary investigations into observed River Red Gum decline along the River Murray below Euston. Technical Report 03 / 03. Murray-Darling Basin Commission, Canberra.
- Measures, R., Hicks, M., Shankar, U., Bind, J., Arnold, J., & Zeldis, J. (2011). Mapping earthquake induced topographical change and liquefaction in the Avon-Heathcote Estuary. Environment Canterbury Report No. U11/13. Environment Canterbury, Christchurch. 28pp.
- Miller, J. R., Dixon, M. D., & Turner, M. G. (2004). Response of Avian Communities in Large-River Floodplains to Environmental Variation at Multiple Scales. *Ecological Applications*, 14(5), 1394-1410. doi:10.1890/02-5376
- Moss, B. (2008). The Water Framework Directive: Total environment or political compromise? *Science of the Total Environment*, 400(1), 32-41. doi:10.1016/j.scitotenv.2008.04.029
- Naiman, R. J., Décamps, H., Pastor, J., & Johnston, C. A. (1988). The potential importance of boundaries of fluvial ecosystems. *Journal of the North American Benthological Society*, 7(4), 289-306. doi:10.2307/1467295
- Navodaru, I., Staras, M., Buijse, A. D., & De Leeuw, J. J. (2005). Changes in fish populations in Danube delta lakes: effects of hydrology and water quality change. Review of results and potential for rehabilitation. *Ecology and Hydrobiology* 5(3), 245-256.
- Nilsson, C., Berggren, K., Institutionen för, n., Fakulteten för naturvetenskap, t. o. m., & Mittuniversitetet. (2000). Alterations of Riparian Ecosystems Caused by River Regulation. *Bioscience*, 50(9), 783-792. doi:10.1641/0006-3568(2000)050[0783:AORECB]2.0.CO;2
- Nichersu, I., 2006. Report of Ecological and Economical Resizing of Lower Danube Floodplain (REELD) Program — Romanian Government Decision HG 1208/06.09.2006. NP Donau-Auen Management Plan, 2009. National Park Donau-Auen GmbH, 2304 Orth/Donau.
- Nilsson C., Reidy C.A., Dynesius M. & Revenga C. (2005). Fragmentation and flow regulation of the world's large river systems. *Science*, 308, 405–408.
- Nilsson C., Jansson R., Malmqvist B., & Naiman R. J. (2007) Restoring riverine landscapes: the challenge of identifying priorities, reference states, and techniques. *Ecology & Society*, 12, 16.
- Norton, B. G. (2005). *Sustainability: a philosophy of adaptive ecosystem management*. Chicago: University of Chicago Press.
- Olden J. D. & Naiman R. J. (2010) Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. *Freshwater Biology*, 55, 86–107.
- Orchard, S. (2016a). Mahinga Kai Exemplar: Baseline survey 2015. Report prepared for Avon Ōtākaro Network, Christchurch, N.Z. 29pp.
- Orchard, S. (2016b). Identifying īnanga spawning sites in plans: options for addressing post-quake spawning in Ōtautahi Christchurch. Report prepared for Christchurch City Council and Environment Canterbury. Waterways Centre for Freshwater Management, University of Canterbury, Christchurch. 14pp.
- Orchard, S. & Hickford, M. (2016). Spatial effects of the Canterbury earthquakes on īnanga spawning habitat and implications for waterways management. Report prepared for IPENZ Rivers Group and Ngāi Tahu Research Centre. Waterways Centre for Freshwater Management and Marine Ecology Research Group. University of Canterbury, Christchurch. 37pp.
- Orchard, S., & Measures, R. (2016). Development of a fine-scale salinity model for the Avon Heathcote Estuary Ihutai. Report prepared for Brian Mason Scientific & Technical Trust. University of Canterbury & NIWA, Christchurch, N.Z. 22pp.
- Orchard, S., Meurk, C., & Smith, E. (2017). Restoration opportunities assessment for the Avon-Ōtākaro Red Zone using a local knowledge approach. Report prepared for Avon Ōtākaro Network, Christchurch, N.Z.
- Pahl-Wostl, C. (2006). The Importance of Social Learning in Restoring the Multifunctionality of Rivers and Floodplains. *Ecology and Society*, 11(1), 10. doi:10.5751/ES-01542-110110
- Paillex, A., Doledec, S., Castella E., & Merigoux, S. (2009). Large river floodplain restoration: predicting species richness and trait responses to the restoration of hydrological connectivity. *Journal of Applied Ecology*, 46, 250–258.

- Pauling, C., Lenihan, T., Rupene, M., Tirkatene-Nash, N., & Couch, R. (2007). State of the Takiwā Te Āhautanga o Te Ihutai. Cultural Health Assessment of the Avon-Heathcote Estuary and its Catchment. Te Rūnanga o Ngāi Tahu, Christchurch, N.Z. 35pp.
- Peake, P., Fitzsimons, J., Frood, D., Mitchell, M., Withers, N., White, M., & Webster, R. (2011). A new approach to determining environmental flow requirements: Sustaining the natural values of floodplains of the southern Murray-Darling Basin. *Ecological Management & Restoration*, 12(2), 128-137. doi:10.1111/j.1442-8903.2011.00581.x
- Phelps, Q. E., Tripp, S. J., Herzog, D. P., & Garvey, J. E. (2015). Temporary connectivity: the relative benefits of large river floodplain inundation in the lower Mississippi River. *Restoration Ecology*, 23(1), 53-56. doi:10.1111/rec.12119
- Poff, N. L., Olden, J. D., Merritt, D. M., & Pepin, D. M. (2007). Homogenization of Regional River Dynamics by Dams and Global Biodiversity Implications. *Proceedings of the National Academy of Sciences of the United States of America*, 104(14), 5732-5737. doi:10.1073/pnas.0609812104
- Quigley, M. C., Hughes, M. W., Bradley, B. A., van Ballegooy, S., Reid, C., Morgenroth, J., . . . Pettinga, J. R. (2016). The 2010–2011 Canterbury Earthquake Sequence: Environmental effects, seismic triggering thresholds and geologic legacy. *Tectonophysics*, 672-673, 228-274. doi:10.1016/j.tecto.2016.01.044
- Rayner, T. S., Kingsford, R. T., Suthers, I. M., & Cruz, D. O. (2015). Regulated recruitment: native and alien fish responses to widespread floodplain inundation in the Macquarie Marshes, arid Australia. *Ecohydrology*, 8(1), 148-159. doi:10.1002/eco.1496
- Regenerate Christchurch (2016). Ōtākaro/Avon River corridor, Brooklands and Southshore residential red zones. Land information as at October 2016. Retrieved 30 March 2017 from <http://www.regeneratechristchurch.nz/assets/Uploads/OTAKARO-AVON-corridor-Southshore-Brooklands-RRZ2.pdf>
- Regenerate Christchurch (2017). Outline for the Ōtākaro / Avon River Corridor Regeneration Plan. Regenerate Christchurch, Christchurch, N.Z.
- Schiemer, F. (2000). Fish as indicators for the assessment of the ecological integrity of large rivers. *Hydrobiologia*, 422, 271-278. doi:10.1023/A:1017086703551
- Schiemer, F., Baumgartner, C., & Tockner, K. (1999). Restoration of floodplain rivers: The 'Danube restoration project'. *Regulated Rivers: Research & Management*, 15(1-3), 231-244. doi:10.1002/(SICI)1099-1646(199901/06)15:1/3<231::AID-RRR548>3.0.CO;2-5
- Schiemer, F., Hein, T., & Reckendorfer, W. (2007). Ecohydrology, key-concept for large river restoration. *Ecohydrology & Hydrobiology*, 7(2), 101-111. doi:10.1016/S1642-3593(07)70176-3
- Schlaepfer, M. A., Sax, D. F., & Olden, J. D. (2011). The potential conservation value of non-native species. *Conservation Biology*, 25(3), 428-437. doi:10.1111/j.1523-1739.2010.01646.x
- Schneider, E. (2002). The ecological functions of the Danubian floodplains and their restoration with special regard to the Lower Danube. *Archiv für Hydrobiologie, Supplement*, 141, 129-149.
- Schober, B., Hauer, C., & Habersack, H. (2015). A novel assessment of the role of Danube floodplains in flood hazard reduction (FEM method). *Natural Hazards*, 75(S1), 33-50. doi:10.1007/s11069-013-0880-y
- Schwarz, U. 2010. Assessment of the restoration potential along the Danube and main tributaries. Report prepared for WWF International Danube-Carpathian Programme, Vienna. 58 p.
- Schwarz, U. (2013). Assessment of the restoration potential in the transboundary Unesco Biosphere Reserve "Mura-Drava-Danube". Report prepared for WWF Austria, Vienna. 167 pp.
- Sommerwerk, N., Bloesch, J., Paunović, M., Baumgartner, C., Venohr, M., Schneider-Jacoby, M., . . . Tockner, K. (2010). Managing the world's most international river: the Danube River Basin. *Marine and Freshwater Research*, 61(7), 736. doi:10.1071/MF09229
- Staras, M. (2001). Restoration programme in the Danube Delta: Achievements, benefits and constraints. In: Eds. H.J. Nijland and M.J.R. Cals. River Restoration in Europe, RIZA Report 2001.023. Lelystad, The Netherlands. 95-102.
- Stewart-Oaten, A., Bence, J. R., & Osenberg, C. W. (1992). Assessing effects of unreplicated perturbations: no simple solutions. *Ecology*, 73(4), 1396.
- Stuart, I. G., & Jones, M. (2006). Large, regulated forest floodplain is an ideal recruitment zone for non-native common carp (*Cyprinus carpio* L.). *Marine and Freshwater Research*, 57(3), 337-347. doi:https://doi.org/10.1071/MF05035
- Suciu, R., Constantinescu, A., & David, C. (2002). The Danube Delta: filter or bypass for the nutrient input into the Black Sea? *Archiv für Hydrobiologie, Supplement*, 141 (1-2), 165-173 (Large Rivers 13/1-2).
- Suding, K. N. (2011). Toward an era of restoration in ecology: successes, failures, and opportunities ahead. *Annual Review of Ecology, Evolution, and Systematics*, 42(1), 465-487. doi:10.1146/annurev-ecolsys-102710-145115

- Tau, T., Goodall, A., Palmer, D., & Tau, R. (1990). *Te Whakatau Kaupapa: Ngāi Tahu resource management strategy for the Canterbury region*. Wellington, New Zealand: Aoraki Press.
- Thomas, R. J., Constantine, J. A., Gough, P., & Fussell, B. (2015). Rapid channel widening following weir removal due to bed-material wave dispersion on the River Monnow, Wales. *River Research and Applications*, 31(8), 1017-1027. doi:10.1002/rra.2803
- Thorp, J. H., Thoms, M. C., & Delong, M. D. (2006). The riverine ecosystem synthesis: biocomplexity in river networks across space and time. *River Research and Applications*, 22(2), 123-147. doi:10.1002/rra.901
- Tockner, K., Bunn, S., Gordon, C., Naiman, R. J., Quinn, G. P., & Stanford J. A. (2008). Flood plains: critically threatened ecosystems. In: *Aquatic Ecosystems* (Ed. N.V.C. Polunin), Cambridge University Press, Cambridge. pp.45–61.
- Tockner, K., Malard, F., & Ward, J. V. (2000). An extension of the flood pulse concept. *Hydrological Processes*, 14(16-17), 2861-2883. doi:10.1002/1099-1085(200011/12)14:16/17<2861::AID-HYP124>3.0.CO;2-F
- Tockner, K., Pennetzdorfer, D., Reiner, N., Schiemer, F., & Ward, J. V. (1999). Hydrological connectivity, and the exchange of organic matter and nutrients in a dynamic river-floodplain system (Danube, Austria). *Freshwater Biology*, 41(3), 521-535. doi:10.1046/j.1365-2427.1999.00399.x
- Tockner, K., Pusch, M., Borchardt, D., & Lorang, M. S. (2010). Multiple stressors in coupled river-floodplain ecosystems. *Freshwater Biology*, 55, 135-151. doi:10.1111/j.1365-2427.2009.02371.x
- Tockner, K., & Stanford, J. A. (2002). Riverine flood plains: present state and future trends. *Environmental Conservation*, 29(3), 308-330. doi:10.1017/S037689290200022X
- Toth, L. A. (1991). Environmental responses to the Kissimmee River Demonstration Project. Technical Publication 91-02. South Florida Water Management District, West Palm Beach, Florida, USA.
- Toth, L. A. (2005). Plant community structure and temporal variability in a channelized subtropical floodplain. *Southeast Naturalist*, 4, 393–408.
- Toth, L. A. (2010). Unrealized Expectations for Restoration of a Floodplain Plant Community. *Restoration Ecology*, 18(6), 810-819. doi:10.1111/j.1526-100X.2010.00731.x
- Toth, L. A. (2015). Invasibility drives restoration of a floodplain plant community. *River Research and Applications*, 31(10), 1319-1327. doi:10.1002/rra.2836
- Toth, L. A. (2016a). Variant restoration trajectories for wetland plant communities on a channelized floodplain: River floodplain restoration. *Restoration Ecology*. doi:10.1111/rec.12427
- Toth, L. A. (2016b). Cover thresholds for impacts of an exotic grass on the structure and assembly of a wet prairie community. *Wetlands Ecology and Management*, 24(1), 61-72. doi:10.1007/s11273-015-9451-1
- Toth, L. A., & Anderson, D. H. (1998). Developing expectations for ecosystem restoration. *Transactions of the North American Wildlife and Natural Resource Conference*, 63:122-134.
- Toth, L. A., Arrington, D. A., Brady, M. A., & Muszick, D. A. (1995). Conceptual evaluation of factors potentially affecting restoration of habitat structure within the channelized Kissimmee River ecosystem. *Restoration Ecology*, 3(3), 160-180. doi:10.1111/j.1526-100X.1995.tb00168.x
- Toth, L. A., Melvin, S. L., Arrington, D. A., & Chamberlain, J. (1998). Hydrologic manipulations of the channelized Kissimmee River. *Bioscience*, 48(9), 757-764. doi:10.2307/1313338
- Toth, L. A., & van der Valk, A. (2012). Predictability of flood pulse driven assembly rules for restoration of a floodplain plant community. *Wetlands Ecology and Management*, 20(1), 59-75. doi:10.1007/s11273-011-9241-3
- Turnhout, C. v., Leuven, R. S. E. W., Heniks, A. J., Kurstjens, G., Strien, A. v., Foppen, R. P. B., & Siepel, H. (2012). Ecological strategies successfully predict the effects of river floodplain rehabilitation on breeding birds. *River Research and Applications*, 28(3), 269-282. doi:10.1002/rra.1455
- Twedt, D. J., & Best, C. (2004). Restoration of Floodplain Forests for the Conservation of Migratory Landbirds. *Ecological Restoration*, 22(3), 194-203. doi:10.3368/er.22.3.194
- Underwood, A. J. (1992). Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. *Journal of Experimental Marine Biology and Ecology*, 161(2), 145-178. doi:10.1016/0022-0981(92)90094-Q
- UNEP/GPA (2006). Ecosystem-based management: Markers for assessing progress. Report commissioned by the Coordination Office of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) of the United Nations Environment Programme (UNEP). The Hague, Netherlands.
- U.S. Army Corps of Engineers. (1956). *Central and Southern Florida, Kissimmee River basin and related areas (supplements). General Design Memorandum*. U.S. Army Corps of Engineers: Jacksonville District, 467.
- U.S. Army Corps of Engineers (1991). Final Integrated Feasibility Report and Environmental Impact Statement, Environmental Restoration, Kissimmee River, Florida. United States Army Corps of Engineers:



- Jacksonville, FL. Retrieved 14 April 2017 from  
[https://www.sfwmd.gov/sites/default/files/documents/1a\\_krr\\_ifr\\_eis\\_1991\\_blanksremoved.pdf](https://www.sfwmd.gov/sites/default/files/documents/1a_krr_ifr_eis_1991_blanksremoved.pdf)
- Vaughan, I. P., Diamond, M., Gurnell, A. M., Hall, K. A., Jenkins, A., Milner, N. J., . . . Ormerod, S. J. (2009). Integrating ecology with hydromorphology: a priority for river science and management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 19(1), 113-125. doi:10.1002/aqc.895
- VEAC (2006) River Red Gum Forests Investigation Discussion Paper. Victorian Environmental Assessment Council, East Melbourne. 17pp.
- VEAC (2008a) River Red Gum Forests Investigation Final Report. Victorian Environmental Assessment Council, East Melbourne. 208pp.
- VEAC (2008b) Identifying flood-dependent natural values on the Victorian floodplains of the River Murray and its tributaries. Victorian Environmental Assessment Council, East Melbourne. 40pp.
- Ward, J. V., & Stanford, J. A. (1995). Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. *Regulated Rivers Research & Management*, 11, 105 – 119.
- Ward, J. V., Tockner, K., Arscott, D. B., & Claret, C. (2002). Riverine landscape diversity. *Freshwater Biology*, 47(4), 517-539. doi:10.1046/j.1365-2427.2002.00893.x
- Ward, J. V., Tockner, K., & Schiemer, F. (1999). Biodiversity of floodplain river ecosystems: Ecotones and connectivity. *Regulated Rivers Research & Management*, 15, 125 – 139.
- Warne, A.G., Toth, L.A. & White, W.A. (2000). Drainage-basin-scale geomorphic analysis to determine reference conditions for ecologic restoration - Kissimmee River, Florida. *Geological Society of America Bulletin* 112, 884-899.
- Welcomme, R. (2008). World prospects for floodplain fisheries. *Ecohydrology & Hydrobiology*, 8(2-4), 169-182. doi:10.2478/v10104-009-0013-0
- Whited, D. C., Lorang, M. S., Harner, M. J., Hauer, F. R., Kimball, J. S., & Stanford, J. A. (2007). Climate, hydrologic disturbance, and succession: drivers of floodplain pattern. *Ecology*, 88(4), 940-953. doi:10.1890/05-1149
- Wohl, E. E. (2011). A world of rivers: environmental change on ten of the world's great rivers. Chicago: University of Chicago Press.
- WWF (2000). A Green Corridor for the Danube. An initiative of the Ministries of Environment (Bulgaria, Moldova, Romania, Ukraine) supported by WWF. WWF-Danube-Carpathian Programme, Vienna, Austria.
- WWF (2002). Waterway transport on Europe's lifeline, the Danube. Impacts threats and opportunities. Worldwide Fund for Nature. 134 pp.
- Zedler, J. B., & Callaway, J. C. (1999). Tracking wetland restoration: do mitigation sites follow desired trajectories? *Restoration Ecology*, 7(1), 69-73. doi:10.1046/j.1526-100X.1999.07108.x
- Zeldis, J., Skilton, J. South, P., & Schiel, D. (2011). Effects of the Canterbury earthquakes on Avon-Heathcote Estuary/Ihutai ecology. Environment Canterbury Report No. U11/14. Environment Canterbury, Christchurch, N.Z. 27pp.
- Zöckler, C. (2000). Wise Use of Floodplains - review of restoration projects in a number of European countries. WWF European Freshwater Programme, Worldwide Fund for Nature. 100pp.