Drainage Services Department Practice Note No. 3/2021

Guidelines on Design for Revitalisation of River Channel

Version No. : 1

Date of Issue: 30 December 2021

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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.

The Government 2015 Policy Address stating *"We will adopt the concept of revitalising water bodies in large-scale drainage improvement works and planning drainage networks for new development areas (NDAs) so as to build a better environment for the public."* Later on, the Government in Policy Address 2019, announced to develop and take forward the concept of "Rivers in the City" through river revitalisation projects, with an aim to allow the public to enjoy river facilities, appreciate multiple values and treasure water bodies, and create a better living environment.

DEVB Technical Circular (Works) No. 9/2020 – Blue-Green Drainage Infrastructure was issued in July 2020 to promote wider adoption of blue-green elements in the design of drainage measures of government projects.

This Practice Note (PN) presents the essential environmental, ecological, and social considerations that should be taken into account in the design of river channels. It takes immediate effect and replaces the existing Drainage Services Department PN No. 1/2015 Guidelines on Environmental and Ecological Considerations for River Channel Design. Details of blue-green drainage infrastructure and existing guidelines on river channel projects are given in Annex 1.

2. ECOLOGICAL CONSIDERATIONS

2.1 Ecological Impacts Due to River Channel Works

River channelisation 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.

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 channelisation, 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/widening 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 minimise 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 minimise environmental impacts on the river channels.

Channelisation 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 minimise these impacts (see Annex 2).

Another 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.

2.2 Selection of Engineering Measures

2.2.1 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, minimisation and compensation. Hence, the minimisation approach refers to engineering solutions which would minimise 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 summarises the considerations of different options of engineering measures, which would be described in detail in the following sections.

<u>Engineering and Environmental Performance</u>

Design Option	Description	Advantages	Disadvantages	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
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	Utilise 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, operation and maintenance effort to protect the original habitats and flora

Engineering and Environmental Performance

Design Option	Description	Advantages	Disadvantages	Limitations
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 operation and maintenance effort to manage the amount of siltation
Preservation and enhancement of cutoff meanders	Retain cut-off meandering sections after channelisation 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

TABLE 1 CONSIDERATIONS OF SELECTING ENGINEERING MEASURES

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 utilised 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 can demonstrate the disturbance to the ecology of the river channel is minimal.

2.2.2 Distant Flood Banks

If land is available, distant flood banks (see Figure 1) offer the optimal solution for flood alleviation as well as conservation of riverine habitats.

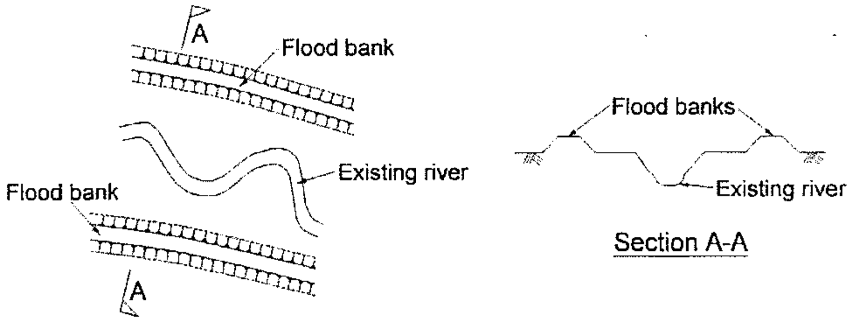

FIGURE 1 TYPICAL ARRANGEMENT FOR DISTANT FLOOD BANKS

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.

2.2.3 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).

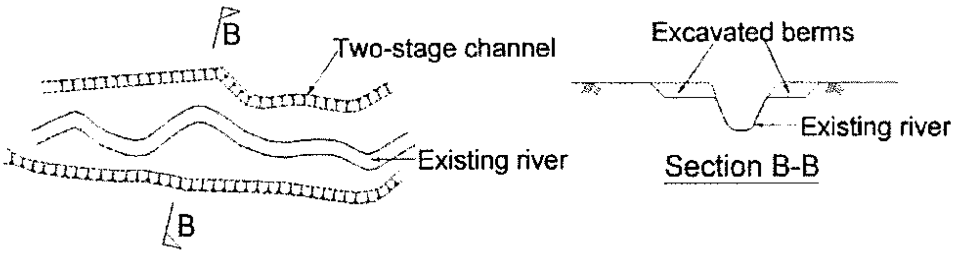

FIGURE 2 TYPICAL ARRANGEMENT FOR TWO-STAGE CHANNEL

An ideal two-stage or multi-stage channel (see Figure 2) 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.

2.2.4 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 minimise 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 3 shows the typical arrangement for flood relief channel.

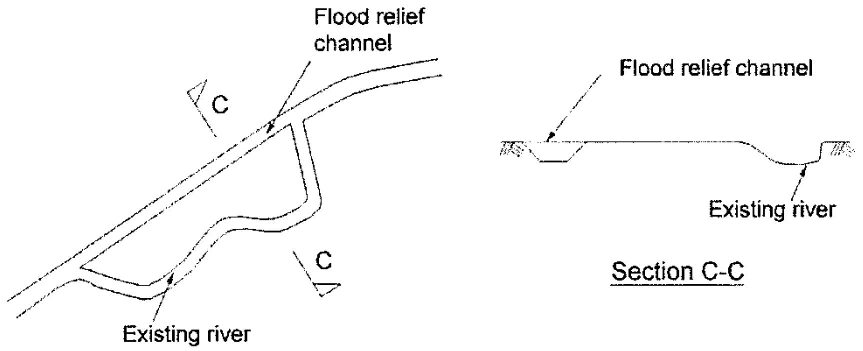

FIGURE 3 TYPICAL ARRANGEMENT FOR FLOOD RELIEF CHANNEL

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.

2.2.5 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 to make use of an existing river bend, would attenuate peak flow, thereby controlling the amount of flow into the downstream during heavy rainstorms. In dry season, the flood retardation basin also serves as a wetland to maintain riparian habitats, purify water, and improve aesthetic and ecological values (see Figure 4). 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 4 FLOOD RETENTION LAKE AT SHENZHEN RIVER

2.2.6 Alternation of Works

As mentioned in Section 2, river channelisation would certainly cause different impacts to its environment and ecology even though different mitigation measures are deployed to minimise such impact. Therefore, one possible way to minimise the environmental and ecological impacts is to alternate the proposed channelisation 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 5). 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.

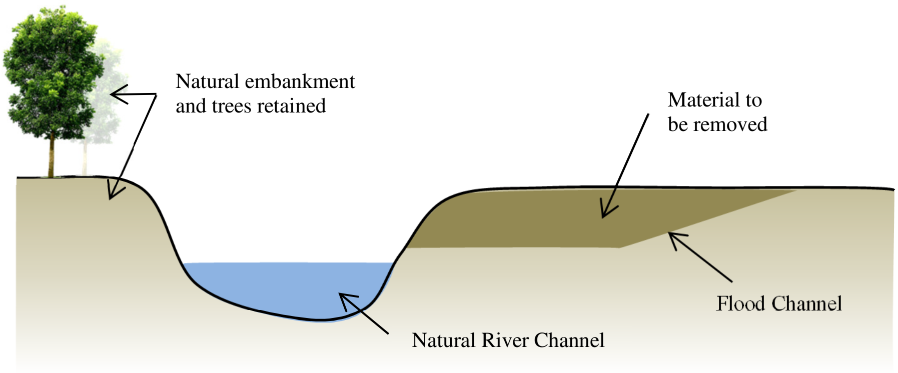

FIGURE 5 ALTERNATION OF WORKS

2.2.7 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). Lateral connectivity should be maintained along the river as far as practicable, subject to actual site constraints.

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 stabilisation, 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 6). Sloping embankments that allow passage for terrestrial animals would maintain ecological linkage within the local habitat because these animals may utilise 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. Alternatively, escape ramp can also be installed at the vertical embankment wall in case slanted embankment is not able to be constructed.

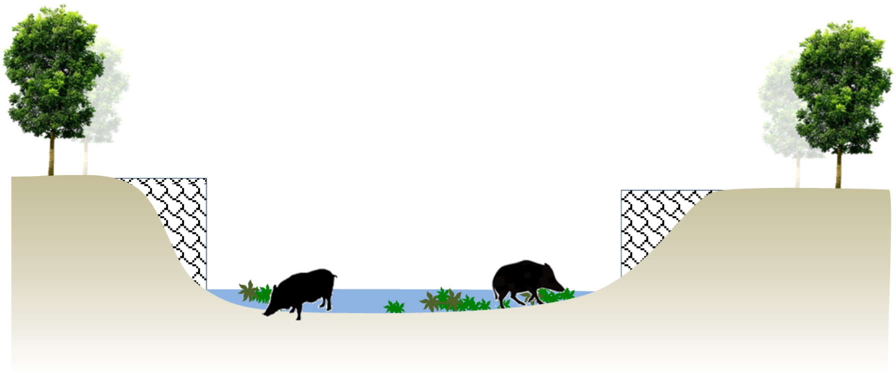

FIGURE 6 ANIMALS COULD BE TRAPPED IN CHANNEL WITH VERTICAL EMBANKMENT WITHOUT PROVISION OF ANIMAL CORRIDOR

b. Longitudinal Connectivity from Upstream to River Mouth

In Hong Kong, full width inflatable dam is commonly utilised 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; mobilisation 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 addition to inflatable dam, movable barrier/tidal gate with carefully designed operation mode should be considered for better longitudinal connectivity of river.

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 2.3.6. 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). The designers should evaluate the ground water level change and its effect (e.g. farming activity) to the areas adjoining the river.

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 for fishes and other aquatic wildlife.

2.2.8 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 minimise siltation during low flow condition (see Figure 7). 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 minimise 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 7 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. 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.

2.2.9 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 and maintained to provide a wide range of ecological habitats. Figure 8 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.

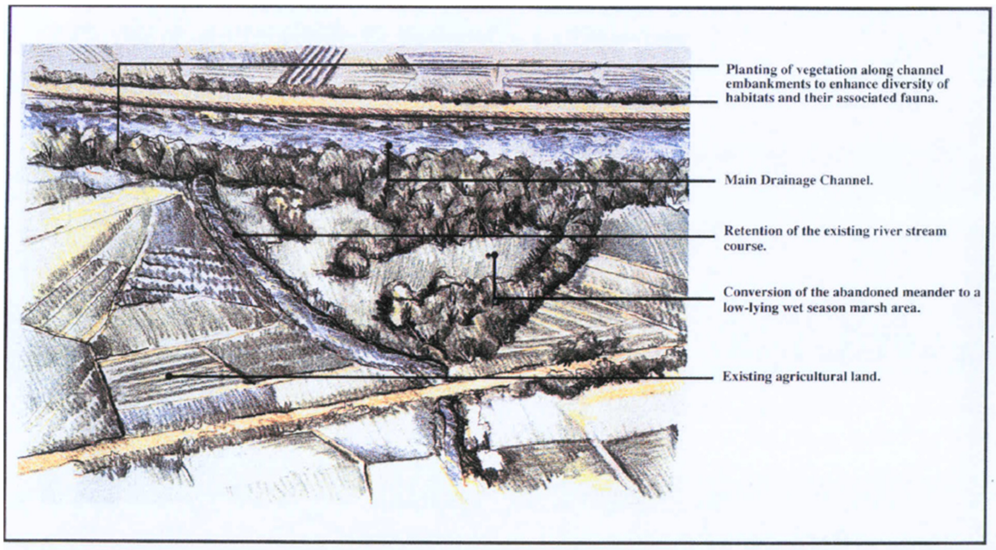

FIGURE 8 PRESERVATION AND ENHANCEMENT OF CUT-OFF MEANDERS (SOURCE: EXAMPLES OF ENVIRONMENTALLY FRIENDLY DRAINAGE CHANNEL ARISING FROM ENVIRONMENTAL IMPACT ASSESSMENTS BY EPD, DSD, AFCD & TDD)

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 unauthorised 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 3).

2.3 Ecological Enhancement of Engineering Measures

2.3.1 Objectives

Following the selection of options to minimise the impact of the engineering works, there are ecological enhancement measures that can be adopted to further minimise the residual impact of river channelisation 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 4.

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 optimise the hydraulic flows with due consideration of preservation of the local ecology.

In the investigation and preliminary design stage for river revitalisation scheme for the existing river channels, reference can be made to the Rapid Stream Evaluation (RSE) tool developed under DSD's eco-hydraulics study on river channels to review the existing environmental conditions and potential areas that could be enhanced to further develop a blue-green drainage infrastructure with consideration of promotion of river biodiversity. Details are provided in Annex 4.

2.3.2 Natural Bed Substrate

Preservation of original and 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 9). 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 9 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 10) or reused for planting riparian vegetation as far as practicable 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 10 PRESERVATION OF BED SUBSTRATE AT HO CHUNG STREAM

Careful planning should be exercised to carry out the works in stages to minimise 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, recolonisation 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 3. Due to the ecological requirements mentioned above, more operating and maintenance effort would be expected. Preconstruction / periodic walk-through survey should be planned and conducted as appropriate.

2.3.3 Sinuosity

A sinuous channel (see Figure 11) 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 11 SINUOUS CONFIGURATION AT MA TSO LUNG RIVER

2.3.4 Pools, Riffles and Falls

Boulders or logs can be reorganised 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 colonisation 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.

Another method of forming pools and riffles is to install current deflectors (also called wing deflectors) (see Figure 12), 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 12 CURRENT OR WING DEFLECTORS

HALF-MOON DEFLECTOR

GABION BASKET DEFLECTOR

PALM ROCK DEFLECTOR

FLOATING PLANTER

FIGURE 13 VARIOUS TYPES OF DEFLECTOR

 

BEFORE ENHANCEMENT AFTER ENHANCEMENT

FIGURE 14 QUICK FIX FOR ENHANCEMENT OF ECOLOGICAL VALUES OF THE EXISTING CHANNEL

2.3.5 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 15 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 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).

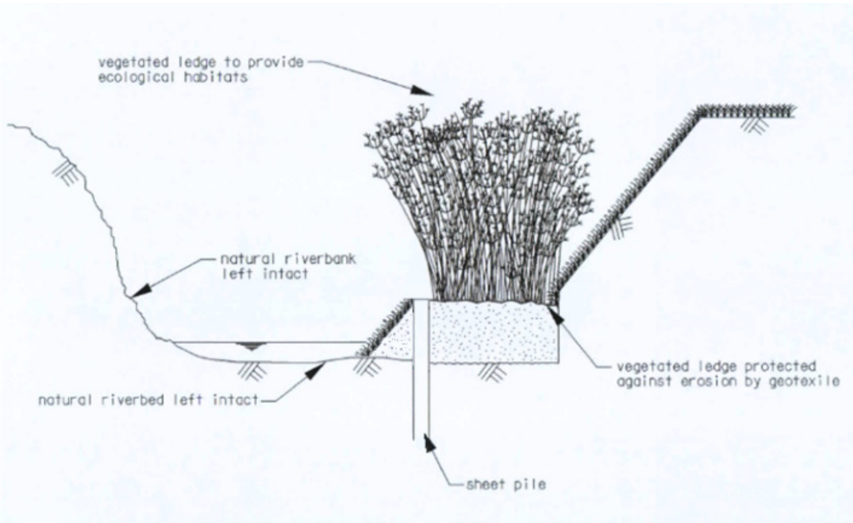

FIGURE 15 CREATION OF VEGETATED LEDGE BY SHEET PILES

2.3.6 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, provision of irregular surface and small pools on each step will assist the movement of fish and other aquatic organisms (see Figure 16). 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.

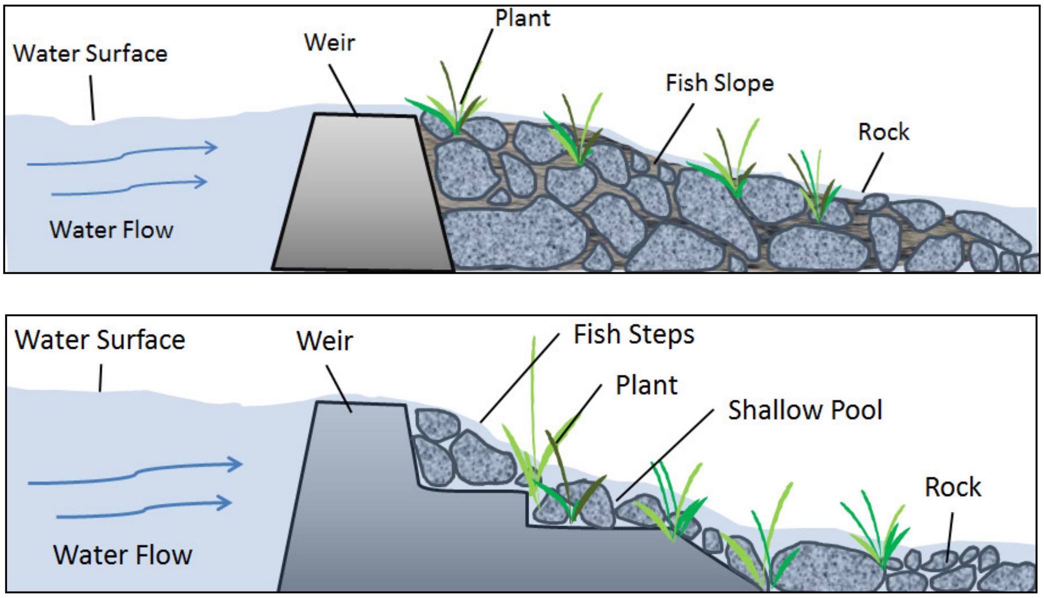

FIGURE 16 SIDE VIEW OF FISH SLOPE (UP) AND FISH STEP (DOWN)

2.3.7 Microhabitat

Microhabitat is defined as a small-scale habitat, 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 17). To be effective in providing ecological enhancement, microhabitat should be carefully designed with suitable planting and proper maintenance practice. The provision of these features should make reference to original natural state, neighbouring stream sections and/or tributaries.

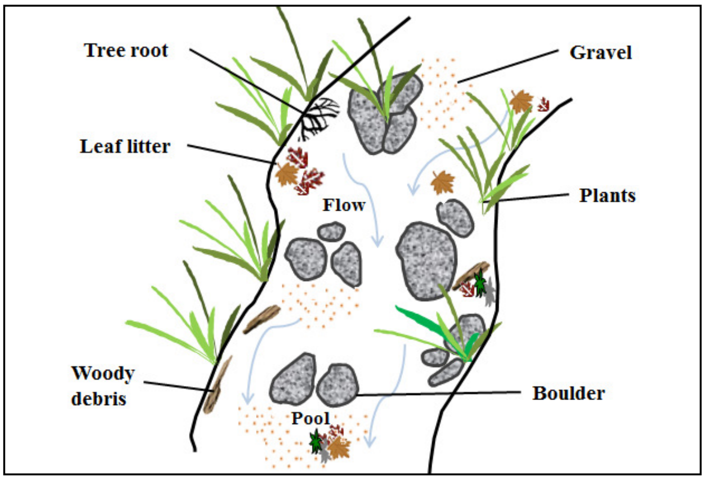

FIGURE 17 MICROHABITAT CREATION IN A STREAM

2.3.8 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 18). 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 18 IN-CHANNEL SHALLOW POND AT YUEN LONG BYPASS FLOODWAY

2.3.9 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 19) and the artificial island in Ho Chung River (see Figure 20). 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 19 TREE ISLAND IN LAM TSUEN RIVER

FIGURE 20 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 21). 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 utilise 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.

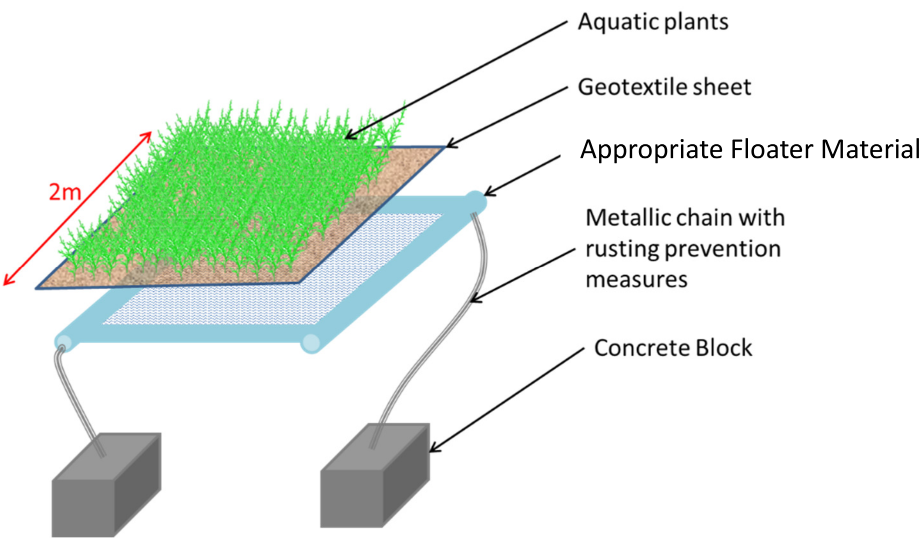

FIGURE 21 EMPLOYMENT OF FLOATING STRUCTURE

2.3.10 Silt Deposition

Deposition of sediment in channels (see Figure 22) 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 22 SILT DEPOSITION PROVIDED HABITATS FOR MACROINVERTEBRATES AND ASSOCIATED WETLAND FAUNA AT NGAU TAM MEI CHANNEL (LEFT) AND FAVOURS RECOLONISATION OF WETLAND VEGETATION AT NGONG PING RIVER (RIGHT)

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[1] should be carefully considered in order to minimise the adverse impacts to aquatic communities. Based on the above requirements, increased operating and maintenance effort is expected.

Design of silt traps or similar structures should take into account the operation and maintenance requirements to facilitate the phasing of desilting work. Desilting programme should be carefully planned and the desilting work should only be conducted in areas in need. 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.

2.3.11 Geotextile Bags (Geobags)

Geotextile bags or geobags have been used in many parts of the world for bank stabilisation. 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 to provide important refuge habitats for wildlife during both wet and dry seasons. 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 23.

[1] https://www.afcd.gov.hk/english/conservation/con_wet/streams_rivers_hk/Con_NSR/Ecologically_Important_Streams.html

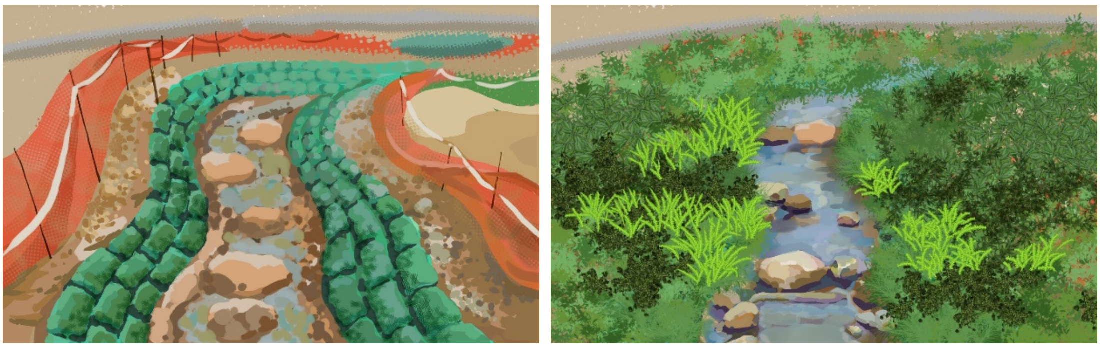

FIGURE 23 DESIGN OF GEOTEXTILE-BAGS BEFORE (LEFT) AND AFTER CONSTRUCTION (RIGHT)

2.3.12 Ground-sill

Arc-shape stone streambed sill (see Figure 24) can be installed in the channel bed to prevent the stream from eroding vertically and horizontally. The arc-shape stone can also stabilise 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 Feng, 2006).

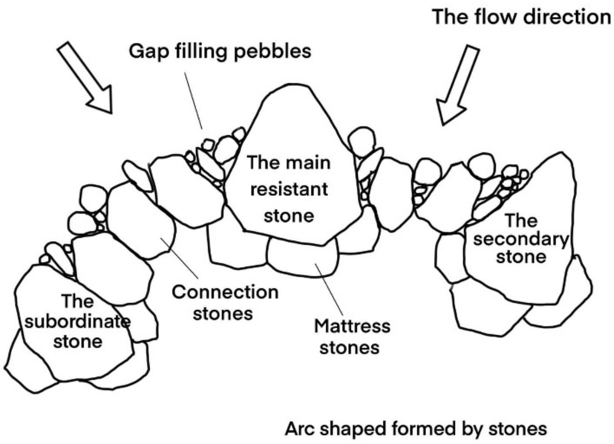

FIGURE 24 ARC-SHAPE STONE STREAMBED SILL

2.3.13 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 25).

FIGURE 25 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 colonisation of birds also. Bird species recorded prior to channelisation 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).

2.3.14 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 stabilise 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 channelisation, appropriate vegetation should be selected carefully for replanting the riparian zone (see Section 3.2). Proper control and maintenance of riparian vegetation is needed to balance between improving habitat, aesthetic and water quality, while at the same time minimise 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 26. 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.

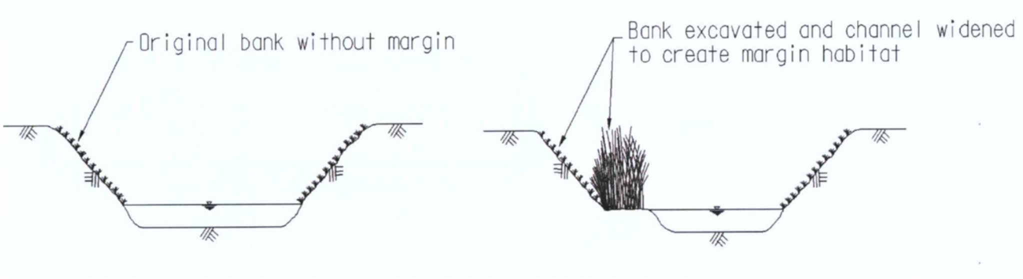

FIGURE 26 CREATION OF MARGIN HABITAT

2.3.15 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 maximise 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 operation and maintenance 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 27). 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. Stabilisation 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).

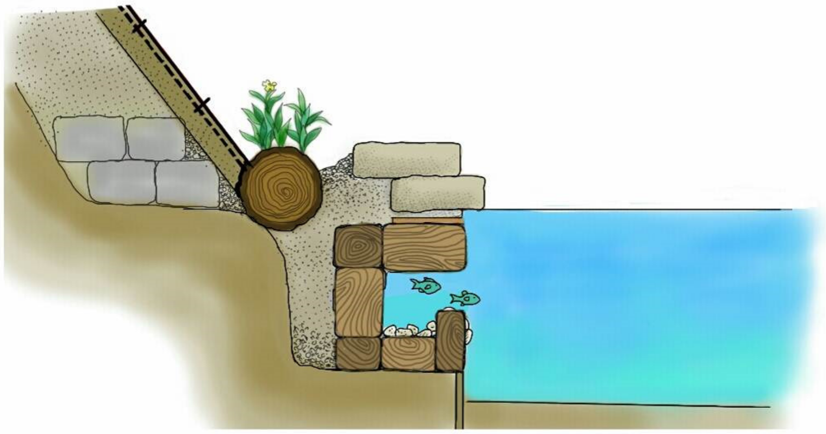

FIGURE 27 AN UNDERCUT BANK TO PROVIDE FISH SHELTER

2.3.16 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. colonisation, 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 5. 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 3.

2.4 Compensation Design Measures

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 channelisation through creation of a new river channel is very difficult. Therefore, the impacts on natural streams and rivers should be avoided and minimised 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 channelisation works) and should only be applied when there is no other alternative. One of the examples of applying the compensation approach in Hong Kong is 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. Measures for revitalisation and enhancement of disturbed fish ponds are provided in Annex 6.

3. EFFICIENT DRAINAGE FACILITIES AND CHANNEL GREENING AND BEAUTIFICATION

3.1 Design of Channel Bed and Embankment 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. From the maintenance point of view, hard-paved access may be considered to allow mechanical desilting in channels/ streams/ sections in which no alternatives for facilitating maintenance operation can be provided.

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).

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

3.1.1 Natural / Unlined Bed and Embankment

Natural or unlined bedding and embankment 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 retain its natural condition. This option preserves the habitat of the eco-system to mimic natural substrate and create habitats as far as possible. 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. 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. Another constraint on the use of this type of bedding is the erosion problem 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 lining can only be applied in locations where the flow velocity and discharge volume are low or otherwise scouring problem would be severe. More frequent inspections and maintenance efforts are required to prune excessive growth of vegetation and repair damaged bank (see Annex 3).

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 9 shows a good example of the natural earth bedding of Kam Tin River Channel during low tide. The unlined river channels may need regular control checks and provision of adequate bank protection.

Soft bank revetment methods could be used to protect the natural or unlined embankment, for example brush mattresses, coconut fiber roll, etc.

3.1.2 Rip-rap Bed Lining and Embankment

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-colonisation of stream fauna. Heterogeneous bottom includes sand and stones of different sizes are also encouraged.

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 recolonisation of native plants. It also provides the opportunity to reuse excavated rocks and soils and thereby reduce burden on landfill sites. 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 river ecology and appearance would be dreadful during dry season, as the surface flow would become sub-surface flow and the aquatic ecosystems would be affected (see Figure 28). The designer shall carefully design the size, shape and layout of the rocks/boulders in particular in the areas with low water flow 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. 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.

FIGURE 28 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 drawdown 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-colonisation of stream fauna. In view of its fair ecological performance and poor hydraulic performance, use of rip-rap lining is not recommended.

3.1.3 Gabion Basket / Mattress Bed Lining and Embankment

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. With application of gabion basket/mattress lining, the river ecology and appearance would be affected during dry season. Designer shall carefully design the gabion basket/mattress in particular in the areas with low water flow during dry season.

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° 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 29). However, it is more difficult for the establishment of riparian vegetation in vertical gabion walls compared with sloped mattress lining (see Figure 30). Tree can also be planted where space is available along gabion embankment. The reuse of excavated materials would help to reduce the need for offsite disposal. Placing of soil bags on top layer of gabion filling for vegetation should be considered.

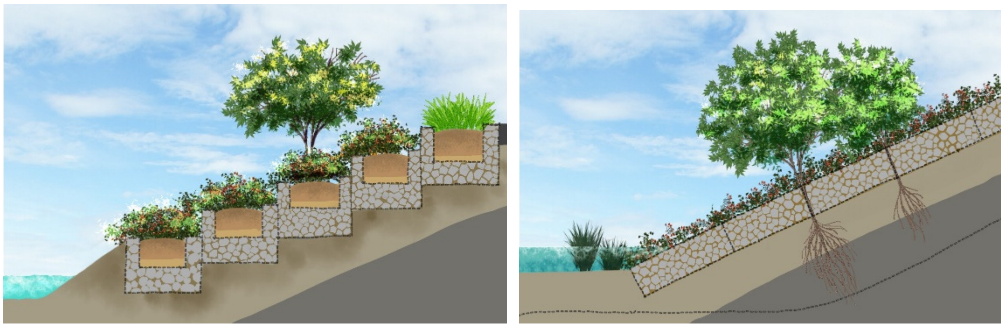

FIGURE 29 GABION BASKETS WITH PLANTING PITS (LEFT) AND VEGETATED GABION MATTRESS (RIGHT)

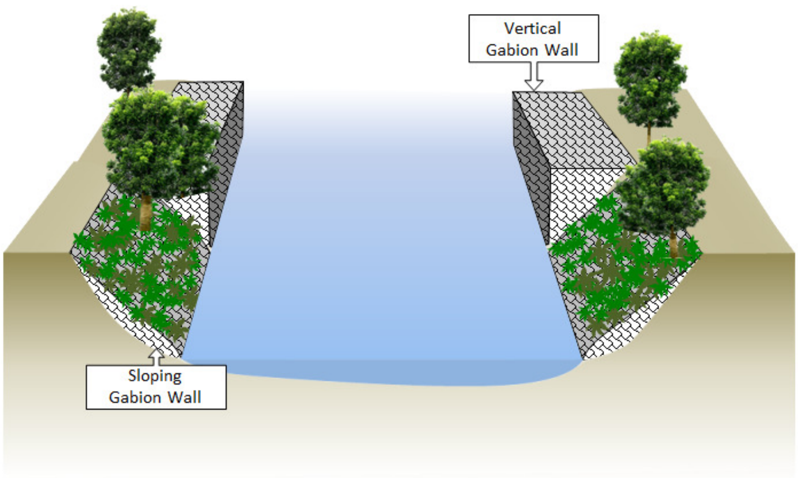

FIGURE 30 THE DIFFERENCE IN VEGETATION RE-COLONISATION PERFORMANCE OF SLOPING GABION AND VERTICAL GABION

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 minimise the land requirement (see Figure 31).

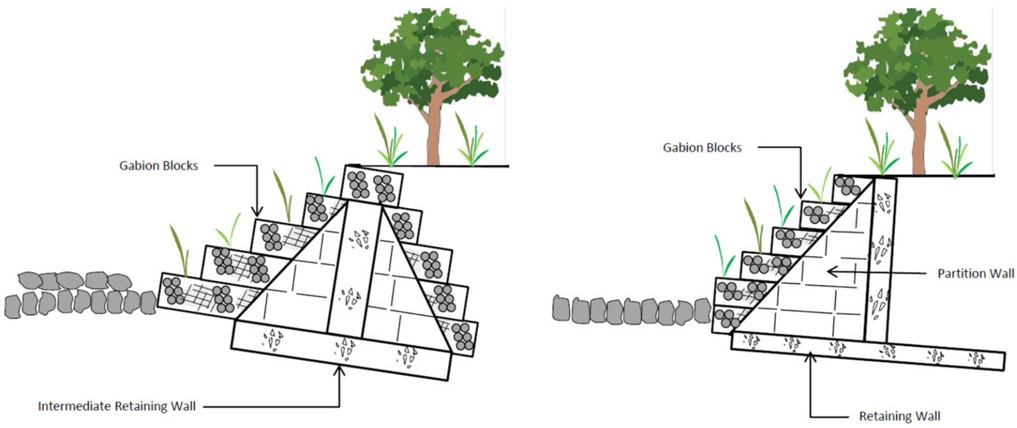

FIGURE 31 COMPOSITE STRUCTURE OF CONCRETE RETAINING WALL WITH GABION LINING

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.

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.

3.1.4 Geotextile Reinforced Grass for Embankment

Geotextile reinforced grass may be used as river embankment lining (see Figure 32). 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. In view that the reinforced grass lining may not be able to withstand strong flow of flood water due to stormy weather and cost much to replace after typhoon, the project proponent should further improve its robustness and ease of maintenance when considering such lining. Typical examples of such river embankments are found in the rehabilitation works at Ng Tung River (see Figure 33), Sheung Yue River and Kau Lung Hang Stream.

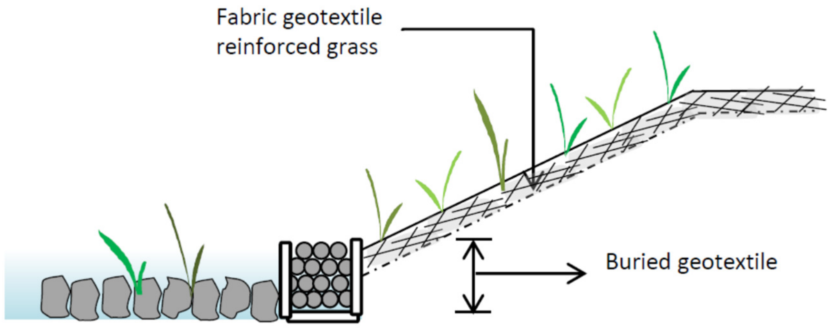

FIGURE 32 GEOTEXTILE REINFORCED GRASS EMBANKMENT

FIGURE 33 GEOTEXTILE REINFORCED GRASS EMBANKMENT AT NG TUNG RIVER

3.1.5 Rubble / Stones Embedded in Concrete / Mortar for Bed Lining

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.

3.1.6 Grassed Cellular Concrete Paving for Bed Lining and Embankment

This method has been commonly adopted in the recent drainage channel projects. 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 (see Figure 34). 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 because its surface is less irregular. However, the grassed cellular concrete paving would not provide a good habitat for establishment of the ecosystem within a newly constructed river channel. If sufficient silting materials are left on the concrete surface, habitats may start to form. Adverse environmental effects may incur during the construction phase and precautionary measures should be employed (see Annex 2). Maintenance cost on the grassed embankment is high because regular cutting of grass is required. Figure 35 shows the cellular concrete paving at the channel bed of Yuen Long Bypass Floodway under construction. Typical example of this type of embankment lining can be seen along Ma Wat River (see Figure 36). In Ping Yuen River, channels with reinforced concrete grids planted with vegetation only provide habitats for non-wetland dependent species.

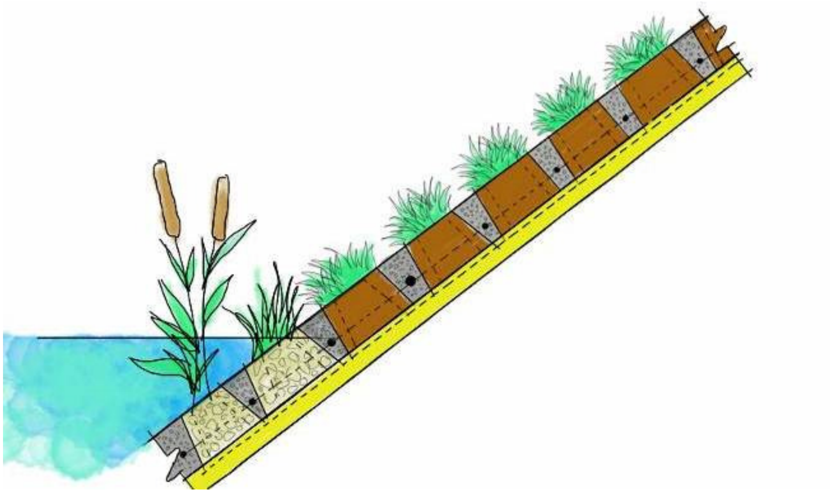

FIGURE 34 GRASSED CELLULAR CONCRETE PAVING AT EMBANKMENT

FIGURE 35 GRASSED CELLULAR CONCRETE PAVING AT YUEN LONG BYPASS FLOODWAY (DURING CONSTRUCTION)

FIGURE 36 GRASSED CELLULAR CONCRETE PAVING AT MA WAT RIVER

3.1.7 Climber System for Embankment

Climber system may be used for greening of river embankments. Two basic types of climber systems can be considered. First type involves self-climbing species planted on a planter located at the toe of the embankment walls. A climbing device, such as wire mesh, can be installed to assist the growth of climbers. Typical examples can be seen at Lower Lam Tsuen River and Mat Wat River (see Figure 37). Second type of climber system includes planters installed along the top of the embankment walls and plants are hanging from the top to cover the embankment walls.

Major benefit for adopting a climber system is that it tends to have less structural impact on the existing embankment walls as compared to the river embankment lining methods mentioned from Sections 3.1.1 to Section 3.1.6. However, routine maintenance (irrigation, removal of invasive species, pruning, etc.) and repair after a heavy storm event may be required, especially the wire mesh replacement may result in high maintenance efforts and cost. From a hydraulic point of view, the second climber type shall not have significant impact on the river hydraulics since the plants can move freely with the currents, but the first climber type with a climber device that is fixed on the embankment walls may induce additional hydraulic roughness.

FIGURE 37 CLIMBER SYSTEM AT MA WAT RIVER

3.2 Planting Design for River Channel

3.2.1 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 3.2.2). 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. Designer should also make reference to the Greening Master Plan developed by the Civil Engineering and Development Department. Functional requirements of the planting should be clearly identified before plant species are proposed for the environmental enhancement. These functions may include stabilisation 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 minimise 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 minimise the effects of root action of some species. Alternatively, species with non-invasive root system should be used.

3.2.2 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 38 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 5.

FIGURE 38 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 39 shows some examples of plants commonly found in Hong Kong at embankments and a non-exhaustive list of suggested plants is given in Annex 7.

 

FIGURE 39 MELASTOMA MALABATHRICUM IN YUEN LONG BYPASS FLOODWAY (LEFT), RHAPHIOLEPIS INDICA IN NGAU TAM MEI RIVER (RIGHT)

3.2.3 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 40 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 8.

 

FIGURE 40 STERCULIA LANCEOLATA IN TONG FUK RIVER (LEFT), LIQUIDAMBAR FORMOSANA IN NGAU TAM MEI RIVER (RIGHT)

3.2.4 Quality Improvement of Riparian Vegetation

Riparian vegetation is an important part of channels which contributes to the overall ecological and landscape functions. To improve the quality of riparian vegetation of disturbed channels, different planting methods can be adopted (see Annex 9).

3.2.5 Maintenance of Vegetation in Rural Areas

To minimise ecological disturbance due to vegetation trimming / cutting works, a rotational schedule should be adopted where possible. Selective cutting of grass on the embankment and slopes of the channel within the flow cross section area should be conducted in a rotational schedule and pattern to permit re-colonisation. Non-woody (and non-invasive) vegetation species at the land-water margin should be preserved. The mowing regimes at different areas of the riverbed should be decided depending on the land use beyond the river banks. More frequent mowing schedule may be needed for those locations adjacent to populated areas.

When maintenance cutting is required, the maintenance area should be divided into strips. Each strip covers one side of the slope and should be no more than 100m in length or 5 folds of the channel width, whichever is shorter. Maintenance cutting should then be rotated in a 'chequered' pattern, with alternating strips on either side of the slopes being cut, and leaving the adjacent strip uncut until the next scheduled maintenance event. The cutting pattern is illustrated in Figure 41 (i.e. the 'blue' strips being cut on the first maintenance event, leaving the 'yellow' strips untouched until the next maintenance event). The intervals between rotations should be at least 2-3 weeks, to allow the habitats and ecology within the previously cut 'blue' strips to recover before the 'yellow' strips are cut. This rotational pattern should be adopted whenever maintenance cutting is required on large sections of the channel. The project proponent should consult the operation and maintenance parties at an early stage and consider the maintenance requirements such as provision of training sessions and workshops for vegetation cutting works. The project proponent is reminded to provide proper maintenance access for vegetation cutting works.

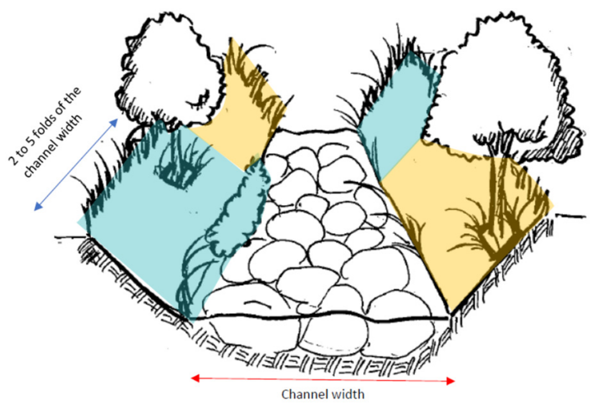

FIGURE 41 ROTATIONAL CUTTING

4. WATER FRIENDLINESS CULTURE AND ACTIVITIES

4.1 Water Quality Enhancement

4.1.1 Water Quality Goals for Revitalised River Channels

Good water quality is essential to maintain a healthy aquatic ecosystems and to build a pleasant and inviting environment for the community to immerse in water friendliness culture and participate in water friendliness activities. Therefore, this section provides a set of water quality goals that project proponent should aim to accomplish and maintain by implementing water quality enhancement measures in revitalised river channels.

Existing water quality guidelines in Hong Kong are reviewed for application to achieve the water quality goals for revitalised river channels as described below.

Water Quality Objectives by EPD

Under the Water Pollution Control Ordinance (WPCO), Hong Kong's waters are divided into ten Water Control Zones (WCZ) each of which has its own set of Water Quality Objectives (WQOs) appropriate to its characteristics and beneficial uses. The WQOs describe various physical, chemical and biological properties, either numerical or narrative, that the Government shall achieve and maintain in the long run.

Water Quality Objectives for Bathing Beaches by EPD

Waterborne diseases pose serious threats to people who participate in aquatic recreational activities. A Water Quality Objective for Bathing Beaches was developed under the WPCO, which states that the geometric mean *E. coli* level shall not exceed 180 counts/100mL for recreational activities such as swimming. This threshold was based on epidemiology studies conducted on bathers at local beaches where the risk of contracting swimming associated illness (e.g. minor gastrointestinal and skin illnesses) was observed. For secondary contact recreational activities, such as boating, canoeing, rowing, geometric mean *E. coli* level shall not exceed 610 counts/100mL.

Technical Specifications on Grey Water Reuse and Rainwater Harvesting by WSD

Grey water is referred to water collected from wash basins, baths, kitchen sinks, etc. Rainwater can be harvested from sources including roofs, permeable/non-permeable paving, and surface runoff from landscaped areas, etc. The Technical Specifications set the water quality standards for treated grey water and rainwater, which can be used potentially for various non-potable purposes such as toilet flushing, irrigation, firefighting, and industrial processes, etc.

Water Quality Goals for Revitalisation of Water Bodies

The Water Quality Goals shall be suitable for the designated water uses of the revitalised water bodies, which are classified into 3 types of designated uses (see Table 3). The Project proponent should aim to achieve/maintain the Water Quality Goals as far as practicable by adopting water quality enhancement measures.

TABLE 3 WATER QUALITY GOALS BASED ON DESIGNATED WATER USES

Type	Designated Use	Description	Example of Water Friendly Activities	Water Quality Goals
1	Aquatic Life and Aesthetic Value (including public access to the river but	Water provides a suitable condition for propagation of aquatic life.	Riverside walkway	1) WQOs of the corresponding Water Control

	primary/secondary contact to river water is not allowed)	Also, the water quality shall be of acceptable odour and appearance to the public who participate in water friendliness activities	Public is allowed to access riverbed and stay close to the water body, but direct contact of the water is not recommended	Zone (WCZ) 2) No objectionable odour
2	Secondary Contact Recreation	Water supports recreational activities, such as boating and paddling, that may involve limited contact with water with no significant risk of water ingestion	Boating, canoeing, rowing	1) WQOs of the corresponding WCZ 2) Geometric mean *E.coli*** ≤ 610 counts/100mL 3) No objectionable odour
3	Primary Contact Recreation	Water is likely come in full body contact and/or incidental water ingestion	Water play zone, interactive fountains, splash pad	1) WQOs of the corresponding WCZ 2) Geometric mean *E.coli* **≤ 180 counts/100mL 3) No objectionable odour

* For types 1 and 2, if treated grey water/harvested rainwater (from sources like roofs of buildings, permeable/non-permeable road pavement and surface runoff from hard/soft landscaped areas) is used to replenish the river, the designer may make reference to Technical Specifications on Grey Water Reuse and Rainwater Harvesting to specify the water quality. Users who choose to adopt this Technical Specifications are responsible for making their own assessments and judgement of all guidelines and information contained in the Technical Specifications. If treated grey water/harvested rainwater is used to replenish the river where there is potential human contact, project proponent should seek advice on whether treated grey water is fit for targeted human contact from the relevant authorities and the appropriate specialist(s) on a case-by-case basis.

**WQO of *E.coli* under WPCO is calculated as annual geometric mean

4.1.2 Water Quality Enhancement Measures

Water pollution from both point sources and non-point sources threatens the health of rivers and nearby neighborhoods. The following sections explore various water quality enhancement measures that can be considered under a river revitalisation project.

Expedient Connection (EC) Study

Discharge of sewage into storm drains is not uncommon, especially in old buildings and some rural villages. Pollutants are carried to downstream by drainage network and eventually, reach the receiving water bodies. This is why drainage outlets with polluted flows can often be seen along rivers, causing offensive odour and discoloration of the water. In general, for a point source, reducing pollution at its source is a more effective option than treating or intercepting the pollution in the downstream system. Therefore, project proponent shall allow time for collaboration with the EPD, if EC study is necessary to be conducted within the catchment areas to identify and rectify any mis-connection of sewer to storm drains.

Dry Weather Flow Interceptor (DWFI) System

In the apparent absence of a more effective measure to improve the river water quality, project proponent may consider installing DWFI to intercept polluted discharge from drainage outlets. In view of the various operation and maintenance problems, hydraulic deficiencies to the existing stormwater drainage system, as well as overloading of the existing sewerage system that may be brought about by the implementation of DWFIs, the design of DWFIs can only be considered if it can be demonstrated that a reasonable degree of effectiveness is achievable. DSD PN No. 1/2016 provides a set of design criteria and procedures for dealing with new DWFI proposals.

There are two types of conventional DWFIs, namely conventional upstream DWFI and conventional downstream DWFI (e.g. Jordan Valley DWFI). A DWFI system normally consists of interceptors at the problematic drainage outlets, pipes or covered channels to convey the intercepted flows, connection points to the existing sewerage, and automatic penstocks which prevent excessive dry weather flows overloading the downstream sewage network during heavy rainstorms. The system will likely include desilting facilities, and a sewage pumping station if the invert levels of the proposed DWFI are lower than the downstream sewage system. If such new ancillary buildings are required for the planned project, the project proponent should follow the established procedures in seeking advice from the authorities on aesthetic aspect. For DWFI system in a tidal region, flow regulating devices such as flap gates, flap valves, check valves, tidal barrier or other proprietary devices should be installed to prevent the seawater ingress during high tide.

FIGURE 42 DWFI AT KAI TAI RIVER

Impact assessments shall be carried out to ascertain that there will be no adverse impact on the hydraulic and capacity of the stormwater drainage, sewerage system, and the sewage treatment works downstream. Water quality and flow survey shall be conducted to pinpoint the exact outlets with polluted flows for estimation of the intercepted flow volume.

Decorative elements can be added to enhance the visual appearance of the DWFI. For example, the recently completed DWFI system at Kai Tak River adopted man-made rocks decorated with pockets plants that are sympathetic to the surrounding environment.

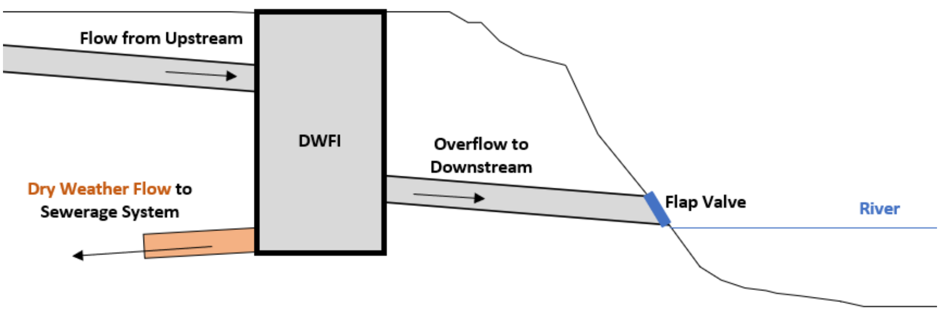

FIGURE 43 SCHEMATIC DIAGRAM FOR A TYPICAL DWFI

<u>Newly Designed DWFI System</u>

The newly designed DWFI is an off-the-network system and is independent from the existing sewage system. The intercepted flow will be diverted to a separate unit that typically comprises two processes, namely screening process and filtering process.

The screening process, by vortex grit trap, can remove the coarse particles. The filtering process, by a filter system, can remove finer particles to reduce biochemical oxygen demand (BOD) and total suspended solids (TSS). A filter system is a compact unit that can perform solid separation, sludge thickening and dewatering. The processed effluent from the newly designed DWFI system will then be discharged back to the rivers.

Separate units with small footprints are generally preferred due to the land scarcity in Hong Kong. Pollutant removal efficiency of the unit should be reviewed, and filter types should be tailored for target pollutants in the existing water bodies and meet the Water Quality Goals. Project proponent should have due considerations regarding the residue solid disposal if such newly designed DWFI system to be adopted. Opportunities of having some architectural features in these newly design DWFI system could be explored by project proponent for an integrated design.

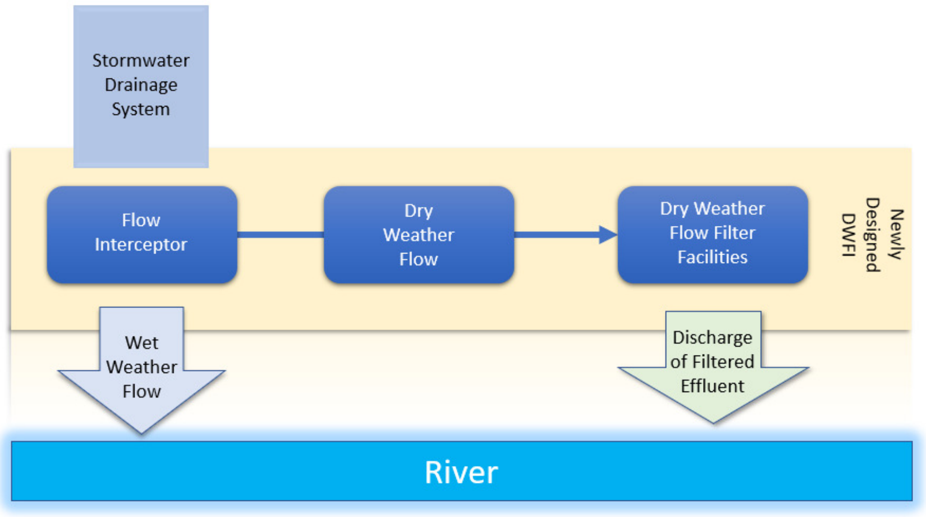

FIGURE 44 SCHEMATIC DIAGRAM OF NEWLY DESIGNED DWFI SYSTEM

The implementation of different types of DWFI should be reviewed case by case, considering various factors (land availability, cost-effectiveness, system hydraulics, and sewerage capacity, etc.).

Engineered Wetland

Engineered wetland can be provided for flood attenuation, water purification, and amenity enhancement. Main mechanisms of water treatment are the settling of silts and suspended sediments, microbiological conversion/degradation and absorption, the process of biological uptake by aquatic vegetation, etc. The pollution removal efficiency depends on the plant species, soil properties, flow paths, retention time, and pollution loading rates, etc. Engineered wetlands normally require regular maintenance of the site vegetation and hydraulic structures to ensure their proper operation.

FIGURE 45 EXAMPLE OF ENGINEERED WETLAND NEAR YUEN LONG BYPASS FLOODWAY

Garbage Collection

Sediments and trash, whether they are accumulated at the bottom of the river or floating on the surface, cause unfavourable aesthetic and odour problems in the nearby community and may be harmful to aquatic ecosystems.

Trash booms or trash grill can be installed at strategic locations to corral floating debris without causing adverse impact to the river hydraulics and allow aquatic creatures to pass freely without harm.

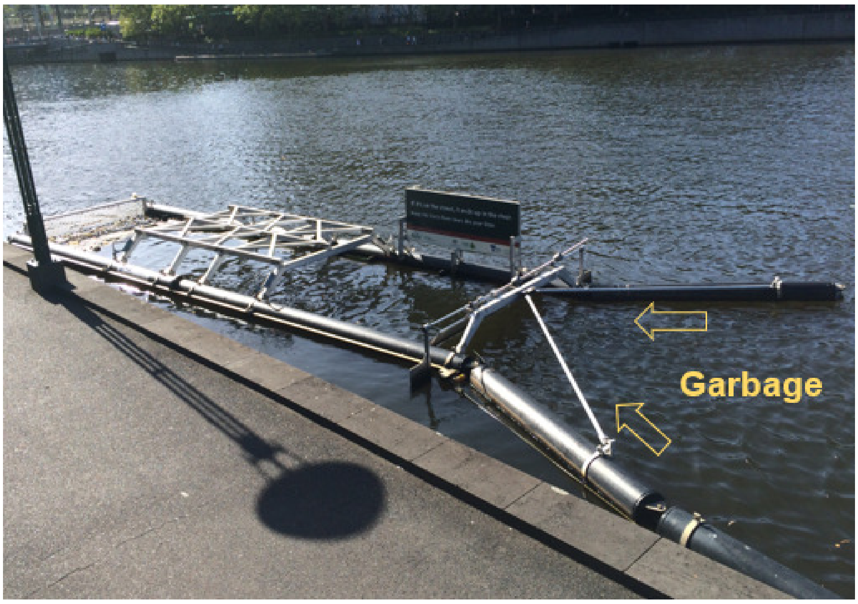

FIGURE 46 EXAMPLE OF GARBAGE COLLECTION SYSTEM IN RIVER

Desilting Works

Desilting works by removing silt and sediment from the bottom of a river is traditionally used to restore a river's flood carrying capacity, while it may also help to improve the water quality. However, project proponent shall exercise due cautions when planning and implementing desilting works since it can potentially cause disruption of river ecology, bank erosion, and adversely affect the water quality. In addition, foul odour emanating from the excavated materials is likely to affect the surrounding neighborhood.

FIGURE 47 DESILTING WORKS IN RIVER CHANNEL

Bioremediation

Contaminated sediments usually have a lack of oxygen (i.e. they are under anoxic/anaerobic conditions). Degradable portion of organic pollutants in the contaminated sediment may decompose and under anaerobic conditions may react with sulfate in the water to form odorous compounds.

Hydrogen sulfide (H_2S) is one of the most common odorous compounds that cause odour problem in water bodies. To reduce the odour issue due to the reaction of the organic pollutants in the sediment, bioremediation can be used.

The principle of bioremediation is to change the sulfate reducing anaerobic conditions in sediment to a more preferable condition. This could be achieved by introducing nitrates (in the form of calcium nitrate solution) into the sediment. Since the reaction of nitrate is more thermodynamically favourable than sulfate in the natural environment, nitrogen gas will be produced instead of H_2S – thus reducing the odour generated from sediments. In the nitrate reaction, nitrate, with the help of denitrifying bacteria, will degrade the organic pollutants to form the non-odorous nitrogen gas.

FIGURE 48 INJECTION VESSEL

The main advantage of bioremediation is that it does not involve any dredging works, which tends to be more costly and may not be a viable solution in some of the water bodies.

However, there are some disadvantages of bioremediation. The effectiveness is unpredictable because odour issue for each case is different. It may require on-site testing to determine the dosage and effectiveness of the calcium nitrate.

Another main disadvantage is that as the chemical will decay over time, reinjection of the chemical is likely required if the odour problem persists. Moreover, over-dosage of calcium nitrate can lead to unintended pollution in the water.

Bioremediation treatment has been proven to be effective in resolving odour problems at Shing Mun River Channel and Sam Ka Tsuen Typhoon Shelter. A more recent application is the Kai Tak Approach Channel.

Mixing

Recharging the river with relatively clean water may help to improve water quality by reducing contaminants concentration, especially for rivers with low flow volumes.

Possible sources to replenish the rivers include WSD water supply facilities and rainwater harvesting as discussed in Section 4.2, effluents discharged from sewage treatment works or reuse of grey water. The standard of quality of the replenished water should be fulfilled as per Section 4.1.1.

Gross Pollutant Traps

Gross pollutant traps are structure units that can use physical processes to trap solid waste such as litter and coarse sediment and is commonly used overseas such as Australia because of its efficiency of removing large, non-biodegradable pollutants. Regular cleaning is required and relevant residue solid disposal should be planned and considered.

4.1.3 Water Quality Monitoring

Baseline water quality monitoring shall be conducted prior to the selection and design of water quality enhancement measures. Sampling locations, sampling frequency, and monitoring parameters shall be carefully selected to serve the following purposes:

- evaluate the overall pollution status of river waters;
- assess seasonal and spatial variation of water quality;
- identify the source of polluted flows;
- facilitate the selection and development of water quality enhancement measures.

After completion of the project, site specific long-term water quality monitoring programme shall be established to achieve the Water Quality Goals. The long-term monitoring programme shall serve the following purposes:

- assess the compliance with the Water Quality Goals;
- monitor long-term water quality trend;
- facilitate the emergency response plans for failing to achieve water quality goals;
- facilitate the development and implementation of operation and maintenance plan.

4.2 Water Resources Management

4.2.1 Environmental Flow

Environmental flow refers to "the quality, quantity, and timing of water flows required to maintain the components, functions, processes, and resilience of aquatic ecosystems which provide goods and services to people." (World Bank, 2019).

The concept of environmental flow was first developed in the 1950s, relating to the maintenance of fisheries in river systems (Gopal, 2013). Since that time, other important aspects of environmental flow have been recognised, including maintenance of basic hydrological processes, restoring aquatic ecosystems, and maintaining water levels for aesthetics and landscape design (Arthington et al., 2004). These different aspects of the importance of environmental flow are reflected to some extent in the different methodologies used to assess flow requirements. Among these approaches, perhaps the most appropriate methodologies in Hong Kong is to use holistic scientific panel methodologies based on available information of relationships between ecological communities and hydrology. Using suitable assessment approach can help identify and reflect the important relationships between water bodies, target species, and communities.

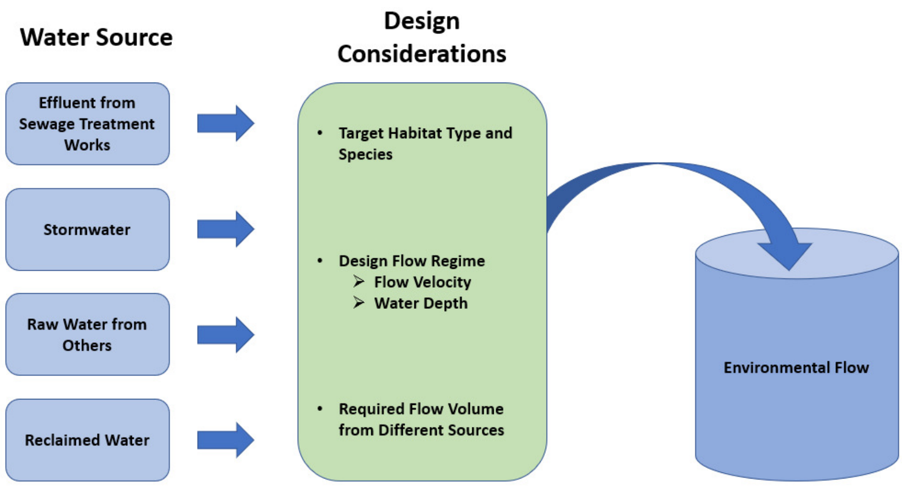

FIGURE 49 ENVIRONMENTAL FLOW SCHEME

4.2.2 Water Retention and Storage

<u>Rainwater Harvesting</u>

Recognising the importance of water conservation, project proponent can consider installing rainwater harvesting systems. Water harvested can be used potentially for river replenishment, irrigation, or other non-potable uses, etc. Depending on the runoff source and use, treatment process such as filters can be added to the system.

Size of the storage tank is highly dependent on the rainfall characteristics, catchment area, design level of the tank with respect to the control of surface water, land availability, water demand patterns, etc.

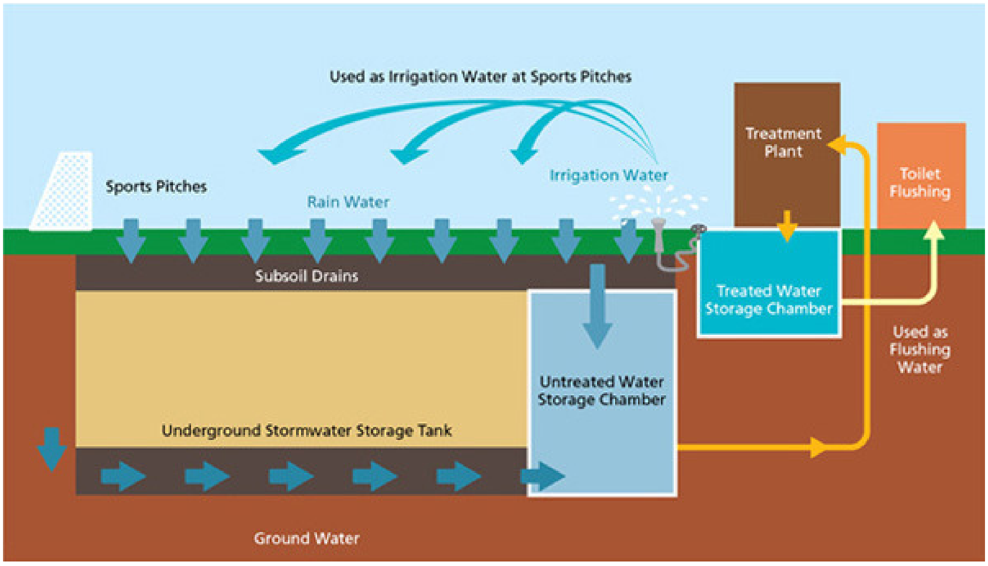

FIGURE 50 WATER HARVESTING SYSTEM AT HAPPY VALLEY UNDERGROUND STORMWATER STORAGE SCHEME

Alternative Water Sources

Alternative water sources including treated effluents from sewage treatment works, treated grey water, and some of the collected raw water to be released from others (such as upstream irrigation reservoirs, catchwaters, etc. after coordination with WSD) can be used to maintain environmental flows in the rivers. Water quality of the alternative sources should comply with the Water Quality Goals for various designated water uses.

Weirs

A weir structure is a barrier across the width of a river that is commonly used to raise the water level and act as a water retention structure. By impounding floodwater or environmental flows, weirs are particularly useful in these short-lived channels and relatively dry watercourses. A series of weirs can be constructed at suitable locations so that water can be retained on the upstream river section for a longer period, which may promote plant growth and aquatic species survival in dry environment.

The location and height of the weir should be carefully reviewed to avoid detrimental effect on the river hydraulics and existing aquatic ecosystems. Since the weirs are designed to be overtopped, sediment and debris may accumulate behind the weirs. Moreover, erosion and scouring may occur at downstream of the weir.

4.2.3 Environmental Flow Monitoring

Monitoring and assessment of environmental and ecological responses of a river to environmental flow regimes can help project proponent to confirm whether the environmental flows have achieved the desirable outcomes and apply any lessons learnt to future river management. The monitoring programme should specify the variables to be monitored, sampling frequency/ time, and locations.

For variables that are related to flow characteristics, it is recommended to regularly measure flow depth and velocity since they both play a vital role in aquatic ecosystems. Water depth can influence the other crucial environmental factors such as underwater light intensity, temperature vibration, and nutrient contents, while flow velocity determines the kinds of organisms that can survive in the river. For instance, some organisms thrive in fast-flowing water while others prefer stable pools.

In addition, variables to be monitored should reflect the environmental flow objectives. For instance, if an environmental flow objective is to protect or restore native fish populations, project proponent should specify the species of interests, targets of abundance, spatial extent, etc.

5. COMMUNITY DEVELOPMENT

5.1 Community Improvement Features

By drawing people in closer contact with water, rivers encourage social interaction and physical activities. This section discusses the social aspect of revitalisation of water bodies and look into revitalisation features that can be incorporated into the project to improve urban connectivity and support leisure and recreational activities. The project proponent should engage specialists, such as architects, branding agencies etc., to design the revitalisation features with an aim to encourage social interaction and public enjoyment. Branding agencies should create brand identities for the river revitalisation project. They should also develop strategy plan to promote the unique identity of the river and develop interactive communication through community events and social media, with aid of innovative technology.

5.1.1 Connectivity Enhancement

In Hong Kong's highly compact built environment, many urban drainages channels flow through dense residential blocks and district centre with bustling commercial and industrial activities. Footpaths and cycle tracks that run alongside river banks can be a great addition to the existing pedestrian and cycling network by providing a more pleasant way to get around.

Existing pedestrian and bicycle paths can be revamped or widened if there is sufficient space. However, many urban channels abut on the vehicular roads, leaving little to no additional space for widened or new paths. In those cases, project proponent can consider partially or wholly cantilever the paths over the river but should avoid to completely cover a long river section.

To further enhance the riverine connectivity, existing footbridges can be revamped or new footbridges can be constructed. In lieu of footbridges, viewing decks can be built and serve as a destination for pedestrians as well as a cross-river connection. Footbridge and viewing decks can also be constructed to mask over extruding utilities across the river.

FIGURE 51 PROPOSED REVITALISATION OF TSUI PING RIVER FOR CONNECTIVITY ENHANCEMENT

5.1.2 Leisure Facilities[2]

Among all the street furniture that can be placed along the riverfronts, seating, shelters and lighting generally hold the widest appeal. Shading is also essential when it comes to seats/benches placement. Ideally, benches should be placed under a tree and get most shade

[2] Please note the "Design Manual: Barrier Free Access" issued by the Buildings Department for reference.

during the summer. Otherwise, other shade structures like pavilion and shelters should be provided. Public lighting should be consistently lit where night time use is expected to ensure a safe and pleasant environment. The chosen light fixtures should co-ordinate with selection of other street furniture for the space and resonate the overall revitalisation theme. Type of lighting should be carefully designed especially in rural areas in order to avoid adverse effect on river ecology. More environmental friendly lighting system should be considered to help contribution of carbon neutrality.

FIGURE 52 LEISURE FACILITIES ALONG RIVER IN LONDON

5.1.3 Art Displays

In addition, public arts can be integrated into the revitalisation of rivers to foster social and urban regeneration. Project proponent is encouraged to collaborate with local arts organisations and artists to install art exhibitions on open spaces in or along rivers to create a culturally appealing environment.

FIGURE 53 ART DISPLAY IN RIVER IN ROTTERDAM

5.1.4 Social and Recreational Activities

Revitalisation of water bodies enable more opportunities for water friendly activities. Cantilevered viewing decks can be constructed to create more open spaces for the public to engage in leisure activities and social gatherings while overlooking the river. For rivers that allow secondary contact recreation, people can participate in various water sports like canoeing, kayaking, boating. Primary contact recreation such as water play zone, interactive fountains, splash pad are also encouraged given that the water complies with the Water Quality Goals in Section 4.1.1. Storage space for relevant equipment should also be considered when planning the project.

FIGURE 54 LANTERN EXHIBITION CELEBRATING BIRTH OF BUDDHA AT CHEONGGYECHEON (SOURCE: KOREA TOURISM ORGANIZATION)

5.1.5 Public Access to River Bed

Research has shown that being near water can inspire a sense of peacefulness and promote mental health and physical well-being. For short-lived channels or watercourses with minimal flows, project proponent can explore the feasibility of transforming the rivers into an open space that can be accessed and enjoyed by the public. The river should be wide enough to create a spacious environment for people to enjoy.

Sufficient stairs and ramps should be constructed at an adequate interval along both sides of the river. This allows for people to have multiple escape routes in case of an emergency. In-river walkways together with stepping stones that enhance connectives across the river can be constructed to form a well-connected pedestrian network inside the river. Besides pedestrian paths, project proponent should also explore more diversified land uses of the riverbed space, such as soccer field, platform decks, outdoor cafe. When planning the extent of the access for the public, project proponent should consider the balance of ecological function and the promotion of public access.

Public safety is of paramount importance for rivers that allow public access. An accurate, timely and reliable flood warning system should be in place, discussed in Section 7 of this PN. In addition to flood warning system, safety/rescue/security measures should also be in place.

FIGURE 55 PUBLIC ACCESS TO RIVER AT ROTTERDAM

Visitor/Education Centre

A visitor centre can provide a location showing information to promote the multiple benefits of river revitalisation to the public. This visitor centre can be also included in the itinerary of educational tour to promote the value of the project among the community. Project proponent is encouraged to explore available location to provide such visitor centre. Project proponent should consider provide toilet in the visitor centre. Exhibits inside the visitor/education should be carefully considered and some interactive exhibits may be more desirable. Project proponent should have due consideration on long-term management of the centre.

FIGURE 56 VISITOR CENTRE OF MAESLANT BARRIER IN THE NETHERLANDS

Thematic Planting

The provision of greening vegetative elements should resonate the themes of revitalisation wherever feasible with due consideration. For example, for areas subject to tidal submersion, project proponent should review the choices of vegetative species to suit the conditions of seawater and intertidal effects. The selection of planting should also take into account the seasonal effect, overall ecological value and suitability for tourist.

5.2 Communal Space and Associated Land Requirement Issues

Similar to being near to water, spending time in the open spaces is proven to be beneficial to individual's mental and physical health. Well planned open spaces also promote more social interactions and cultivate healthy communities. Project proponent should look for opportunities to incorporate open spaces and vacant spaces near the rivers into the project.

During the planning stage of the project, project proponent should identify existing open spaces like parks, sitting-out areas, children's playground, waterfront promenade, and vacant/abandoned spaces that are in close proximity with the rivers. An integrated approach should be adopted in planning them to bring out more social benefits and synergy. For example, vacant land adjacent to the river can be transformed into a comfortable rest area looking out on the river.

FIGURE 57 INTEGRATION OF COMMUNAL SPACE INTO RIVER IN SINGAPORE BEFORE (LEFT) AND AFTER (RIGHT) REVITALISATION

To reduce solar heating effect, different types of land cover surfaces have been studied with regards to the efficiency of surface temperature reduction. The following non-exhaustive table summarises the efficiency of different land cover types reduce the surface temperature comparing with bare concrete surface. The project proponent should have due consideration of selection of suitable land cover types to improve the human comfort.

TABLE 4 EFFICIENCY OF DIFFERENT LAND COVER TYPES REDUCING SURFACE TEMPERATURE

Land Cover Surface Type	Bare Concrete	Semi-Grass*	Full-Grass**	Under Tree	Water
Surface Temperature Reduction	-	Moderately Effective	Moderately to highly Effective	Highly Effective	Highly Effective

*Semi-grass refers to land cover with 50% of grass cover and 50% of soil/concrete cover
**Full-grass refers to land cover with 100% of grass cover with long grass leaves

Concrete river banks are not recommended due to its ability to absorb solar heat and leading to high surface temperature. The project proponent should avoid concrete river banks as long as the drainage requirements satisfied. River banks covered by grass with a high density but a low grass height can be considered. Land cover effect on human thermal comfort should be considered by project proponent to have a sustainable development. For example, tree with a wide canopy for shading is highly recommended for it can effectively reduce surface temperature and improve human thermal comfort. Combination of blue-green design is highly recommended.

Since these open or vacant spaces may belong to various parties, such as Leisure and Cultural Services Department, Lands Department, MTRCL or utilities companies, etc. Project proponent should delineate the extent of the project area as well as land requirement and duly evaluate the potential impacts and risks of land acquisition. Community engagement at planning stage, such as through design thinking approach, is essential to identify the appropriate scheme for river revitalisation.

6. CARBON NEUTRALITY

The Government announced in 2020 Policy Address striving to achieve carbon neutrality before 2050. To echo with the pledge, project proponent should formulate appropriate measures, such as generation and application of renewable energy, in the river revitalisation projects to contribute in carbon neutrality. Project proponent should make reference to the latest Hong Kong's Climate Action Plan and propose renewable energy measures such as photovoltaic (PV) systems and hydro turbine systems in the river revitalisation projects.

FIGURE 58 SOLAR-POWERED AERATORS AT SHAN PUI RIVER

Furthermore, with recent rapid growth of implementation of floating photovoltaic (FPV) systems in water bodies around the world, the Government would explore the feasibility of implementing FPV systems in the polders and river channels. Project proponent should assess the feasibility of implementation of FPV systems in river revitalisation projects with due consideration of various aspects (e.g. mooring method to resist strong wind, storm surge and high flow due to typhoon and heavy storm, etc). The project proponent should formulate design and identify specifications of equipment and works as appropriate. The design should take into account public concerns such as glare, visual impact, hindrance to water activities, etc. The project proponent should also consult and seek agreement with operation and maintenance parties at design stage of the project regarding the operation and maintenance requirements of FPV systems.

7. FLOOD FORECASTING AND WARNING SYSTEM

7.1 Definition

Safety is of the paramount importance for any river assessable by the public during flooding. A flood forecasting and warning system plays an important role to allow people to have sufficient time to evacuate the river.

A flood forecasting system is "the use of real-time precipitation and stream flow data in rainfall-runoff and stream flow routing models. It predicts flow rates and water levels ranging from few hours to days ahead" (Rauf et al. 2016), depending on the catchment and stream characteristics. On the other hand, flood warnings are issued when an event is occurring or is imminent. The outcome of flood forecasting is a set of time series of channel flows or river levels at various locations, while flood warning makes use of these forecasts to make decisions for whether and when to issue a flood warning to public or rescind the previous warning.

7.2 Types of Flood Forecasting and Warning Systems

There are three main flood forecasting and warning systems that the project proponent can consider for rivers that allow the public to participate in close to water activities. The project proponent should develop a suitable system based on the need for the project if human activities within the river is engaged and flood forecasting and warning system is necessary.

Type I – Weather Forecast & Hydrological/Hydraulic Model

Type I system is a combination of weather forecasting and hydrological/hydraulic modelling techniques. The system generates flood predictions using the rainfall forecast data, which may be obtained from Hong Kong Observatory. By using modelling technique, floods could be predicted in advance for hours to days, therefore more lead time is allowed for implementing flood management and safety plan.

The flood forecasting and warning highly relies on model outcomes and the system's accuracy and reliability. However, sole model result may lead to the management's miss decision-making due to the model uncertainties. To optimise and maintain the model, sufficient resources needs to be invested, such as maintenance personnel, system operators and corresponding operation and maintenance costs.

An example of Type I system can be found in Salado Creek in the United States. The Salado Creek Flood Forecasting System comprises 4 processes which are data input, data management, model simulation and response.

The system adopts both real-time and forecasted rainfall data from the National Weather Service (NWS) of the United States. In addition, real-time water level observations from river gauges are used to validate the model outputs. The hydrological/hydraulic model will simulate water levels/flows. In addition, the 2-D flood extents are also achievable by the modelling system.

Once the forecast water level exceeds the pre-determined threshold, the system would activate the flood warning signal. Warning message could be disseminated by the model user interface, SMS message and email, and corresponding measures will be carried out.

Type II System- Weather Forecast & Real-time Observation

Type II system is a combination of weather forecasting and real-time monitoring. This system applies no modelling technique but weather warning signals and water level observations for flood warning.

It typically applies to a river where water level is possible to raise rapidly so a certain evacuation time is needed.

The weather forecast may come from information from Hong Kong Observatory and academic units, thus is easier to obtain data sources. Since no model development is needed, this type of system has lower operation and maintenance costs than Type I.

Relatively speaking, Type II provides the management fewer lead time to response to upcoming floods. Therefore, the warning triggers should be carefully determined with comprehensive study on hydrological characteristics and required time for evacuation.

Type II is applied to revitalised water bodies where visitors can quickly evacuate within the time between weather warning signal is issued and the actual occurrence of the flood.

Longgang River in Shenzhen is a typical example of Type II system. The flood warning system uses Rainstorm/ typhoon Warning Signals hoisted by the Meteorological Bureau of Shenzhen Municipality (SZMB). Water level meters are scaled on bridge piers in Longgang River to measure real-time water levels.

In normal condition days, visitors are allowed to enter the river course through secondary platforms and stepping stones; while during warning signals of rainstorms and typhoons are issued, accessibility to river course is limited by a series of warning triggers and actions which were developed by the management authority.

To deal with flood warnings under different weather conditions, the management has developed a series of warning triggers and actions based upon different rainstorm/ typhoon warning signals and observed water levels.

Type III System – Real-time Observation Only

Type III solely relies on real-time water level observations as warning triggers to handle site evacuation. It applies to water body which is not sensitive to water levels and people can timely evacuate.

The management of Kallang River Park uses the Type III system for flood warning by water level observations. Water levels are measured by the stream gauges installed along the river. Moreover, the park has installed red markers at risky spots at a level of 3m to remind people of the instant water level.

The flood warning is triggered when river level rises for a certain height (e.g. 0.3 – 0.5m). The operator will disseminate warning announcement through broadcasting system, while also flash the alert lights on safety nodes. People should leave the water immediately once aware of the warning message.

The red markers also serve as a warning trigger. Once the water level reaches the red marker (i.e. water depth is at 3m), people within the park will be guided by site personnel to locations where levels are higher than red markers as soon as possible.

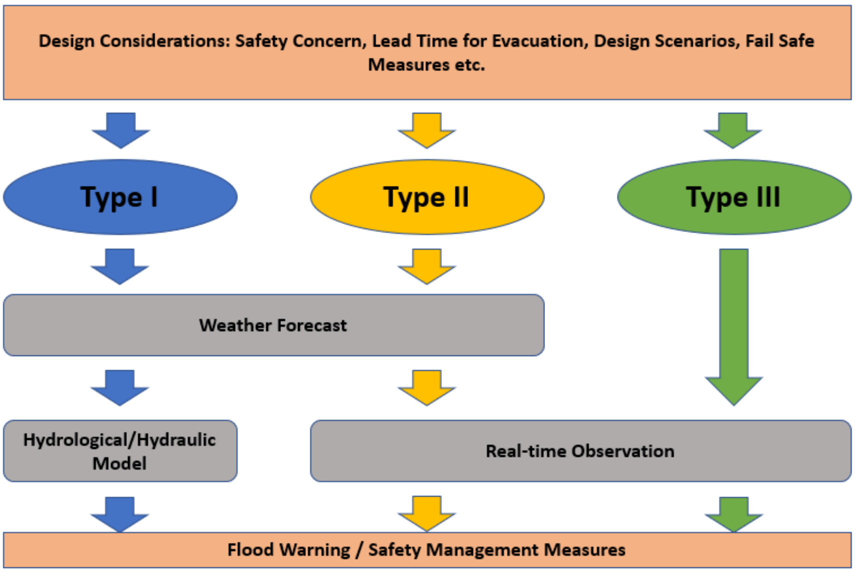

FIGURE 59 TYPES OF FLOOD FORECASTING AND WARNING SYSTEM

7.3 Infrastructure and Human Resources

Generally speaking, a flood forecasting and warning service requires a central operational office to communicate with outstations and those dependents on the service. In addition, monitoring devices (e.g. river gauges, CCTV monitors), flood warning signs and life-saving equipment also form part of the flood forecasting and warning system.

It is also necessary to have adequate and suitably qualified staffing for operating and overseeing the flood forecasting and warning system. A team of field staff is recommended to patrol along the river to identify unsafe behaviours and evacuate people in time during emergency. Management team/ office should be established to manage overall man power. Emergency action plan should also be developed for operational phase. The number of the field staff highly depends on the extent of the river that allows people to come into close contact with water. Project proponent should conduct site specific assessment to determine the suitable inputs for the revitalised river and liaise with Hong Kong Observatory and other relevant authorities as early as possible for such services.

8. MANAGEMENT AND MAINTENANCE ISSUES

8.1 General

This Section identifies the maintenance and management requirements and potentially operation issues for a revitalised river channel, along with possible solutions. The requirements will vary with the type and complexity of the revitalisation features.

It is suggested that the project proponent should initiate the communication with relevant operation and maintenance parties regarding the design, operation and maintenance at early stage of the project. Clear demarcation of maintenance and management responsibilities is essential. The project proponent should consult and seek agreement with operation and maintenance parties regarding the need and area requirement of management office and storage areas at design stage of the project in a collaborative manner. The design, recurrent cost, operation and maintenance manual of the revitalised river channel should be agreed by the operation and maintenance parties during the design stage of the project. The operation and maintenance manual should be provided by the project proponent upon the completion of the works and should be reviewed and updated whenever necessary.

Table 5 shows the maintenance matrix for a revitalised river channel.

8.2 Structure Maintenance

River channel structures include embankments, river bed, pipework, gates, etc. They require regularly inspecting and maintaining to remove obstacles and litters and repair physical damage immediately.

For the river bed, the maintenance authority should inspect it before and after wet season respectively while water level is low. Where the flow is deep and fast, they should inspect the river bed after every rainstorm event. The responsible department should immediately repair the observed scouring and consider feasible protection measures.

There may be various forms of special features established within revitalised river channels, e.g. fish ladders, climber system, DWFI system, artificial islands, stepping stones, social and recreational facilities, walkways, weirs. They need to be regular inspection and repairs as well, especially after flood events.

The project proponent should consider the maintenance effort when formulating the design and should target to minimising the maintenance effort during operational phase. (e.g. Zhonggang Main Drainage, Taiwan)

8.3 Flood Control

Large obstacles within river channel will reduce the flood conveyance capacity of river, while litters and debris can cause blockage in drainage outlets. If the flood capacity is significantly reduced by sediment deposits, desilting may be required. Appropriate mitigation measures should be implemented to minimise potential odour issues and ecological disturbance during desilting, e.g. covering the removed silt with tarpaulin sheet. Non-woody (and non-invasive) vegetation species at the land-water margin should be preserved.

8.4 Vegetation Control

Vegetation like trees, shrubs, grasses, vines are likely to be introduced in the river revitalisation design because they are essential to transform a concrete-lined channel into a green river with natural habitat. Regular mowing and cutting are needed. Desilting programme should be carefully designed and should only be conducted in areas in need. Consideration should be given to the trimming, pattern of mowing and correct disposal of cuttings, especially if there are invasive species. Safety for the workers of vegetation maintenance at the river channel should also be considered, for example, the safety code of practice, safety precautions, access and PPE.

8.5 Safety Management

As discussed in the previous section, a flood forecasting and warning system is required ensure public safety for rives that allow public to participate in close water activities. The system comprises hardware (e.g. river gauges, CCTV monitors, flood warning facilities, life-saving equipment, operations centre, management office) and software (e.g. forecasting model, patrol team).

For hardware, regular inspection, testing and replacement are required to ensure normal functioning; while for software, maintenance and update for forecasting model and man power inputs are needed.

It is also important to maintain sufficient and safe access and egress taking into account the evacuation route/ time. They should be clearly identified, well-lit and unobstructed so people can evacuate quickly in the event of an emergency.

Planning for both hardware and software of safety management should start at early stage, with sufficient desktop study (e.g. routing of patrol, number of visitors within the river to be managed, evacuation route and plan). Once the need for a flood forecast system is identified for the project, the project proponent may consider engaging an engineering consultant/ local institution to develop such system if necessary.

8.6 Organising Events

The revitalised river channel can be used as a venue for organising events for education / cultural promotion. Project proponents may approach relevant parties/ authorities in due course for liaison of organising events. Organising events within the revitalised river channel should be properly planned in advance, taking into account the relevant considerations such as crowd control, access control, safety management as discussed separately.

8.7 Facility Management

If amenity areas adjacent to the river have been incorporated into the revitalisation scheme, leisure facilities and art exhibition in these areas require regular maintenances and repairs.

Damaged facilities not only cause inconvenience but may also post safety hazards to users. Weed and litter should be removed in a regular interval.

8.8 Ecological Control

The project proponent should also pay attention to controlling invasive alien species. Alien faunal and floral species could cause damage to the ecological system. Project proponent should prevent introduction of invasive alien species in the first place. Regular inspections may be required to ecological enhancement measures free from invasive alien species. Continuous monitoring after the project implementation should be considered as one of the maintenance and management issues in order to ensure the proper functioning of the ecological enhancement measures in providing benefits to the ecology.

TABLE 5 CONSIDERATIONS FOR DESIGN, MANAGEMENT AND MAINTENANCE ISSUE FOR RIVER REVITALISATION

Key Issue		Solution to Key Issue and Operation Consideration
Safety and Risk Management	• People safety concern in river which allows public access • River bed and bank erosion causing structural instability • Overbank flow engaging adjacent footpaths and properties • Emergency procedures related to human activities, e.g. injury, drowning • Flood forecasting and warning system to be maintained	• Develop a warning system and evacuation plan to protect people when the area needs to be evacuated • Stabilise river bed and banks with appropriate measures (e.g. deflector) and allow certain level of dynamic fluctuation to appear at the river bed • Provide a broader riparian zone with a floodplain function to storage overbanks flows; • Redesign/ relocate the parks/sitting-out areas and facilities to tolerate occasional flooding • Develop a standard operating procedure in case of people are injured or drowned • Expertise to maintain the forecast and warning system to ensure proper functioning may be required • Inspect the evacuation routes to ensure it is free of obstacles • Inspect river bed and banks to ensure the shape of the river is retained and to identify any scouring spots • Regularly check the furniture stability to ensure they are not loose • River that allows close water activities should deploy a patrol team to safeguard the public's safety • Experienced officer should be on duty to operate the warning and evacuation system during the opening time

Key Issue		Solution to Key Issue and Operation Consideration
Flood Control	• Weed growth in channel and on batters, reducing the flood conveyance • Obstruction/litters in river reducing its flood conveyance • Sedimentations in river reducing its flood conveyance • Maintain the design flood conveyance of river	• Control weed growth in the river and on batters • Plant shade trees, sedges, and rushes in riparian zone to control weed growth • Inspect inlets, outlets, river bed, and overflows for blockages, leakage, collapse, erosion, and fix them if required • Regularly trim weeds at side banks to maintain certain roughness. • Regularly remove litters and sedimentations in the river • Carry out post rainstorm inspections to ensure the normal performance of the drainage system • Maintain vegetation density and height to prevent soil erosion • Minimise potential effects of leaf litter on flood conveyance, especially during regular grass cutting and wedding • Disposal of excavated sediments should comply with the local waste management regulations

Key Issue		Solution to Key Issue and Operation Consideration
Water Quality	• Poor water quality after rainstorm events or typhoons • Poor water quality caused by litters and sedimentations • Poor water quality cause public nuisance or water-borne diseases for people engaging primary and secondary contact recreation activities • Poor water quality due to inappropriate connection	• Install DWFI system to intercept polluted flows • Provide blue-green elements such as engineered wetlands and bioretention system to treat polluted surface runoff from adjacent catchments • Remove litters and sediments in the river • Recharging the river by introducing other water sources • Garbage collection unit / system should be considered • Explore other dry weather flow intercepting and treatment system (e.g. Newly Designed DWFI) • Regularly sample and test water quality • Regularly maintain the treatment unit to meet its design treatment effectiveness • Facilities that allow primary contact recreation (e.g. water play zone) should develop its standard operating procedure in case of not meeting the Water Quality Goals • Re-use of the "used water" from recreational activities for other uses such as irrigation should be considered • Develop emergency response plan on how primary/secondary contact recreation activities shall be suspended when water quality fails to achieve the water quality goals • Maintenance frequency and water sampling parameters for various treatment elements may vary depending on water quality

Key Issue		Solution to Key Issue and Operation Consideration
Leisure and Amenity	• Additional leisure and recreational spaces and facilities needed • Lack of educational resources to raise environmental awareness of the river and its ecosystem	• Arrange leisure spaces for various purposes (e.g. cycling tracks, footpaths, green areas, benches, shelters) • Arrange educational resources (e.g. information boards, signage, and community engaged courses) • Maintain the landscape and cleanness of the adjacent areas to the river
	• Hygiene issues due to overgrown weeds • Threat of alien faunal and floral species	• Regularly remove litters in amenity areas • Regularly remove weed and cut grass • Regularly inspect, identify and remove invasive species, trained staff may be required • Inspect and repair leisure facilities • The leisure facilities should provide detailed user instructions and safety warnings

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10. ANNEXES

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Annex 4	Rapid Stream Evaluation (RSE) Scoring Criteria for Evaluating the Ecological Value of River Channels
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Annex 1 Blue-Green Drainage Infrastructure and Existing Guidelines on River Channel Projects

What is Blue-Green Drainage Infrastructure

Blue-green drainage infrastructure (with "blue" representing the city's water bodies and "green" referring to vegetation) is a form of development aiming at improving the sustainability and flood adaptive capacity 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 drainage infrastructure reduces urban runoff, water pollution, solar heating effect, carbon footprint and energy consumption, and blends the natural water environment into the city. As blue-green drainage 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 drainage infrastructure include revitalised river channel, flood lake/wetland, flood storage tank, floodable area, bioretention system (rain garden and bioswale), green roof, porous pavement system, and water harvesting.

Benefits of Blue-Green Drainage Infrastructure to Hong Kong

The benefits of blue-green drainage infrastructure could be well demonstrated by different overseas examples, such as Cheong Gye Cheon in Seoul and Kallang River located at Bishan-Ang Mo Kio Park of Singapore.

In Hong Kong, continuous land development and climate change lead to an increase in surface runoff, and become vulnerable to 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 drainage 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 drainage 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 solar heating 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, provide ecological functions, act as ecological corridors connecting natural habitats, or even support urban 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 drainage 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 drainage 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.

Key Items to Consider

Project proponent should take a liberal approach when designing a blue-green drainage 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 drainage infrastructure in the planning and design of revitalised river channels, this guidelines 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 guidelines.

Collaboration of inter-disciplinary teams forms the basis of the blue-green drainage infrastructure design approach, and should likewise be established from the project outset when undertaking revitalised 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 drainage 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. Community engagement at planning stage is essential to identify the appropriate scheme for river revitalisation.

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 (5th 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 (5th 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 latter 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 design and planning of revitalised river channels are listed below:

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 (Chapter 4)	Oct 2015
PLAND	Study of Landscape Value Mapping of Hong Kong	Dec 2005
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
DEVB TC(W) No. 4/2020	Tree Preservation	Feb 2020
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
DEVB TC(W) No. 5/2020	Registration of Old and Valuable Trees, and Guidelines for their Preservation	Feb 2020
ETWB TCW No. 14/2004	Maintenance of Stormwater Drainage Systems and Natural Watercourses	Jun 2004

DEVB	Cyber Manual for Greening http://devb.host.ccgo.hksarg	Mar 2020
DEVB TC(W) No. 6/2015	Maintenance of Vegetation and Hard Landscape Features	Oct 2015
DEVB TCW No. 5/2017	Community Involvement in Planting Works	Sep 2017
WBTC No. 4/1997	Guidelines for Implementing the Policy on Off-site Ecological Mitigation Measures	Feb 1997
ENB	Hong Kong Biodiversity Strategy and Action Plan	Dec 2016

<u>Overseas Examples of River Revitalisation</u>

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

The first project is an example on revitalising the channel to provide enhanced urban landscape and water bodies, while the second example demonstrates the revitalisation of the channel all the way back to a natural river state. In addition to this guidelines, 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 drainage infrastructure in river channel design, and on similar concepts such as 'green infrastructure', 'low impact development', and 'water sensitive urban design'.

Cheong Gye Cheon, Seoul, Korea

Cheong Gye Cheon is a revitalisation 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.
- Construction of large sewers alongside the river to protect the revitalised channel from sewage discharge during storm events.

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.

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 revitalisation 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.

Izumi River (和泉川), Yokohama, Japan

There were numerous river restoration projects in Japan during the 80s and 90s. Kadoorie Farm & Botanic Garden and Japan River Restoration Network visited several of these sites in 2018. In general, those river channels were revitalised by removing the concrete and man-made structures and re-profiling the cross sections. In order to cope with the increased roughness brought by new substrates, the revitalised sections were usually widened and deepened. Izumi River in Yokohama is one of the examples. The revitalised section was widened by relocating the original residential areas alongside the river channel. The concrete river bed and vertical embankment were largely replaced by natural bed substrate and vegetated gentle slope respectively. Usually, only simple facilities such as stairs and ramps were installed alongside those revitalised rivers to allow people to get close to them. At present, the revitalised section of Izumi River is mainly managed (e.g. vegetation management) and monitored (e.g. biological and water quality monitoring) by a local concern group on a voluntary basis.

IZUMI RIVER AFTER REVITALISATION (CREDIT: KADOORIE FARM & BOTANIC GARDEN)

Guides for Revitalisation of Channelised Rivers

1 Goals and Objectives of Revitalisation / Habitat Enhancement

The ecological impacts arising during river regulation works have been discussed in Section 2 of this PN. For any given project, determination of goals and objectives is critical in the project design, implementation, evaluation and management. For a channelised stream which has lost many of its ecological and riverine functions, the ultimate goal of revitalisation 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; stabilising baseflows to support food-webs in shallow water habitats; recreating seasonal temperature patterns; maximising dam passage to allow recovery of fish population; and implementing a management system that relies upon a sustainable habitat which utilises natural instead of artificial processes for revitalisation and maintenance (Stanford et al., 1996).

2 Review of Pre-channelisation Information

Pre-channelisation 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 organisations. 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 channelised section is not available, reference may also be made to the environmental setting and biota of river stretches upstream and/or downstream to the channelised section. These areas would share certain similarity to the channelised river courses under study at their pre-channelised 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 channelised 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 revitalisation 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 river 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 operation and maintenance 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 revitalisation/habitat enhancement works. It should also assess the funding requirements to support all components (including post-project evaluation). The relationships among project objectives, revitalisation/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 revitalisation/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 revitalised river banks could provide attractive green trails and cycle tracks to encourage low-carbon living. Co-use of the revitalised rivers as public recreation space and scenic area could increase the usable public area within the community. The revitalised water bodies could help mitigate solar heating 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 2 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 summarise 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. Pre-construction briefing to site workers and foremen should be conducted to reiterate the precautionary measures/ environmental practices, and to behave in an environmental friendly way. Disciplinary consequences for not properly following the measures/ practice or relating to any misbehaviours should be written clearly in the contracts and the workers and foremen should be well informed before commencement of works.

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 3 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, minimisation of discharge into the river, and road improvements), minimisation of impervious cover through low impact designs options, stabilisation of eroding banks with vegetation or bioengineering measures, removal of artificial stream bank and bed armouring/linings where practicable, and minimisation of the adverse effect of urbanisation 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). Spatial variation should also be considered (e.g. weeding only a selected section/ side/ area in different times of the year).

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 colonisation 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 colonisation 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 colonisation 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.

Chemical methods should not be considered for removal of exotic/invasive species as these methods would also kill native species and pose hazards to human. However, 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. Quarantine is suggested to apply for planting of new trees or vegetation from non-local nursery, but not from in-situ preservation of vegetation/seeds from existing soil. For transplantation/ translocation, quarantine of species may be considered to minimise risks of invasion. 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 minimise 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 4 Rapid Stream Evaluation (RSE) scoring criteria for evaluating the ecological value of river channels

The RSE scoring criteria are developed for evaluation of the environmental conditions of river channels and lowland rivers in Hong Kong. For the biological factors, the scoring categories are set with reference to the ecological database. River channels with higher number of native and wetland dependent species and species of conservation importance will score higher marks. The following criteria are identified for evaluating the ecological value of river channels:

(1) **Physical and chemical factors of importance to ecology**

- **water quality** - the water quality indicates the state of health of the river channel in supporting the aquatic life; and
- **instream habitat** – the ability of a stream to meet basic physical requirements necessary for the support of a diverse aquatic community (e.g. the naturalness or diversity of channel bed substrates).
- **embankment profile** – shows the cross section design of the channel. Design may be varied to meet hydraulic and biological needs. It should balance between the self-cleansing capability and animal passage.
- **Aquatic habitat diversity and longitudinal connectivity** – more natural and diverse aquatic microhabitats provide more diverse habitat to support different wildlife; the lack of artificial impediment along the channel will provide better ecological connectivity between upstream and downstream.
- **Stream-riparian ecosystem –** the lateral inundation of stream-riparian zone indicated by the duration and volume of flow in wet and dry seasons in supporting the aquatic ecosystems.

(2) **Biological factors**

- **species richness** – number of native and wetland dependent species including wetland dependent birds, dragonfly, and wetland dependent herpetofauna;
- **species of conservation concern –** number of faunal species of conservation concern which are native and wetland dependent;
- **freshwater/estuarine fish species** – with consideration of species richness and percentage of native fish species;
- **freshwater invertebrates** – with consideration of species richness and the number of biological indicator for poor water quality;
- **riparian habitat conditions** (habitat diversity, habitat coverage, and ecological linkage); and
- **riparian vegetation at water margin & channel embankment** – provides channel bank stabilisation as well as habitats and shading for in-stream organisms.

Table 4-1: Criteria Selected for Evaluation of the Habitat Quality of Green Channels

Criteria		Description	Ranking*	Description
(1) Physical and chemical factors of importance to the biota (Weighting: 32%)				
(a) Water quality (Weighting: 8%)	(i) pH	Provides indication of anthropogenic pollutants. Acidification is harmful to organisms when pH falls below 5.0 (Allan and Castillo, 2007)[17]. Lowered pH is often accompanied by a number of chemical changes that aquatic fauna respond to.	0	pH < 3.0 or >12.0: industrial and municipal wastewater pollution
			1	pH 3.0 – 5.0: polluted surface water that is harmful to most organisms
			2	pH 8.6 – 11.9: polluted surface water supporting only less susceptible biota.
			3	pH 5.1 – 6.4: supporting less susceptible biota
			4	pH 6.5–8.5: unpolluted surface water supporting most of the aquatic biota.
	(ii) DO (%)	Dissolved Oxygen (DO) indicates the total amount of oxygen dissolved in the river channel water. DO supports aquatic fauna for respiration and maintenance of life. Ranking is based on the WQI for river water quality monitoring established by the HKSAR EPD.	0	<30% or >130%: very poor water quality
			1	30 – 50%: poor water quality
			2	51 – 70% or 121 – 130%: fair water quality
			3	71 – 90% or 111 – 120%: good water quality
			4	91 – 110%: excellent water quality with dissolved oxygen near or at saturation
	*(iii) BOD5	BOD5 is the measure of the amount of dissolved oxygen consumed to break down organic material in five days by biological processes. Ranking is based on the WQI for river water quality monitoring established by the HKSAR EPD. High BOD5 level indicates water pollution.	0	>15.0 mg/L: severely-polluted water quality
			1	9.1 – 15.0 mg/L: poor water quality with moderate pollution
			2	6.1 - 9.0 mg/L: fair water quality
			3	3.1 – 6.0 mg/L: good water quality
			4	≤3 mg/L: excellent water quality
	(iv) NH3-N	Ammonia-Nitrogen (NH3-N) Indicates the extent of organic contamination of the river channel. Ranking is based on the WQI for river water quality monitoring that established by the HKSAR EPD.	0	>5.0 mg/L: high level of contamination by municipal and industrial discharge or fertilizer runoff from agricultural land
			1	2.1 – 5.0 mg/L: medium level of contamination by municipal and industrial discharge
			2	1.1 – 2.0 mg/L: low to medium level of contamination by nutrient
			3	0.5 – 1.0 mg/L: low level of contamination by nutrient
			4	<0.5mg/L: limited contamination by nutrient
(b) Instream habitat (Weighting:	Substrate	Different kinds of substrates found in running waters influence the distribution and	(I) + (II)	Subscore (I): natural vs. artificial substrate; Subscore (II): homogeneity vs. heterogeneity

Criteria		Description	Ranking*	Description			
6%)		abundance of the biota, as they provide the platform and habitat where benthic organisms attach, forage, complete part or whole of their life cycles and seek refuge from current and predators. Invertebrate diversity and abundance tend to increase with substrate stability and heterogeneity (Allan and Castillo, 2007)[18]. Furthermore, artificial substrate was shown to have fewer abundance and taxon richness as compared to natural substrates, as well as supporting more dipterans, mayflies and stoneflies Concrete, gravels (grain size < 4mm), pebbles (grain size from 4 to 64mm) and cobbles (grain size > 64mm) are the four type of substrate in this assessment	0	0	Dominated by artificial substrates i.e. > 50% coverage is concrete	0	Homogeneous substrates: > 90% for any type of substrate
			1	1	Mixed artificial and natural substrates i.e. 1 – 50% coverage is concrete	1	Slightly heterogeneous substrates: 70 - 90% for any type of substrate
			2				
			3	2	Completely natural substrates i.e. 0% coverage is concrete	2	Heterogeneous substrates: < 70% for each substrate found at the channel
			4				
(c) Embankment profile (Weighting: 6%)	Embankment profile of the channel	Different cross-section shapes will affect the hydraulic performance and biological need. Gentle sloping embankment would facilitate animal passage to the channel, thus improving the ecological connectivity to the adjacent habitats. Vertical embankment would trap the animals (especially terrestrial mammal e.g. Red Mutjac) that go down to the channel but cannot climb back up due to the steep profile. A slope with gradient less than 35° is suitable for planting a wide range of floral species, including small trees.[20] This in turn increases the microhabitat available for organisms and also increases the ecological connectivity of the channel with surroundings.	0	Vertical embankment at both sides of the channel.			
			1	Stepped embankment at one side and vertical embankment at the other side; or Stepped embankment at both sides.			
			2	Sloping embankment at both sides with gradient higher than 55°; or Stepped embankment with sections of sloping embankment with gradient within 35° to 55°.			
			3	Sloping embankment at both sides with gradient within 35° to 55°; or Stepped embankment with sections of sloping embankment with gradient lesser than 35°.			
			4	Gentle sloping embankment at both sides with gradient lesser than 35°.			

Criteria		Description	Ranking*	Description			
*(d) Aquatic Habitat Quality (Weighting: 6%)	Aquatic habitat diversity and longitudinal connectivity	River channel with more types of aquatic habitat would provide more diverse and complex habitat for wildlife. The aquatic habitats that are considered for scoring include: ▪ Pools ▪ Riffles ▪ Wood Debris ▪ Emerged or Submerged Vegetation ▪ Shading ▪ Root Mat ▪ Underbank Cover For the longitudinal connectivity along the river channel, river channel without any blockage of water flow by artificial barrier is ranked with higher score. Some artificial structures such as stepped structures, fish ladder or movable dam are helpful to mitigate the blockage of water flow and species migration in some extends.	(III) + (IV)	Subscore (III): Aquatic Habitat Diversity		Subscore (IV): Longitudinal Connectivity	
			0	0	Dominated by 1 habitat type	0	Water flow blocked by artificial structures
			1 2	1	Moderate variety of habitat types (only 2-4 habitat types)	1	Presence of artificial designs to mitigate flow blockage
			3 4	2	Wide variety of stable aquatic habitat types (>4 types of in-stream habitats)	2	No blockage of flow by artificial structures
*(e) Stream-riparian Ecosystem (Weighting: 6%)	Lateral inundation of stream-riparian zone	From a biological perspective, a flowing stream with sufficient water would be possible to support flow-dependent aquatic life, including fish and gill-breathing amphibians, benthic insects, crustaceans, and mollusks. Maintaining a basal flow is also vital to stream ecology.	0	No flow / ephemeral flow			
			1	Water flow only confine to dry weather flow channel during most of the time			
			2	Water flow do not confine to dry weather flow channel, but stream-riparian area coverage less than 50% of the channel bed area.			
			3	Water flow do not confine to dry weather flow channel for most of the time,and stream-riparian area coverage 50-70% of the channel bed area.			
			4	Perennial flow covers both the emergent and submerged planting zone.			
(2) Biological factors (Weighting: 68%)							
* (a) Species richness (Weighting: 12%)		Native and wetland dependent species (e.g. wetland birds, dragonfly and wetland dependent amphibian) recorded are counted (excluding flora, fish and freshwater invertebrates). The more diverse the species assemblages, the higher the ranking.	0	Insignificant species richness (0-2)			
			1	Low species richness (3-8)			
			2	Moderate – low species richness (9-15)			
			3	Moderate species richness (16-25)			
			4	High species richness (>25)			
* (b) Species of conservation concern (Weighting: 12%)		Channel with more species of conservation concern recorded which are wetland dependent and native are ranked higher	0	No wetland dependent and native species of conservation concern recorded			
			1	1 – 2 number of wetland dependent and native species of conservation concern recorded			

Criteria	Description	Ranking*	Description			
		2	3 – 4 number of wetland dependent and native species of conservation concern recorded			
		3	5 – 8 number of wetland dependent and native species of conservation concern recorded			
		4	>8 number of wetland dependent and native species of conservation concern recorded			
(c) Freshwater/estuarine fish species (Weighting: 12%)	Channel with a higher number of native fish species recorded are ranked higher	(V) + (VI)	Subscore (V): Fish species richness		Subscore (VI): Percentage of native fish species	
		0	0	0-5 freshwater fish species	0	0 – 30 % native species recorded
		1	1	6-15 freshwater fish species	1	31 – 60% native species recorded
		2				
		3	2	>15 freshwater fish species	2	> 60 % native species recorded
		4				
*(d) Freshwater invertebrates (Weighting: 12%)	Channel with a higher freshwater invertebrate species richness recorded are ranked higher. Channel with lower number of biological indicators for poor water quality are also ranked higher. The biological indicators for poor water quality are identified based on various published literature and reports which utilize the Biological Monitoring Working Party (BMWP) scoring system. Where possible scoring for species which occurred closest to Hong Kong were utilized.	(VII) + (VIII)	Subscore (VII): Freshwater invertebrate species richness		Subscore (VIII): Number of biological indicators for poor water quality	
		0	0	0 – 6 freshwater invertebrate species recorded	0	>5 biological indicators for poor water quality
		1	1	7- 15 freshwater invertebrate species recorded	1	3-5 biological indicators for poor water quality
		2				
		3	2	> 15 freshwater invertebrate species recorded	2	0-2 biological indicators for poor water quality
		4				
*(e) Riparian habitat conditions (Weighting: 10%)	The ecological connectivity with adjacent habitats within 30m riparian buffer may affect the ecological value of the channel. The greater the	(IX) + (X)	Subscore: Number of habitats with ecological value (IX):		Subscore: Coverage of habitats with ecological value (X):	

Criteria	Description	Ranking*	Description			
	number and coverage of habitats with ecological value, the greater the overall importance of the channel. Habitats with ecological value refer to woodland, brackish or freshwater marshes, managed pond, natural streamcourse and habitats have special conservation importance by documented scientific studies.	0	0	Containing no natural habitats or habitats which are of no or low ecological value	0	Coverage of habitats with ecological value ≤ 10%
		1	1	Containing one to two habitats with ecological value	1	Coverage of habitats with ecological value 11-50%
		2				
		3	2	Containing three or more habitats with ecological value	2	Coverage of habitats with ecological value > 50%
		4				
*(f) Riparian vegetation at water margin & channel embankment (Weighting: 10%)	The more natural the embankment riparian vegetation, the higher the ranking. Furthermore, more diverse wetland vegetation along the water margin would provide more micro-habitats for a variety of animals, and hence the ranking is also higher. Determination of wetland dependent plants are based on Photographic Guide to Aquatic Plants of Hong Kong (AFCD, 2015) and the native plant species based on Hong Kong Herbarium (AFCD, 2015)[21]	(XI) + (XII)	Subscore (XI): Number of wetland plant species		Subscore (XII): Number of native plant species	
		0	0	0-10 wetland plant species recorded	0	0-30 native plant species recorded
		1	1	11-20 wetland plant species recorded	1	31-60 native plant species recorded
		2				
		3	2	>20 wetland plant species recorded	2	>60 native plant species recorded
		4				

Table 4-2: Categorization of Physical and Chemical Factors

Categories	Scores
Excellent	27.1 – 32
Good	22.1 – 27
Average	16.1 – 22
Fair	8.1 – 16
Poor	0 – 8

Table 4-3: Categorization of Biological Factors

Categories	Scores
Excellent	57.1 – 68
Good	47.1 – 57
Average	34.1 – 47
Fair	17.1 – 34
Poor	0 – 17

Table 4-4: Categorization of Total Scores

Categories	Total Scores
Excellent	85.1 – 100
Good	70.1 – 85
Average	50.1 – 70
Fair	25.1 – 50
Poor	0 – 25

<table>
<tr><th colspan="3">Physical and Chemical Factors of Importance to Biota</th></tr>
<tr><th colspan="2">Criteria</th><th>Measures</th></tr>
<tr><td rowspan="5">(a) Water quality</td><td>(i) pH</td><td>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.</td></tr>
<tr><td rowspan="2">(ii) DO (%)</td><td>Creation of pools and riffles and use of high-head flow systems, weirs and cascades to increase aeration</td></tr>
<tr><td>Preservation and planting of riparian vegetation to lower the surface water temperature and increase the solubility of oxygen in water correspondingly</td></tr>
<tr><td rowspan="2">(iii) NH3-N</td><td>Identify source(s) of pollution (e.g. industrial and municipal wastewater, stormwater) and implement controls on their discharge into the river</td></tr>
<tr><td>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.</td></tr>
</table>

Physical and Chemical Factors of Importance to Biota		
Criteria		Measures
(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 stabilise 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

Biological Factors	
Criteria	Measures
	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.

Note: Any reintroduction of species should be well planned and implemented by qualified ecologists, and the habitats of species and risks of genetic pollution should be duly considered.

Annex 5 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
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	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	兩歧飄拂草	Herb	Open grassy fields

Scientific Name	Chinese Name	Growth Habit	Natural Habitat
dichotoma			
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
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

Scientific Name	Chinese Name	Growth Habit	Natural Habitat
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 6 Revitalisation 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 channelisation 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 channelisation should be compensated.

The primary goals of revitalisation 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 revitalisation and enhancement of disturbed fishponds are listed below:

a. Reconfiguration of the ponds

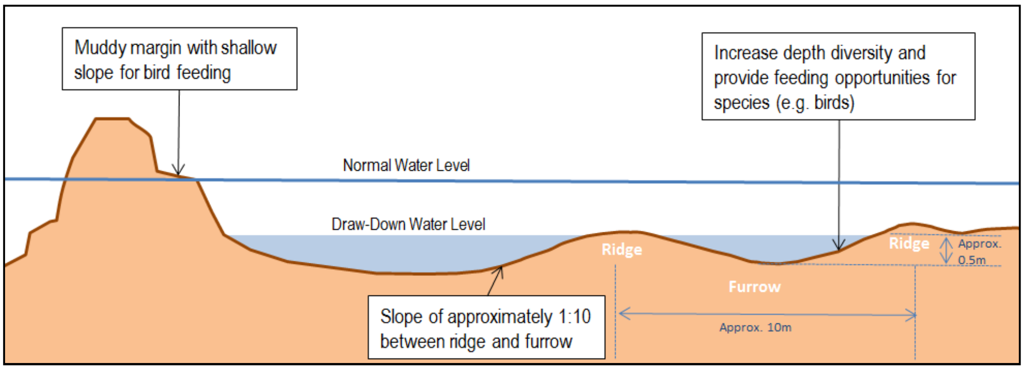
Reconfiguration of fishponds can be achieved through creation of fewer and larger ponds. Ponds with increased size will be more attractive to waders and waterfowls as abundant evidences indicate that many wetland bird species prefer larger, less enclosed water bodies to small ponds.

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 minimise 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 below).



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.

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 channelised 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, of which the mangrove species *Kandelia obovata* (秋茄樹/水筆仔) and *Aegiceras corniculatum* (蠟燭果/桐花樹) are commonly used in mangrove planting. This is because they are common in Hong Kong and they have been successfully implemented in the past for mangrove compensation.


MANGROVE SPECIES *AEGICERAS CORNICULATUM* (LEFT) 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 revitalisation or enhancement of a degraded/ channelised river can be further explored but it would be difficult to demonstrate that the compensation could be provided on a like-for-like basis.

Annex 7 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

Scientific Name	Chinese Name	Growth Habit	Natural habitat
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
Rhaphiolepis indica	石斑木	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	鹵地菊	Herb	Sandy places near seaside

Annex 8 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
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	Naturalised along tickets and

Scientific Name	Chinese Name	Growth Habit	Natural Habitat
		Shrub	roadsides
Maesa perlarius	鯽魚膽	Shrub	Margins of forests and shrubby area
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

Annex 9 Quality Improvement of Riparian Vegetation

Riparian vegetation is an important part of channels which contributes to the overall ecological and landscape functions. 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 colonisation 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.

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 functions. 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.