15 Surface Water Environment

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15 Surface Water Environment

15.1 OVERVIEW

15.1.1 Introduction

The Hydraulic 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 Hydraulic 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 must 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 Threatened and Endangered Species (T&E) specialist;
- Fishery and wildlife compatible drainage facilities, with assistance from the CDOT Landscape Architect, wetland specialist, T&E specialist and/or Colorado Parks & Wildlife (CPW).

Photo 15.1

Photo 15.2

15.1.2 Purpose

The hydraulic designer must be involved in estimating impacts to surface-water environments in the planning stage of a project, and is responsible for preparing hydrologic and hydraulic designs to avoid, minimize, or mitigate the transportation project's impact[1].

15.1.3 Surface Waters

Surface waters addressed by this chapter are:

- Streams or rivers; and
- 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 consideration by a regulatory or resource agency are likely to be sensitive to impacts. Examples listed below, in Table 15.1, are Colorado's Gold Medal trout streams, which are recognized for their outstanding recreational-fishing value.

15.1.4 CDOT's Phase I Municipal Separate Storm Sewer System (MS4) Discharge Permit[2]

CDOT is required to evaluate and consider "special requirements," or enhanced stormwater-quality Best Management Practices (BMPs), for new or redevelopment construction projects discharging to a pre-determined list of "sensitive waters[2]." This requirement is an attempt to better match BMP design and existing conditions in receiving waters to runoff pollutants likely to result from highway projects. The design practitioner is charged with considering more-specific types of structural and non-structural controls to meet the special requirements, which are beyond the standard 100% Water Quality Capture Volume (WQCV), or 80% TSS removal. Because structural-control design poses significant limitations within CDOT right-of-way, the practitioner must consider a combination of supporting structural and non-structural BMPs. Special-requirement planning and design requires project-by-project, site-specific considerations and determinations.

Table 15.2 presents a list of CDOT's specifically-identified Sensitive Receiving Waters.

Table 15.1 Colorado Division of Wildlife's Gold Medal Trout Streams

River	Location
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

Specific stormwater quality design guidelines are provided in Chapter 16 - Permanent Water Quality, additional guidelines can be found in the *CDOT Erosion Control and Stormwater Quality Guide* (2014).

15.2 POLICY

15.2.1 Introduction

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

15.2.2 Federal Rules and Regulations

Refer to Chapter 2 of *CDOT Erosion Control and Stormwater Quality Guide* (2014); for a discussion on federal rules and regulations pertinent to water quality see Chapter 16 – Permanent Water Quality.

15.2.3 State Rules and Regulations

In addition to the information below, refer to Chapter 2 of *CDOT Erosion Control and Stormwater Quality Guide* (2014). Additionally, see Chapter 16 – Permanent Water Quality for a discussion on state rules and regulations applicable to water quality.

Table 15.2 List of Sensitive Receiving 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
Sloan's 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

The Basic Standards and Methodologies for Surface Waters

Regulations required by the Clean Water Act present a classification system for Colorado's surface waters, and establish beneficial-use categories and 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 - Memorandum of Agreement

In 1990, CDOT and CDOW (now CPW) signed a Memorandum of Agreement (MOA) that allows the programmatic use of SB 40 (Wildlife Certification) without formally contacting CPW on certain types of projects with minor impacts. Within the programmatic SB 40 certification, activities which require formal written application are identified. Required mitigation is outlined if use of the programmatic approach is applicable. CDOT construction activities falling under the jurisdiction of SB 40 must comply with 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 construction contract documents, or programmatic SB 40 clearance may not remain valid.

15.2.5 Cost-Effectiveness

Some costs associated with surface-water environmental engineering cannot be reliably quantified, commonly, those associated with the functional values of a resource. Nevertheless, it is important that any mitigation either be cost-effective or provide clearly-beneficial improvements.

15.2.6 Enhancing Functional Values

It is the intent of CDOT to provide those mitigation measures necessary to maintain the existing functional values, or acceptable equivalents, of surface waters disturbed by a transportation project. An existing function's values should be enhanced only when a cost-effective benefit to the state can be demonstrated, unless otherwise negotiated with the appropriate resource and regulatory agencies.

Some examples of negotiable benefits are:

- Wetland banking;
- Citizen buy-in;
- Substitution of a more cost-effective, easier to construct or maintain (or both) functional value; and
- Receiving concessions on other project issues.

15.2.7 Environmental Evaluation Complexity

The level of detail of any environmental evaluation involving an assessment or analysis should be commensurate with the surface-water sensitivity, and the importance of the resource's functional values.

Close coordination and ongoing negotiations with the appropriate resource and regulatory agencies should be maintained throughout the plan-development process to ensure an acceptable level of assessment or analysis detail. Only the level of detail essential to securing approval of the transportation project from the resource and regulatory agencies should be developed. A surface-water analysis should be prepared when activities create a major alteration of a surface-water feature, or when a detailed analysis is required by resource and regulatory agencies. Surface-water assessments will suffice for most sites that affect sensitive surface waters.

15.2.8 Surface-Water Assessment

An assessment is a subjective form of surface-water analysis. It eliminates the need for either a complex study, or one that requires large amounts of costly data.

Assessments should be limited to comply with requirements of appropriate resource and regulatory agencies. If an assessment is acceptable to those agencies, a surface-water analysis may not be required. The intent is to develop constraints for construction within areas containing sensitive surface waters. Assessment findings are used to identify effects of a proposed project on these waters. Concerns raised by resource and regulatory agencies should be resolved utilizing CDOT's BMPs whenever practicable.

If the assessment findings or proposed BMPs are unacceptable to the appropriate regulatory agencies, or if other issues related to surface water are raised that cannot be resolved without a surface-water analysis, then the analysis must be performed.

15.2.9 Surface-Water Analysis

An surface-water analysis is more quantitative than an assessment. Issues addressed in an analysis should be limited to those CDOT determines to be significant based on their interactions with resource and regulatory agencies. All other issues should be addressed at the assessment level of investigation.

15.2.10 Stormwater Management Plan (SWMP)

Preparation of a SWMP is discussed in detail in the *CDOT Erosion Control and Stormwater Quality Guide* (2014).

15.2.11 Stormwater Quality Management

Chapter 16 - Permanent Water Quality, and the *CDOT Erosion Control and Stormwater Quality Guide* (2014) should be utilized to address stormwater-quality issues. Theses guides can be used to predict whether stormwater runoff from the operating transportation system will adversely affect receiving-water quality. Stormwater-quality BMPs are identified which mitigate adverse water-quality impacts. The guides also designates structural BMPs appropriate for installation on CDOT construction projects, with 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 mitigation alternatives and BMPs.

15.3.2 Mitigation Alternatives

Several transportation design alternatives may be considered when a proposed project will disturb surface waters. Some of these involve mitigation. Mitigation is the practice of anticipating effects to surface waters so that pre-disturbance functional values, permit requirements, enhancement, or acceptable equivalents are maintained by the design of the project.

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 a surface-water feature is preferable. It must be demonstrated that this alternative is not practicable before any other alternative can be considered.

Minimization

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

On-Site Mitigation

Measures that implement mitigation at the geographic point of disturbance usually are 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 implemented 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 above alternatives for mitigation at a site.

Compensatory Offsets

This option includes out-of-kind mitigation and contributions to CDOT's State-maintained environmental fund. An example is using stream-bank restoration as mitigation for disturbing a wetland area.

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

15.3.3 Best Management Practices

CDOT BMPs, as described in Chapter 16 - Permanent Water Quality and the *CDOT Erosion Control and Stormwater Quality Guide* (2014), must be routinely used to mitigate adverse surface-water impacts.

15.3.4 Functional Values

Surface-water functional values describe the quality of functional categories such as riparian diversity, fish and wildlife habitat, flood protection, water-quality effects, erosion protection, groundwater recharge and discharge, aesthetics, recreation, and education. Design criteria for surface-water functional values must be based on seasonal preconstruction values and/or expected future values. Seasonal values may be used as a baseline to evaluate the expected state 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 discussions about design criteria for four hydraulics-related surface-water features:

- Water quality and quantity;
- Channels;
- Wetlands;
- Fish passage

For additional design criteria see Volume 2 Chapter 7 – Surface Water Environment of the AASHTO *Drainage Manual*.

15.3.6 Water Quality and Quantity

Water quality is discussed in detail in Chapter 16 - Permanent Water Quality and the *CDOT Erosion Control and Stormwater Quality Guide* (2014).

Water quantity or the continuation of water flow should be considered an important factor in supporting aquatic habitats. Any diversion of flow from a water-dependent environmental feature should be carefully considered. It should be noted that some of the aquatic habitat may depend on availability of groundwater, and others on surface waters.

15.3.7 Channels

Chapter 8 - Channels addresses 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, when cost effective, can be employed as discussed in Chapter 8 - Channels, and Chapter 17 - Bank Protection.

Criteria for functional value in channel design include:

- Classification;
- Ordinary high water;
- Stability; and
- Mitigation.

Classification

Channels must be classified by type and stability. Classifications must be determined for preconstruction and long-term (future) time periods. Classification by stability is addressed below. In addition, Chapter 5 of HDS-6 can be used for classification of river-channel types.

Ordinary High Water

The ordinary high water (OHW) line is a jurisdictional boundary line. It can be determined based on any of the following indicators:

- A clear or natural line impressed on the bank or shore;
- Shelving;
- Changes in soil character;
- Destruction of terrestrial vegetation;
- Presence of litter and debris; and
- The inundation line of the normal operating pool elevation (NOPE) for reservoirs.

If none of these indicators is present, use the inundation line of the water surface corresponding to the channel-forming discharge, or floods ranging from a 1.5 return period to a 2.33 return period to estimate the OHW line.

Stability

The stability of a channel reach should be based on an evaluation of criteria shown below, over a discharge range of the mean annual flow, Q_a (not mean annual flood, $Q_{2.33}$) to Q_{100}. The designer must ensure the stability of the channel affected by the action, as practicable. The practices and criteria in Chapter 8 - Channels are used to determine design-flood channel stability.

A channel must first be stable for the design flood before being modified to serve as an environmental channel. The geomorphic definition of "stability" for a channel is that it is neither aggrading nor degrading over time. Channel stability should be assessed using the procedures in Chapter 16 - Stream Stability of the AAHTO *Drainage Manual*. A channel is considered relatively stable for a particular discharge when displaying some or all of the following characteristics, except as noted, for braiding and headcutting:

- Tractive Shear - bed and bank shears approximate those allowable in a stable channel, and allow the sediment transport rate of the channel to balance the inflow and outflow sediment transport rate of the channel.
- Regime Slope - the present or expected channel slope approximates the channel's regime slope for a stable channel, the slope at which a channel is considered stable.
- Bank Caving - presence of nominal bank caving or no caving.
- Braiding - there is no evidence of braiding.
- Headcuts - there is no evidence of headcutting.

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; and
- Unstable - braided, or head-cutting channels. Aggrading or degrading channels.

Channel Control Facilities

Before deciding to mitigate impacts to a transitionally stable, marginally stable, or unstable channel using channel control facilities, consider if the mitigation:

- Is cost-effective;

- Is necessary to protect the road;
- Is necessary to protect property;
- Is considered to be effective in the long term;
- Is in the best interest of the public; and
- Will require periodic maintenance.

Other measures for stabilizing a channel are discussed in Chapter 17 - Bank Protection and Chapter 18 of the AASHTO *Drainage Manual.*

Mitigation

Where significant adverse impacts are expected to occur, mitigation criteria include:

- Identifying and not exacerbating existing channel-stability problems;
- Providing cost-effective measures to improve 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 must include consideration of:

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

15.3.8 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:

- 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 by 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 wetlands area or functional values a proposed transportation horizontal alignment should be modified wherever practicable. For roadway-widening projects, avoidance can be accomplished by widening to the side opposite the wetlands, or by modifying the cross-section geometry. Consideration should be given to narrower shoulders or steeper fill slopes to avoid impacts.

If wetland impacts cannot be avoided, it should be determined early in 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 placement of detour embankment. Replacement mitigation for permanent impacts is usually based on replacing one unit of wetlands 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, or adequate type and functional value cannot be achieved.

15.4 CHANNEL MITIGATION GEOMETRIES

This section briefly discusses stream restoration and mitigation methods that have been used by CDOT to maintain or restore functional values of channels.

15.4.1 Grade-Control Structures

Grade-control structures may be used to establish stable channel profile slopes. They should not be used where fish passage is a design criterion without the modifications listed below because they do not provide a pool from which fish can jump to ascend upstream.

In order to use a grade-control structure to establish a stable channel where fish passage is required:

- The length must be equal to the distance the design fish can swim at its darting speed. Otherwise, boulders must be embedded immediately upstream and downstream of the structure to provide resting areas.
- The channel flow depth and velocity during fish migration periods must be compatible with the design fish's darting swimming speed; and
- The overflow velocity must be compatible with the burst velocity or burst swim speed of the design fish species.

Preferred types of grade-control structure compatible with fish movement are discussed in Volume 2, Chapter 9 of the Denver Regional Council of Governments, *Urban Drainage and Flood Control District Criteria Manual*, Chapter 14 of NRCS *National Engineering Handbook*, Part 654, and are illustrated in the Federal Interagency Stream Restoration Working Group's (FISRWG) *Stream Corridor Restoration: Principles, Processes and Practices*.

Grade control may be also accomplished by using a culvert placed on a grade flatter than the modified or unstable channel. However, where fish passage is important, the culvert geometry must be determined using procedures and criteria in FHWA's *Hydraulic Engineering Circular 26, Culvert Design for Aquatic Organism Passage* (HEC-26).

15.4.2 Fish Habitat Structures

Figure 15.1 shows examples of in-stream rock placement for fish habitat.

15.4.3 Aquatic Organism Passage Structures

HEC-26 should be consulted if a project crosses a stream that has aquatic organism passage (AOP) concerns where a culvert is proposed. If a culvert is not involved, refer to the stream restoration techniques discussed in FISRWG *Stream Corridor Restoration: Principles, Processes and Practices*, and NRCS *National Engineering Handbook*, Part 654.

15.4.4 Non-Structural Bendway Bank Protection

Figure 15.2 illustrates a more environmentally-compatible bank protection than provided by riprap spurs (see Chapter 17 - Bank Protection). These environmentally-compatible devices are also useful in establishing a pool-riffle sequence.

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

15.5 FLOODPLAINS

15.5.1 Introduction

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

15.5.2 Floodplain Benefits

Floodplain benefits include flood control and wildlife habitat.

15.5.3 Flood Control

Natural floodplains enhance flood control. Floodplains 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 floodplain impacts depend on 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 subsequent bed and bank erosion. Erosion of the channel bed can lead to an undesirable 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 floodplain's 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 rise. The additional water depth may inundate property that would not have been inundated prior to encroachment, creating a potential liability to CDOT.

15.5.4 Floodplain Regulations

Federal, State, and local regulations control development within a floodplain. CDOT must comply with 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.

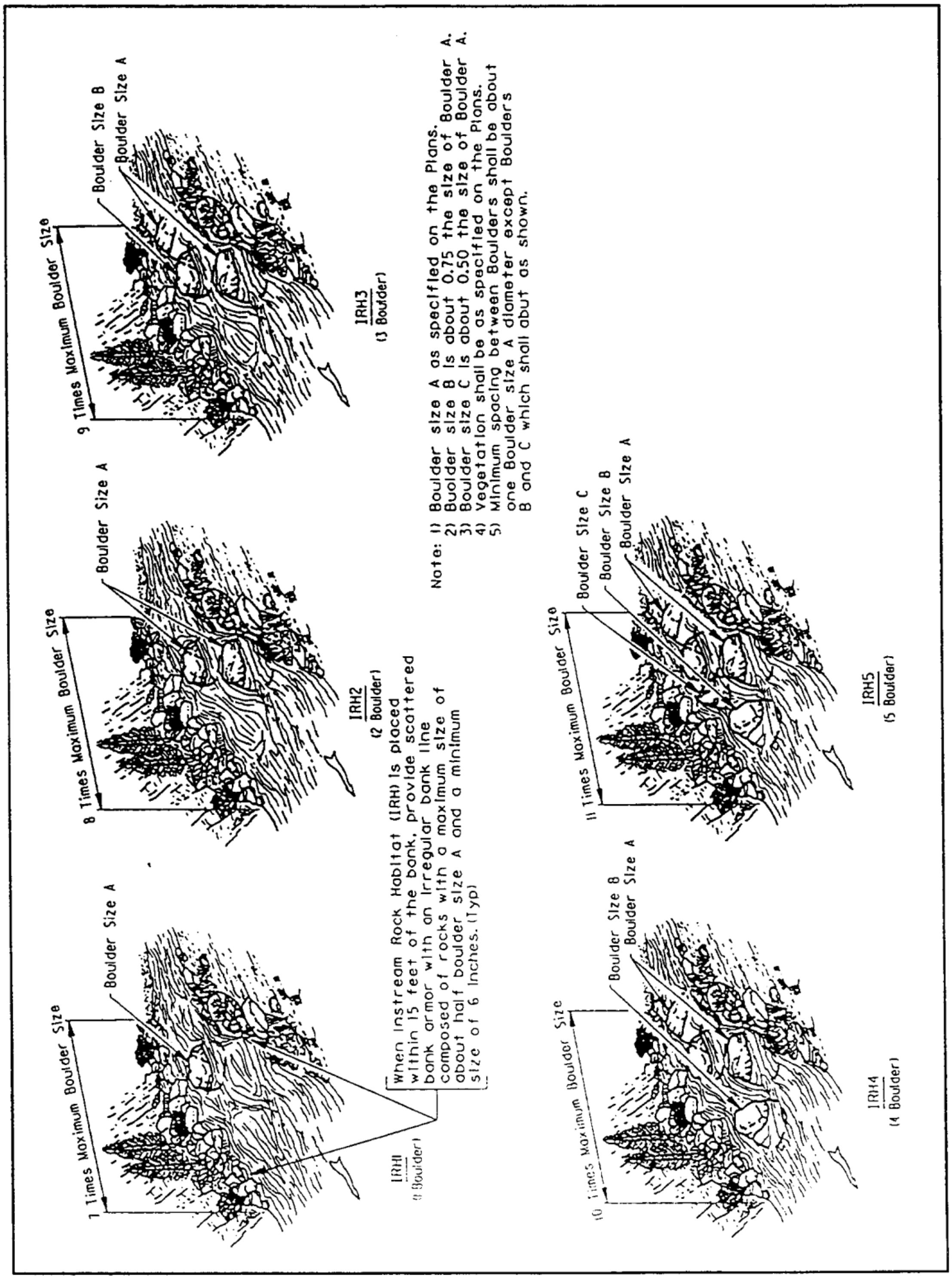

Figure 15.1 Instream Rock Habitat (to be coordinated with specific DOW criteria)

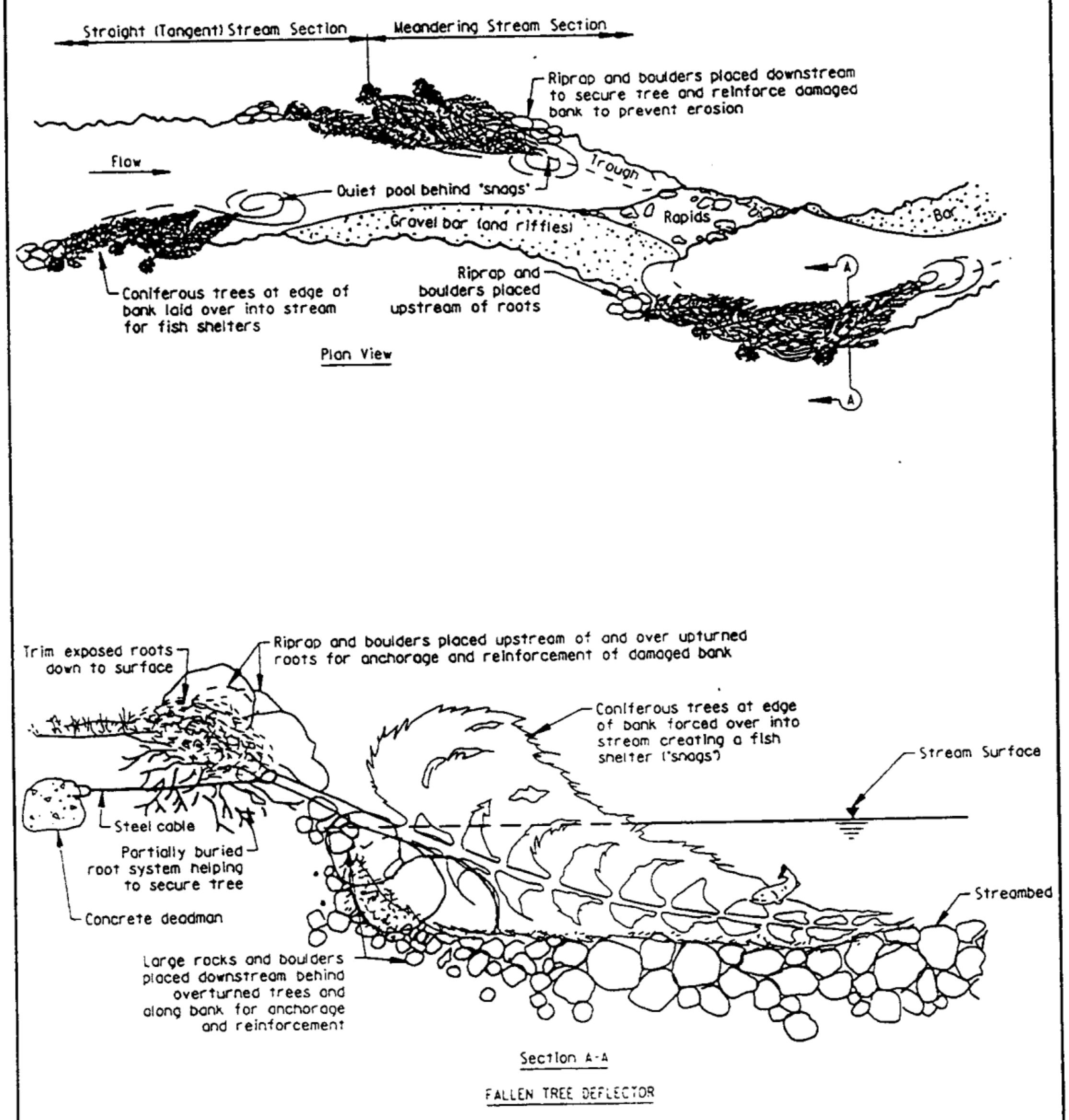

Figure 15.2 Bank Deflector Structure (Log Type) (to be coordinated with specific DOW criteria)

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

15.6 FISH PASSAGE CRITERIA

15.6.1 Introduction

The practices and criteria provided in this Section were developed using guidance from Norman, Watts, McClellan, King and Brater, (see References) except where noted otherwise.

The fish-passage discussion included in this section is based on the 2007 AASHTO *Highway Drainage Guidelines*. That manual contains a thorough discussion of fish passage along with detailed design guidelines, and should be consulted as necessary when designing CDOT drainage facilities. Because Senate Bill 40 applies to fisheries, Colorado Parks and Wildlife may also have 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.

15.6.2 Channels

Primary considerations are aquatic habitat and channel stability. Channel design related to aquatic habitat is briefly addressed in Section 15.3.7, and channel stability is addressed in Chapter 8 - Channels.

15.6.3 Bridges

Bridges are considered part of the channel. Where practicable, the bridge should span the ordinary high-water channel. Although not desirable, piers within the ordinary high water channel are sometimes acceptable in that any scour holes commonly provide a desirable pool-type habitat. However, predicted pier-scour depth and resulting foundation depth and cost determine whether 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 *CDOT Bridge Design Manual* drainage chapter for bridge-drainage issues.

15.6.4 Culverts

The most common fish passage concern on highway projects involves culverts. Failure to consider fish passage may block or impede upstream fish movements in many ways:

- The outlet of the culvert is installed above the streambed elevation and 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.

- The 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 block fish movement.
- Shallow depths within the culvert during minimum flow periods may prevent fish passage.

More information may be found in the HEC-26.

15.6.5 Structure Type

The choice of a structure type may require a compromise between structure economics and optimum fish passage. For fish passage at transportation crossings, preferred structure types in order of preference considering acceptable hydraulics and economics, are:

- 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, with grades between 0.5% and 5.0%; and
- Structure with a special, separate fishway.

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

15.6.6 Fish Swimming Speed

Information about swimming speed may be available from the responsible resource and regulatory agencies such as the Colorado Department of Natural Resources, and the Division of Parks and Wildlife. The following guidelines are used for design when there are no existing guidelines. When there are 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 facilities such as culverts, bridge openings, and channel modifications, the swimming speeds from Table 15.3 should be considered. The table provides general velocity criteria to be used in designing a culvert, bridge, or channel for the passage of adult fish. 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.

15.6.7 Design Flow Depths

During migration runs, fish-passage designs must ensure that minimum-depth criteria are met. These depth criteria are contained in Table 15.4.

Table 15.3 Sustained or Burst* Swimming Speeds of Average Size Adult Fish

Species	Cruising Speed 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*

* Some “darting speeds” and “speeds” are believed to be burst speeds.

Table 15.4 Minimum Culvert Flow Depths For Migration

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

15.6.8 Culvert Geometric Elements

The geometric elements of a culvert that influence fish migration are the inlet, barrel, and outlet.

15.6.9 Inlet Geometry

Care must be taken to ensure the culvert inlet does not block fish passage. The culvert entrance should be submerged or have sufficient backwater and flow depth so that migrating fish moving upstream do not have to jump to exit. Where this is not practicable, the maximum allowable entrance jump height from Table 15.5 applies.

Table 15.5 Maximum Jump Heights of Fish

Fish	Jump Height, ft
Trout	0.5

15.6.10 Outlet Geometry

Care must be exercised to insure that migratory fish can enter, transit, and exit a drainage facility, particularly where highly-contracted flows occur such as within a culvert-type structure. Figure 15.3 provides some commonly-used geometry, and criteria for outlet geometry, of a culvert-type structure. This same geometry also may be used to improve inlet conditions. Where structures other than culverts have high exit velocities due to conditions such 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 adopted.

The key to the outlet-geometry criteria in Figure 15.3 is the downstream sill. The sill controls flow depths and velocities through the culvert during critical migration periods. Figure 15.4 provides design criteria for a sill. If it is necessary to avoid excess sill height, more than one sill may be considered. The sills on Figures 15.3 and 15.4 are shown as rock, but other materials may be used. Sills must be located beyond any expected scour hole (see Chapter 11 - Energy Dissipators).

15.6.11 Barrel Geometry

Barrel geometry and material in the bottom of the barrel can influence fish passage. Figure 15.5 illustrates how a culvert can be imbedded (depressed) below the streambed so as to:

- Increase 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 must be used to evaluate the stability of backfilled substrate. The flood-recurrence interval used for this tractive shear analysis must be the design flood used for the project drainage design. Sills periodically affixed to the culvert invert or randomly-placed large boulders (only for larger culverts) may be useful to hold substrate material in place when it is not practicable to meet tractive-shear criteria. It should be recognized that if substrate material is scoured out from between sills and from around boulders, upstream bed-load material will be transported into the culvert and deposited, preserving the substrate to some degree. When this occurs, the need to provide a substrate that is stable during design flows is eliminated. Even if substrate is flushed out of the imbedded area, the culvert may still provide acceptable fish passage. With the backfill material gone or partially gone within the culvert, there will be more-desirable deeper depths and slower velocities.

The placing of substrate, boulders, or fishways inside of culverts decreases culvert capacity and may increase flood hazards. Placement of such appurtenances must not be considered if additional flood hazards are created.

A culvert substrate similar to that in a natural channel will facilitate fish passage. Figure 15.5 provides guidelines and criteria for this geometry.

15.6.12 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 periods for fishways. Maintenance must be informed by the Region Environmental Planning Manager to prevent inadvertent removal of such devices when cleaning channels and structures. This also allows maintenance forces to ensure 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. When these stream-transported items may cause partial or total blockage of a culvert, preference must be given to such things as smooth-culvert fishways with downstream sills, substrate fishways, and bridges where ever practicable. Higher maintenance costs must be considered when comparing alternate fishways where deposited sediment has to be removed frequently from sill or baffle fishways.

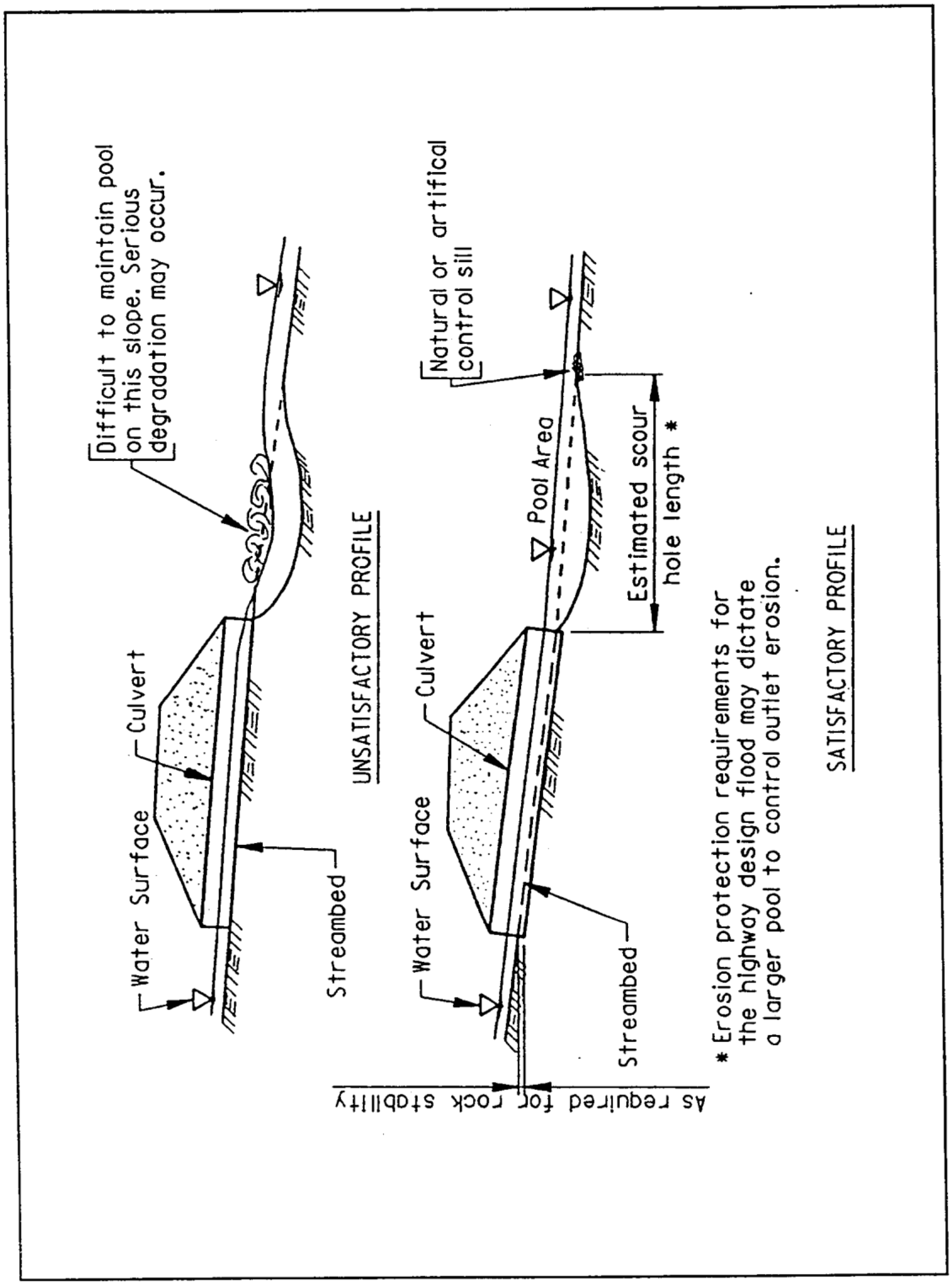

Figure 15.3 Outlet Geometry for Fish Passage

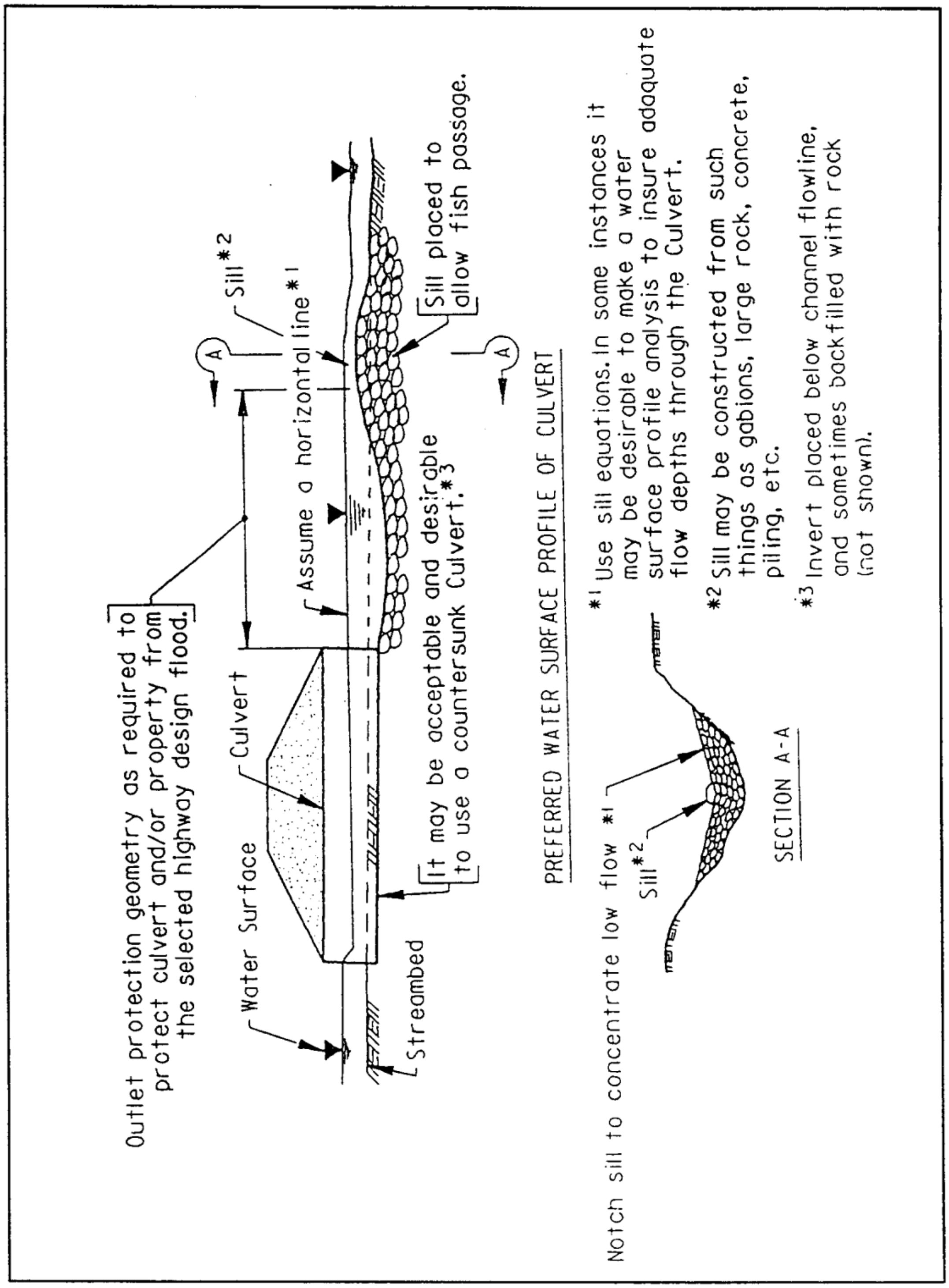

Figure 15.4 Sill Criteria at Culvert Outlet

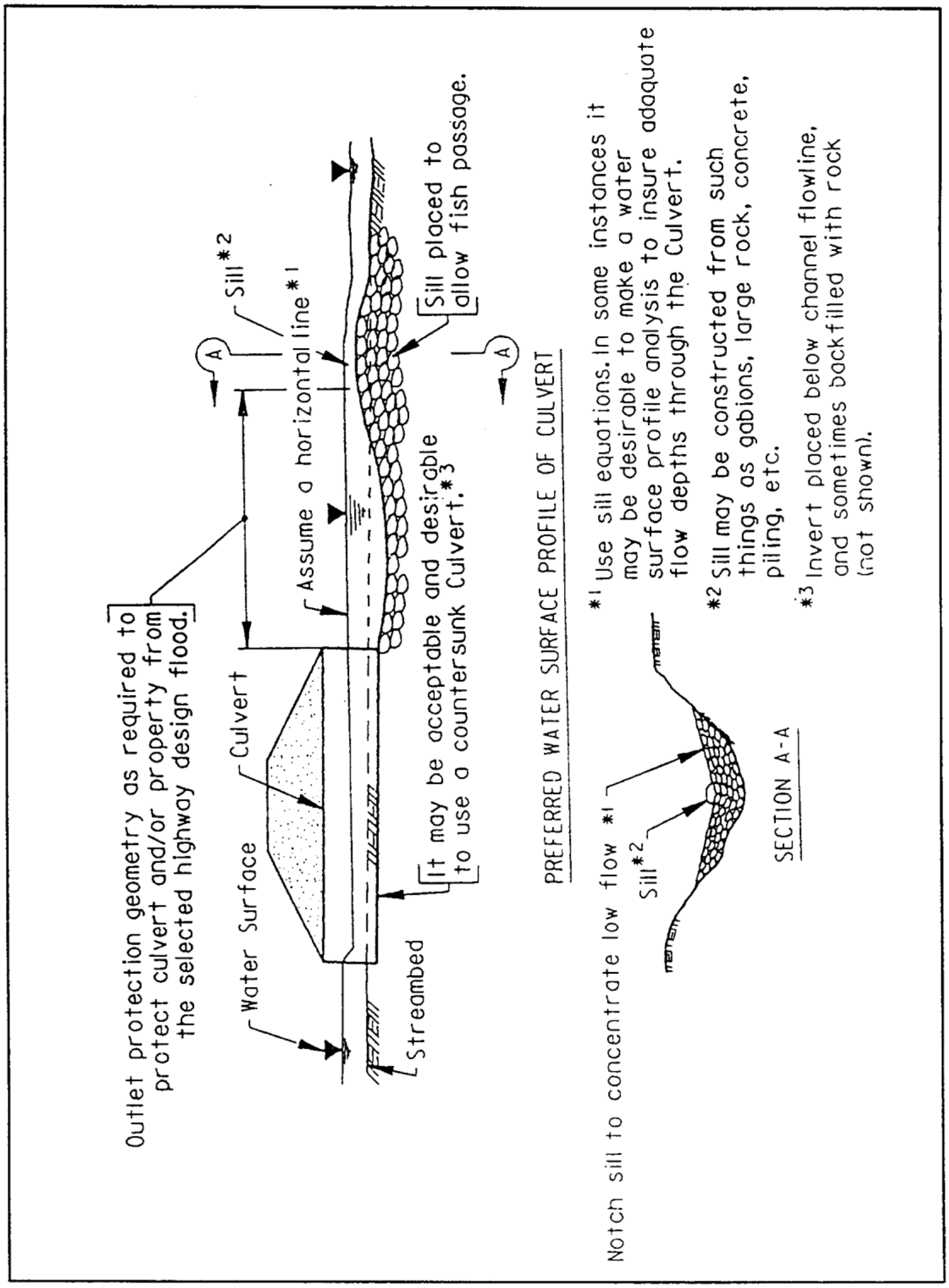

Figure 15.5 Natural Substrate for Fish Passage

NOTES

1. In negotiations with regulatory and resource agencies, 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.
2. Refer to CDOT Water Quality Program Report, "Special Requirements for Discharges to Sensitive Waters," submitted to CDPHE-WQCD June 4, 2004.
3. For specific reporting and documentation requirements, consult the appropriate regional or CDOT Water Quality Program representative.

15.7 LOW-WATER CROSSINGS

Low-water crossings are hydraulic structures designed for low-traffic-volume roads that experience infrequent flooding. They offer a cost-effective alternative to culverts and bridges for stream crossings on roads where average daily traffic (ADT) is less than 200 vehicles per day, and where stream-flow conditions are appropriate. A flow depth corresponding to bankfull discharge of 6 inches or less is considered appropriate. When selecting the type and design, site considerations, and specific hydrologic, hydraulic, and biotic analyses must be considered just as with any other hydraulic structure for stream crossings.

There are three types of low-water crossings:

Unvented Fords - are constructed of riprap, concrete, or gabions to provide a crossing where streams are dry most of the year. For safety reasons, water depth over an unvented ford should not exceed 6 inches.

Vented Fords - use single or multiple pipes, concrete box culverts, or arch culverts under the crossing to allow low flows to pass through without regularly overtopping the crossing. These pipes or culverts may be placed in riprap, aggregate, or concrete. For vented fords, the ratio of vent opening area to the bankfull channel area is defined as vent-area ratio (VAR), and can be used as a guide in selecting an appropriate low-flow crossing type. In general, a high VAR is associated with a small amount of blockage to stream flow, and is preferred where aquatic organism passage (AOP) is important, and where high-debris flows are expected.

Low-water Bridges - use a single box culvert, or a series of box culverts, with a combined width of 20 feet or greater, embedded with continuous streambed material through the structure. Hydraulically, these structures perform like a bridge spanning the channel width, and are used where habitat protection is important.

The unvented and vented types of low-water crossings are further classified as follow:

Unvented Fords

- At-grade, simple rock-reinforced fords;
- Improved surface, concrete-slab fords;
- Improved surface, precast-concrete planks;
- Improved surface, articulated concrete-block mattress;

- Improved surface, geo-cell fords;
- Porous, large rock-fill fords; and
- Jersey-barrier / gabion /concrete-wall fords.

Vented Fords

- Vented fords with single or multiple culverts;
- Vented fords with concrete box culverts; and
- Vented fords with bottomless arch culverts

Figure 15.6 presents the types of low-water crossings.

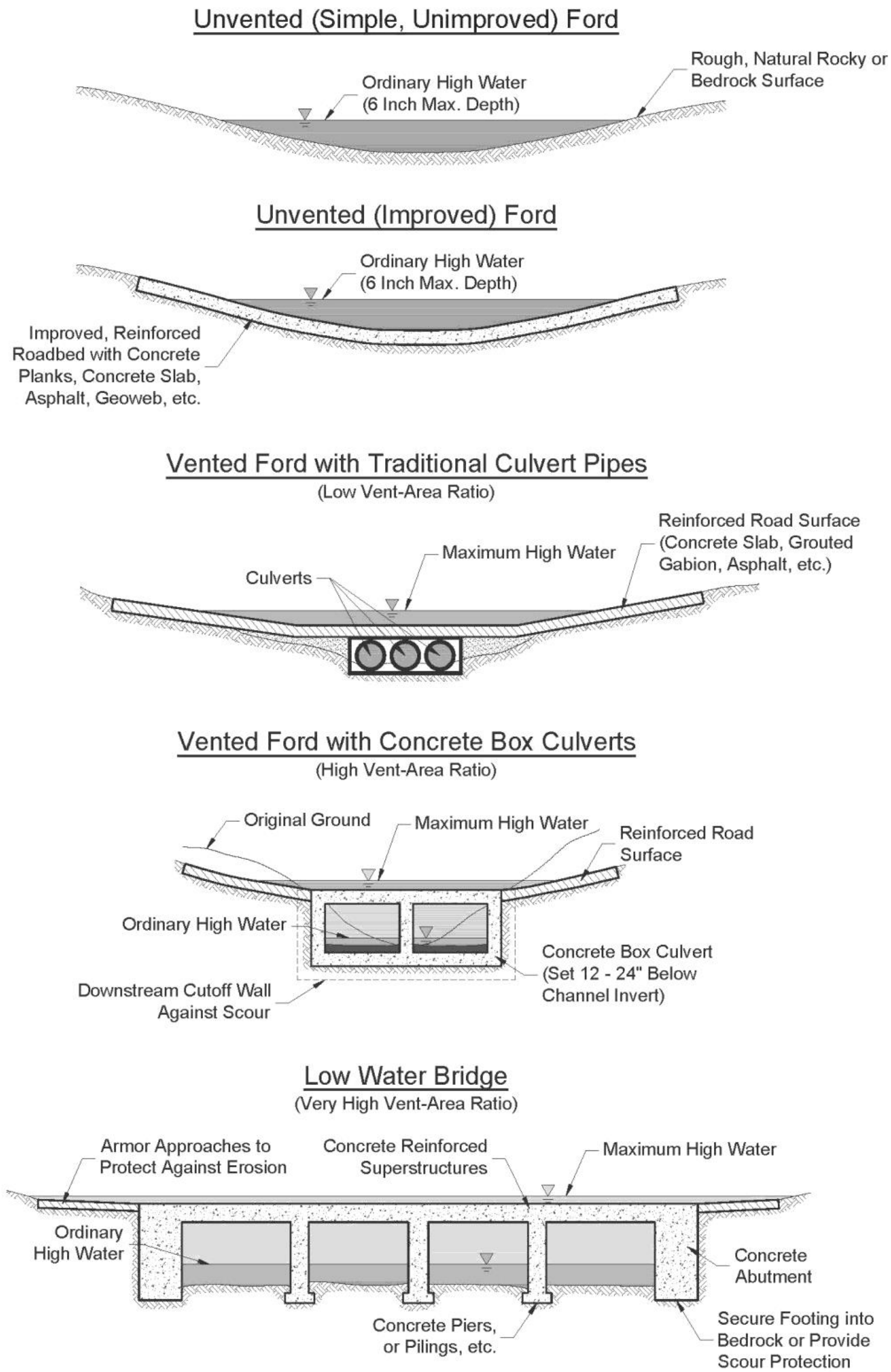

Figure 15.6 Types of Low-Water Crossings.

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