STREAM CROSSINGS GUIDELINES

An Ecological Approach

Department of Irrigation and Drainage
Ministry of Natural Resources and Environment
Malaysia

Department of Irrigation and Drainage
MSMA DID'2000 compliance

ACKNOWLEDGEMENTS

The Department of Irrigation and Drainage Malaysia under the on-going stream restoration activities that aligned with the Urban Storm-water Management Manual for Malaysia, 2000 (MSMA), promotes the conservation, rehabilitation and restoration activities that support the ecological integrity of rivers, streams, wetlands, waterways and lands adjacent to these resources. The utmost goal for these activities are to maintain and preserve the physical, biological and chemical processes adhered by any water bodies in such a manner that these processes are not affected at large by any crossings constructed across them.

This guideline is meant to help Governments Agencies, consultants, developers and contractors among others to design and construct cross-ings that will be usable not only to solve the water quantity problems like providing effective passage for flood waters but also enhancing water quality, bio-diversity and structural stability as well. In this context, types of crossings that will induce the sustainability of existing eco-sys-tem will be introduced and promoted. This guideline should be used in conjunction with the Hydrological Procedures (HPs) and MSMA manual to ensure proper hydrological and hydraulic design requirements are fully scrutinized.

The Department is also deeply in dept to those who help this guideline to be visualized especially to the entire personnel belongs to the Federal, State and District DID. The editorial committee would like to thank those who provided the information, photos and ideas especially to the dedicated staff in Urban Drainage Division, Department of Irrigation and Drainage Malaysia. Without their support this guideline would not become a reality.

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Pier in the middle obstructs stream flow causing blockage, backwater and scouring

Without obstruction, water flows freely to the sea

INTRODUCTION

Malaysia is blessed with beautiful rivers and streams that are landscaped with green tropical forest – rich in natural resources. Besides providing food, water and space for human settlements, for thousand of years life forms comprise mammals, reptiles, amphibians, fish and invertebrates depend on the river environment to survive on the abundant food chains along the river system. No doubt rivers that are rich in bio-diversity are the trade mark of Malaysian rivers since the establishment of Malay Archipelago more than a millennium year ago.

Human needs like property development, transportation facilities – highways and railways, commercial and industrial estates often cause conflicts in shrinking the buffer zone requirements along rivers and streams. In most cases, artificial structures are required to fulfill our needs such as crossings like culverts and bridges. In the conventional approach, stream crossings only consider the option of providing save passage of flood waters without any particular interest in stream continuity, habitat conservation or in general term known as eco-system sustainability.

Crossings like culverts that do not consider ecological approach will tend to block the stream continuity that in the long run cut off the natural migration of aquatic life upstream and downstream of such structure. Malaysian rivers and streams used to have rich species of Mahsier (Kelah); however, human interventions have induced these species to be in the state of extinction due to imprudent construction and installation of crossings.

Most of us don't realize that in the event of flood, this fish species has to migrate upstream for spawning and return back downstream at the later stage. The truth is that annual flood event triggers such species survival rate. Provided that human constructed structures like dams, weirs and crossings that impede their migratory path, the next generation of Kelah will not be materialized.

To avoid such phenomenon to occur, there is a need to develop this guidelines so that eco-friendly river crossings could be promoted and utilized widely while in the long run indulges our ultimate goal in achieving clean, living and vibrant rivers.

NATURAL CHARACTERISTIC OF RIVERS AND STREAMS

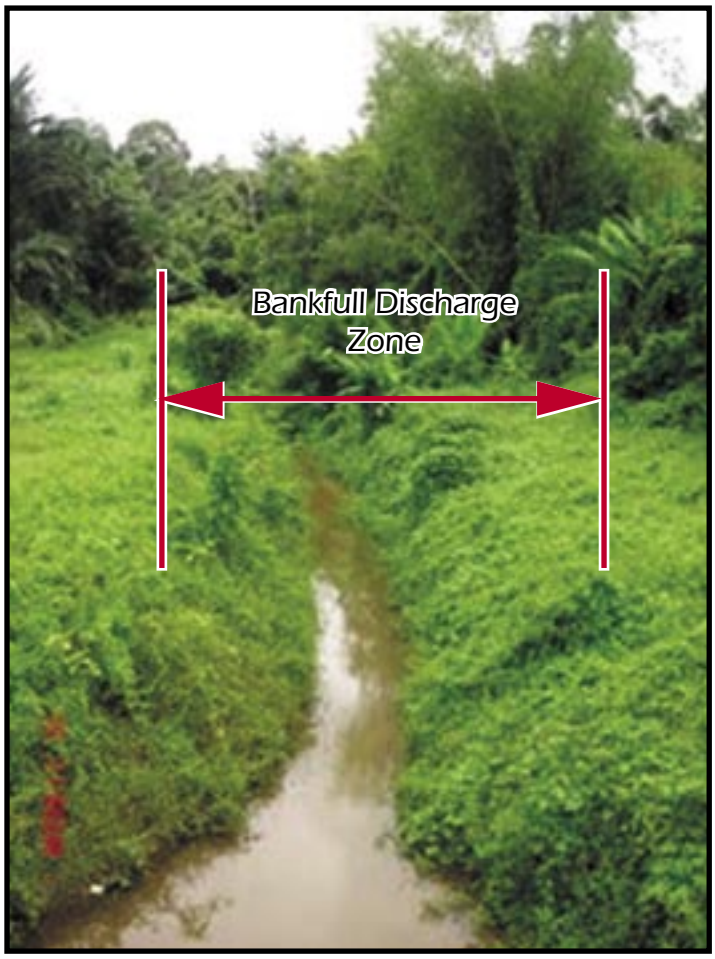
The ecology of tropical rain forests is said to be the richest on earth. There is only one season in the year and the annual precipitation can reach more than 3,000 mm, supporting rich vegetation. The abundant wildlife in these rain forests is said to be the storage house of genetic resources. There is biological diversity, particu-

larly of fish, partly because of abundant supply of plankton as food from upstream. Along the coastline and river mouth, the ecosystem is constructed by mangrove trees, water birds, small seaweeds, and microscopic algae, crabs, shrimps, clams, snails, mudskippers and mud lobsters. The mangrove forest is very high in biological productivity and has rich diversity.

Clearance of forests and urbanization in a drainage basin affect discharge and water quality, and thus, changing channel morphology. Impacts of such changes in turn affect river ecosystem. A flood plain is flat lowland along a channel which is inundated by river water during annual flood event and its surface is covered by unconsolidated river deposits. River ecosystem in a flood plain is affected by certain specific link between channel and flood plain. During a flood season, a river transports nutrient to flood plain. Thick growth of aquatic plants and breeding of fish can be observed in both channel and along riverbanks. These changes resulting from flooding produce biological diversity in and around a river. Natural channel (rivers and streams) morphology changes frequently at flood plain. Scientifically, channel morphology is determined by the gradient, topography, discharge and sediment load.

Shallow flow through culvert increases flow velocity and blocks fish movement upstream

Channel morphology can be classified into 5 categories - straight channel, sinuous channel (slightly meander), meandering channel, braided channel and anastomosing channel.



Bankfull discharge is equivalent to 2 years return period

Pools and riffles are one of the characteristic of channel. In reality, more than one pools and riffles are formed in each meandering at upstream while the number of pools and riffles correspond to the sinuosity at midstream as well as downstream. Water falls will run rapidly through a cascade at upstream but smoothly descends at midstream and downstream. Pools and riffles can be examined from viewpoints of bed morphology and ecology. In this context, pools are classified into three types, i.e. meander type, rock type and scouring type. A meander type is formed at a bend of channel. It is created at the outer bank of a bend by secondary flow. A pool is formed at a place where bed slope is gentle while a riffle is at where bed slope is steep.

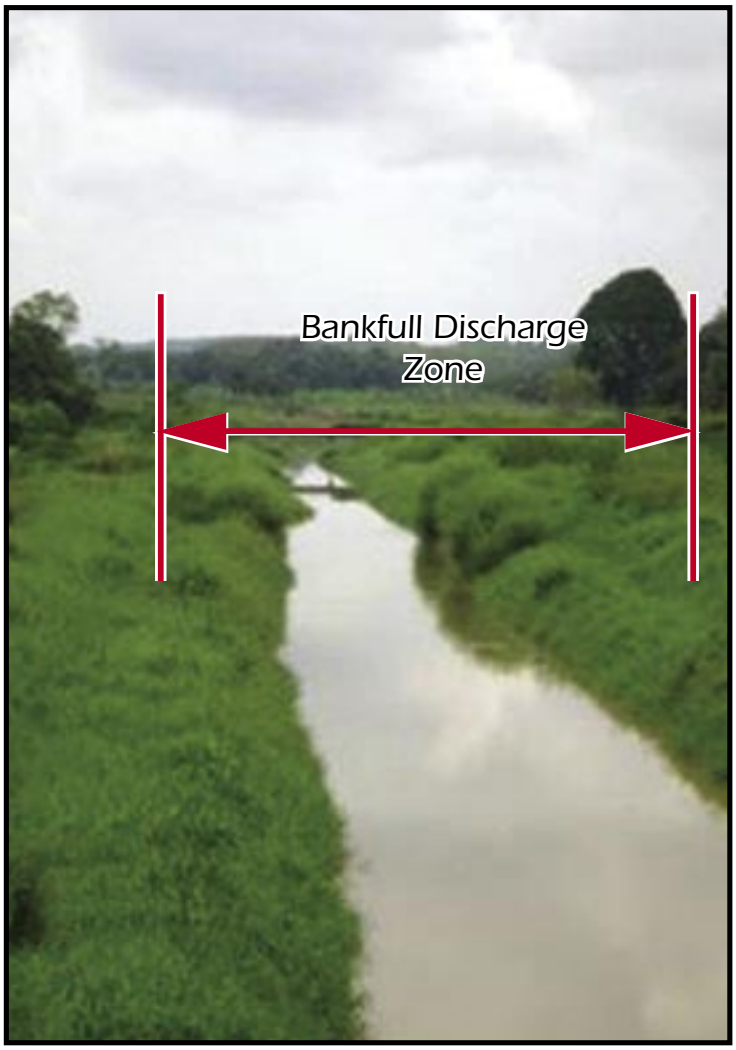
A rock type pool is formed around a huge rock or at a concave section around exposed bedrock. Pools are also formed due to scouring around structures, such as bridge piers. A typical pool of scouring type is where there is a waterfall at bedrock of different hardness. Pools are also formed at downstream of groundsills due to scouring.

Sediment produced at upper reaches of a river is transported through channels and deposited at downstream and river mouth. The production of sediment in a drainage basin is mainly affected by geology, ground cover and rainfall characteristics. The production will be low if basin surface is covered by forests and high if the ground is bare.

The amount of discharge has important implications on channel behavior. Discharge depends on topography, geology and size of drainage basin and of course rainfall. According to experts, scale of a low flow channel and bars of large rivers correspond to mean annual maximum discharge or bankfull discharge. This discharge generally infers to a return period of 2 years and has important implications on the formation of a channel and its micro-topography which are the basic elements of habitat for wildlife. Flow capacity of a channel is determined to prevent a flood with a return period of 100 – 200 years for a large river and 5 – 30 years for a medium size or small river. The flood discharge is important for planning as well as design of a channel and is related to a possible scale of damage or disruption to natural environment. Low water discharge is also important as drying up of channel at time of spawning season or migration can possibly cause devastating damage to wildlife. Low water discharge is an item to be well managed so as to maintain normal functions of a river, i.e. good water quality and ecosystem.

Fluctuations of discharge can change distribution of riparian vegetation, depending on scale of fluctuations. Conditions affecting plant growth include flooding frequency, intensity of external forces at the time of flooding, type of deposited sediment, groundwater level and occurrence of flooding at the time of plant germination. When the water flows from a spring or lake, providing a stable discharge, water grasses often grow on riverbed. In contrast, wildlife finds it difficult to inhabit when discharge is unstable and a constant change of riverbed.

Wildlife in a river basin is closely related to water quality. Water quality items closely related to wildlife are dissolved oxygen (DO) concentration, bio-chemical oxygen demand (BOD), nutrients (phosphorus and nitrogen), turbidity (sediment), salt content, water temperature, pH, metallic ion concentration and toxic substances.



Provide low flow passage and habitat for aquatic biota to sustain

RIVERINE COMMUNITY

Different types of environment can be observed among rivers from upstream to downstream sections. Many different life forms make use of these different types of environment as their habitat. At upper reach river, valleys are deep and banks are covered by thick forests. Water is clear, temperature is low and speed of the flow is fast. There are several shallows, which alternate with deep waters. Numerous aquatic insects thrive at river bottom. Fishes, crabs and amphibians living in the river feed on these aquatic insects. Birds and small animals live at riverbanks so that they can easily come to river for water and food.

Catfish - a popular tropical fish species

Kelah (Mahsier) – High end species once dominating Malaysian rivers. Migrates upstream during annual flood to spawn and moves downstream to mate. Well known for its natural ability to swim through rapids and small waterfalls

At middle reach river, flow becomes rather slow and area opens up. Distance between shallows and deep waters become wider. Algae grow in abundance on surfaces of stones in the shallows. This attracts aquatic insects and shellfish to live on the sides and at the bottom of the stones and deep waters. They become prey to herbivorous, carnivorous and omnivorous types of fishes in the river. The biota here is richer when compared with end of riverbank. Different types of birds come here in search of food. There are also some birds which build the nests by riverbank. Small reptiles and mammals can also be found in grassy patches by riverbanks. Even freshwater terrapins find sand bars and beaches as heaven spots for their annual spawning event.

At lower reach river, as width of river widens, river flow becomes much slower. Riverbed becomes more open with swampy areas, flood storage pond and ditch reed plains. Bottom of river becomes muddy. Where there are still water areas, aquatic plants flourish. At bottom of river, most aquatic insects disappear, except dragonflies. Instead, shellfish becomes plentiful. Here, fishes feed mostly on benthonic organisms and other fishes. Fishes which swim upstream against current from sea can often be seen at river mouth, where the biota becomes complex. At river mouth, one can note seasonal migration of water edge birds and water birds, as they often stop to find food

Spotted stream frog or Rana Signata - a beautiful ranid that occurs in lowland to mid-level rainforest along streams

Firefly – commonly seen along the stream

and to rest. Numerous insects and small animals live at riverbanks and many land birds can also be found. Besides, there exist also reptiles and mammals which come here to prey on small animals.

CHANNEL CHARACTERISTIC AND HABITAT

Habitat of plants and animals is defined differently by ecologists. Here, it is so defined as the specific place where living things use in each stage of their life cycle, from egg-laying, hatching, feeding, biting, resting to nesting, adopting and adapting to the mass of land forms. Size of habitat varies from plants or animals since large animals generally need large habitat. Habitat is a basic unit indicating a living place of plants and animals. Macro-topography of a river is formed through a course of interaction of flowing water and sediment. The habitat, living place of plants and animals, exists on various river forms. It is closely related to bed form, water flow, and riverbank shape. Shallows, pools and loose stone strips, in which stones are supporting without mud or sand, are typical habitats in water areas. Plants and animals use specific habitats on each life stage and move from one habitat to another if necessary. Similarly, its size and characteristics are important together with its distribution and inter-relationship.

The habitat structure is stratified due to various sizes of plants and animals, moving range of each animal, interaction of different species and material flow in the ecosystem. In rivers, the largest scale of habitat is the entire river basin. The upper, middle and lower reaches are the larger habitat, shallows and pools are intermediate and loose stone strip is smaller one. The essential and the most important characteristics in river habitat are that they can be lost and reproduced repeatedly. This is so because the habitat in a river is always changing by flood and sediment transport. In such a case, it can be naturally restored through movement of sediment and growth of wildlife. In short, habitat is perpetually changing, repeating the cycle of destruction and restoration. Smaller habitat requires a shorter time for restoration while restoration of large habitat can be a lengthy process.

The habitat in river can be classified into three zones, namely water zone, land zone and water edge zone. Each zone is characterized by several elements. Typical elements are water quality, water flow, bed form, bed material and vegetation. These characterizations are then defined into river eco-system consists of diversity of habitat and diversity of species, which in the end complete the entire loop into open ecosystem that normally summarized as "flowing water that is generated by various inflow substances from surrounding land area either are consumed by various animals and plants or transported downstream and eventually emptied to the sea".

The Batagur or mangrove terrapin (Batagur baska) is a species of riverine turtle.

STREAM CONTINUITY

Human interventions often alter the natural behavior of rivers and streams. River training works like straightening, hard lining (concrete line and sheet piles), installation of impeded structures (weirs and dams), and crossings among others disturb the natural channel morphology including the physical, biological and chemical processes adhered by such water bodies. These in turn induce the overall disturbance within the ecological cycles that used to establish thousands of years ago.

Animals need continuous access to river eco-system for refuge, transit, feeding, spawning and breeding. Crossings will limit the size of refuge i.e. feeding, breeding and spawning areas thus become congested, overcrowded and vulnerable to disease, predators and even anglers. Besides, impeded structures form a barricade obstructing them from identifying suitable spawning areas upstream. Crossings block the movements through transit points for amphibians that used to track along the water edges thus diverting them from utilizing their natural trail yet inducing them to opt for suicide missions - crossing the roadway.

SCRUTINIZING PROBLEMS

Generally, problems associated to crossings are the followings but not limited to 1) undersized crossings, 2) shallow crossings, and 3) hanging crossings. Undersized crossings restrict natural stream flow and susceptible to flooding, clogging, and scouring. Shallow crossings only allow few inches of water flowing during normal flow, which restrict the movement of fauna through them especially fish. Perched crossings as normally known as hanging culverts are initiated by poor installation, scouring of downstream section and land subsidence as generally found in peat soil areas.

Scrutinizing these conditions, one may find out that most of the time it is associated with high velocity flow of water through these crossings, which is not favorable since it will discourage fishes from swimming through them. Besides, high velocity will tend to initiate scouring problems downstream of these structures. One may argue that perched conditions may be favorable because it induces higher dissolve oxygen (DO) as generated by pool and riffle system; however, further observation indicates that only certain strong species of fish may be able to jump through it i.e. Kelah (Mahsier). Characteristics of natural pool and riffle system (rock and scour type) consists of long length of pool associated with short riffle. A perched crossing only provides short pool for fish to rest at the downstream side while having long riffle line that is not helpful for fish to travel through it. Fish will need a lot of energy to pass through a long culvert – long riffle.

Shallow crossings result in unnatural bed materials that are not friendly to animals. Without the natural substrate, the stream continuity is obstructed and again the hourly water and sediment discharge are disturbed. Supply of sediments is also an important factor for the establishment of sand bars and natural beaches along the river, which provides the spawning ground of freshwater terrapins.

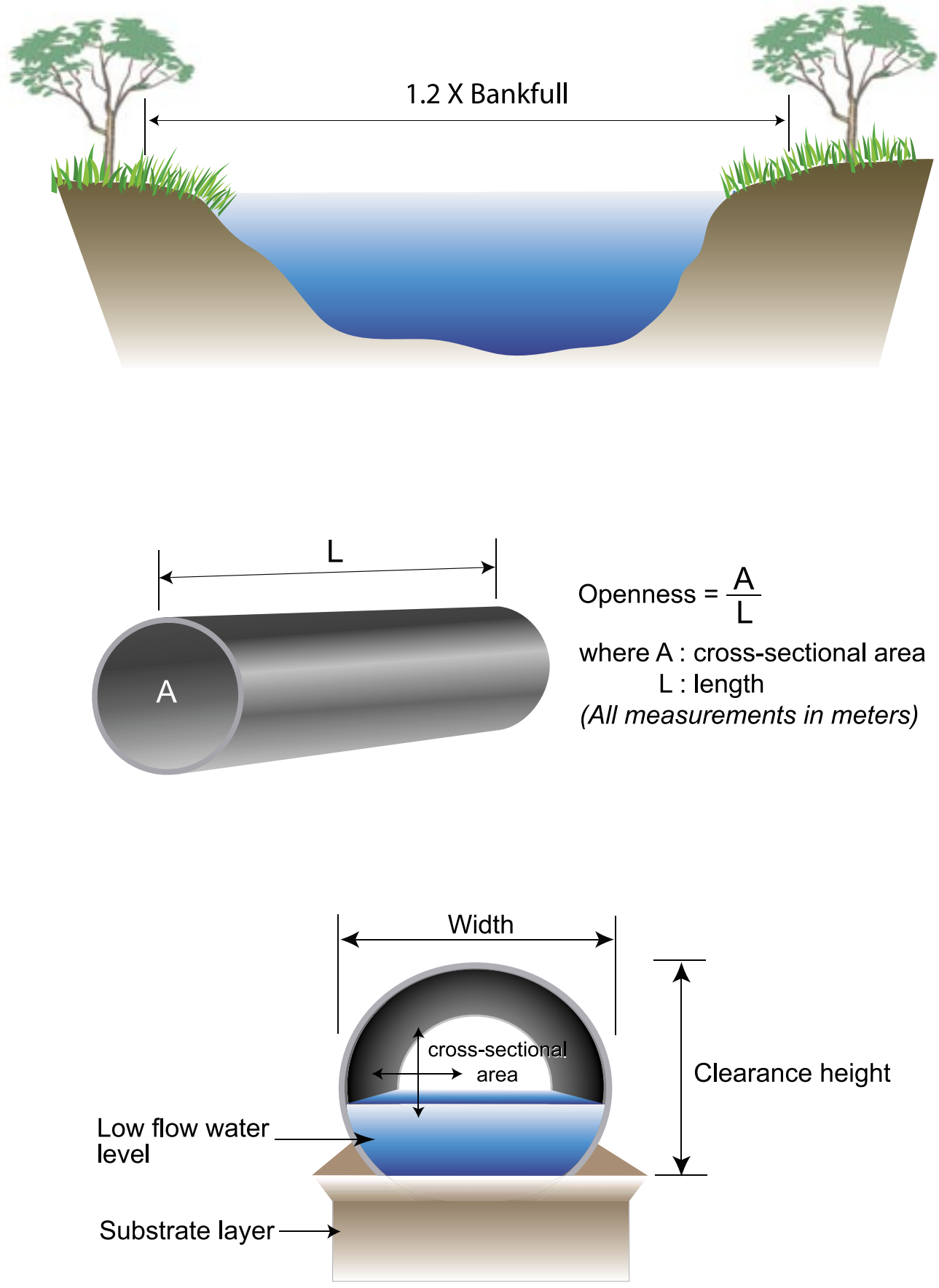


Figure : Criteria for width, openness ratio and substrate layer

Hanging culvert blocks fish from moving upstream

Submerge culvert encourages fish to move freely.

Undersized culvert creates problems during flood

Adequate culvert size allows safe passage for flood water

CROSSINGS STANDARDS

Engineers and decision makers should embark towards eco-friendly crossings that help the entire river eco-system to sustain through the concept of "invisible crossings"; features that are unnoticeable by animals with adequate water level and substrate while compromising on the water quantity aspect.

In this context, all crossings should be designed according to this guideline to ensure provisions for animal passage, stream continuity, wildlife passage and save passage of flood. In estimating the hydrology and hydraulic criteria engineers ought to refer the relevant Hydrological Procedures (HP) or Manual Saliran Mesra Alam (MSMA), Chapter 13, 14 and 27.

Good and effective crossings should fulfill the above criteria. In short, a bridge should be constructed at full length of a river without any pier in the middle. Abutment shall only be located outside the bankfull discharge cross section i.e. 2 years flood area. A culvert is not preferable and should be replaced by open bottom arch structures. If culvert has to be utilized instead, which is not highly recommended, it should have enough span and depth to ensure above criteria are fulfilled.

Good crossings provide natural substrate, good openness and adequate water depth

Bottomless open arch - minimize construction disturbance while substrate remains intact

MINIMUM STREAM CROSSING STANDARDS

1. **Type of Crossings: Open arches and bridges are preferred over culverts;**

2. **Culverts: Preferred short and large culverts. Should be embedded into the stream at least 0.3 meter for box culverts or at least 1/4 of pipe culverts diameter;**

3. **Width: Crossings should be at least 1.2 times the bankfull width of the stream (2 years design flood);**

4. **Openness: Openness ratio (cross sectional area/crossing length) should be at least 0.3 meter with minimum clearance height of 1 meter;**

5. **Substrate: Natural bottom substrate should be installed to match the existing upstream and downstream substrates. The design should counter the displacement effect occurred during floods while maintaining it during normal flow;**

6. **Depth and Velocity: At low flows, water depths and velocities should be the same as they are in natural areas upstream and downstream of the crossings;**

7. **Hydrology and Hydraulic: Governed by DID Hydrological Procedures (HP) or Manual Saliran Mesra Alam (MSMA), Chapter 13, 14 and 27;**

8. **Clearance Soffit level: Minimum clearance soffit level should be 100 years design flood plus 1 meter; and**

9. **Temporary culverts: Governed by criteria 2 above with minimum 0.6 meter diameter and number of culverts should cover the entire width of bankfull discharge.**

Typical arch bridge for small stream

Typical arch bridge for wider stream

CONCLUSIONS

In the past stream crossings have caused tremendous ecological problems to Malaysian rivers. The conventional approach only considers safe passage for flood that focuses on minimizing water quantity problems. Crossings without proper planning, design and minimize construction disturbance shall alter the overall river landscape; thus, abruptly disturb the natural habitat and the livelihood of riverine aquatic and non-aquatic biota. Compliance to this 'invisible crossings' concept increases the chances for the largest mammals and reptiles down to the smallest organisms to sustain and survive. Failure means destruction to this valuable frontier species, thus burdening ourselves with guilt and irresponsible conduct forever. Think of our children and grandchildren since they are the one to be our judges and inherit the good and the bad things that we do today.

Having 189 river basins consist of almost 10,000 streams and rivers network, compulsory installation of 'invisible crossings' help to avoid unnecessary disputes in the future. Additionally, this new standards combine with MSMA and eco-system needs create smart partnership between humans and environment; bringing us closer to our dreams of achieving Clean, Living and Vibrant rivers. Once a wise man said, "If you cannot fight it then join it'. When dealing with nature, whatever we do, we will lose. To stay as a winner we must join with nature.

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