CHAPTER 15[1]
SURFACE WATER LANDSCAPE

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[1] This is draft chapter requiring significant updates and revisions

15.1 OVERVIEW

15.1.1 Introduction

The Hydraulics Engineer is a key individual on any interdisciplinary team involved in surface water and environmental engineering. Surface waters include: streams or rivers, ponds or lakes, floodplains and wetlands. In general, the Hydraulics Engineer's role is to assist determination of hydrologic, hydraulic, and water quality impacts of transportation projects on the surface water environment. Depending on the location and type of transportation project, the Hydraulic Engineer shall quantitatively and/or qualitatively evaluate:

- Stormwater quality impact and mitigation;
- Channel stability impact and mitigation;
- Floodplains;
- Wetland and riparian impact and mitigation with assistance from the CDOT Landscape Architect, wetland specialist, and/or T&E specialist;
- Fishery and wildlife compatible drainage facilities with assistance from the CDOT Landscape Architect, wetland specialist, T&E specialist and/or DOW.

Photo 15.1

Photo 15.2

15.1.2 Purpose

The hydraulic designer shall be involved in estimating impacts to surface water environments in the planning stage of the project and shall be responsible for preparing hydrologic and hydraulic designs to avoid, minimize, or mitigate the transportation project's impact [2].

15.1.3 Surface Waters

Surface waters addressed by this Chapter are:

- Streams or rivers;
- Ponds, lakes and reservoirs;

Not addressed in this Chapter are groundwaters such as:

- Underground streams or rivers; and
- Underground ponds or lakes and aquifers.

Some surface waters are more sensitive to impacts than others. Surface waters or watersheds designated for special uses or considerations by a regulatory or resource agency are also likely to be sensitive to impacts. Listed below, for example, are Colorado's Gold Medal trout streams.

[2] *Regarding "Practicability": In negotiations with the regulatory and resource agencies the choices and alternatives may be contingent upon what is practicable. For the purpose of this chapter, one interpretation could be: "available and capable of being done after taking into consideration cost, existing technology, and logistics in light of overall project purposes". This is the definition used in the Memorandum of Agreement between the EPA and COE for the determination of Mitigation under the Clean Water Act Section 404(b)(1) Guidelines dated February, 1990.*

Colorado Division of Wildlife's Gold Medal trout streams:

Blue River	Dillon Reservoir to the Colorado River
Gore Creek	Red Sandstone Creek to Eagle River
Colorado	Windy Gap To Troublesome Creek
Frying Pan	Ruedi Reservoir To Roaring Fork River
Gunnison	Black Canyon To North Fork Of The Gunnison River
Rio Grande	Farmers Union Canal To Coller State Wildlife Area
Roaring Fork	Crystal River To Colorado River
South Platte	Various Locations
Spinney Mountain	Spinney Mountain Reservoir
North Platte	Routt National Forest to Colorado/Wyoming State Line
Delaney Butte	Delaney Butte Lakes State Wildlife Area

15.1.4 CDOT's Phase I Municipal Separate Stormsewer System (MS4) Discharge Permit[3]

The Colorado Department of Transportation is required to evaluate and consider "special requirements," or enhanced stormwater quality Best Management Practices, for new or redevelopment construction projects discharging to a pre-determined list of "sensitive waters[4]." The requirement is an attempt to to better match BMP design and existing conditions in receiving waters to likely resulting highway project runoff pollutants. The design practitioner is charged with considering more specific types of structural and non-structural controls to meet the "Special Requirements" - beyond the more standard 100% Water Quality Capture Volume or 80% TSS removal. Because structural control design poses significant limitations within D.O.T right-of-ways, the practitioner must consider a train of supporting structural and non-structural BMPs. The Special Requirements planning/design requires project-by project, site specific consideration and determination.

CDOT's MS4 permit requires an Annual summary, or separate explanation to some degree for projects discharging to the identified sensitive waters[5]. The CDOT Water Quality Program acknowleges the value in this MS4 Phase I requirement as a model for statewide projects. Enhanced treatment, considering specific pollutants of concern, "makes sense" in conjunction with assuring the required Water Quality Capture Volume (WQCV) or necessary (TSS) removal rates.

[3] COS 000005 effective January 2001. See Chapter 18 of this Manual for the entire *New Development/Redevelopment Stormwater Management Program* requirements.

[4] Reference CDOT Water Quality Program Report "*Special Requirements for Discharges to Sensitve Waters*"; submitted to CDPHE-WQCD June 4, 2004.

[5] For specific reporting and documention requirements, consult the appropriate Regional representative or CDOT Water Quality Program.

Following is a list of CDOT's specific identified "Sensitive Receiving Waters."

Table 1

List of Sensitive Waters

Receiving Water	Basin and Segment	Basis for Sensitive Water Determination
Cherry Creek	Cherry Creek, Segments 1 and 3	Domestic Water Supply
Cherry Creek Reservoir	Cherry Creek, Segment 2	303(d) Listed, Recreation 1 and Domestic Water Supply
Sloans Lake	Upper South Platte River, Segment 17b	Recreation 1
Clear Creek	Clear Creek, Segment 15	303(d) Listed and Domestic Water Supply
Bowles Reservoir	Upper South Platte River, Segment 17c	Recreation 1
South Platte River	Upper South Platte River, Segment 14	303(d) Listed and Domestic Water Supply
South Platte River	Upper South Platte River, Segment 15	303(d) Listed and Domestic Water Supply
Turkey Creek	Bear Creek, Segment 5	Domestic Water Supply
Fountain Creek	Fountain Creek, Segment 1	Aquatic Life Cold 1, Domestic Water Supply and Threatened Species
Fountain Creek	Fountain Creek, Segment 2	Domestic Water Supply
Camp Creek	Fountain Creek, Segment 1	Aquatic Life Cold 1, Domestic Water Supply and Threatened Species
Monument Creek	Fountain Creek, Segment 6	Domestic Water Supply

15.2 POLICY

15.2.1 Introduction

Listed below are the principle rules and regulations applicable to this chapter; others which may have some limited application are listed in Chapter 2 - Legal Aspects or Chapter 3 - Policy of this manual. Each of the rules or regulations not described in those chapters, are discussed briefly below.

15.2* CDOT Stewardship Guide and Environmental Ethics Statement

15.2.2 Federal Rules and Regulations [6]

15.2.3 State Rules and Regulations[7]

[6] Reference Chapter 2 of CDOT Erosion Control and Stormwater Quality Guide (2002).

The Basic Standards and Methodologies for Surface Waters

This regulation, as required by the Clean Water Act, presents a classification system for Colorado's surface waters and establishes beneficial use categories together with basic standards. Waters are classified according to the uses for which they are presently suitable or intended to become suitable. These classifications include; recreation, agriculture, aquatic life, and domestic water supply. Stream segment classifications and numeric standards are published by the Water Quality Control Commission for river basins and water bodies within the state.

15.2.4 State Memorandums of Understanding and Agreement (MOUs and MOAs)

Senate Bill 40 - MOA

In 1990 CDOT and CDOW signed a Memorandum of Agreement (MOA) that allows the programmatic use of SB 40 without formally contacting CDOW on certain type of projects with minor impacts. Within the programmatic SB 40 certification and activities which require formal written application are identified. Third, required mitigation is outlined if use of the programmatic approach is determined applicable. CDOT construction activities falling under the jurisdiction of SB 40 must comply with the Best Management Practices, described in the MOA, regardless of whether the activities require formal application or are covered under the programmatic certification. Formal certifications may result in additional requirements. All mitigation requirements outlined in the MOA must be included in the contract documents - or programmatic SB 40 clearance may not remain valid.

15.2.5 Enhancing Functional Values

In general it is the intent CDOT to provide those mitigation measures necessary to maintain the existing functional values or acceptable equivalents of those surface waters disturbed by a transportation action.

15.2.6 Stormwater Management Plan (SWMP)

Preparation of the SWMP is discussed in detail in the CDOT Erosion Control and Stormwater Quality Guide 2002.

15.2.7 Stormwater Quality Management

The CDOT Erosion Control and Stormwater Quality Guide (2002) should be utilized to address stormwater quality issues. The guide can be used to help predict whether or not stormwater runoff from the operating transportation system will adversely affect receiving water quality. Stormwater quality best management practices (BMPs), used to mitigate adverse water quality impacts, are identified. The guide also designates structural BMPs that are appropriate for installation on CDOT construction projects, including specific design guidelines for each BMP.

15.3 DESIGN CRITERIA

15.3.1 General Criteria

General criteria to be considered at all surface water locations include the following:

- Mitigation alternatives; and
- BMPs.

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[7] Reference Chapter 2 of CDOT Erosion Control and Stormwater Quality Guide (2002).

15.3.2 Mitigation Alternatives

Several transportation design alternatives may be considered when disturbing surface waters, some of which involve mitigation. Mitigation is the practice of designing the transportation project to anticipate the effects to surface waters so that predisturbance functional values, permit requirements, enhancment, or acceptable equivalents are maintained.

There are seven general mitigation alternatives, including:

- Avoidance;
- Minimization;
- On site mitigation;
- Off site mitigation;
- Combination; and
- Compensatory offsets.

Avoidance.

Wherever practicable, avoiding disturbance of the surface water feature is generally the preferred alternative. It shall be demonstrated that this alternative is not practicable before any other alternative can be considered.

Minimization

Where surface water disturbances cannot be avoided, such disturbances may be minimized through adjustments in project alignment, profile, template, and other geometry. The intent of minimization is to reduce the impacts to surface water resources when avoidance is not practicable.

On Site Mitigation

Those measures that allow mitigation to occur at the geographic point of disturbance usually are the most successful.

Off Site Mitigation

Occasionally, with wetlands and channel modifications, it may not be practicable to provide mitigation at the point of disturbance. This requires that mitigation measures be accomplished away from the disturbed site but usually within the same river basin system, geographic area and biological region.

Combination

A combination is the use of two or more of the foregoing alternatives for mitigation at a site.

Compensatory Offsets

This option would be for out-of-kind mitigation or contributions to CDOT's State-operated environmental funds. An example of this might be stream bank restoration as mitigation for disturbing a wetlands or visa versa.

Findings for rejecting any alternative shall be documented to the satisfaction of the cognizant regulatory agencies before selecting a lower priority alternative. Mitigation shall typically be accomplished within the same primary watershed, geographic region and biologic region.

15.3.3 Best Management Practices

CDOT BMPs, as contained in CDOTs Erosion Control and Stormwater Quality Guide (ECSQG), shall be routinely used to mitigate adverse surface water impacts.

15.3.4 Functional Values

Surface water functional values design criteria shall be based on seasonal preconstruction values and/or expected future values. These seasonal values may be used as a baseline to evaluate the expected fate of the functional values during four periods:

- Pre-construction;
- During construction;
- Immediate post construction; and
- Long-term (future).

15.3.5 Design Criteria

Below are design criteria for the following six hydraulic-related surface water features:

- Water quality;
- Channels;
- Lakes or ponds;
- Wetlands;
- Fish passage; and
- Stream geometry and cover.

15.3.6 Water Quality[8]

15.3.7 Channels

Functional value design criteria for channels address:

- Classification;
- Ordinary High Water (OHW);
- Stability; and
- Mitigation.

Classification

Channels shall be classified as to type and stability. Classifications shall be determined for the preconstruction and expected long-term (future) time periods. Classifications for stability are addressed later.

Ordinary High Water

[8] Discussed in detail in the Erosion Control and Stormwater Quality Guide2002

The ordinary high water (OHW) to be used in regulatory permit processes (section 404 of the Clean Water Act) shall be that water surface elevation within a channel that corresponds to the elevation at which vegetation appears on the channel banks or where the vegetation is not visible the elevation of the two year flood.

Stability

A channel must first be stable for the design flood before being modified to serve as an environmental channel. The practices and criteria set forth in Chapter 8 - Channels, shall be used to determine design flood channel stability.

For environmental purposes channels can be classified into four groups.

- Relatively Stable - meandering alluvial channels or straight channels incised into rock.
- Transitionally Stable - straight alluvial channels.
- Marginally Stable - alluvial channels in a transitional range between types.
- Unstable - braided or head-cutting channels.

Mitigation

Mitigation criteria where significant adverse impacts are expected to occur shall consist of such things as:

- Identifying and not exacerbating existing channel stability problems;
- Providing cost effective measures to improve the channel stability where it is necessary to protect a transportation facility and/or enhance the channel environment.

Where mitigation is required, channel design and construction shall include consideration of:

- Riparian cover;
- In-stream cover;
- Riffles;
- Pools;
- Substrate;
- Bank geometry; and
- Conveyance.

Grade Control Structures

Grade control structures recommended in this section are for small channels (design discharge less than 50 to 100 cfs). Procedures and criteria found in Chapter 11-Energy Dissipators, shall be used to design grade control structures if the design discharge is greater than 100 cfs.

Grade control structures similar to those shown on Figures 15.1 and 15.2 (Appendix) may be used to establish a stable channel profile. They are not acceptable where fish migration is a design criteria as they do not provide a pool from which the fish can jump in order to ascend upstream. A grade control structure that is compatible with fish migration is shown in Figure 15.3 (Appendix).

Grade control may also be accomplished by using a culvert placed on a grade steeper than the modified or unstable channel. However, where fish passage is important, the culvert geometry must be determined using those procedures and criteria found in Section 15.6.

15.3.8 Fish Habitat Structures

Figure 15.4 (Appendix) shows in-stream rock placement for fish habitat (examples).

15.3.9 Bendway Bank Protection

Figures 15.5 and 15.6 (Appendix) illustrate how to provide more environmentally compatible bank protection than is provided by riprap spurs (see Chapter 17 - Bank Protection). These environmentally compatible devices are also useful in establishing a pool ripple sequence.

The use of grade control structures, fish habitat structures, and/or bendway bank protection features recommended in this section shall be determined on a project-by-project basis. Aggressive revegetation and soil stabilization practices associated with these features shall also be used to restore a disturbed stream's riparian cover, floodplain vegetation and other aquatic functional values.

15.4 FLOODPLAINS

15.4.1 Introduction

This section briefly describes benefits of floodplains and regulations that control their development.

15.4.2 Floodplain Benefits

Possible floodplain benefits include:

- Flood Control; and
- Wildlife Habitat.

15.4.3 Flood Control

Natural floodplains serve to enhance flood control. Floodplains that are encroached upon by a transportation activity can increase the flow velocity in the encroachment reach, decrease the flood storage capability, and increase the water surface elevation upstream of the encroachment. The magnitude and significance of the floodplain impacts depends upon the degree of encroachment.

Flow velocity, in the encroachment reach, increases due to the decrease in cross sectional flow area. Higher velocities can lead to increased sediment transport and consequent bed and bank erosion. Erosion of the channel bed could potentially lead to an undesired lowering of the channel invert. Bank erosion can lead to decreased wildlife habitat.

A natural floodplain can slow water velocities and store floodwaters thereby decreasing the peak flows downstream and subsequent potential flood damage. Encroachment adversely affects the floodplains storage potential and may increase the peak flows downstream of the encroachment, depending upon the degree of encroachment.

The water surface elevation, upstream of an encroachment, will increase. The additional water depth may inundate more property that would not have been inundated prior to encroachment thereby creating a potential undesired liability to CDOT.

15.4.4 Floodplain Regulations

Federal, State, and local regulations control development within the floodplain. For the most part, CDOT must comply with the Federal Emergency Management Agency (FEMA) floodplain regulations. However, in some cases the local entity may have floodplain regulations that are more stringent than FEMA. CDOT will generally comply with the more stringent requirements.

The FEMA program is intended to identify areas that are prone to flooding, provide flood insurance to those located within the floodplain, and prevent or minimize floodplain encroachment. A discussion of the FEMA regulation and procedures CDOT uses in order comply with the regulation can be found in Chapter 2 - Legal Aspects.

15.4.5 Wetlands

A wetland is an area that is inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions. Generally wetlands are characterized as having all three of the following attributes:

The soils are hydric or possess hydric characteristics. Hydric soils are wet long enough to periodically produce anaerobic conditions.

The substrate is saturated with water or covered shallow water at some time during the growing season of each year.

The land supports primarily hydrophytes (plants typically adapted to aquatic and semiaquatic environments).

Wetlands are an important national resource, and Federal Transportation Administration policy mandates that there be no net loss of wetlands area or functional values.

To avoid loss of wetland's area or functional values a new transportations horizontal alignment should be adjusted where ever practicable. For transportation widening projects, avoidance can be obtained by widening to the side opposite the wetlands or by modifying the standard transportation cross section geometry. Consideration should be given to narrower shoulders or steeper fill slopes to avoid impacts.

If wetland impacts can not be avoided, it should be identified early in the project design, and methods to minimize and mitigate those impacts identified. The intent of wetland mitigation is to:

- Avoid impacts;
- Minimize temporary and permanent impacts; and
- Replace wetlands areas that are permanently lost

Mitigation can include temporary wetlands protection such as fencing of wetlands during construction, or placing geotextile over an existing wetlands prior to detour embankment placement. Replacement mitigation for permanent impacts is usually based on one unit of wetlands replaced for each unit lost if the same type and functional value for the replacement wetlands can be obtained. Greater than a one to one replacement may be required if wetlands are replaced off-site and adequate type and functional value cannot be achieved.

15.4.6 Channels

Chapter 8 - “Channels” addresses the hydraulic design of channels. Desirable environmental functions and values of channels depend on a number of factors, including:

- Terrestrial habitat;
- Aquatic habitat;
- Riparian habitat;
- Flood conveyance;
- Flood storage;
- Recreational uses;

- Agricultural and silvicultural uses; and
- Municipal uses.

Channel stability mitigation measures, where cost effective, can be employed as set forth in Chapter 8, “Channels” and Chapter 17, “Bank Protection.”

15.5 FISH PASSAGE CRITERIA

15.5.1 Introduction

The practices and criteria provided in this Section were developed using guidance from Norman *(9)*, Watts *(11)*, McClellan *(7)*, King and Brater *(5)*, except where noted otherwise.

The fish passage discussion included in this section was abridged from Chapter 15 of the AASHTO Model Drainage Manual. The AASHTO Manual contains a thorough discussion of fish passage issues along with detailed design guidelines, and should be consulted when necessary to design CDOT drainage facilities. Because Senate Bill 40 applies to fisheries, CDOW may also have specific comments and concerns related to fish habitat or passage.

There are three primary transportation drainage facilities where fish passage is a consideration:

- Channels;
- Bridges; and
- Culverts.

15.5.2 Channels

The primary considerations are the aquatic habitat and channel stability. Channel design related to aquatic habitat is briefly addressed in Section 15.5, and channel stability is addressed in Chapter 8 - Channels.

15.5.3 Bridges

Bridges shall be considered as part of the channel. Where practicable, the bridge should span the ordinary high water channel. Piers within the ordinary high water channel are acceptable, if not desirable, in that any scour holes commonly provide a desirable pool type habitat, however, predicted pier scour depth and consequent foundation depth and cost shall determine whether or not a pier should be located in the ordinary highwater channel. See Chapter 10 - Bridges for recommended methods to predict pier scour depth. REFER to the bridge manual drainage chapter for bridge drainage issues.

15.5.4 Culverts

The most common fish passage concern with highway projects is usually associated with culverts. Failure to consider fish passage may block or impede upstream fish movements in many ways:

Outlet of the culvert is installed above the streambed elevation to where fish may not be able to enter.

Scour lowers the streambed downstream of the culvert outfall and the resulting dropoff or perch creates a potential vertical barrier.

High outlet velocity may provide a barrier.

Higher velocities occurring within the culvert than in the natural channel may prevent fish from transiting the culvert.

Abrupt drawdown, turbulence and accelerating flow at the culvert inlet may prevent fish from exiting the culvert.

Natural channel is replaced by an artificial channel that may have fewer zones of quiescent water in which fish can rest.

Debris barriers (including ice) upstream or within the culvert may stop fish movement.

Shallow depths within the culvert during minimum flow periods may preclude fish passage.

15.5.5 <u>Structure Type</u>

The structure type may require a compromise between structure economics and optimum fish passage. For fish passage at transportation crossings, structure type in order of preference, given acceptable hydraulics and/or economics, is as follows:

- Bridge;
- Structural plate arch;
- Open-bottom culvert;
- Countersunk* culvert with or without baffles;
- Corrugated pipe with a grade less than 0.5%;
- Culverts with sills, baffles or slot orifices on grades between 0.5% and 5.0%; and
- Structure with a special, separate fishway.

*Flowline invert depressed 2 ft below streambed and backfilled with bed material resistant to movement at the expected barrel velocities during the design flood.

15.5.6 <u>Fish Swimming Speed</u>

Swimming speed may be available from the cognizant resource and regulatory agencies. The following guidelines are used for design where there are no guidelines. Where they do have guidelines, the following are used for negotiating purposes in arriving at mutually acceptable criteria for fish swimming speeds:

- Fish size;
- Maturity;
- Water temperature; and
- Species.

For the design of a fish passage through such facilities as culverts, bridge openings, and channel modifications, the swimming speeds from Table 15.1 shall be considered. The table provides general velocity criteria to be used in designing a culvert, bridge, or channel for the passage of adult fishes. In the design of facilities, velocities must be kept well below the darting speeds for general passage. When guiding or directing fish, smooth velocity, velocity transitions and accelerations are desirable.

Species	Cruising Speed Table 15.1 Sustained or Burst* Swimming Speeds of Average Size Adult Fish (ft/s)	Sustained Speed (ft/s)	Darting Speed (ft/s)
Carp	0 to 1.2	1.2 to 4.0	4.0 to 8.4

Suckers	0 to 1.4	1.4 to 5.2	5.2 to 10.3
Whitefish	0 to 1.3	1.3 to 4.4	4.4 to 9.0
Grayling	0 to 2.5	2.5 to 7.0	7.0 to 14.2*
Brown Trout	0 to 2.2	2.2 to 6.2	6.2 to 12.7*
Trout	0 to 2.0	2.0 to 6.4	6.4 to 13.5*
Shad	0 to 2.4	2.4 to 7.3	7.3 to 15.0*

Source: Reference *(3)*.

**Some "darting speeds" and "speeds" are believed to be burst speeds; the source of this belief is unclear.*

15.5.7 <u>Design Flow Depths</u>

During migration runs, fish passage designs shall insure that minimum depth criteria are met. These depth criteria are contained in Table 15.2.

Table 15.2 Minimum Culvert Flow Depths For Migration

Fishes	Minimum Depth, inches
Trout (over 20 inches)	8
Trout (20 inches or less)	6

15.5.8 <u>Culvert Geometric Elements</u>

The three geometric elements of a culvert that influence fish migration are the:

- Inlet;
- Barrel; and
- Outlet.

15.5.9 <u>Inlet Geometry</u>

Care shall be taken to insure the culvert inlet does not preclude fish passage. It is preferred that the culvert entrance be submerged or have sufficient backwater and flow depth so the migrating fish moving upstream do not have to jump to exit. Where this is not practicable, the maximum allowable entrance jump heights from Table 15.3 shall apply.

Table 15.3 Maximum Jump Heights of Fish

Fishes	Jump Height, ft
Trout	0.5

15.5.10 Outlet Geometry

Care must be exercised to insure migratory fishes can enter, transit, and exit a drainage facility particularly where highly contracted flows occur such as with culvert type structure. Figure 15.7 (Appendix) provides some commonly used geometry and criteria for the outlet geometry of a culvert type structure. This same geometry may be used to improve inlet conditions as well. Where structures other than culverts have high exit velocities due to such things as low flow depths and steep slopes, or for any reason need a pool from which fish can ascend upstream by jumping into the outlet, a similar geometry may be adapted.

Key to the outlet geometry criteria in Figure 15.7 (Appendix) is the downstream sill. This sill controls the flow depths and velocities through the culvert during critical migration periods. Figure 15.8 provides criteria for this sill. If it is necessary to avoid excess sill height, more than one sill may be considered. The sills on Figures 15.7 and 15.8 (Appendix) are shown as rock; other materials may be used, however. Sills shall be located beyond any expected scour hole (see Chapter 11 - Energy Dissipators).

15.5.11 Barrel Geometry

The barrel geometry and material in the bottom of the barrel can influence fish passage. Figure 15.8 (Appendix) illustrates how a culvert can be imbedded (depressed) below the streambed so as to:

- Increase the flow depth;
- Decrease velocity; and/or
- Provide a substrate.

When needed, a "natural" substrate may be obtained by backfilling the depressed portion of the culvert with stones. As a minimum, a tractive shear analysis shall be used to evaluate the stability of the backfilled substrate. The flood recurrence interval for this tractive shear analysis shall be the design flood used for the project drainage design. Sills periodically affixed to the culvert invert or randomly placed large boulders (larger culverts only) may be useful to help hold substrate material in place where it is not practicable to meet the tractive shear criteria. It should be recognized that if substrate material is scoured out from between the sills and from around any boulders, upstream bed load material must necessarily be transported into the culvert and deposited, thereby preserving the substrate to some degree. Where this occurs, the need to provide a substrate that is stable during design flows shall be voided. Even if the substrate is "flushed out" of the imbedded area, the culvert may still provide acceptable fish passage; i.e. with the backfill material gone or partially gone within the culvert there would be more desirable, deeper depths and thus slower velocities.

The placing of substrate, boulders, or fishways inside of culverts decreases the culvert capacity and therefore may increase flood hazards. Placement of such appurtenances shall be avoided if additional adverse flood hazards are created.

A culvert substrate similar to that in a natural channel will facilitate fish passage. Figure 15.9 (Appendix) provides guidelines and criteria for this geometry.

15.5.12 Maintenance Of Fishways

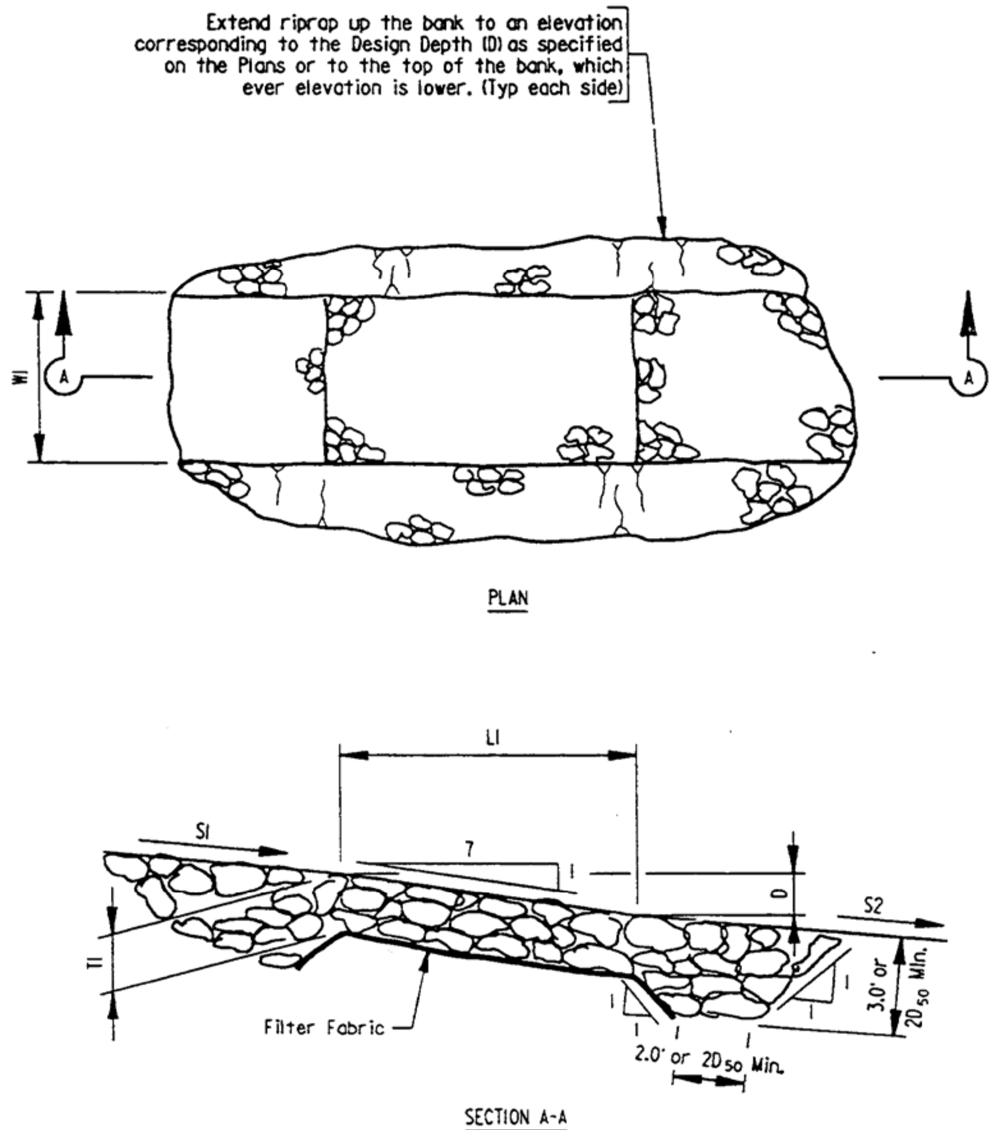
Problems can occur when maintenance forces are unaware that such things as boulders inside a culvert or deposition in a countersunk culvert are essential. Also, maintenance forces must be made aware of the migration period(s) for fishways. Accordingly, maintenance shall be alerted by the Region Environmental Planning Manager accordingly, so as to preclude inadvert removal of such devices when cleaning channels and structures. Further, this allows maintenance forces an opportunity to insure fishways are in good repair and clean prior to critical migration periods.

Caution is required when considering special devices where drift, debris, ice and high bed load sediment transport rates occur. Where these stream transported items may cause partial or total blockage of a culvert, preference shall be given to such things as smooth culvert fishways with downstream sills, substrate fishways, and bridges where ever practicable. Higher maintenance costs shall be considered when comparing alternative fishways where deposited sediment may have to be frequently removed from sill or baffle fishways.

APPENDIX - FIGURES[9]

[9] These are provided as examples only. CDOT projects require site specific coordiantion with the proper agencies.

Figure 15.1 Grade Control Structure (Marginal Fishway Compatible)



Note:
1) Vertical Drop (D) varies as specified on the Plans.
2) Channel Width (W1) as specified on the Plans.
3) Drop Length (L1) varies by 7D in feet.
4) Riprap Thickness (T1) is 2.0' or $2D_{50}$ minimum for Machine Placed Riprap and gradation or as specified by the Standards for Wire Enclosed Riprap.
5) Channel Slope (S1 and S2) as specified on the Plans.
6) Toe details typical for upstream end as shown.

Figure 15.2 Log Drop Grade Control Structure (Fishway Incompatible)

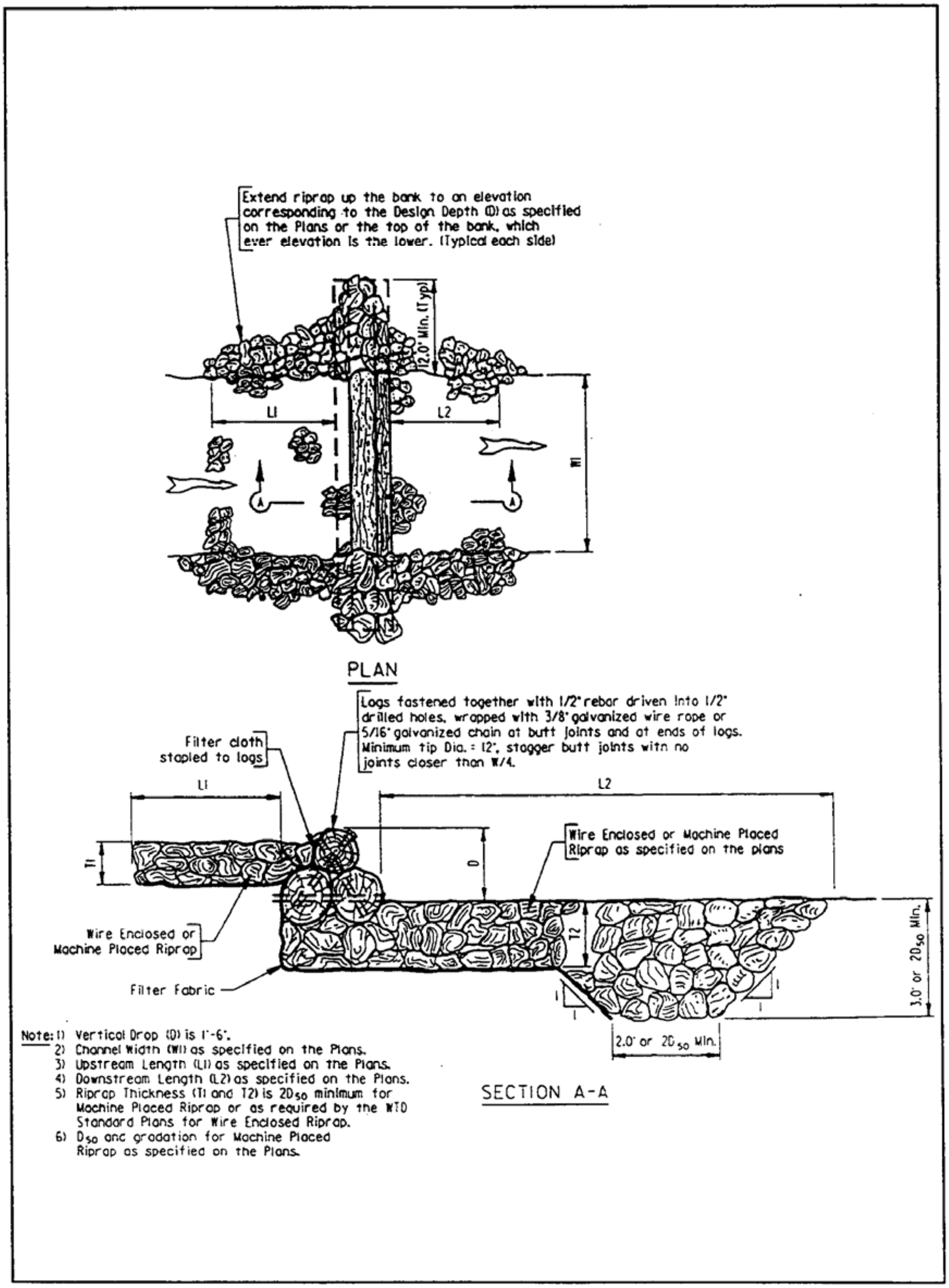


Figure 15.3 Log Drop Grade Control Structure (Fishway Compatible)

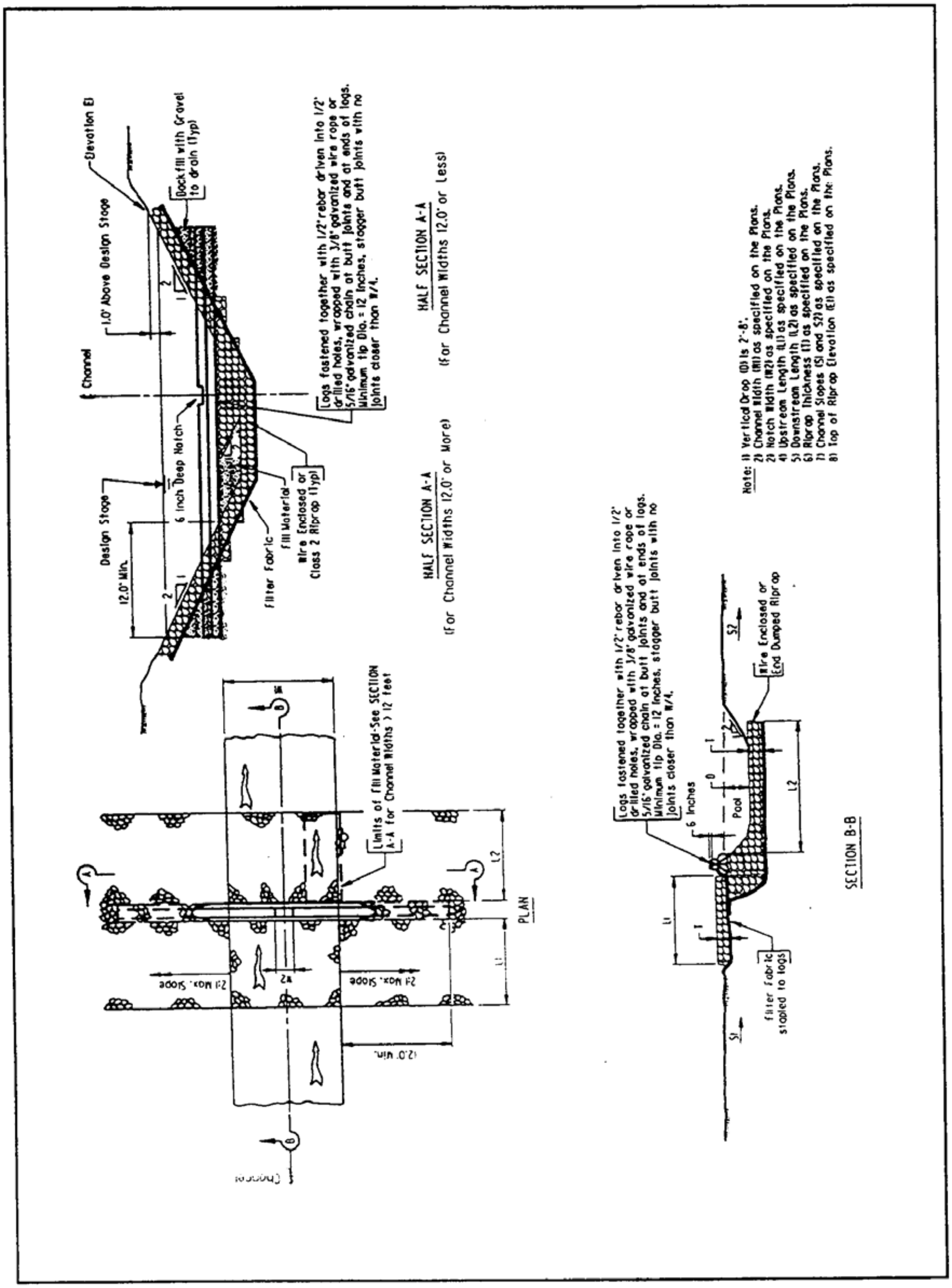


Figure 15.4 Instream Rock Habitat (Coordinate with DOW. DOW requirements are very specific)

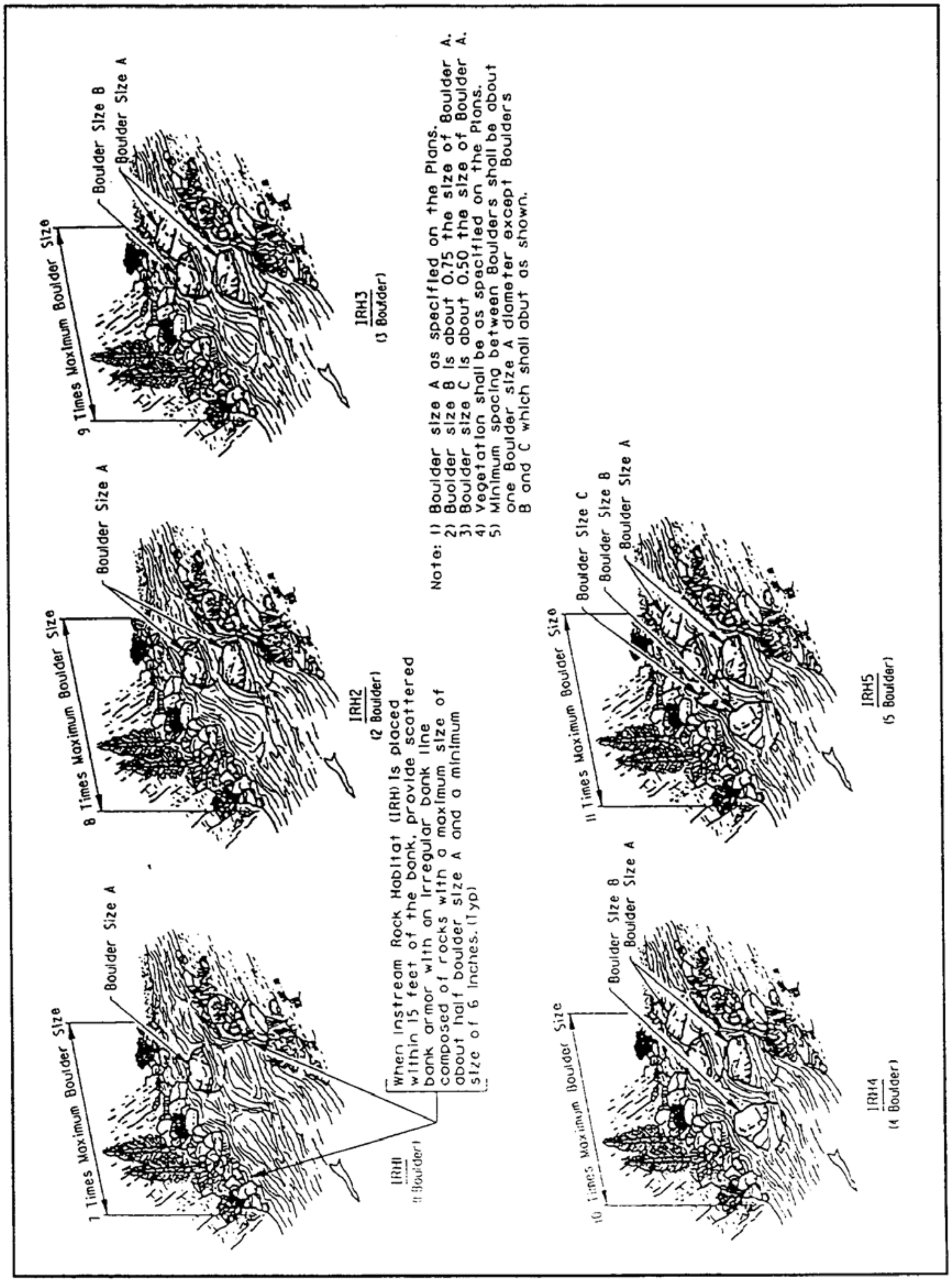


Figure 15.5 Bank Deflector Structure (Log Type) (Coordinate with DOW. DOW requirements are very specific

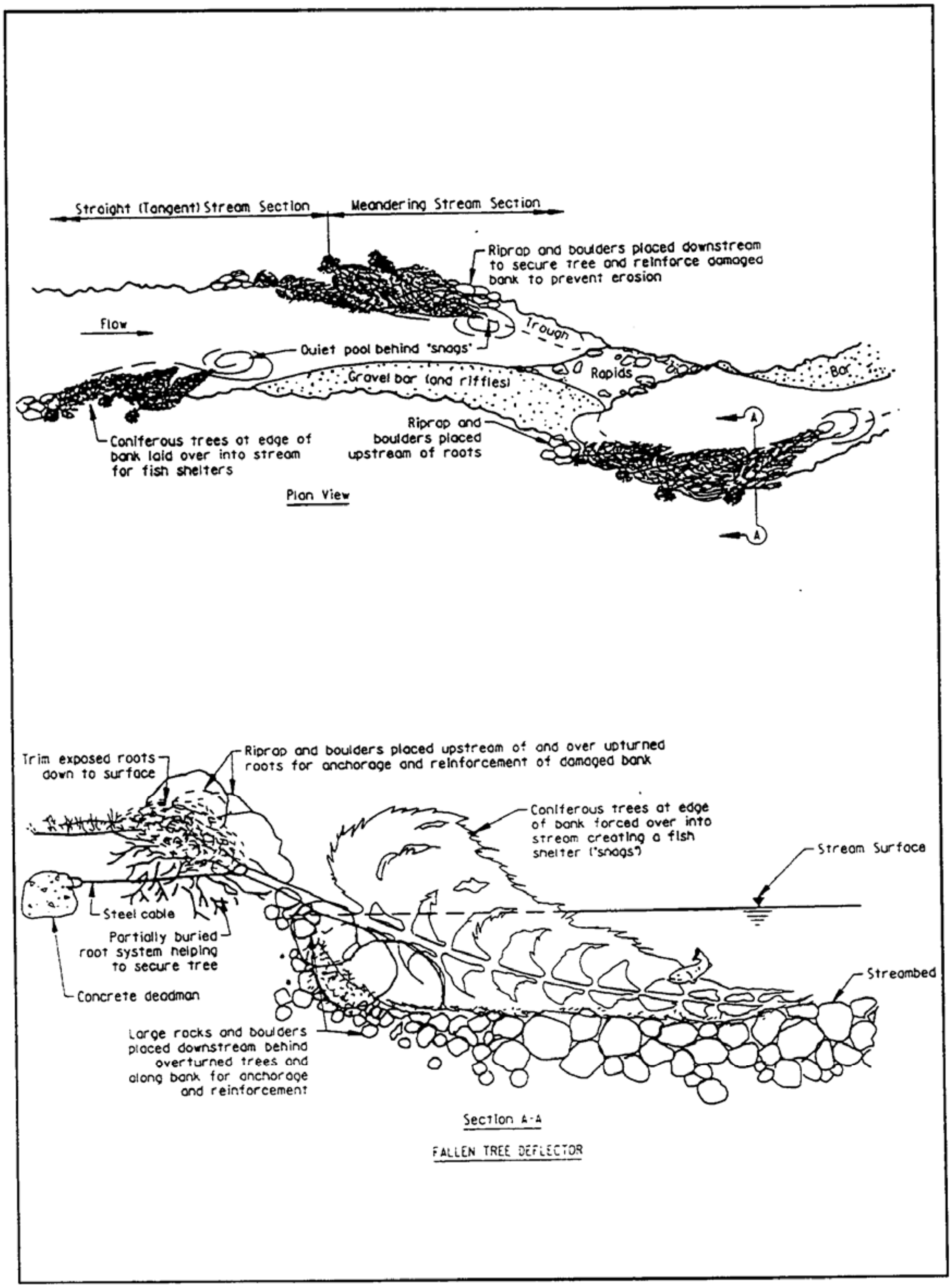


Figure 15.6 Outlet Geometry for Fish Passage

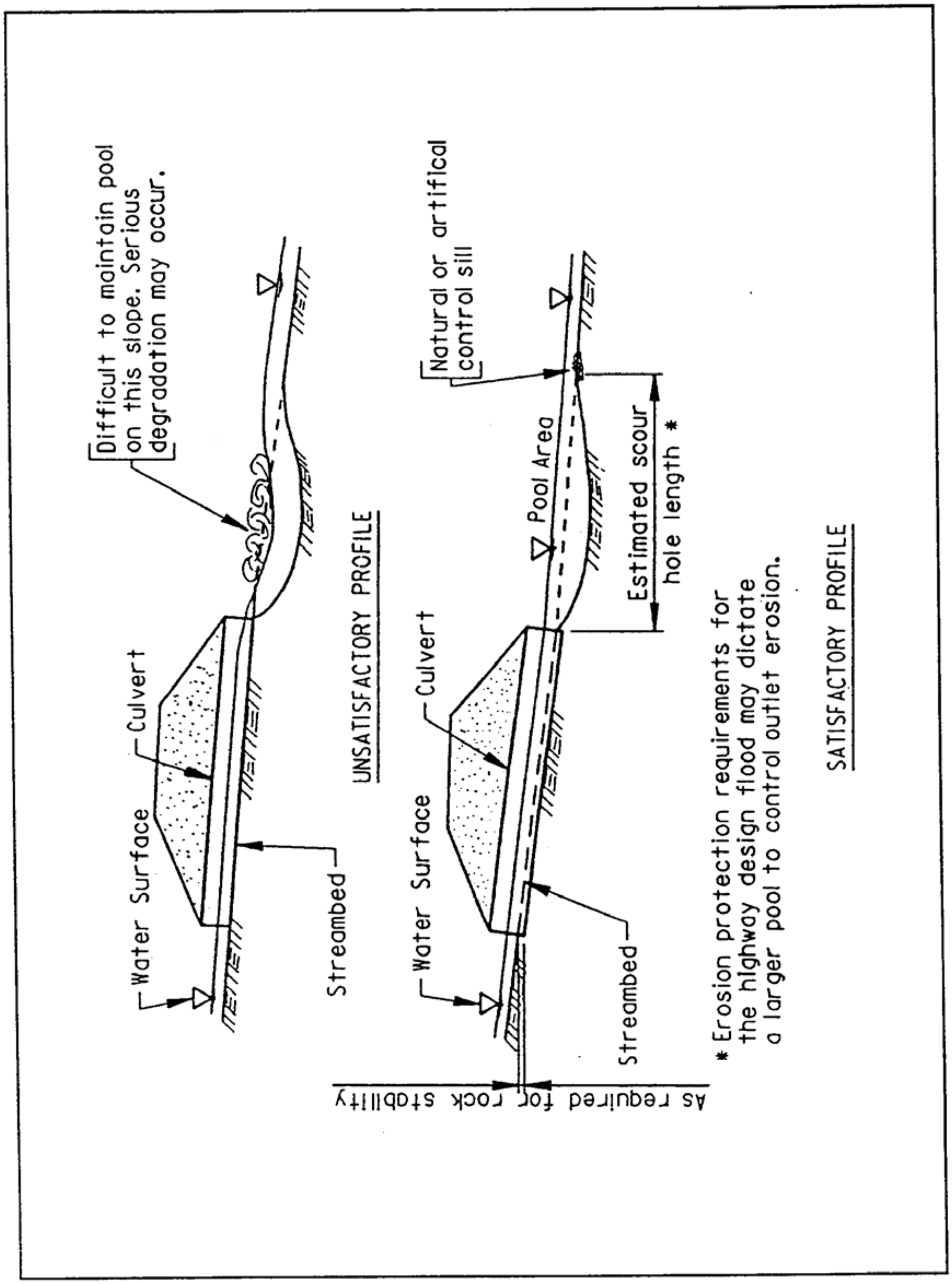


Figure 15.7 Outlet Geometry for Fish Passage

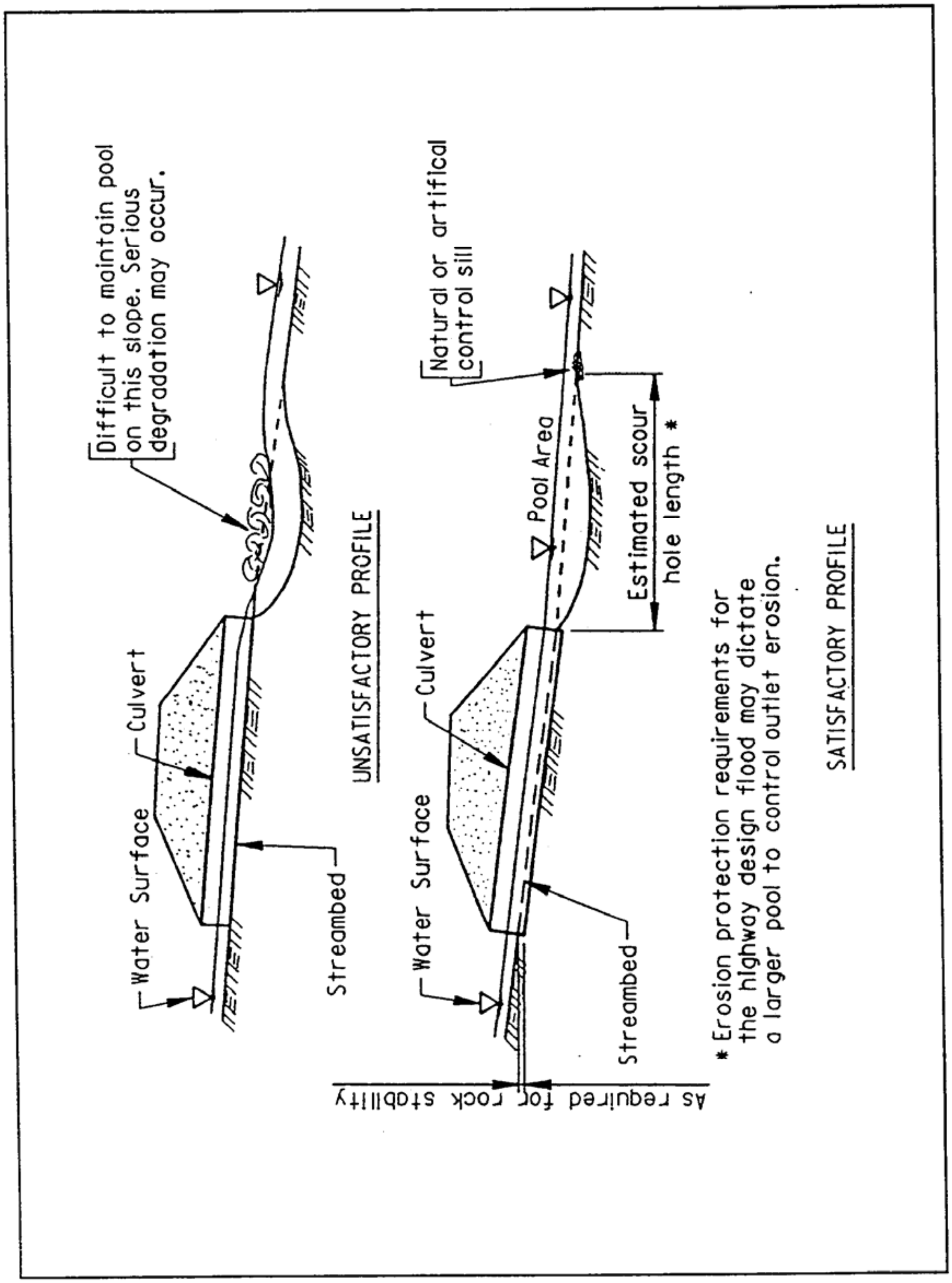


Figure 15.8 Sill Criteria at Culvert Outlet

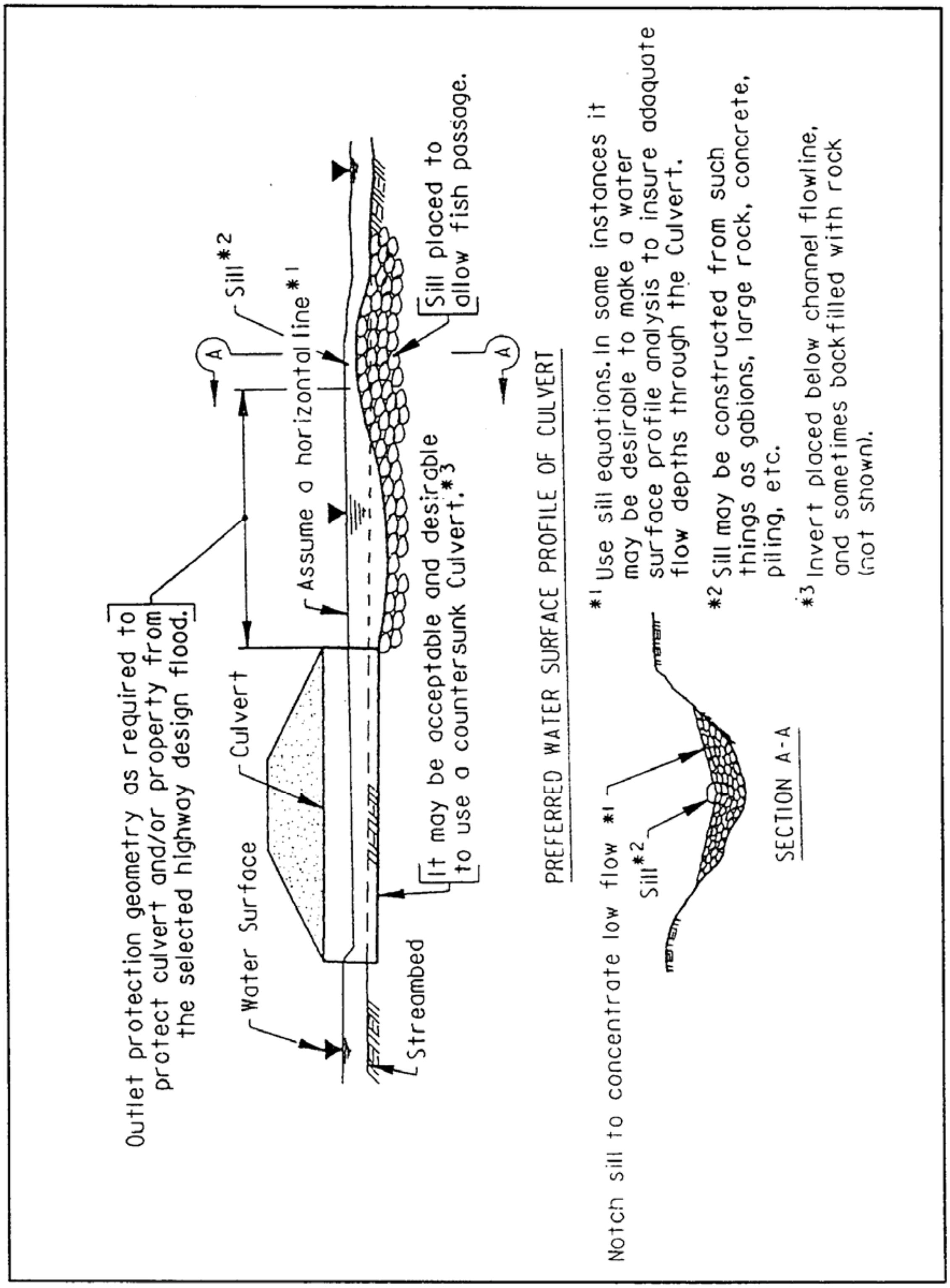
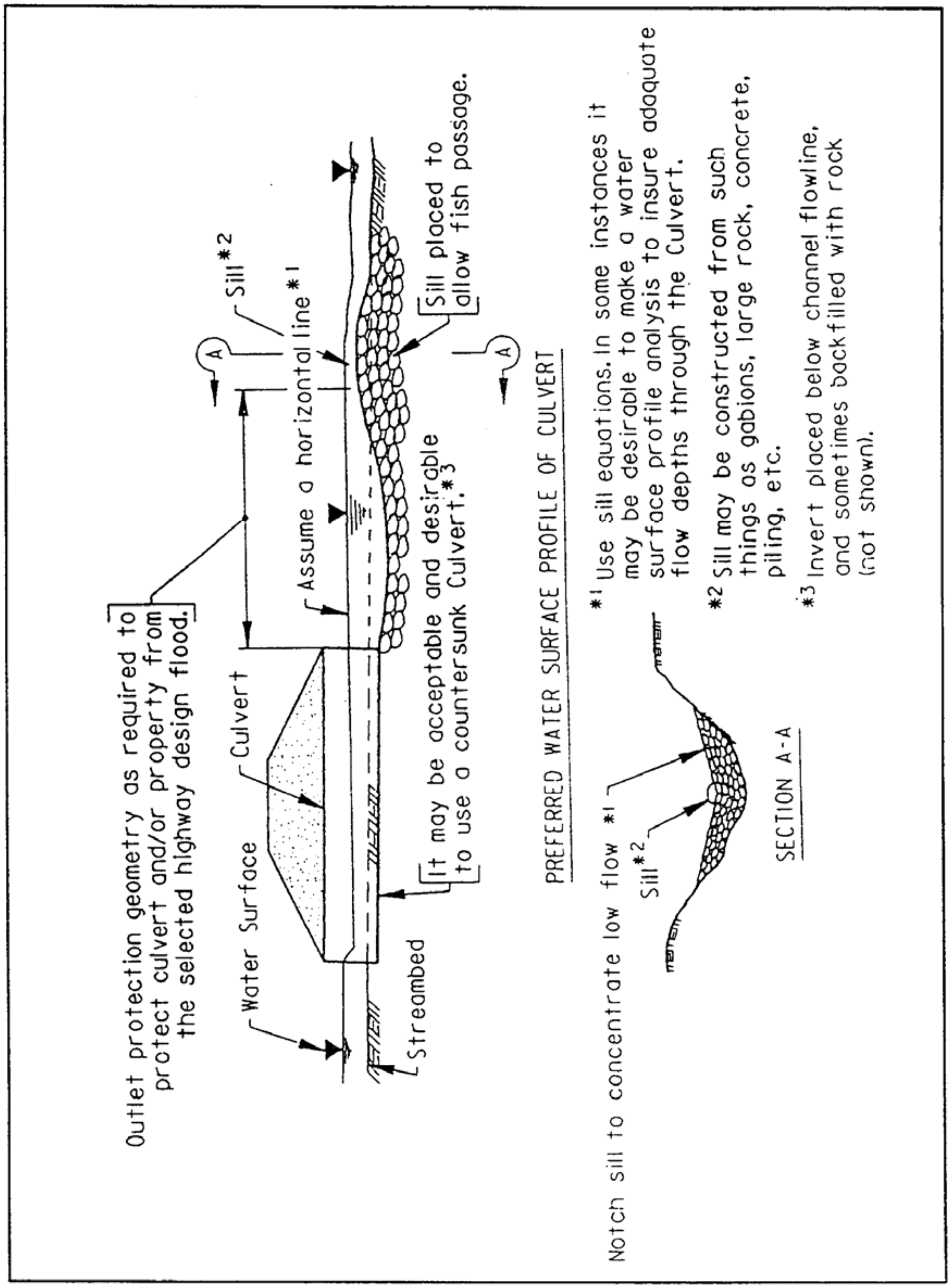


Figure 15.9 Natural Substrate for Fish Passage



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