



DESIGN GUIDANCE For Fish Passage On Small Barriers



OPW

Oifig na
nOibreacha Poiblí
Office of Public Works

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Iascach Intíre Éireann
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An Roinn Tithíochta,
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List of Abbreviations and Definitions

D fish	Average width of design fish species
GEP	Good Ecological Potential
GES	Good Ecological Status
GP #	Generic Principle No. #
IFI	Inland Fisheries Ireland
L fish	Average length of design fish species
NPWS	National Parks and Wildlife Service
OPW	Office of Public Works
Q_{95}	Discharge of a water body that is exceeded in 95% of the year
Q_{90}	Discharge of a water body that is exceeded in 90% of the year
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research
$v(Q_{95})$	Flow velocity of the water in a water body while having a discharge that is exceeded in 95% of the year in the water body
WD	Water depth, distance between river bottom and surface of the water
WFD	Water Framework Directive

Section 1 Introduction

1.1 Background to this Guidance

Small barriers to fish passage caused by culverts and similar small (drop) structures are known to be a major impactor on potadromous and anadromous fish species in Ireland's small rivers and streams. In the context of this guidance 'small structures' means structures with a head drop of up to 1.0 m during low flow, and streams and rivers with mean flow of less than 1.0 m³/s.

These structures can impede ascending fish for hydraulic reasons (e.g. the flow velocity is too high in the structure) or for structural reasons (e.g. the drop is too high to overcome). They influence the continuity and connectivity of the river system, which can disrupt the natural river processes, and cause habitat fragmentation and river discontinuity, altering river hydromorphology. The structures can influence sediment transport and the flow regime of the river, with some acting as gravel or sediment traps and others ponding water upstream of the structure, changing the habitat type available to stream biota. Culverts and similar small structures can also restrict the use of upstream habitat for both resident and migratory fish species (e.g. salmonid species that require habitat with plentiful gravels and high water quality for spawning). Such habitat is generally found in the upper reaches of streams to which these culvert and similar small structures may prevent access.

Collectively, the negative impacts caused by small barriers can reduce the ecological status of the water body assigned under the Water Framework Directive (WFD) compared to a natural river without these barriers. Mitigation measures to aid fish passage in both the upstream and downstream direction and sediment transport have the potential to benefit fish communities by both permitting access to previously unreachable sections and by providing downstream dispersal of spawning substrate via sediment transport.

To address the impact of these types of structures in Ireland, the Office of Public Works (OPW) commissioned this design guidance for the improvement of fish passage by their removal or mitigation. The guidance is based on barriers identified by OPW and Inland Fisheries Ireland (IFI) in the Inny catchment in Co. Westmeath as part of the Environmental River Enhancement Programme (EREP) (IFI & OPW, 2018, 2019).

This guidance is for use on barriers to fish passage caused by small culverts or similar in-stream structures with a head drop of up to 1.0 m during low flow and with a mean flow of less than 1.0 m³/s. While the guidance is based on barriers identified in a specific catchment, it is intended to be suited to the variety of conditions and fish species that would be expected in Irish small rivers and streams. The guidance will help mitigate against the barrier itself, and also take account of water levels in the vicinity of the barrier, both upstream and downstream to ensure that levels are adequate for fish passage in all flow conditions.

1.2 European and National Policy

The last three decades have seen an increase in global awareness of the need for fish species to migrate to fulfil life cycles. In general, the necessity for free movement of both diadromous and potadromous fishes in rivers is now readily acknowledged (Kroes et al., 2006; Brink et al., 2018). In Europe, since 1992, three pieces of European Union legislation have forced the focus of fisheries management and fish protection to expand beyond the commercially relevant

salmonids to include all fishes, namely (a) the Habitats Directive (92/43/EEC), (b) the Water Framework Directive (2000/60/EC), and (c) the Regulation establishing measures for the recovery of the stock of European eel (EC/1100/2007). Further the European Commission agreed in 2020 the EU Biodiversity Strategy for 2030 “Bringing nature back into our lives.”, which follows the EU Biodiversity Strategy for 2020 and also claims for removal or adjustment of barriers to fish, restoration of rivers into free-flowing rivers and re-establishment of fish spawning and nursery areas in European rivers.

River continuity is a key environmental objective of these three EU legislations, especially the WFD, and is used as an indicator for assessing whether water bodies are meeting Good Ecological Potential/Status (GEP/GES). To achieve good status, a river water body must (approximately) support the populations of all naturally occurring migratory and non-migratory fish that inhabited the water body before the construction of the man-made barrier, and there must be sufficient river continuity and connectivity to permit the free movement of all migratory fish species. The WFD requires Member States to apply measures to improve the ecological status/potential of all water bodies that do not meet GES/GEP.

1.3 Involved Organisations

The development of the guidance involved a cooperation between OPW and IFI, supported by the Department of Housing, Local Government and Heritage.

- OPW is the lead agency for flood risk management in Ireland, and responsible for arterial drainage schemes, having a statutory obligation to maintain OPW drained rivers and channels;
- IFI is responsible for the conservation, protection, management, marketing, development and improvement of Irelands inland fisheries and sea angling resources; and
- Department of Housing, Local Government and Heritage is responsible for implementation of the WFD in Ireland.

A Project Steering Committee comprising staff from each organisation with expertise in different aspects of addressing fish passage issues in Ireland was formed. The committee contributed to the development of this guidance through four workshops held between August 2020 and May 2021. The committee included:

- OPW: Nathy Gilligan and Fergal Kelly;
- IFI: Brian Coghlan, Alan Cullagh, Karen Delanty, Ciara Fleming, Rossa Ó Briain and Ciara O’Leary; and
- Department of Housing, Local Government and Heritage: Barry McDonald.

OPW appointed CDM Smith Ireland Ltd as a consultant to support preparation of the guidance, and their project team comprised Marq Redeker, Marlene Sikora and Ruairi O’Carroll. CDM Smith has Irish and international experiences of improving fish passage on rivers.

1.4 Structure of this Document

The barriers identified in the Inny catchment in Co. Westmeath by OPW and IFI as part of the EREP and used as the basis for the development of the guidance are described in **Section 2**. The remainder of this guidance is then comprised of three technical sections:

- **Section 3** discusses the **Decision Tree** which structures the decision-making process with the objective to distinguish the best measure (decommissioning / reconstruction / improvement) to improve the fish passage through the culvert / barrier structure.
- **Section 4** contains the **Improvement Matrix** which allows suitable measures regarding barrier issue and structure types to be identified.
- **Section 5** covers the set of **Generic Design Principles** which set out the design approach to each of the improvement measures. **Appendix A** contains drawings to support the design principles.

Section 2 Description of Barriers in the Inny Catchment

2.1 Introduction

In 2017 and 2018, OPW and IFI carried out a survey of the Inny catchment as part of the Environmental River Enhancement Programme which identified culverts and similar small structures that may act as barriers to fish movement. The aim of the survey was to examine all potential barriers sites, based on a desk-assessment method, and to collect baseline information of structures considered being an obstacle to fish passage.

IFI then assessed these barriers by applying their Barrier Assessment and Screening Tool (I-BAST) to assess structural parameters before SNIFFER thresholds were applied to the measured variables to get a risk score for its overall passability score. The SNIFFER protocol considers both upstream (adult salmon, adult lamprey, juvenile eel) and downstream migrations (salmon smolts; adult silver eel). The protocol also facilitates passability performance of fish passage solutions or fish passes.

Nine barriers caused by culverts and similar small structures were highlighted for potential mitigation on channels managed by the OPW in the Inny catchment. The range of head drop was between 0.2 m – 1.0 m during low flow. The barriers are located in streams with a mean flow of less than 1.0 m³/s. These barriers to fish passage were considered by OPW and IFI to have high potential and to meet criteria for achieving WFD compliance. The barrier structures are described individually in Section 2.2.

Four different types of structures were observed on the Inny catchment and these represent typical small structure types to be found in all Irish river catchments:

- Culverts;
- Bridges;
- Artificial bed drops; and
- Gauging structures.

2.2 Description of Selected Sites

The nine selected barriers caused by culverts and similar small structures for potential mitigation on OPW channels in the lower Inny catchment are described in this section. For each barrier, the following information is provided:

- Location Details;
- Photo;
- Structure Type;
- Dimensions of the Structure;
- Water Depth & Flow Velocity; and

- Summary of Key Issues for Fish Passage.

The location of the selected barriers in the Inny catchment is shown in Figure 1.



Figure 1: Location of Barriers in Inny Catchment

Location 1:

East: 642679 / North: 787514
 Ballynarry (Bells Grove), Co. Cavan
 OPW Structure ID: 26_3738_89



Structure type:

- Culvert (road bridge) and Gauging Station

Dimensions of structure:

- Length: 11 m
- Width: 1.5 m

Water depth (16.07.2021):

- In structure: 10 – 15 cm
- Downstream: 25 cm

Flow velocity (16.07.2020):

- In structure: 0.1 m/s
- Downstream: 0.2 m/s

Issues:

- Drop of 1.0 m height
- Bed erosion downstream
- Maintenance (debris)

Location 2:

East: 643647 / North: 786270
 Bells Grove (Bells Grove), Co. Cavan
 OPW Structure ID: 26_3738_322



Structure type:

- Culvert (road bridge) and Gauging Station

Dimensions of structure:

- Length: total length: 9 m, Zone C: 4 m (see section 4.2.2)
- Width: 3.0 m

Water depth (16.07.2020):

- In structure: 20 - 30 cm
- Downstream: 20 - 30 cm

Flow velocity (16.07.2020):

- In structure: 0.2 m/s
- Downstream: 0.2 m/s

Issues:

- Drop of 0.35 m height
- Bed erosion downstream

Location 3:

East: 641716 / North: 779339
 Finnea (Cornacreevy), Co. Westmeath
 OPW Structure ID: 26_2926_26

**Structure type:**

- Culvert (road bridge) and Bridge Apron

Dimensions of structure:

- Length: total length: 15.5 m, Zone C: 10 m (see section 4.2.2)
- Width: 1.6 m

Water depth (16.07.2020):

- In structure: 20 - 30 cm
- Downstream: 20 - 30 cm

Flow velocity (16.07.2020):

- In structure: 0.3 m/s
- Downstream: 0.3 m/s

Issues:

- Drop of 0.5 – 1.0 m height,
- Bed erosion downstream
- Flow velocity
- High turbulences
- Water depth
- Missing natural bed material
- Potential for lack of resting place during higher flow conditions. More investigation recommended.

Location 4:

East: 638272 / North: 776974
 Rathcronan (Newgrove), Co. Longford
 OPW Structure ID: 26_1491_190

**Structure type:**

- Culvert (road bridge)

Issues:

- Drop of approx. 0.2 – 0.3 m height
- Bed erosion downstream

Location 5:

East: 637812 / North: 776809
 Rathcronan (Newgrove), Co. Longford
 OPW Structure ID: 26_1491_126



Structure type:

- Culvert (road bridge) and Bridge Apron

Issues:

- Drop of approx. 0.3 – 0.5 m height
- Bed erosion downstream

Location 6:

East: 632153 / North: 771799
 Street, Co. Westmeath
 OPW Structure ID: 26_3649_23



Structure type:

- Culvert (farm crossing) / Bridge Apron

Dimensions of structure:

- Length: 3.8 m
- Width: total: 1.8 m, each pipe 0.9 m

Water depth (16.07.2020):

- In structure: 7 cm
- Downstream: 25 cm

Flow velocity (16.07.2020):

- In structure: 0.2 m/s
- Downstream: nearly 0

Issues:

- Drop of 0.45 m height,
- Bed erosion downstream
- Water depth
- Lighting within culvert
- Missing natural bed material
- Potential for hydraulic issues during higher flow conditions. More investigation recommended

Location 7:

East: 633754 / North: 770425

Street, Co. Westmeath

OPW Structure ID: 26_3649_254

**Structure type:**

- Drop structure / Step

Dimensions of structure:

- Length: -
- Width: total: 2.4 m

Water depth (16.07.2020):

- Upstream: 10 – 15 cm
- On top: 7 cm
- Downstream: 20 cm

Flow velocity (16.07.2020):

- Upstream: 0.3 m/s
- Downstream: 0.2 m/s

Issues:

- Drop of 0.45 m height
- Bed erosion downstream
- Water depth

Location 8:

East: 636802 / North: 768730

Street, Co. Westmeath

OPW Structure ID: 26_3649_635

**Structure type:**

- Farm crossing

Dimensions of structure:

- Length: 5 m
- Width: total: 2.5 m

Water depth (16.07.2020):

- Upstream: 15 – 35 cm
- In structure: 10 – 15 cm
- Downstream: 40 cm

Flow velocity (16.07.2020):

- upstream: 0.2 m/s
- Downstream: 0.2 m/s

Issues:

- Drop of 0.9 m height
- Bed erosion downstream
- Water depth

Location 9:

East: 645386 / North: 758905

Gaine (Kilmaglish) Co. Westmeath

OPW Structure ID: 26_3068_22



Structure type:

- Culvert (road bridge) and Bridge Apron

Issues:

- Drop of approx. 0.3 – 0.4 m height
- Bed erosion downstream

Section 3 Decision Tree for Identifying Best Measure

3.1 Introduction

All possible measures to improve fish passage fall into one of three categories:

- Decommissioning (removal) of the structure;
- Reconstruction / bypass of the structure; and
- Improvement of the structure.

As selecting the best measure requires assessment of a number of issues, a Decision Tree was developed to structure the decision-making process to identify the best measure to improve fish passage through culverts and similar small structures.

This Decision Tree, shown in Figure 2, assists the assessment process by breaking it down into a set of questions with the objective to identify the most appropriate measure. In some cases, additional information will be required to finalise a decision.

The set of questions is structured into four categories which lead through the decision-making process to arrive at the most appropriate measure:

1. Initial Considerations;
2. Fish passage improvement Considerations;
3. Technical Considerations; and
4. Potential Third-Party Considerations.

These categories are described in more detail in the following sections.

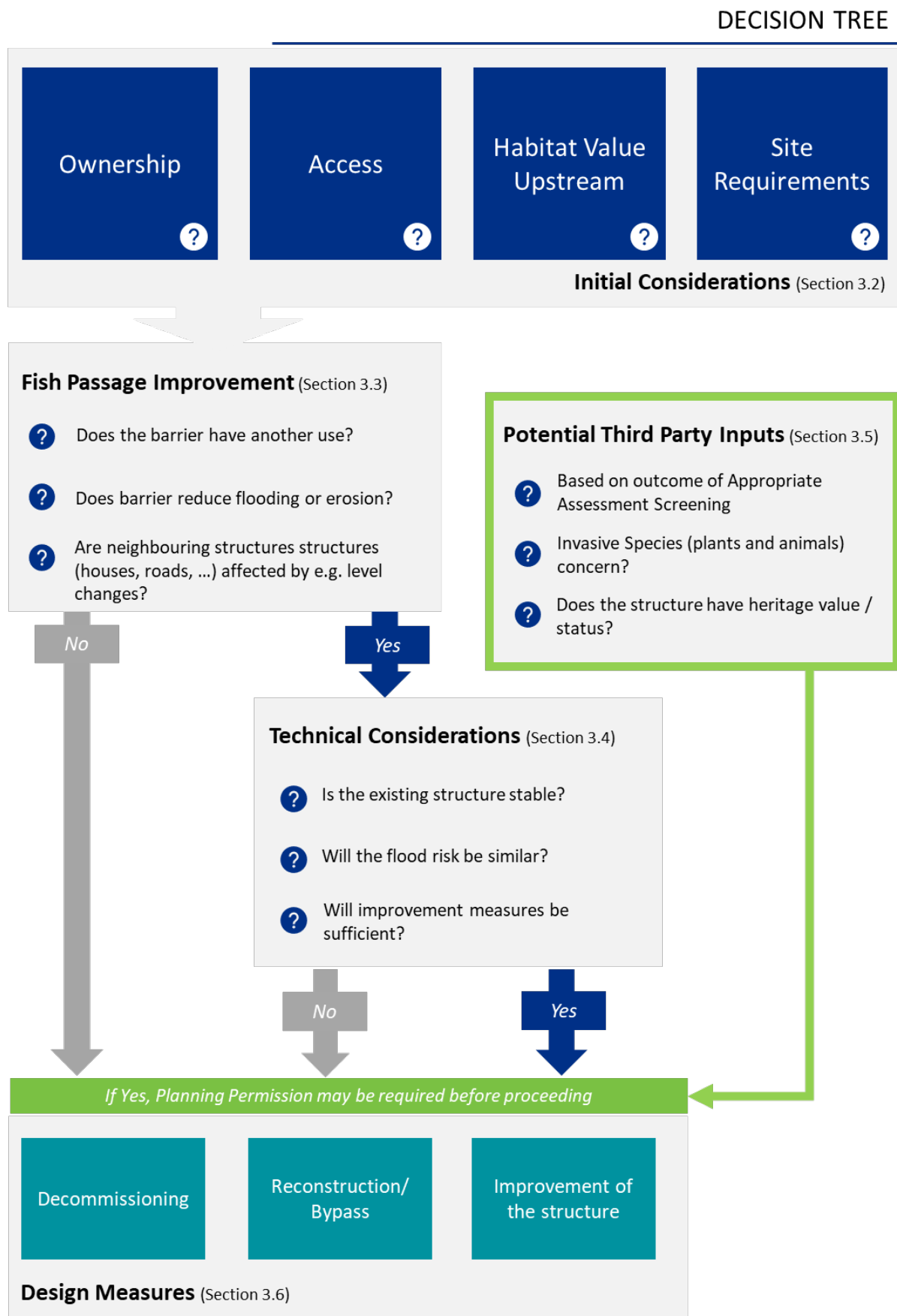


Figure 2: Decision Tree

3.2 Initial Considerations

The first category addresses questions which need to be considered at the outset in order to ensure a realistic implementation of the project. The initial considerations and their possible impact on the process are:

- Ownership;
- Access;
- Habitat values upstream; and
- Site requirements.

When it has been confirmed that no conflicts or contradictions exist with respect to these considerations, the process can proceed to the next stage.

3.2.1 Ownership

If the structure is not owned by the OPW, the first step of the process is to clarify ownership:

- Who owns the structure and the surrounding land?
- Are negotiations with the owner of the structure and/or the landowner required to implement any proposed measures?
- Does the structure have other restrictions (e.g. water rights, abstraction etc.)?

Early contact with landowners to request access or permission to undertake measures avoids conflicts and delays later in the process. Written permission may be required at this time.

3.2.2 Access

In parallel with ownership being clarified, access to the barrier should be considered:

- How will machinery and materials be brought to the site?
- Will additional works be required to create access?
- Who owns the land through which temporary access for works is required?

Early contact with landowners to agree access or permission to undertake works avoids conflicts and delays later in the process. Written permission may be required at this time.

3.2.3 Upstream Habitat Value

Identification of upstream habitat values requires a walking survey some distance upstream of the barrier (it is usually necessary to look to at least the next barrier structure upstream, including accessible tributaries). This helps to clarify whether ecological enhancement can be achieved by restoring continuity or if there is another barrier a short distance upstream. If there is little ecologically valuable habitat upstream of the barrier, measures to restore the continuity may be assessed as not worthwhile.

Identification of upstream habitat values is a key aspect of considering what is required and this should be discussed with the local representative of IFI who will confirm if upstream habitat value exists and also how far upstream it is necessary to look for existing habitat value

3.2.4 Site Requirements

Most of the barriers caused by culverts and similar small structures which fall under this guidance will not require significant enabling works to facilitate the barrier improvement because of their small size. However, consideration should be given to the following issues:

- Will temporary land be required for a storage area and/or space to work?
- Will it be necessary to divert the stream during construction (e.g. with diversion channels)? How will this be done?

Early contact with landowners to request permission for temporary use of land avoids conflicts and delays later in the process. Written permission may be required at this time.

3.3 Fish Passage Improvement Criteria

The second category of questions considers the criteria for fish passage improvement. Before any improvement measure for fish passage can be discussed and examined, other functions or uses of the structure should be identified. This will give clarification of boundary conditions for possible improvement options. The questions which need to be considered are:

- Does the structure have another function or use? Examples of other functions include use as a gauging station, a mill race or a gravel trap. If yes, then it needs to be considered if this additional function has to be retained.
- Does the structure mitigate flooding or erosion? If it does, then any fish passage improvement should normally be designed so that the situation does not become worse.
- Will any neighbouring structures (e.g. adjacent buildings, roads, etc) be affected? These structures need to be considered by a structural engineer in the context of any fish passage improvements. Impacts of barrier removal could include groundwater level changes which could have a detrimental effect on the foundation stability of an adjacent structure.

If the answer to all these questions is no, the culvert or similar small structure is no longer required, and it can be decommissioned (removed). Otherwise, further questions need to be considered.

3.4 Technical Considerations

The third category of questions considers other potential issues not previously addressed. These questions apply where the outcome is not the decommissioning (removal) of the structure:

- Is the existing structure stable? If not, is it feasible to make improvement measures to the structure? If not, it may need to be rebuilt.
- Will the flood risk be similar after improving the structure for fish passage? If the answer is no, then the structure needs to be fully redesigned (reconstruction/bypass). If the

answer is yes, then an improvement solution can be chosen from the matrix (see Section 3).

- Will improvement measures be adequate? This depends on hydraulic conditions and the durability of the structure. It should be checked if the design water volume can still be discharged through the structure.

These questions are intended to clarify which measure category is the most suitable one where the structure is retained.

3.5 Potential Third-Party Issues

The final category of questions considers the requirements for the involvement of third parties to the decision-making process. When this arises, it may create additional boundary conditions for improvement measures. Typical situations where third party issues arise include:

- Is the barrier structure located in or near a designated European site under the Habitats Directive? An Appropriate Assessment Screening should be undertaken, and if a Natura Impact Statement is required it shall be completed when all works are known. Early consultation with local National Parks and Wildlife (NPWS) and IFI staff is essential.
- Are there concerns about invasive species in the vicinity of the proposed works? An Invasive Species Management Plan and/or an Ecological Impact Assessment may be required.
- Does the structure have a heritage value or heritage status or is it in a zone of archaeological or architectural importance? This includes not just the barrier structure itself, but potentially, for example, a bridge that forms part of the overall structure. An architectural heritage assessment may be required, and potentially consultation with the relevant Local Authority Heritage Officer and/or the Department of Housing, Local Government and Heritage.

If the answer to any of these questions is yes, then it is likely that the proposed works will require planning permission and they should be discussed with the relevant Local Authority before proceeding to completing the design.

3.6 Design Measures

As noted previously, all improvement measures fall into one of three categories, i.e. decommissioning (removal), reconstruction/bypass or improvement of the structure.

3.6.1 Decommissioning

From an environmental point of view, decommissioning (i.e. removal) represents the best solution in most cases and should always be the objective where feasible. Following decommissioning, the structure that caused the barrier no longer exists and has no further impact to the river ecosystem. The river can then develop naturally.

The complexity of the decommissioning process depends on the nature of the structure. Unlike larger structures, many small structures may be removed without any further investigation, but some consideration may also be required for small-scale protection measures (e.g. on downstream riverbanks or on bridge piers).

Just as construction of river barriers affects stream processes and forms, removal of barriers also affects them. Changes in process and form after barrier removal vary in magnitude, direction, and timing, depending on barrier type and operation as well as stream and catchment physical characteristics. The magnitude and frequency of flood events after barrier removal also play an important role. Stream responses to barrier removal may continue for years to decades and may include:

- Local stream gradient and longitudinal profile change (i.e. channel adjustment) due to shift in patterns of sediment movement and deposition; and
- Change in stream bed particle size distribution (sediment size distributions in the upstream reach may show greater proportions of coarse material as fines are transported downstream; coarsening or fining may take place downstream).

3.6.2 Improvement of the Structure

The focus of this guidance is on design of measures for improvement of the structure. Section 4 describes the selection of the most appropriate improvement measure and Section 5 describes the design principles and process for each measure. The main steps are:

- Identification of target fish species;
- Description of barrier criteria and the objective; and
- Decision of best option to improve the structure.

The process to identify which improvement measure is best suited to improve the structure is supported by an 'improvement matrix', which is described in detail in Section 4.3.

3.6.3 Reconstruction

If the structure cannot be decommissioned and improvement of the structure for fish passage is not possible, reconstruction or a bypass must be undertaken. This will require a full (re)design of the whole structure, incorporating measures for improvement to fish passage.

While reconstruction design is beyond the scope of this guidance, the following aspects should be considered for the new design regarding fish passage improvement:

- For effective reconstruction, the whole structure should be rebuilt in such a way that the river bed is continuous throughout the entire structure. This means drops and future scouring effects up- and downstream of the structure must be prevented. A continuous bed substrate for ground living organism must be included.
- By adjusting the slope of the structure, the depth of the water should be made as deep as possible and the flow velocity as low as possible. It is recommended to define target fish species for the definition of the required minimum values for these parameters.
- The chosen cross-section should be as large as possible to avoid lighting issues in the swim-in and swim-out area of the structure.

The cross-section in the culvert should be designed in such a way that, at low and medium discharges, bank berms are provided for the migration of terrestrial animals (e.g. otters).

Section 4 Selection of Measures to Improve the Structure

4.1 Introduction

In general, improvement measures represent the least impact option of improving fish passage at structures compared with reconstruction measures or creation of bypass systems. The decision tree identified improvement measures are the best solution at all nine selected sites on the Inny catchment. Using these selected structures as examples, an “Improvement Matrix” was developed to identify the most appropriate improvement measure at each site. Fish passage will be improved with the implementation of the chosen measure and there will be a positive impact on other quality elements of the WFD (e.g. hydromorphology, river structure, ecological diversity).

4.2 Barrier Criteria and Objectives

Technical criteria and improvement objectives were established using the selected sites in the Inny catchment as representative examples of the types of small barriers found on Irish rivers. To improve a structure, the objective “target fish species” needs to be defined as well as an analysis of the existing barriers caused by the structure. A structural approach for determining the best implementation of improvement measures is presented below.

4.2.1 Target Fish Species

It is necessary to define target fish species in the selected catchment at the outset. This determines the target values for the design parameters to be used (i.e. minimum water depth, maximum flow velocity, drop height, etc.) depending on the size and swimming and/or jumping capabilities of the target species.

The Project Steering Committee agreed that following fish species should be prioritised for improvements in fish passage on the Inny catchment and other small Irish rivers and streams:

- Brown and Sea Trout;
- Salmon;
- Lamprey species (sea and river lamprey); and
- Eel (elvers, yellow, and glass eel).

The target fish species need to be confirmed or defined for each river catchment. This should be discussed with the local IFI representative. In particular, the presence of any of the four representative species should be confirmed as they each impact the design parameters in this guideline (Section 5).

With regards to Sections 4.2.3 and 4.2.4 it should be noted that there are different approaches internationally to defining fish-specific design criteria. A comparison of the following international guidelines was undertaken and discussed with the Project Steering Committee: *Larinier et al. (2002)*, *ONEMA (2014)*, *DWA-M 509 (2014)*, *(AMBER, 2016)* and *USFWS (2019)*.

Suitable design criteria (parameters) for use in Ireland were agreed on for the above target fish species (see Section 5.1).

4.2.2 Zonation of Culverts

Culverts and similar small structures can be complex in their layout resulting in different issues at different parts of the structure. It is necessary to use a systematic analysis of the structure and for the purposes of this guidance, a zonation approach based on *Culvert Fishway Planning and Design Guidelines* (Kapitzke, 2010) has been chosen. This divides the structure into four hydraulic zones as shown in Figure 3.

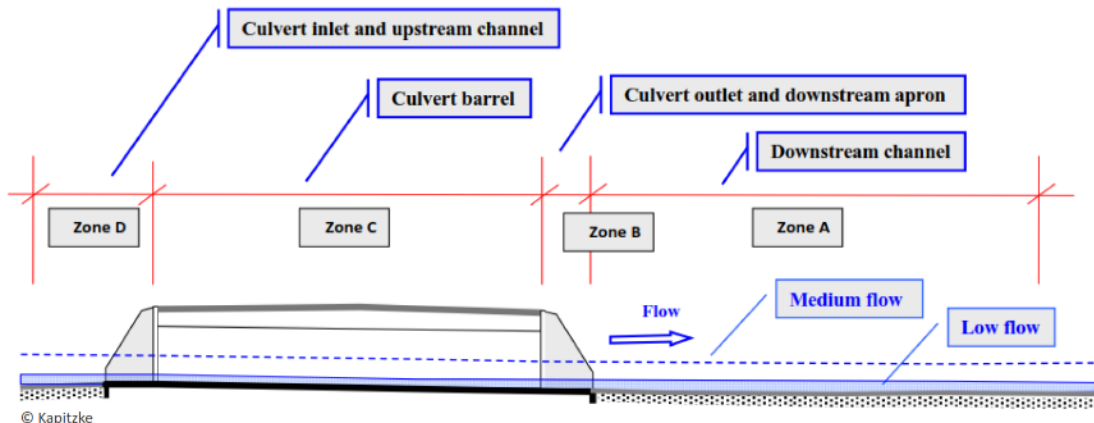


Figure 3: Zonation of culvert structure (Kapitzke, 2010)

Each zone can represent more than one type of barrier. The four investigation zones of culverts and similar small structures, listed from downstream, are:

- Zone A: Downstream channel, until culvert does not have any direct effect to the river structure;
- Zone B: Culvert outlet and downstream apron;
- Zone C: Culvert barrel; and
- Zone D: Culvert inlet and upstream channel, until the structure does not have any direct effect to the river channel.

For each zone, an independent investigation of hydraulic, structural and/or maintenance issues should be undertaken, to identify all issues of the structure and the best solution for improvement.

4.2.3 Hydraulic Criteria

Based on the zonal approach described in Section 4.2.2, hydraulic criteria were identified in Zones B, C and D. Depending on discharge, barriers to fish passage include:

- **Flow velocity** → if fish cannot swim upstream because the flow velocity is too high (Zones B/C/D);
- **Turbulences** → if fish cannot swim upstream because the turbulence is too high (Zones B/C); and

- **Water depth** → if fish cannot swim upstream, because the water depth is too shallow (Zone C).

Since all of these values are discharge dependant and can represent different barriers for different fish species, the scope of the objective for improvement depends on the target fish species.

4.2.4 Structural Criteria

Based on the zonal approach, structural criteria were identified in all zones of the selected structures in the Inny catchment. Barriers for upstream fish passage may be:

- **Bed erosion downstream** → process gradually causes/increases a drop (Zones A/B);
- **Drop** → if fish cannot swim upstream because the drop height is too high or the water depth to swallow downstream of the drop for a jump (depending on fish species, e.g. salmon can leap over obstacles whereas lamprey cannot jump at all) (Zones A/B);
- **Lighting Transition** → if fish do not want (or are delayed) to swim into the structure, because the transition in lighting (from light to dark) is too great (Zones B/D);
- **Channel bed material** → missing channel bed material represents an issue for ground orientated species to migrate upstream (Zone C); and
- **Absence of resting place** → in combination with a high flow velocity the fish cannot pass the structure in one attempt (Zone C).

Since all of these values are discharge dependant and represent different barriers for different fish species, the objective for improvement depends on the target fish species.

4.2.5 Maintenance Issues

Flood events can cause blockages which impact fish passage. This is generally not a problem so long as the structure is maintained on a regular basis, as happens on channels managed by the OPW.

4.3 Improvement Measures by Structure

While the criteria focus on the type of barrier to fish movement, the improvement measure needs to focus on the type of structure. The four different types of culverts and similar small structures which were observed on the Inny catchment and described in Section 2 (culverts, bridges, a small weir or artificial bed drop and gauging structures) are considered to represent typical examples which will be found in all Irish small rivers and streams.

The matrix shown in Figure 4 allows the identification of an improvement measure with an associated Generic (Design) Principle (GP #) which represents the best solution for improvement measure, depending on the barrier criteria (hydraulic, structural, maintenance issues) and structure type.

Criteria		Relevant zones where issues occur	Objective	Improvement measures			
				Culvert	Bridge	Weir	Gauging station
Hydraulic	flow velocity	B, C, D	flow velocity depends on → target species	Roughening of the bed or addition of roughness elements → GP 1 / GP 6 / GP 7			Generally no problem
	high turbulence	B, C	limit turbulence to levels which are passable → target species				
	water depth	C	water depth depends on → target species				
Structural	bed erosion downstream	A, B	constant river bed	Reinsertion of natural bed material and bed protection / construction of a rock ramp → GP 2			
	drop	A, B	drop depends on → target species	Existing drop reduction with construction of a rock ramp → GP 3 / GP 6			→ GP 4
	lighting	B, D	avoid abrupt changes of light	Aim for shading → GP 5	Generally no problem		
	channel bed material	C	natural bedrock, min. 30 cm	Roughening of the bed or insertion of natural bedrock material → GP 1			
	lack of resting place	C	adequate hydraulic conditions to allow the fish to pass barrier in one go	Roughening of the bed or addition of roughness elements → GP 1 / GP 7			Generally no problem
Main-tenance	debris removal	B, C, D	check after flood events	Generally no problem			

Figure 4: Improvement Matrix for culverts and similar small structures

The improvement matrix identifies the most effective improvement measure for the structure under consideration. Seven Generic (Design) Principles have been developed, which are described in detail in Section 5 :

- **GP1:** Reinsertion of bed material and bed protection / construction of a rock ramp;
- **GP2A:** Rock ramp with staggered array;
- **GP2B:** Pool and Boulder Pass;
- **GP3:** Rock ramp at gauging station;
- **GP4:** Lowering of culvert bed level;
- **GP5:** Aim for shading; and
- **GP6:** Roughening of the bed or addition of roughness elements.

The Generic Principles describe the basic process and construction method of the improvement measure.

It should be noted that an engineering design may still be required for locations which need further investigation regarding hydraulic or structural issues.

Section 5 Description of the Generic Design Principles

5.1 Design Parameters

The design parameters for the implementation of the Generic Principles are shown in Table 1.

Table 1: Summary of Design Parameters

Design parameter	Abbreviation	Unit
Min. water depth	$h_{\min, WD}$	(m)
Slope	s	(-)
Boulder stone thickness	ds	(m)
Max. drop height between up- and downstream water level	Max. Δh	(m)
Stone diameter at 50 mass percent sieve passage	d50	(cm)
Centre distance between boulders in river width	a_x	(m)
Centre distance between boulders in river length	a_y	(m)
Min. slot width	$s_{\min.}$	(m)
Min. clear pool length	$L_{\min}$	(m)

The Generic Principles have been developed in such a way so that based on local boundary conditions, the design can be easily adapted for each site (i.e. the structure and the impacted upstream and downstream area). The relevant design parameters will depend on target fish species and site boundaries such as flow discharge and topography.

As outlined in Section 4.2.1, based on a review of international guidelines design parameters were agreed for the Generic Principles as shown in Table 2 for the fish species prioritised by the Project Steering Committee for improvements in fish passage on small Irish rivers and streams.

Table 2: Design Parameters and Values for Generic Principles depending on Fish Species

Recommendation:	Brown Trout	Sea Trout & Salmon	Sea Lamprey	River Lamprey	Glass Eel	Elvers / Yellow Eel
Generic Principle 2, 3A, 4, 6: rock ramp / staggered arrays						
min. water depth (m)	0.24	0.42	0.15	0.15	0.01	0.02
preferred slope (see note on slope)	1:30	1:30	1:30	1:30	1:30	¹⁾
min. slope (see note on slope)	1:20	1:14	1:20	1:20	1:1	²⁾
max. energy dissipation (W/m ³)	200	200	250	200	¹⁾	¹⁾
Generic Principle 3B: pool & boulder pass						
min. water depth (m)	0.24	0.42	0.15	0.15	0.01	0.02
min. slot width (m)	0.15	0.2 - 0.3	0.15	0.15	0.01	0.06
max. drop (m)	0.17	0.2	0.07	0.07	¹⁾	¹⁾
min. clear pool length (m)	1.5	2.5	2.0	1.25	¹⁾	¹⁾
max. energy dissipation (W/m ³)	150	200	150	150	¹⁾	¹⁾

1) no recommendation available to date 2) depends on ramp length

Note on Slope

Rock ramp fishways represent a rough equivalent to a natural river with a high slope. They generally require the installation of large rock boulders to dissipate the energy, reduce flow velocities and increase the water depth. Rock ramps (without perturbations boulders) made solely of riprap, forming a continuous rough surface, are known to pose problems for many fish species. On rock ramps with staggered arrays of elements the flow energy is dissipated by the more or less regularly distributed large boulders spread separately over the rock chute. Both, rock ramps without perturbations boulders and rock ramps with staggered array do not offer shelter and rest zones. Successful negotiation of these structures “in one go” typically requires fish to exhibit their burst swimming speed, which they can only maintain for a very short time (<10 sec). Therefore, these structures can only be considered true fish passes if the longitudinal slope remains very low (less than 3%), in particular long rock ramps (>5m in length). The higher the head, the flatter the ramp should be designed.

Pool & boulder passes maintain sufficient water depths while limiting the discharge by means of arranging rock boulders in rows at regular intervals. The result is a set of pools where fish are likely to find rest zones. As such, their gradients can be higher than that of rock ramps without perturbations boulders and rock ramps with staggered array.

A preferred slope for Irish conditions has been identified in Table 2. However, in the event of insufficient space being available at the site, a minimum slope based on international guidance has also been identified.

5.2 Design and Implementation of the Generic Principles

In the following subsections, a description of the design process and implementation of each Generic Principle is provided. Accompanying drawings for each Generic Principle are included in **Appendix A**.

5.2.1 GP1 – Rock Ramp

GP1 represents the most practical solution for the improvement of structures where the main barrier to fish passage is caused by bed erosion downstream in Zone A and/or B in combination with:

- Sufficient space downstream; and/or
- No hydraulic issues in the structure itself.

To improve a structure using GP1, Table 3 summarises the design process. **Appendix A** contains schematic drawings to support the design process and represent the basis for the construction:

- Current Situation: Long Section;
- Improvement: Long Section; and
- Improvement: Cross Section 1-1.

An example of this situation in the Inny catchment (Location 4, upstream) is shown in Figure 5 alongside a completed rock ramp in Zone A built downstream of a culvert that previously had a drop at its end.

Table 3: Design process for GP1

No.	Design Step	Action
1	Identification of target fish species	Design values are listed in Table 2.
2	Investigation of existing drop height and current slope of river	With Table 2 determine required length of rock ramp check: existing drop height on mean flow vs. max. slope
3	Investigation of river width and current slope of river	With Table 2 determine amount of required bed material (erosion stable), based on the existing bed level and the improved bed level
4	Investigation of existing bed material	Determination, if geotextile is required between riverbed substrate and rock ramp material to avoid a washout. A geotextile is required, if the ratio of d50 of new inserted bed material to d50 of the existing bed material is not between 6 and 10.



Figure 5: Example of situation where GP1 should be used (Inny Catchment, left photo) and for completed site implementing GP1 as the solution (right photo)

5.2.2 GP2A – Rock ramp with staggered array

GP2A represents the most practical solution for the improvement of culverts and similar small structures where the main barrier for fish passage is caused by bed erosion downstream and /or a drop in Zone A and/or B in combination with:

- Enough space downstream;
- Requirement for the reduction of flow velocity; and / or
- Availability of sufficient boulders.

Based on international guidelines (see also Section 5.1), the design values shown in Table 4 are recommended to construct a rock ramp with staggered array (GP2A). There are a number of additional design values (highlighted in blue) that need to be determined for GP2A. These are easier to understand by referring to the GP2A-plan view drawing in **Appendix A**.

Table 4: Design values for GP2A

Parameter		Value
$h_{\min. WD}$	min. water depth	Table 2
1:x	max. slope	Table 2
a_x	min. centre distance between boulders (in longitudinal direction)	$2*d_s - 3*d_s (\geq 3x \text{ target fish length})$
a_y	min. centre distance between boulders (in cross direction)	$0.9 * a_x$
$a_y - d_s$	min. clear distance between boulders regarding river width	min 6* D fish = 0.5 m
$2*a_x - d_s$	min. clear distance between boulders regarding river length	$\geq 3*L \text{ fish} = 1.5 \text{ m}$

To improve a structure using GP2A, Table 5 summarises the design process.

Table 5: Design process for GP2A

No.	Design Step	Action
1	Identification of target fish species	Design values are listed in Table 2
2	Investigation of existing drop height and current slope of river	With Table 4 determine required length of staggered array section ▪ check: total drop height vs. max. slope
3	Investigation of river width	With Table 4 determine ▪ amount and size of boulders required ▪ amount of bed material required (erosion stable)
4	Investigation of existing bed material	Determination, if geotextile is required between riverbed substrate and rock ramp material to avoid a washout. A geotextile is required, if the ratio of d50 of new inserted bed material to d50 of the existing bed material is not between 6 and 10.

Appendix A contains schematic drawings to support the design process and represent the basis for the construction:

- Current Situation: Long Section;
- Improvement: Long Section;
- Improvement: Plan View; and
- Improvement: Cross Section 1-1.

A typical example of bed erosion downstream and drop issues where the most practical solution is construction of a rock ramp with staggered array in the Inny catchment is shown in Figure 6 alongside an example of a completed rock ramp with staggered array in a stream downstream of a bridge.



Figure 6: Example of situation where GP2A should be used (left photo) and for completed site implementing GP2A as the solution (right photo)

5.2.3 GP2B – Pool and Boulder Pass

GP2B represents the most practical solution for the improvement of culverts and similar small structures where the main barrier for fish passage is caused by bed erosion downstream and/or a drop in Zone A and/or B in combination with:

- Requirement for the reduction of flow velocity;
- Not enough flow, to guarantee the minimum water depth for the target fish species during the relevant migration times

$$\text{Check: min. } h_{WD} \leq \frac{Q_{95}}{\text{width} \times v(Q_{95})}$$

(minimum required water depth fish $\leq Q_{95}$ divided by width of the culvert and flow velocity of Q_{95} flow discharge);

- Space availability (limited available footprint for construction) downstream of the structure; and/or
- Availability of sufficient boulders.

A typical example of drop issue where the most practical solution is construction of a pool and boulder pass in the Inny catchment is shown in Figure 7.



Location 7, view upstream



Location 7, site view

Figure 7: Example of situation where GP2B should be used (Inny catchment)

To improve a structure using GP2B, Table 6 summarises the design process.

Table 6: Design process for GP2B

No.	Design Step	Action
1	Identification of target fish species	Design values are listed in Table 2.
2	Investigation of existing drop height	With Table 2 determine number of boulder rows Check: total drop height / max. Δh . (round up always, to identify how many rows of boulder are required)
3	Estimation of Q90	With Table 2 determine number of slots Check: if Q90 > 60 l/s, two slots necessary if Q90 > 120 l/s, three slots necessary and add an additional slot for every additional 60 l/s
4	Investigation of river width	With Table 2 determine - amount and size boulders required - amount of required bed material (erosion stable)
5	Investigation of existing bed material	Determination, if geotextile is required between riverbed substrate and rock ramp material to avoid a washout. A geotextile is required, if the ratio of d50 of new inserted bed material to d50 of the existing bed material is not between 6 and 10.

Appendix A contains schematic drawings to support the design process and represent the basis for the construction:

- Current Situation: Long Section;
- Improvement: Long Section;
- Improvement: Plan View; and
- Improvement: Cross Section 1-1.

Figure 8 shows a pool and boulder pass downstream of Tuckmill Bridge, Co. Wicklow during and post construction.



Figure 8: Example for completed site implementing GP2B as the solution (Photos: IFI)

5.2.4 GP3 – Rock ramp at a gauging structure

GP3 represents the most practical solution for the improvement of culverts and similar small structures where a gauging structure exists. Since the improvement for fish passage has to guarantee the future function of the gauging structure, the weir (typically a horizontal concrete bar downstream of the gauge which ensures the water level and flow measurements) has to remain in place. The design solution represents a reduction of the drop with the construction of a rock ramp downstream of the gauging weir.

Typical examples of drop issues at gauging structures where the most practical solution is construction of a rock ramp in the Inny catchment are shown in Figure 9.



Location 2, view downstream



Location 1, view upstream

Figure 9: Example of situation where GP3 should be used (Inny catchment)

To improve a structure using GP3, Table 7 summarises the design process.

Table 7: Design process for GP3

No.	Step	Action
1	Identification of target fish species	Design values are listed in Table 2
2	Investigation of existing drop height and current slope of river	With Table 2 determine required length of staggered array section check: max. drop height vs. max. slope
3	Investigation of river width	With Table 2 determine amount of required bed material (erosion stable), based on the existing bed level and the improved bed level
4	Investigation of existing bed material	Determination, if geotextile is required between riverbed substrate and rock ramp material to avoid a washout. A geotextile is required, if the ratio of d50 of new inserted bed material to d50 of the existing bed material is not between 6 and 10.
5	Re-calibration after modification	It may be necessary to re-calibrate the gauge after the modification is done.

Appendix A contains schematic drawings to support the design process and represent the basis for the construction:

- Current Situation: Long Section;
- Improvement: Long Section; and
- Improvement: Cross Section 1-1.

An example of a gauging station (Beuron, Danube River) upgraded with a rock ramp downstream is shown in Figure 10. The rock ramp does not hydraulically interfere with the gauging section.



Figure 10: Example for completed site implementing GP3 as the solution (Photos: Stephan Heimerl / RP Tuebingen)

5.2.5 GP4 – Reduced invert level

GP4 represents the most practical solution for the improvement of culverts and similar small structures where the main barrier for fish passage is caused by bed erosion downstream and / or a drop in Zone A and/or B in combination with

- Spaces issues downstream of the structure; and
- Adequate stability of the existing structure-

An example of drop issues where the most practical solution is reducing the invert level is shown in Figure 11 at a site in Co. Wickow (Donard catchment).



Figure 11: Example of situation where GP4 should be used (Photo: IFI)

To improve a structure using GP4, Table 8 summarises the design process.

Table 8: Design process for GP4

No.	Step	Action
1	Identification of target fish species	Design values are listed in Table 2.
2	Investigation of existing drop height and current slope of the structure and river up- and downstream	With Table 2, determine required reduction of the invert level and length of the rock ramp ▪ check: total drop height vs. max. slope
3	Investigation of river width and current slope of river	With Table 2, determine ▪ amount of bed material required (erosion stable)
4	Investigation of existing bed material	Determination, if geotextile is required between riverbed substrate and erosion fill material downstream of the culvert/bridge to avoid a washout. A geotextile is required, if the ratio of d50 of new inserted bed material to d50 of the existing bed material is not between 6 and 10.

Appendix A contains schematic drawings to support the design process and represent the basis for the construction:

- Current Situation: Long Section;
- Improvement: Long Section; and
- Improvement: Cross Section 1-1.

Figure 12 illustrates an example of a lowered invert at Donard Bridge, Co. Wicklow. Low flow is concentrated within one bridge span to increase water depth.



Figure 12: Example for completed site implementing GP4 as the solution (Photos: IFI)

5.2.6 GP5 – Improvement in Lighting Transitions

GP5 represents the most practical solution for the improvement of culverts and similar small structure where lighting issues in Zone B and/or D exist (typically in long and/or small diameter culverts).

Typical examples of lighting issues at structures where the most practical solution is a change of vegetation in the Inny catchment are shown in Figure 13.



Location 6, view upstream

Location 6, view upstream

Figure 13: Issues examples in Inny catchment for use of GP5

The design idea of this Generic Principle is to develop a smooth transition from light to dark using the shade of wide crested trees, which are common to the investigated area. Examples of suitable tree species include:

- Alder (*Alnus glutinosa*); and
- Willow (*Salix alba*, *Salix fragilis*).

IFI can provide site-specific advice if requested.

When planting, it is important to ensure that the trunk and roots are located away from the riverbed. **Appendix A** contains schematic drawings to support the design process and represent the basis for the construction:

- Current Situation: Plan Section; and
- Improvement: Plan View.

5.2.7 GP6 – Roughening of the bed / addition of roughening elements

GP6 represents the most practical solution for the improvement of culverts and similar small structures where the main barrier for fish passage is caused by hydraulic issues in Zone B and/or C.

A typical example of hydraulic issues in the structure where the most practical solution is by roughening the river bed/invertor installing roughness elements is shown in Figure 14:



Figure 14: Example of situation where GP6 should be used (Inny catchment)

Including a layer of coarse (erosion stable) gravel/rock material, and loosely placed perturbation boulders where applicable, represents the most practical solution (Figure 15).

Installing artificial roughness elements into the structure, is an alternative (Figure 16). The general idea is to arrange baffles, blocks or other structures in the culvert or similar small structure, which are attached to the culvert invert or walls to increase water depth, diversify the flow conditions or lower the flow velocity in Zone C to improve fish passage. There exist several options of different types. A good overview of applicable options of roughness elements in culverts and similar small structures is provided in the guidelines *Culvert Fishway Planning and Design Guidelines* (Kapitzke, 2010, Part C) and *Fishways: biological basis, design criteria and monitoring* (Larinier et al., 2002, Section 8).

All artificial roughness elements have been designed for gradients of culverts from less than 0.5% to 5%. Their use on steeper gradients must be considered very carefully and requires expert knowledge. They all significantly increase the depth of water in the culvert for any given discharge. This effect increases as the ratio of the depth of water to the height of the baffles increases. The effect of the baffles on the discharge capacity of the culvert is related to their equivalent “rugosity”; this means that the installation of baffles in a culvert drastically reduces its hydraulic capacity. Therefore, a hydraulic assessment may be necessary before the installation of artificial roughness elements. There are no drawings for GP6 as many different solutions of roughness elements exist. Further examples of completed sites are shown in **Appendix A**.



Figure 15: Example for completed site implementing GP6 as the solution using natural material (Photos: Jens Gorlach)



Figure 16: Example for completed site implementing GP6 as the solution GP6 using artificial baffle elements (Kapitzke, 2010)

5.3 Solutions for Barriers in Inny Catchment

For the nine selected sites of the Inny catchment, improvement measures would improve fish passage. Table 9 gives a summary of the Generic Principle which would be suggested using the Decision Tree and Improvement Matrix at each selected site and also gives values for the design parameters (Section 5.3.2).

Table 9: Solutions for Barriers in Inny Catchment

Location	Recommendation	Comment
Location 1	Generic Principle 3	
Location 2	Generic Principle 3	
Location 3	Generic Principle 2A for zones A and B (Generic Principle 6 for zone C)	Recommendation to investigate if hydraulic issues occur during higher flow. If yes, recommendation to implement GP4.
Location 4	Generic Principle 1	Site visit recommended, to confirm implementation of GP6.
Location 5	Generic Principle 1 for zones A and B Generic Principle 5 for Zone A and D (Generic Principle 6 for zone C)	Site visit recommended, to confirm implementation of GP4. Recommendation to investigate if hydraulic issues occur during higher flow. If yes, recommendation to implement GP4.
Location 6	Generic Principle 1 for Zone A and B Generic Principle 5 for zone A and D (Generic Principle 6 for zone C)	Recommendation to investigate if hydraulic issues occur during higher flow. If yes, recommendation to implement GP4.
Location 7	Generic Principle 2B	
Location 8	Generic Principle 2B	
Location 9	Generic Principle 2A	Site visit recommended, to confirm the useful implementation of GP2A.

5.3.1 Design Fish Species

The Project Steering Committee determined Brown Trout and Eel to be the target fish species for the Inny catchment. It was decided not to include Lamprey (weak swimmers) and Salmon (strong swimmers) as target fish species for the following reasons:

- There is always a variation of flow pattern (water depth and velocity) in a river bed and typically on rock ramps a sufficient migration corridor for weak swimmers exists (e.g. on the side of the river banks) and for larger fish in the centre of the ramp;
- The main migration time of salmonids (sea trout/salmon) is in seasons with higher flow conditions (mostly winter time), when a salmon should be able to cross potential improvement structures in any case. Further, grilse or adult salmon return to their river in late spring and summer when flow conditions may be lowest. Trout run in the winter when flows are highest.

5.3.2 Design Values for Generic Principle in the Inny Catchment

Because the Project Steering Committee has identified the most relevant fish species for the Inny catchment, it is not necessary to redetermine design values for each site. The tables below

provide an overview of the applicable parameters for the implementation each Generic Principle within the Inny catchment.

Based on international guidelines (see also Section 5.1) and input from the Project Steering Committee, the design values shown in Table 10 (GP1), Table 11 (GP2A), Table 12 (GP2B), Table 13 (GP3) and Table 14 (GP4) are recommended for implementation of a relevant Generic Principles in the Inny catchment.

Table 10: Design values for implementation of GP1 (rock ramp) in the Inny catchment

Parameter		Value
$h_{\min, WD}$	min. water depth	0.24 m
1:x	max. slope	1:30

Table 11: Design values for GP2A (rock ramp with staggered arrays) in the Inny catchment

Parameter		Value
$h_{\min, WD}$	min. water depth	0.24 m
1:x	max. slope	1:30
a_y	min centre distance between boulders regarding river width	$0.9 \cdot a_x$
a_x	min centre distance between boulders regarding river length	$2 \cdot d_s - 3 \cdot d_s$
$a_y - d_s$	min clear distance between boulders regarding river width	min $6 \cdot D_{\text{fish}} = 0.5 \text{ m}$
$2 \cdot a_x - d_s$	min clear distance between boulders regarding river length	$\geq 3 \cdot L_{\text{fish}} = 1.5 \text{ m}$

Table 12: Design values for GP2B (pool and boulder pass) in the Inny catchment

Parameter		Value
$h_{\min, WD}$	min. water depth	0.24 m
$S_{\min}$	min. slot width	0.15 m
max. Δh	max. drop between rows	0.13 m
$L_{\min}$	min. clear pool length	1.5 m

Table 13: Design values for GP3

Parameter		Value
$h_{\min, WD}$	min. water depth	0.24 m
max. Δh	max. drop between rows	0.13 m
1:x	max. slope	1:30

Table 14: Design values for GP4 (reduction of floor level) in the Inny catchment

Parameter		Value
$h_{\min, WD}$	min. water depth	0.24 m
1:x	max. slope	1:30

Section 6 Conclusion

This guidance was developed by OPW with IFI and the Department of Housing, Planning and Local Government to support the process of addressing the significant impact of small barriers to fish passage caused by culverts and similar small structures in Ireland's small rivers and streams.

The guidance is for use on barriers to fish passage caused by small culverts or similar in-stream structures with a head drop of up to 1.0 m during low flow and with a mean flow of up to 1.0 m³/s. While the guidance is based on barriers identified in a specific catchment, it is intended to be suited to the variety of conditions and fish species that would be expected in Irish small rivers and streams. The guidance will help mitigate against the barrier itself, and also take account of water levels in the vicinity of the barrier, both upstream and downstream to ensure that levels are adequate for fish passage in all flow conditions.

The guidance comprises a decision tree to identify the best measure to improve fish passage through culverts and similar small structures. Decommissioning represents the best solution in most cases and should always be the objective where feasible. Where this is not possible, improvement measures represent the least impact option of improving fish passage at structures compared with reconstruction measures or creation of bypass systems.

The decision tree identified improvement measures are the best solution at all nine selected sites on the Inny catchment. Using these selected barriers as examples, an "Improvement Matrix" was developed to identify the most appropriate improvement measure at each site. Fish passage will be improved with the implementation of the chosen measure and there will be a positive impact on other quality elements of the WFD (e.g. hydromorphology, river structure, ecological diversity).

For each improvement measure for the structure under consideration. Seven Generic (Design) Principles have been developed:

- **GP1:** Reinsertion of bed material and bed protection / construction of a rock ramp;
- **GP2A:** Rock ramp with staggered array;
- **GP2B:** Pool and Boulder Pass;
- **GP3:** Rock ramp at gauging station;
- **GP4:** Lowering of culvert bed level;
- **GP5:** Aim for shading; and
- **GP6:** Roughening of the bed or addition of roughness elements.

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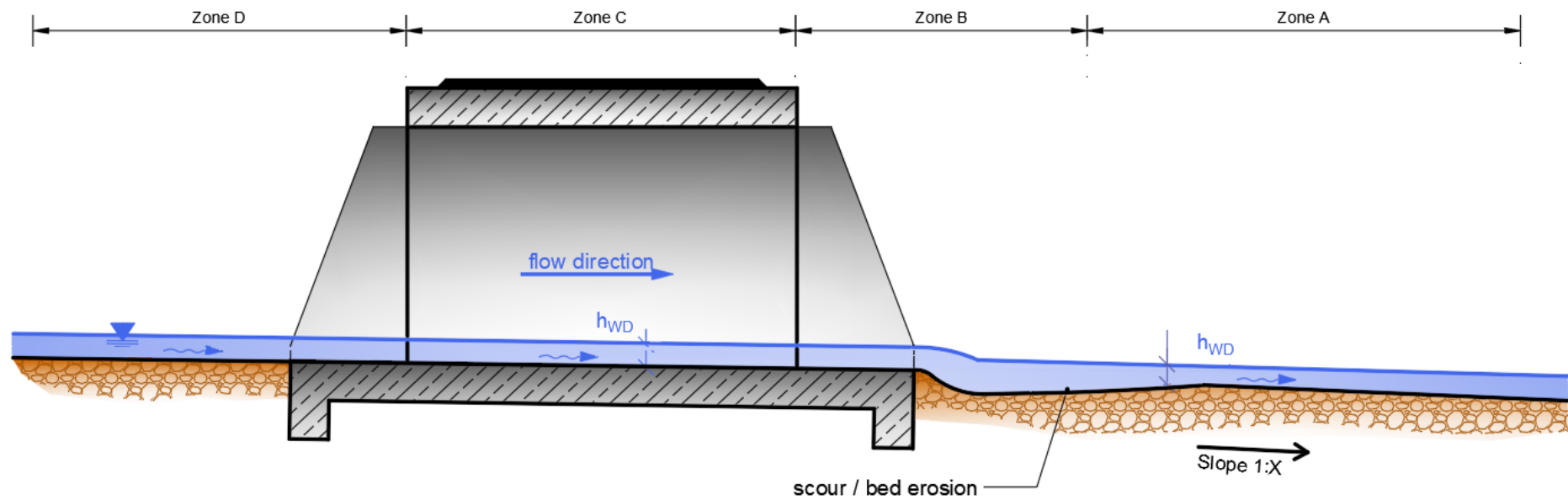
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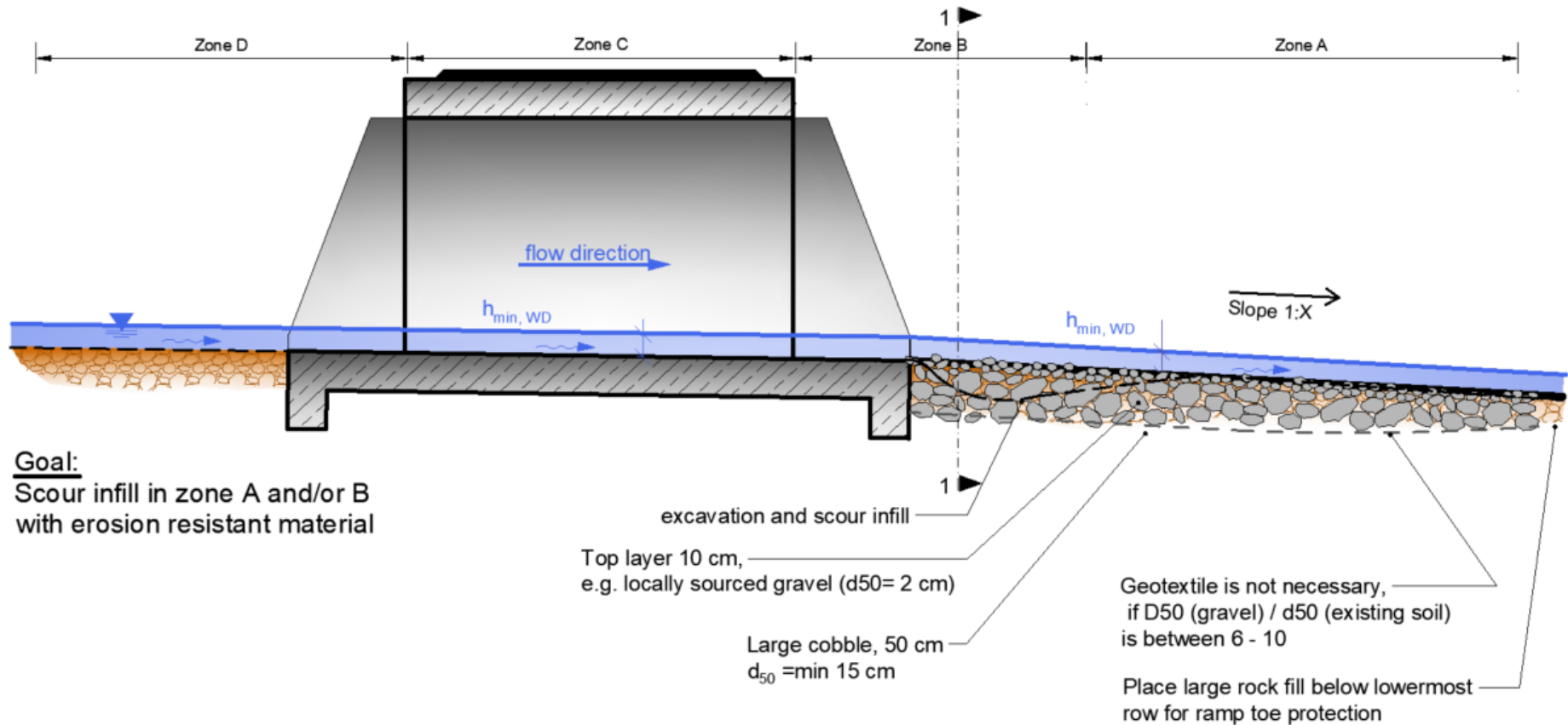
Appendix A Generic Principle Drawings

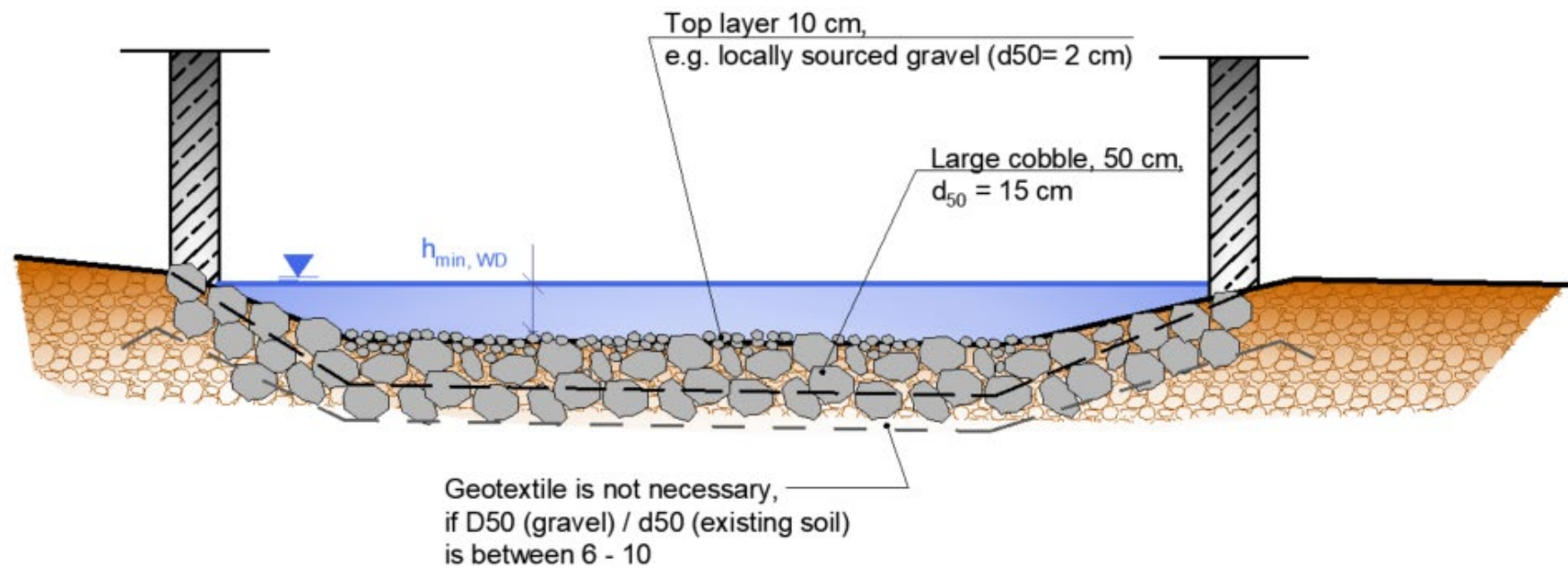
Generic Principle 1 – Rock Ramp

GP1 Current Situation: Long Section



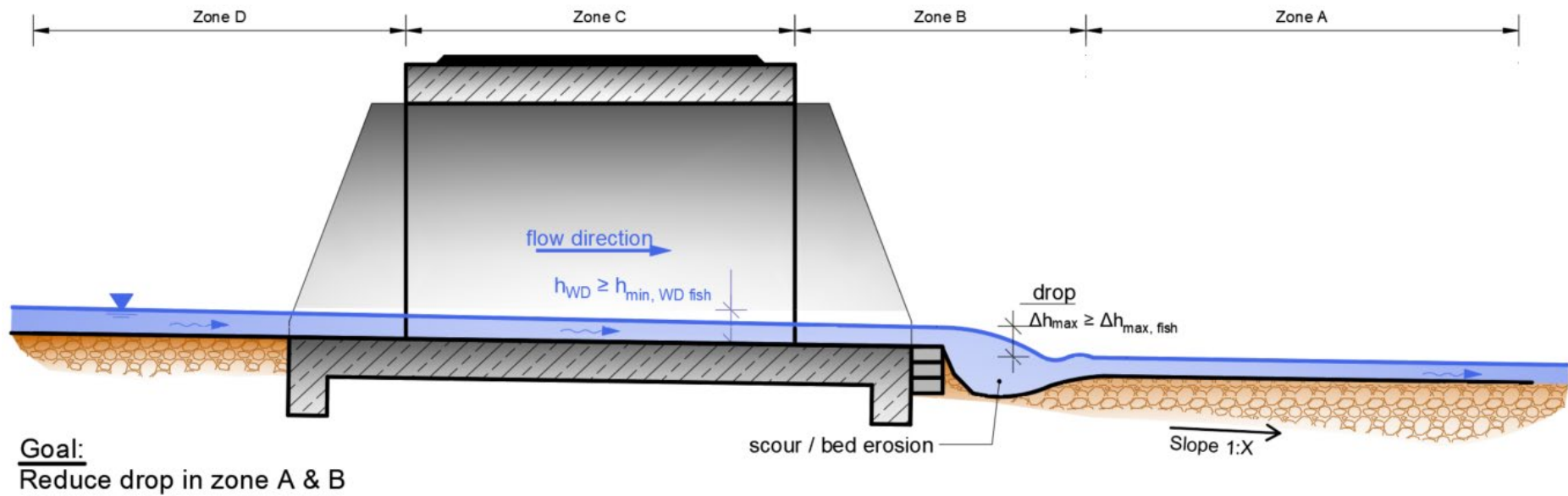
GP1 Improvement: Long Section



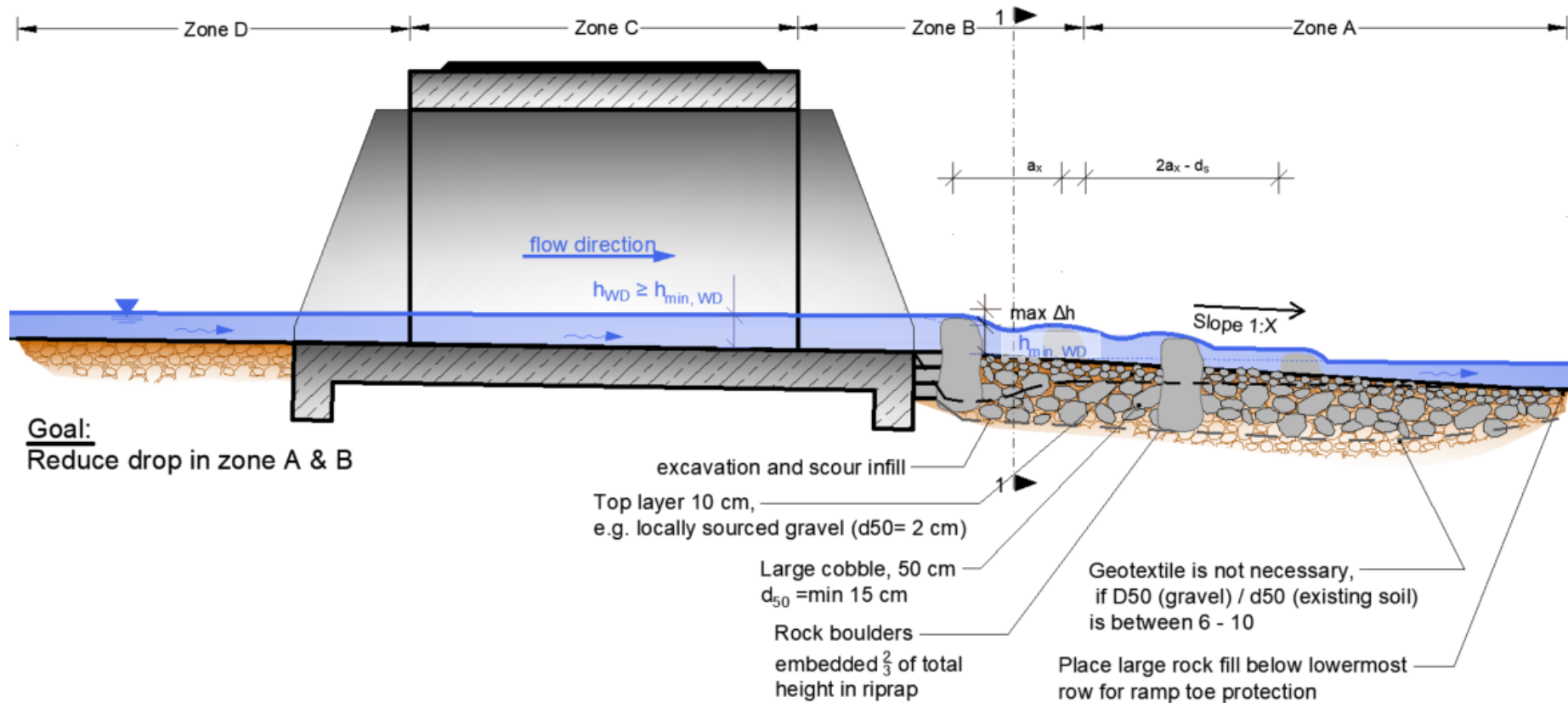
GP1 Improvement: Cross Section 1-1

Generic Principle 2A – Rock Ramp with Staggered Array

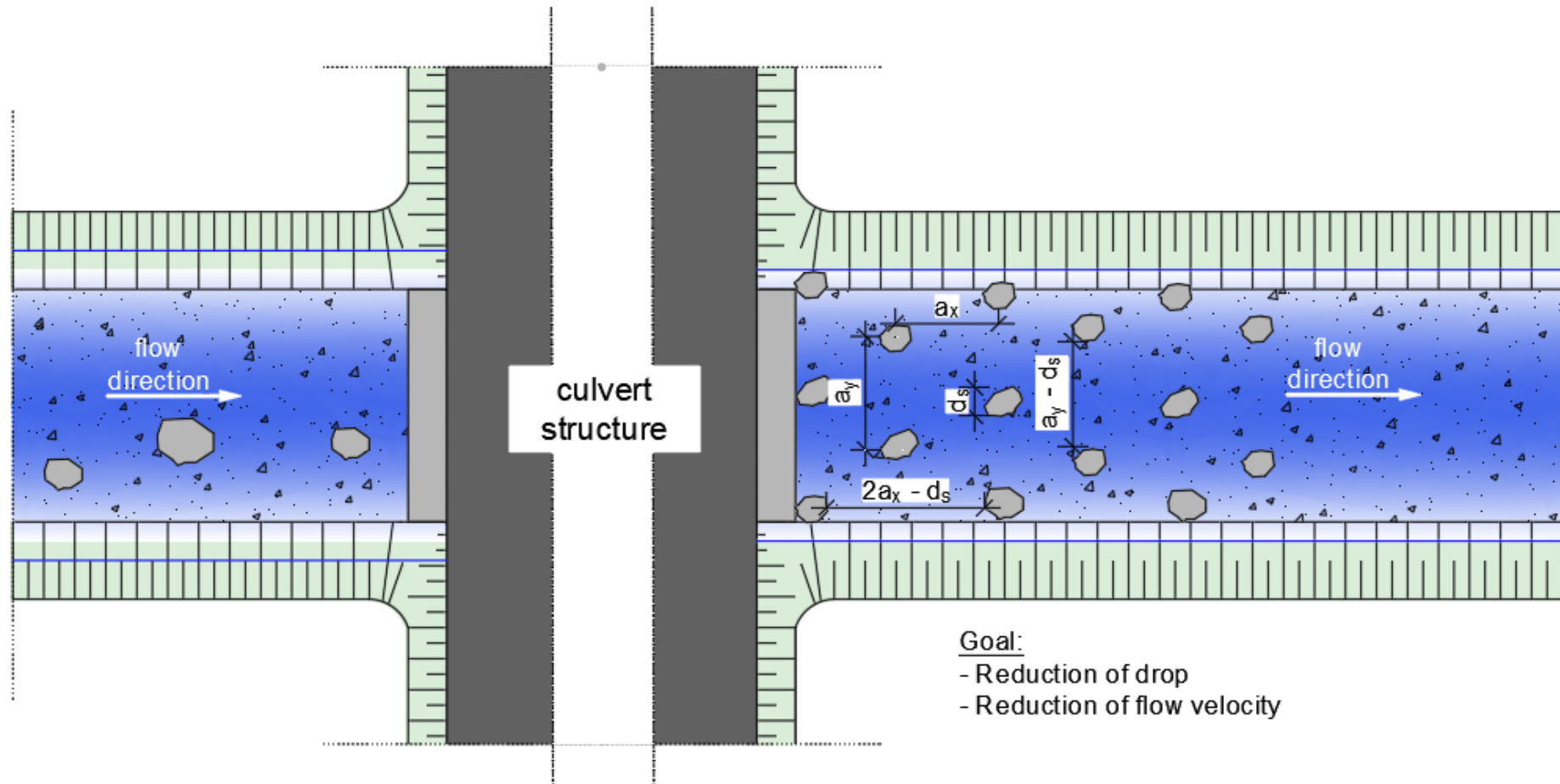
GP2A Current Situation: Long Section

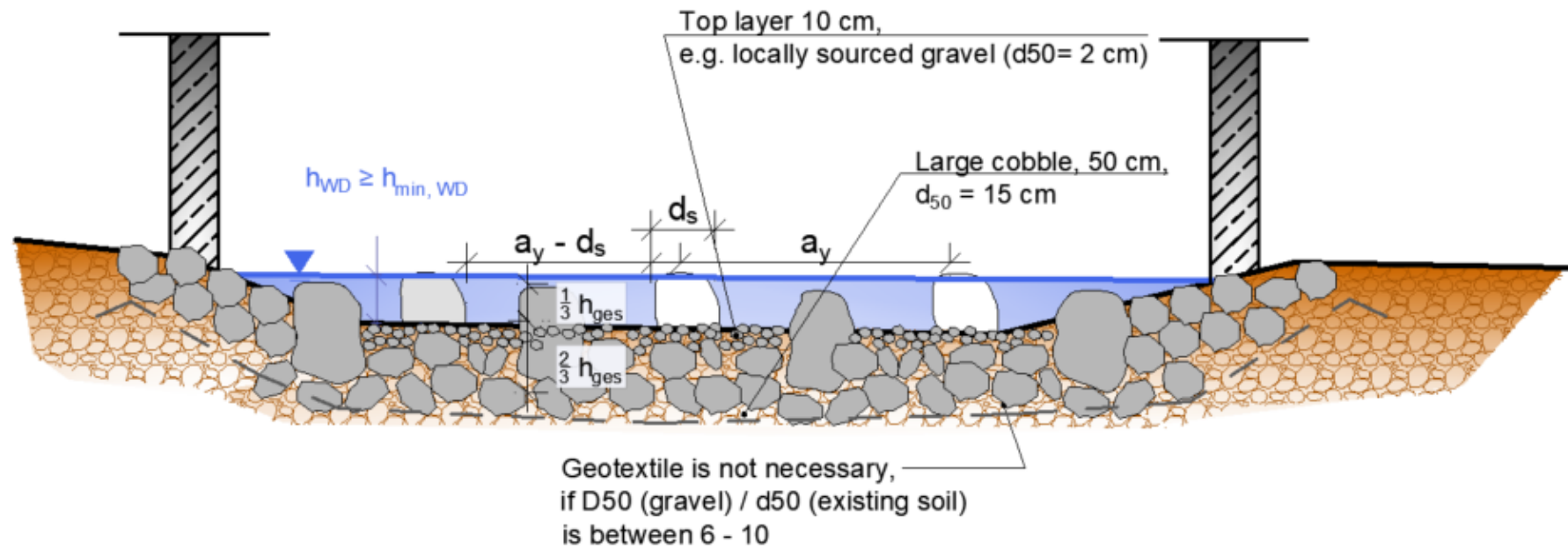


GP2A Improvement: Long Section



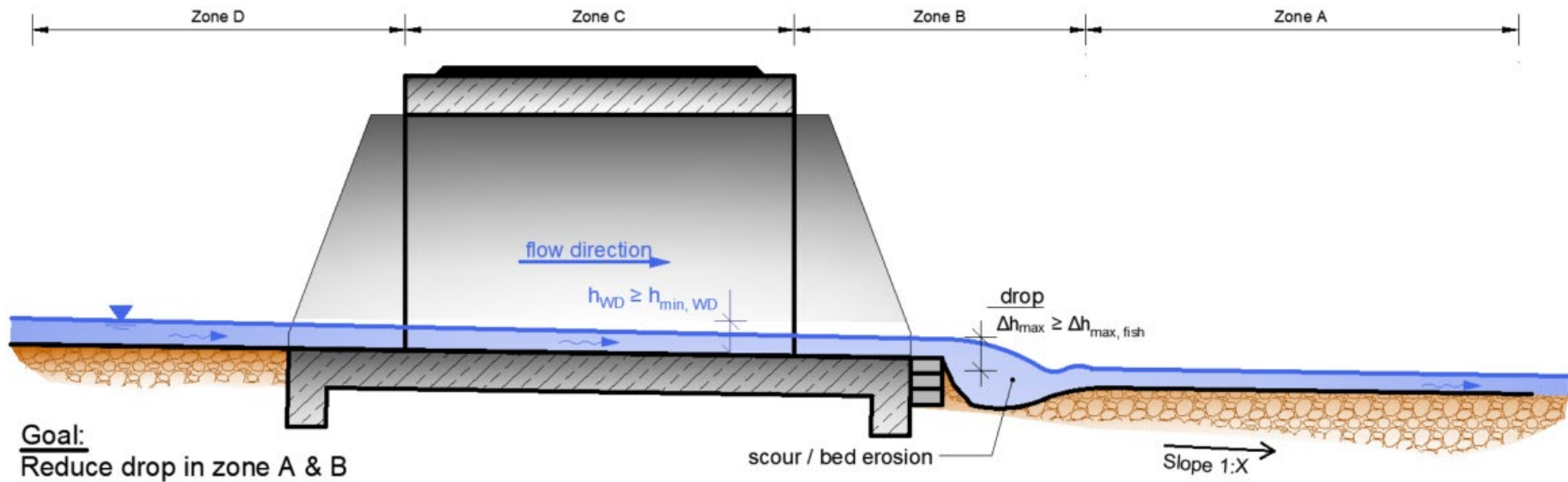
GP2A Improvement: Plan View



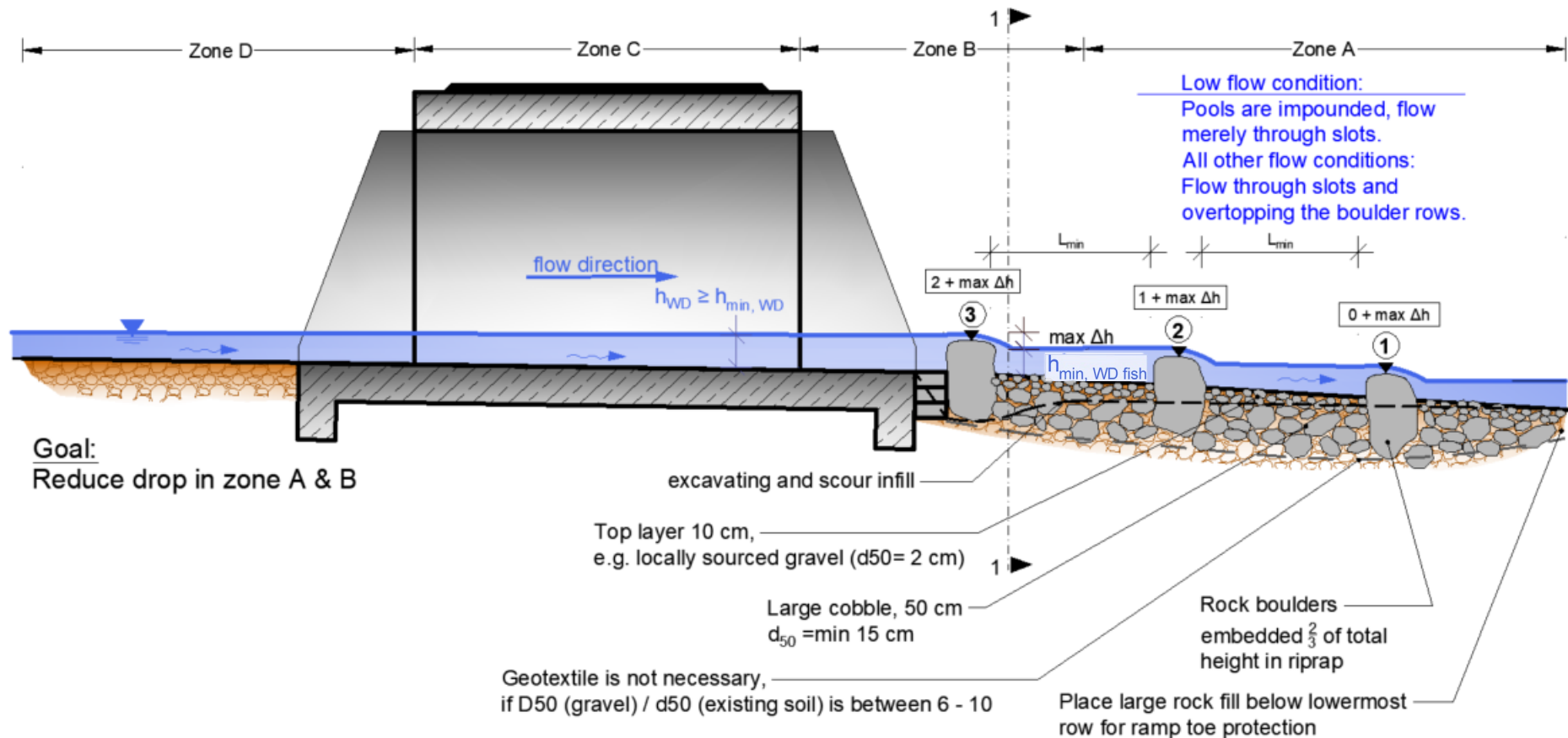
GP2A Improvement: Cross Section 1-1

Generic Principle 2B – Pool and Boulder Pass

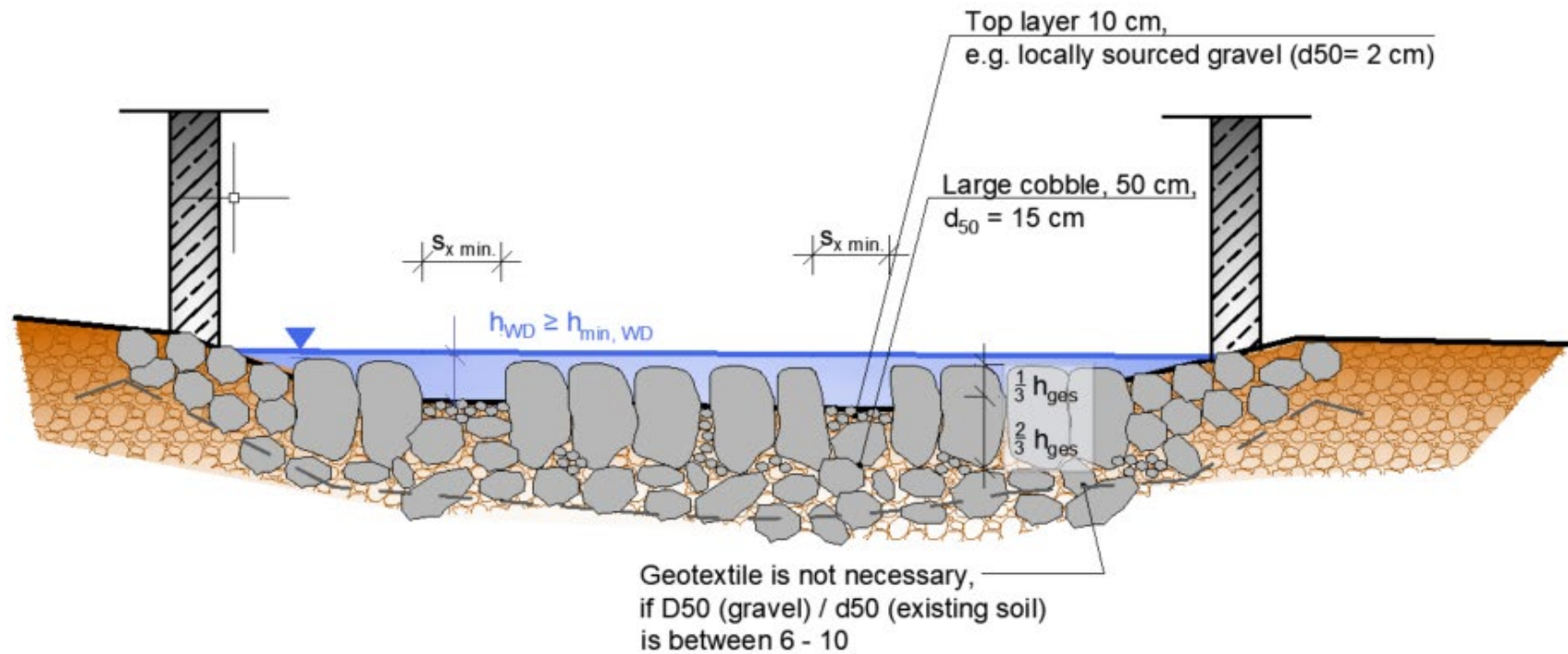
GP2B Current Situation: Long Section



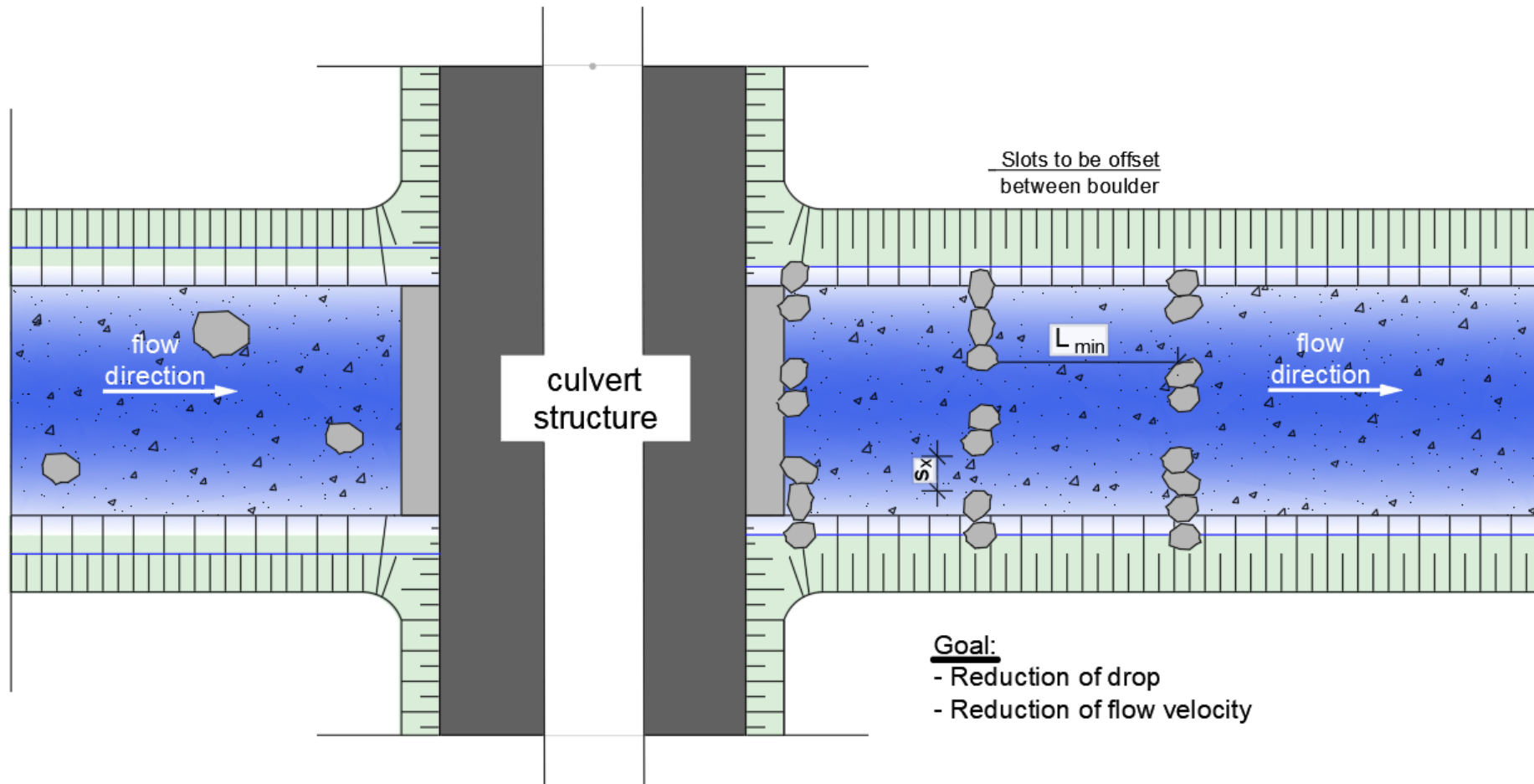
GP2B Improvement: Long Section



GP2B Improvement: Cross Section 1-1

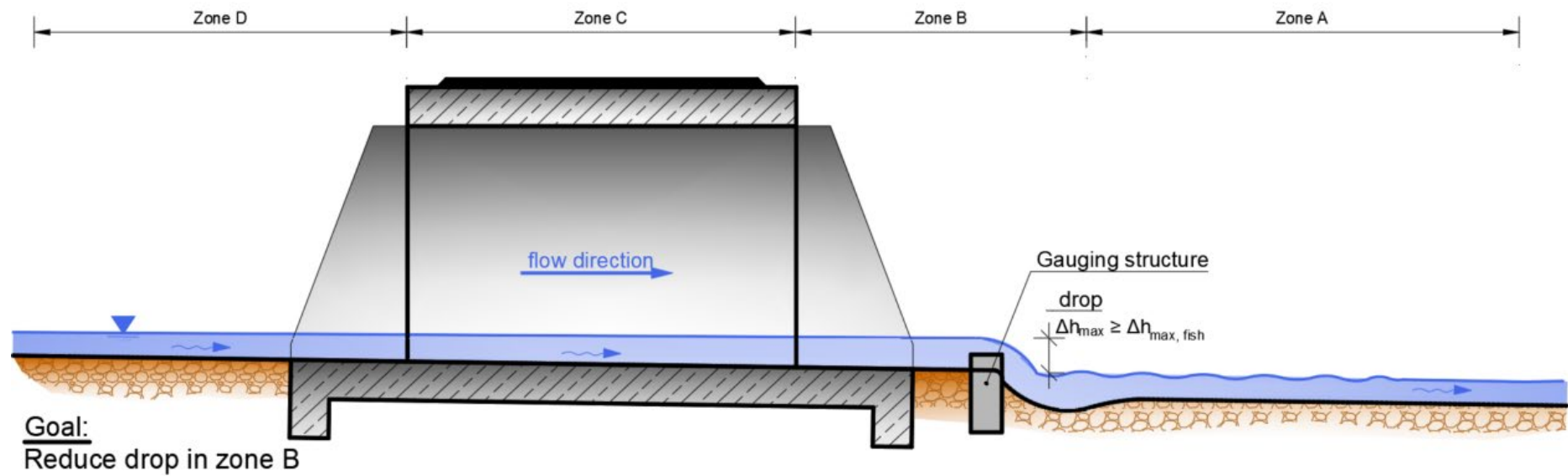


GP2B Improvement: Plan View

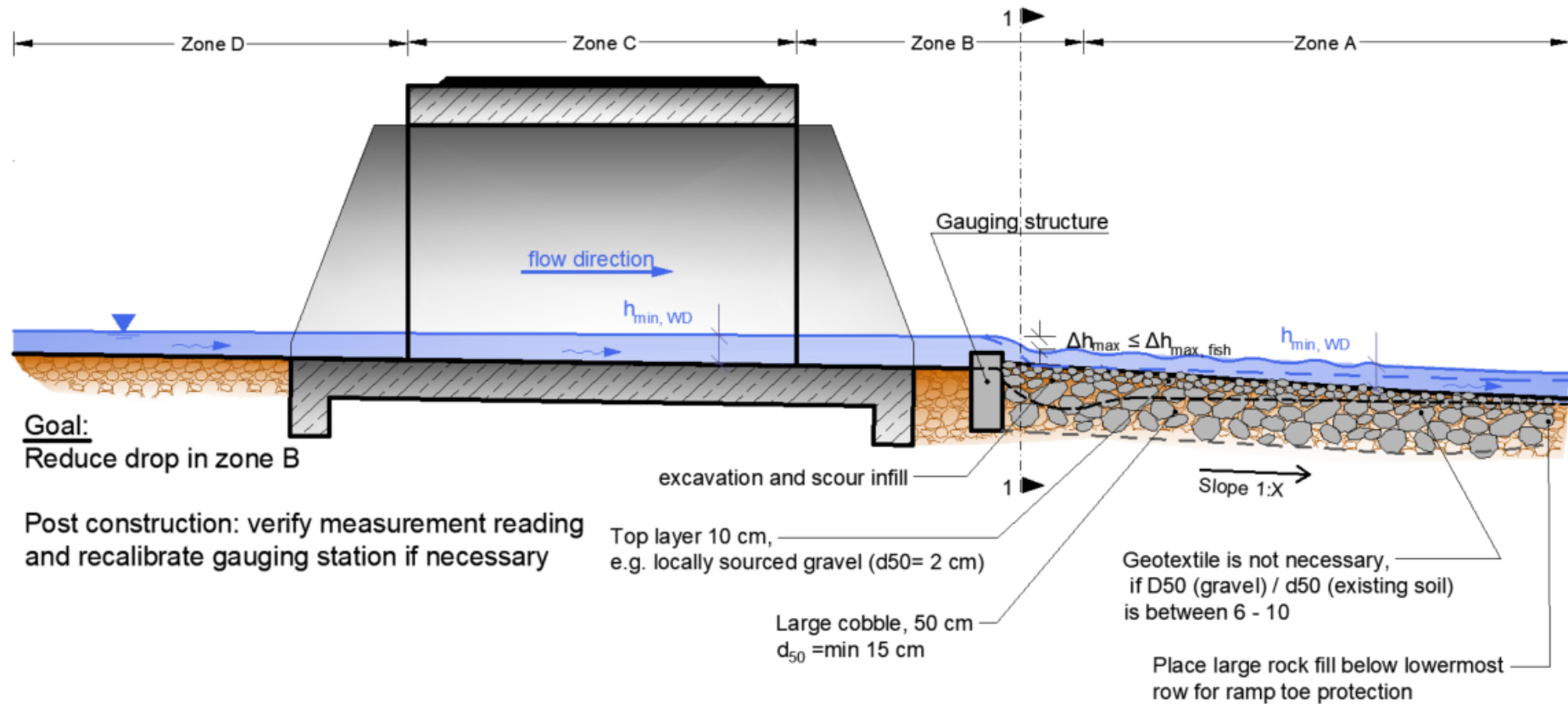


Generic Principle 3 – Rock Ramp at Gauging Station

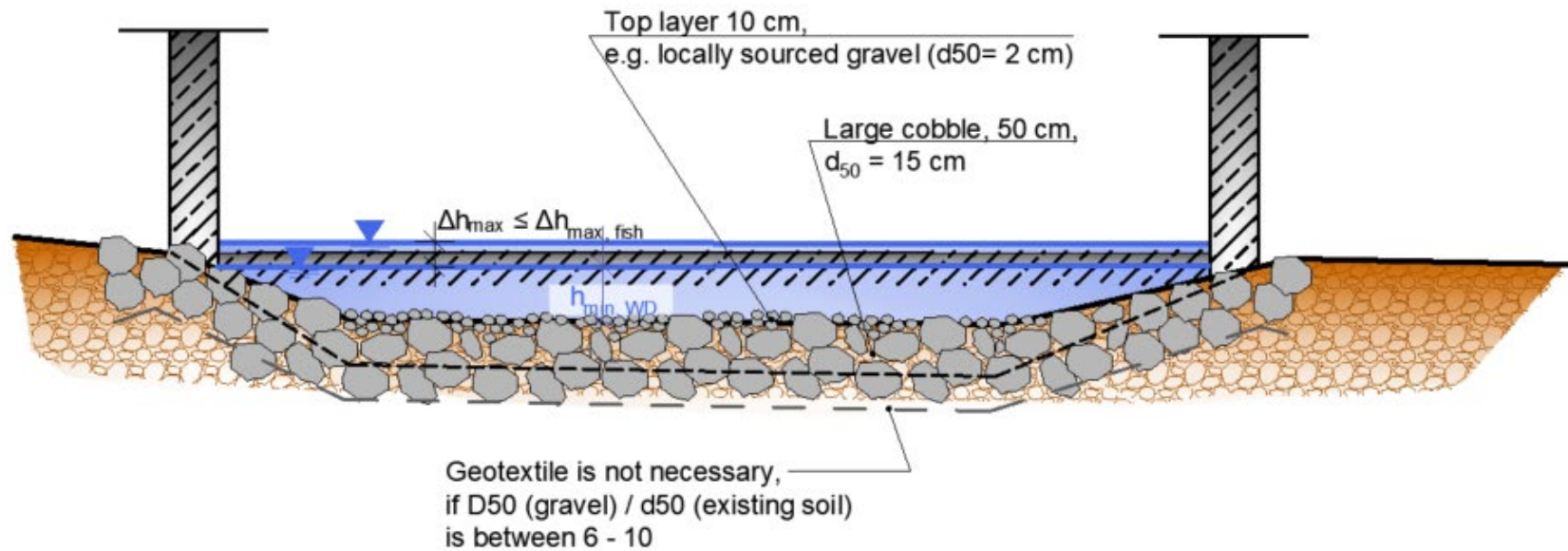
GP3 Current Situation: Long Section



GP3 Improvement: Long Section

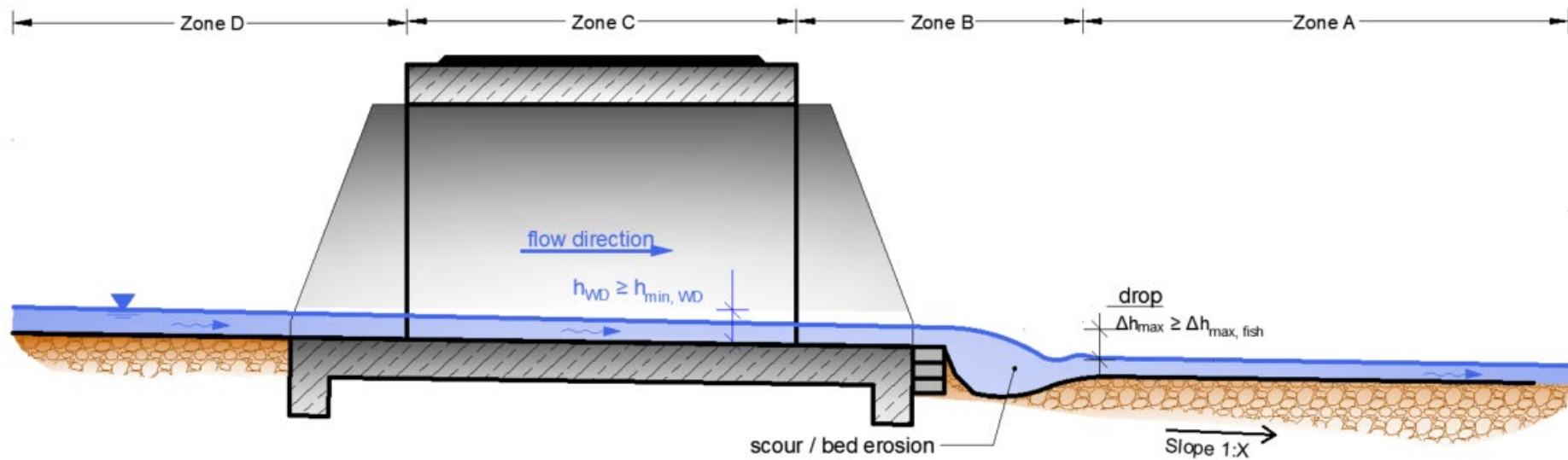


GP3 Improvement: Cross Section 1-1

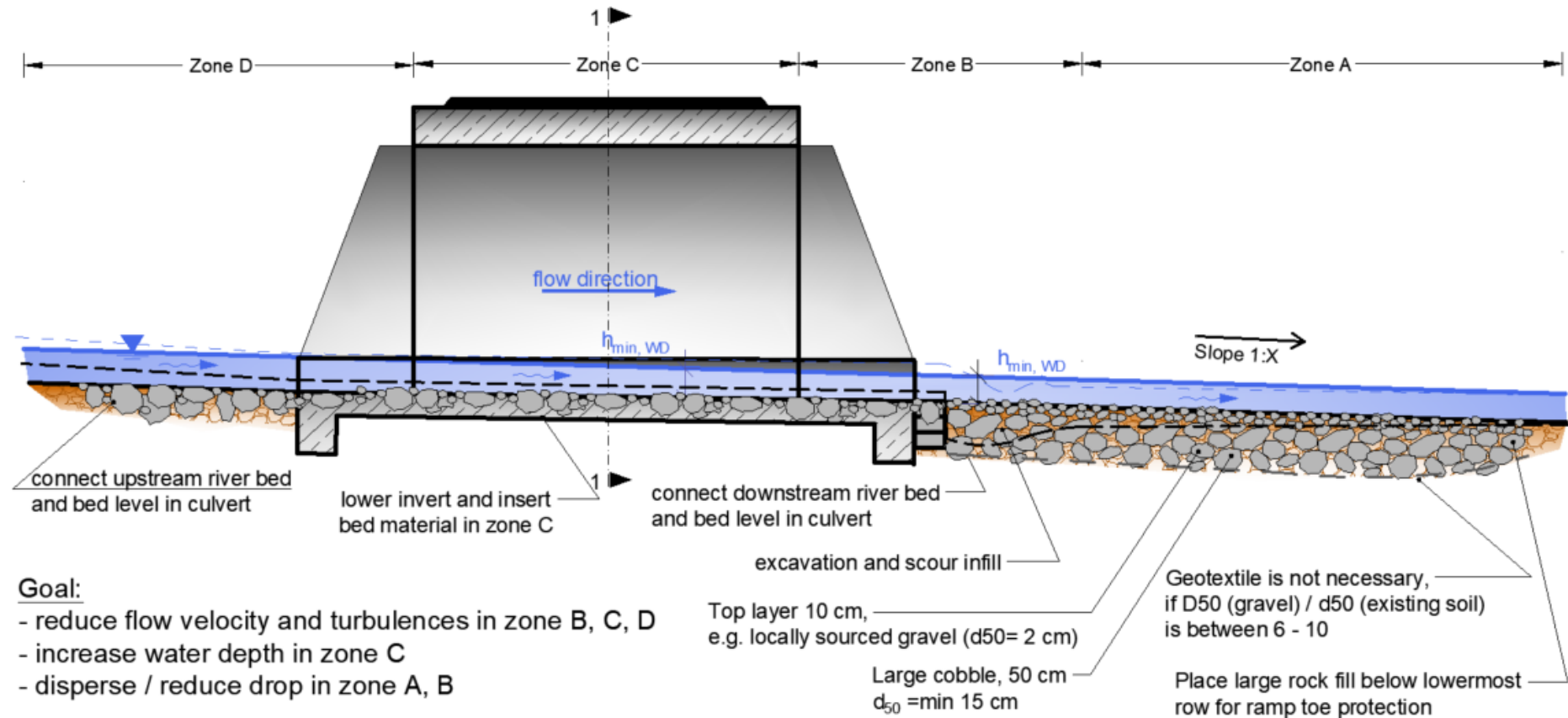


Generic Principle 4 – Reduced Floor Level

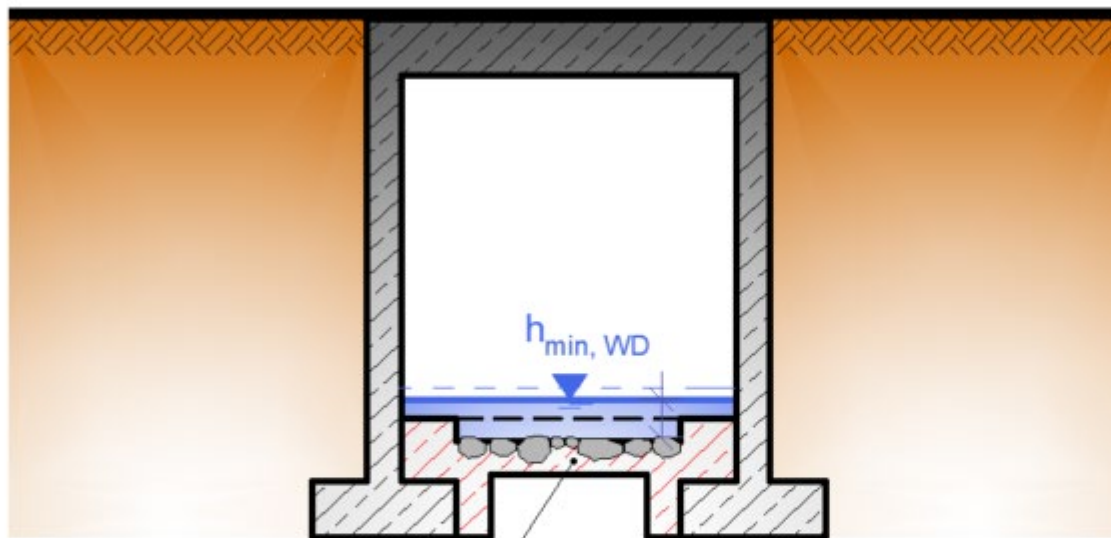
GP4 Current Situation: Long Section



GP4 Improvement: Long Section



GP4 Improvement: Cross Section 1-1



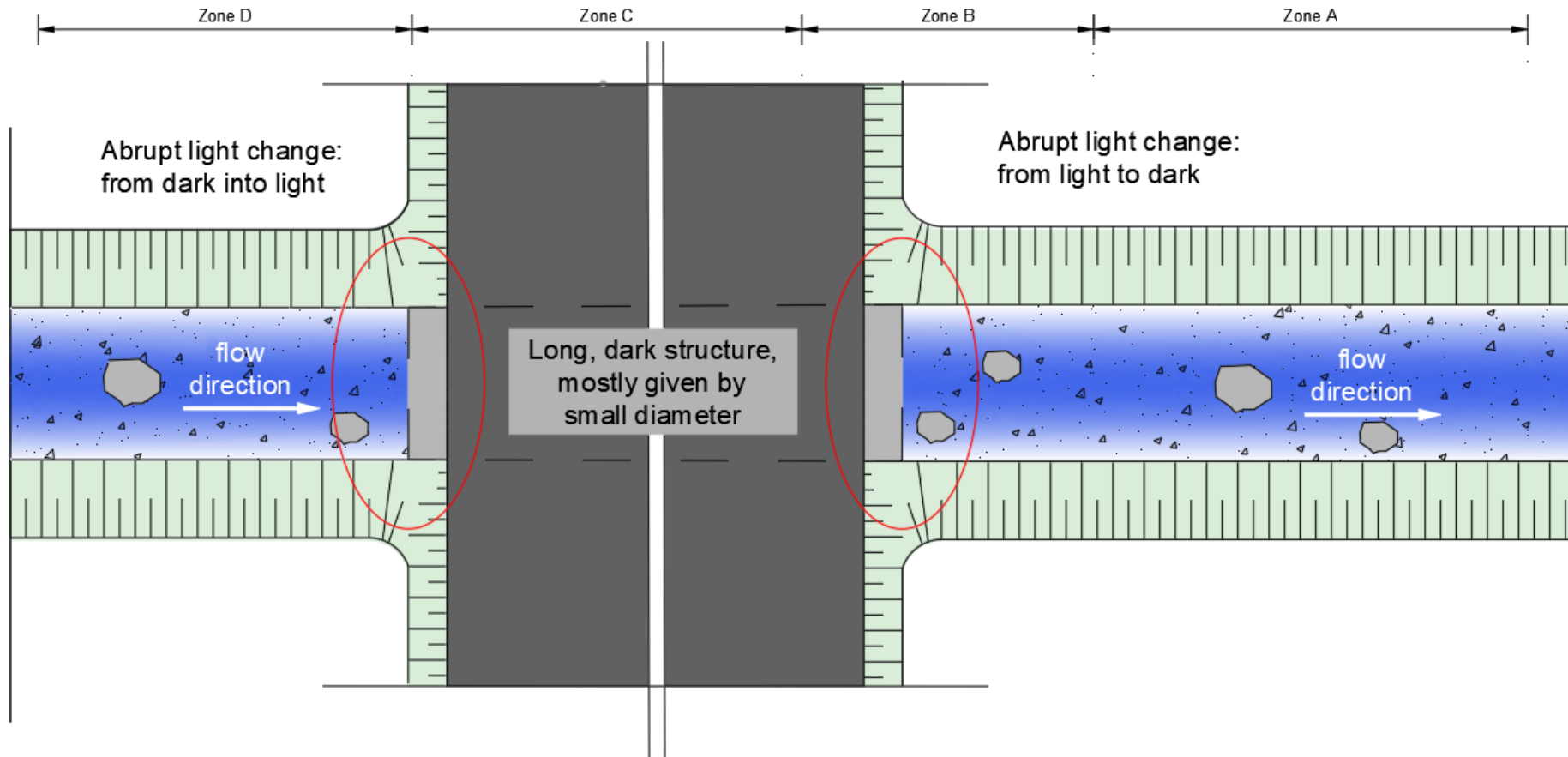
lower invert and insert
bed material in zone C

Goal:

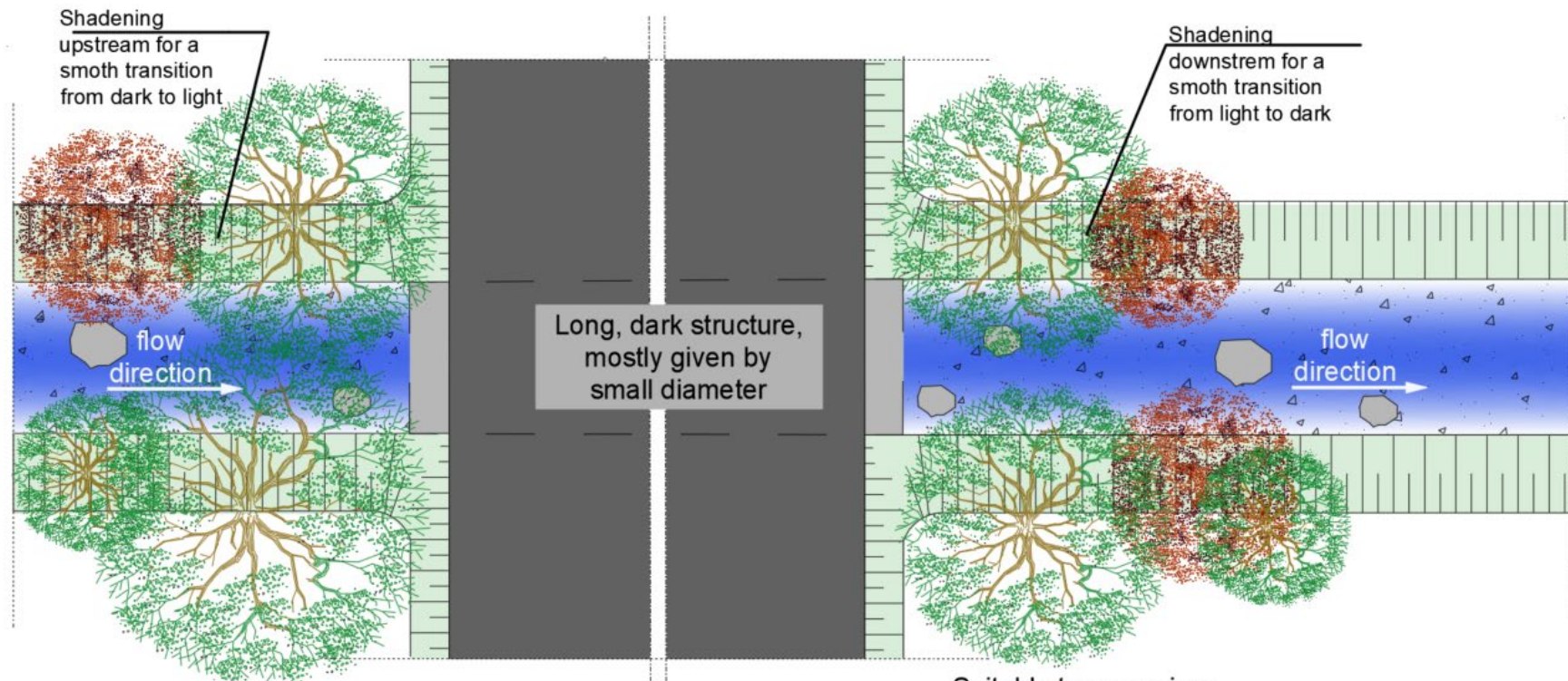
- reduce flow velocity and turbulences in zone B, C, D
- increase water depth in zone C
- disperse / reduce drop in zone A, B

Generic Principle 5 – Improvement in Lighting Transitions

GP5 Current Situation: Plan View



GP5 Improvement: Plan View



Goal:

Avoid abrupt changes of light in Zone B and D to reduce visual barrier

Suitable tree species:

wide crested trees,
typically growing along streams
e.g.- Alder (*Alnus glutinosa*)

- Willow (*Salix alba*, *Salix fragilis*)

Advised is to plant whatever tree species are growing locally and request IFI for more information

Generic Principle 6 – Roughening of the bed / addition of roughening elements

GP6 Design options



Offset baffle in box culvert (©Kapitzke 2010)



Offset baffle in pipe culvert (©Kapitzke 2010)



Corner "EL" baffle in box culvert (©Kapitzke 2010)



Corner "Quad" baffle in pipe culvert (©Kapitzke 2010)



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