Drainage Services Department Practice Note No. 1/2015

Guidelines on Environmental and Ecological Considerations for River Channel Design

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1. INTRODUCTION

The Drainage Services Department (DSD) has paid attention to eco-hydraulics design in implementing flood mitigation works in recent years. Various ecological features have been adopted in the river improvement works to provide habitats for aquatic life. Post-construction ecological monitoring was conducted to assess the effectiveness of the ecological features, and it served the management and maintenance purpose. This approach would help mainstream biodiversity into drainage and flood prevention designs, which promotes the conservation of biodiversity and sustainable use of biological resources.

The project proponent should apply the recommended framework in the project planning and design stages, by detailed appraisals, assessment, comparison and careful balancing to achieve a design which is sustainable, environmentally friendly as well as effective in engineering performance. Due consideration should also be given to the possible increase in future operating and maintenance efforts for green river channels. Relevant authorities, green groups and stakeholders should also be adequately consulted before finalizing the design.

This Practice Note (PN) presents the essential environmental and ecological considerations that should be taken into account in the design of river channels. It takes immediate effect and replaces the existing Drainage Services Department Practice Note No. 1/2005 Guidelines on Environmental Considerations for River Channel Design. The flow chart in Annex 1 demonstrates the use of relevant Sections in this PN during the environmental design of river channel.

2. BLUE-GREEN INFRASTRUCTURE

Policy Address on Revitalization of Water Bodies

"We will adopt the concept of revitalising water bodies in large-scale drainage improvement works and planning drainage networks for NDAs so as to build a better environment for the public." (Hong Kong Government 2015 Policy Address).

FIGURE 1 REVITALISING WATER BODIES IN DRAINAGE IMPROVEMENT WORKS IN UPPER TAI PO RIVER

The revitalization of water bodies in large scale drainage improvement works (see Figure 1) and in the planning of drainage networks for New Development Areas (NDAs) is a key environmental protection and conservation note of the Hong Kong Government 2015 Policy Address. The policy is a formal recognition of the opportunity presented by integrating environmental and ecological considerations in the design of drainage infrastructure to make Hong Kong a better place to live. Revitalising water bodies manifests the concept of blue-green infrastructure, which has recently been introduced as a sustainable approach to stormwater and flood management in Hong Kong.

What is Blue-Green Infrastructure

Blue-green infrastructure (with "blue" representing the city's water bodies and "green" referring to plants) is a form of development aiming at improvement of the sustainability and resilience of Hong Kong's drainage system to meet the contemporary public aspirations in respect of the natural environment and protection of the local culture and rural lifestyle.

The key is to manage surface water as close as possible to where it falls by allowing sufficient space to retain it, rather than the current practice of conveying it offsite as quickly as possible. It facilitates the infiltration of rainfall and the process of natural filtering to improve the quality and reduce the quantity of runoff. Therefore, blue-green infrastructure reduces urban runoff, water pollution, heat island effect, carbon footprint and energy consumption, and blends the natural water environment into the city. As blue-green infrastructure offers so many benefits, it is prudent to integrate it as a standard practice within different infrastructure and urban landscaping projects.

Examples of blue-green infrastructure include swales and conveyance channels, filtrations (filter strips, filter trench and bioretention areas), infiltrations (soakaways, infiltrations trenches, infiltration basins and rain gardens), retention and detention facilities (detention basins, retention ponds, geocellular storage systems), wetlands, inlets and outlets design features and vortex control systems. It also embraces sustainable drainage system such as green roofs, porous pavements and rainwater harvesting facilities (CIRIA, 2014).

Benefits of Blue-Green Infrastructure to Hong Kong

The benefits of blue-green infrastructure could be well demonstrated by different overseas examples (see Figure 2). The revitalization of the eight kilometre long urban waterway at Cheong Gye Cheon, Seoul, Korea, creates a vibrant public recreation open space in the congested urban environment. Another example is Kallang River located at Bishan-Ang Mo Kio Park of Singapore, which has been transformed from a conventional concrete waterway into an aesthetically-pleasing river park for the public. The details of the above overseas project could be found at Annex 2.

FIGURE 2 CHEONG GYE CHEON POST-REVITALIZATION – FEATURE ELEMENTS (LEFT) AND KALLANG RIVER POST-REVITALIZATION (RIGHT)

In Hong Kong, continuous land development and climate change lead to surface runoff increase, more extreme rainfall events and sea level rise, thus increasing the future flood risk. This would considerably impact the performance of existing drainage systems.

Blue-green infrastructure supplements the conventional one by reducing the volume of surface runoff and attenuating peak flow, thereby preventing the downstream existing drainage infrastructure from being overloaded, and thus enhancing the drainage system's capability to handle unexpected extreme events. Its application also provides wider environmental benefits to the community, which should be considered by the project proponent.

Given the land limitations in Hong Kong, one potential benefit of blue-green infrastructure design is the possibility to release drainage reserved lands for other public co-use. Integration of land use with a flood prevention purpose in mind means drainage facilities could be absorbed into recreational area, natural buffer zone, urban greening, green belt or conservation area. For example, a flood retention lake could be deployed to serve as an amenity lake in wet season if designed as a wet pond; while in dry season it could be used as open space if designed as a dry pond. The water body and green features could also help mitigate climate change impact and heat island effect. The co-use of land is an opportunity to meet expectations and aspirations for improving the quality of life for communities, celebrating local character, and reshaping the relationship between the community and their local environment.

Enabling multiple use of rainwater resource is another potential benefit. For example, retention lakes could be used for amenity or form part of the landscape feature. The retained water could couple with a rainwater harvesting system for irrigation or toilet flushing, thus reducing water supplies demand. The water body could provide a softening effect to the surrounding hard urban landscape, or if located at the boundary between rural and urban area could provide ecological value and support biodiversity.

By manifesting water in our cityscape, people start to care more about its quality and its preservation. This may bring in a change in people's value and attitude towards water in the long term. Some blue-green infrastructure provides the benefit of treating urban runoff pollution. Examples include bioswale, rain garden, and constructed wetland. This could potentially benefit the protection of sensitive receiving water bodies, such as Deep Bay.

There could be other potential benefits of using blue-green infrastructure, and project proponents are encouraged to deploy the smart city concept to bring in co-benefits when planning drainage networks for NDAs or revitalising existing drainage facilities. Annex 3 contains general guides for revitalization of channelized rivers.

Key Items to Consider

Project proponent should take a liberal approach when designing a blue-green infrastructure, and incorporate as much as possible these “value added” blue-green elements on top of the basic drainage needs. To assist the project proponent in the adoption of blue-green infrastructure in the planning and design of river channels, this PN includes an expansion on environmental and ecological considerations in the selection of channel design approach. Further technical guidance on the design of “ecological enhancement” and “compensation” elements are provided, including design considerations around the balance of engineering and ecological performance, and appearance and landscape design considerations. Real case examples are also included in this PN.

Collaboration of inter-disciplinary teams forms the basis of the blue-green infrastructure design approach, and should likewise be established from the project outset when undertaking river channel design. Collaboration between Town Planners, Architects, Urban Designers, Landscape Architects, Civil Engineers, Ecologists, Land Developers and other built environment practitioners can bring new perspectives and expertise and is seen as critical for the successful integration of best practice measures and blue-green infrastructure principles in a development. It is important that all stakeholders to this process, including relevant government departments, project proponent, and the community, also be engaged at an early stage, and throughout the development process.

3. ECOLOGICAL IMPACTS DUE TO RIVER CHANNEL WORKS

River channelization is carried out for the purposes of drainage improvement, flood prevention, reduction of bank erosion or river realignment to blend in with future development. It involves engineering works, such as bank protection, widening, deepening and realignment of original river channel that will cause direct and indirect impacts on the river and riparian ecosystems.

3.1 Direct Impacts

The use of artificial non-vegetative smooth lining (such as concrete on the river bed and embankment) causes a direct loss of riverine habitats including pools, riffles, aquatic, benthic and riparian habitats, and the associated flora and fauna communities inhabiting those riverine habitats. The faster water current and lowered water level after river channelization, particularly those provided with a dry weather flow channel, also creates unfavourable conditions for the aquatic organisms to re-colonise in the new channel.

River realignment/straightening might cause sections of meanders to be cut off from constant water supply, resulting in loss of riverine habitats and affecting the inhabiting aquatic organisms. Special consideration wherever possible and practicable should be given in the design to minimize such ecological impact.

Construction of embankment along the river to replace natural bank and margin with steep artificial channel bank would affect the ecological and hydrological connectivity between the aquatic and adjacent riparian and terrestrial habitats (e.g. amphibians, which rely on both aquatic and terrestrial habitats, might not be able to complete their life-cycle; mammals and reptiles may not be able to get to the stream for water).

Installation of dams and/or weirs would fragment the river channel longitudinally and obstruct the upstream and downstream movement of fish and other aquatic organisms.

Channel widening might damage riparian vegetation which subsequently reduces shading, increases water temperature and reduces nutrient input to the river. These changes have subsequent ecological impacts on the aquatic communities.

Too frequent dredging for desilting or weed cutting in a river channel would cause ecological impact and arrest natural recovery of aquatic and riparian organisms. These operations should be planned carefully in terms of frequency, phasing and timing in order to minimize environmental impacts on the river channels.

3.2 Indirect Impacts

Channelization works would affect water quality (e.g. increase in sedimentation) and flow regime (such as increase in water current and peak flow) of downstream river section. These hydrological changes alter the habitats of aquatic organisms and subsequently cause impacts on those species with low tolerance to environmental change. In addition, water, air and noise pollution caused by construction activities would also induce indirect impacts on river channels. Precautionary measures shall be adopted to minimize these impacts (see Annex 4).

Another indirect impact is the drawdown of groundwater table which would affect the riparian vegetation and the adjacent wetland habitat. Where water tables are lowered or surface waters drained, the aquatic organisms and associated communities (e.g. wetland birds) would gradually be replaced by terrestrial communities.

4. EXISTING GUIDELINES ON RIVER CHANNEL PROJECTS

The Stormwater Drainage Manual (SDM) provides important guidance on the planning, design, operation and maintenance of stormwater drainage works constructed in Hong Kong. It stipulates that "all the drainage works should be designed to blend in with the environment." (SDM (4th ed.) Cl. 3.4.1) and "In addition to the air, noise, dust and water aspects which are usually considered for most civil engineering works, issues such as ... the impact of large-scale drainage works on the ecology of the surrounding areas should also require detailed assessment. Mitigating measures such as wetland compensation should be devised accordingly." (SDM (4th ed.) Cl. 3.4.3). Users are reminded to ensure that the eco-hydraulic design of the river channel projects satisfies the requirements of the SDM.

In addition, every river channel construction project in Hong Kong has to either go through an environmental impact assessment (EIA) or an environmental review during the planning and design stages to ensure that the proposed works will have minimal impacts on the environment. The former is a requirement under the Environmental Impact Assessment Ordinance (Cap. 499) (EIAO) enacted in February 1997 while the later is a requirement under the ETWB TCW No. 13/2003 – Guidelines and Procedures for Environmental Impact Assessment of Government Projects and Proposals. To facilitate the use and understanding of the EIAO, the following documents are available from the Environmental Protection Department (EPD) website (http://www.epd.gov.hk/eia):

- “A Guide to the Environmental Impact Assessment Ordinance” published by EPD in 2007
- “The Technical Memorandum on Environmental Impact Assessment Process” or the “Technical Memorandum” issued under Section 16 of the EIAO by EPD in 1997

Other guidelines which are useful reference materials for preparing an eco-hydraulic design of river channels are listed in Annex 5.

5. SELECTION OF ENGINEERING MEASURES FOR FLOOD PREVENTION

5.1 General Principles

From the environmental and ecological point of view, the general principle / approach for flood prevention by engineering measures should be in the order of avoidance, minimization and compensation. Hence, the minimization approach refers to engineering solutions which would minimize any direct environmental impacts on the watercourses, including their in-channel and river-bank components. These solutions can provide not only flood alleviation but also the potential to increase both the amount and diversity of riverine habitats (RSPB et al., 1994, Hey, 1996 and Anonymous, 2000). Table 1 summarizes the considerations of different options, which would be described in detail in the following sections.

TABLE 1 CONSIDERATIONS OF SELECTING ENGINEERING MEASURES FOR FLOOD PREVENTION

Engineering and Environmental Performance				
Option	Description	Advantages	Disadvantages	Design Limitations
Distant flood banks	The flat land close to the river banks is reserved as flood banks for the river channel	Original river/stream unaffected	Large land intake Land resumption complication	Not suitable in urban areas Potential need to change land use in flood storage zone
Two-stage channel	Excavated level plain on both sides of the river for vegetation growth, allowing the cross section of the river to be widened	Original riverbed and lower part of river bank unaffected	Large land intake Land resumption complication If berm surface becomes overgrown, design flood capacity is lost	May not be suitable in urban area Not suitable to upland-type rivers Larger space requirement

Engineering and Environmental Performance

Option	Description	Advantages	Disadvantages	Design Limitations
Relief channel and by-pass channel	Man-made channels which act as tributaries for diverting excess water when there is high water flow	Original river/stream unaffected	Flow in original river/ stream may be affected	May not be suitable to upland-type rivers
Flood Storage	Utilize an upstream pond or storage area for storing the excess water during high flow periods and release the water during low flow periods	Original river/stream unaffected	Large land intake Land resumption complication	Substantial site formation works may be required for the flood storage pond/area at upland rivers
Alternation of Works	Apply channel works to part of the river channel only, and retain other parts or sections in their original natural state	Provide refuge to original habitats and flora	Flow in original river/ stream may be affected Larger space requirement	May require more construction and O&M effort to protect the original habitats and flora
Ecological linkage and connectivity	Removal or redesign of structures that inhibit animal passage both laterally and longitudinally	Creates habitat connectivity and pathways for species dispersal and migration	Large land intake Land resumption complication	May not be suitable in urban areas or areas requiring flow control
Avoid using dry weather flow channel	Avoid providing a “sub” channel to convey flow during low flow condition	Maintain natural groundwater table to support aquatic life	Siltation may increase	May increase O&M effort to manage the amount of siltation
Preservation and enhancement of cutoff meanders	Retain cut-off meandering sections after channelization to provide aquatic habitat	Habitats and flora in original river unaffected	Possible conflict with adjacent land uses Regular maintenance required	May not be suitable in urban areas Not suitable in polluted areas

In addition to selecting different options in carrying out the main river channel works, the design of the maintenance access is also important as it may disturb the ecological habitats in river channel. Provision of ecologically friendly maintenance access, for example, planted geotextile, can be a good alternative (Lewis et al., 2010). Grass species such as *Axonopus compressus*, *Cynodon dactylon* and *Eremochloa ciliaris* can be utilized to withstand the compaction of vehicles. This may help to maintain the ecological connectivity between river channel and surrounding habitats. Grassed cellular concrete paving is another option for maintenance access which can withstand higher compaction force, but the ecological value is lower due to the presence of concrete surface. Moreover, it is suggested that the width and specifications of the access should be reduced to a minimum that needed for equipment access and operation.

For any vehicular bridges or footbridges crossing the river channels, their pier and embankment locations should be designed to avoid disturbance to the river beds and the riparian zones where possible. Bridge designers may consider incorporating ledges and holes to provide potential nesting/roosting sites for bats or amphibians, while at the same time maintaining the bridge integrity and strength without causing future maintenance problems (Environment Agency, 1997). Besides river crossing structures, laying utility services within the channel should be avoided except the case where no alternative route is available. Utility services may be allowed to be laid below the river bed using trenchless construction methods if the utility undertaker could demonstrate the disturbance to the ecology of the river channel was minimal.

5.2 Distant Flood Banks

If land is available, distant flood banks (see Figure 3) offer the optimal solution for flood alleviation as well as conservation of riverine habitats.

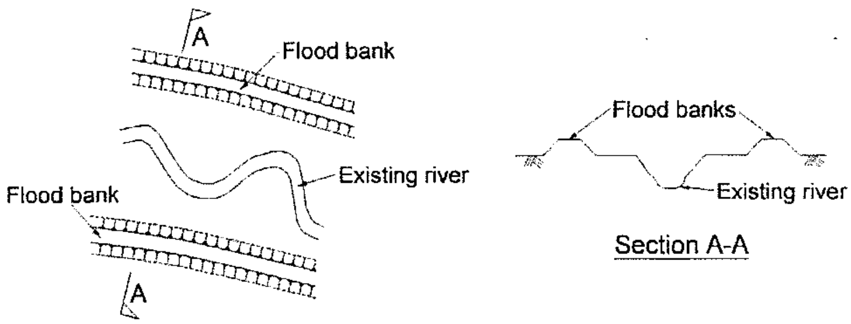

FIGURE 3 TYPICAL ARRANGEMENT FOR DISTANT FLOOD BANKS

In this method, the flood banks are set back from the rivers as compared to the traditional bank formation of trained rivers. The river is, therefore, allowed to meander freely within their bounds. As a result, there is little interference between the natural stability of the river and the artificial embankment. At the same time, additional storage capacity and flood prevention are achieved.

The main advantage of this method is that the flood banks can be built in relatively smaller sizes and the natural habitats of the main channel are kept relatively undisturbed with the in-stream and margin habitats and vegetation untouched. Care should be taken to ensure that the flood banks are gentle enough to allow passage of wildlife across flood banks. The floodway bounded by the flood banks can also provide opportunity for ecological development or as a sanctuary of wetland associated wildlife, although ad-hoc maintenance may be required from the drainage point of view.

The main constraint of this method is the space availability along and within the flood banks to spare for flooding. This will be a problem in developed areas. But in rural areas, it may work well with a modification in the land use pattern in the flood plain areas, which are inside the flood banks allowed for flooding. To add more value to the flood plain areas, they can be modified and maintained as a river park or conservation areas.

5.3 Two-stage Channel

Two-stage (or multi-stage) channel can be used to avoid the widening of the original river bed but provide significant increases in cross-sectional area during high flows. It can also be used for rehabilitating channels that are over-widened.

Two-stage channel is created by excavating the surface section of the flood plain adjacent to the river and a level space or berm is created on both sides. The original river channel is thus preserved while higher flows are contained within the newly created berms. A "flexible" approach, where the excavations alternate from bank to bank, can be adopted to achieve specific purposes (e.g. to avoid private land or preserve large trees).

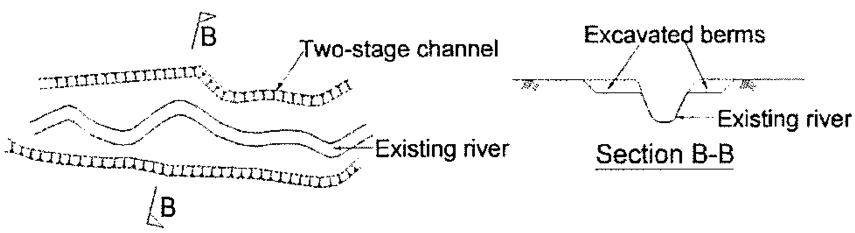

FIGURE 4 TYPICAL ARRANGEMENT FOR TWO-STAGE CHANNEL

An ideal two-stage or multi-stage channel (see Figure 4) will comprise a relatively wide corridor profile so that the flood water is contained in a series of berms and slopes until it eventually spills out from the artificial embankment onto the wider flood plain area. Sedimentation at the created berms is, moreover, likely to occur and the vegetation on these will need to be managed to prevent the development of overgrown scrub which may impede flow during periods of flood. Hence, more operating and maintenance effort is required for a two-stage channel.

Environmental benefits of this engineering solution are that differed flooding regimes and water tables in each section of the channel will result in the development of different types of habitat and contribute to biodiversity. The construction of a two-stage or multi-stage channel in upland portion of a river is, however, less likely to be successful due to sedimentation, rapid bank erosion and destruction of created berm during flood flows. Moreover, land availability would pose a great constraint in applying this design.

In lowland urban areas, creation of multi-stage channel is a viable alternative as sedimentation can be minimal and the channel can actually increase the environmental value due to the addition of habitats and landscape features. Furthermore, the flood berms can be modified and maintained as an urban park or landscaping areas.

5.4 Relief / By-pass Channel

Relief or by-pass channels act as tributaries for diverting excessive water from the main natural channel during periods of high flow, and consequently reduce the likelihood of flooding and erosion. When comparing this design with channel straightening, the original river, particularly the meandering sections, would remain undisturbed and with constant water flow during low and high flow situations. There are two broad types of relief channels:

a. Type 1: Relief channels which have permanent water flow can be designed to have either a small base flow even during the dry seasons, or the base flow can be shared equally between the relief channel and the main channel. This option is of great value to wildlife habitats because the riverine habitat in the relief channel can be created and maintained all year round, although care must be taken to ensure that sufficient flows are maintained in the main channel.

b. Type 2: Relief channels which are predominantly dry except during periods of high flow are less beneficial to wildlife, but may be less prone to erosion due to binding of the soil by a permanent cover of vegetation. This type of relief channels can be constructed in the form of underground box culvert to minimize land requirement. A storage tank can be built next to the box culvert with a movable weir to prevent any flow to the tank when downstream channel still has spare capacity. This option offers much less benefit to wildlife due to the lack of habitat creation but has an advantage of creating much less footprint than an open channel. Figure 5 shows the typical arrangement for flood relief channel.

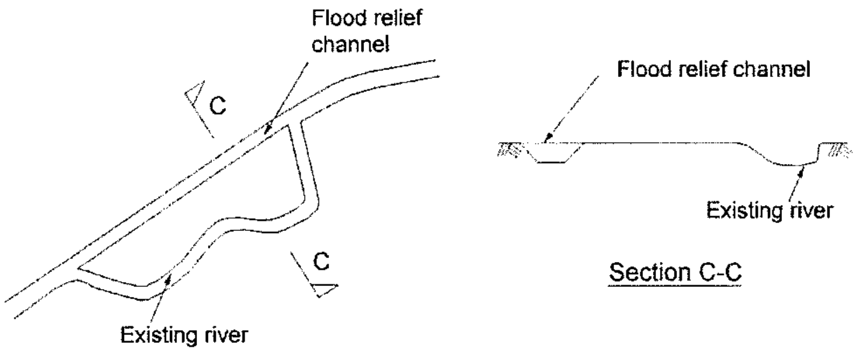

FIGURE 5 TYPICAL ARRANGEMENT FOR FLOOD RELIEF CHANNEL

Typically, relief channels are shorter than the original main channels, and consequently flow velocities in them are greater, which can cause scour and bed erosion. This situation, if not managed properly, would continue to worsen and ultimately the majority of flow would be conveyed via the wider and deeper relief channel instead of along the original main channel. This may result in significant reduction of flow in the original main channel and thereby affect the original habitats and organisms living therein. Such potential problems can be avoided by protecting the channel sides and bed or by constructing a weir at the upstream inlet of the relief channel. Another potential problem is the increase of deposition at the main channel due to the decreased flow rate. To avoid the above potential problems, it is suggested to design a bypass that would only intercept the flow in heavy raining (e.g. during amber rainfall signal). The level of the inlet of the bypass must be carefully adjusted and built to achieve this. Also, the angle at which the relief channel re-joins the main channel downstream should be acute to prevent scouring in the main channel.

The drawback of this engineering solution is that a considerable amount of land will be required. However, comparing with the distant flood banks and two-stage channel, less land may be required for this option.

5.5 Flood Storage

The concept of flood storage is to intercept the runoff at the upstream area and temporarily store in a flood storage pond/area. When the water level in the downstream river recedes, water at the flood storage pond/area will be re-diverted into the river. This will substantially reduce the volume of runoff discharged into the downstream river during heavy rainstorm and flooding in low lying/downstream areas will also be relieved. The original river will remain undisturbed and this actually preserves the nature of the river. If new development land is not to be extracted from the natural river flood plain, flood storage offers an optimal solution for flood alleviation as well as conservation of riverine habitats. In fact, this is often the only way to upgrade the flood protection standard of the upstream stretch of the river if it is not practical to further increase the capacity of the already-trained downstream stretch of the river. One example is the proposed flood retardation basin in Shenzhen River which is designed based on the largest existing river bend, and will help store floodwater during heavy rainstorms, thereby controlling the amount of water flowing into the downstream (see Figure 6). The flood retardation basin can be modified and maintained as a river park or landscaping areas. Underground storage or retention tank can also be considered as an alternative, but the operating and maintenance cost would be high. In Tai Hang Tung Storage Scheme, Sheung Wan Stormwater Pumping Station and Happy Valley Underground Stormwater Storage Scheme, the open space at the top of the storage tank provides different recreational facilities such as grass football fields for public use.

FIGURE 6 PROPOSED FLOOD RETENTION BASIN AT SHENZHEN RIVER

5.6 Alternation of Works

As mentioned in Section 3, river channelization would certainly cause different direct and indirect impact to its environment and ecology even though different mitigation measures are deployed to minimize such impact. Therefore, one possible way to minimize the environmental and ecological impacts is to alternate the proposed channelization works in different sections of the river channel such that some sections could be remained in natural state. For example, widening can be done by modifying one bank only and leaving the opposite bank intact. Deepening can be done by partial dredging to create a deeper channel in one part while maintaining sufficient base flow over the un-deepened part of the bed. The same concept should be applied to relining the channel with artificial non-vegetation smooth materials such that one side of the embankment could be retained in natural states (see Figure 7). The retained sections could then serve as refuge for aquatic organisms. The temporal and spatial phasing of the construction work and the regular maintenance works should also be carefully designed to reduce the ecological impacts. The alternation of engineered and non-engineered sections along the river channel may cause complications in future operating and maintenance stage.

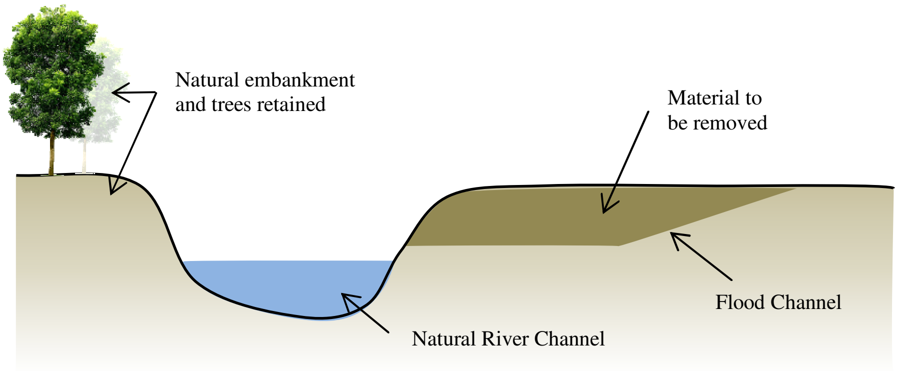

FIGURE 7 ALTERNATION OF WORKS

5.7 Ecological Linkage and Connectivity

a. Lateral Connectivity between Floodplain and River

Lateral connectivity between floodplain and river is essential for a number of reasons, such as enhancing species diversity, facilitating exchange of matter and energy, providing refuges and other resources for species, and creating pathways for species dispersal and migration (Soar and Thorne, 2001).

Installing concrete structures at embankment toes may lead to disconnection of the migration zone and impede animal passage. Bioengineering techniques such as natural fiber rolls, live fascines and live crib walls may be considered to replace the concrete embankment toes (Maryland Department of the Environment, 2000). These techniques also propagate vegetation growth, hence improving the lateral connectivity between river and riparian habitats.

If concrete structures are considered as indispensable to the bank toe stabilization, two layers of geotextile may be laid over the concrete surface with topsoil mixed with grass seed in between to propagate vegetation growth.

The shape of the channel should be trapezoidal except where land is a constraint. Vertical embankments have a negative effect on ecological connectivity as animals can become trapped in the channel (see Figure 8). Sloping embankments that allow passage for terrestrial animals would maintain ecological linkage within the local habitat because these animals may utilize the river channels as water source and foraging source, or simply to cross to the other side during low flow. As a result, animal corridors should be provided in the form of gentle slope at regular channel sections to serve as connection point to and from the channels.

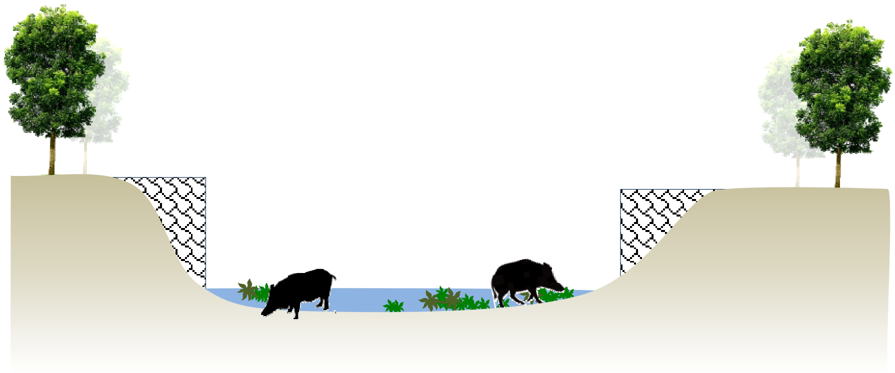

FIGURE 8 ANIMALS COULD BE TRAPPED IN CHANNEL WITH VERTICAL EMBANKMENT WITHOUT PROVISION OF ANIMAL CORRIDOR

b. Longitudinal Connectivity from Upstream to River Mouth

In Hong Kong, full width inflatable dam is commonly utilized as tidal control at the river mouth. Particularly, several inflatable dams have been installed across tidal channels which discharge into Deep Bay so as to prevent the backflow of heavily polluted tidal water to the upstream area. Other functions of inflatable dam include irrigation, creating a pool of amenity water and acting as source of water for wetlands. The use of tidal control structures such as inflatable dam would alter the river-estuarine environment and obstruct the river-floodplain connectivity as tidal channels are isolated from tidal influence and connection with the marine environment is broken. Adverse impacts include sharp transitions in water temperature which represent a barrier to migrating fish and create unsuitable conditions for fish nursery grounds; mobilization of polluted soil trapping metals (e.g. iron and aluminium) which is toxic for many marsh plants; reduction in salinity which causes changes in the plant community as salt-tolerant plants are replaced by freshwater plants; and deterioration of the quality and connectivity of fish habitats by modifying the composition of plant and invertebrate communities in their estuarine habitats (DSD, 2010).

In the long run, water quality at the estuaries may improve to the extent that the tidal gates can be decommissioned. In the meanwhile, to reduce the negative impact due to disconnection of flow path, intermediate measures such as provision of fish ladder may be considered. For details on fish ladder, reference could be made to Section 6.6. Where a project requires the installation of large or medium scale tidal control structures, the pros and cons of different tidal control structures, including environmental considerations, need to be evaluated and ecologists need to be consulted.

c. Vertical Connectivity between Surface Water and Ground Water

The interaction between surface water and ground water plays an important function in several stream processes such as the cycling of nutrient and organic matter, detoxification of contaminant, etc. These processes are important to support the aquatic life. Hence, replacement of natural bed and embankment lining with concrete or other artificial materials which prohibits such interaction is not recommended. In addition to the preservation of the natural river bed, designers should also pay attention to the water level in dry weather condition so that natural low flow could be maintained at all time. Potential rehabilitation measure such as introduction of woody debris into the stream could further enhance the heterogeneity of the hyporheic habitats (Boulton, 2007).

d. Tributary Connectivity

Tributary connectivity is similar to that of longitudinal connectivity but it is between the main stem river and its tributaries. The loss in tributary connectivity would confine populations to small isolated patches with restricted gene flows which make local and regional species highly vulnerable to extinction risks; intensifying predation, competition and overcrowding effect through the reduction in habitat size; and possibly result in dominance of non-native species which are tolerant to the degraded ecological conditions (Miyazono and Taylor, 2013). To restore tributary connectivity, considerable effort has to be devoted to encourage removal or bypass of the barriers to improve flow characteristics and restore the river continuum during the design of river channel works. In Regulation of Shenzhen River Stage IV, a 300mm low flow channel and matched riverbed levels were adopted at the confluence between Shenzhen River and Kong Yiu River to maintain the ecological connectivity.

5.8 Avoidance of Dry Weather Flow Channel

In previous drainage projects, a dry weather flow channel made of concrete was normally provided in non-tidal channels in order to minimize siltation during low flow condition (see Figure 9). However, the presence of such dry weather flow channel will give rise to dry channel bed, lowering of groundwater level at river channel and high velocity of flow in the dry weather flow channel, which are not favourable conditions for supporting aquatic life. Due consideration should be given to minimize the use of dry weather flow channel in the design of river channels except where it may be necessary to intercept and divert polluted flow from the channel. It is also recommended to keep the natural bottom as much as possible as a low flow channel can be recreated naturally without any artificial modification. However, more effort in managing the siltation issue in future operating and maintenance stage should be expected.

FIGURE 9 DRY WEATHER FLOW CHANNEL AT TAI KONG PO

The water table of a channel can be maintained through proper planning prior to channel construction. Some structures may be considered to sustain base flow in urban channel during dry season. Setting small weirs in the channel can maintain base flow water surface. In addition, ground depression in the channel to a point lower than the ground water level allows groundwater recharge in dry weather flow channels. The practicability of above measures is subject to the channel structure and properties.

5.9 Preservation and Enhancement of Cut-off Meanders

After realignment or straightening of a river, the previous meandering sections will be left behind and the flow will follow the newly constructed channel. Such cut-off sections, depending on its original ecological value, are either backfilled for landscape purpose or preserved as aquatic habitats. In the latter scenario, the preserved meanders should be properly designed to provide a wide range of ecological habitats. Figure 10 shows one typical arrangement of preserving and enhancing a cut-off meander. For meanders close to village houses with potential water pollution problems, consideration should be given to remove the pollution at source, or to intercept the polluted flow away from the meander.

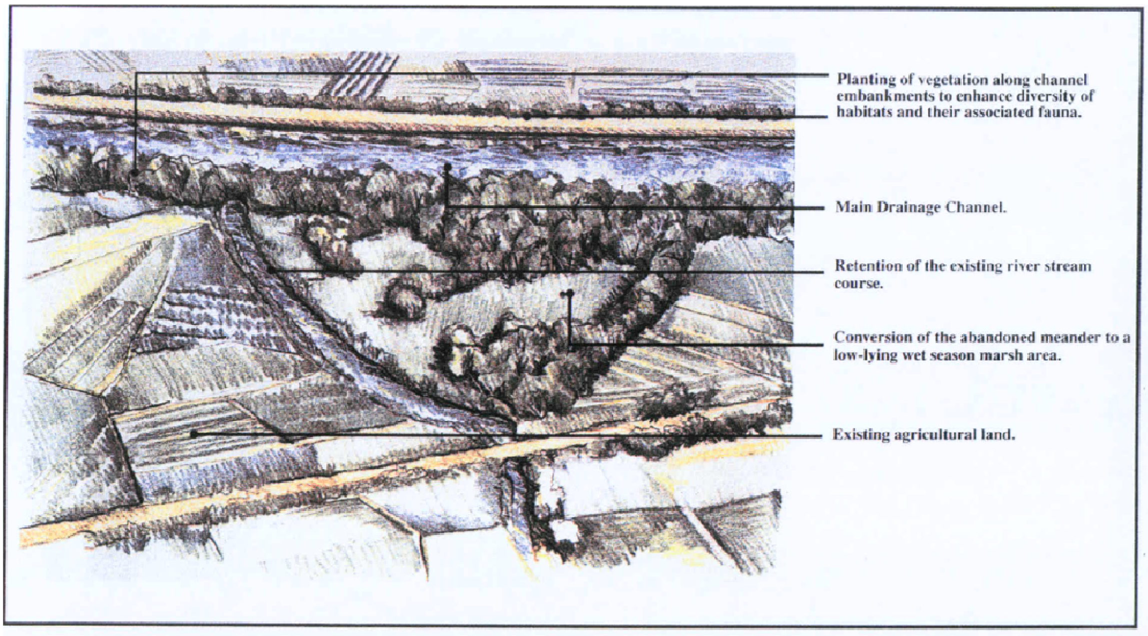

FIGURE 10 PRESERVATION AND ENHANCEMENT OF CUT-OFF MEANDERS (SOURCE: EXAMPLES OF ENVIRONMENTALLY FRIENDLY DRAINAGE CHANNEL ARISING FROM ENVIRONMENTAL IMPACT ASSESSMENTS BY EPD, DSD, AFCD & TDD)

There are a number of local examples of meanders which have been cut-off after river regulation projects (e.g. Ng Tung River, The Yuen Long and Kam Tin Main Drainage Channels, Main Drainage Channels for Fanling, Sheung Shui and Hinterland). Recent experience demonstrates that its application should be carefully considered taking into account the possible conflicts with adjacent land use and the resources required for long-term maintenance. It may not be pragmatic to indiscriminately retain them all for preservation purpose. Meanders with easy access would be susceptible to illegal dumping and unauthorized land use, resulting in potential degradation. The slow flow or stagnant water may also be seen as environmental nuisance by local residents.

For those selected sections of cut-off meanders with high potential for enhancement, the inlet and outlet should be carefully designed to ensure that there is constantly sufficient water flow in the meander to maintain the water quality and ecological balance in terms of nutrients and food sources. The natural river bed substrates and the bankside vegetation should be preserved as far as possible. Enrichment planting of native species should be undertaken to establish the marsh or riparian habitats. Regular maintenance such as weeding of unwanted plant species, desilting of channel and removing rubbish trapped in the meanders is essential for the ecological sustainability of the cut-off meanders (see Annex 6).

6. ECOLOGICAL ENHANCEMENT OF ENGINEERING MEASURES

6.1 Objectives

Following the selection of options to minimize the impact of the engineering works, there are ecological enhancement measures that can be adopted to further minimize the residual impact of river channelization works. These measures may also enhance the ecological conditions of river channels. However, it should be noted that different enhancement measures serve different purposes. The goals of ecological enhancement should therefore be set in advance for each river channel, and the baseline ecological conditions should be reviewed prior to the design. Some suggested measures to improve habitat quality, water quality and ecological conditions of the channel are provided in Annex 7.

Ecological monitoring after the completion of the project will provide useful information for the assessment of the ecological enhancement of the engineering measures, which is a useful reference material for the design of future projects. Nonetheless, the provision of ecological enhancement design measures may cause reduction in hydraulics performance, and engineers should consider in the design to optimize the hydraulic flows with due consideration of preservation of the local ecology.

6.2 Natural Bed Substrate

Preservation of natural bed materials of the river corridor achieves the best result from the ecological viewpoint. Boulders, cobbles, coarse gravels, sand or mud (depending on the nature and location of the stream section) provide habitats for fishes and macro-invertebrates. Natural earth bottoms at inter-tidal section are attractive to wetland bird. The natural bedding at Kam Tin River Channel is a good example which provides an inter-tidal section to wetland birds (see Figure 11). The preservation of natural bed substrates for Pak Ngan Heung River, Tong Fuk River and Deep Water Bay Stream created diverse habitats for fish and freshwater invertebrates.

FIGURE 11 NATURAL EARTH BOTTOM OF KAM TIN RIVER CHANNEL

During construction or maintenance operation, the original substrates can be stockpiled and protected along the bank. Those stored substrates can be either reinstated after works (see Figure 12) or reused for planting riparian vegetation such that the survival of native species propagules could be enhanced. The latter use can not only reduce the chances of importing vegetative disease from unknown stocks, but also allow rapid establishment of late-successional species and reduce invasion of exotic species. It also reduces the necessity of seedling with cultivated varieties which may eventually lead to loss of natural diversity (Kusler, 1990). If the bank slope is steep, it will have to be pinned in place; alternatively it may be used in combination with geotextiles (SEPA, 2009).

FIGURE 12 PRESERVATION OF BED SUBSTRATE AT HO CHUNG STREAM

Careful planning should be exercised to carry out the works in stages to minimize the disturbance to the original ecosystem and to allow time for the aquatic organisms to migrate. If flora and fauna with high ecological value are identified and disturbance is unavoidable, mitigation measures such as translocation, temporary mitigation pathways, recolonization and compensation plan should be considered by the project proponent based on the advice of experienced ecologists. Design of channel bed lining is further discussed in Section 8. Due to the ecological requirements mentioned above, more operating and maintenance effort would be expected.

6.3 Sinuosity

A sinuous channel (see Figure 13) is more stable, aesthetically more pleasing, has a slower flow and provides a greater variety of water flow conditions and aquatic habitats. It also creates small physical habitats such as pool, cascade, run, guide, etc. Due consideration should be given to the velocity of river at the upstream section as scouring at outer bank might cause stability problem to the embankment and higher maintenance cost would be required.

FIGURE 13 SINUOUS CONFIGURATION AT MA TSO LUNG RIVER

6.4 Pools, Riffles and Falls

Boulders or logs can be reorganized to create pools, riffles and falls. They enhance the complexity in benthic habitat of riverbed and flow velocity. The pools formed behind the weirs trap organic debris which would provide food source for invertebrates, subsequently enhance the feeding opportunity for vertebrates (i.e. fish, amphibians and birds).

The riffles and falls increase aeration in the river channel. Crevices of riffles filled with gravel and sand provide habitat for some marcoinvertebrate species. To enhance fine materials holding capacity of riffles, rocks with different sizes and round shapes are more preferable than rocks with similar sizes and irregular shapes. In addition, to speed up the colonization process of aquatic life to riffles, a mixture of pebbles, gravel and sand should be added to the cervices of rocks. Care should be taken that weirs should not be too high which form barriers to the passage of fish species and other aquatic organisms. Concrete structures should also be avoided in the design. Figure 14 shows a typical design of weir constructed of boulders.

Another method of forming pools and riffles is to install current deflectors (also called wing deflectors) (see Figure 15), which has the ability to change the flow direction to eliminate accumulated sediment, protect eroding bank, increase velocity thus creating a scour pool with a corresponding downstream riffle. It is recommended that the length of the current deflector to be at least half the channel width and spacing between deflectors should be five to seven channel widths apart. The deflector should also be placed in sections with flow rate > 0.6 m/s and angled in a downstream direction at approximately 45° from the current (Chan, 2001).

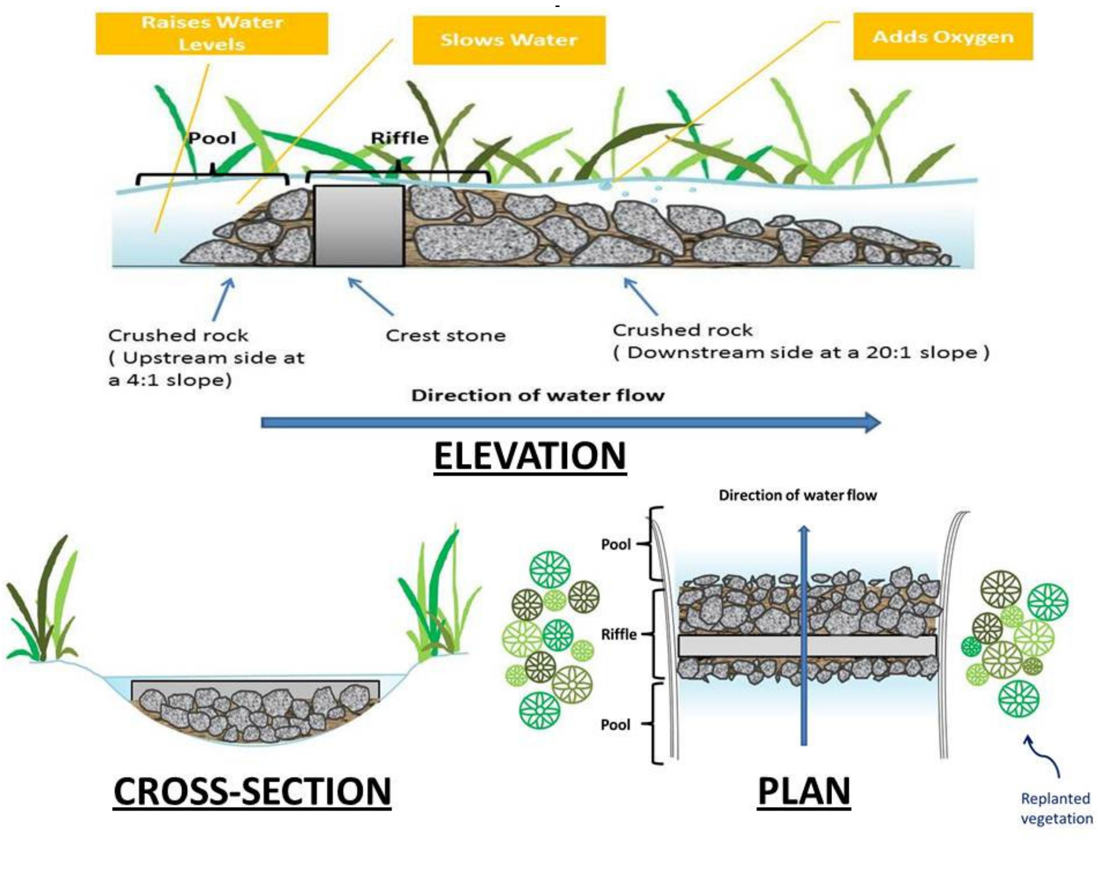

FIGURE 14 PLAN, ELEVATION AND CROSS-SECTION VIEWS OF A BOULDER WEIR AND ITS MAIN FUNCTIONS

FIGURE 15 CURRENT OR WING DEFLECTORS

6.5 Vegetated Ledge / Aquatic Planting Bay

Vegetated ledges can be created by installing sheet pilings along the edges or in form of planting bays. The purpose of the sheet piling is to prevent erosion. Figure 16 shows the type of vegetated ledge formed by sheet piles. Natural materials such as rocks with different size should be placed beside the sheet pile so that channel organisms can move laterally. Alternatively, natural materials such as timber boards treated with preservative solution under high pressure treatment processes or stones may be considered to replace sheet piling. The vegetation in the ledge could provide habitat as well as a silt trap for improvement of water quality. To ensure that the aquatic plant is properly established, the ledge should be installed at a location where water current is relatively slow (e.g. inside of a bend where point bar have been developed) and with constant water supply. It should be noted that vegetation will be washed away after heavy rainstorm and maintenance of the vegetation may be essential from the drainage point of view (e.g. weed cutting).

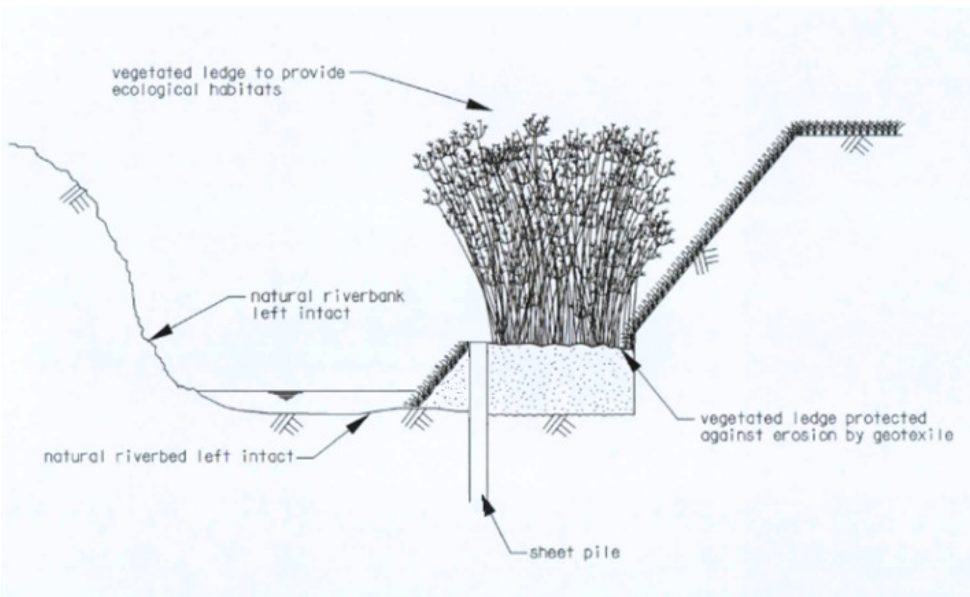

FIGURE 16 CREATION OF VEGETATED LEDGE BY SHEET PILES

6.6 Fish Passage / Ladder

Weirs sometimes exist in rivers and channels due to various reasons such as Fung Shui or irrigation. They will produce a physical barrier preventing the free passage of fish and other aquatic organisms along the stream. To facilitate the passage of aquatic organisms, weirs can be designed in the form of a ladder-shaped water trough with low steps and low gradients. Provision of irregular surface and small pools on each step will also assist the movement of fish and other aquatic organisms (see Figure 17). The cross-section widths, water depth and current should be made as diverse as possible to contribute towards the naturalness of the fish ladder design. Other factors to be taken into consideration include fish ladder entrance and hydraulic criteria that are subject to site-specific conditions. Designers could consult experts or refer to the guideline on fish ladder and fish pass designs published by Food and Agriculture Organization of the United Nations.

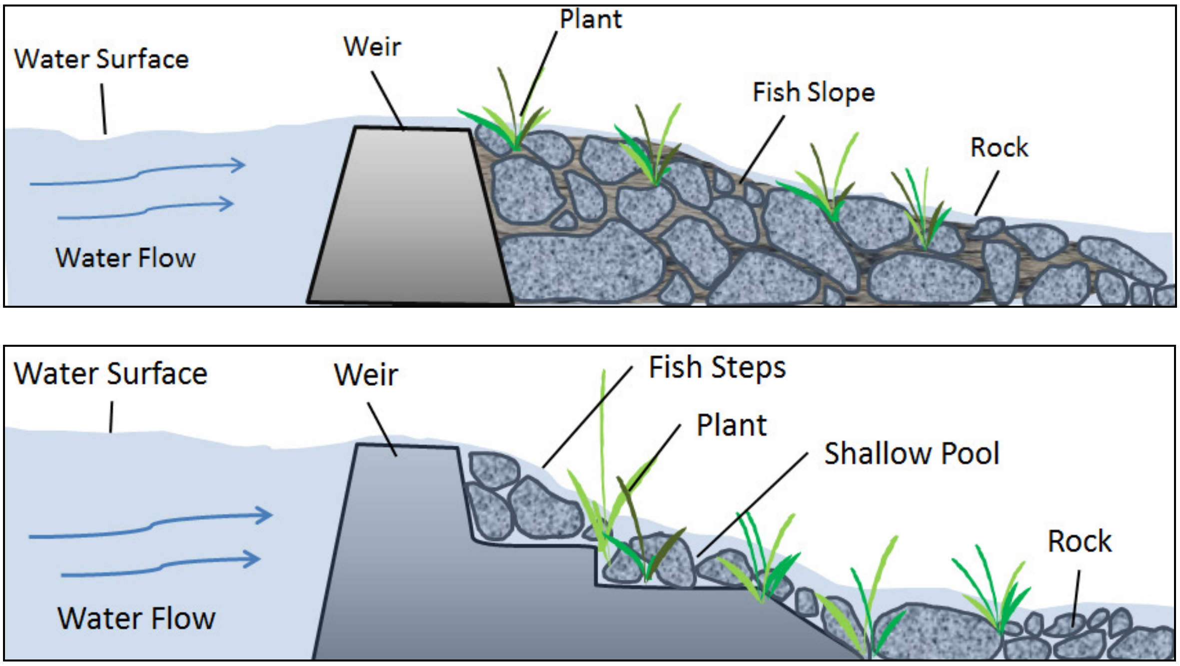

FIGURE 17 SIDE VIEW OF FISH SLOPE (UP) AND FISH STEP (DOWN)

In Ho Chung River and Pak Ngan Heung River (see Figure 18), fish ladders have been shown to facilitate the passage of the Japanese Mitten Crab (*Eriocheir japonicus*), which had been recorded in locations upstream of the fish ladders. The fish ladder at Pak Ngan Heung River is less preferable from the nature conservation point of view as the gradient is steeper and the level difference between the weir and its immediate downstream section is rather large.

FIGURE 18 FISH LADDER AT HO CHUNG RIVER (LEFT) AND PAK NGAN HEUNG RIVER (RIGHT). FOR PAK NGAN HEUNG RIVER, THE FISH LADDER MAY BE FURTHER IMPROVED THROUGH THE USE OF NATURAL SUBSTRATES AND SLOPING GRADIENTS FOR THE EMBANKMENTS AT THE WEIR UPSTREAM TO FACILITATE ANIMAL PASSAGE.

6.7 Microhabitat

Microhabitat is defined as a small-scale habitat less than or equal to one meter across, such as components of the substrate in a riffle, that are important elements of aquatic habitat in a river. Damage of microhabitat should be avoided as much as possible. Creation of microhabitat by adding different substrates can provide a diverse environment with different biotic and abiotic components for different species which further enhance channel complexity (see Figure 19). To be effective in providing ecological enhancement, microhabitat should be carefully designed with suitable planting and proper maintenance practice.

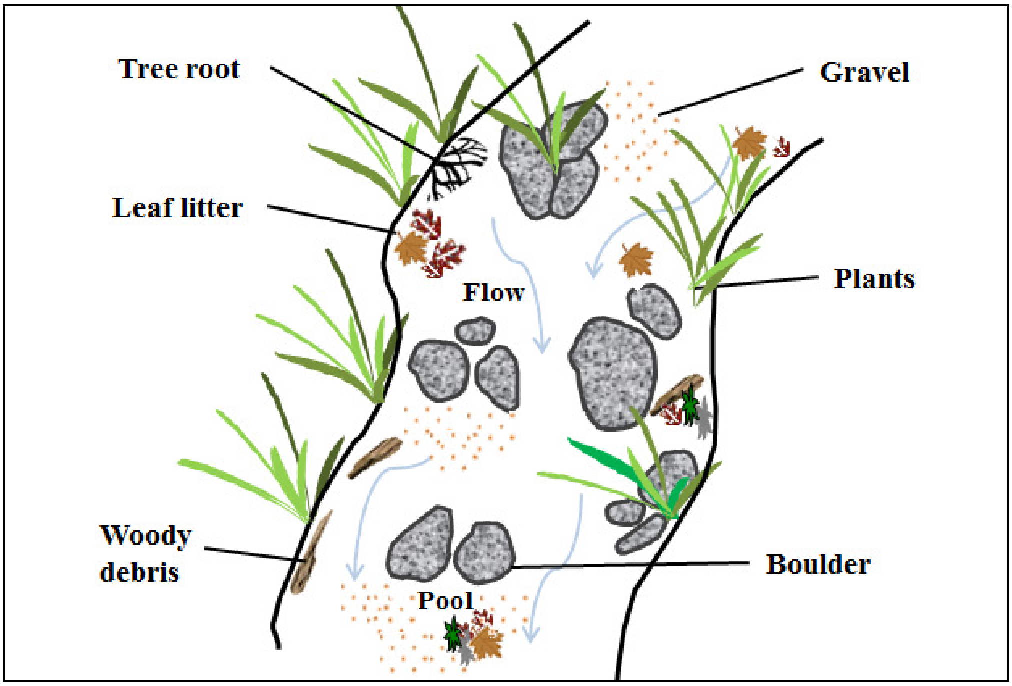

FIGURE 19 MICROHABITAT CREATION IN A STREAM

6.8 Shallow Ponds

In the Yuen Long Bypass Floodway Project, three shallow ponds within a 350m length of channel bed were created to form a freshwater ecosystem (see Figure 20). The water level of the shallow ponds is controlled by the operation of the inflatable dam and the pumping station by pumping water away from the floodway. The ponds play an important role in maintaining aquatic life and provide an essential habitat to fauna such as fish and water birds. A shallow pond provides bird landing and resting points during high tide, and also facilitates the establishment of emergent plants which can attract birds. For instance, post-EIA monitoring results showed that Zitting Cisticola (*Cisticola juncidis*) and Dusky Warbler (*Phylloscopus fuscatus*) had been recorded at Yuen Long Bypass Floodway with the provision of shallow ponds.

FIGURE 20 IN-CHANNEL SHALLOW POND AT YUEN LONG BYPASS FLOODWAY

6.9 Emerging Structures

Island structures with plantation in a channel can provide habitats for species and also standing points for bird species. Examples include the tree island in Lam Tsuen River (see Figure 21) and the artificial island in Ho Chung River (see Figure 22). However, construction of an island structure requires a relative large area and the main disadvantage of the island structure deployment is that it would inevitably change the hydraulic characteristics of the river channels. Therefore, not all channels are suitable for implementation of island structures. An island structure would require a relatively higher cost for deployment and the hydraulic effect need to be assessed prior to the deployment.

FIGURE 21 TREE ISLAND IN LAM TSUEN RIVER

FIGURE 22 ARTIFICIAL ISLAND IN HO CHUNG RIVER

Floating structure in the form of artificial floating raft (AFR), which is a vegetated floating platform, can support the growth of aquatic plant and thus create a habitat and offer shelter for birds, insects and other organisms (see Figure 23). It also provides spawning ground for fish and helps to purify water. Species of conservation concern including Little Grebe (*Tachybaptus ruficollis*) and Rose bitterling (*Rhodeus ocellatus*) had been reported to use AFRs in other countries, in particular the former utilize them as nesting sites (Nakamura and Muller, 2008). One of the advantages of using floating structure for enhancement measure is that it can provide the ecological function regardless of water level, i.e. wet or dry seasons. However, it should be noted that improper design of floating raft can result in short life span and high maintenance cost. Special attention should be paid to the choice of materials and the design of the anchorage.

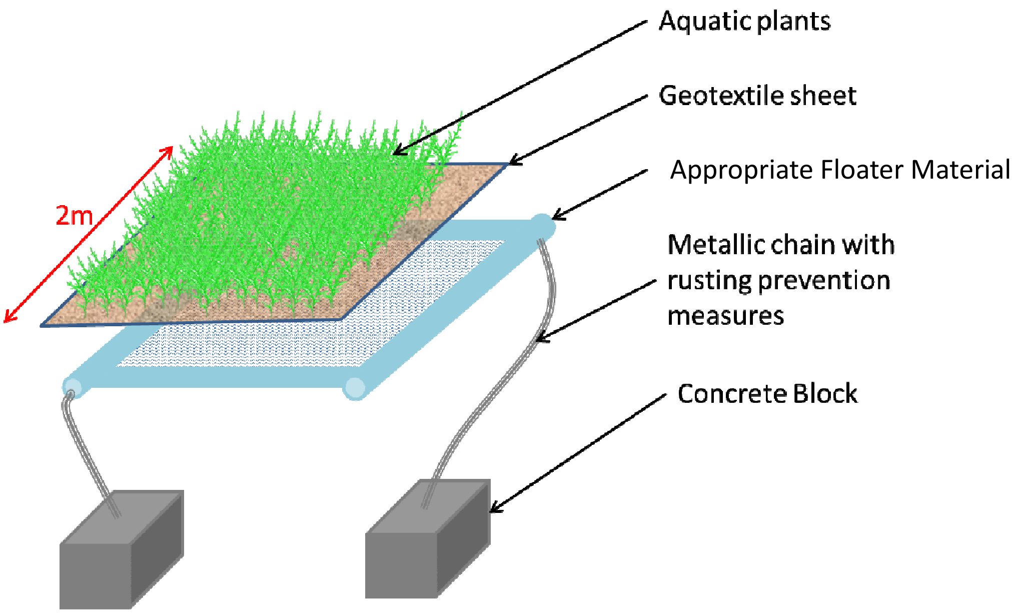

FIGURE 23 EMPLOYMENT OF FLOATING STRUCTURE

6.10 Silt Deposition

Deposition of sediment in channels (see Figure 24) is inevitable. From hydraulic viewpoint the sediment shall be completely removed to restore the channel flood conveyance capacity. From the ecological viewpoint, certain amount of silt deposition at the invert of the channel is beneficial to the ecosystem. The two considerations are conflicting to each other to certain extent.

FIGURE 24 SILT DEPOSITION PROVIDED HABITATS FOR MACROINVERTEBRATES AND ASSOCIATED WETLAND FAUNA AT NGAU TAM MEI CHANNEL (LEFT) AND FAVOURS RECOLONIZATION OF WETLAND VEGETATION AT NGONG PING RIVER

According to Section 9.3 of the Stormwater Drainage Manual (SDM), silt deposition has already been catered for newly designed channels by reducing the flow area. As a result, certain amount of siltation could be retained for ecological considerations during operations and maintenance. In particular, the frequency, timing and phasing of desilting operations in Ecologically Important Streams should be carefully considered in order to minimize the adverse impacts to aquatic communities. Based on the above requirements, increased operating and maintenance effort is expected.

The above consideration is only limited to locations where the flow is clean and unpolluted. In polluted environment the silt deposit will likely create odour and aesthetic problems and more frequent desilting might be necessary.

6.11 Geotextile Bags (Geobags)

Geotextile bags or geobags have been used in many parts of the world for bank stabilization. They are made from Polypropylene (PP) or Polyethylene ester fiber (PET) by ironing needle-punch non-woven fabric on both sides. They are non-degradable and resistant to corrosion and ultraviolet (UV), anti-aging and also non-toxic (Zheng et al., 2012). In Mainland China, a special type of geotextile ecological bag (or eco-bag) has been developed through filling the bags with a special type of fiber soil consisting of rich nutrient and organic matter. The bags are perforated and allow the growth of shallow root species such as grass, creepers and short shrubs through the surface. The fiber soil can retain moisture to support vegetation growth during dry season.

However, the system is not entirely self-sustaining and watering may still be needed to maintain vegetation growth during dry season. The compressibility of the filler soil has to be considered during the design stage to achieve a balance between providing room for vegetation growth while preventing slope failure. Furthermore, the nutrients and organic matter in the bags may be washed out and affect the water chemistry, such as pH, phosphate level, etc. This could affect the benthic fauna directly, or foster the excessive growth of algae at the river bed which in turn may affect the microhabitats therein. Therefore, the use of geotextile bags should be carefully planned.

Eco-bags are widely used in southern China for bank slope protection due to the convenient construction method, soil conservation and vegetation-friendly performance. For example, they are employed as bank revetment materials in the Stage IV Regulation of Shenzhen River. Due to lack of application experience, the ecological and re-vegetation performance of eco-bags are yet to be evaluated. A sample design of eco-bags is shown in Figure 25.

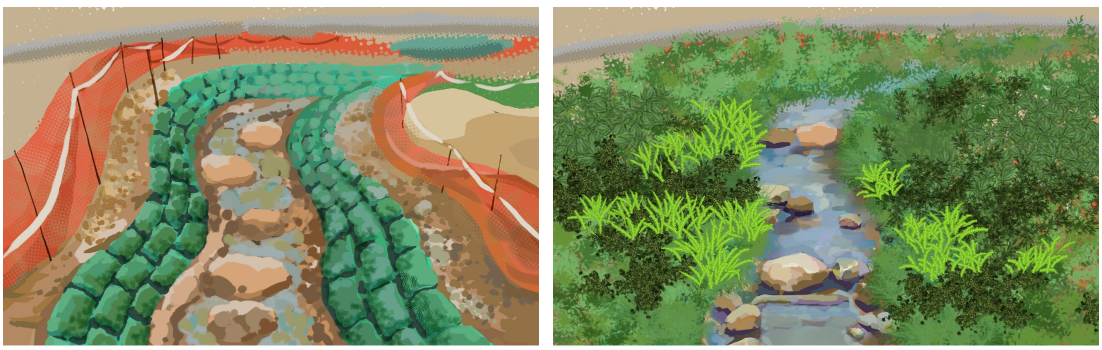

FIGURE 25 DESIGN OF GEOTEXTILE-BAGS BEFORE (LEFT) AND AFTER (RIGHT) CONSTRUCTION

6.12 Ground-sill

Arc-shape stone streambed sill can be installed in the channel bed to prevent the stream from eroding vertically and horizontally. The arc-shape stone can also stabilize the streambed and reduce flow velocity. After application of ground-sill technique, the velocity of stream water will be reduced to create a diversified water environment such as pool, shoal, and slack. The level of dissolved oxygen will also increase which benefits aquatic fauna. This technique is adopted in Taiwan and research found that the population of fish increased after the installation of arc-shaped stone (Wu and Fung, 2006).

6.13 Creation of Marshes and Planted Embayment

Marshes are utilised by a number of wetland - dependent bird species, for instance, egrets, buttonquails, rails and coots, and jacanas. They can be created or restored from original natural wetlands such as abandoned fish ponds. Hydrology is important in maintaining the plant community, and water level needs to be properly managed such that the emergent vegetation is inundated for appropriate length of time. Artificial habitat creation area was established along Yuen Long Bypass Floodway (see Figure 26).

FIGURE 26 ARTIFICIAL HABITAT CREATION AREA ALONG YUEN LONG BYPASS FLOODWAY

In certain cases where water level is low and riparian vegetation is limited (e.g. dry weather flow channel), planted embayment may be provided adjacent to the river channel to allow colonization of birds also. Bird species recorded prior to channelization may be obtained to facilitate selection of plant species that are known to be preferred by these bird species. Vegetation maintenance is needed to prevent domination of a few species and to control the spread of invasive species (Lau, 2004).

6.14 Riparian Vegetation

Naturally vegetated and undisturbed riparian buffers are important for aquatic habitat for the following reasons:

a) to mitigate the landscape and visual impacts along a river channel by providing green elements;
b) to mitigate ecological impacts by re-establishing the terrestrial and riparian habitats along and within the river channel;
c) to provide shading to maintain cool water;
d) to provide leaf litters as food source for the wildlife and aquatic organisms;
e) to stabilize stream bank to prevent erosion;
f) to filter nutrients and sediments to improve water quality;
g) to modify stream flow, create resting cover pools or retain gravel to improve fish habitats;
h) to provide off-channel refuge for invertebrates;

i) to provide nutrients to enrich aquatic system; and
j) to provide habitat for nesting, roosting, foraging and other terrestrial wildlife activity.

Therefore, unnecessary vegetation clearance should be avoided and native plant species should be preserved as much as possible. After river channelization, appropriate vegetation should be selected carefully for replanting the riparian zone (see Section 10). Proper control and maintenance of riparian vegetation is needed to balance between improving habitat, aesthetic and water quality, while at the same time minimize the impacts on flow resistance especially at flood sensitive areas and periods. In this regard, riparian vegetation may cause operational cost of channel maintenance to rise accordingly.

In case physical disturbance to the margins cannot be avoided, mitigation should be applied, usually in the form of the creation of new marginal habitats. Creation of margin habitats is shown in Figure 27. In general, margins should either be retained or created at least on one bank or at alternative sections between hard banks. The margin should be varied in height and profiles as well as width so that the diversity of the habitat can be ensured. Appropriate vegetation variability at the re-profiled margins can also provide benefits to the wildlife.

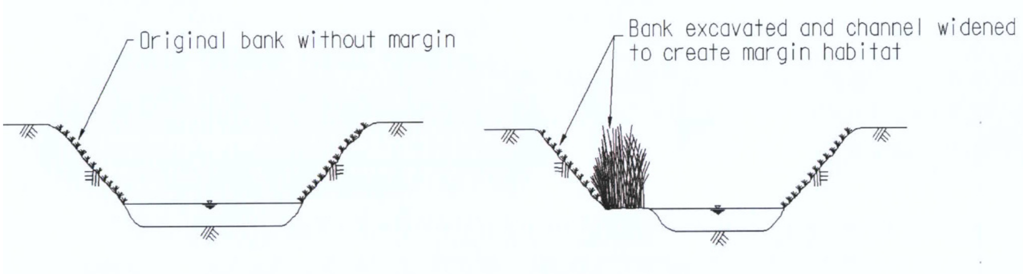

FIGURE 27 CREATION OF MARGIN HABITAT

6.15 Bends / Shelters

Bends or some man-made shelters such as local embayment can provide refuge for aquatic life during the passage of flood water. In-stream covers provide refuge for fish, protecting them from predators and adverse environmental conditions. They may be constructed from any suitable material (e.g. boulders, woody debris, riparian vegetation that overhangs the stream), and can be floating, emerged or submerged. They should be designed for low flow in the dry season to ensure continuous submersion of the sheltered area (Chan, 2001). The structure of fish shelter should be complex with many uneven surfaces, crevices and holes of different sizes to maximize areas available for hiding. Non-toxic, preferably natural materials such as logs and trees should be used (Illinois Environmental Protection Agency, 2004). It should be noted that logs and trees will decay over time and may generate maintenance issues. Therefore, the possible increase in O&M cost should be considered when deploying them for fish shelter. The in-stream refugia (which were recesses purposely designed for and built into concrete wall surface) within Ho Chung River might have served the function of providing shelters for invertebrates and aquatic animals during high flow and resting places for birds such as Little Egret (*Egretta garzetta*) during times of low flow.

Undercut banks are one way of creating a submerged in-stream cover (see Figure 28). It is most effective on the outside of meanders, or on the opposite end of a current deflector. An undercut bank should not be placed in areas with unstable bottom substrate, extreme flow or severe flooding. Stabilization can be achieved with reinforcing rods, rip-rap, vegetation and geotextile. The built structures need to be inspected regularly to ensure that it is not filled up with sediment and debris, or causing erosion problems (Fisheries and Oceans Canada, 2013).

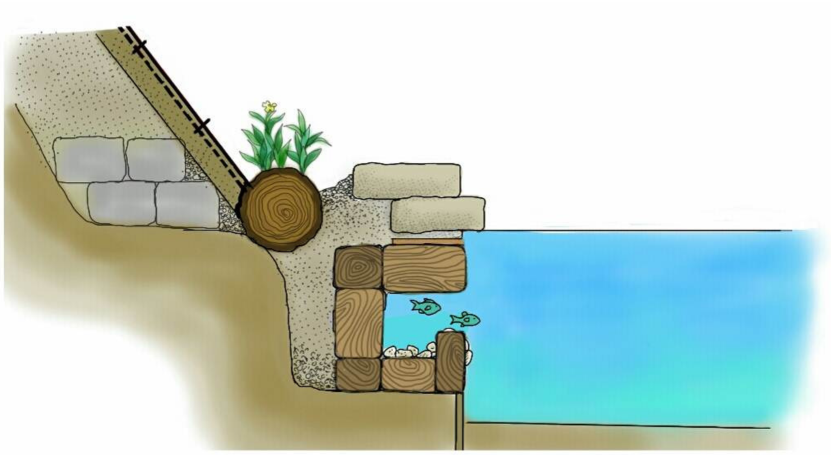

FIGURE 28 AN UNDERCUT BANK TO PROVIDE FISH SHELTER

6.16 Emerged or Submerged Plants

Emerged or submerged plants could provide microhabitats for aquatic fauna and birds. Aquatic vegetation has been shown to affect the life-history dynamic of aquatic macroinvertebrates (e.g. colonization, distribution, predation, food availability and trophic relationships). Temporal and spatial variation of aquatic macrophytes may therefore influence the aquatic macroinvertebrate abundance, diversity and biomass. Generally, plants with highly dissected leaves or high structural complexity provide greater substrate surface area and may support higher density of macrcoinvertebrate (Theel et al., 2008).

Considerations should be given to the location and ratio of different types of vegetation (emergent or submerged) as they would have an impact on flow resistance, sediment transport and flood discharge efficiency. A better understanding of physical processes determining flow resistances (e.g. roughness coefficients) in vegetated area (flexible, rigid or semi-flexible aquatic plants) would help to balance between engineering and ecological considerations (Xia and Nehal, 2013). A list of suitable emergent plant species to be provided in the channel is provided in Annex 8. Examples of submerged plants include Aubert's Blyxa 無尾水篩 (*Blyxa aubertii*) and Eel grass 苦草 (*Vallisneria natans*). Structures like plant holders can be used to secure aquatic plants and enable them to withstand water flow. The maintenance issues of emerged or submerged plants are further discussed in Annex 6.

7. COMPENSATION DESIGN MEASURES

7.1 Objectives

It is generally considered that ecosystems of natural streams and rivers are difficult to recreate. As such, compensating loss of riverine habitat due to river channelization through creation of a new river channel is very difficult. Therefore, the impacts on natural streams and rivers should be avoided and minimized as far as possible. Compensation approach should be applied on a like-for-like basis (e.g. re-creating fish ponds to compensate for the fish ponds lost or disturbed; and mangrove planting to compensate for mangroves removed during channelization works) and should only be applied when there is no other alternative. Some recent examples of applying the compensation approach in Hong Kong are:

a) Revitalization and enhancement of disturbed fish ponds have been carried out to compensate for the loss in fish ponds in the Shenzhen River Regulation project.

b) Wetland habitats created as compensatory measures for the fish ponds lost in the construction of the San Tin Eastern Main Drainage Channel and Yuen Long Bypass Floodway.

7.2 Revitalization and Enhancement of Disturbed Fish Ponds

Fishponds are considered crucial ecological habitats for avifauna and most of them are found in rural area of North New Territories of Hong Kong. Particularly, fishponds within the Wetland Conservation Area (WCA) as well as the ones within the Wetland Buffer Area (WBA) which form an integral part of the wetland ecosystem in the Deep Bay area have abundant ecological resources and high ecological value. River channelization may have a negative impact on these fishponds and the potential adverse impacts include permanent loss of habitat, temporary damage of habitat, increased fragmentation, disturbance to wildlife, dust pollution, and soil erosion. Therefore, it is recommended that any loss or disturbance of fish ponds associated with the river channelization should be compensated.

The primary goals of revitalization and enhancement of wetland fishponds are to maintain the population of the species of conservation importance to be greater than the baseline level and in the long run to be at the sustainable level in order to support more diverse flora and fauna.

Some measures for the revitalization and enhancement of disturbed fishponds are listed below:

a. Reconfiguration of the ponds

   Reconfiguration of fishponds can be achieved through creation of fewer and larger ponds. Ponds with increased size will be more attractive to waders and waterfowls as abundant evidences indicate that many wetland bird species prefer larger, less enclosed water bodies to small ponds.

b. Pond lining with natural clay/grass planting on geotextile

   Grass planting on geotextile lining can be used for the embankment and embankment toe of the pond. Clay lining will minimize the leakage of water to ensure sufficient water depth during the dry season. This will facilitate the growth of grasses, sedges and reeds which will in turn offer habitat for invertebrates (insects) and higher fauna (birds).

c. Provision of gentle slope

   It is found that the shallow edge of the ponds could provide greater seclusion with waterfowls and offer suitable habitats to invertebrates. The gentle slope in the ponds provides more shallow water areas along the edge of the ponds which are preferable for many wetland dependent birds. The profiling of enhanced ponds would create a suitable wetland and marsh habitat for both waterfowls and invertebrates (see Figure 29).

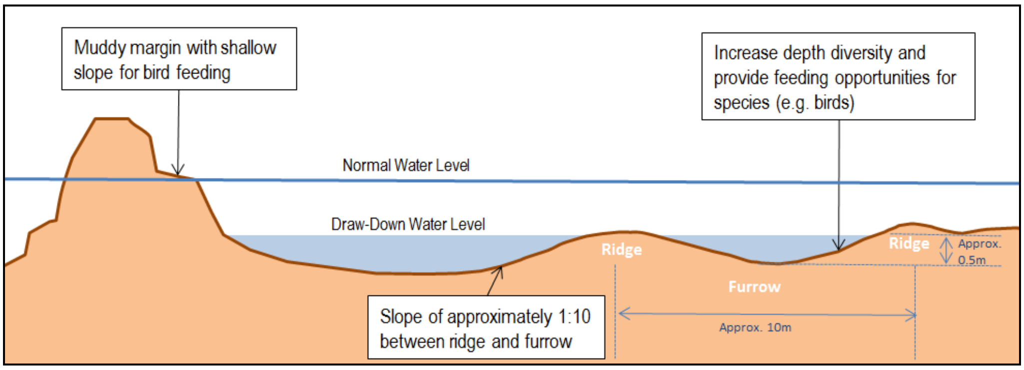

FIGURE 29 PROFILING OF FISH POND BUNDS

d. Vegetation planting

The vegetation planted on the bunds and embankment slope of the fishponds provides small insects and birds with feeding and sheltering habitats. In addition, the establishment of vegetation improves the naturalness of the site as well as offering a natural barrier for birds against predators and human disturbance.

e. Tree planting

The planting of trees along the bank would serve as a buffer between the disturbance source and the fishpond, which reduces interruption of birds feeding within the ponds. However, special attention should be paid to ensure the planting does not deter flight lines for birds or fragment of pond habitat.

7.3 Mangrove Planting

Mangrove is a unique intertidal habitat with a high primary productivity. They can be found in sheltered tropical and subtropical shores, which receive inputs from regular tidal flushing and from freshwater streams and rivers. Mangrove communities are made up of taxonomically diverse groups of plants and animals.

Mangrove plants have high ecological value. They not only supply food and feed for fisheries and aquaculture but also offer diverse habitats, breeding sites and feeding ground for a large variety of coastal species. Observations indicated that wetland dependent birds, including the endangered species Black-faced Spoonbill, would feed in the mangrove area of the rivers during their wintering in Hong Kong. Moreover, the mangroves near the intertidal mudflat area are often used as a vantage point for wetland birds, noticeable kingfishers, to search for and prey upon mudskippers and crabs on mudflat (Wong et al., 2009). In terms of engineering, mangroves facilitate protection of shorelines from erosion due to currents, waves and rain.

The primary goals of mangrove planting are to preserve and improve the ecological value of channelized river by providing mangroves as a corridor for wildlife and also as a natural barrier against human disturbance.

The following is the design parameters of mangrove planting:

a. Mangrove seedlings are recommended to be planted along the embankment toes on both sides of the river. Random rubbles deposited on the upper and lower section of the sloping embankment could further strengthen the stability of the river banks. This kind of feature will increase the habitat value by providing additional habitats.

b. There are 8 true mangrove species in Hong Kong. But only the mangrove species *Kandelia obovata* (秋茄樹/水筆仔), *Acanthus ilicifolius* (老鼠簕), and *Aegiceras corniculatum* (蠟燭果/桐花樹) are recommended to be used in mangrove planting (see Figure 30). This is because they are common in Hong Kong and they have been successfully implemented in the past for mangrove compensation.

FIGURE 30 MANGROVE SPECIES *ACANTHUS ILICIFOLIUS* (LEFT), *AEGICERAS CORNICULATUM* (MIDDLE) AND *KANDELIA OBOVATA* (RIGHT)

c. The proposed planting should preferably be carried out during the dry season when the river flow is low. Rapid flow in river during the wet season will have a high potential of inducing collapse of riverbanks and resulting in highly turbid water. However, the planting of species should also depend on the seedling season for the selected mangrove species.

The option of compensating impact on a natural stream through revitalization /enhancement of a degraded/channelized river can be further explored but it would be difficult to demonstrate that the compensation could be provided on a like-for-like basis.

8. DESIGN OF CHANNEL BED LINING

The channel bed is where fishes, macro-invertebrates and other aquatic organisms dwell. From the ecological point of view, the choice of channel bed lining should be as close to the natural condition as possible. The use of concrete will defeat such purpose and should be avoided wherever possible. There is a wide range of bed lining and materials that can be considered for use. The pros and cons of these are discussed in this section. A brief comparison on the construction cost, re-vegetation capability, ecological value, visual appearance, hydraulic performance and cost of maintenance is given in Table 2. The suitability and adoption of each type of lining may be governed by the particular reach of river channel involved, its ecological value, the flow characteristics, etc, and will involve a careful balance of these factors. It is therefore likely that the optimum choice may comprise different types of linings for different sections of a river channel.

TABLE 2 BRIEF COMPARISON OF DIFFERENT TYPES OF LINING

	Natural/ Unlined	Rip Rap	Gabion/ Mattress	Geotextile Reinforced Grass	Grassed Cellular Concrete	Rubble/Stone Embedded in Concrete / Mortar	Concrete
Ecological Value	Very Good	Fair	Fair	Good/ Moderate (depending on vegetation maintenance)	Moderate/ Bad (depending on vegetation maintenance)	Bad	Bad
Re-vegetation Capability	Good	Fair	Fair (if provided with planting pits or coupled with other bioengineering measures such as brush layer)	Good	Good (though mostly for exotic species)	Bad	Bad
Visual Appearance	Very Good	Moderate	Moderate	Good/ Moderate (depending on vegetation maintenance)	Moderate	Moderate	Bad
Hydraulic Performance	Poor	Poor	Moderate	Moderate	Moderate	Good	Good
Construction Cost	Very low	Low to Moderate	Moderate	Moderate	Moderate	High	High
Maintenance cost	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low

8.1 Natural / Unlined Bed

Natural or unlined bedding is the most preferred option with minimal impact on the environment. After excavation and trimming to the required level, the channel bed is left untouched or paved with original bed substrates to restore its natural condition. This option preserves the habitat of the eco-system and disturbance is only limited to that during the construction stage. Other benefits may include groundwater recharge and water quality enhancement. However, the hydraulic performance is poor compared to other types of engineered/lined channel bedding. The irregular surface of the natural bedding, or even with vegetation on top, would induce a high roughness on the channel. Another constraint on the use of this type of bedding is the erosion problem. The lining can only be applied in locations where the flow velocity and discharge volume are low or otherwise scouring problem would be severe.

The most common application of natural bedding is at the estuary or near the very downstream of the channel. The maintenance cost is increased if desilting is required. Figure 11 shows a good example of the natural earth bedding of Kam Tin River Channel during low tide. Other examples of river channels which retain the natural bed include Pak Ngan Heung River and downstream of Tong Fuk River. The unlined river channels may need regular control checks and provision of adequate bank protection.

8.2 Rip-rap Lining

Rip-rap lining is formed by layers of different-sized and different-shaped rocks or boulders. Sometimes rip-rap is underlain with a layer of filter fabric or granular materials. Beam structures may be provided at intervals to prevent washing down of rip-rap to downstream. Rocks/boulders in round shape should be used as far as practicable and those with angular shapes should be minimised. If the latter were used, the interstitial spaces between rocks/boulders would be too large for deposition of finer sediments, and the instream habitats will be unstable that could not provide stable refuges for re-colonization of stream fauna. Heterogeneous bottom includes sand and stones of different sizes are also encouraged. From past experience, the ecological performance of rip-rap lining is considered to be fair. The overall appearance is pleasant if the design is in close simulation of the condition of natural rivers. However, the appearance of rip-rap lining would be dreadful during dry season when it is fully exposed due to low water level (see Figure 31). To avoid the unpleasant appearance, the designer shall carefully design the size, shape and layout of the rocks/boulders by taking into account the lowest water level during dry season. The hydraulic performance is poor due to the irregular surface of the rocks or boulders which would induce a high roughness over the channel section. Similar to natural/unlined bedding, this method can only be applied in locations where the flow velocity and discharge volume are low.

 

FIGURE 31 RIP-RAP BEDDING IN KAU LUNG HANG. THE ORIGINAL DESIGN OF RIP-RAP BEDDING (LEFT) AND MODIFICATION OF THE RIP-RAP BEDDING IN THE CHANNEL DURING DRY SEASON (RIGHT)

Scouring is a problem to be dealt with for this type of lining. The size and distribution of the rocks need to be properly designed to withstand the flow velocity and any scouring forces. This will in general limit the application to the middle to downstream portion of the channel only. Another issue which may arise when replacing existing concrete channel bed with rip-rap lining is the possible draw down of existing ground water level.

As such, post-project arrangement includes setting up of action plan to ensure surface flow and adaptive management are necessary to ensure good performance of the rip-rap channel. Ngong Ping Stream is one such river channel which employs rip-rap bed with proper design and good post-project management. In Ping Yuen River and So Kwun Wat River, the performance of rip-rap in enhancing the ecological value is considered not ideal because it cannot retain sediment to provide suitable habitats for re-colonization of stream fauna. In view of its fair ecological performance and poor hydraulic performance, use of rip-rap lining is not recommended.

8.3 Gabion Basket / Mattress Lining

Gabion / mattress lining consists of wired gabion baskets filled with small to medium size rock or granular material, placed over the channel bed. This lining provides a moderate habitat for establishment of the aquatic communities. The hydraulic performance is moderate. The surface of gabion is irregular but the extent of irregularity is not as severe as rip-rap. The gabion bedding will be gradually covered by the gravels and silt which would accumulate over times. From past experience, it was found that the ecological value of gabion lining is fair only as it would bring down the water table.

Particular attention is to be paid for the design of the wires of the baskets as they are susceptible to corrosion. Furthermore, gabions are not suitable for areas subject to high scour action and flowing debris as the wires are prone to damage and will break. Besides unsightliness, damaged gabions require high maintenance efforts and costs in replacement. Rubbish trapped within the wires is also a potential management problem. Hence, gabion lining should be avoided in locations polluted or susceptible to pollution by rubbish, livestock waste, etc. Appropriate measures (e.g. adding semi-permeable or impermeable cut-offs) should be taken to prevent water flowing at the interface between the gabions and the natural soil which would lower the water table within channel and cause loss of riverine habitats.

8.4 Rubble / Stones Embedded in Concrete / Mortar

The rubble/stone embedded in concrete/mortar lining is indeed not much different from the concrete lining from the ecological viewpoint. The main advantage over concrete lining is that it can provide a slightly better appearance. This method provides a barren environment for the ecosystem and offers little opportunity for riparian vegetation and benthic organisms to survive and grow. It also imposes adverse impacts on the environment during construction. Hence, it is considered not to be the optimal solution from an ecological point of view although it offers good hydraulic performances. Yuen Long Nullah is an example of channel with concrete bed .

8.5 Grassed Cellular Concrete Paving

The channel bed is covered with interlocking hollow concrete panels/blocks that are filled with topsoil and grassed. It allows some degree of re-vegetation and provides a green appearance. However, the bedding cannot provide a good habitat for establishment of the ecosystem. Hydraulic performance is moderate and is better than that for natural bed and rip-rap. Adverse environmental effects may incur during the construction phase and precautionary measures should be employed (see Annex 4). Figure 32 shows the cellular concrete paving at the channel bed of Yuen Long Bypass Floodway under construction.

FIGURE 32 GRASSED CELLULAR CONCRETE PAVING AT YUEN LONG BYPASS FLOODWAY (DURING CONSTRUCTION)

9. DESIGN OF EMBANKMENT LINING

Similar to channel bed lining, the use of concrete lining for bank revetment is both ecologically and aesthetically undesirable and should be avoided, unless there are severe site constraints (land problem and/or stability issue): The different types of lining and revetment materials that can be used are the same as those described for the channel bed, except that these are applied at the two sides of a river channel.

9.1 Natural / Unlined Embankment

Natural or unlined embankment with vegetative treatment is an option with minimal impact on environment. This option preserves the riparian habitat. However, the hydraulic performance is lower than other types of engineered/lined channel embankment because the irregular shape and surface of the natural bank and the vegetation on the side slope would induce a high roughness over the channel sections. A wider channel may hence be needed to cater for the poor hydraulic performance which in turn imposes environmental impact to adjacent areas. This option is hence applicable to areas where land is available or the consequence of flooding to surrounding area is less significant. The major drawback of natural or unlined embankment is the erosion and settlement problems that may lead to slope failure or damage to the embankment, giving rise to an unsafe situation that may affect the public and nearby properties. The application of this option may not be appropriate for areas susceptible to scour action of high velocity flow or abrupt change in flow direction. More frequent inspections and maintenance efforts are required to prune excessive growth of vegetation and repair damaged bank (see Annex 6).

Soft bank revetment methods could be used to protect the natural or unlined embankment. For example, brush mattresses, coconut fiber roll, etc. More examples can be found in the Stream Corridor Restoration Handbook prepared by the Federal Interagency Stream Restoration Working Group (FISRWG) of the US government.

9.2 Rip-rap Embankment

Rip-rap embankment is flexible and will not be impaired by slight movement from future settlement or other adjustments. The gaps and spaces between the rocks or boulders, which are usually bigger than those in gabions, may provide habitats for aquatic organisms during high flow and establishment of riparian vegetation in a longer term. Using excavated soil material to cover the embankment toe would encourage the recolonization of native plants. It also provides the opportunity to reuse excavated rocks and soils and thereby reduce burden on landfill sites. The visual appearance is good with the usage of natural material. From past experience, the ecological value and re-vegetation capability are considered to be fair.

Besides, the hydraulic performance is low because the irregular surface of the rocks or boulders induces a high roughness over the channel section. Compared with gabion, rip-rap cannot be applied on steep side slope. So the land requirement for rip-rap is larger than that for gabion. Furthermore, as rubbish can be easily trapped in rip-rap lining and cause environmental nuisance, more frequent clearing work is required. The maintenance cost of rip-rap embankment is therefore moderate.

9.3 Gabion Wall / Mattress Lining

Gabion baskets can be used to form vertical river embankments by placing the baskets in single layer or multiple layers in steps, depending on the depth of the channel. Sloping embankments can be formed by gabion mattress which is laid at a flattened slope. Vertical gabion walls usually have a tilted slope of 6^o and a foundation mattress extending out to protect the toe of the wall from undermining. Planting pits may be provided in the gabion baskets to propagate vegetation growth, while branches or cuttings may be inserted through rocks in the cages for mattress lining (see Figure 33). However, it is more difficult for the establishment of riparian vegetation in vertical gabion walls compared with sloped mattress lining (see Figure 34). Tree can also be planted where space is available along gabion embankment. Similar to rip-rap lining, the reuse of excavated materials would help to reduce the need for offsite disposal. However, gabion embankment may not be suitable for areas subject to the scour action from high velocity flow or abrupt change in flow direction as the wires of the baskets are susceptible to corrosion and abrasion. Damaged gabions require high maintenance efforts in replacement as the baskets are usually laid in layers which are offset to increase their strength. Similar to that of gabion bed lining, it should be avoided in locations polluted or susceptible to pollution by rubbish, livestock waste, etc.

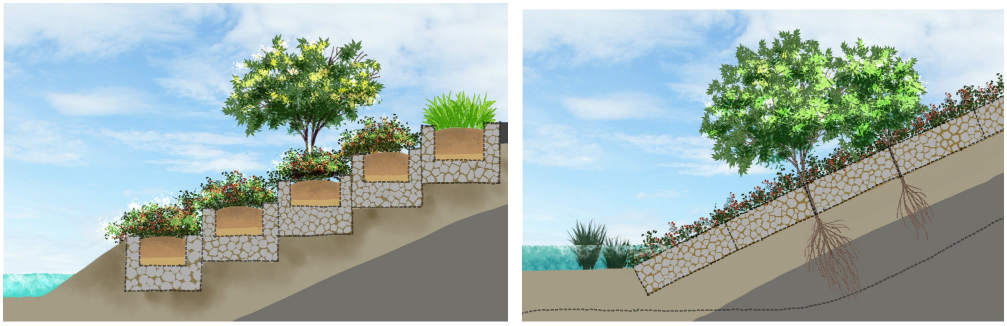

FIGURE 33 GABION BASKETS WITH PLANTING PITS (LEFT) AND VEGETATED GABION MATTRESS (RIGHT)

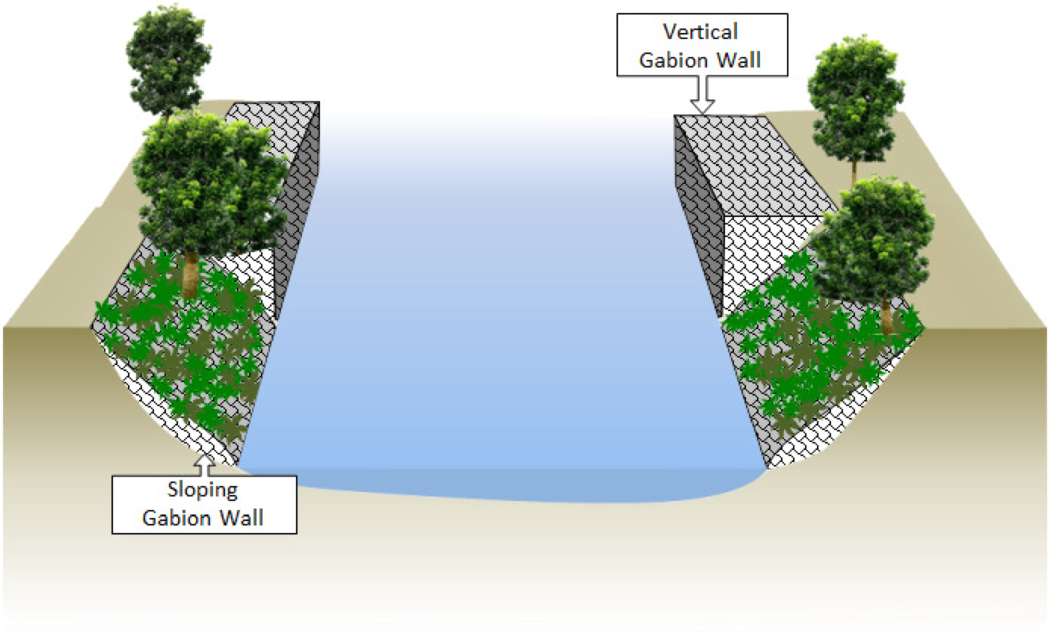

FIGURE 34 THE DIFFERENCE IN VEGETATION RE-COLONIZATION PERFORMANCE OF SLOPING GABION AND VERTICAL GABION

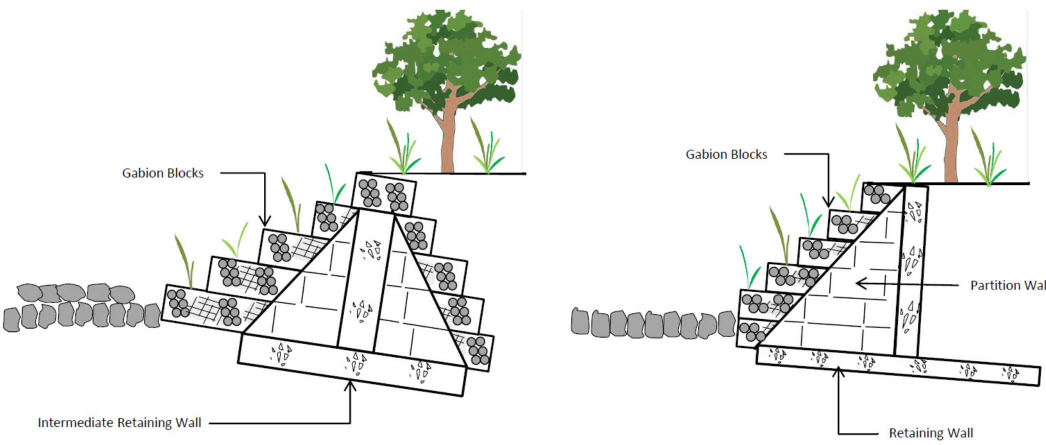

FIGURE 35 COMPOSITE STRUCTURE OF CONCRETE RETAINING WALL WITH GABION LINING

Where possible and applicable, the slope of gabion embankment should be gentle and the step height of multistage gabion should be low. As gabion would certainly affect the connectivity in particular to organisms of small size, it is found to be not optimal in ecological enhancement and it has poor re-vegetation capability. Raw gabion is even not recommended. The hydraulic performance of gabion is low because the irregular surface of the gabion baskets and the rocks filled inside the basket induces a high roughness over the channel sections. For deep drainage channel, it requires a great extent of land for the construction of the gabion due to its thickness. A composite structure of concrete retaining wall with gabion lining may be an option to minimize the land requirement (see Figure 35).

To improve the re-vegetation capability of gabion, proper structuring of the gabion baskets and combination of mattress lining with reused topsoil can be considered. It was proven to be effective at Ngong Ping Stream where vegetation can grow properly along the embankment. Proliferative vegetation growth from the gabion embankment was also observed at Pak Ngan Heung River (see Figure 36).

FIGURE 36 GABION EMBANKMENT AT A CHANNELIZED SECTION ALONG PAK NGAN HEUNG RIVER ORIGINALLY AFTER INSTALLATION (LEFT) AND AFTER TWO YEARS (RIGHT)

9.4 Geotextile Reinforced Grass Lining

Geotextile reinforced grass may be used as river embankment lining (see Figure 37). However, due to the presence of the geotextile woven fabric, it does not provide a good habitat for wildlife along the newly constructed river embankments. The ecological value could be improved with proper vegetation maintenance. The hydraulic performance is better than that for rip-rap and gabion because its surface is less irregular. The maintenance cost of reinforced grass embankment is high as regular cutting of grass is required and there are chances of damage to the embankment under very strong flow of flood water. Typical examples of such river embankments are found in the rehabilitation works at Ng Tung River (see Figure 38), Sheung Yue River and Kau Lung Hang Stream.

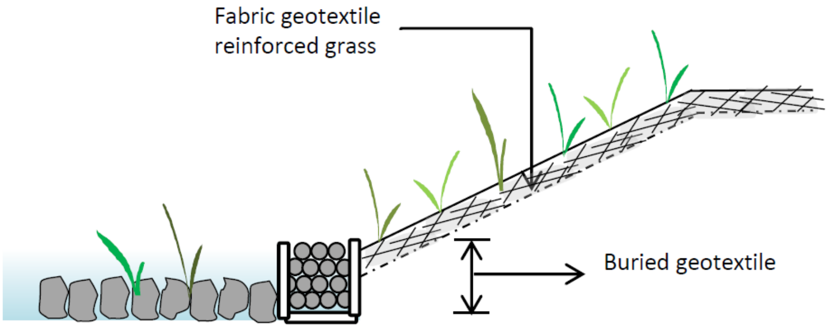

FIGURE 37 GEOTEXTILE REINFORCED GRASS EMBANKMENT

FIGURE 38 GEOTEXTILE REINFORCED GRASS EMBANKMENT AT NG TUNG RIVER

9.5 Grassed Cellular Concrete Paving

This method has been commonly adopted in the recent drainage channel projects. It allows some degree of re-vegetation and provides a green appearance (see Figure 39). The hydraulic performance is better than that for rip-rap and gabion because its surface is less irregular. However, the grassed cellular concrete paving would not provide a good habitat for establishment of the bankside ecosystem within a newly constructed river channel. If sufficient silting materials are left on the concrete surface, habitats may start to form. Maintenance cost on the grassed embankment is high because regular cutting of grass is required. Typical example of this type of embankment lining can be seen along Ma Wat River (see Figure 40). In Ping Yuen River, channels with reinforced concrete grids planted with vegetation only provide habitats for non-wetland dependent species such as avifauna.

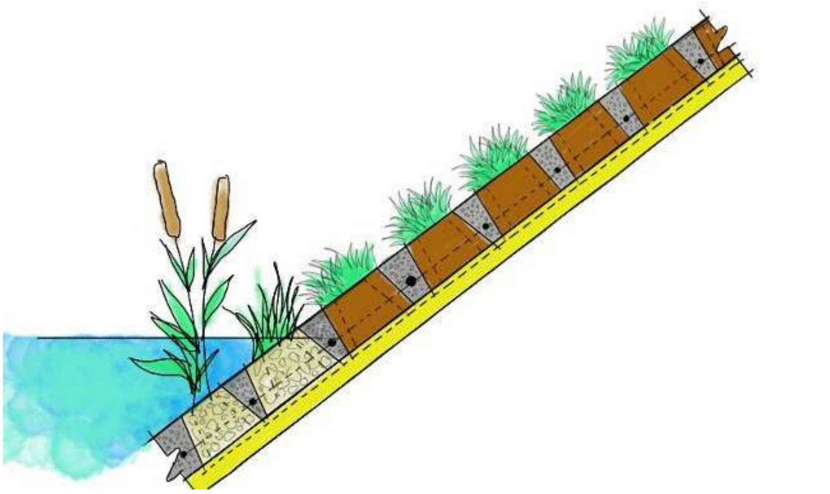

FIGURE 39 GRASSED CELLULAR CONCRETE PAVING AT EMBANKMENT

FIGURE 40 GRASSED CELLULAR CONCRETE PAVING AT MA WAT RIVER

10. PLANTING DESIGN FOR RIVER CHANNEL

10.1 Criteria for the Choice of Species

The use of planting to enhance the environmental and ecological conditions of a river channel requires comprehensive consideration of design objectives, microclimate, site constraints, soil conditions, initial cost, subsequent maintenance commitment and engineering constraints. Its success depends on the evaluation of substrate characteristics and the hydrology of river, followed by the proper selection of species. Information on natural variations in water table is needed to select appropriate species to be planted at different zones (see Section 10.2). Certain plant species could only be established at areas where the rate and extent of water table decline not exceeding the biological capacity of root growth; while at lower limits of the floodplain, only the plant species which can sustain the high water table could be established. Reference can be made to the ecological impact assessment where species recommended for compensatory planting can usually be found, whilst at the same time taking note of any identified insurmountable engineering constraints for the planting design. Coordination and consultation with ecologists and engineers to avoid conflict of the planting design with the wildlife and daily operation of the engineering works are highly recommended. Functional requirements of the planting should be clearly identified before plant species are proposed for the environmental enhancement. These functions may include stabilization of slopes on river banks to reduce runoff and enhancement of ecological linkage to surrounding natural habitat. The criteria for the choice of species therefore may include:

a. Colour, texture, habitat and form of plant materials

Depending on the design objectives and other relevant considerations, it may be necessary to introduce plant species with different foliage colour, texture, habitat and form so as to enrich the visual attractiveness of planting in riparian zone and for breaking up the monotonous linear nature of the embankment. The amenity value of the plant is therefore taken into consideration. In addition, the mature height and spread should be taken into account as they may affect the shading over channel and input of debris (for deciduous trees) and hence the physical environment which would in turn affect the riverine organisms.

b. Species with low maintenance requirement

In consideration of the scale of planting at the areas along the top of channels, its embankments and channel bed (where required and applicable), species with low maintenance requirements is preferred so as to minimize the maintenance cost.

c. Native species

Where possible, native species should be planted to provide food and shelters for local wildlife of riparian habitats, particularly for the cases where the planting objectives are mainly for ecological mitigation.

d. Compatibility with the surrounding

Species growing vigorously in the surrounding areas of the channel give a good indication that such species can establish well in similar microclimate and can therefore be considered for further use.

e. Tolerance to alternate wet and dry condition (for the species to be planted on toe zone and channel bed)

The depth of water inside the channel may vary considerably during the wet season (April to October) and dry season (November to March). In the wet season, the plant species may be submerged below water, however, in dry season, the channel bed may dry out and the plant species may be exposed to air and grow in a comparatively dry condition. Hence, the selected species should be tolerant of both wet and dry conditions and have ability to survive in such extreme conditions and regenerate in the next growing season.

f. Non-woody Plants (for species to be planted on toe zone and channel bed)

Periodic pruning is required for maintenance of vegetation. Non-woody species is preferred for ease of maintenance and pruning as they are easier to be pruned and will impede the flow of water to lesser extent during large flow as the vegetation will just collapse and spring back.

g. Tolerance of saline environment (for species to be planted in tidal zone)

For areas within tidal zone and areas subject to salt spray, species that can adapt to saline conditions should be considered.

h. Non-invasive root system species (for species to be planted on the channel bed, embankment and top of channel)

The scope and scale of planting works should be integrated in the design of the drainage channel so that the normal entitlement of soil to support plant growth will not be unnecessarily compromised. Root barriers or other suitable means can be proposed to minimize the effects of root action of some species. Alternatively, species with non-invasive root system should be used.

10.2 Planting at Channel Bed, Toe Zone and Embankment

Plants provided inside a drainage channel will obstruct water flow and will reduce the hydraulic efficiency of the channel. It is thus desirable to avoid large-scale planting at the channel bed and the portions of embankments below the design water level except where there are ecological needs. If planting is required at channel bed, toe zone or embankment, sufficient planting medium such as soil-mix should be provided so as to accommodate rootballs of the proposed plants in accordance with relevant clauses of the "General Specification for Civil Engineering Works". In addition, appropriate provision should be made to facilitate plant growth and to avoid the plant materials from being washed away during large flows.

The toe zone is the portion of the embankment that lies between the average high water level and the bottom of the channel. During the wet season, the water level will rise and the channel bed together with the toe zone will be flooded with water; however, in the dry season, the water level will drop and the channel bed with the exception of the dry weather flow channel and toe zone will experience dry condition. Hence, the proposed plants should be able to adapt to the alternate wet and dry conditions and have the ability to regenerate in the next growing season. Figure 41 shows some examples of plants commonly found in Hong Kong in channel bed or toe zone and a non-exhaustive list of suggested plants is given in Annex 8.


FIGURE 41 COIX LACRYMA-JOBI (LEFT), SAGITTARIA TRIFOLIA SUBSP. LEUCOPETALA (RIGHT) (SOURCE: HONG KONG HERBARIUM, AFCD)

The embankment is the area between the average high water level and top of the embankment. As this part is close to water table, the moisture content in soil is relatively high during the wet season. However, this zone is also affected by alternate wet and dry seasons. Figure 42 shows some examples of plants commonly found in Hong Kong at embankments and a non-exhaustive list of suggested plants is given in Annex 9.


FIGURE 42 MELASTOMA MALABATHRICUM IN YUEN LONG BYPASS FLOODWAY (LEFT), RHAPHIOLEPIS INDICA IN NGAU TAM MEI RIVER (RIGHT)

10.3 Planting along Channel Side

This area is situated above the embankment. If planting is required in the area along top of channel to mitigate the landscape and visual impacts of the drainage works, sufficient planting medium such as soil-mix should be provided so as to accommodate rootballs of the proposed plants in accordance with relevant clauses of the "General Specification for Civil Engineering Works". In addition, the base of planting areas should be provided with a free drainage layer of minimum 150mm in depth.

A linear strip with proper landscaping can become a recreational resource. It can also provide good opportunity for creating woodland for wildlife. Hence, avenue tree planting with feature/ornamental trees and/or woodland mix planting with native species can be proposed depending on the design objective. Figure 43 shows some examples of plants commonly found in Hong Kong by the rivers and a non-exhaustive list of suggested plants is given in Annex 10.


FIGURE 43 STERCULIA LANCEOLATA IN TONG FUK RIVER (LEFT), LIQUIDAMBAR FORMOSANA IN NGAU TAM MEI RIVER (RIGHT)

10.4 Quality Improvement of Riparian Vegetation

Riparian vegetation is an important part of channels which contributes to the overall ecological and landscape values. To improve the quality of riparian vegetation of disturbed channels, different planting methods can be adopted, including:

a. Natural re-vegetation

In disturbed riparian zones, vegetation can usually re-establish by itself provided that suitable environmental conditions are available. No effort and cost is required to initiate this natural re-vegetation process and the plant species naturally established are the ones well adapted to the particular environment. However, this process takes time. It may take decades before the natural re-vegetation process completes. Also, the success and speed of the natural re-vegetation process are dictated by the availability of seeds naturally dispersed to the site. The risk of natural colonization by invasive species, such as *Mikania micrantha* (薇甘菊), will also be a concern if this natural re-vegetation approach is adopted. Mikania is a perennial herbaceous vine which climbs up other plants to reach the canopy for better sunlight, and damage or kill other plants either by shading them with their proliferous growth of leaves and preventing light from reaching these plants to facilitate photosynthesis, or smothering them. Its efficient reproductive mode ensures that it spreads at an aggressive rate, and causes problem by reducing native riparian plant diversity, structure, and function. Details on its removal may refer to Annex 6.

b. Re-vegetation by soil translocation

To facilitate fast recovery of the riparian vegetation, soil in the riparian zone of the same channel or other nearby channels, which usually contains seeds, roots and rhizomes, can be translocated to the riparian zone of the disturbed channel. This process should be carefully designed and managed. The seeds, roots and rhizomes will often re-establish in the translocated sites. The cost of this method is relatively low. The sources of the vegetation (i.e. seeds, roots and rhizomes) are local and these plant species should be well adapted to the riparian environment. However, this method involves physical disturbance to other parts of the same channel or other channels which may induce impact on water quality and consequently aquatic fauna. Also, the soil translocation should ideally be undertaken in the growing season of the riparian vegetation to allow fast re-establishment. Nevertheless, the risk of translocating seeds, roots and rhizomes of invasive species, which will lead to establishment of invasive species in the recipient sites, can hardly be completely eliminated.

c. Re-vegetation by soil collection and transplantation

Instead of placing soil from nearby riparian zones directly to the riparian zone of the disturbed channel, the soil collected can be transferred to a nursery to allow the seeds, roots and rhizomes to germinate and grow. The vegetation can then be transplanted to the riparian zone of the disturbed channel to improve the riparian vegetation. The cost of this method is higher compared to the soil translocation method as a nursery is required. Similar to the soil translocation method, this method guarantees that the sources of vegetation are local, the plant species are well adapted to the riparian environment and physical disturbance to other parts of the same channel or other channels is involved. The benefits of using this method instead of the soil translocation method are that it displays an instinct effect after the transplantation of vegetation and allows the exclusion of invasive species by selectively transplanting only the non-invasive ones.

d. Re-vegetation by seed collection and transplantation

Rather than collecting soil (with seeds, roots and rhizomes) as local sources of vegetation, seeds can be collected from plants growing in the riparian zone of the same channel or nearby channels. Plants can then be grown in a nursery for subsequent transplantation to a disturbed channel. The cost is similar to the soil collection and transplantation method. This method guarantees that the sources of vegetation are local and the plant species are well adapted to the riparian environment, while physical disturbance to other parts of the same channel or other channels can be eliminated. Also, this method allows flexibility for species selection. Hence, selective planting of species with high ecological value (such as food plants of butterflies) is feasible.

e. Re-vegetation by seed translocation

When seeds are collected from plants growing in the riparian zone of the same channel or nearby channels, spreading them directly onto the disturbed section of a channel and allowing them to germinate naturally is another alternative. The cost of this method is low because no nursery is required. While this method shares the same benefits with the seed collection and transplantation method, the germination rate of the seeds could be low. Also, it takes time for the establishment of the plants from seeds and there will not be an immediate effect after seed translocation.

f. Re-vegetation by seed sowing

Other than "translocating" seeds from local sources, seeds can also be purchased from suppliers, especially when the species are absent from the nearby habitats but selected for vegetation improvement due to their landscape or ecological values. This method shares similar costs and benefits of the seed translocation method except that the sources of seeds could be from outside of Hong Kong when purchased from suppliers.

g. Re-vegetation by planting

The most direct method of riparian vegetation improvement is by planting selected species purchased from suppliers. The species to be planted are under total control and immediate effect results after planting. However, the cost is heavily dependent on the market prices of the selected species and the maintenance requirements during the initial establishment period. Sources of the plants could be from outside of Hong Kong. Moreover, the success of this method requires careful selection of species. Replanting with replacement species will be required if the initially selected species do not thrive.

Before determining which method, or combination of the above methods, should be adopted for riparian vegetation improvement works, the pros and cons of different methods should be carefully evaluated on a case by case basis. In addition, the following should also be considered when designing riparian vegetation improvement works:

- Ecological linkage of the riparian vegetation to adjacent habitats;
- Management requirements (such as regular pruning);
- Potential impacts (both direct and indirect, permanent and temporary) of the riparian vegetation improvement works on aquatic fauna and adjacent habitats; or
- Habitat heterogeneity along the channel.

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12. ANNEXES

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Mak Kau Lai

(K W MAK)
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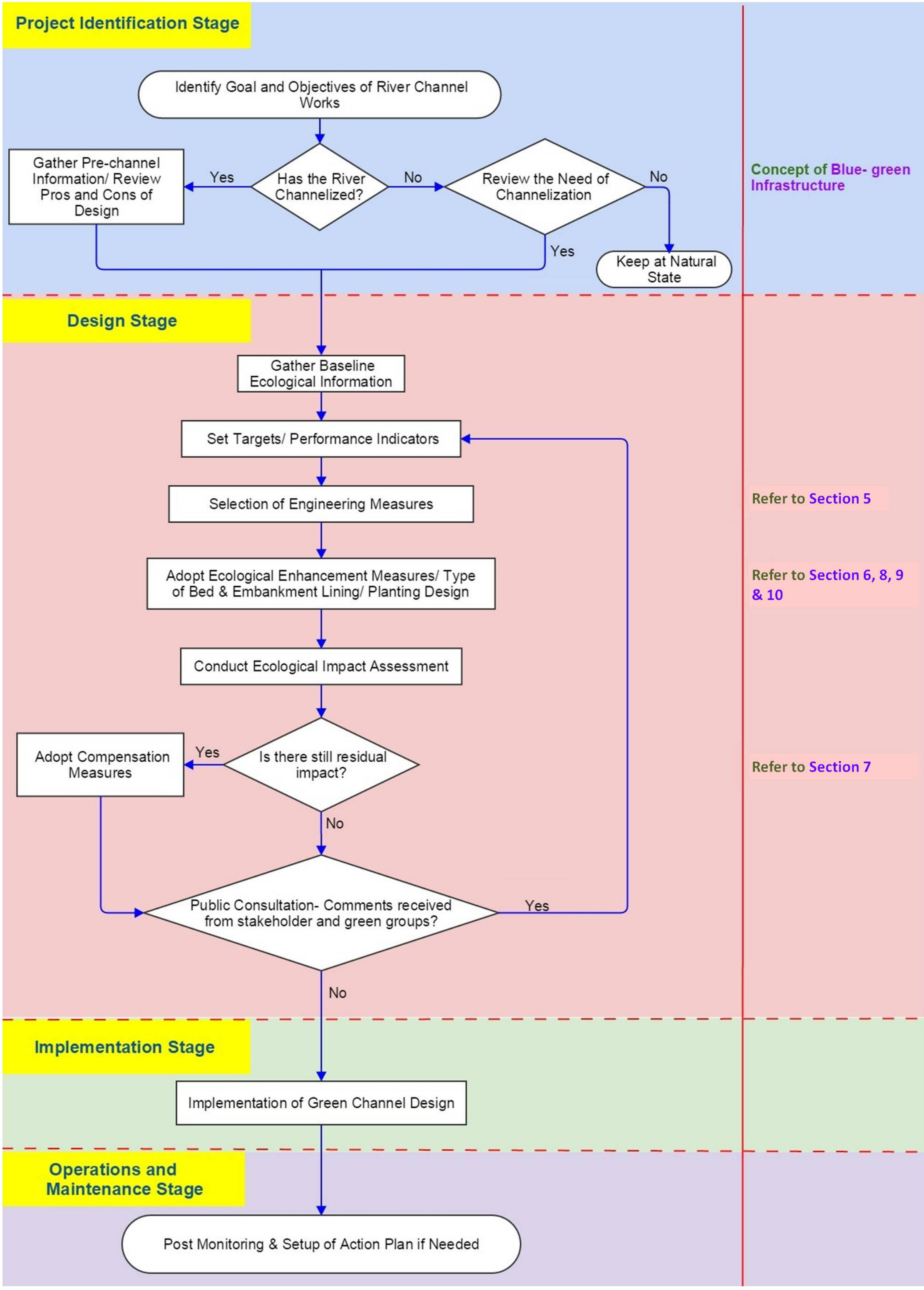
Annex 1 Flow Chart of Environmental Design of River Channel



Annex 2 Overseas Examples of River Revitalization

Introduction

The revitalization of water bodies in Hong Kong is in alignment with global best practice of other countries such as Australia, Singapore, and the United States.

Case studies are provided below as examples on how blue-green infrastructure and river revitalization principles may be successfully integrated into river channel projects. While both projects involve the restoration of river channels within urban areas, the first project is an example on revitalising the channel to provide enhanced urban landscape and water bodies, while the second example demonstrates the revitalization of the channel all the way back to a natural river state.

In addition to this practice note, the project proponent may seek to refer to researches, guidance materials and design tools published by organisations such as the CRC for Water Sensitive Cities (Australia), CIRIA (United Kingdom), the United States Environmental Protection Agency and other relevant institutes worldwide for further guidance on the application of blue-green infrastructure in river channel design, and on similar concepts such as 'green infrastructure', 'low impact development', and 'water sensitive urban design'.

Case Study 1: Cheong Gye Cheon, Seoul, Korea

Cheong Gye Cheon is a revitalization project located in the old central business district of Seoul. With over 600 years of history, Cheong Gye Cheon historically was an open stream that initially served as a water resource, stormwater drainage system, and then later as a sewerage system, before being undergrounded in the 1950-70s with the construction of an elevated freeway.

In the early 2000s, there was a movement to remove the eight kilometre long concrete roadway and restore the waterway in favour of creating a vibrant public recreation open space. This was in the interest of revitalising the area economically and improving the living environment of the area.

The main features of the revitalised Cheong Gye Cheon include:

- Restoration of six kilometres of watercourse and riverbed, providing flood protection for up to a 200 year flood event.
- Landscaping of close to six kilometres of corridor – Landscaping focused on providing a balance between urban ecology and public access. Northern side provides seating and

strolling areas for people. Southern side is designed for plants and wildlife.
- Small public squares, public art works and waterfront decks located at regular intervals along the river.
- Improved public transport and construction of 22 new bridges to improve multi-mode transportation movements across the river corridor.
- Construction of large sewers alongside the river to protect the revitalised channel from sewage discharge during storm events.

The beneficial outcomes of the project have included a measured increase in diversity of plant, bird, aquatic animal, insect and mammal species; reduction in urban heat island effect in the vicinity of the river corridor, and reduction in air pollution. Social and economic benefits include an increase in use of public transport, attraction of visitors and tourists, increased number of businesses in the area and increase in property values. Community engagement was a significant contributor to the success of this project.

However, one should also note that the lively water body in the river at Cheong Gye Cheon is maintained by continuously pumping water from the downstream section to the upstream section, which should not be considered as an environmentally friendly design.

Case Study 2: Kallang River at Bishan-Ang Mo Kio Park, Singapore

Kallang River is the longest river in Singapore and plays a crucial role in the country's water supply and drainage system. Three kilometres of the river is located within Bishan-Ang Mo Kio Park, which is one of the most popular parks in Singapore.

The revitalization of the Kallang River involved restoration of the concrete channel into a naturalised meandering river with bio-engineered riverbanks, using a variety of plants and natural materials. It was instigated as part of Singapore's Active, Beautiful, Clean Waters (ABC Waters) Programme launched in 2006 to transform the country's water bodies beyond their functions of drainage and water supply into beautiful and clean rivers and lakes with new spaces for community bonding and recreation. The project sought to increase the capacity of the river in parallel with redeveloping the areas so that the park, river and surrounding residential estates could be integrated as one. The transformation of the river and park led to the establishment of a new waterfront community and recreational spaces for the public.

The design of the river involves minimal hard landscape. The banks of the river are reinforced using various techniques of bio-engineering to stabilise the banks and prevent erosion. Examples include the use of stone filled wire mesh gabion basket, wood crib walls built from timber logs, and geotextile fastened with short wooden stakes. Selection of technique was dependant on the slope of the banks, the planting scheme, as well as the type and intensity of recreational activities next to it. Plants were designed to act as a retention system that slows down the water flow, and plant type were specifically selected for their capacity to act as a filter medium to maintain the water quality of the waterway without the use of chemicals. Playgrounds, bridges, stepping stones in the water and a riverside gallery were also built to encourage increased interaction with water.

Annex 3 Guides for Revitalization of Channelized Rivers

1 Goals and Objectives of Revitalization / Habitat Enhancement

The ecological impacts arising during river regulation works have been discussed in Section 3 of this PN. For any given project, determination of goals and objectives is critical in the project design, implementation, evaluation and management. For a channelized stream which has lost many of its ecological and riverine functions, the ultimate goal of revitalization works is to restore the integrity of the river ecosystem, by re-establishing river dynamics and connectivity functions with the adjacent flood plains, wetlands, riparian zone and farmland (Arlettaz et al., 2011).

Once the goal of the project is established, objectives which represent specific characteristics of the target river channel conditions that can be verified via monitoring and analysis are created. Objectives which correspond to the goals stated above include reinstating peak flows which connect channel and flood plain habitats; stabilizing baseflows to support food-webs in shallow water habitats; recreating seasonal temperature patterns; maximizing dam passage to allow recovery of fish population; and implementing a management system that relies upon a sustainable habitat which utilizes natural instead of artificial processes for revitalization and maintenance (Stanford et al., 1996).

2 Review of Pre-channelization Information

Pre-channelization information can be derived from various sources such as historical maps, boundary lines, aerial photography, surveys for bridge and pipeline crossings, gauging records, field evidence and archival sources. Aerial photography is of special importance as it can provide initial data on channel alignment, meander shape and size, adjacent land uses, vegetative cover, wetlands, bank erosion problems, sediment bars and other features. Information on biota composition and distribution can be gathered from aerial photography, resource inventories, environmental impact studies, habitat conservation plans, and records from non-government organizations. It should be noted that the historical information only provides a temporal context to interpret evaluation results as the river system is under continuous impact from other causes than the project works. As a result, long-term changes may not be observable over the relatively shorter time scale of the project design period. In addition, the historical analysis should cover an area large enough to identify all events (e.g. base-level lowering) possibly affecting the project reach (e.g. flow regime and sediment load) (Kondolf and Micheli, 1995). Where past information for channelized section is not available, reference may also be made to the environmental setting and biota of river stretches upstream and/or downstream to the channelized section. These areas would share certain similarity to the channelized river courses under study at their pre-channelized states. Streams of similar size or nature in the same district can also be examples to show the original outlook of the concerned watercourse.

3 Review of Existing Channel Condition

Initial assessment of the existing channel conditions is also needed, which include gathering and reviewing of existing data on fluvial geomorphology (referring to the shape, size, slope and patterns of river channels and their flood plains; geomorphic data requirements include channel width and depth, general alignment, bank conditions, size of bed material, type of profile, channel capacity and flood plain inundation, channel stability, streamflow data and flood frequency, depth to water table and groundwater interactions), mapping of watershed features, hydrology, flood plain, ecological resources and water quality, followed by a site visit to view the field conditions.

During the site visit, photographs should be taken to qualitatively document present conditions. Cross-section surveys along the channel surveyed with an automatic level or total station laser theodolite can be conducted to detect changes in channel form. To measure flow data and flood frequency, a staff gauge can be installed at a site upstream of the channelized section and periodic current meter measurements can be taken. Depth to water table can be monitored with shallow wells installed along monitoring transects, and water table elevations can be evaluated using simple electric well probes, analog strip-chart recorders or electronic data loggers.

For water quality, physical and chemical constituents such as temperature, pH, conductivity, turbidity, salinity levels, concentrations of dissolved oxygen, nitrogen, phosphorous, toxic chemicals such as herbicides and insecticides, pathogen including virus and bacteria, suspended and floating matters, odour and opacity may be measured. Water quality sampling stations should be located in relation to cross sections established for geomorphic and ecological monitoring. Sediments may also be monitored for particle size, nutrients and contaminant concentrations.

For ecological monitoring, there are two general approaches to evaluation of habitat: 1) looking at physical habitat features such as pools and riffles, naturalness of the stream and riparian habitat types; and 2) assessing species diversity in the project reach. For the first approach, field measurements of water depth, bed material, water velocity, temperature, vegetation cover and habitat types need to be recorded. For the second approach, species of concern including aquatic vegetation, invertebrates, fish and wetland associated fauna will be monitored. Project proponents may also refer to The Technical Memorandum on Environmental Impact Assessment Process under Section 16 of the EIAO for evaluating the impacts to ecological resources arising from a project.

4 Target Improvement / Performance Indicators

To judge whether the revitalization and ecological enhancement of a river channel is successful, evaluation standards and suitable indicators need to be provided. The choice of a specific indicator will depend on the focus of the evaluation criteria such as hydrology, chemistry, geomorphology, physical habitat and biology (e.g. floral coverage and fauna usage), especially wetland species of conservation importance. The criteria for selecting the species of conservation importance could be referred to Note 3 of Annex 16 of the Technical Memorandum under the Environmental Impact Assessment Ordinance (Cap. 499).

For example, in the Yuen Long Bypass Floodway habitat creation area, several target levels had been set for different groups of ecological attributes (including habitats, species, hydrology and water chemistry) in addition to monitoring the use by fauna. These target levels include but are not limited to:

a) percentage cover of plant species below wet season water level,
b) percentage cover of target plant species above wet season water level,
c) percentage of undesirable invasive species and exotic species,
d) percentage of planted or translocated plant species survival,
e) frequency of individual plant species,
f) cover of individual plant species,
g) formation and zonation,
h) presence of fish in shallow pools,
i) water quality indicators such as water levels, salinity, pH, BOD, dissolved oxygen, ammonia concentration, total oxidised nitrogen

concentration, total phosphate concentration and orthophosphate concentration etc.

(Black & Veatch Hong Kong Limited, 2003).

Other performance standards include percentage increase in species richness or population size of species of conservation concern which use the site after completion of works (Lau, 2004).

Where a target level is not reached for a parameter, the original design should be reviewed and necessary management measures should be implemented to improve the situation. At the same time, the management process needs to be adaptive; in particular during the establishment period and the target and/or target level may need to be adjusted as appropriate (Black & Veatch Hong Kong Limited, 2003). The effort, cost and complexity of the evaluation process should be balanced with project cost and societal concern, and should be simple and inexpensive whenever possible.

5 Post-enhancement Monitoring

Post project monitoring is important for evaluation of the effectiveness of the green channel designs. It should include water quality, flow measurement and ecological field survey. These monitoring should be twice a year for a minimum of two years after the project completion (Once in wet season and once in dry season). The subsequent monitoring frequency should be reviewed to suit the O&M needs. The cost of the post-enhancement monitoring should be either included in the works contract or in the maintenance term contract.

6 Establishment of Action Plan

Comprehensive and clear action plan is needed to guide project implementation and to achieve the established goals and objectives. It should integrate evaluation considerations into each phase of the revitalization/habitat enhancement works. It should also assess the funding requirements to support all components (including post-project evaluation). The relationships among project objectives, revitalization/habitat enhancement measures, evaluation success criteria, contingency measures, and evaluation techniques should be clearly defined. If the original project design fails to meet the objectives, contingency measures should also be proposed along with the planned revitalization/habitat enhancement measures.

7 Integration into the Smart City Concept

There are many new development areas being implemented by adopting the smart city design concept, whereas connectivity, walkability and low-carbon living are some vital elements.

Enhanced environment along the revitalized river banks could provide attractive green trails and cycle tracks to encourage low-carbon living. Co-use of the revitalized rivers as public recreation space and scenic area could increase the usable public area within the community. The revitalized water bodies could help mitigate urban heat island effect. Furthermore, by reconnecting people and the water bodies, a water friendly culture could be developed in time and people's respect for water as a valuable resource could be raised. All the above contribute towards the smart city concept.

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Annex 4 Construction Stage Precautionary Measures

There are a number of Ordinances applicable to construction works at natural streams/rivers. Besides making sure that the contractor complies with the statutory requirements, it is also critical to promote the environmental awareness and the use of environmentally friendly construction technology. References should be made to the specific guidelines on developing precautionary measures during the construction works on natural streams, as stipulated in ETWB TCW No. 5/2005. The recently published "Best Practice Guide for Environmental Protection on Construction Sites" by Hong Kong Construction Association provides a concise overview on the environmental protection measures during the construction phase. The sub-sections below summarize some key issues discussed in this guideline.

1 Project Planning

Environmental protection measures should be considered during each stage of the project, starting from the tendering and contract award stages. During the tender stage, the following environmental measures should be considered:

a. Tender document review and pay for environment;
b. Budgeting;
c. Programming;
d. Method statement preparation;
e. Preparation and review of sub-contractor tender documents; and
f. Selection of sub-contractor.

Upon award of the contract, the following should be conducted:

a. Site planning for environmental protection;
b. Set up performance targets on resources management for specific construction site;
c. Green purchasing policy;
d. Document Environmental Management Plan;
e. Immediate training needs; and
f. Notification and permit and licence applications to EPD.

During construction, the following should be undertaken:

a. Implement Environmental Management Plan;
b. Carry out impact monitoring;
c. Maintain public relations; and
d. Implement emergency response procedures.

The construction programme should allow constructing the channel in phases. For example, one side of the channel embankment would be constructed first in order for the habitats to be re-established before works start on the other side of the channel. Constructing the channel in phases can reduce the disturbance and allow re-establishment of habitat and species.

During construction, close monitoring is necessary. It is recommended to employ additional staff to ensure good environmental performance of the work. Site workers should be briefed about the Environmental Management Plan.

2 Pollution Control Measures

Various control measures for air, noise, water and waste pollution have been recommended by the Best Practice Guide for Environmental Protection on Construction Site from Hong Kong Construction Association.

For channel construction, specific attention should be paid on following items:

a. All wastewater should first be treated on-site for removal of suspended solid before discharging to the public drains;
b. The pH value of the wastewater should be monitored before discharge; and
c. Silt curtain should be employed to prevent silt runoff.

3 Protection of Ecological Resources

3.1 Tree Management

During construction, no trees should be cut down or pruned unnecessarily. Tree management should follow the considerations below in order of priority:

a. Retain trees at existing locations with protection;
b. Transplant affected tree to other permanent locations within the site (also taking into account the conservation and amenity of the trees, and their chances of survival after transplantation);
c. Transplant affected tree to permanent location off site; and
d. Only cut down tree when it is the last resort.

Good site practices for tree management include:

a. Set up temporary protective fencing along or beyond the perimeter of the tree protection zone (i.e. the zone encompassing the tree along its drip line projecting vertically from the tree canopy and extending 2 m below ground level and 2 m above the top of the tree) to protect preserved trees prior to construction works;
b. Avoid actions which might damage the trees including driving nails or other fixings into the trees, affixing signs or fencings to any part of the trees, using the trees as anchorages for any purposes;
c. Prohibit construction or construction related activities within the tree protection zone including wheel washing bay, stockpiling or storage of soil, materials, equipment, machinery, chemical or chemical waste, or installing site offices, workshops, canteens, containers etc., or allowing passage or parking of vehicles;
d. Drain excessive water away from the tree protection zones; and
e. Avoid removal of surface vegetation or top soil within tree protection zone.

3.2 Ecological Sensitive Receivers

Wild animals specified in Schedule 2 of the Wild Animals Protection Ordinance (Cap. 170) are protected by law. Activities which wilfully disturb the listed animals, including their nests or eggs, are prohibited. Another statutory protection in Hong Kong is the Forest and Countryside Ordinance (Cap. 96), which protects plant species.

In addition to the animals and plants listed under the two Ordinances, care should also be taken to avoid disturbance to other species of conservation importance found at the construction sites. These may be identified from international, regional or local inventories which assess the conservation status of species, such as the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species, China Species Red List, Hong Kong Biodiversity Database, Hong Kong Herbarium Database, and available relevant literature.

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Annex 5 List of Existing Guidelines on the Eco-Hydraulics Aspect of the River Channel Projects

BY / TCW NO.	TITLE	DATE
CEDD	Project Administration Handbook	Oct 2014
HKCA	Best Practice Guideline on Environmental Protection on Construction Sites	May 2013
PLAND	The Hong Kong Planning Standards and Guidelines	Aug 2011
PLAND	Study of Landscape Value Mapping of Hong Kong	Dec 2005
DSD	Aesthetic, Environmental and Ecological Consideration in the Design of Drainage Channels	Oct 2003
DSD PN No. 3/2003	Design Consideration for Open Channels Accommodating Supercritical Flows	Nov 2003
EPD, DSD, AFCD & CEDD (then TDD)	Examples of Environmentally Friendly Drainage Channel Designs Arising from Environmental Impact Assessments	May 1999
ETWB TCW No. 10/2013	Tree Preservation	Dec 2013
DEVB TCW No. 2/2012	Allocation of Spaces for Quality Greening on Roads	Apr 2012
ETWB TCW No. 5/2005	Protection of Natural Streams/Rivers from Adverse Impacts Arising from Construction Works	Mar 2005
ETWB TCW No. 36/2004	The Advisory Committee on the Appearance of Bridges and Associated Structures (ACABAS)	Dec 2004
ETWB TCW No. 29/2004	Registration of Old and Valuable Trees, and Guidelines for their Preservation	Sep 2004
ETWB TCW No. 14/2004	Maintenance of Stormwater Drainage Systems and Natural Watercourses	Jun 2004
ETWB TCW No. 11/2004	Cyber Manual for Greening	Jun 2004
ETWB TCW No. 2/2004	Maintenance of Vegetation and Hard Landscape Features	Mar 2004
ETWB TCW No. 34/2003	Community Involvement in Greening Works	Dec 2003
WBTC No. 4/1997	Guidelines for Implementing the Policy on Off-site Ecological Mitigation Measures	Feb 1997

Annex 6 Long-term Management Measures

1 Control of River Channel Aggradation and Erosion

Measures to mitigate river channel aggradation and erosion include implementation of sediment control (e.g. using riparian vegetation to entrap the sediment), restriction of building structures on the floodplains, prohibition of piping and infilling of streams, development of guidelines for urban developments (e.g. stormwater management through identification of stormwater sources, minimization of discharge into the river, and road improvements), minimization of impervious cover through low impact designs options, stabilization of eroding banks with vegetation or bioengineering measures, removal of artificial stream bank and bed armouring/linings where practicable, and minimization of the adverse effect of urbanization on stream hydrology without compromising other stream functions (Auckland Regional Council, 2004; Iowa Department of Natural Resources, 2006).

2 Vegetation/ Channel Bed Maintenance

Vegetation maintenance regimes need to be tailored to suit the hydrogeological conditions of different streams. For areas prone to flood risk and channels which were originally designed without taking into account future vegetation conditions, stricter maintenance (mowing) of floodplain vegetation may be required. Measures need to be taken to control vegetation height and type of vegetation. Other factors which should be taken into consideration during vegetation maintenance include spatial complexity and temporal variability of the plant communities. Spatial complexity may refer to vertical stratification, rhizosphere, the ratio of vegetation spacing to vegetation diameter (greater spacing may reduce flow resistance), and the extent of riparian zone in proportion to sediment bed. For example, where banks and floodplains form a small portion of the wetted perimeter around the stream, they would have no to low impact on flood risk, and the maintenance regime can be relaxed to save cost and allow the development of a more natural assemblage of riparian vegetation (Darby, 1999).

Strategic maintenance of emergent vegetation may allow them to act as point bars to alter stream flow direction and create meandering conditions within a straight channel, thus restoring the functionality of stream corridors (Bennett et al., 2002). To achieve this purpose, it requires input from channel engineers to model the stream flow under different vegetation regimes.

Periodic inspection or assessment of vegetation conditions should be conducted to judge if maintenance of vegetation is necessary. Instead of conducting vegetation maintenance across the whole channel within a short period, it may be conducted at different sections at different times to ensure that sufficient riparian habitat is retained for wetland dependent fauna. The vegetation in Tong Fuk and Pui O, which are maintained by Home Affairs Department are good examples of vegetation at embankment. A study from WWF shows that freshwater pond bund and bankside habitats can be enhanced to attract more bird roosting through the implementation of a more frequent vegetation cutting regime in the preceding months before wintering birds arrive (WWF, 2006).

Channel bed degradation may occur as a result of natural processes such as geologic uplift, increased runoff and increase in watershed and bank vegetation which reduces the natural supply of sediment (Milone & MacBroom Inc., 2007). Natural grade control such as falls or cascades through placement of boulder clusters, and check dams can be used to stop the upstream movement of a head cut and reduce upstream channel degradation. However the placement of these grade control structures should be well designed to avoid trapping of sediments, flow deflection, and imposing barriers to fish passage. Accumulation of some mud or silt can improve the ecological performance in the channel. However, a fine balance is needed to avoid too much accumulation of mud or silt.

3 Weed Control/ Invasive Species Control

It is highly encouraged to start the weed control planning before project commencement. Habitat environment which is not favourable for the colonization of invasive species could be designed by riparian planting at channel embankments to provide shading which suppress the growth for Mikania. During operation, active management and continuous monitoring are required to minimise the chance of invasive species colonising the newly formed or established channel.

Domination of plant composition by a few species should be avoided. To control the invasion of Mikania, the whole plant should be ripped out by roots as far as practicable and properly disposed off-site to minimise the chance of its regeneration. For those which hang on trees, the aerial part can be cleared up to about 3 meters from the ground, while the rest will wither and die off naturally. Weeding has to be avoided during the blossoming and fruiting periods (June to December), as such action may aid the dispersal of the seeds. However, it should be noted that manual removal of underground parts of Mikania is labour intensive and hence this is not considered as cost-effective method (Wong, 2005). Where large-scale eradication of Mikania and other invasive weeds is deemed impossible, substitute strategies need to be considered such as containment of large patches to prevent their further expansion, or creation of corridors of alternate vegetation to promote the colonization of alternate vascular flora and mosses (Hartwig and Kiviat, 2009). Hydroseeding or planting tree saplings with topsoil should be done immediately after the creation of openings to allow establishment of native species and avoid colonization by exotic species. Since the growth of Mikania is retarded in shaded environment, it is suggested to plant trees and shrubs to prevent its proliferation, as the plantings can compete with Mikania for sunlight, space, water and nutrients. The planting programme needs to be supported with continuous maintenance (e.g. weeding and protection of seedlings with tree guards) until the target vegetation are successfully established (Wong, 2005). Landscape contractors, skilled landscape workers or gardeners could be appointed to clear Mikania where necessary.

The Golden Apple Snail (*Pomacea canaliculata*) is another invasive species common in most streams and newly formed channels. Apple snail would impact the biomass and diversity of macrophytes in Hong Kong wetlands as macrophytes are their major dietary component. It also has huge appetites and high feeding rate. There have been reports of predation by apple snail on freshwater bryozoans, adults and egg capsules of several species of pulmonates, as well as juveniles of *Melanoides tuberculata* and *Sinotaia quadrata* (Kwong et al., 2010). Control measures for the Apple Snail include chemical, physical and biological methods which involve pesticides, handpicking of snails and egg clutches, and indigenous predators to get rid of the species respectively (Cowie, 2002). Each method has its pros and cons. For example, pesticides are costly and may impose environmental and human health risk. Physical removal is useful but labour intensive and require recurrent efforts. The contractor hired to do pest control may also trample the plants.

When chemical method is engaged, only approved equipment and chemicals should be used; and only trained personnel (e.g. registered to the Authority under the Pesticide Ordinance if applicable) should be assigned to carry out the task. Biological method is environmental friendly, but precaution has to be exercised as the predators may affect non-target species. The use of other exotic species to control apple snail should be avoided. Whichever method is applied, eradication of apple snails needs to be supplemented by re-introduction of native herbivorous snails to control the excessive growth of filamentous algae. More details of invasive species can be found in the Global Invasive Species Database. Where re-introduction or translocation of any living organism is considered necessary, reference should be made to the guidelines and case studies published by the Re-introduction Specialist Group under Species Survival Commission of the IUCN.

Other notable introduced species which have become widespread in Hong Kong and posed ecological problems to the aquatic systems include Popianc (*Leucaena leucocephala*) and Gairo Morning Glory (*Ipomoea cairica*). The best way to reduce the probability of an introduced species from being established to the newly formed environment is to eliminate it before it has time to proliferate and become abundant, and evolve adaptations that would allow the species to out-compete the native species (Allendort and Lindquist, 2003). Therefore, close monitoring of the streams after stream improvement works is required to minimize the chances for establishment of invasive species. The monitoring frequency is subject to adjustment until the native species are confirmed to have been fully established in the post-construction ecosystem.

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Annex 7 Measures which can be Taken to Improve Selected Physical, Chemical and Biological Parameters within the River Channel (site specific; to be reviewed during detailed design)

Physical and Chemical Factors of Importance to Biota		
Criteria		Measures
(a) Water quality	(i) pH	Identify source(s) of pollution (e.g. industrial and municipal wastewater, stormwater) and implement controls on their discharge into the river (e.g. through installation of bioswales, bioretention basins, sedimentation basins). Retention of vegetated riparian zone.
	(ii) DO (%)	Creation of pools and riffles and use of high-head flow systems, weirs and cascades to increase aeration
		Preservation and planting of riparian vegetation to lower the surface water temperature and increase the solubility of oxygen in water correspondingly
	(iii) NH3-N	Identify source(s) of pollution (e.g. industrial and municipal wastewater, stormwater) and implement controls on their discharge into the river
		Retention and recreation of river margins; construct artificial wetlands and cleansing biotopes to remove colloidal particles and dissolved organic matter. Retention of vegetated riparian zone.
(b) Instream habitat	Substrate	Increasing channel complexity through the creation of pools and riffles at riverbed, and use rubble and cellular concrete grassing slabs to replace concrete lining. Cellular grassing slabs should be avoided.
		Preservation or reinstatement of bed substrate
(c) Embankment profile	Embankment profile of the channel	Provision of gentle slope for planting
		Provision of animal passage at embankment

Biological Factors	
Criteria	Measures
(a) Species richness	Provide more natural habitats for species through creation of sinuosity, preservation and enhancement of cut-off meanders, and use of natural materials to stabilize banks
	Provision of engineered wetlands, fish ponds and in-channel shallow pond
	Provision of animal corridor (landscape provisions that allow corridors for animal movement)
	Riparian vegetation to provide food and habitat for different species
	See (b), (c) and (d) below
(b) Species of conservation concern	Reintroduction of species by translocation from other streams in the same catchment
(c) Freshwater/estuarine fish species	Provision of fish passage, fish shelter and in-channel shallow pond
(d) Aquatic invertebrates	Increase channel complexity
	Creation of microhabitats
	Provision of fish passage, fish shelter and in-channel shallow pond
	Preservation and reuse of natural bed substrates
(e) Riparian habitat conditions	Switch to channel designs such as distant flood banks and relief (or by-pass) channels
	Employ bedding which allow vegetation growth (e.g. natural, geo-textile, reuse of topsoil and riparian vegetation from existing channel)
	Increase ecological linkage and connectivity
(f) Riparian vegetation at water margin & channel embankment	Preservation of natural vegetation
	Planting of native riparian vegetation
	Provision of emergent and submerged plants at channel bed and toe zone. Avoid any concrete toe.

Annex 8 A Non-exhaustive List of Native Species Suitable for Planting at Channel Bed or Toe Zone

a. Wetland Plants

Scientific Name	Chinese Name	Growth Habit	Natural Habitat
Acorus gramineus	金錢蒲	Perennial Herb	Streamside
Alopecurus aequalis	看麥娘	Herb	Banks of ditches, rice fields, farmlands
Bacopa monnieri	假馬齒莧	Herb	Wet places
Callipteris esculenta	菜蕨	Herb	Open marshy areas, stream banks
Cleistocalyx nervosum	水翁	Tree	Places near water
Coix lacryma-jobi+	薏苡	Herb	Wet places by streams, ditches and open fields
Colocasia esculenta	芋	Herb	Wet fields, near banks of ponds and streams
Commelina diffusa	節節草	Herb	Margins of forests, streamsides and other moist places
Cyperus distans	疏穗莎草	Herb	Paddy fields and other wet places
Cyperus haspan	畦畔莎草	Herb	Wet places and paddy fields
Cyperus iria	碎米莎草	Herb	Wet places and paddy fields
Cyperus malaccensis	茳芏	Herb	Ditches and muddy places near estuary
Cyperus malaccensis var. brevifolius	短葉茳芏	Herb	Wet places near streams
Cyperus pilosus	毛軸莎草	Herb	Marshes, paddy fields and other wet places
Cyperus polystachyos	多枝扁莎	Herb	Streamsides and other wet places
Drymaria cordata	荷蓮豆	Herb	Margins of forests, streamsides and other damp shaded places
Eclipta prostrata	鱧腸	Perennial Herb	Streamsides, banks of paddy fields, roadsides and other wet places
Eleocharis geniculata+	黑籽荸薺	Herb	Brackish marshes
Eleocharis ochrostachys+	假荸薺	Herb	Marshes, paddy fields and lakes
Equisetum debile	筆管草	Herb	Besides streams, still water bodies, swamps
Eriocaulon sexangulare	華南穀精草	Herb	Paddy fields and other moist situations
Fimbristylis dichotoma	兩歧飄拂草	Herb	Open grassy fields
Fimbristylis subbispicata	雙穗飄拂草	Herb	Hillslopes, ravines along streams, marshes
Floscopa scandens	聚花草	Herb	Forests, wet places in ravines
Hygrophila salicifolia	水蓑衣	Biennial Herb	Streamsides and other wet places

Scientific Name	Chinese Name	Growth Habit	Natural Habitat
Impatiens chinensis+	華鳳仙	Herb	Wet places near ponds, ditches and paddy fields
Isachne globosa	柳葉箬	Perennial Herb	Moist places of grasslands, path between paddy fields
Juncus effusus+	燈心草	Herb	Wet places
Leersia hexandra+	李氏禾	Perennial Herb	Marshlands, stream banks, shallow water
Limnophila aromatica	紫蘇草	Herb	Wet places
Lindernia anagallis	長蒴母草	Herb	Margins of forests, streamsides, wet places
Lobelia chinensis	半邊蓮	Perennial Herb	Lower banks of paddy fields and other wet places
Ludwigia adscendens	水龍	Perennial Herb	Margin of ponds
Ludwigia hyssopifolia	草龍	Perennial Herb	Ditches, marhses and other damp to wet places
Marsilea quadrifolia	田字草	Aquatic herb	Shallow pools, edge of rivers, canals and ditches, rice fields
Oenanthe javanica+	水芹	Perennial Herb	Borders of rice fields, ditches and other wet places
Panicum repens *	鋪地黍	Perennial Herb	Streamsides, paddy fields and other moist places
Paspalum distichum	雙穗雀稗	Perennial Herb	Farmlands, grassy fields, roadsides, ditches and other disturbed places
Paspalum longifolium	長葉雀稗	Perennial Herb	Hillslopes, grassy fields, swampy places
Pentasachme caudatum	石蘿藦	Perennial Herb	Streamsides
Philydrum lanuginosum+	田蔥	Perennial Herb	Freshwater ponds and marshes at low altitude
Polygonum barbatum+	毛蓼	Herb	Ditches and other wet places, swamps
Polygonum dichotomum+	二歧蓼	Herb	Ditches and wet places
Ranunculus sceleratus	石龍芮	Herb	Wet places, near ponds and ditches and paddy fields
Rotala rotundifolia	圓葉節節菜	Herb	Paddy fields and wet places
Rumex trisetifer	長刺酸模	Herb	Field margins, moist valleys, watersides
Sacciolepis indica	囊穎草	Herb	Margins of paddy fields and other moist places
Sagittaria trifolia sub sp. leucopetala	慈姑	Herb	Ponds, paddy fields and marshes
Schoenoplectus subulatus	鑽苞水蔥	Herb	Brackish marshes
Sphaerocaryum malaccense	稗藎	Herb	Watersides and other damp places
Xyris pauciflora+	蔥草	Herb	Ravines, damp sandy soils, swamps

b. Planting in Areas Affected by Brackish Water

Scientific Name	Chinese Name	Growth Habit	Natural Habitat
Acanthus ilicifolius	老鼠簕	Shrub	Mangrove swamps
Acrostichum aureum	鹵蕨	Herb	Mangroves, freshwater environments, salt marshes
Crinum asiaticum var. sinicum	文殊蘭	Herb	Sandy places near seaside and river banks
Cyperus malaccensis	茳芏	Herb	Ditches and muddy places near estuary
Cyperus malaccensis var. brevifolius	短葉茳芏	Herb	Wet places near streams
Fimbristylis dichotoma	兩歧飄拂草	Herb	Open grassy fields
Fimbristylis sieboldii	銹鱗飄拂草	Herb	Margins of ponds and wet places
Paspalum vaginatum	海雀稗	Perennial Herb	Sandy seashores, margins of streams
Phragmites australis *	蘆葦	Perennial Herb	Beaches, river banks, margins of ponds
Rumex trisetifer	長刺酸模	Herb	Field margins, moist valleys, watersides
Sesuvium portulacastrum	濱莧	Herb	Sandy beaches
Sporobolus virginicus	鹽地鼠尾粟	Perennial Herb	Coastal sands
Zoysia sinica	中華結縷草	Perennial Herb	Coastal sands, river banks, roadsides and weedy places

* invasiveness of the species must be carefully considered

+ suitable as emergent plant species

Annex 9 A Non-exhaustive List of Native Species Suitable for Planting at Embankment

Scientific Name	Chinese Name	Growth Habit	Natural habitat
Adina pilulifera	水團花	Tree or Shrub	Thickets by streams and in ravines
Alocasia macrorrhizos	海芋	Perennial Herb	Forests and shaded places
Apluda mutica	水蔗草	Perennial Herb	Margins of forests and thickets
Arundinella nepalensis	石珍芒	Perennial Herb	Mountain grasslands, hill thickets
Cleistocalyx nervosum	水翁	Tree	Places near water
Cyperus haspan	畦畔莎草	Herb	Wet places and paddy fields
Cyperus iria	碎米莎草	Herb	Wet places and paddy fields
Cyrtococcum patens	弓果黍	Herb	Moist places in forests and grasslands
Derris trifoliate	魚藤	Climbing Shrub	Thickets near seashore
Eurya chinensis	米碎花	Shrub	Thickets on hillslopes or by streams
Ficus hirta	粗葉榕	Shrub or Small Tree	Forests, thickets, near villages by streams
Ficus pyriformis	舶梨榕	Shrub	Along ditches, in thickets
Ficus variolosa	變葉榕	Shrub or Small Tree	Thickets or forests
Gardenia jasminoides	梔子	Shrub	Ravines and thickets on hills
Glochidion hirsutum	厚葉算盤子	Shrub or Small Tree	Thin forests, stream banks, shrublands
Glochidion zeylanicum	香港算盤子	Shrub or Small Tree	Ravines, stream banks, shrublands
Ilex asprella	梅葉冬青	Shrub	Margins of woods
Ilex pubescens	毛冬青	Shrub	Thin forests and thickets
Ixora chinensis	龍船花	Shrub	Thickets and thin forests
Kyllinga brevifolia	水蜈蚣	Herb	Thickets on hillslopes, wet places
Lepidosperma chinense	鱗子莎	Herb	Grasslands in valleys
Litsea rotundifolia var. oblongifolia	豺皮樟	Shrub	Thin forests, thickets
Melastoma dodecandrum	地菍	Diffuse Subshrub	Open fields, hillslopes, thickets, roadsides
Melastoma malabathricum	野牡丹	Shrub	Secondary forests, hillslopes, roadsides, streamsides, thickets
Melastoma sanguineum	毛菍	Shrub	Disturbed forests, streamsides, thickets on low hills, roadsides
Paspalum distichum	雙穗雀稗	Perennial Herb	Farmlands, grassy fields, roadsides, ditches and other disturbed places
Paspalum longifolium	長葉雀稗	Perennial Herb	Hillslopes, grassy fields, swampy places
Paspalum scrobiculatum var. orbiculare	圓果雀稗	Perennial Herb	Hillslopes, roadsides, fields
Pennisetum alopecurodies	狼尾草	Perennial Herb	Grassy fields, roadsides, paths between paddy fields
Psychotria asiatica	山大刀	Tree or Shrub	Thickets and forests on hillsides and by streams

Scientific Name	Chinese Name	Growth Habit	Natural habitat
Rhaphiolepis indica	石班木	Shrub	Forests or open fields
Rhododendron simsii	紅杜鵑	Shrub	Secondary shrubland on hillsides and along streams
Rhodomyrtus tomentosa	崗棯	Shrub	Thickets
Sacciolepis indica	囊穎草	Herb	Margins of paddy fields and other moist places
Schefflera heptaphylla	鴨腳木	Tree	Forests
Uvaria macrophylla	紫玉盤	Climbing Shrub	Shrublands and forests
Wedelia prostrata	滷地菊	Herb	Sandy places near seaside

Annex 10 A Non-exhaustive List of Native Species Suitable for Planting along the Top of Channel

a. Trees

Scientific Name	Chinese Name	Growth Habit	Natural Habitat
Cleistocalyx nervosum	水翁	Tree	Places near water
Ficus fistulosa	水同木	Tree	Forests in valleys or by streams
Ficus subpisocarpa	筆管榕	Tree	Open field and forests
Hibiscus tiliaceus	黃槿	Tree or Shrub	Thickets, seashores behind mangroves
Ilex rotunda var. microcarpa	小果鐵冬青	Tree	Secondary forest
Liquidambar formosana	楓香	Tree	Forests
Litsea glutinosa	潺槁樹	Tree	Forest edges, stream sides or thickets
Litsea monopetala	假柿木薑子	Small Tree	Thickets or sparse forests on sunny slope
Macaranga tanarius	血桐	Tree	Forests at lower altitudes
Mallotus paniculatus	白楸	Tree or Shrub	Thin forests, shrublands
Melia azedarach	楝	Tree	Forest, open fields near villages, roadsides
Phyllanthus emblica	油甘子	Tree or Shrub	Dry and open forests or shrublands
Pongamia pinnata	水黃皮	Tree	Seashore, near streams and ponds
Sapindus saponaria	無患子	Tree	Lowland forests
Sapium sebiferum	烏桕	Tree	Banks of streams and ditches, sparse forests near villages
Saurauia tristyla	水東哥	Small Tree	Broadleaved forests and thickets in ravines
Schefflera heptaphylla	鴨腳木	Tree	Forests
Sterculia lanceolata	假蘋婆	Semi-deciduous Tree	Lowland secondary forests and valleys

b. Shrubs

Scientific Name	Chinese Name	Growth Habit	Natural Habitat
Camellia oleifera	油茶	Small Tree	Forests
Eurya chinensis	米碎花	Shrub	Thickets on hillslopes or by streams
Ixora chinensis	龍船花	Shrub	Thickets and thin forests
Ligustrum sinense	山指甲	Tree or Shrub	Naturalized along tickets and roadsides
Maesa perlarius	鯽魚膽	Shrub	Margins of forests and shrubby area

Scientific Name	Chinese Name	Growth Habit	Natural Habitat
Melastoma malabathricum	野牡丹	Shrub	Secondary forests, hillslopes, roadsides, streamsides, thickets
Polyspora axillaris	大頭茶	Shrub or Small Tree	Thickets and early secondary forests
Psychotria asiatica	山大刀	Tree or Shrub	Thickets and forests on hillsides and by streams
Rhododendron simsii	紅杜鵑	Shrub	Secondary shrubland on hillsides and along streams