Auckland's Urban Estuaries Management Opportunities

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Reviewed by

Name: Wolfgang Kanz

Position: Stormwater Technical Specialist

Organisation: Auckland Council

Date: 4th June 2013

Approved for Auckland Council publication by

Name: Matthew Davis

Position: Manager Development and Technical Services

Organisation: Auckland Council

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1.0 INTRODUCTION

1.0 INTRODUCTION

1.1 BACKGROUND

OVERVIEW

For over 10 years, Auckland's Councils have investigated options for managing stormwater contamination by carrying out detailed studies on contaminant sources, transport, accumulation, treatment and options for source control. This has provided a thorough understanding of the issues involved. However, practicable solutions for addressing the contamination of fully urbanised estuaries in older parts of the city (particularly those with relatively large catchments) have yet to be identified. Key reasons for this are the lack of suitable space for implementing and integrating water quality and attenuation devices within existing land use patterns, the difficulties associated with eliminating contaminant sources, and the rate of land use change. Consequently, progressive degradation of some of the region's tidal creeks and estuaries is continuing.

The focus of most investigations into the health of urban estuaries has been on the heavy metals copper, lead and zinc as indicators of contaminant levels. Zinc and copper are the most problematic of these three indicators. Modelling NIWA indicates that the phasing out of galvanised steel roofs could marginally reduce but not arrest zinc accumulation rates across the board. However, this will not address copper accumulation.

This suggests that different approaches need to be considered for managing contaminants in Auckland's worst affected areas..

SEDIMENT TEXTURE AND CONTAMINATION

Auckland's most contaminated estuaries include Henderson Creek, Whau River, Waterview Inlet, Meola and Motions Inlets, and the upper Tamaki Estuary. These estuaries have some common features. They mostly contain thick deposits of soft muddy sediment. Monitoring indicates that the proportion of mud (i.e. sediment <63 um in diameter) in sediment samples commonly exceeds 70%, although some sites have lower, albeit still relatively high levels (30-40%). Sediment zinc concentrations exceed the "red" environmental response criteria (ERC) guideline value at many monitoring sites in these estuaries, which indicates that the onset of ecological effects is likely. Copper and lead concentrations also exceed the lower level "orange" ERC quality guideline values at many sites, and "red" ERC values at some sites (*Mills and Williamson 2012*). The concentrations of a variety of other urban contaminants are correlated with copper, lead and zinc. As a result, their concentrations are also expected to be higher in these estuaries.

FUTURE CONTAMINANT LEVELS

Contaminant accumulation models produced by the University of Auckland predict that concentrations of zinc will continue to increase, resulting in substantial ecological effects in the upper Whau, Motions, Panmure, Bowden St and Middlemore (Upper Tamaki) sites by 2050. Accumulation rates are predicted to be slower at the other sites, but the lower Whau, Meola, and Princess St sites are predicted to exceed 500 mg/kg in the fine (<63 um) sediment fraction in the long term (*Croucher and O'Sullivan 2005a to 2005d*). These predictions are generally consistent with those obtained by NIWA. However, NIWA's model averaged concentrations across whole estuaries, and therefore dampened site-specific trends *(Green 2008)*.

Concentrations of copper and zinc are relatively low in the Central Waitemata Harbour, and are not predicted to increase markedly in the future. Risks therefore appear to be mainly confined to the upper to mid sections of tidal creeks and estuaries.

1.0 INTRODUCTION

1.1 BACKGROUND

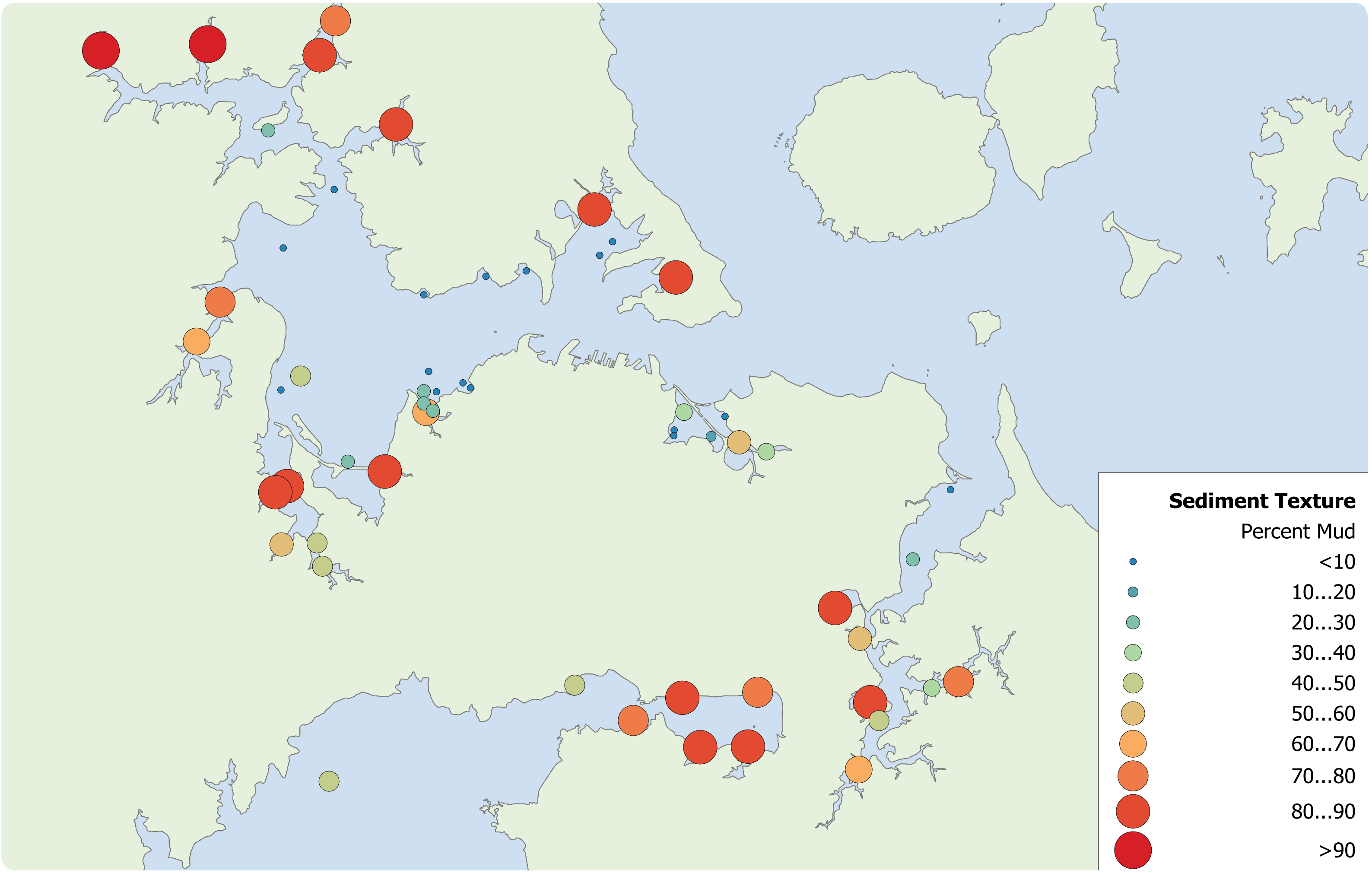

Figure 1: Existing Sediment
The circle reflects the proportion of mud (<63 um in diameter) in fine sediment samples.

1.0 INTRODUCTION

1.1 BACKGROUND

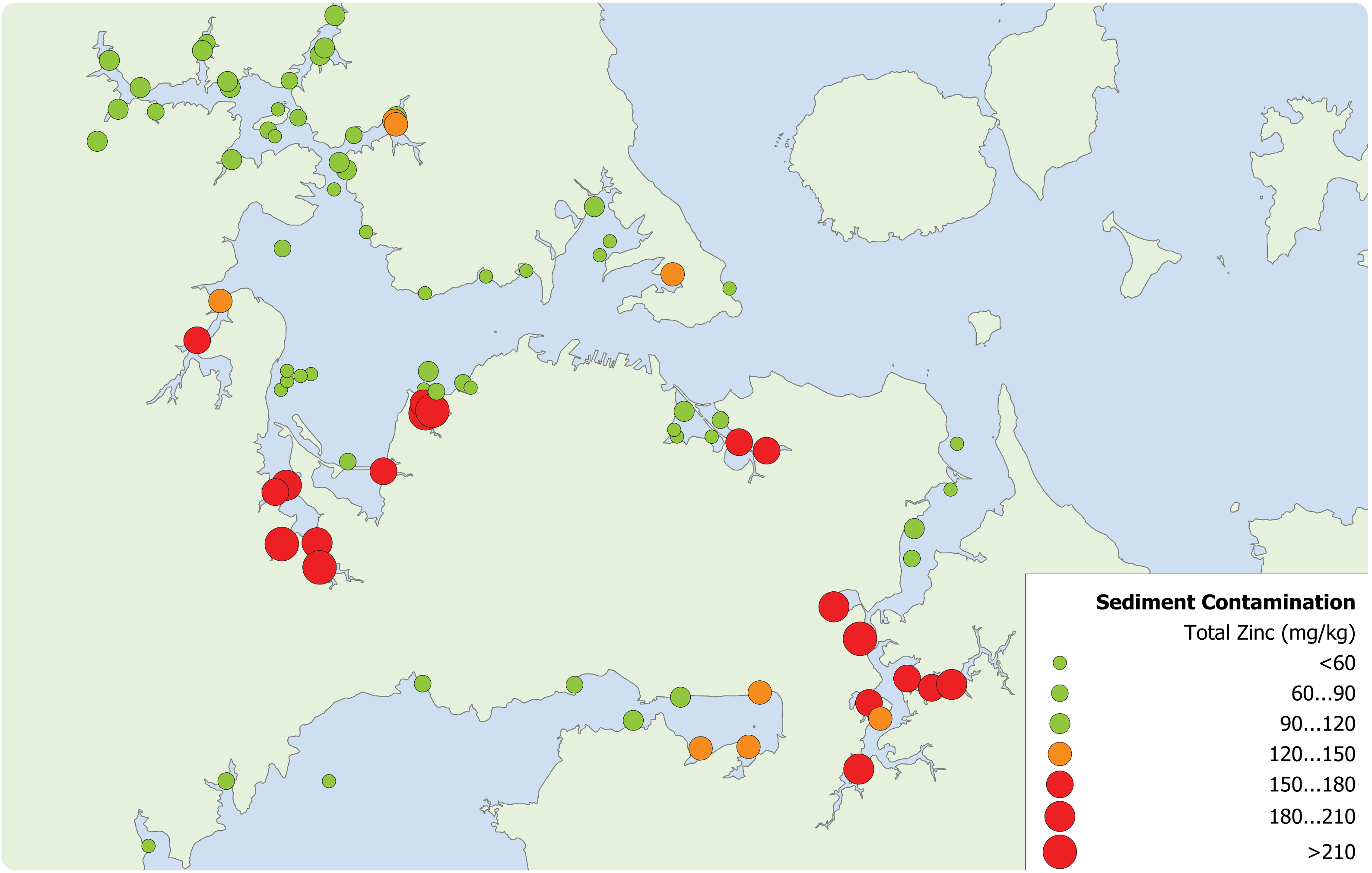

Figure 2: Contaminant Concentration - Zinc

This map reflects the concentrations of zinc at the sites with the highest level of overall storm water contaminants in the Auckland Region. Dot size varies with concentration (in the <500um sediment fraction) and dot colour reflects excedence of environmental response criteria (ERC) sediment quality guideline values.

1.0 INTRODUCTION

1.2 OVERVIEW

PURPOSE

The purpose of this report is to investigate alternative concepts for the containment and treatment of stormwater contaminants, in order to improve the overall outcomes for Auckland's most degraded estuarine and tidal creek habitats. The intent is to generate discussion on the utilisation of the near shore coastal environment to treat stormwater contaminants, while factoring in increasing resilience to effects such as climate change, and maximising outcomes for the local environment, native wildlife, and recreational, aesthetic and amenity values. The project encapsulates stormwater engineering, ecological enhancement and landscape design within an integrated framework.

Detailed analyses is not carried out, and it is anticipated that more information is likely to be required to properly identify and tailor potential options to a specific site.

OBJECTIVES

The key objectives of this project are to:

- Develop high level concepts for the near shore coastal environment to treat stormwater contaminants using constructed stormwater treatment options such as wetlands, bunds or other structures.
- Develop conceptual designs with features that maximise outcomes for the local communities, including amenity and aesthetic values, while minimising ecological impacts, or preferably, enhancing ecological values.

These objectives will take advantage of the opportunity that exists along coastal margins to install attractive and functional devices that enhance community values, contain contaminants and protect downstream areas. Best practice suggests that infrastructure of this nature should integrate and encompass ecological and social outcomes and consider the effects of climate change.

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2.0 EXISTING INTERTIDAL ENVIRONMENTAL VALUES

2.0 EXISTING INTER TIDAL ENVIRONMENTAL VALUES

2.1 INTRODUCTION

This section examines the Whau and Tamaki estuaries. These estuarine systems have been selected as 'example environments' because they exhibit a number of characteristics that are shared by other estuaries in the metropolitan Auckland region. The intent of the analysis is not to investigate specific sites for intervention, but rather to describe typical and characteristic patterns and relationships to inform the development of a range of concept designs, which are presented in Section 4.

Appendices 6.1 - 6.5 provide further information describing the catchment conditions of the Whau and Tamaki estuaries.

2.0 EXISTING INTER TIDAL ENVIRONMENTAL VALUES

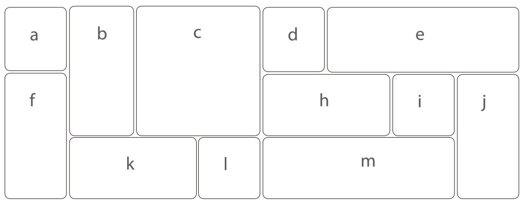
2.2 EXAMPLE ENVIRONMENTS

Figure 3: Example Enviornments

EXISTING INTER TIDAL ENVIRONMENTAL VALUES

2.3 LANDSCAPE CHARACTERISTICS

Figure 4: These images are taken from across the two example environments, illustrating the range of common vegetation, edge conditions and topographic characteristics found throughout the Auckland isthmus.



IMAGES
a. View of coastal cliff from Kawakawa Bay
b. View of Tamaki Estuary towards Pakuranga and Mt Wellington
c. Pampus at Highbrook looking towards Otahuhu
d. View of mud flats from Ken Maunder footbridge, New Lynn
e. Avicennia marina subsp. australasica / Mangroves
f. View from Tahuna Torea towards Riddell Road, Glendowie
g. View from Tony Segedin Esplanade Reserve, Avondale
h. Channel mangrove edge in Whau Estuary
i. View of Tamaki Estuary form Highbrook
j. Mangroves and mud flats in Tamaki Estuary
k. Eucalyptus along Tamaki Estuary
l. View of Whau Estuary from Avondale

2.4 HABITAT TYPES

The environmental values of the focal areas are broadly summarised in terms of their ecological and socio-cultural values.

Key habitats include:

1. Riparian Edge / Coastal Margin
2. Mangroves;
3. Mud flats; and
4. Channel.

Areas of salt marsh are also found in some places, but these tend to be relatively small and isolated features.

RIPARIAN EDGE / COASTAL MARGIN VALUES

These areas vary in topographic and vegetated conditions across the two example environments. The conditions can be generalised into three main types:

- Vegetated banks - Sloping areas that have been recently revegetated, or contain well established native riparian species (Refer Appendix 6.6) plus a mixture of other common exotic plants and invasive species. Where vegetation does exist it tends to be discontinuous and isolated.
- Grass banks - Grass dominant sloping areas containing some shrubby weed species commonly leading into mangroves. During spring tides, inanga (an indigenous freshwater fish) spawn amongst the grassy vegetation upstream of the estuarine salt wedge. Once the tide recedes, their eggs develop in the humid air within the vegetation and hatch on a later spring tide.
- Flat land - Parks and playing fields leading into mud flats and/or mangrove areas.

Public access is generally restricted in areas where industrial activity exists along the margins, such as Rosebank and Mt Wellington, with narrow lanes between buildings the only connection to the waters edge.

MANGROVES VALUES

Mangrove forests and scattered mangroves are an extensive habitat features in Whau Creek, Waterview Inlet, Meola and Motions creek mouths, and also cover large areas in the upper Tamaki.

Mangrove forests are a common feature in northern New Zealand estuaries and have been expanding in Auckland and other regions. They are often perceived as providing few tangible functions and services to humans, and are frequently considered a nuisance by the public. This has led to legal and illegal removals in some areas.

Despite this, mangroves form an important and unique coastal habitat in New Zealand, albeit one with different functions and values to the adjoining mud and sand flats. Ecological functions in mangrove forests are mainly influenced by the sheltered physical structure and primary production provided by the trees. Benthic processes are dominated by the decomposition of leaves and woody material, with the fauna mainly comprised of microscopic "mesofaunal" species that consume the fungi and bacteria involved in the decomposition of organic material (*Ornate-Pacalioga 2005*). Mangroves are also used by a variety of insects, reptiles and coastal birds. Two fish species are considered to use mangroves as nursery habitats on the east coast: short-finned eels (*Anguilla australis*) and parore (*Girella tricuspidata*) (*Morrisey et al. 2007*).

The expansion of mangroves in tidal creeks with elevated sedimentation rates, and their apparent tolerance of elevated contaminant levels suggests that they may actually benefit from some of the contaminant management options. Furthermore this quality could be exploited to enhance contaminant trapping in future proposals.

2.4 HABITAT TYPES

MUDFLAT VALUES

In general, mudflat communities tend to be less diverse than benthic communities areas with coarser sediments. In the focal areas being considered in this study, the effects of mud are compounded also by contamination. The Council's monitoring data indicates that the ecological health of mudflat communities in the focal areas have health scores of 1 to 3 (1 being worst, 5 being best). All of the monitoring sites in Whau Estuary, Meola and Motions Creek, the upper Tamaki and upper Mangere Inlet have health scores of 1 to 2. (*Kelly 2007*).

This is reflected in the distribution of a number of species that are known to be sensitive to contaminants and muddy sediments, such as cockles and wedge shells (*Gibbs and Hewitt 2004, Hewitt et al. 2009*). These species are either absent from sites in the estuaries and tidal creeks where alternative options for contaminant management should be considered, or they only occur in low numbers. Conversely, tolerant species such as the small bivalve *Arthritica bifurcata* and polychaetes from the family *Nereidae* occur in greater numbers at these sites.

Sites with low health scores also tend to have fewer and/or lower numbers of patchily distributed species and large species. Patchily distributed species make a substantive contribution overall biodiversity, and help maintain the stability and resilience of ecosystems. Large sediment-dwelling, animals make a disproportionately large contribution to ecosystem functions such the turnover of sediments, the modification of water flows near the seabed, and the provision of larger food items for fish and other consumers. The high mobility of many large taxa also helps exchange oxygen and nutrients between the water column and the seabed (*Hewitt et al. 2009*) .

CHANNEL VALUES

Shallow channels in the upper reaches of tidal creeks and estuaries can have coarser sediments than the surrounding mud flats, and generally have firm substrates. However, very little is known about the ecology of these features. Available information suggests that they are likely to provide a low-tide refuge for fish, and act as an important conduit for fish movements and sediment transport. Bird species such as white faced heron also forage in tidal channels.

Channels are particularly important for the passage of native freshwater fish. Over half (18) of New Zealand's 35 or so indigenous freshwater species migrate between fresh and salt water during their life cycle, mostly as small juveniles. Similar migrations are also made by the freshwater shrimp (*Paratya curvirostris*). Consequently, barriers that prevent these species from moving between stream headwaters and the sea are a significant ecological issue (*Boubée et al. 1999*).

SOCIO-CULTURAL VALUES

Too many, if not most people, the upper reaches tidal creeks and estuaries are not highly valued. In particular, the lack of open water is commonly viewed as a negative attribute. Upper tidal creeks are perceived as "dirty" inaccessible places with dense mangrove forests and soft deep mud flats creating a visual and physical barrier between the land and water channel. This negative impression is reflected in their historic and ongoing use as repositories for household rubbish, the general lack of care that most areas receive, and the desire by some community groups to clear mangroves. Weed infestation and the disposal of organic and inorganic waste along the margins of upper creeks is common, leading to an unsightly and unhealthy looking environment that prompts avoidance rather than use and appreciation.

However, in a few places the aesthetic and amenity values of upper tidal creeks have been enhanced by planting along the coastal margin, and constructing walkways that link thoroughfares and parks. In a number of cases dams have been created to pond the upper sections of tidal creeks. These have been installed to create water reservoirs for industry (Otara Lake and Chelsea Ponds), ponds on golf courses (e.g. Auckland Golf Course) and maintain water levels for recreation purposes (Orakei Basin).

EXISTING INTER TIDAL ENVIRONMENTAL VALUES

2.5 COASTAL CONDITION - COMMON EDGE CONDITIONS

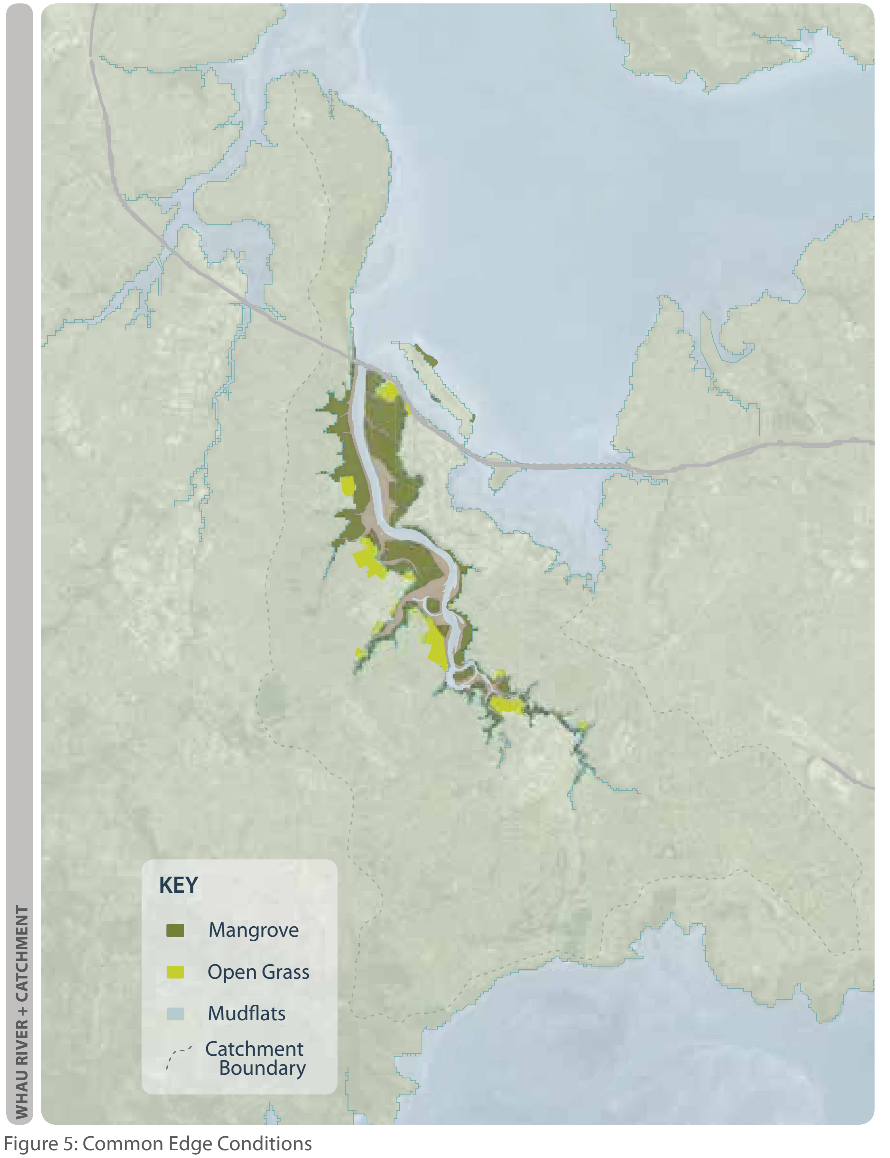


Figure 5: Common Edge Conditions

2.0 EXISTING INTER TIDAL ENVIRONMENTAL VALUES

2.6 GENERAL ESTUARINE PATTERNS

A model estuary was created for this study based on the characteristics of the Whau Creek and the Tamaki Inlet. The model estuary contained three clear elements:

1. *Land / Foreshore*
2. *Intertidal*
3. *Channel*

Section 2.7 demonstrates the relationship of these components to one another.

Section 2.8 demonstrates how these three components come together to form four typical *Edge Conditions*:

1. *Grass Bank*
2. *Vegetated Bank*
3. *Flat land*
4. *Incised gully*

The combination of these characteristics presents different constraints and opportunities for direct intervention.

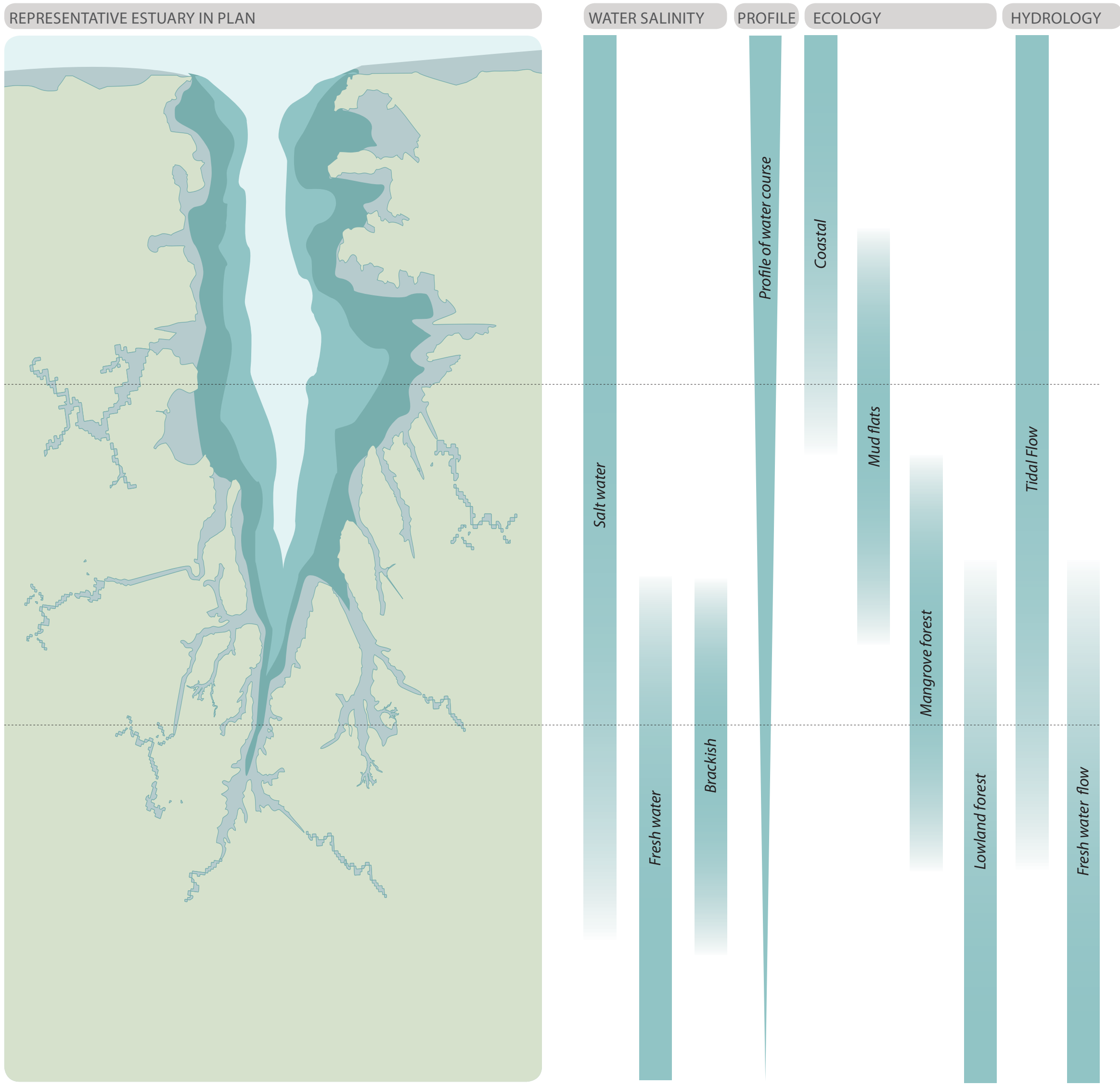


Figure 6: Representative Estuary

EXISTING INTER TIDAL ENVIRONMENTAL VALUES

2.7 EXISTING CONTEXT

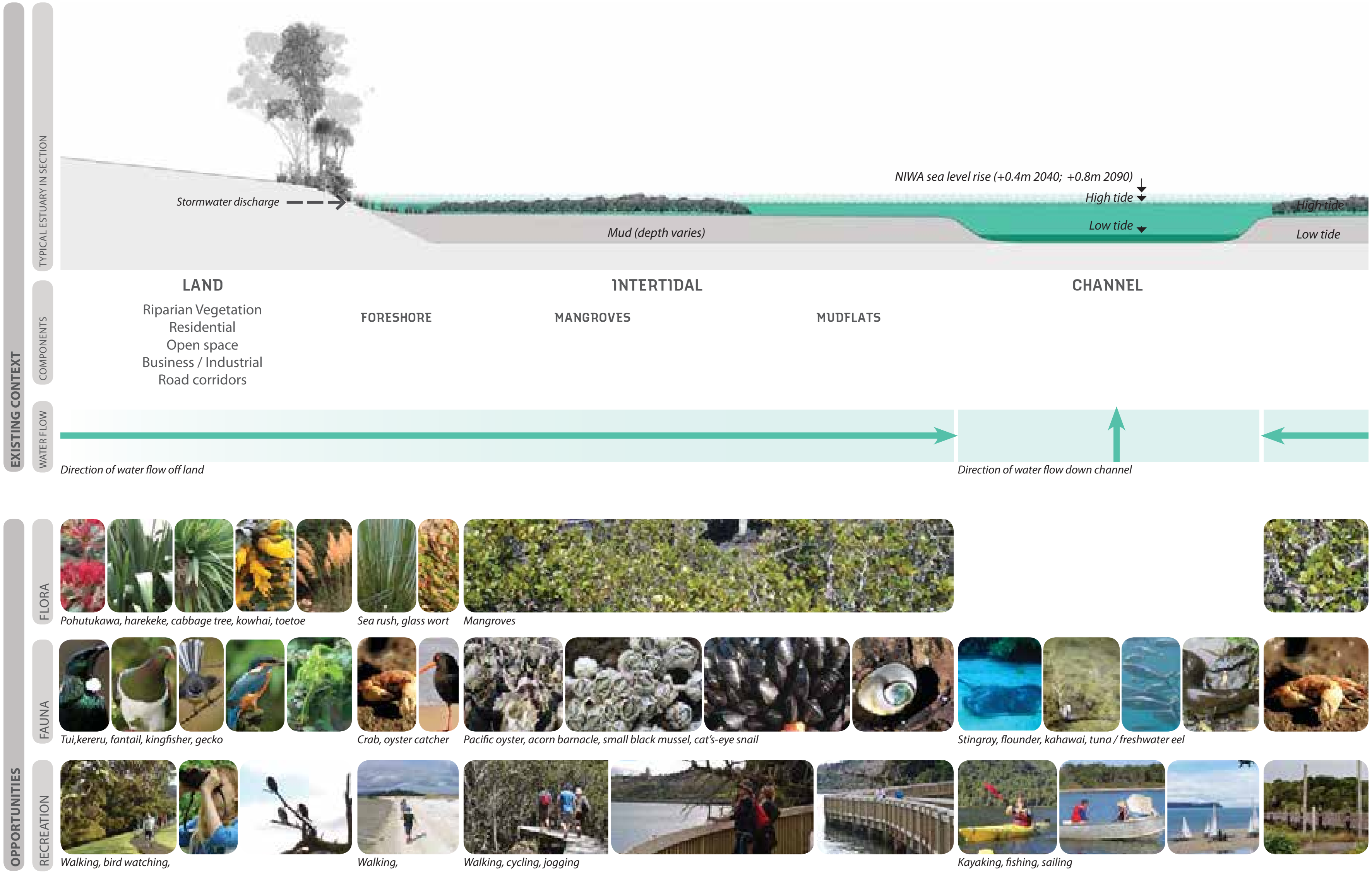


Figure 7: Typical Section

2.0 EXISTING INTER TIDAL ENVIRONMENTAL VALUES

2.8 TYPICAL EDGE CONDITIONS

GRASS BANK

LAND

Coastal Margin / Riparian Vegetation
Residential
Open space
Business / Industrial
Road corridors

INTERTIDAL

FORESHORE

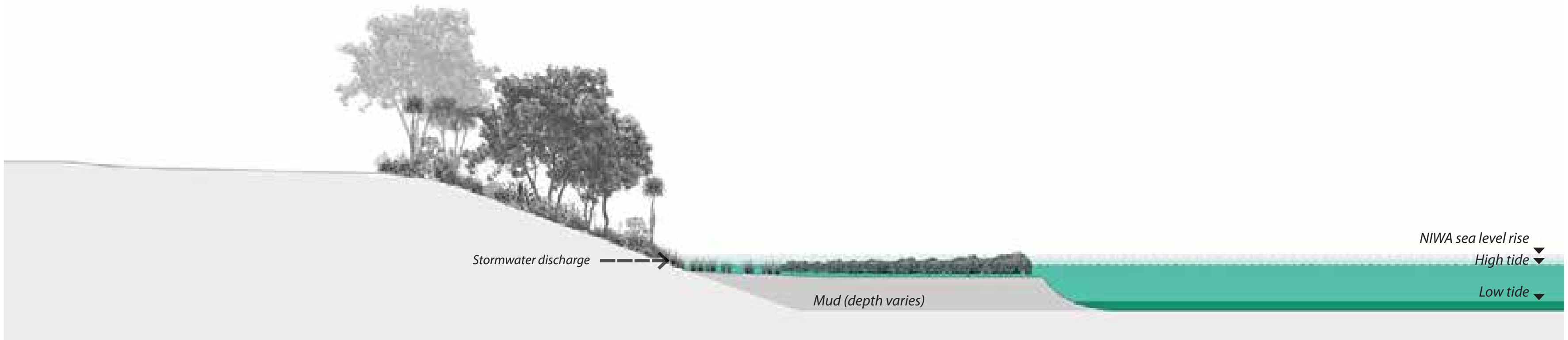
MANGROVES

MUDFLATS

CHANNEL

Figure 8: Typical 'Grass Bank'

VEGETATED BANK



LAND

Coastal Margin / Riparian Vegetation
Residential
Open space
Business / Industrial
Road corridors

INTERTIDAL

FORESHORE

MANGROVES

MUDFLATS

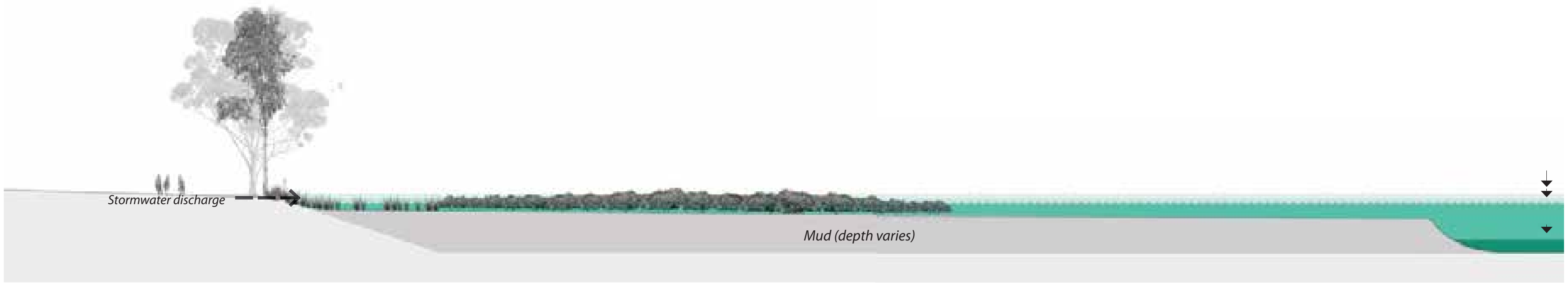
CHANNEL

Figure 9: Typical 'Vegetated Bank'

EXISTING INTER TIDAL ENVIRONMENTAL VALUES

2.8 TYPICAL EDGE CONDITIONS

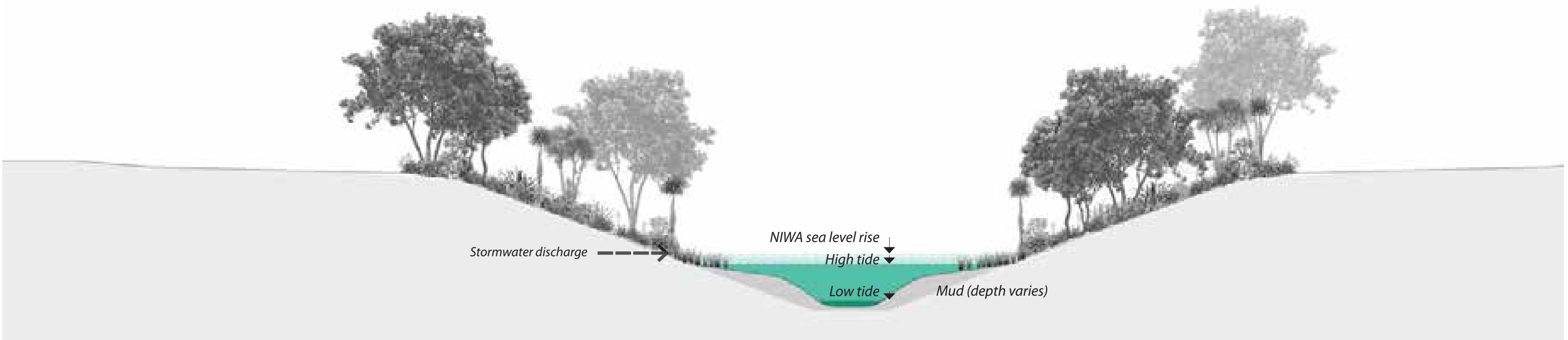
FLAT LAND



LAND		INTERTIDAL		CHANNEL
Coastal Margin / Riparian Vegetation Open space	FORESHORE	MANGROVES	MUDFLATS	

Figure 10: Typical 'Flat land'

INCISED GULLY



LAND	INTERTIDAL	CHANNEL	INTERTIDAL	LAND
Coastal Margin / Riparian Vegetation Residential Open space Business / Industrial Road corridors	FORESHORE/ MANGROVES/ MUDFLATS		FORESHORE/ MANGROVES/ MUDFLATS	Residential Open space Business / Industrial Road corridors

Figure 11: Typical 'Incised Gully'

3.0 DESIGN STRATEGIES

3.0 DESIGN STRATEGIES

3.1 INTRODUCTION

This section outlines a range of design considerations and strategies that, together with the previous section, inform the concept designs presented in Section 4.

A number of engineering considerations are presented and constraints, opportunities and design objectives are outlined. From these considerations and objectives, a clear set of design principles are formulated, which underpin the remaining case studies and concept designs. Finally, six case studies are presented, which include three local examples and three international examples. The case studies range from simple interventions that allow public access to the foreshore environment through to a comprehensive urban development plan, which is shaped by the estuarine environment and coastal processes.

3.2 ENGINEERING CONSIDERATIONS

HYDRODYNAMIC PROCESSES

Tidal creeks are dynamic environments that are exposed to both stormwater flows that drain the catchments and tidal cycles that flood and ebb. The combination of these flows can create complex hydrodynamic processes that can both be advantageous and detrimental to the potential stormwater treatment solutions. Saline wedges areas can enhance flocculation of entrained sediments. Eddies and reduced flow velocities may also occur when flows oppose one another. The tidal prism volume may be reduced - changing the level of downstream tidal areas. Design should understand these hydrodynamic processes, and where practical, enhance these to provide improved stormwater treatment outcomes for flows discharged from the catchment.

FLOOD FLOWS

Stormwater management options must consider conveyance of flood flows during extreme event conditions. Failure to do so may lead to entrainment and remobilisation of contaminants previously captured within a device, and or, reduced reliability of the device's performance. Design should therefore incorporate an appropriate mechanism for high flow bypass to ensure the integrity of the device is maintained.

Design should also consider the potential for restricting flows and consequently exacerbating flooding up stream of the stormwater treatment device. This can become an issue if existing building freeboards are compromised.

MAINTENANCE REQUIREMENTS AND ACCESS

All stormwater management devices require routine and corrective maintenance actions to be carried out regularly to ensure the design performance of the device is maintained. Within a tidal creek environment, sedimentation rates could be significantly greater compared to a freshwater environment due to the potential for increased flocculation processes occurring. A design therefore must allow access for required machinery to carry out such maintenance and in particular remove sediment. This should be timed in consideration of tidal influences to reduce re-suspension and discolouration of receiving waters.

An assessment of potential routine and corrective maintenance requirements for a storm water treatment device located within a tidal creek should therefore be undertaken - with ease of maintenance and access being accommodated into the final design of the storm water treatment device.

GEOTECHNICAL STABILITY

Tidal creeks are commonly areas of unconsolidated sediments, comprised mostly of muds or silts. Design should therefore consider the requirements for adequate foundations, settlement and ensure that sufficient lateral support is provided to structures that have flows pushing against them.

Consideration should be given to pore water pressure changes of sediments located within the intertidal margin where tidal influence is pronounced. Changes to pore water pressure can influence the stability of sediments. Existing embankments and channel banks which have adjacent structures should also be assessed for the potential of bank instability. These issues need to be considered both in the existing state prior to construction of the stormwater treatment device and also post construction. The potential for scour can also undermine structures and cause instability. As detailed in further discussion, adequate scour protection is a critical part component of ensuring geotechnical stability.

The above assessments may indicate the need for implementation of ground improvement techniques such as; preloading, geofabric wraps, or geogrid foundations. The aim of such techniques is to spread the load of the device over a greater surface area to achieve adequate stability and reduced settlement of sediments.

SCOUR AND EROSION PROTECTION MEASURES

As sediments within a tidal creek are predominantly unconsolidated, the risk for scour and erosion may be increased by new structures concentrating flows. A proposed stormwater treatment solution within a tidal creek may create new direction of flows via refraction and reflection processes. As a consequence, these processes may produce areas of enhanced scour and/or erosion. By understanding these processes and their associated potential for scour and erosion, appropriate protection measures can be incorporated into the stormwater treatment design to manage this risk.

WATER QUALITY AND STORMWATER TREATMENT

Stormwater treatment within a tidal creek can combine multiple processes, such as;

- Physical processes: sedimentation, filtration.
- Chemical processes: flocculation, adsorption.
- Biological processes: plant uptake, microbial decomposition.

Tidal creeks contain a combination of fresh and saline waters. If sufficient mixing of these waters occurs, flocculation can be enhanced. Alternatively, improved sedimentation can be achieved if concentrated flows can be dispersed over larger areas where sufficient space can be provided.

Design of stormwater treatment devices within a tidal creek should therefore have an understanding of what the contaminants of concern are within the stormwater discharge and what combinations of the above processes can be accommodated into the design to facilitate enhanced stormwater treatment.

3.2 ENGINEERING CONSIDERATIONS

COLLECTED SEDIMENT DISPOSAL

Any stormwater management option within a coastal environment needs to provide consideration of how and where accumulated contaminants will be disposed of. Due to the salinity, pH, and water content of coastal sediments, landfills will commonly not accept these. The contaminant accumulation rates and disposal options should therefore be researched as a design component of the stormwater management options.

MATERIALS

Materials used for a stormwater treatment device within a tidal creek are exposed to a diverse range of environmental conditions. Materials commonly regarded as durable within freshwater environments may not be suitable within a tidal creek due to a reduced durability or increased corrosion potential. Use of highly durable materials or planned maintenance should therefore be utilised to ensure structures are robust and last the anticipated design life without failure.

The opportunity should also be considered for the use of in situ materials from the stormwater treatment device location. For example, dredged sediments could be used for filling of geofabric bags to form bunds as a part of a stormwater treatment device structure.

EASE OF CONSTRUCTION

Tidal creeks can be difficult environments for construction due to poor construction access, variable ground and flow conditions. Access needs to be considered during the design phase, so that any works are incorporated and there is adequate space for machinery. Such access could be through the use of barges to provide access to the location, temporary access routes, the use of long reach diggers, or the pumping of sediments. Construction of structures may also be more easily achieved through methods such as sheet piling or piling from barges.

CLIMATE CHANGE

Climate change is anticipated to increase stormwater flows from catchments due to increased rainfall intensities and therefore have a greater ability to transport contaminants, such as sediment, to receiving environments. In addition, sea levels are predicted to rise and storm surges are expected to become more significant.

Design of stormwater management devices within tidal creeks should therefore consider how a particular device will be managed and how it will adapt over time. Examples of how this can be achieved is by acknowledging that structures may need to be rebuilt, adapted, or made redundant over time. For example, a structure such as a bund may need to be 'topped up' following settlement, or a vegetation species incorporated within an initial design may need to change over time.

3.0 DESIGN STRATEGIES

3.3 CONSTRAINTS, OPPORTUNITIES + DESIGN OBJECTIVES

	CONSTRAINTS	OPPORTUNITIES	DESIGN OBJECTIVES
Coastal Processes	• Interruption of coastal processes could accentuate existing and /or create new detrimental effects such as scouring or upstream flooding	• Utilise coastal processes to develop on line devices • Utilise off line devices • Potential to arrest existing erosion	• Provide for sea level rise • Minimise erosion • Harness currents to direct flows to sedimentation areas
Geology / Underlying Ground Condition	• Underlying material is soft and subject to compaction and on-going differential settlement • Mud flats are susceptible to erosion and scouring	• Clay banks, rocky outcrops and sandstone reefs provide areas of greater stability	• Where possible utilise stable geology and underground conditions for devices requiring earth works and landform manipulation
Water Quality	• Elevated sediment and contaminant levels in existing environment can be mobilised • Diffuse contaminant sources (may require multiple treatments) • Options for sediment disposal may be limited • The invert level of the tidal channel is below adjacent tidal flats meaning that base flow will bypass treatment	• Vegetated banks can provide some filtration of sheet flows from adjacent land uses • Coastal margin can potentially be used to provide treatment • Capture contaminants in storm flows / tidal movements • Mixing of fresh and saline waters to enhance sedimentation • Highly degraded areas could be used to protect downstream habitats	• Filter water through natural materials • Enhance sediment and contaminant retention in near-shore and upper estuary zone • Utilise natural chemical, physical and biological processes • Trap sediment and contaminants
Water Quantity	• Flash flood flows • Narrow coastal edge provides limited opportunity to manage catchment wide water quantity issues • Scouring around outlets & inlets •	• The invert level of stormwater outlets is often at or near current high tide levels • Up stream flooding may prevent raising water levels to avoid affecting existing low-lying property	• Provide for flood flows • Provide for sea level rise • Slow water flows • Attenuate storm flows • reduce erosion / scour
Landscape Connectivity + Biodiversity	• Vegetation is susceptible to disturbance from invasive species and predators; • Vegetated banks lack connectivity; • Limited 'cues to care'[1] in vegetated banks, particularly adjacent to business / industrial uses and road corridors; • 'Planned and design' planting strategies can be prohibitively expensive and may not be as adaptable as 'naturally selected' compositions of species • Limited habitat complexity • Tidal fluctuations • Saline wedge • Topography and slope stability • Existing access limitations • Spatial limitations *1. 'Cues to care' are elements and patterns in the landscape that indicate human intention and management. They include, but are not limited to mown edges, formed pathways, pruned trees and manicured garden beds. Cues to care in design does not mean maintaining traditional landscape forms but rather a means of adapting cultural expectations so that ecosystems that may look 'messy' to the untrained eye appear to fit within a larger, consciously designed landscape pattern (Nassauer,1995).*	• Expand habitat and biological diversity within vegetated banks via direct planting and active management of invasive species and predators; • Enhance landscape connectivity by linking areas of vegetated banks; • Engage local communities for collective management, particularly in areas adjacent to open spaces and residential areas • Engage with AT and/or NZTA for improvement management at interfaces with other infrastructure elements • Increase education around value of landscape connectivity and biodiversity • Utilise 'managed succession' strategies to maximise investment in planting • Large areas of mangroves with low biodiversity provide opportunity for intrusion into CMA • Enhance connectivity for people and wildlife; • reduce litter	• Maximise vegetated edges to improve treatment, diversity and connectivity • Integrate broad community and stakeholder engagement in design process • Integrate educational outcomes into both engagement processes and finished design outcomes • Where practical, integrate managed succession strategies into design outcomes • Development and enhancement of wildlife movement corridors

3.3 CONSTRAINTS, OPPORTUNITIES + DESIGN OBJECTIVES

Accessibility	• Vegetation limits access to water's edge and intertidal area for both recreation and construction works • Tall vegetation may obstruct views across mangroves, channels, mudflats and to the wider in harbour • Areas adjacent to business / industrial land uses typically have limited access	• Provide confined access points through areas of vegetation for construction and on-going maintenance requirements through walkways, boardwalks, jetties etc • Vegetation can be selected to provide views to and across mangroves, channel and wider in harbour environs	• Ensure adequate access is created for assessment and maintenance of infrastructure • Create space within vegetated banks and mangroves to provide for passive recreation and enable access for people and maintenance operations.
Recreational + Social Values	• Vegetated banks and mangroves currently provide limited recreational value beyond visual amenity • Negative public perceptions of mangroves and degraded parts of the existing coastal edge.	• Provide access to vegetated banks and mangroves through boardwalks and constructed pathways for passive recreation • Raise public expectations	• Integrate passive recreation outcomes into design interventions • Enhance local environmental and social values
Land Use	• Contention around value of mangroves as ecological outcomes and amenity • Constrained space for stormwater treatment throughout catchment • Prevailing / surrounding land use	• Align interventions with proposed land use changes highlighted in Auckland Plan • Potential for development of currently under used land for public recreational or commercial gain	• Align catchment wide and coastal edge strategies with land use change, particularly those associated with intensification
Climate Change + Sea Level Rise	• Existing banks may not provide enough elevation for potential sea level rise • Existing vegetation may be susceptible to inundation, particularly from saline waters; • Existing vegetation may be susceptible to stress from increased drought condition • The invert level of stormwater outlets is often at or near current high tide levels and may reduce future infrastructure capacity	• Elevated land provides some buffer to potential sea level rise • Vegetated banks provide soft / adaptive edge to sea level rise and storm surges • Elevated land provides opportunity to implement stormwater devices less susceptible to future inundation areas	• Increase vegetated edges to improve shore line defence and adaptability to sea level rise as a result of climate change. • Utilise elevated areas to create interventions less susceptible to future inundation • Utilise hardy plant species, tolerant to both inundation and stress • Utilise managed succession as a means of creative adaptive ecological compositions

3.4 DESIGN PRINCIPLES

KEY

- Design principles have been formulated to help guide and assess case studies and development of concept designs
- Design principles logos will be used through the remainder of the document to provide a quick visual indication of where and how design principles have been applied
- Design principles will be colour coded to indicate the primary application, outcome and proposed benefit

ENVIRONMENTAL / ECOLOGICAL

SOCIOCULTURAL

INFRASTRUCTURE / ENGINEERED

LINK

- Create linkages between habitats to enhance landscape connectivity
- Create linkages between existing and new access points for recreation
- Maintain and enhance linkages between land and sea for the passage of fish
- Maintain linkages between land and sea for the passage of peak flows during storm events
- Link infrastructure devices with existing access points for maintenance and monitoring

LEVERAGE

- Leverage and amplify natural processes such as tidal currents, sedimentation and natural succession
- Do more with less - leverage the maximum potential from any given element, material and/or structure
- Leverage opportunities presented by under utilised space

SLOW

- Slow the movement of water through the landscape to allow for the containment of contaminants including heavy metals and minimise their re suspension
- Utilise a combination of solutions undertaken over a period of time that together collectively control the sedimentation process

COUPLE

- Couple functions to ensure that every element has multiple benefits and that every function is met by more than one element
- Couple design interventions with other projects and initiatives that are occurring in the local environs to ensure that maximum value is achieved

DIVERSIFY

- Maintain and enhance biodiversity and ecosystem complexity
- Diversify the number of ways people can explore and experience the environment
- Diversify infrastructure devices to ensure redundancy allowed for in the system

CELEBRATE

- Celebrate the natural and cultural heritage of the site through expressive design that 'include and transcend the past'
- Celebrate the local community as conscious and active participants of the local ecosystem through early and ongoing community consultation and education
- Celebrate the communities engagement in the ongoing evolution of the site by incorporating 'Cues of Care' into the design

PREPARE

- Prepare for change through the design of robust and durable infrastructure elements that resist the entropic forces of the estuarine environment such as scouring and flooding
- Prepare for change by designing infrastructure elements and ecologies that respond and adapt to ongoing environmental processes, including the effects of climate change
- Prepare the environment for community use by ensuring safe and equitable access

3.5 LOCAL EXAMPLES OF INTERVENTIONS IN COASTAL MARGINS WITH POSITIVE OUTCOMES

LITTLE SHOAL BAY, NORTH SHORE, AUCKLAND

INTRODUCTION

Little Shoal Bay Stream was originally a shallow, mangrove fringed, tidal inlet, with a shell bank extending across the entrance of where Maritime Terrace now runs. Edward Le Roy purchased much of the valley in 1918 and established lily ponds, culverted parts of the stream to bypass the ponds and prevent flooding, and enriched the flora with species collected from other parts of New Zealand. Reclamation in the late 1950's and early 1960's subsequently restricted stream flows, eventually leading to the formation of wetland and raupo swamps in the western and northern arms of the bay, which had previously been salt water and mangrove areas (*North Shore City Council 2005*) . These have become a defining feature of the bay.

Council staff have been working in partnership with communities across the city since early 2008 as part of its "Naturally Smarter Projects". The aim is to involve private property owners in protecting and enhancing streams on their private land. The project is expanding with an additional site in the Birkenhead - Northcote area and a focus on the Little Shoal Bay stream and Le Roys Bush reserve (*Auckland Council*).

APPLICATION / DESIGN

As with previous sites, Council is working intensively with targeted groups of property owners who have streams within their private property in order to improve the riparian environment. This involves looking at how stormwater is managed on site; removing and controlling pest plants; planting natives; controlling animal pests where necessary and generally minimising impacts on the stream and bush environment. Already in 2010, extensive weed management has been undertaken, rubbish has been removed and native plants and trees have been planted. Council is working in partnership with the Le Roys Bush Management Committee to install a series of environmental interpretation panels in Le Roys Bush reserve to inform reserve users about key environmental features of the area.

Natural streams and their wetland vegetation close to and within the estuarine environment provide an effective method for managing rain run-off whilst also creating opportunities for the enhancement and diversification of the natural ecosystem. These streams and associated wetlands act as filters, purifying the water as it moves down towards the sea contributing to cleaner beach water at Little Shoal Bay beach whilst reducing flooding and erosion. It will create greater natural diversity for native fish, insects and birds. And will ultimately mean a better environment for everyone to enjoy (*Auckland Council*).

3.5 LOCAL EXAMPLES OF INTERVENTIONS IN COASTAL MARGINS WITH POSITIVE OUTCOMES

ORAKEI WALKWAY, AUCKLAND

INTRODUCTION

The Orakei Walkway is an example of how the provision of public access can be successfully integrated into the coastal environment.

Orakei Basin is a natural explosion crater, that was originally more than 100m deep before being inundated by the sea and largely in-filled with mud and sand (*Homer, Moore, Kermode 2000*). It straddles a western tributary of Purewa Creek, but was isolated in the 1920's by the construction of the railway embankment. This created a very sheltered environment and altered the natural tidal flow in and out of the basin. In the early 1930's a set of sluice gates were installed to provide flushing and control water levels. Auckland City Council then removed the mangroves to create an area for water-based activities. Orakei Basin was heavily used for 15 years for swimming and other water-based activities. Water quality and use subsequently declined due to pollution from the adjacent catchments (*Auckland City Council*).

However, it remains the largest fully impounded body of seawater in the Auckland region that allows water-based recreation at all tides. It is still used by the community and various groups, particularly for activities such as waterskiing and sailing. The Akaranga Young Mariners, Auckland Water Ski Club, and Orakei Sea Scouts all have their club rooms on the basin's shoreline.

APPLICATION / DESIGN

Its sluice gates are opened once a fortnight by the Auckland Water Ski Club. The gates are also opened when 15mm of rain in any 4 hour period and/or 5mm of rain falls in any one hour period. This allows sewage, sediment and other contaminants to be released. This flushing programme makes it difficult for both intertidal and sub-tidal species to colonise the area. Consequently, the species found in the basin are generally opportunistic species well adapted to disturbed environments. Sediments in the basin are contaminated with elevated levels of nickel, lead and zinc. The accretion of sediment within Orakei Basin is a problem and a number of dredge operations have been carried out to maintain water depths (*Kingett Mitchell Ltd. 2005*).

However, the basin remains a highly valued community asset. Completed last year, the picturesque Orakei Basin Walkway is the perfect place to spot ducks, shags, pukeko and waterskiers practising their moves on Orakei Basin. The walkway includes a 650m long boardwalk, which runs over the water alongside the existing rail corridor, and a footbridge that crosses the Orakei Creek arm of the basin. Public access to the 2.9km walkway is available at numerous points, including Upland and Orakei roads. (*Auckland Council 2012*)

3.5 LOCAL EXAMPLES OF INTERVENTIONS IN COASTAL MARGINS WITH POSITIVE OUTCOMES

WAITAKERE TWIN STREAMS PROJECT, AUCKLAND

INTRODUCTION

In 1997, Waitakere City Council commissioned studies to investigate the effects of stormwater on the Oratia and Opanuku Streams. The study indicated that there were critical issues facing the catchment:

- High levels of pollution in the discharge from Henderson Creek to the Waitemata Harbour
- Sporadic flooding
- Erosion and sedimentation of stream beds
- Unacceptable levels of sewage overflows during storms

With the added pressure of urbanisation and escalating extreme weather events attributed to climate change, a growing population, demand for water and an aging stormwater infrastructure, the challenges and costs were set to increase.

To combat these stresses, Project Twin Streams was established. It was decided that restoring natural systems to manage stormwater was the preferred solution. With the aim of reducing pollution, flooding, erosion and sedimentation in our waterways, the project set out to restore the riparian margins of the two streams. This is now widely recognised as a significant mechanism for improving water quality and enriching stream ecology, both in New Zealand and internationally (*Project Twin Streams*).

APPLICATION / DESIGN

Project Twin Streams is a large-scale environmental restoration project. In order to improve water quality in Waitakere streams, 56km of stream banks were revegetated with native trees and shrubs. The Council also purchased properties within the flood plain for removal. This was intended stabilise stream bank, reduce erosion, create a shaded environment for native species to thrive and filter contaminants entering the streams.

Through its unique approach, Project Twin Streams has engaged local residents in the project through partnering with local community organisations to deliver the planting program.

Project Twin Streams is a local project with regional benefits. It works with nature and with people to improve the health of the waterways and harbour. It relates to urban estuaries as an example of what can be achieved along riparian margins and how this could be undertaken (*Project Twin Streams*).

3.0 DESIGN STRATEGIES

3.6 INTERNATIONAL EXAMPLES OF INTERVENTIONS IN COASTAL MARGINS WITH POSITIVE OUTCOMES

RENAISSANCE PARK, CHATTANOOGA, TENNESSEE, USA

INTRODUCTION

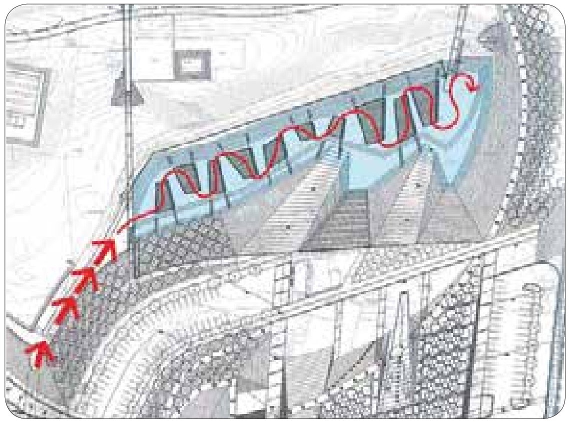
The 10ha Renaissance Park on Chattanooga's North Shore has been designed and constructed on a former industrial site. An intermittent stream draining over 70 ha of urban watershed cuts through the park, contributing to significant non-source point pollution of the Tennessee River. Enamel frit waste cells left in the water table by previous owners threatened to leach a range of contaminants into the surrounding site and water systems *(Hargreaves, Czerniak, Berrizbeitia, Campbell-Kelly 2009).*

APPLICATION / DESIGN

This design by Hargreaves Associates focuses on slowing the water flow and integrating natural ecosystem function into the constructed elements of the intervention.

Buried waste was removed and stabilized chemically and geotechnically on site rather than be exported to landfills. A constructed wetland system now collects and cleans urban runoff generated on site and runoff brought onto the site via another tributary, before release into the Tennessee.

Finally, unstable and actively erosive stream and river banks have been stabilized with a unique vegetative revetment system and the use of fascines and live-staking, as well as a series of gabion structures and rip-rap armature *(Hargreaves et al 2009)*.



3.6 INTERNATIONAL EXAMPLES OF INTERVENTIONS IN COASTAL MARGINS WITH POSITIVE OUTCOMES

BARKING CREEK, RIVER THAMES, LONDON (2006)

INTRODUCTION

This scheme in London, England attempts to create an ecologically rich, attractive new intertidal embayment and educational area on Barking Creek, 100m upstream of Barking Barrier on the north bank of the Thames.

- River over 50m wide and subject to 7m tidal range.
- Low risk of wave-wash from vessels.
- High sediment load in water column.
- Large area of riverside available.
- Relatively low flood risk in the event of loss of integrity of the design.

This technique creates sedimentation areas to provide an environment for the development of native riparian plant species. In addition to enhanced natural and aesthetic values the control of sedimentation and revegetation process provides opportunities for treatment of contaminants *(Thames Estuary Partnership and Environment Agency 2008).*

APPLICATION / DESIGN

This example Illustrates the technique of a 'brushwood fascine' (or 'brushwood faggot)' installation on the steeper upper slopes which are less frequently inundated by the tide. Brushwood fascines are bundles of cut branches, tied with cord and entrenched in a woven pattern between closely placed driven poles to create quite robust low 'fences'. Sediment rapidly accumulates between the fascines where the technique has been correctly sited.

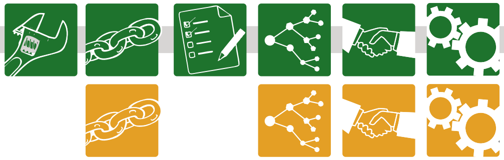
This bioengineered solution is quite likely to be effective if a bank already exists that is fully stabilised by vegetation and where adjacent landform provides sufficient additional volume to accommodate both the flood water and a reduction in water velocity, encouraging sedimentation in these areas. This solution may not be appropriate where existing plant cover is failing near the site *(Thames Estuary Partnership and Environment Agency 2008).*

500 mm deep brushwood mattress

3.0 DESIGN STRATEGIES

3.6 INTERNATIONAL EXAMPLES OF INTERVENTIONS IN COASTAL MARGINS WITH POSITIVE OUTCOMES

LOWER DON LANDS, TORONTO, CANADA



INTRODUCTION

This design was one of four invited entries in the second phase of an urban design competition for Toronto's Lower Don Lands. It was not the winning entry; however, the jury felt the work by this team, led by Boston's Stoss Landscape Urbanism, presented a vision of the integration of urban form with natural process.

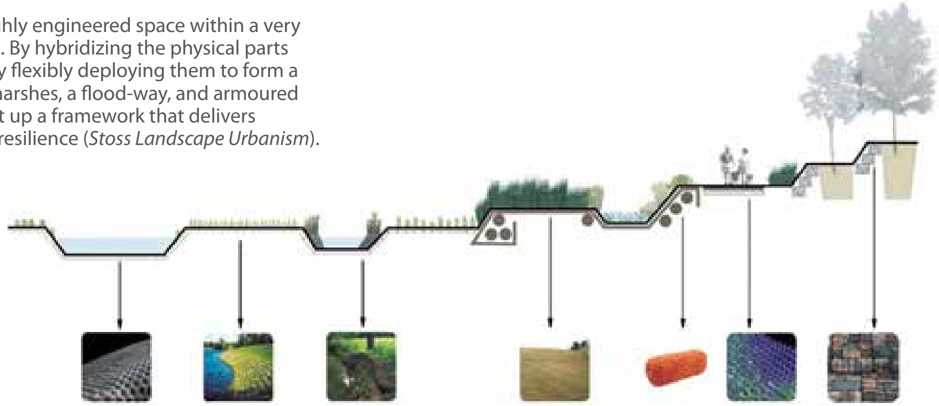
The river-lake interface is a rich breeding ground for fish and other wildlife. Mapping the fish passage, this design chose to re-establish the broad estuarine plate that slopes gently toward the harbour, thus maximizing the effects of river and lake fluctuation and ecological resilience.

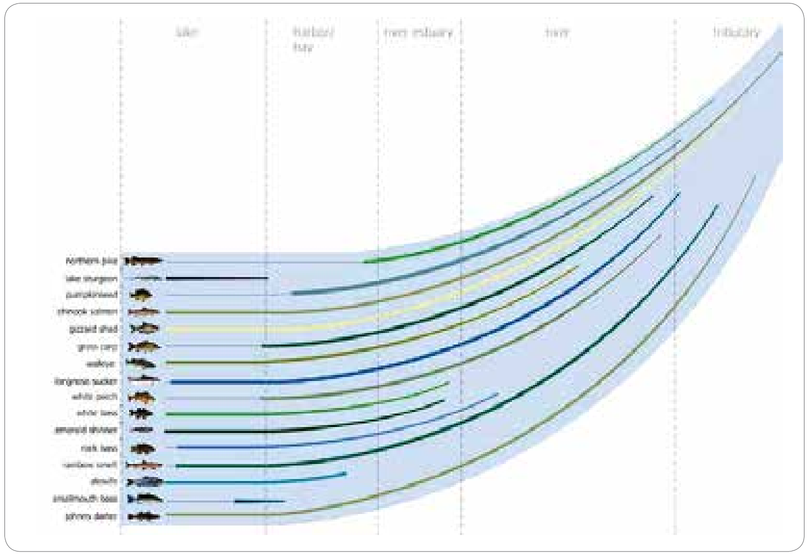
Although the scheme relates to non-tidal freshwater environment the principles that it investigated are relevant to tidal water bodies (*Stoss Landscape Urbanism*).

APPLICATION / DESIGN

Rather than re-shaping the river strictly according to the needs of the emerging city, this design puts the ecology of the river first, allowing it to shape the metropolis, giving rise to unique, dynamic, urban form and open spaces.

The river is currently a highly engineered space within a very constructed environment. By hybridizing the physical parts of the river system, and by flexibly deploying them to form a primary channel, broad marshes, a flood-way, and armoured uplands, the designers set up a framework that delivers ecological and structural resilience (*Stoss Landscape Urbanism*).





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4.0 CONCEPT DEVELOPMENT

4.0 CONCEPT DEVELOPMENT

4.1 INTRODUCTION

This section presents a range of concept designs, which apply the design strategies outlined in Section 3 to the characteristic conditions and patterns presented in the second section. The first 19 concept designs present a single intervention at a time to ensure that each proposed intervention is clearly articulated in its own right. Each intervention is described and constraints and opportunities explored.

The final three 'hybrid interventions' demonstrate how a range of the individual concept designs could be combined and integrated to form a congruent design with multiple outcomes and benefits. The design principles applied to each intervention are presented in the top right of each page.

1 - REVEGETATION - OVERLAND FLOW CONTAINMENT

Description

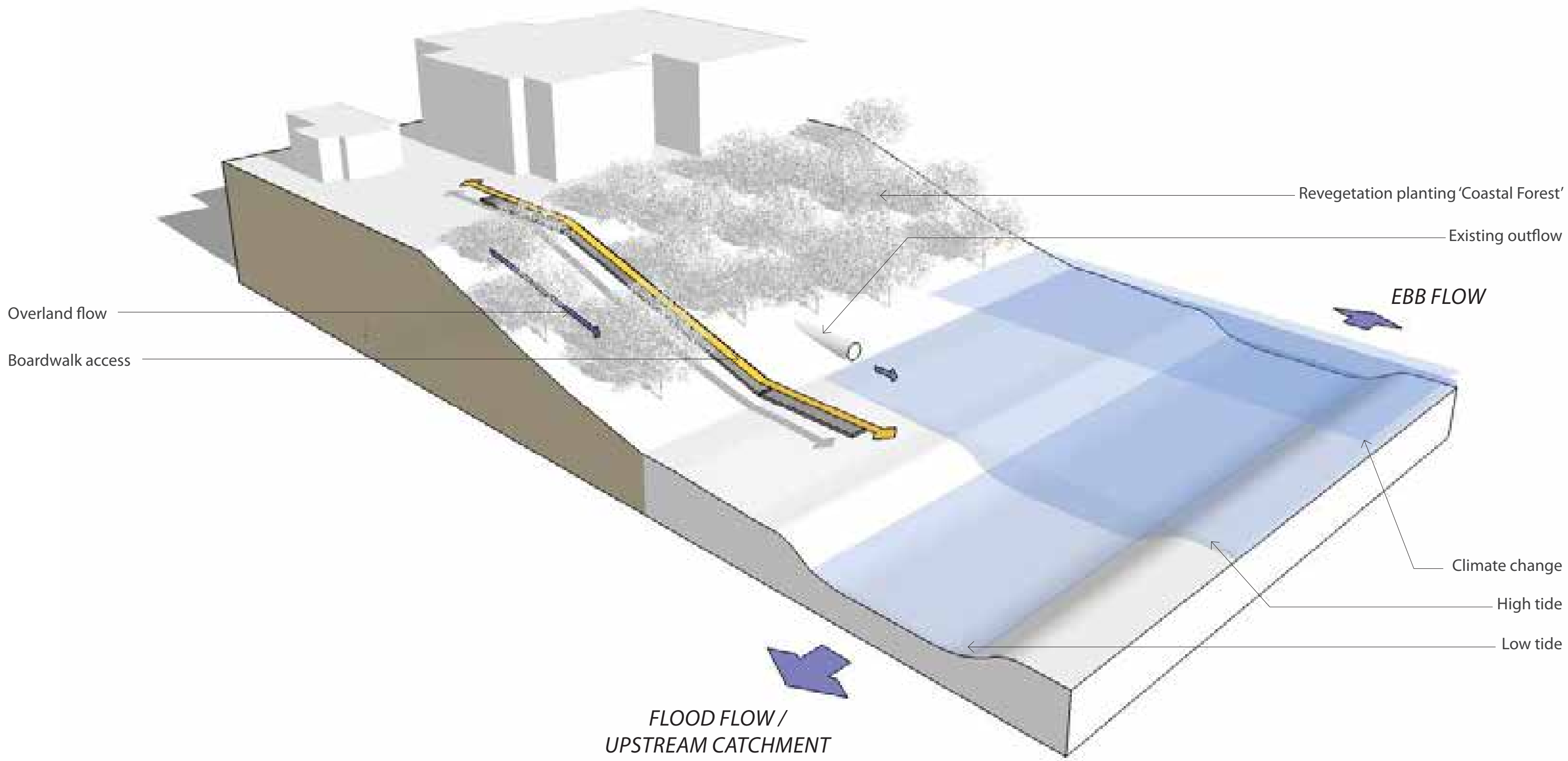
- *Grass bank revegetated with appropriate coastal forest species or existing vegetated banks are managed to increase coverage, connectivity and complexity*
- *Access via constructed path to reduce sapling damage and aid in forest establishment*

Constraints

- *Minimal sediment and contaminant treatment*
- *Water treatment limited to overland sheet flows*
- *Only small volumes can be treated*
- *Will affect views to open water, and may be perceived as undesirable in existing residential areas*
- *Existing pipe reticulations may not align with the preferred wetland level*

Opportunities

- *Assumed to be cost effective if weeds are controlled in early stages*
- *Potential volunteer project / community participation*



2 - OVERLAND FLOW BUNDING - OVERLAND FLOW CONTAINMENT

Description

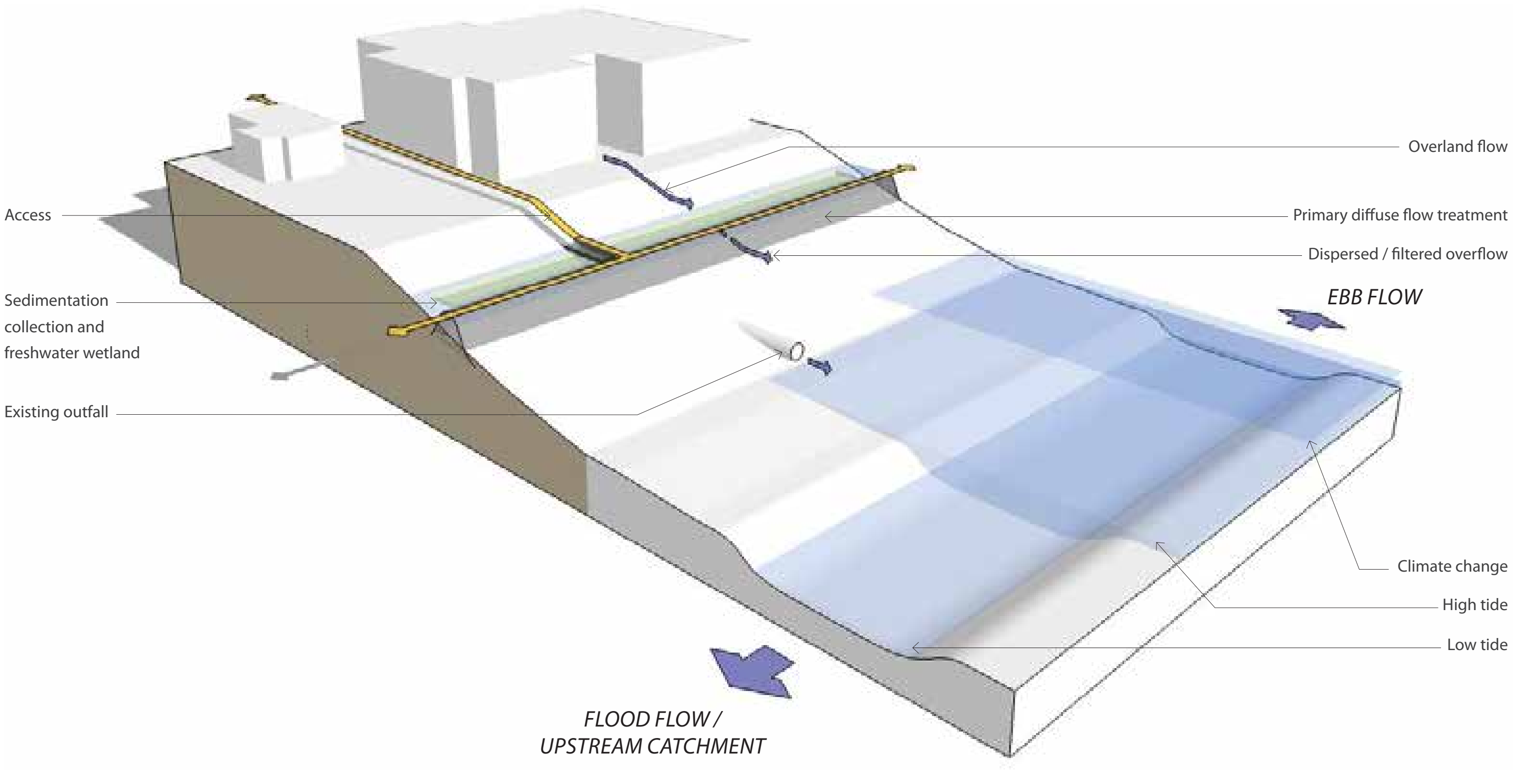
- *Create a bund at or near the top of the bank to capture the overland flow and construct a freshwater wetland environment*
- *Public access is achieved via onto formed pathway on top of bund*

Constraints

- *If existing vegetation is valued then this may limit the space available for enhancement proposals and may shade out wetland vegetation*
- *Water treatment limited to overland flows*
- *Existing pipe reticulations may not align with the preferred wetland level*
- *Topography and access*

Opportunities

- *Low cost overland flow treatment*
- *Minimum construction disturbance / efficient use of space*
- *Wetland habitats and habitat linkage*
- *Easy to top up and maintain*
- *Bunds could be constructed out of a number of different materials and construction methodologies including: on-site sediment in geofabric; shells; gabions; vegetation*
- *Easy to maintain and adapt design for climate change effects*
- *Link / collect multiple discharges*



3 - TERRACING - OVERLAND FLOW CONTAINMENT

Description

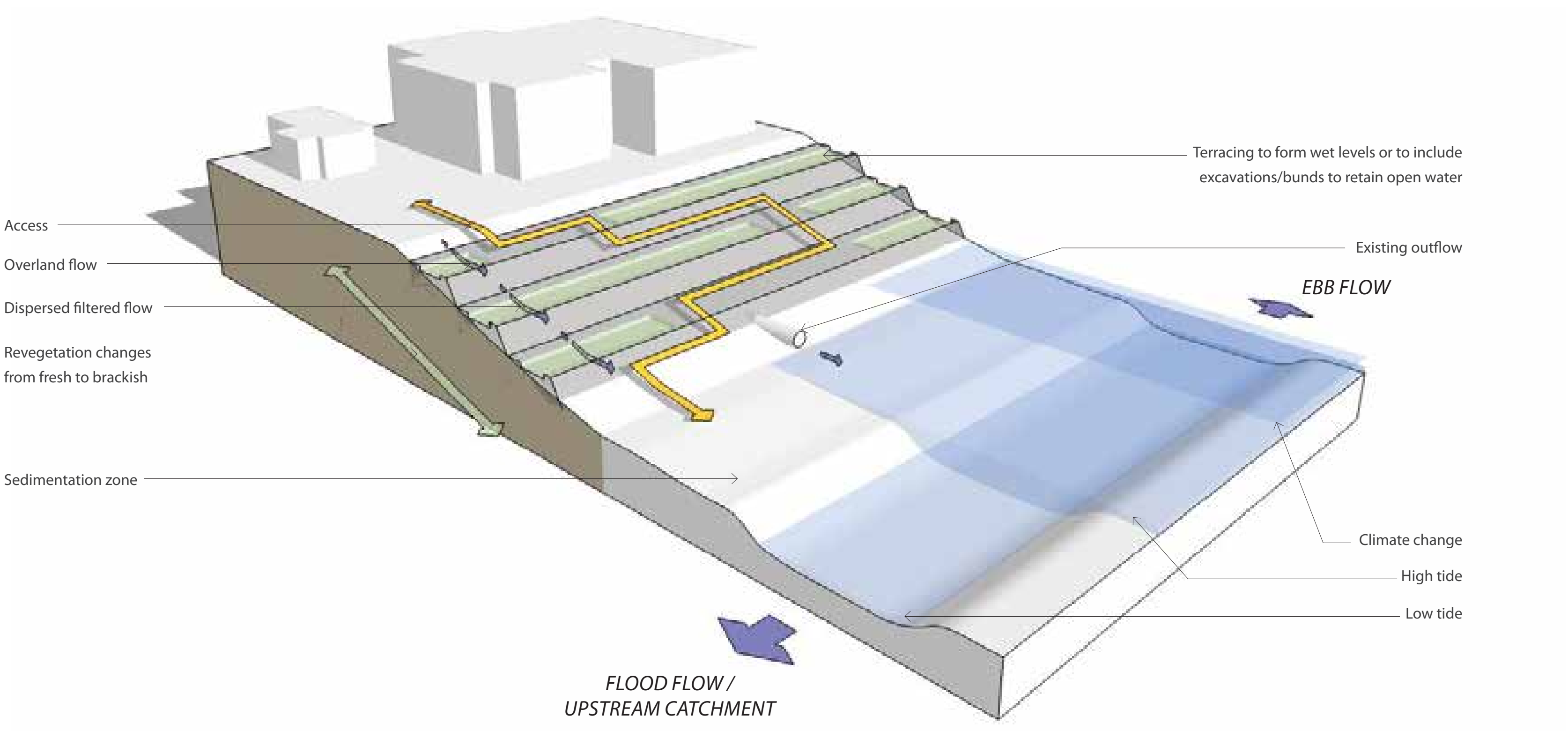
- *Cut and fill excavation into bank to create terraced wetland structures to capture and treat overland flow, with a gradient of suitable saline to fresh water fauna.*
- *Carefully considered system of pathways (controlled access to waters edge)*

Constraints

- *Limited stormwater contamination treatment to existing overland outfalls*
- *Requires reasonable change in levels for multiple tiers*
- *Existing pipe reticulations may not align with the preferred wetland level*

Opportunities

- *Possible extension of terracing to lower slopes for treatment of high tide flows and existing outfalls*
- *Good habitat linkage and diversification of outcomes with differing wetland types*
- *Accessible for construction and maintenance*
- *Responsive to sea level rise*
- *Facilitates good access to water edge*



4 - GENTLE SLOPE BUNDING - OVERLAND FLOW CONTAINMENT

Description

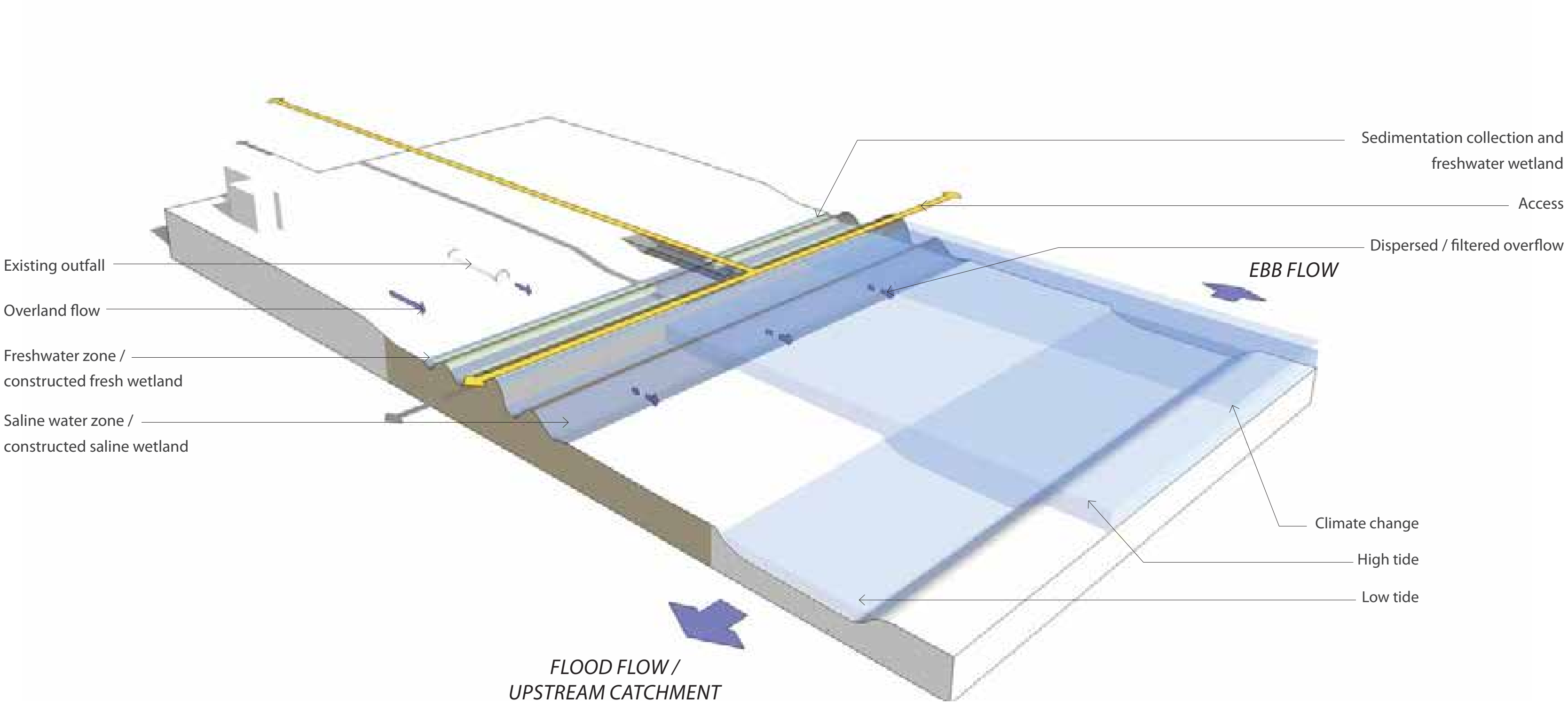
- *Create bunds along coastal edge to capture the overland flows (freshwater zone) and tidal flow (saline zone)*
- *Top of bund generally at the upper range of tidal influences*
- *Public access is achieved via formed pathway on top of bund*

Constraints

- *Water treatment generally limited to overland and existing outfalls*
- *Existing pipe reticulations may not align with the preferred wetland level*

Opportunities

- *Overland flow treatment*
- *Minimum construction disturbance*
- *Multiple wetland habitats and habitat linkage*
- *Low construction cost*
- *Resilient – easy to adapt to climate change and maintain*
- *Bunds could be constructed out of a number of different materials and construction methodologies including: on-site sediment in geofabric; shells; gabions; vegetation*



5 - NETS - OVERLAND FLOW CONTAINMENT

Description

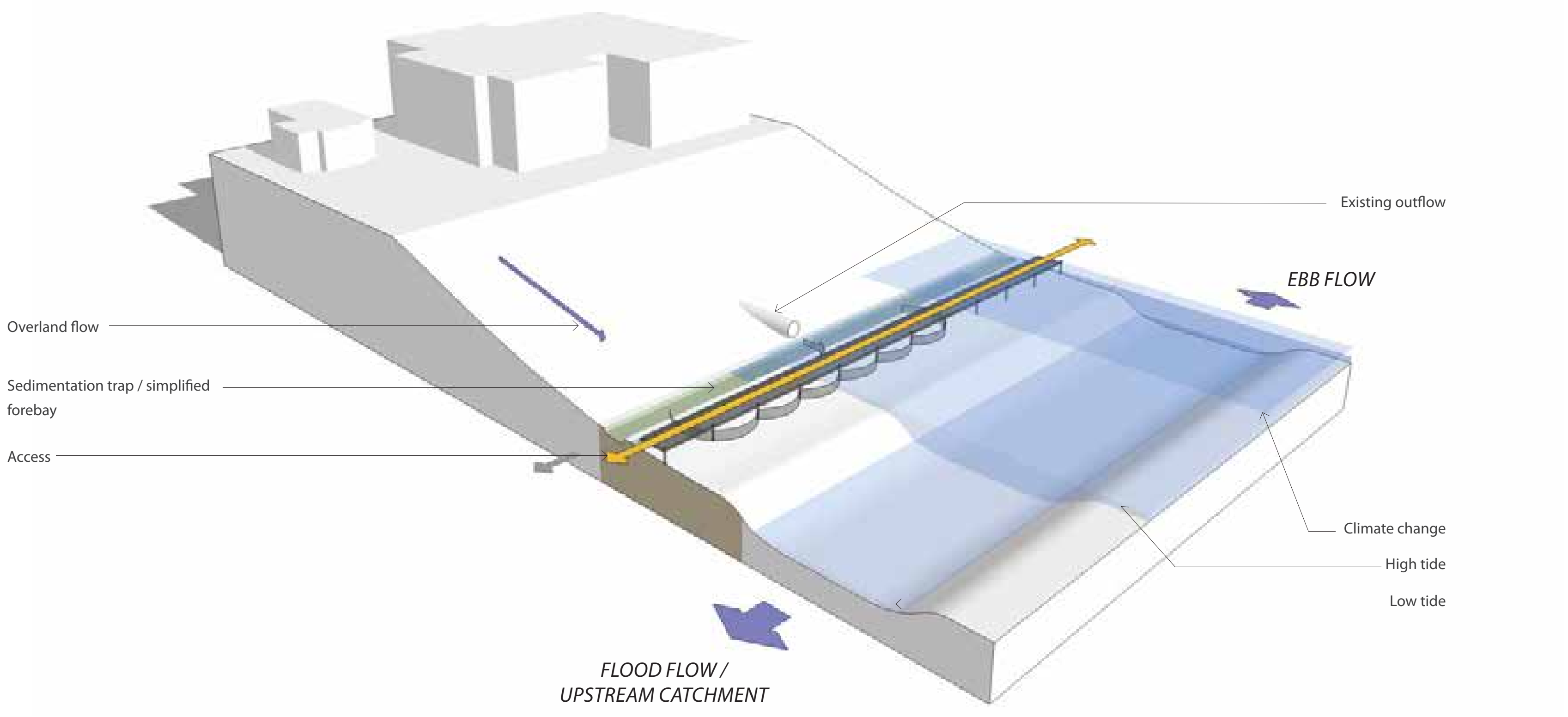
- *Simplified forebay constructed with net to capture sediment from overland flow, stormwater spills over net, eventually sedimentation will generate a natural bund*
- *Access via constructed boardwalk utilising same posts as fence*

Constraints

- *Sedimentation and vegetation may take time to develop*
- *Land stability for foundations*
- *May be at risk from vandalism and storm damage*
- *Silt fence requires design to resist stormwater flow forces*
- *Water treatment limited to overland and existing outfalls*
- *Will collect litter and debris requiring additional maintenance*
- *Sediments in the main flow are not treated*
- *Existing pipe reticulations may not align with the preferred wetland level*

Opportunities

- *Low construction cost, uses natural process to win material to form bunds*
- *Easy to construct in constrained areas*



6 - MUSSELL SHELL FILTER TRAPS - BIO-FILTRATION AND SUSPENDED SEDIMENTATION CAPTURE

Description

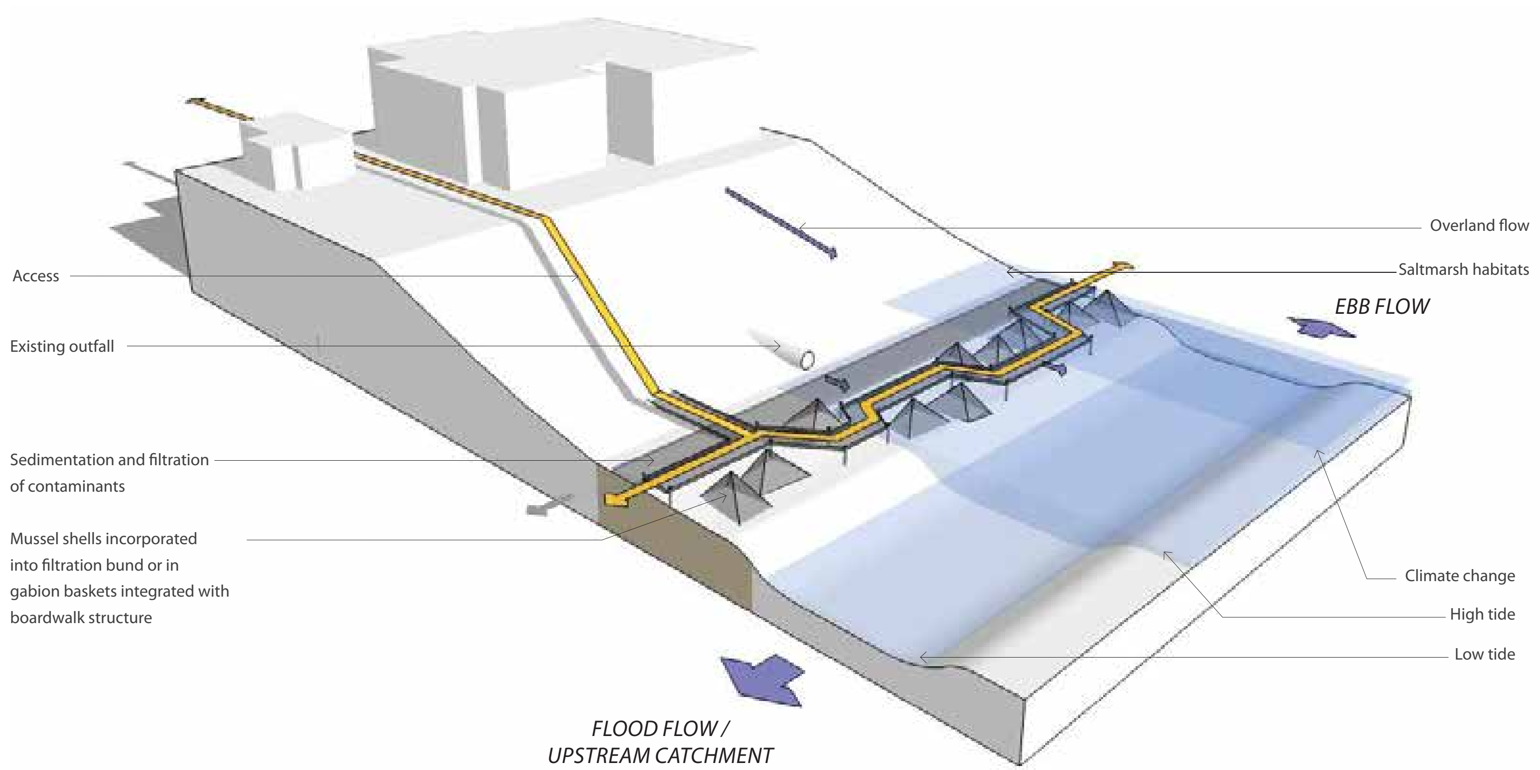
- *Constructed gabion baskets along coastal edge filled with crushed mussel shells*
- *Access via constructed boardwalks over (reinforced) gabion baskets*

Constraints

- *Possible shell supply issues*
- *Land stability for foundations*
- *Sculptural form illustrated will not come into contact with all contaminants*
- *Not suitable for high velocity flows and high energy wave conditions unless method of binding shells is engaged / stabilised*
- *Water treatment limited to overland and existing outfalls*

Opportunities

- *Makes use of waste from the local shellfish industry*
- *Treats most contaminant flow conditions except main channel*
- *Suitable for contained areas where bankside treatment may not be possible*
- *Resilient to sea level rises and can be topped up.*



7 - BRUSH PACKING - OVERLAND FLOW CONTAINMENT AND SUSPENDED SEDIMENTATION CAPTURE

Description

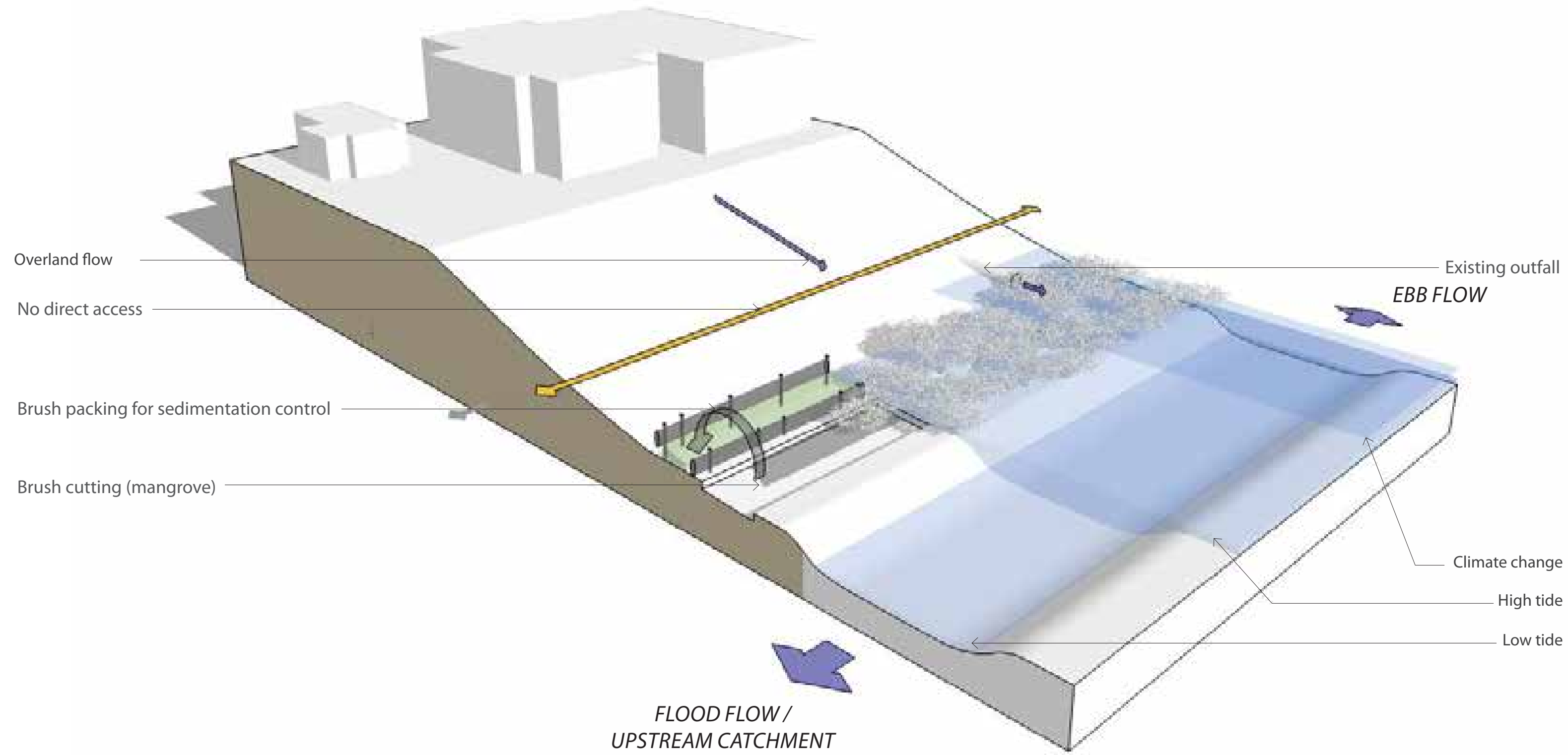
- *Brush cutting of mangrove forest, with bundles of mangrove timber laid parallel to stream flow / perpendicular to overland flow to create brushwood 'fences' to trap sediment*

Constraints

- *May not be resilient to climate change unless device is reinstated*
- *Treatment limited to existing outfalls and upper tidal flows*
- *Vegetation establishment and repeat treatment may be required in high sedimentation areas*
- *Public access not incorporated into infrastructure*
- *May be at risk to vandalism and storm damage*

Opportunities

- *Low construction cost*
- *Makes use of available resources on-site*
- *Can be undertaken with re-vegetation planting*
- *Potential volunteer project / community participation*
- *Creates open views to water*



8 - WETLAND BUND - OVERLAND FLOW CONTAINMENT

Description

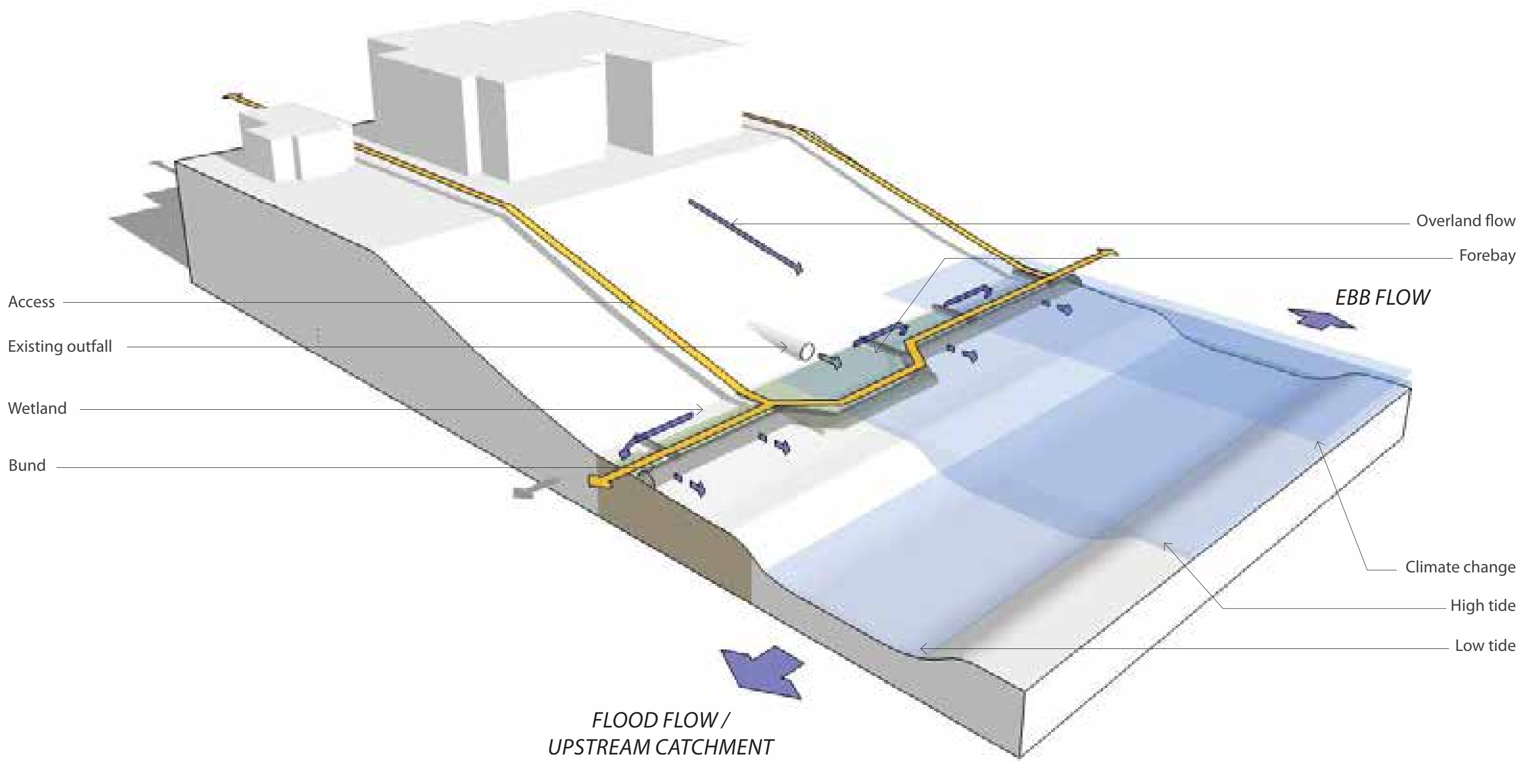
- *Constructed bund at location of outfall pipe to create a wetland forebay to treat stormwater flow along waters edge*
- *Bund provides access around perimeter of wetland*

Constraints

- *Water treatment limited to overland and existing outfalls*
- *Potential scour around outfall*
- *Land stability for foundations*
- *Potential of re-suspension of collected sediment*
- *Existing pipe reticulations may not align with the preferred wetland level*

Opportunities

- *Brackish or freshwater wetlands*
- *Low cost*
- *Habitat creation and linkage potential*
- *Integration with access paths possible*
- *Bunds could be constructed out of a number of different materials and construction methodologies including: on-site sediment in geofabric; shells; gabions; vegetation*
- *Resilient - can be topped up*



9 - TIMBER POSTS - SEDIMENT CAPTURE

Description

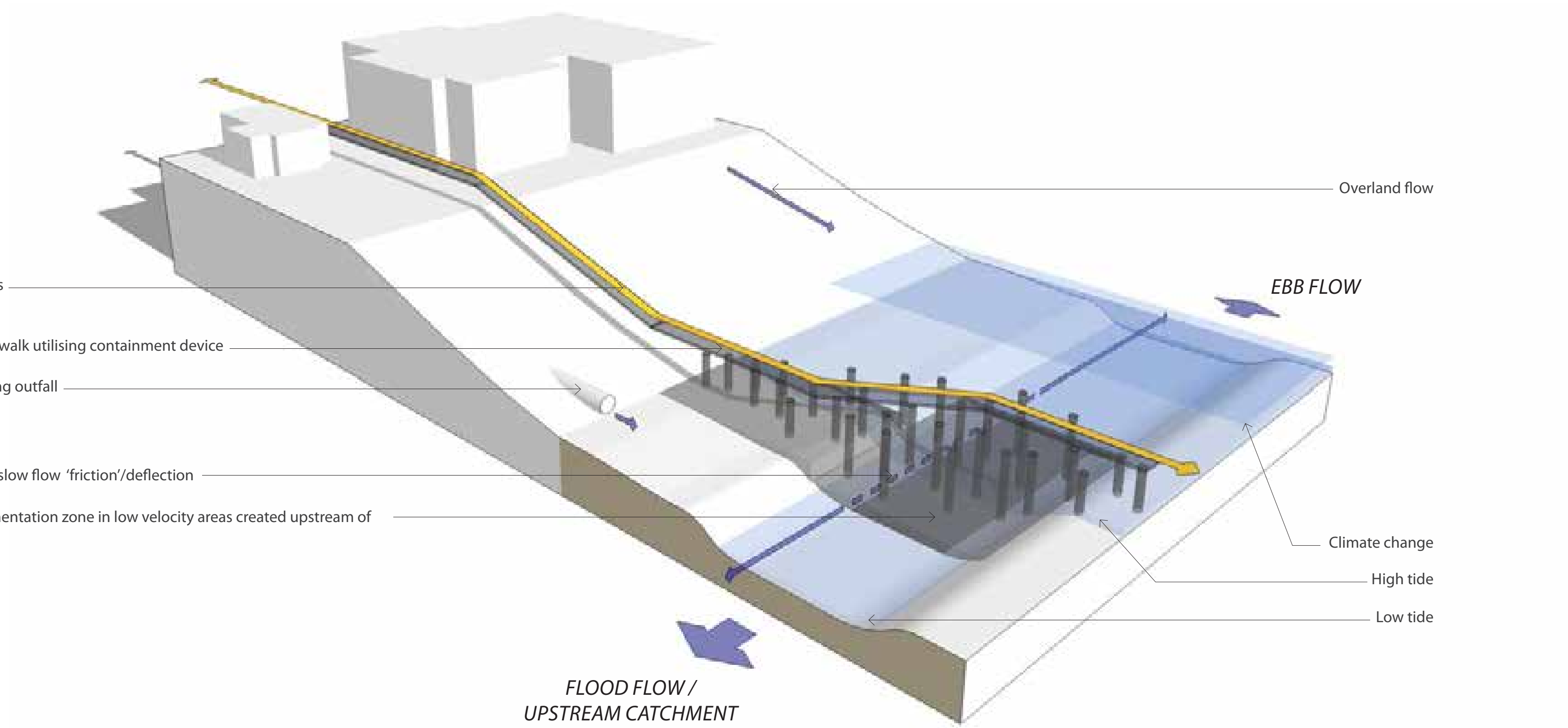
- *Timber poles driven into channel to create head loss - making it harder for salt water coming in and fresh water coming out, effectively raising upstream water levels thereby pushing flows onto tidal flats*
- *Potential access via constructed boardwalk using timber posts*

Constraints

- *Potential navigation hazard*
- *Potential scour around poles during high flow*
- *Re-suspension of sediments during changes in tidal flows*
- *Land stability for foundations*

Opportunities

- *Treats sediment and contaminants at all flow conditions*
- *Provides high tide roosts for waterfowl*
- *Creates access to adjacent bank*
- *Low construction cost*
- *Resilient to climate change - structures can be sized to account for sea level rise*



10 - MID CHANNEL POST DEFLECTORS - FLOW DEFLECTION AND SEDIMENTATION CAPTURE

Description

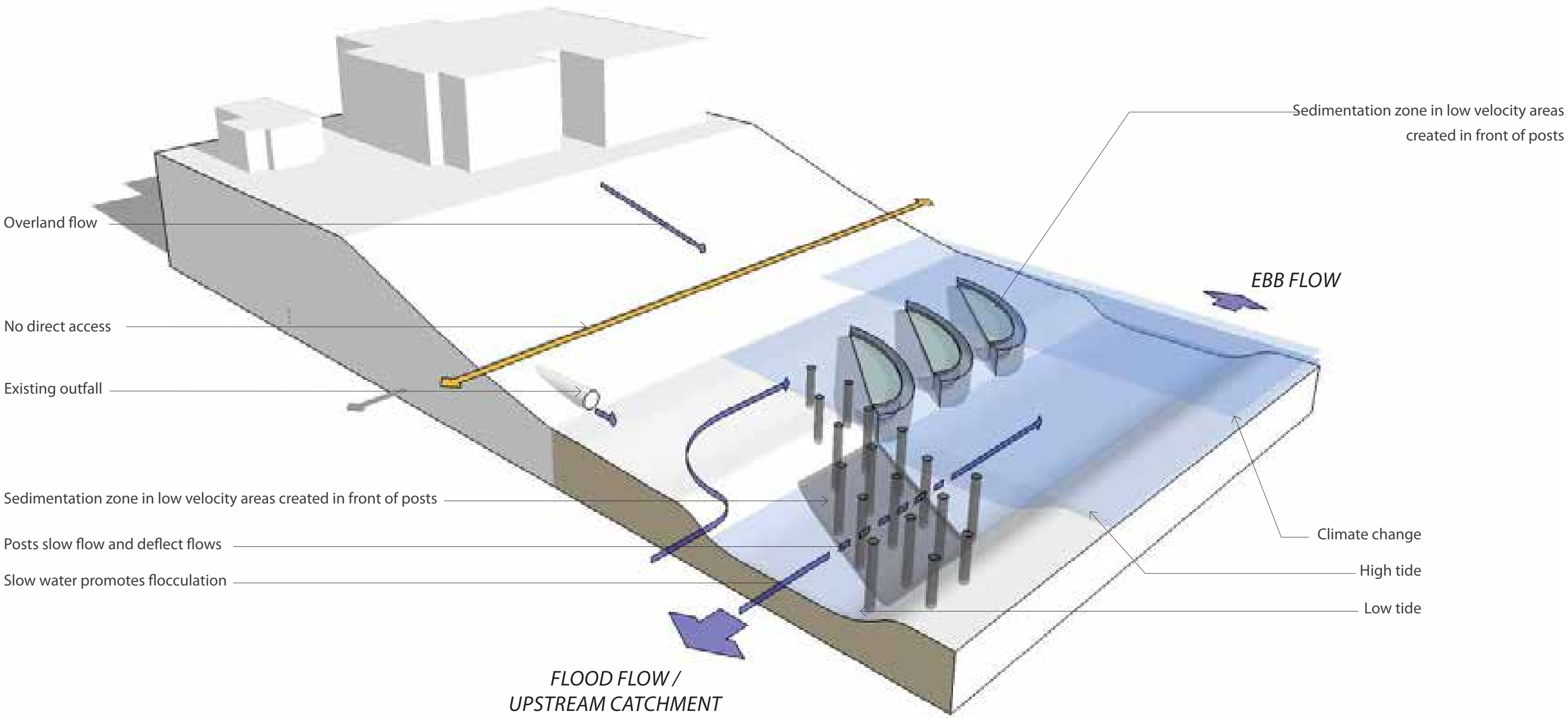
- *Timber poles driven into channel to create head loss during storm event and effectively raise upstream water level thereby pushing flows into saltmarsh and tidal flats*
- *Deflectors bend to spread and slow the flow thereby creating opportunities for sedimentation revegetation*
- *Water slowed to enhance sediment settlement*
- *Maintenance of saltwater intrusion promotes flocculation*

Constraints

- *Potential navigation hazard*
- *Difficult maintenance access for removing accumulated sediment*
- *Potential scouring affect in high velocity areas*
- *No additional access created*
- *Preferably used on large intertidal public areas*
- *Land stability for foundations*

Opportunities

- *Treats sediment and contaminants at all flow conditions*
- *Potential to develop design as an amenity feature*
- *Provides high tide roosts for waterfowl*
- *Provides opportunities for saltmarsh vegetation*
- *Potential to integrate access structure with poles*
- *Resilient to climate change - structures can be sized to account for sea level rise*



11 - MID CHANNEL SOLID DEFLECTOR - FLOW DEFLECTION AND SEDIMENT CAPTURE

Description

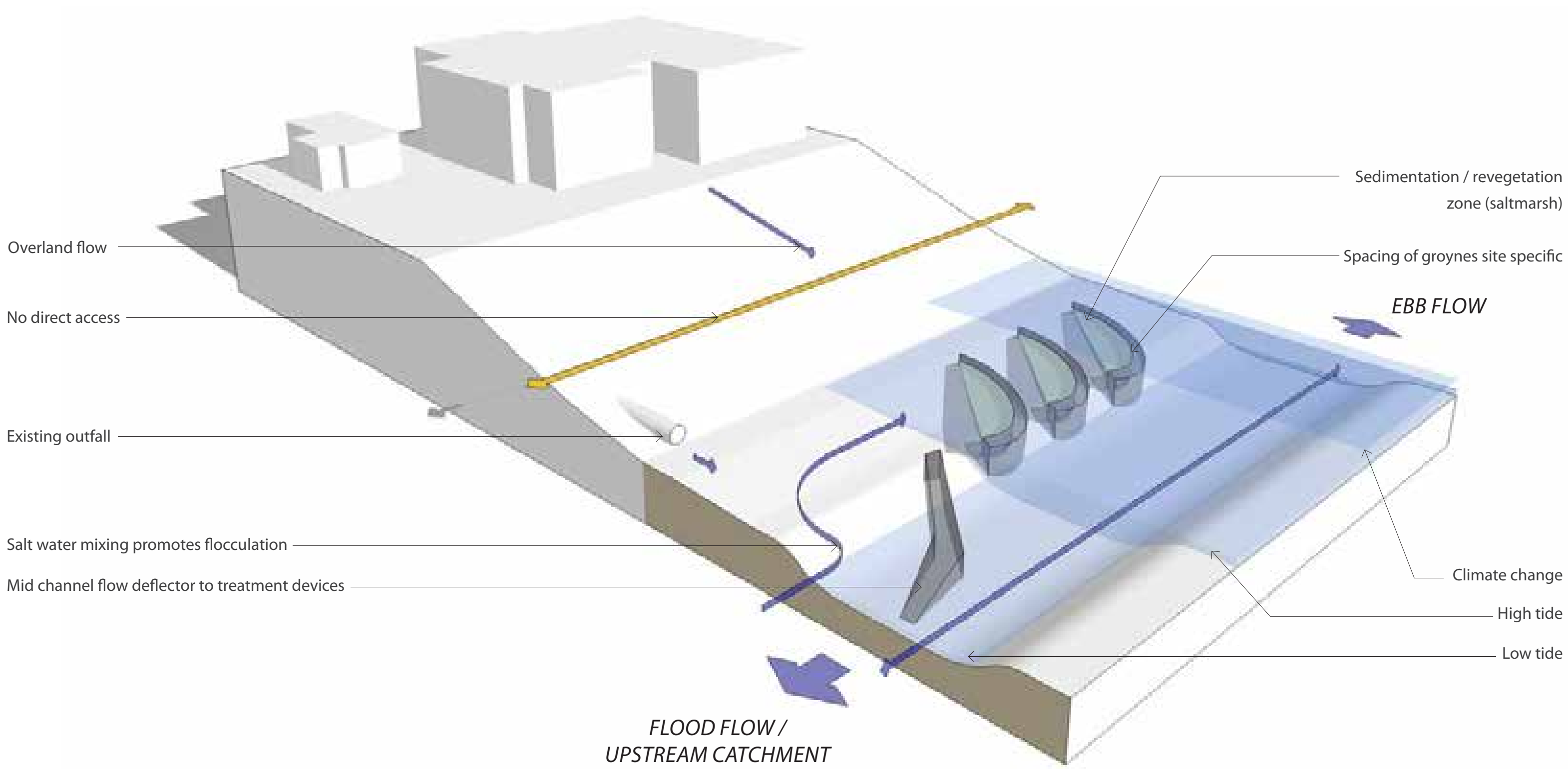
- *Split main channel to divert flows into constructed salt-marsh and tidal flats*
- *Deflector bends to spread and slow the flow and creates opportunities for revegetation*
- *No direct access*
- *Salt water mixing maintained to provide flocculation*

Constraints

- *No significant linkage to opposing bank*
- *Difficult access to deflector if maintenance is required*
- *Disturbance and intervention to the low flow channel*
- *Potential scouring affect in high velocity areas*
- *Potential geotechnical constraints*
- *Requires significant engineering works in the channel*
- *Land stability for foundations*

Opportunities

- *Treats overland, existing pipe outlets and high water conditions*
- *Freshwater habitats created in upper estuary conditions, brackish / salt-marsh or sediment habitats elsewhere*
- *Allows fish passage*
- *Resilient to climate change - structures can be sized to account for sea level rise*



12 - FILTER BUNDS - FLOW DIVERSION AND SEDIMENT CAPTURE

Description

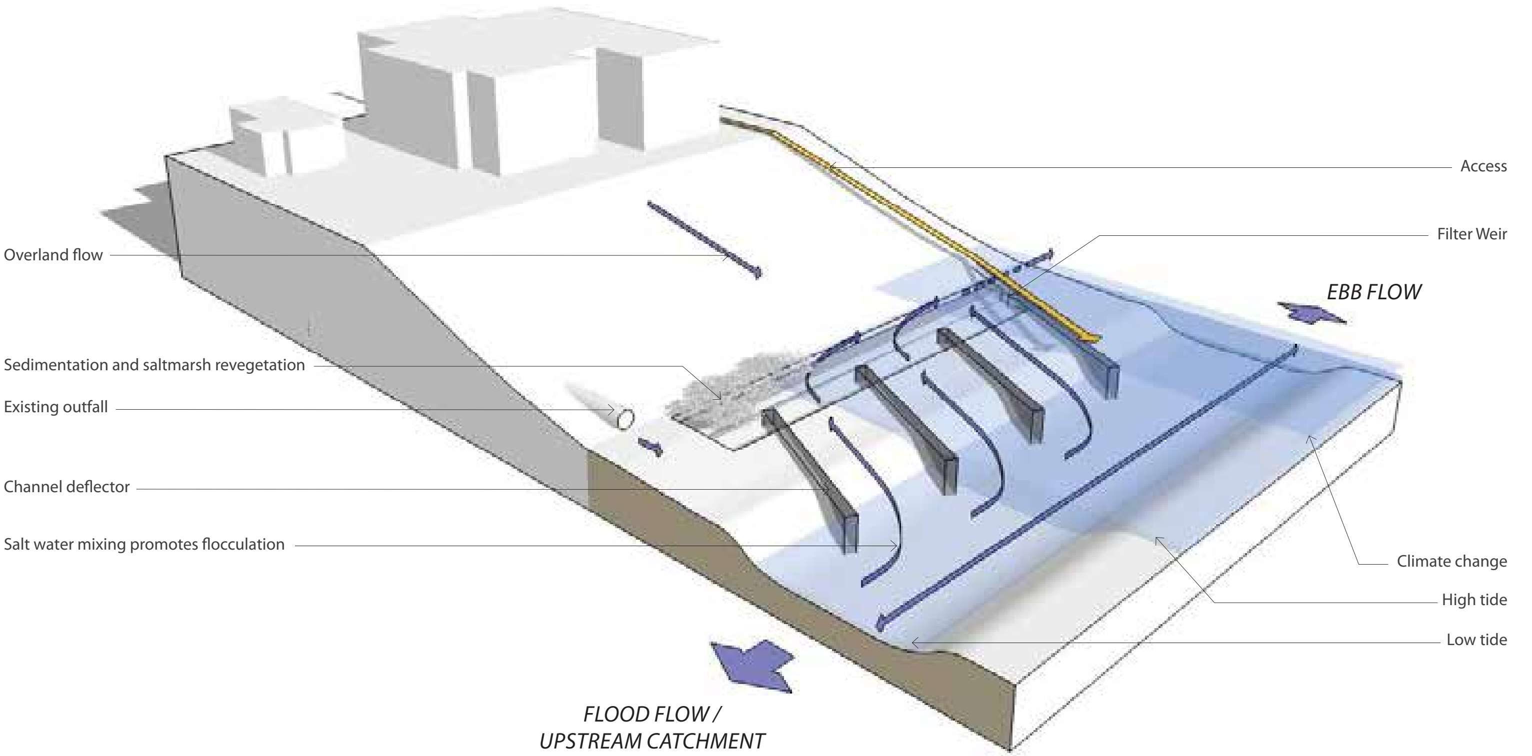
- *Divert fresh water into constructed salt marsh in tidal flats by restricted main channel to build up head to divert flows*
- *Access along constructed divertors*
- *Salt water mixing maintained to provide flocculation*

Constraints

- *Disturbance to low flow channel*
- *Potential scour effects in high velocity areas, leading to reduced sedimentation extents*
- *Requires significant engineering works in the channel*
- *Risk of increased bank erosion*
- *Land stability for foundations*

Opportunities

- *Treats sediment and contaminants at all flow conditions except at low water*
- *Waterside access created*
- *Saltmarsh vegetation habitat potential*
- *Diversion devices could be constructed out of different materials and construction methodologies including: on-site sedimentation in geofabric; shells; gabions; vegetation*
- *Could be used in conjunction with bund in main channel*
- *Resilient to climate change - structures can be sized to account for sea level rise*



13 - SOLID OFF SET CHANNEL DEFLECTOR - FLOW DEFLECTION AND SEDIMENT CAPTURE

Description

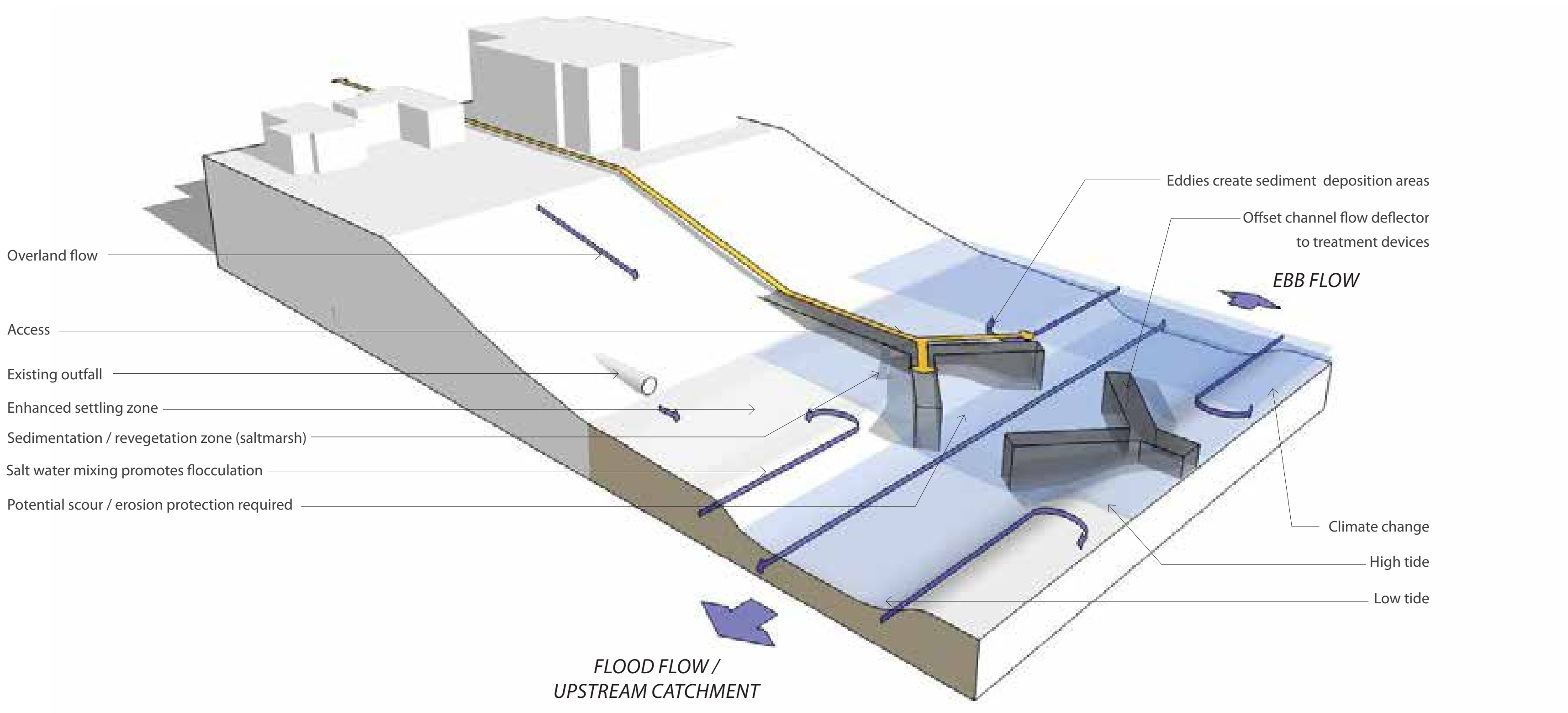
- *Constructed groynes to disrupt flow pattern of main channel, raising upstream water levels and slowing flows, creating deposition areas and settling zones*
- *Access to waters edge across groynes*
- *Salt water mixing maintained to provide flocculation*

Constraints

- *No significant linkage to opposing bank*
- *Disturbance and intervention to the low flow channel*
- *Access preferred from both banks for maintenance and construction*
- *Potential scouring effect in high velocity areas*
- *Land stability for foundations*
- *Risk of increased bank erosion*

Opportunities

- *Access to open water*
- *Treats overland, existing headwall and high water conditions*
- *Allows fish passage*



14 - DEFLECTOR FILTER DAM - FLOW DEFLECTION AND SEDIMENT CAPTURE

Description

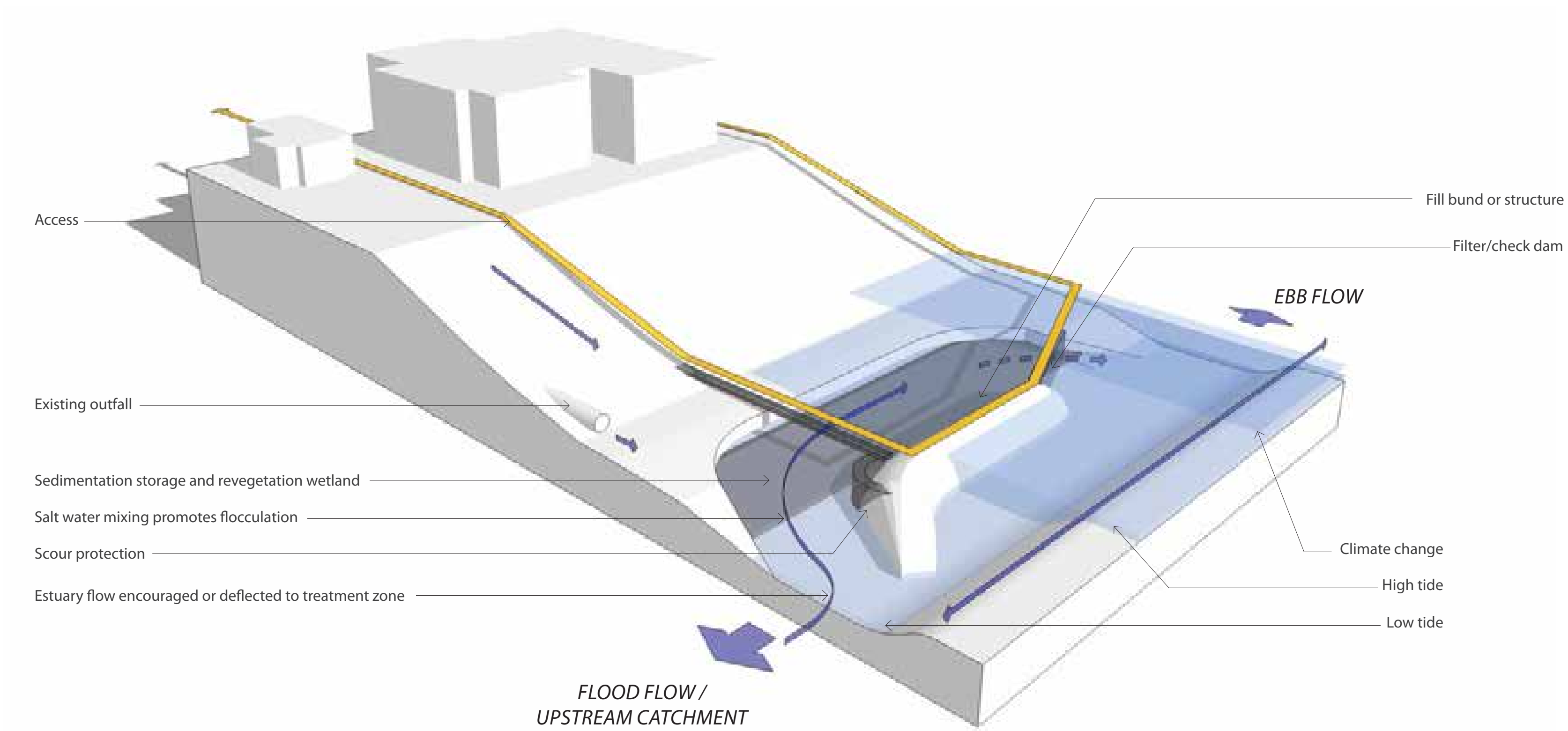
- *Redirection of stream flow into excavated treatment zone, reusing fill to create lateral bund structure with reinforced scour protection. Treated water re-enters stream flow via a check / filter dam.*
- *Access via formed path across dam / bund*
- *Salt water mixing maintained to provide flocculation*

Constraints

- *Potential engineering constraints such as slope stability of excavated banks adjacent areas of permanently saturated estuarine deposits and bund foundations.*
- *Land stability for foundations*
- *Risk of increased bank erosion*

Opportunities

- *Access to open water*
- *Treats most flow conditions except low water.*
- *Suitable for high velocity environments subject to scour protection*
- *Potential to use locally won material*
- *Allows for sedimentation at high velocity mid-tides*



15 - PONTOONS - BIO-FILTRATION

Description

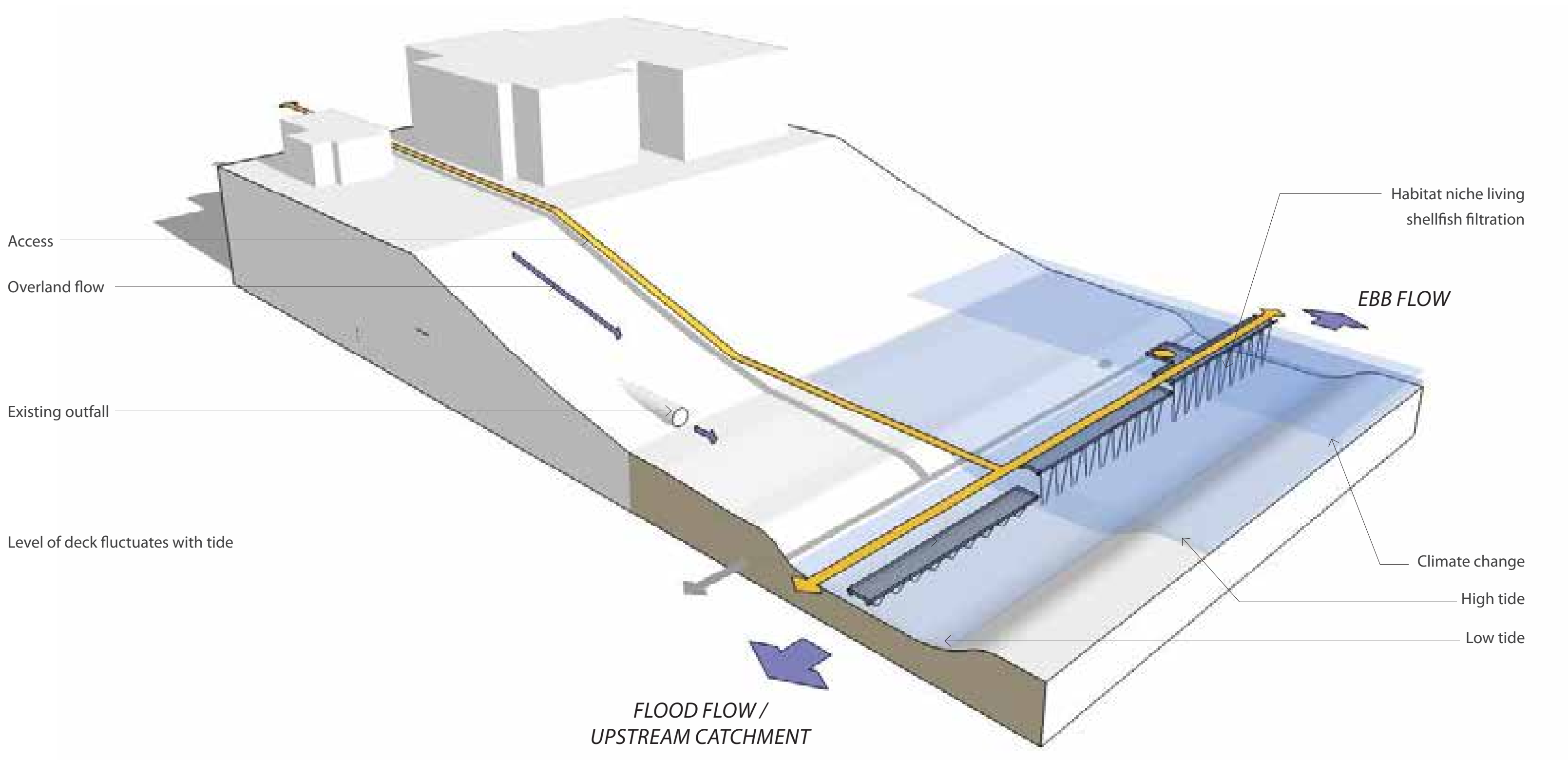
- *Anchored boardwalk,floating at high tide, which provide habitat for sessile species and other aquatic filter feeders*
- *Structures assumed to be aligned with the direction of flow*

Constraints

- *Needs suitable anchorage*
- *Water treatment limited to edge of main channel and upper tidal flows*
- *Limited by tolerance of filter feeders to low salinity water*
- *More suitable where tidal influence is less pronounced*
- *Land stability for foundations*

Opportunities

- *Good pedestrian access to waters' edge*
- *Creates habitat structure for sessile species and bio-filtration*
- *Responsive to sea level rise*
- *May be more culturally acceptable than other options*
- *Resilient to climate change - structures can be designed to account for sea level rise*
- *Alignment of structures perpendicular to flow*



16 - HABITAT PONTOONS - BIO-FILTRATION

Description

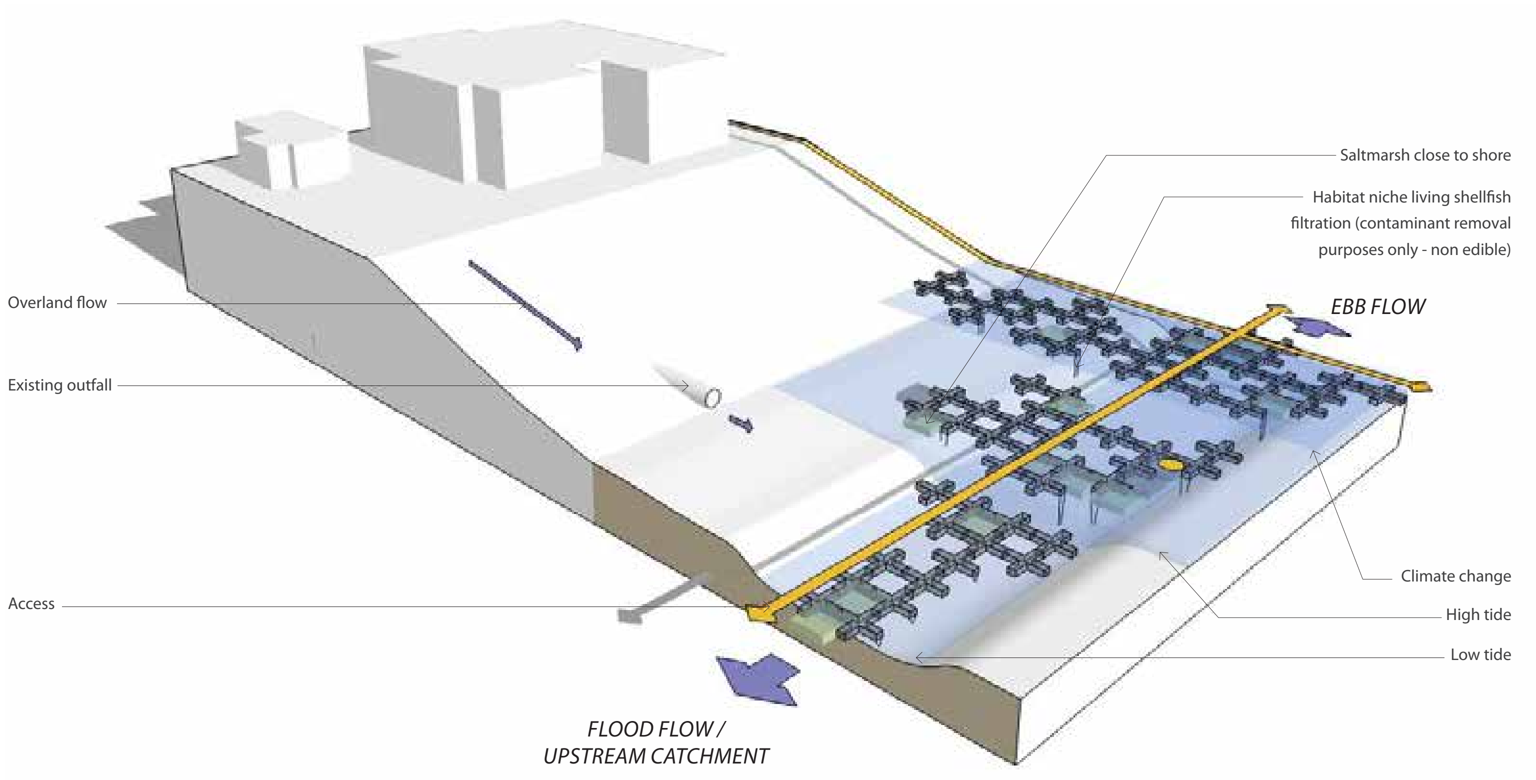
- *Anchored pontoons, floating at high tide, which provide habitat for sessile species and other filter feeders*
- *Access across channel (and along)*

Constraints

- *Navigation restriction*
- *Needs suitable anchorage*
- *Water treatment limited to main channel and upper tidal flows*
- *Limited by tolerance of filter feeders to low salinity water*
- *Less suitable for where tidal influences are more pronounced*
- *Land stability for foundations*

Opportunities

- *Good pedestrian access to waters' edge*
- *Creates habitat structure for sessile species and bio-filtration*
- *Responsive to sea level rise*
- *May be more culturally acceptable than other options*
- *Resilient to climate change - structures can be designed to account for sea level rise*
- *More suitable where tidal influence is less pronounced*



17 - CUT & FILL - SEDIMENTATION CAPTURE

Description

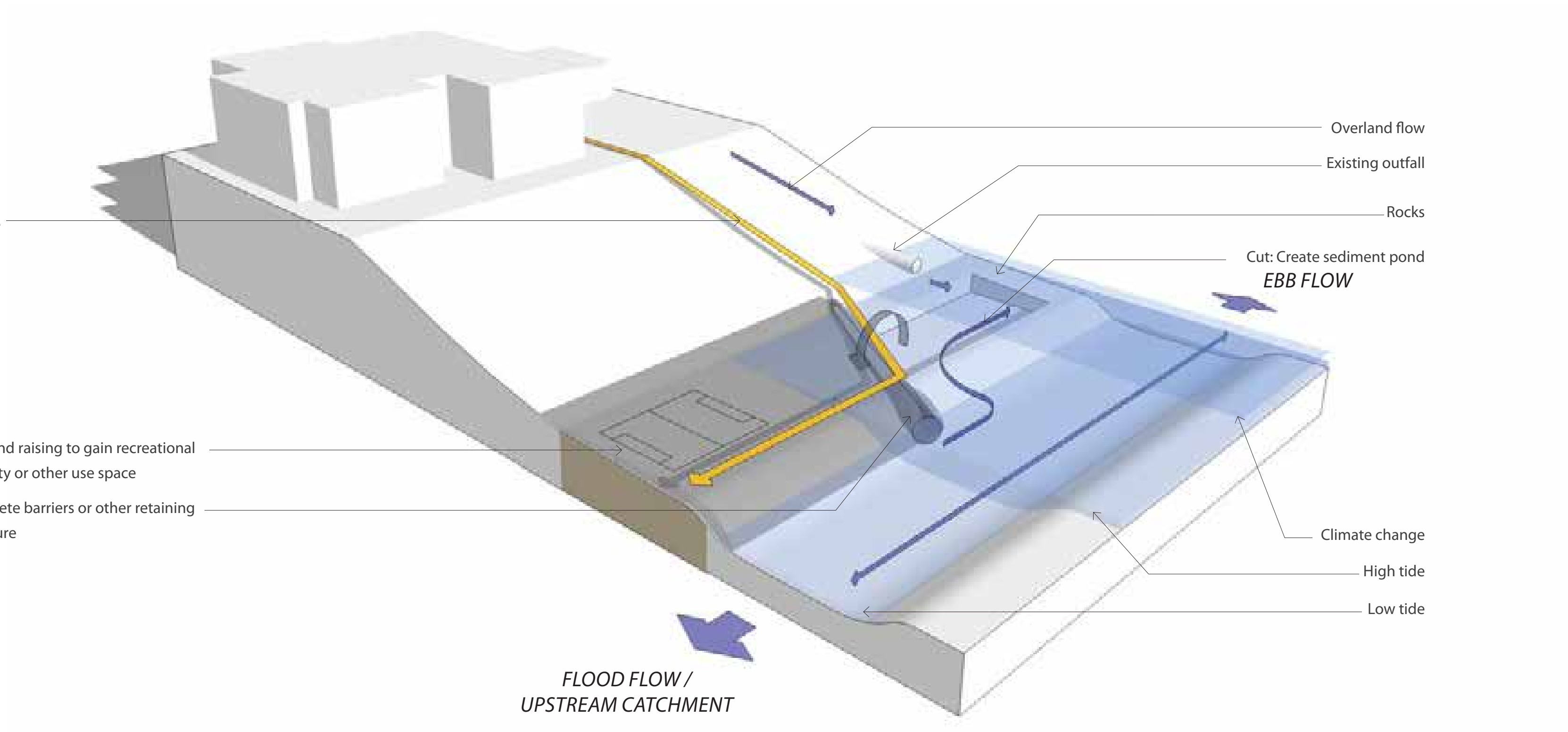
- *Excavate sediment treatment pond at outfall location, using fill to reclaim land for desired land use. Excavated area is allowed to be recolonised by mangroves*
- *Access to water along edge of reclamation*

Constraints

- *Potential engineering constraints such as slope stability of excavated banks adjacent areas of permanently saturated estuarine deposits*
- *Need to design for sea level rise / climate change at outset*
- *Risk of increased bank erosion*
- *Land stability for foundations*

Opportunities

- *Moderate construction costs uses cut fill balance of locally won material*
- *Opens up views to water*
- *Creates new land for new uses which could be designed and shaped for a variety of uses*



18 - LOW TIDE DAM - SEDIMENTATION CAPTURE

Description

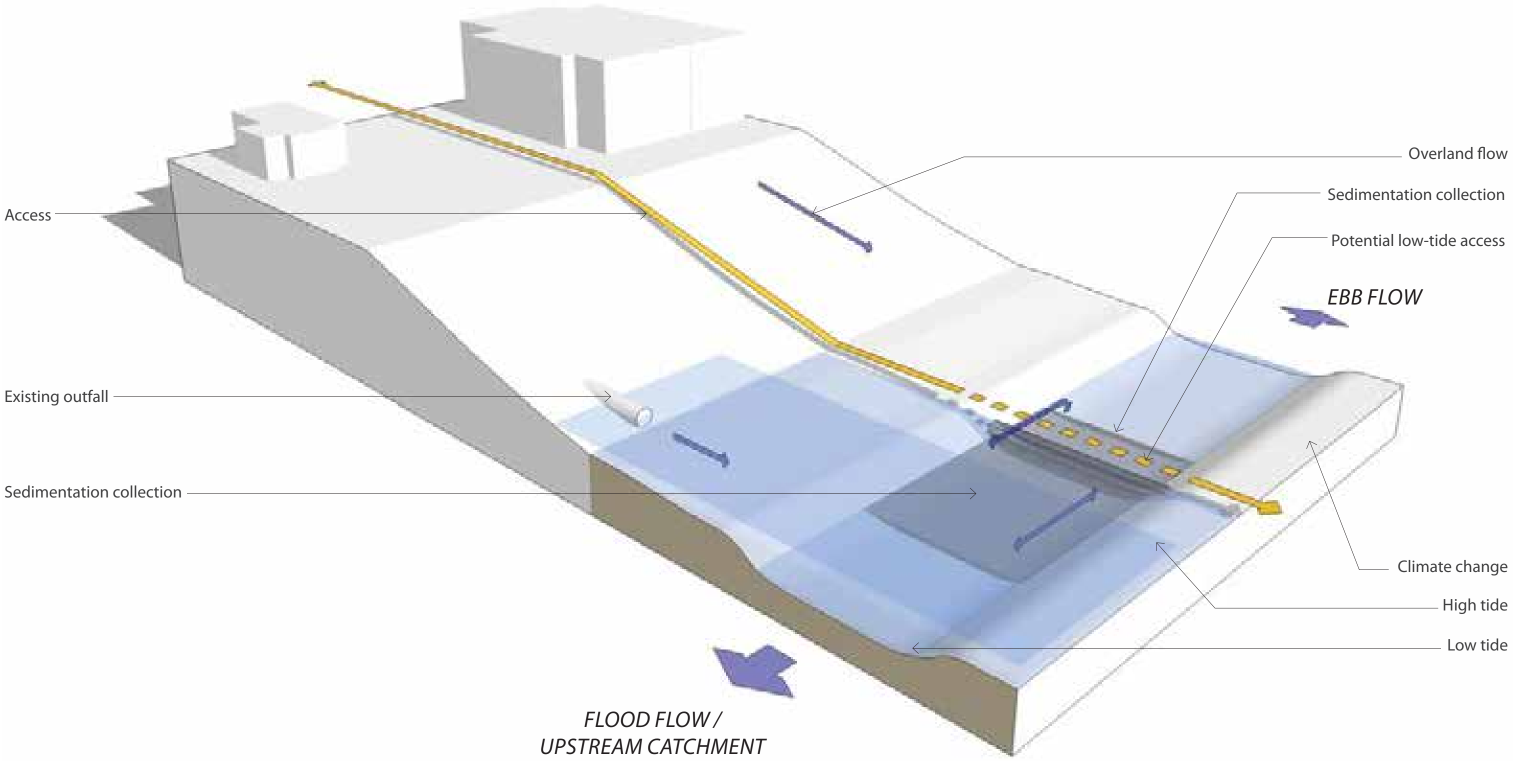
- *Gabion basket / rock dam with impermeable cover installed to 3/4 height across channel to capture up to 3/4 tide*
- *Access is achieved across dam (when above tide line)*
- *Salt water mixing maintained to provide flocculation*

Constraints

- *Construction and maintenance access limited by tide*
- *Sedimentation at low flow levels only*
- *Negligible wetland plant potential*
- *High initial cost*
- *High levels of estuary disturbance and ecological effects*
- *Limits navigation*
- *Geotechnical and construction issues*
- *Generally limited to upper estuaries*
- *Land stability for foundations*

Opportunities

- *Moderate volume of contaminated sediment retention*
- *Creates habitat structure for sessile species*
- *Could be terraced to create multiple habitat outcomes and adaptability to changing water levels*



19 - HIGH TIDE DAM - SEDIMENTATION CAPTURE

Description

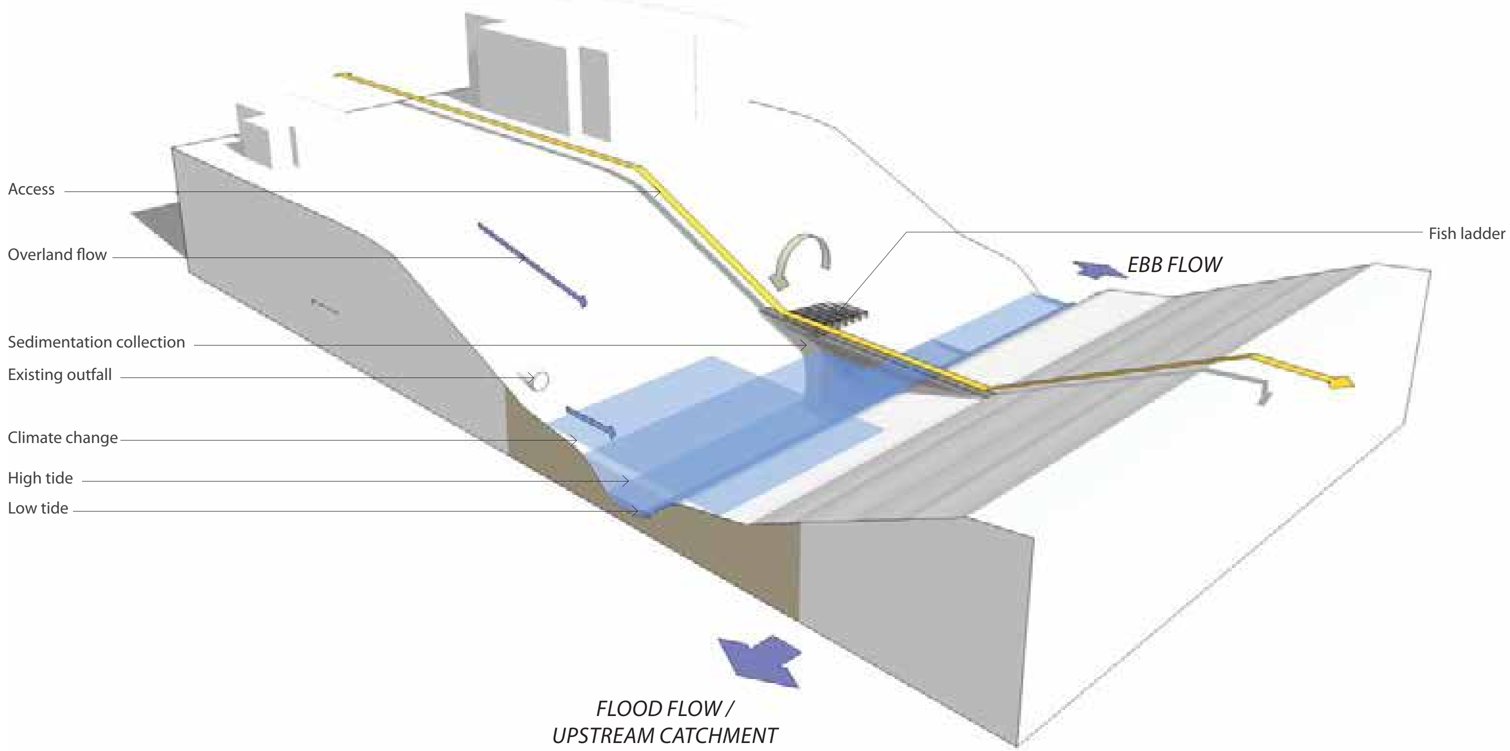
- *Gabion basket / rock dam with impermeable cover installed across incised gully to capture overland flow and collect sediment loads from upper catchment*
- *Integrated fish ladder to maintain passage*
- *Public access is constructed in conjunction with the dam*

Constraints

- *High initial construction cost*
- *High levels of estuary disturbance*
- *Could limit fish passage*
- *Limits navigation*
- *Potential upstream flooding effects*
- *Generally limited to upper estuaries*
- *Potential geotechnical and construction issues*
- *Land stability for foundations*

Opportunities

- *Treats all outfalls above dam*
- *Large volume of contaminated sediment retention*
- *Creates public access linkage to opposing banks*
- *Potential to create amenity lake and public use benefits*
- *Potential creation of extensive freshwater and brackish wetlands, replaces of tidal flats / wading bird feeding habitat*
- *Creates habitat structure for sessile species*
- *Could be terraced to create multiple habitat outcomes and adaptability to changing water levels*
- *May be useful in highly industrial areas*
- *Can be designed to allow for sea level rise*



1 - OVERLAND FLOW BUNDING + TERRACING + WETLAND BUND + HABITAT PONTOONS

Description

Hybrid intervention demonstrates four of the above concepts that can be combined to provide a range of outcomes and benefits:

Overland Flow Bunding

- *Create a bund at or near the top of the bank to capture the overland flow and construct a freshwater wetland environment*
- *Access is achieved via a formed pathway bounding the edge of the wet area.*

Terracing

- *Cut and fill excavation into bank to create terraced wetland structures to capture and treat overland flow, with a gradient of suitable fauna depending on saline inundation.*
- *Access is achieved via a network of carefully constructed pathways*

Wetland Bund

- *Constructed bund at location of outfall pipe to create a wetland forebay to treat stormwater flow along waters edge*
- *Public access is achieved by a formed pathway along top of the bund*

Habitat Pontoons

- *Anchored pontoons, floating at high tide, which provide habitat for sessile species and other filter feeders*
- *Access is provided along top of pontoons. Pontoons can be configured to achieve a range of different linkages and connections.*

Constraints

- *Combination of devices is more suited to lower estuarine systems where tidal influence is less pronounced and areas of tidal flats are available*
- *Existing vegetation, if valued, limits available space and may shade out proposed wetland and salt marsh vegetation*
- *Pontoons may restrict navigation of channel*
- *Pontoons need suitable anchorage and could have potential geotechnical constraints*

Opportunities

- *Achieves a good level of treatment of overland flows and stormwater outlets*
- *Minimum construction disturbance of estuarine system*
- *Efficient use of space*
- *Creation of wetland, salt marsh, sessile species and riparian habitats and habitat linkages*
- *Relatively low construction cost and with the exception of the pontoons, devices utilise well established construction techniques*
- *Bunds could be constructed out of a number of different materials and construction methodologies including: on-site sediment in geofabric; shells; gabions; vegetation*
- *Site a generally accessible for construction*
- *Responsive to sea level rise*
- *Access can be designed into all of the devices in a coordinated manner to achieve a range of different linkages and connections for maintenance and recreation*

4.3 HYBRID INTERVENTIONS

Bunding at top of bank to intercept over land flows and create fresh water environment with amenity value

Terracing to create a series of stepped wetlands integrated with a network of pathways for access

Bund formed in foreshore area along the coastal margin. Forebay located adjacent to outfall pipe, with terraced freshwater and saline wetlands along the coastal edge. Access is created via a formed pathway along the top of the bund

Floating pontoons anchored to bed of estuary, anchor ties provide habitat for sessile species and other aquatic filter feeders while providing access across

2 - STREAM FLOW REDIRECTION + BRUSH PACKING + REVEGETATION

Description

Hybrid intervention demonstrates three of the above concepts can be combined to provide a range of outcomes and benefits:

Stream Flow Redirection

- *Redirection of stream flow into excavated treatment zone, with fill reused to create lateral bund structure with reinforced scour protection. Treated water re-enters stream flow via a check / filter dam.*
- *Access is achieved via a formed pathway along top of bund check/filter dam*

Brush Packing

- *Brush cutting of mangrove forest with bundles of mangrove timber laid parallel to stream flow and perpendicular to overland flow to create brushwood 'fences' to trap sediment*

Revegetation

- *Grass bank is revegetated with appropriate coastal forest species or existing vegetated banks are managed to increase coverage, connectivity and complexity*
- *Access is achieved via constructed pathway to reduce sapling damage and aid in forest establishment*

Constraints

- *Combination of devices is more suited to lower estuarine systems where tidal influence is less pronounced and areas of tidal flats are available*
- *Diversion structures may restrict navigation of channel*
- *Potential engineering constraints such as slope stability of excavated banks adjacent areas of permanently saturated estuarine deposits and bund foundations*
- *Suitable for high velocity environments, however scour protection would need to be given special consideration*
- *Vegetation establishment and repeat treatment may be required in high sedimentation areas*
- *Could affect views to open water, and may be perceived as undesirable in existing residential areas*
- *Require planning from onset for sea level rise and climate change effects*

Opportunities

- *Allows for sedimentation at high velocity mid-tides*
- *Makes use of available resources / Potential to use locally won material*
- *Efficient use of space*
- *Creation of riparian habitats and habitat linkages as well as creating potential for wetland, salt marsh environments in tidal flats*
- *Bunds could be constructed out of a number of different materials and construction methodologies including: on-site sediment in geofabric; shells; gabions; vegetation*
- *Potential to incorporate volunteer project / community participation in implementation and ongoing maintenance*
- *Cost effective if weeds are controlled in early stages*
- *Access can be designed into all of the devices in a coordinated manner to achieve a range of different linkages and connections for maintenance and recreation*
- *Site a generally accessible for construction*
- *Structures can be designed so that they are resilient to sea level rise*

4.0 CONCEPT DEVELOPMENT

4.3 HYBRID INTERVENTIONS

Grass bank revegetated with appropriate coastal forest species or existing vegetated banks are managed to increase coverage, connectivity and complexity. Access via constructed pathway to reduce sapling damage and aid in forest establishment

Brush cutting of mangrove forest with bundles of mangrove timber laid parallel to stream flow / perpendicular to overland flow to create brushwood 'fences' to trap sediment

Stream flow redirected into excavated treatment zone. Cut from excavated zone is reused to create lateral bund structure with reinforced scour protection. Treated water re-enters stream flow via a check or filter dam. Access is provided via formed pathway along top of bund

3 - DAMMING + FILTER BUNDS + REVEGETATION

Description

Hybrid intervention demonstrates three of the above concepts can be combined to provide a range of outcomes and benefits:

Damming

- *Gabion basket / rock dam with impermeable cover is installed across incised gully to capture overland flow to collect sediment loads from upper catchment*
- *Dam is designed with integrated fish ladder to allow passage*
- *Public access is constructed in conjunction with the dam*

Filter Bunds

- *Upstream catchment flows are diverted into constructed fresh water wetlands / salt marshes in the tidal margin. Diversion is achieved by restricting the main channel, which builds up head to divert flows*
- *Access is achieved via a formed pathway along top of bund*

Revegetation

- *Grass bank is revegetated with appropriate coastal forest species or existing vegetated banks are managed to increase coverage, connectivity and complexity*
- *Access is achieved via constructed pathway to reduce sapling damage and aid in forest establishment*

Constraints

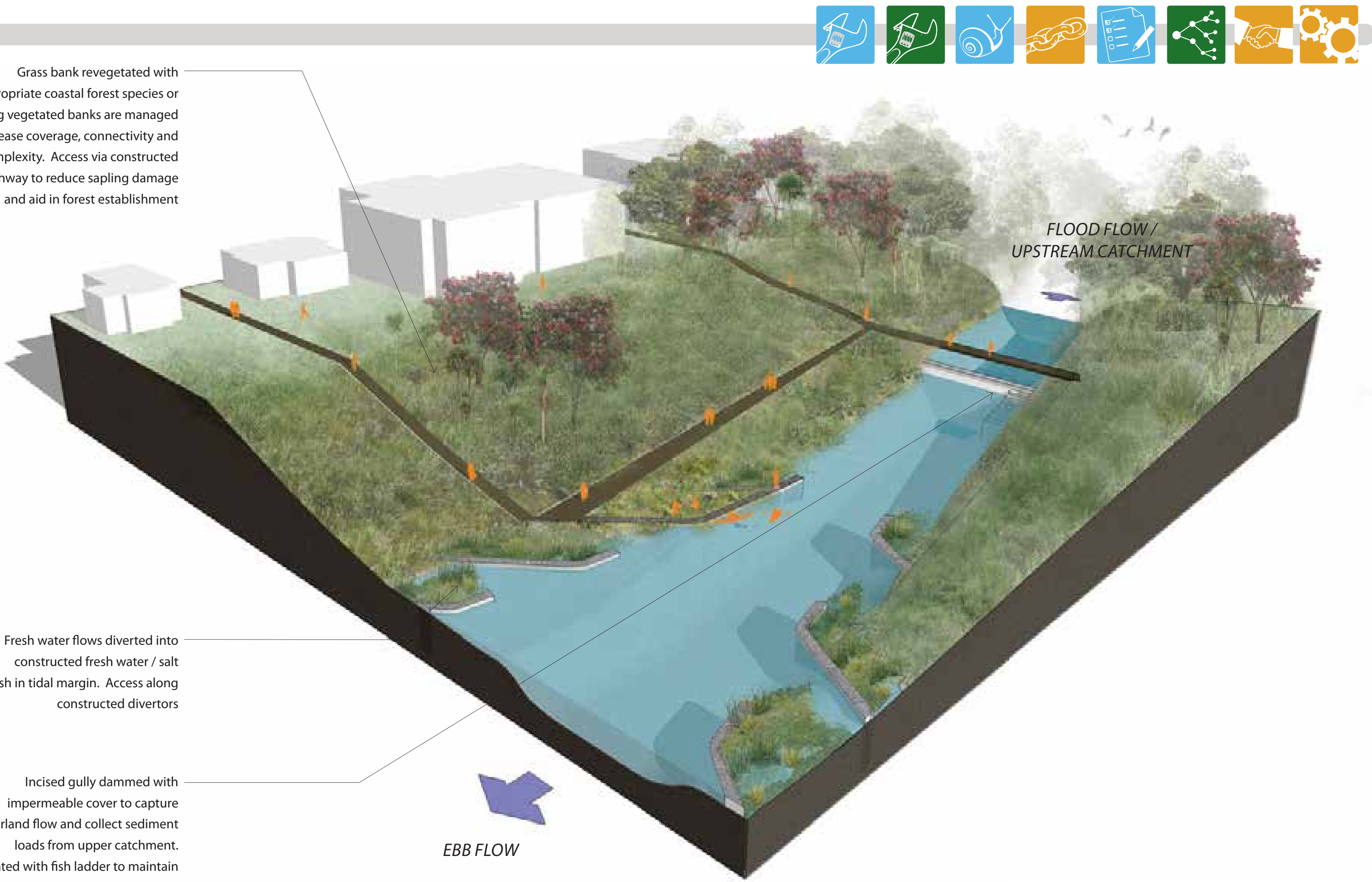
- *Combination of devices is more suited to upper catchments*
- *Potential engineering constraints such as slope stability of excavated banks adjacent areas of permanently saturated estuarine deposits and bund dam foundations*
- *High initial construction cost*
- *High levels of estuary disturbance*
- *Limits navigation of channel*
- *Potential upstream flooding effects*
- *Disturbance to low flow channel*
- *Potential scour effects in high velocity areas, leading to reduced sedimentation extents*
- *Site a accessible for construction and maintenance could be an issue if not consider early in the design phase*
- *Could affect views to open water, and may be perceived as undesirable in existing residential areas*

Opportunities

- *Treats all outfalls upstream of dam*
- *Large volume of contaminated sediment retention*
- *Efficient use of space*
- *Creation of wetland, salt marsh, sessile species and riparian habitats and habitat linkages*
- *Could be terraced to create multiple habitat outcomes and adaptability to changing water levels*
- *Diversion devices and dam could be constructed out of a number of different materials and construction methodologies including: on-site sediment in geofabric; shells; gabions; vegetation*
- *Makes use of available resources / Potential to use locally won material*
- *Cost effective if weeds are controlled in early stages*
- *Potential to incorporate volunteer project / community participation in implementation and ongoing maintenance*
- *Cost effective if weeds are controlled in early stages*
- *Access can be designed into all of the devices in a coordinated manner to achieve a range of different linkages and connections for maintenance and recreation*

4.3 HYBRID INTERVENTIONS

Grass bank revegetated with appropriate coastal forest species or existing vegetated banks are managed to increase coverage, connectivity and complexity. Access via constructed pathway to reduce sapling damage and aid in forest establishment



Fresh water flows diverted into constructed fresh water / salt marsh in tidal margin. Access along constructed divertors

Incised gully dammed with impermeable cover to capture overland flow and collect sediment loads from upper catchment. Integrated with fish ladder to maintain passage. Access is constructed in conjunction with the dam

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.0 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Identifying suitable land-based controls for managing stormwater contaminants in catchments surrounding Auckland's most contaminated urban estuaries can be challenging. These areas tend to lack space suitable for the installation of large stormwater treatment devices, and the cost of installing and maintaining numerous, small treatment units is generally prohibitive.

In some situations, an effective stormwater treatment solution could be provided by utilising a relatively small part of the coastal margin to contain contaminants and prevent the degradation of broader estuarine areas. This would inevitably lead to a change in the characteristics of the affected area. However, the adverse effects of such changes could be minimised (and potentially mitigated) through innovative and appealing design, which seeks to:

- Maximise community outcomes by providing attractively landscaped features and recreational opportunities;
- Increase local habitat complexity and biodiversity; and,
- Reduce the seaward extent of stormwater impacts.

Designs should be underpinned by a clear set of principles, which include:

- **Leveraging** outcomes by harnessing and amplifying natural processes, doing more with less, and using under-utilised space;
- **Diversifying** species, habitats, human experiences, and infrastructural solutions;
- **Slowing** water movement and allowing for progressive and incremental outcomes;
- **Celebrating** communities, our heritage and natural values;
- Linking infrastructure, ecosystems, communities and places;
- **Coupling** outcomes through multifunctional designs and linked projects;
- **Preparing** for change through safe, durable, adaptable and maintainable design.

These principles were adapted into a number of conceptual designs, which covered a range of estuarine morphologies. Multiple options were identified through this process, and further innovation is possible. A more detailed investigation of their actual feasibility is also required. The concepts were primarily based around:

- Obstructing water flows to entrap sediment and contaminants through the construction of various dam and pond configurations,.
- Slowing and redirecting water flows to promote sediment and contaminant retention in dedicated depositional areas;
- Redirecting and filtering stormwater through wetlands or natural media;
- Promoting biological filtration through the culture of robust filter feeding species.

Many of the concepts identified could be combined to maximise overall outcomes. However, the suitability of any particular option would ultimately depend on the characteristics of the site, and regulator and community acceptance.
Structures should be designed to harness and optimise natural processes such as flocculation and sedimentation. However, engineering constraints are likely to determine which options can be applied in any particular situation. Key engineering considerations are related to flood management, geotechnical issues, scour, climate change, access, spoil disposal and construction material selection. Specifically, the following should be considered and understood before contemplating any stormwater treatment approach within a tidal creek;

- Coastal structures must allow flood flows to be bypassed, so upstream flooding is not exacerbated.
- Geotechnical issues such as bearing capacity, settlement, bank stability and lateral support all require careful assessment, particularly due to the unconsolidated nature of sediments within tidal creeks.
- Geotechnical risks may also be increased due to tidal variations on pore pressure or scour undermining a structure. Design adaptability and ground improvement may be required.
- Construction methods need to be identified and allowance made for temporary works and site access.
- The design may also require modification over time to manage effects such as climate change or to replace original materials.
- Maintenance access and adequate space for machinery and accumulated sediment removal provided.
- Disposal options for accumulated sediments must be considered, including life cycle costing.
- Changes to sediment dynamics
- Biodiversity and ecological function.

RECOMMENDATIONS

Overall, this project illustrates a range of potential options for utilising the coastal margin to limit the extent of stormwater contamination through the enhancement of localised sediment and contaminant entrapment. However, further work is required to refine the ideas presented and apply them to a "real life" situation. As such further investigation will need to be undertaken that:

- Considers the financial implications and life time costs of proposals.
- Considers the ecological implications and ecosystem costs of proposals.
- Identifies and addresses regulatory constraints and other impediments to using the coastal marine area to manage urban stormwater contaminants;
- Determines what monitoring requirements are needed to understand stormwater treatment performance, the wider receiving environmental benefit, landscape and public amenity value.
- Carries out hydraulic modelling to understand the extent of potential scour and sediment dynamics.
- Identifies the scope of geotechnical works required within the case study.
- Considers maintenance and sediment disposal issues.

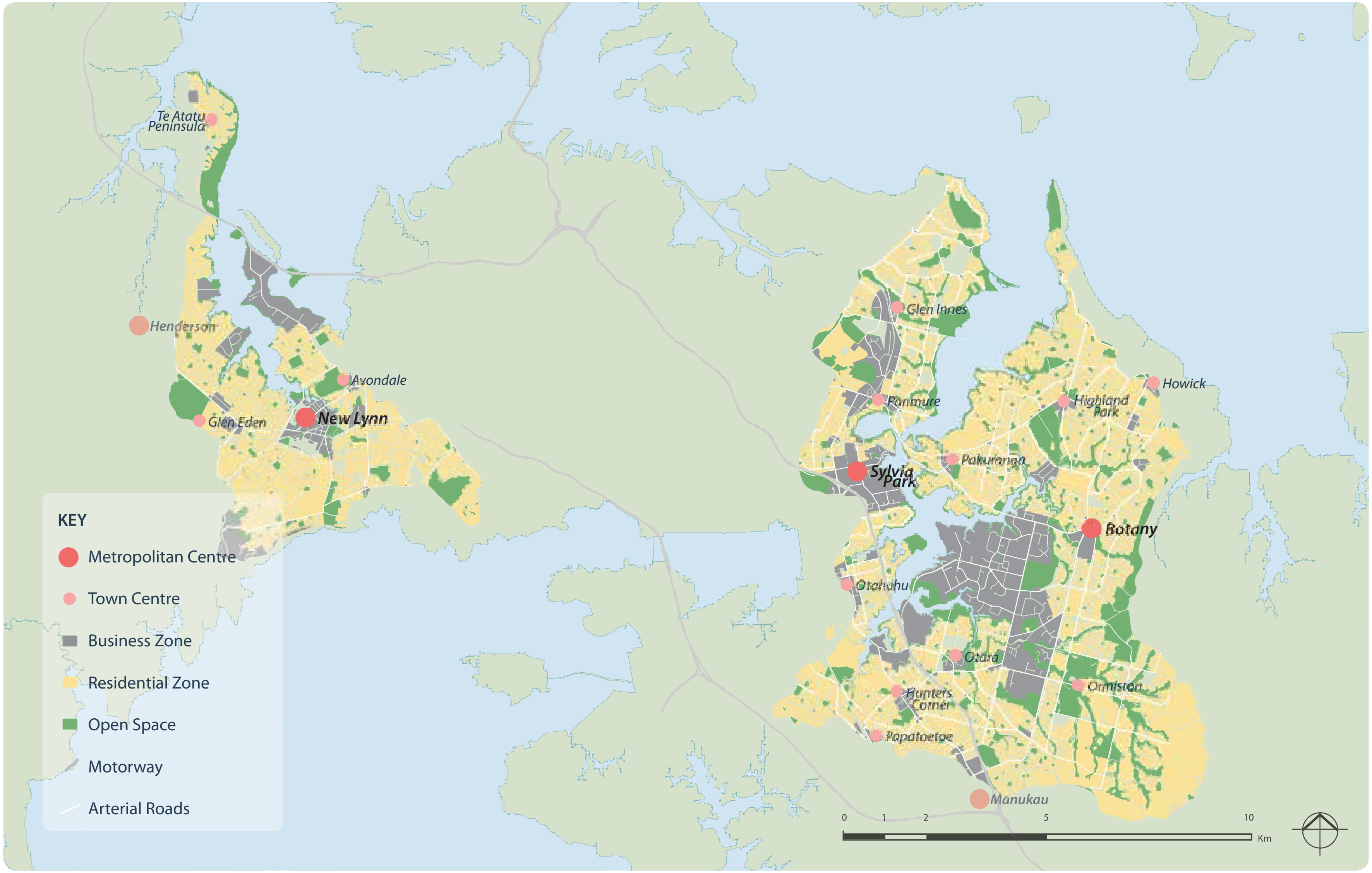
It is therefore recommended that a case study be carried out which:

- Identifies specific locations where this approach could be applied; and
- Develops detailed, site-specific options for utilising the coastal margin to integrate and optimise contaminant retention, and landscape and environmental outcomes.

6.0 APPENDIX

6.0 APPENDIX

6.1 LAND USE AND TARGET GROWTH CENTRES

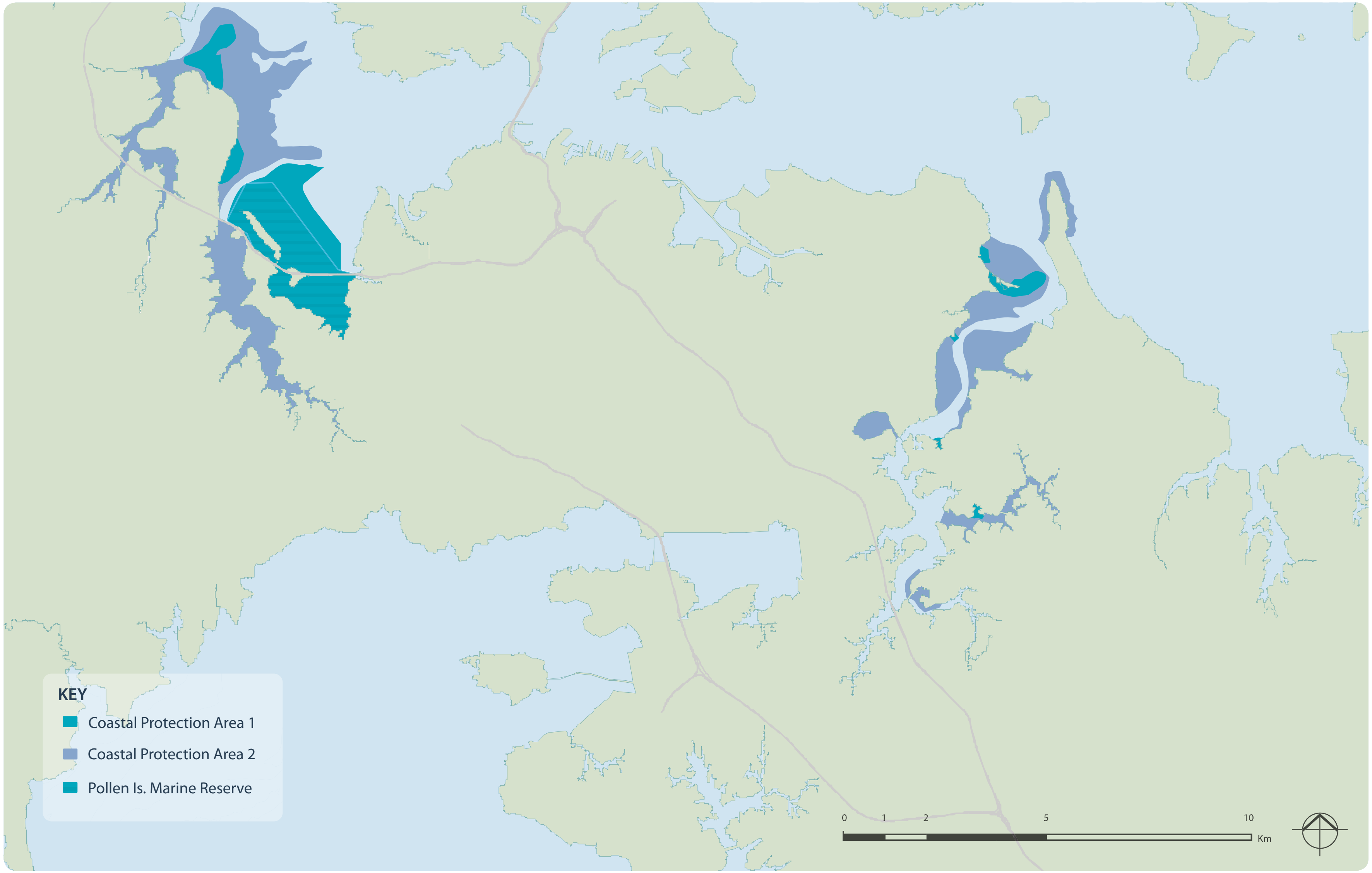


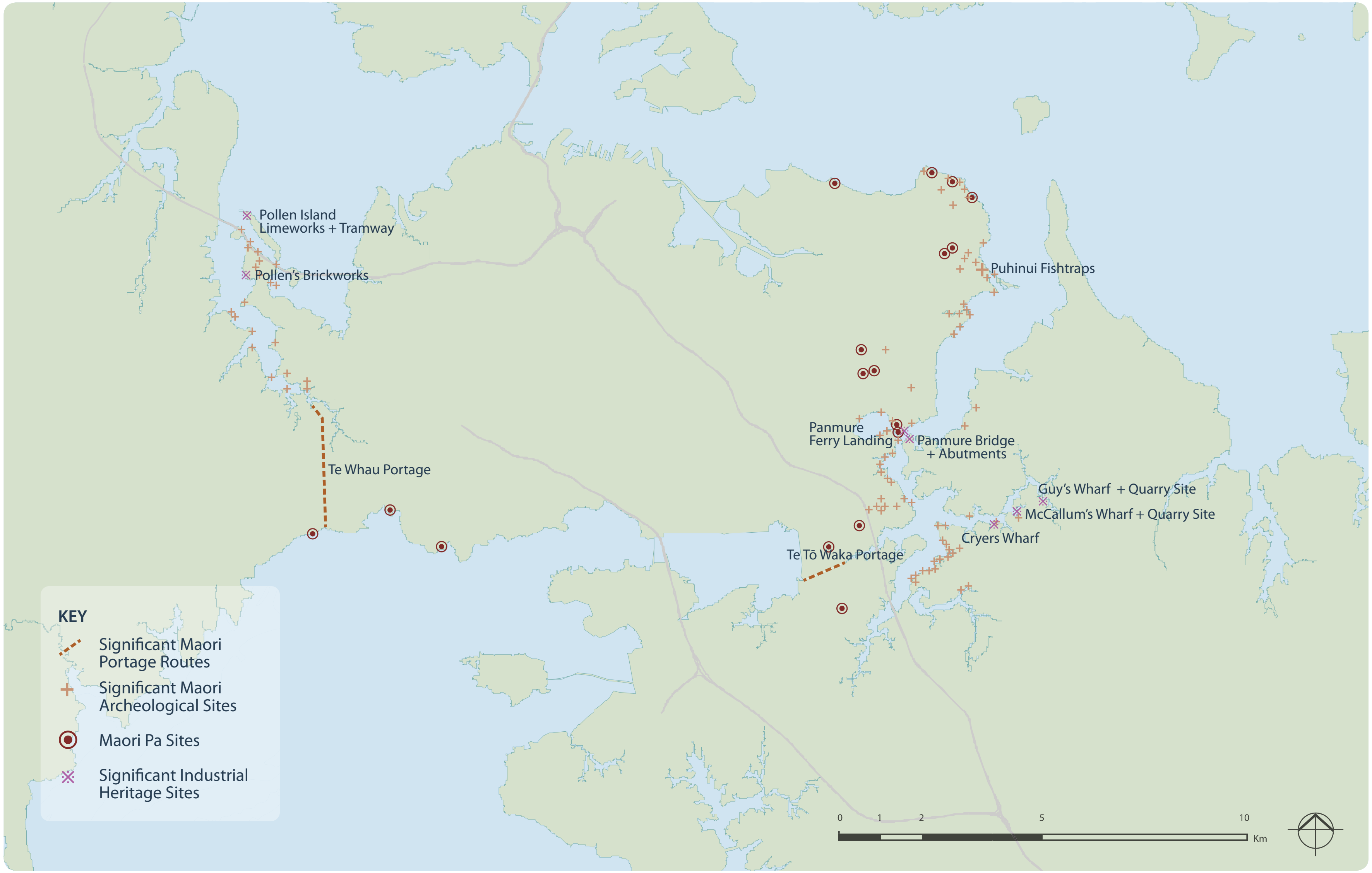
6.0 APPENDIX

6.2 COASTAL ACCESS

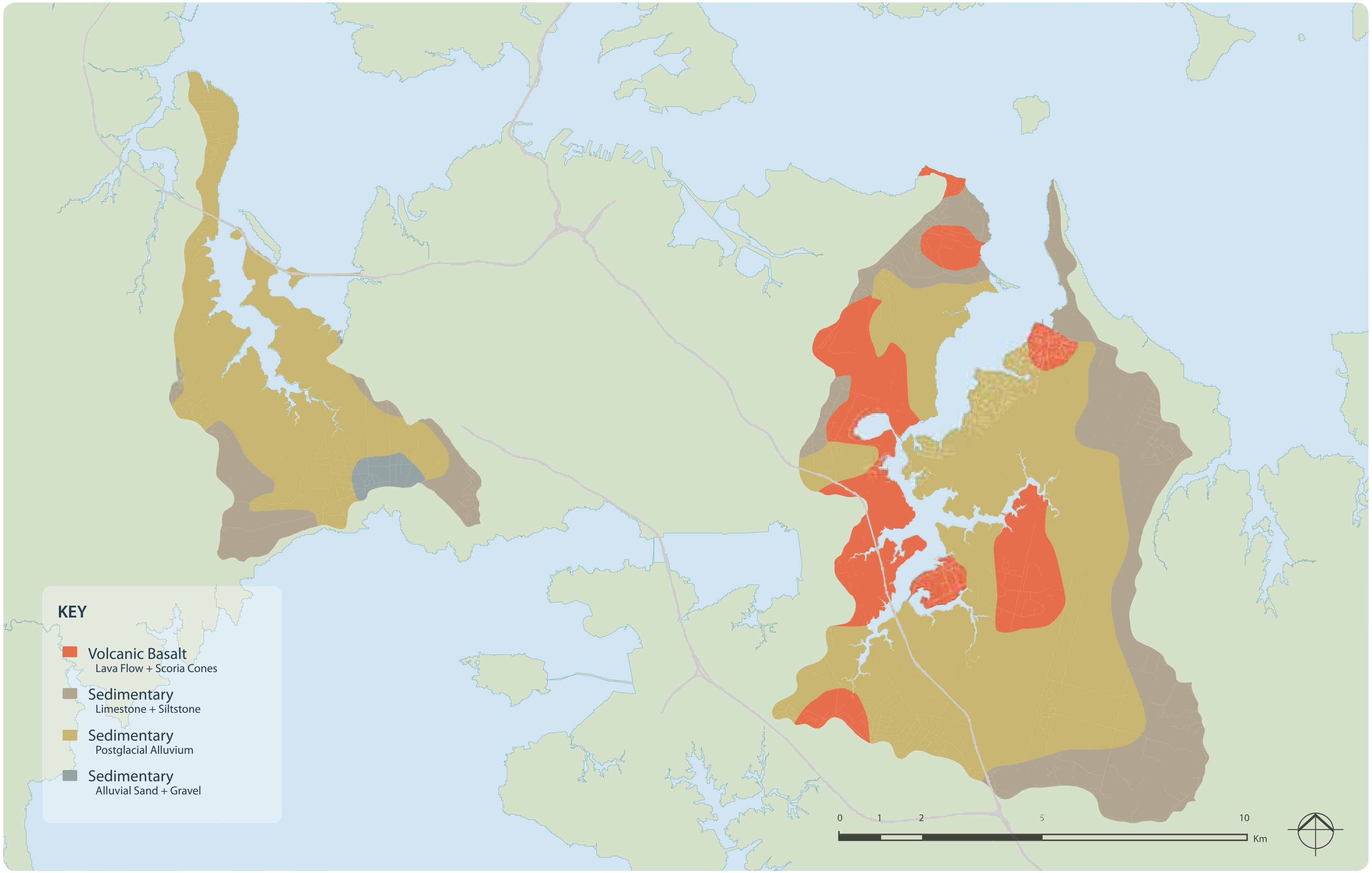
APPENDIX

6.3 COASTAL PROTECTION AREA




Pollen Island
Limeworks + Tramway
Pollen's Brickworks
Te Whau Portage
Puhinui Fishtraps
Panmure
Ferry Landing
Panmure Bridge
+ Abutments
Guy's Wharf + Quarry Site
McCallum's Wharf + Quarry Site
Cryers Wharf
Te Tō Waka Portage
KEY
Significant Maori
Portage Routes
Significant Maori
Archeological Sites
Maori Pa Sites
Significant Industrial
Heritage Sites
0
1
2
5
10
Km

6.5 GEOLOGY


KEY
Volcanic Basalt
Lava Flow + Scoria Cones
Sedimentary
Limestone + Siltstone
Sedimentary
Postglacial Alluvium
Sedimentary
Alluvial Sand + Gravel
0
1
2
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10
Km

6.0

APPENDIX
6.6 COMMON ENDEMIC COASTAL SALTMARSH AND ESTUARINE SPECIES

Name	Botanical Name	Form	Habit / Tolerance	Size	Notes
baumea	*Baumea juncea*	sedge	Standing water	1m	Found in lowland coastal swamps and salt marsh areas.
bachelor's button	*Cotula coronopifolia*	herb	Boggy with temporary flooding	0.2m	Creeping herb. Grows well in wet hollows, banks, estuaries, ditches and swamp margins. Establishes naturally.
coastal tree daisy	*Olearia solandri*	shrub	Moist soils	3-4m	Erect shrub with tiny leaves. Abundant fragrant flowers in autumn. Quick growing. Does well in estuarine swamps.
giant umbrella sedge	*Cyperus ustulatus*	sedge	Boggy with temporary flooding	0.8m	Forms large dense clumps. Good in open spaces. Lowland and coastal swamps, back dune wetlands.
harakeke flax	*Phormium tenax*	herb	Boggy with temporary flooding	2-3m	Upright in habit with tall red flower heads which attract birds. Grows in a range of conditions. tolerant of salt exposure. Excellent shelter.
kapungawha lake clubrush	*Schoenoplectus tabernaemontani*	tall rush	Standing water	1-2m	Grows at the interface between salt marsh and fresh water.
kukaraho, purua marsh clubrush	*Bolboschoenus fluviatilis*	sedge	Standing water	1-2m	Margins of streams, swamps. Fast growing. Stems die back over winter.
maakoako sea primrose	*Samolus repens*	ground-cover	Boggy with temporary flooding	0.1m	Found mainly in salt marshes. Also grows on banks and cliffs.
maakaka salt-marsh ribbonwood	*Plagianthus divaricatus*	shrub	Moist soils	3m	Can be grown in salt marshes and along estuaries. Also grows in dune hollows and coastal gravels.
manawa mangrove	*Avicennia marina* subsp. *australasica*	small tree	Boggy with temporary flooding	8m	Desirable in terms of local ecology as they provide bird and fish habitat, reduce sedimentation in the wider estuary and are an important source of organic material to the estuarine food chain. Will establish naturally in estuaries and tidal creeks.
manuka tea tree	*Leptospermum scoparium*	small tree	Boggy with temporary flooding	8m	A widespread shrub, dry to wet, often fringing lakes, in swamps and bogs. An important pioneer in many plant successions.
needle grass	*Austrostipa stipoides*	grass	Boggy with temporary flooding	1m	Sharp-tipped tussock. Found on rocks, mudflats and sand spits.
oioi jointed wire rush	*Apodasmia similis*	rush	Boggy with temporary flooding	1m	Distinctive grey-green, orange, purple or rainbow colouring. Plant in areas bordering salt marshes and estuaries, or in dune hollows.
raupo	*Typha orientalis*	rush	Boggy with temporary flooding	2m	Tall, dark green foliage. Large brown seed head.
remuremu	*Selliera radicans*	ground-cover	Boggy with temporary flooding	<0.1m	Very dense ground cover with pale green, fleshy leaves and small white flowers. Grows naturally in salt marsh or coastal rocks. Very salt/drought tolerant, although does better if watered in summer.
sea rush	*Juncus maritimus var. australiensis*	rush	Boggy with temporary flooding	0.5m	Fine dark green leaves. Grows in damp sand, salt marsh and estuary margins.
taupata	*Coprosma repens*	shrub small tree	Moist soils	2-4m	Large shrub or small tree with dark green, glossy, rounded leaves. Very hardy, excellent wind and sea spray shelter. Orange berries attract birds.
ti kouka cabbage tree	*Cordyline australis*	tree	Boggy with temporary flooding	17m	Erect tree with crown of narrow leaves tufted at the end of branches, white flowers in spring. Attracts birds. Plant back from the estuarine edge. Requires some protection when young, moderate tolerance to salt and wind.
toetoe	*Cortaderia splendens*	large grass	Boggy with temporary flooding	3m	Tall, dense creamy-gold flowering plumes. Can grow on dry disturbed sites. Tolerates drought and salt wind. Dry edges only. Not to be confused with the invasive pampas grass from South America which is late flowering.
ureure glasswort	*Sarcocornia quinqueflora*	succulent	Boggy with temporary flooding	0.1m	Short red-tipped succulent with minute flowers in summer. Forms a low, dense mat. Grows in salt marsh and salt meadows. Establishes naturally.
wiwi knobby clubrush	*Isolepis nodosa*	rush	Boggy with temporary flooding	0.7m	Fine rush with creeping root mass. Needs full sun. Plant at rear of high tide beach at base of clay bank.

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