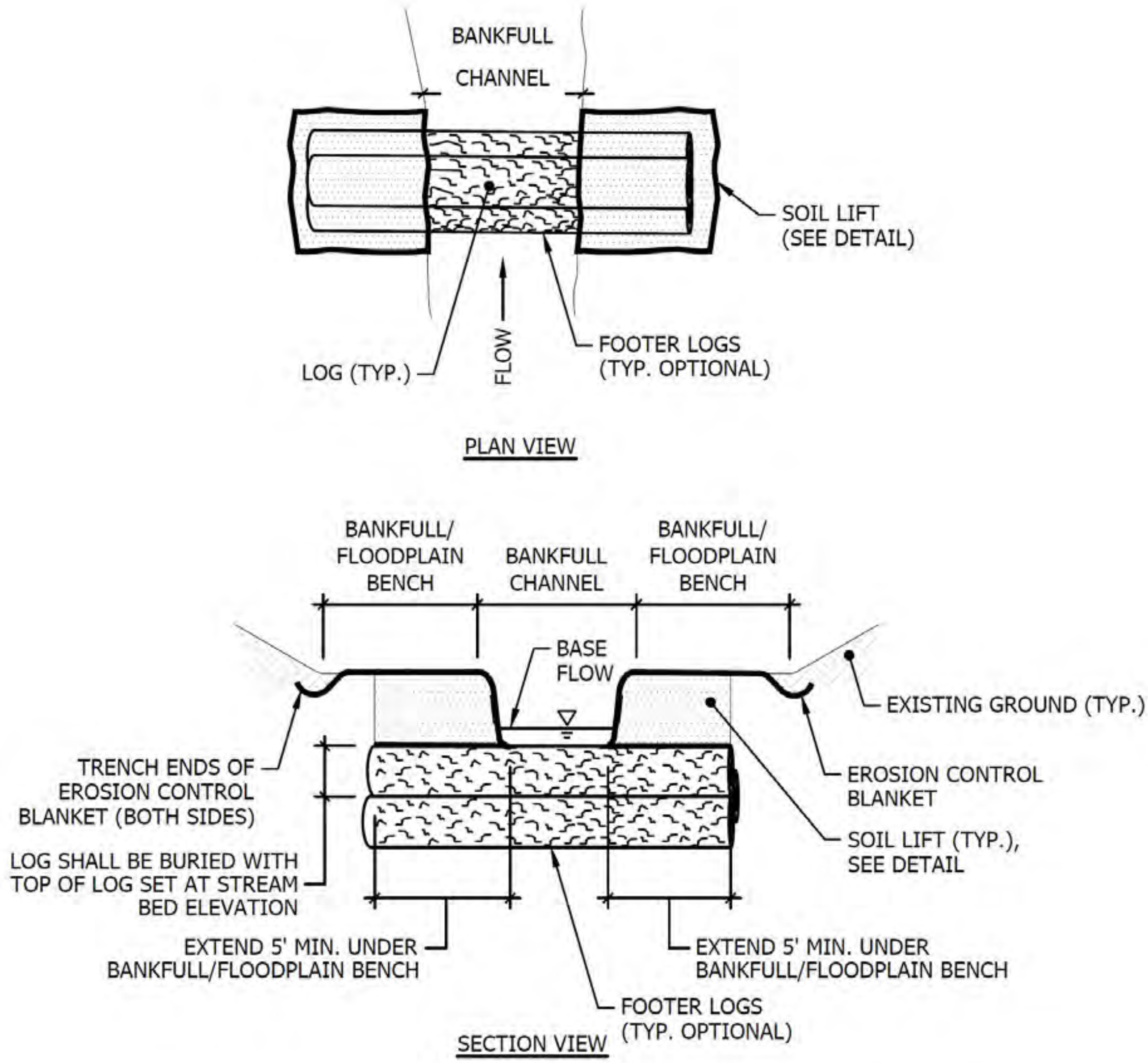

Ecological Restoration Details

Version 2.0 June 2024

PHILADELPHIA WATER DEPARTMENT

What's New

June 2024

- Changed the document name.
- Revised layout and format to match other GSSD Unit resources.
- Added link to CAD files and linked the document internally to the table of contents.
- Renamed the following structures:
    - Soil Stabilization Matting renamed as Erosion Control Blanket
    - Floodplain Rock Sill renamed as Rock Sill
    - Toe Wood Structure renamed as Toe Wood
    - Random Boulder Placement renamed as Engineered Habitat Boulder Placement
    - Rock Step Pool with Boulder Toe renamed as Rock Step Pool with Boulder Toe Revetment
- Added the following new structures:
    - Boulder Cascade
    - Regenerative Step Pool Storm Conveyance
    - Beaver Dam Analog
    - Rock and Roll Logs
    - Soil-Filled Riprap Floodplain Bench
    - Log Planting Terrace
- Removed the following structures:
    - A-Vane
    - J-Hook Vane
- Added PWD Ecological Restoration In-Stream Structure Design Guidance Checklists and provided link to the checklists.
- Removed Construction Guidelines from the manual and added to the Master ER Specifications Template.
- Added Notes to Designer section for each structure.
- Added Photographs: During Construction and Post Construction for each structure.
- All technical notes and calculations moved into a separate section: General Literature.
- Updated the List of References in the References section.
- Added Glossary and Other Resources under the References section.

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1.0

Introduction

1.1 Introduction

The Ecological Restoration (ER) Details Manual provides a collection of stream channel and floodplain structures that aligns with other Philadelphia Water Department (PWD) standards and industry best practices for executing projects within the City of Philadelphia's waterways. The collection combines "soft" and "hard" engineering methods to repair the existing riparian corridor while protecting the critical stream-side infrastructure.

The manual is intended to be used by PWD staff, providers of professional engineering design services, and other agencies/partner organizations that work with PWD during the development of construction documents for all PWD Stream Restoration and Infrastructure Protection projects. The manual outlines the recommended components, effective uses and limitations, computations, and design considerations for each structure. Project teams set the stage for successful implementation and performance through the incorporation of these details during the design phase.

PWD is dedicated to ongoing innovation and continuously exploring new approaches through pilot details. Designers are encouraged to work with the PWD project manager to introduce novel solutions as deemed fit for a particular site. CAD versions of the details presented in this book are available for use by designers and may be tailored according to the specifics of the project.

Figure 1 on the next page highlights the collaborative benefits of properly designed and constructed stream channel and floodplain structures for the stream, infrastructure, ecology, and community. Restoring the stream channel improves in-stream hydraulics and sediment transport, improves floodplain connection, sequesters nutrients, and enhances urban riparian habitats. Streambank and floodplain grading helps protect critical water and sewer infrastructure adjacent to the stream, thereby minimizing the risk of failure and/or damage and accidental discharge during storm events. Ultimately, stream restoration projects aim to improve and enhance the overall health and functionality of the city's streams and their surrounding ecosystems, creating more sustainable and resilient green spaces for the environment and surrounding communities.

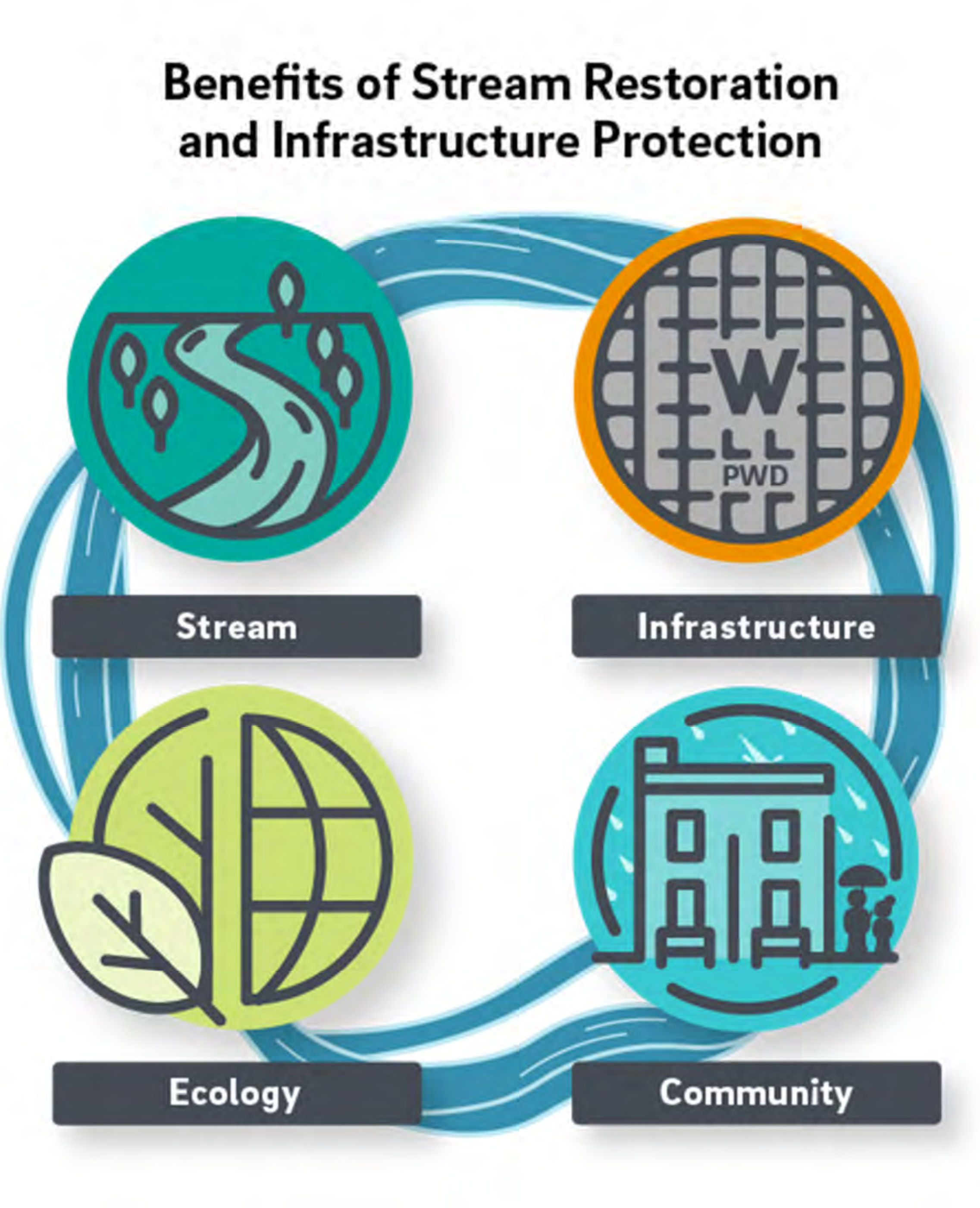


Figure 1: Benefits of Stream Restoration and Infrastructure Protection

1.2 Functional Goals

Six functional goals have been identified to evaluate restoration best management practices. The goals include: **In-Stream Grade Control, Streambank Protection, Floodplain Protection, In-Stream Habitat Enhancements, Riparian Habitat Improvement, and Water Quality Improvement**. These goals encompass a variety of habitat, nutrient, riparian, and geomorphic functions within different regions of the stream corridor and are described in **Table 1** below. Please refer to the Glossary in the ***References*** section for complete definitions of each functional goal. **Table 2** on the following page identifies all the in-stream structures contained with the ER Details Manual and ranks each structure on how well it is suited for the six different functional goals.

Table 1: Functional Goal Descriptions

GOAL	TARGET FUNCTIONALITY	STREAM REGION
In-Stream Grade Control	Vertical Stability	Stream Bed
Streambank Protection	Horizontal Stability	Stream Banks
Floodplain Protection	Velocity and Shear Stress Reduction	Bankfull Bench/Floodplain Surface
In-Stream Habitat Improvement	Promote Stable and Diverse Benthic and Aquatic Habitats	Water Column and Benthic Environments
Riparian Habitat Improvement	Promote Stable and Diverse Riparian Habitats	Floodplain Wetland and Upland Riparian Buffer Habitats
Water Quality Improvement	Source Reduction, Removal, Sequestration or Conversion of Sediment and Nutrients	Hyporheic Zone, Water Column and Stream Banks

1.2.1 In-Stream Structure Design Guidance Checklists

The PWD Ecological Restoration In-Stream Structure Design Guidance Checklists are available for use by designers and are intended to assist the designer in selecting an appropriate structure for a given reach and functional goal based upon the effective uses and limitations of each structure. The checklists can also be used as a framework for selecting appropriate design alternatives. A complete set of instructions for the designers are included with the checklists.

Table 2: Functional Goals of In-Stream Structures

IN-STREAM STRUCTURES	FUNCTIONAL GOALS					
	In-Stream Grade Control	Streambank Protection	Floodplain Protection	In-Stream Habitat Improvement	Riparian Habitat Improvement	Water Quality Improvement
Engineered Riffle	●	◌	◌	○	◌	○
Boulder Terraces	◌	●	●	◌	○	○
Bendway Weir	◌	○	◌	◌	◌	○
Erosion Control Blanket	◌	●	○	◌	◌	○
Live Stake Plantings	◌	○	●	◌	○	○
Pole Plantings	◌	○	●	◌	○	○
Soil Lifts	◌	●	○	◌	◌	○
Preformed Scour Hole	●	○	◌	◌	◌	○
In-Stream Log Sill	●	◌	◌	○	◌	○
Floodplain Log Sill	◌	◌	●	◌	○	○
Rock Sill	●	◌	●	○	○	○
Toe Wood	◌	●	○	●	○	○
Engineered Habitat Boulder Placement	○	◌	◌	●	◌	◌
Root Wad	◌	●	◌	●	◌	○
Log Vane	○	○	◌	●	◌	○
Log Vane-Root Wad	○	●	◌	●	◌	○
Cross Rock Vane	●	●	◌	●	◌	○
Offset Cross Rock Vane	●	●	◌	●	◌	○
Rock Vane	○	●	◌	○	◌	○
Boulder Wall	◌	●	◌	◌	◌	○
Rock Step Pool with Boulder Toe Revetment	●	●	◌	●	◌	○
Riprap Revetment	◌	●	◌	◌	◌	○
Boulder Toe Revetment	◌	●	●	◌	○	○
Boulder Cascade	●	◌	◌	○	◌	○
Regenerative Step Pool Storm Conveyance	●	●	◌	●	◌	●
Beaver Dam Analog	◌	◌	◌	○	◌	○
Rock and Roll Logs	○	○	◌	●	◌	○
Soil-Filled Riprap Floodplain Bench	◌	●	●	○	○	○

Legend: ● well suited ○ moderately suited ◌ not suited

2.0

In-Stream Structures

2.1 Engineered Riffle

An engineered riffle is a constructed channel facet feature intended to mimic the geomorphic functions of a natural riffle. It is a means of conveying stream flow down gradient via a rock-lined channel segment, and typically used for vertical grade control application.

2.1.1 Components

An engineered riffle consists of the following components:

- A layer of angular rock, formed to the dimensions of the channel, and sized to resist the erosive forces of water being conveyed through the structure.
- A choking layer incorporated into the rock, consisting of salvaged channel bed material, to promote expression of base flow conditions above channel grade.

An engineered riffle may contain the following **optional** components based upon site specific conditions:

- A filter layer created by non-woven geotextile or filter stone to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. The filter layer also allows for fine sediments from upstream to naturally fill in void spaces within the rock or riprap.
- An upstream and/or downstream grade control structure can be incorporated into this structure based upon site conditions to prevent the downstream migration of installed materials.

2.1.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Stream flow conveyance down gradient through relatively straight reaches of stream. Typically used as part of a riffle-pool facet sequence, promoting natural channel formation.	Highly sinuous channels or multi-stem channels (stream types D or Da) may not provide adequate riffle length for appropriate use.
	Typically not conducive to stream types: A, G, F and/or channels exceeding 4% slopes.
Stable starting or ending point of a stream restoration or stabilization project.	Consider hydraulic influences directly upstream or downstream and size rock accordingly.
Method of providing resistance to tractive forces (shear stress and velocity) where infrastructure protection is required. Example includes sewer or other utility crossings (perpendicular to channel).	For utilities located adjacent to and parallel to the channel, consider implementing a streambank stabilization structure in conjunction with the engineered riffle.
If properly sized, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.1.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event. The following Rock Sizing Calculations – provided in the ***General Literature*** section – are recommended for use, but other relationships may be used based upon site specific conditions and/or designer's professional judgement:
    - Shields Entrainment Function
    - Leopold, Wolman, and Miller (1964) Entrainment Function
    - Rosgen (or Regionally Developed) Rock Sizing and Mobility Curves
    - Andrews Methodology
    - Ishbash Equation
  - Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

2.1.4 Notes to Designers

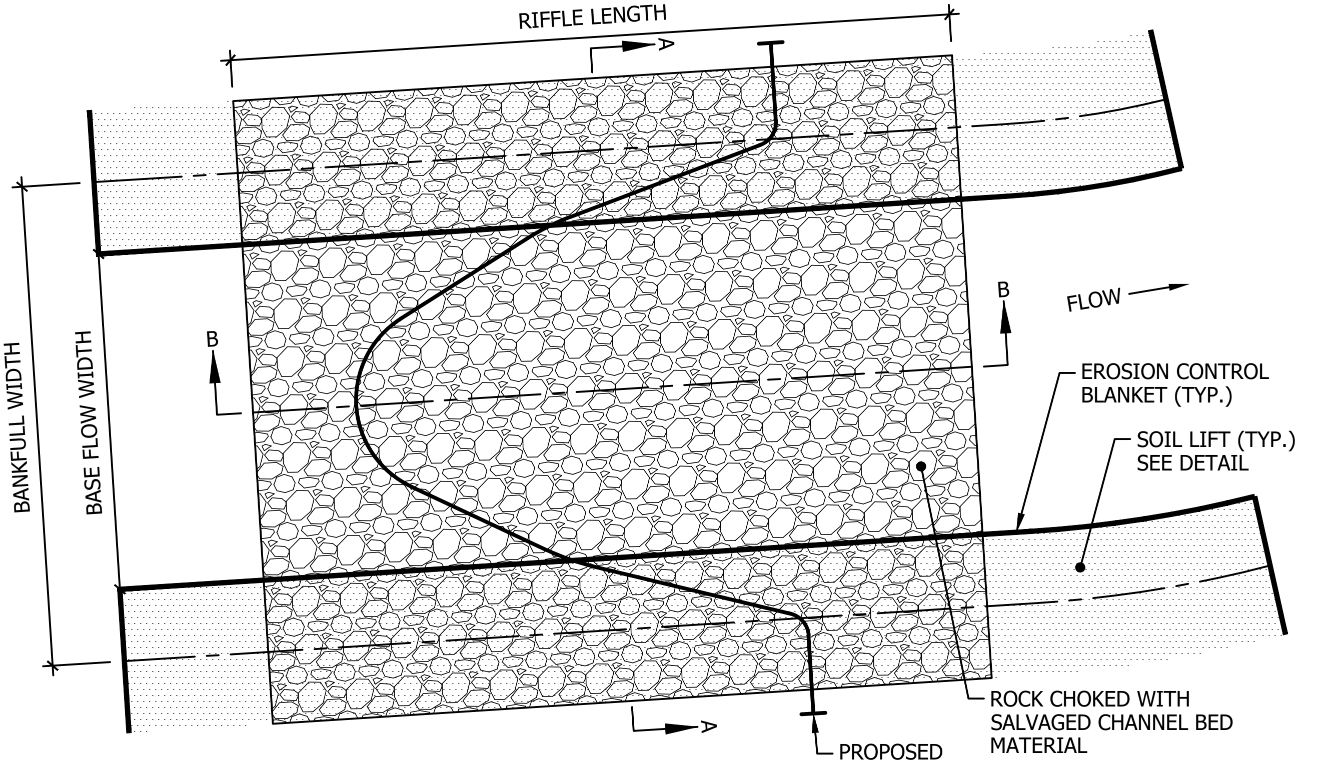
- Non-woven geotextile or filter stone layer between subgrade and structure is optional based upon site specific conditions. Conditions that may warrant non-woven geotextile or filter stone layer include but are not limited to: non-cohesive streambed material (such as sand) or construction of an engineered riffle placed in fill. The designer should consult with their Geotechnical Engineer to determine if an underlayment is necessary.
  - The designer should revise the standard detail and specification to **remove** reference to non-woven geotextile or filter stone if it is not warranted.
- Upstream and/or downstream grade control structures, such as rock/log sills or rock vanes, are optional based upon site specific conditions. Additional grade control structures are typically not required for threshold channel designs since the rock used to construct the engineered riffle should be sized to withstand worst-case geomorphic conditions up to and including the 100-year design storm event.
  - The designer should revise the standard detail and specification to **add** reference to the specific upstream and/or downstream grade control structure details if required.
  - The designer should revise the standard detail and specification to **remove** reference to the upstream and/or downstream grade control structure if it is not warranted.

- The riffle slope should be greater than bankfull slope as determined by reference conditions or utilizing dimensionless ratios developed by Rosgen (or others). Generally, the tail of riffle elevation should be designed to be equal to the next downstream head of riffle elevation.
- Bankfull channel side slopes should be 2(H):1(V) or flatter; and base flow channel side slopes should be 3(H):1(V) or flatter.
- At a minimum, rock used for construction of engineered riffles should be R-4 riprap or larger. The minimum placement thickness of the rock should be at least 2x the D50 of the selected riprap size.
- At a minimum, the rock should be extended 5 feet past the top of bank on both sides of the channel.

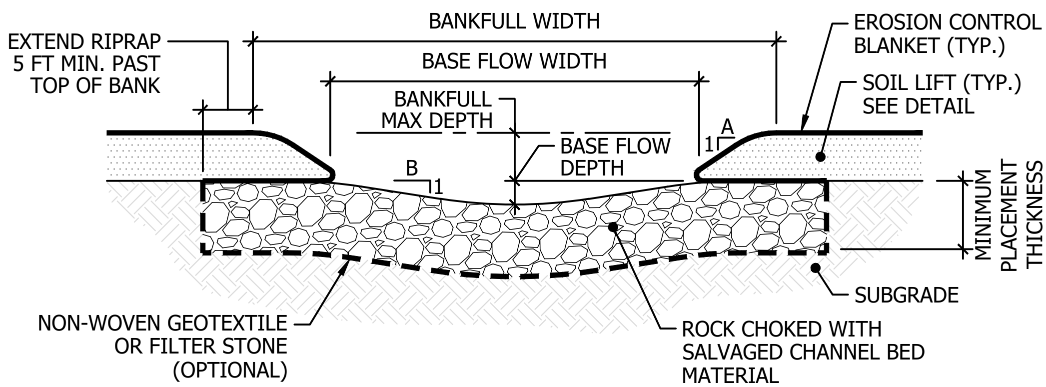
2.1.5 Photographs

Photograph 1: Engineered riffle during construction at West Branch Indian Creek, Philadelphia, PA. Source: PWD.

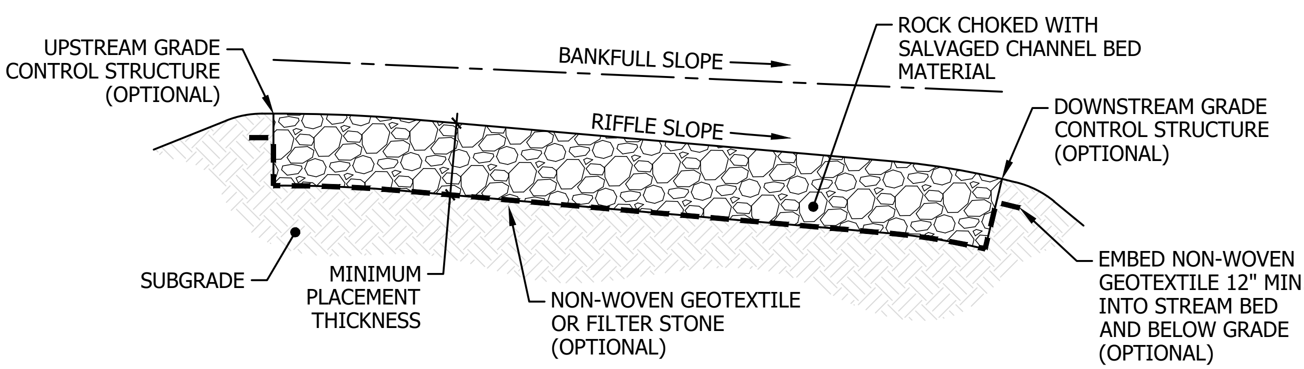
Photograph 2: Engineered riffle following construction at West Branch Indian Creek, Philadelphia, PA. Source: PWD.



PLAN VIEW



SECTION VIEW A-A



PROFILE VIEW B-B

STRUCTURE ID	BANKFULL SLOPE (%)	RIFFLE SLOPE (%)	RIFFLE LENGTH (FT)	BANKFULL WIDTH (FT)	BANKFULL MAX DEPTH (FT)	BANKFULL SIDE SLOPE (A)	BASE FLOW WIDTH (FT)	BASE FLOW DEPTH (FT)	BASE FLOW SIDE SLOPE (B)	ROCK SIZE (R- _)	MINIMUM PLACEMENT THICKNESS (FT)

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

ENGINEERED RIFFLE

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER: S1

2.2 Boulder Terraces

Boulder terraces are a series of low boulder walls used for infrastructure protection, bank protection, and creating a bankfull/floodplain bench for shear stress relief. Boulder terraces provide the ability to maintain appropriate bankfull and base flow channel dimensions within a high-stress or entrenched channel condition.

2.2.1 Components

Boulder terraces consist of the following components:

- Low boulder walls constructed of large, rectangular, blocky rocks that are stackable to create a uniform and stable wall that will resist the erosive forces of channelized stream flow.
- A footer boulder designed to a depth based upon site specific conditions to prevent failure due to long-term bed degradation and/or localized scour.
- Rock toe protection constructed of appropriately sized riprap choked with salvaged channel bed material – and conforming to the footer boulder depth – to resist the tractive forces of channelized stream flow at the interface between the wall and streambed.
- Vegetated terraces consisting of topsoil, seeded and stabilized with erosion control blanket, and planted with live stake plantings or pole plantings.

Boulder terraces may contain the following **optional** components based upon site specific conditions:

- A non-woven geotextile filter layer to prevent soil movement into and through the boulder terraces – which could undermine its footing – while allowing water to freely drain through the structure to avoid failure from freeze/thaw processes and/or the build-up of hydrostatic pressure.
- A key trench constructed of large, rectangular, blocky rocks that are stackable to create a uniform and stable tie-in to existing subgrade based upon site-specific conditions. The key trench is intended to prevent soil movement behind the structure due to the erosive forces of channelized stream flow and/or piping.

2.2.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Method of providing resistance to tractive forces (shear stress and velocity) where streambank stabilization and/or infrastructure protection is required for utilities located adjacent to and parallel to the channel.	For actively incising stream channels and/or utility crossings (perpendicular to channel), consider implementing a streambed vertical grade control structure in conjunction with the boulder terraces.
If properly designed, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.2.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

    Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized boulders for the low boulder walls, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

    The following Rock Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized rock for the rock toe protection but other relationships may be used based upon site specific conditions and/or designer's professional judgement:

    - Shields Entrainment Function
    - Leopold, Wolman, and Miller (1964) Entrainment Function
    - Rosgen (or Regionally Developed) Rock Sizing and Mobility Curves
    - Andrews Methodology
    - Ishbash Equation
  - Footer boulder depth – and corresponding rock toe protection depth – shall be designed to a depth based upon site specific conditions to prevent failure due to long-term bed degradation and/or localized scour.
    - The Federal Highway Administration, Hydraulic Engineering Circular No. 23 Bridge Scour and Stream Instability Countermeasures, Volume 1 Method for Scour at Longitudinal Structures – Scour Depth Calculations provided in the ***General Literature*** section – is recommended for use in determining the localized scour depth, but other methods may be used based upon site specific conditions and/or designer's professional judgement.
  - Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

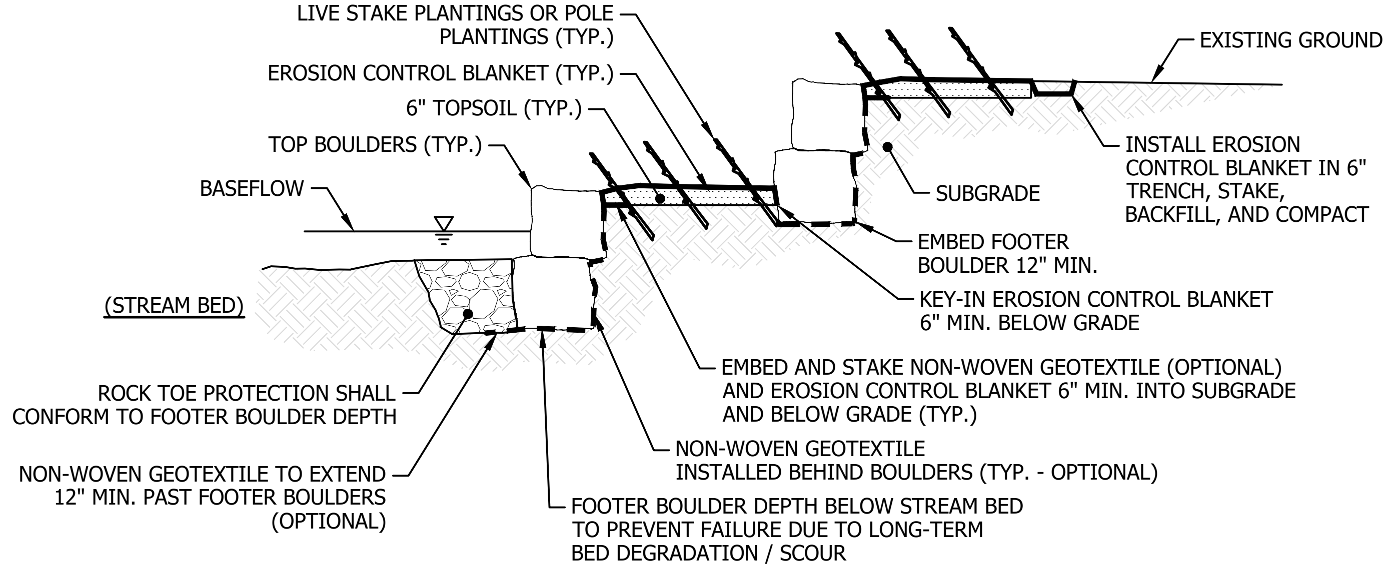
2.2.4 Notes to Designers

- Non-woven geotextile filter layer between subgrade and structure is optional based upon site specific conditions. Conditions that may warrant non-woven geotextile include but are not limited to: non-cohesive bank material (such as sand or gravel) or construction of boulder terraces placed in fill. The designer should consult with their Geotechnical Engineer to determine if non-woven geotextile is necessary.
    - The designer should revise the standard detail and specification to **remove** reference to non-woven geotextile if it is not warranted.
- The length of the longest axis of each rock used to construct the boulder terraces should be the greater of 1/3 the total height of the boulder wall or the size necessary to resist the tractive forces as described under the ***Computations*** section above.
- At a minimum, rock used for construction of rock toe protection should be R-4 riprap or larger. The minimum placement thickness of the rock should be at least 2x the D50 of the selected riprap size or equal to the footing depth, whichever is greater.
- The footer boulder and rock toe protection depths shall be designed to a depth based upon site specific conditions to prevent failure due to long-term bed degradation and/or localized scour as described under the ***Computations*** section above.
    - The designer should revise the standard detail and specification to **add** reference to the site-specific footing depth.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

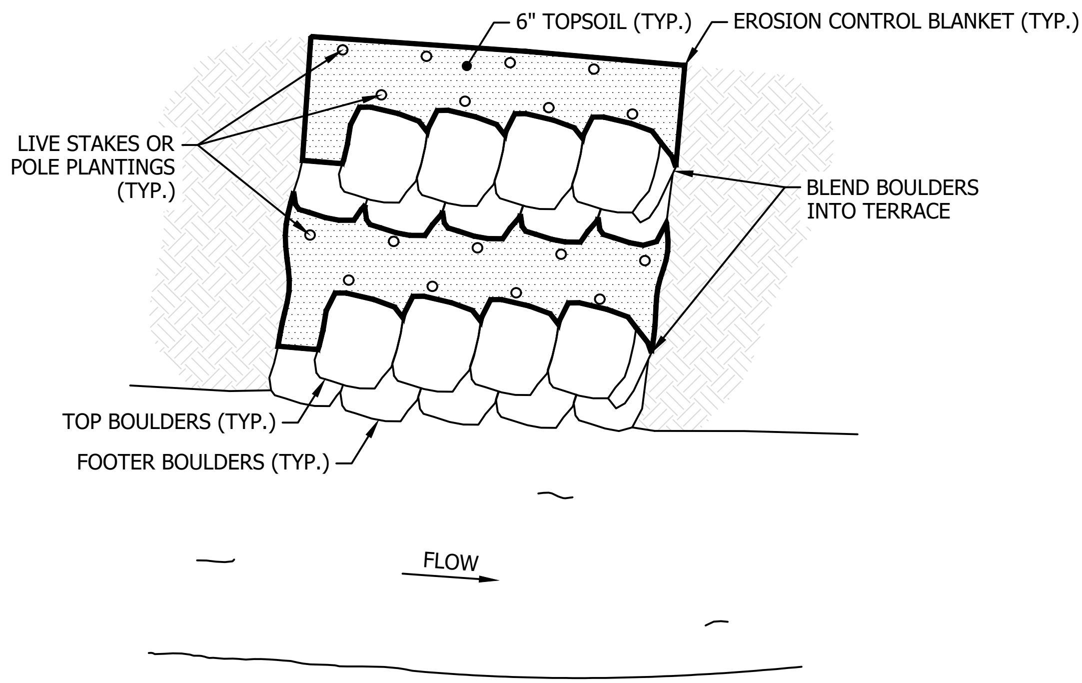
2.2.5 Photographs

Photograph 1: Boulder terraces during construction at Paul's Run, Philadelphia, PA. Source: PWD.

Photograph 2: Boulder terraces following construction at Paul's Run, Philadelphia, PA. Source: PWD.

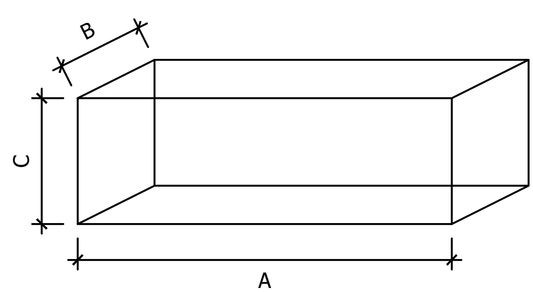


SECTION VIEW



PLAN VIEW

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



BOULDER SIZING DETAIL

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

BOULDER TERRACES

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER: S2

2.3 Bendway Weir

A bendway weir is a barb or spur of rock intended to redirect flows away from the streambank on the outside of a bend. The structure extends linearly from the outside of a bank – either perpendicular to flow or angled slightly upstream – with the top of the weir set at the base flow elevation and is intended to redirect flows using weir hydraulics during overtopping conditions.

2.3.1 Components

A bendway weir consists of the following components:

- A rock weir constructed of appropriately sized riprap to resist the tractive forces of channelized stream flow during overtopping flow conditions.
- A soil lift to reconstruct the bankfull/floodplain bench over the keyed-in rock weir.

A bendway weir may contain the following **optional** components based upon site specific conditions:

- A filter layer created by non-woven geotextile or filter stone to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through.

2.3.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Most suitable for installation on meander bends.	Do not perform well in actively degrading or sediment deficient reaches.
Most suitable for larger riverine systems.	On smaller streams flow constriction may cause erosion of the opposite bank.
If properly designed, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.3.3 Computations

- Bendway weirs may be designed utilizing Design Guideline 1: Bendway Weirs/Stream Barbs from the Federal Highway Administration, Hydraulic Engineering Circular No. 23 Bridge Scour and Stream Instability Countermeasures, Volume 2 or other similar guidelines based upon site specific conditions and/or designer's professional judgement.
- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event. The following Rock Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in

determining properly sized rock for the bendway weir, but other relationships may be used based upon site specific conditions and/or designer's professional judgement:

- Shields' Entrainment Function
- Leopold, Wolman, and Miller (1964) Entrainment Function
- Rosgen (or Regionally Developed) Rock Sizing and Mobility Curves
- Andrews Methodology
- Ishbash Equation

- Consideration should be given to turbulent flow conditions for final rock sizing, which is typically 20% or greater than that computed from non-turbulent flow conditions.
- Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.

- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

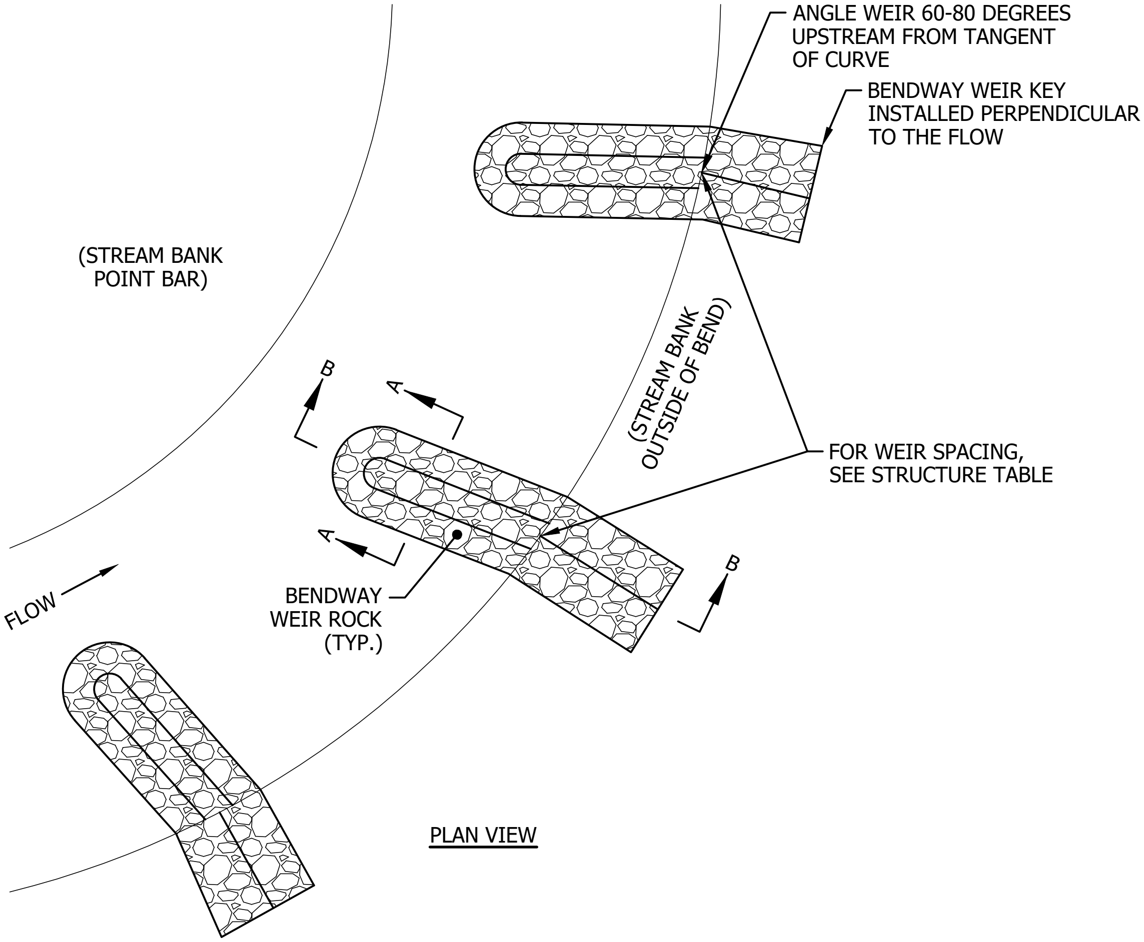
2.3.4 Notes to Designers

- Non-woven geotextile or filter stone layer between subgrade and structure is optional based upon site specific conditions. Conditions that may warrant non-woven geotextile or filter stone layer include but are not limited to: non-cohesive streambed material (such as sand) or construction of a bendway weir placed in fill. The designer should consult with their Geotechnical Engineer to determine if an underlayment is necessary.
  - The designer should revise the standard detail and specification to **remove** reference to non-woven geotextile or filter stone if it is not warranted.
- Additional streambank protection measures, such as boulder walls/boulder toe revetment or riprap revetment, should be considered for installation between bendway weirs based upon site specific conditions. Additional in-stream structures may not be required where bankfull/floodplain benches can be constructed between weirs.
- At a minimum, rock used for construction of bendway weirs should be R-6 riprap or larger. The minimum placement thickness of the rock should be at least 2x the D50 of the selected riprap size or equal to the long-term bed degradation/scour depth, whichever is greater.
- At a minimum, the bendway weir key should be extended 2 feet under the soil lift.

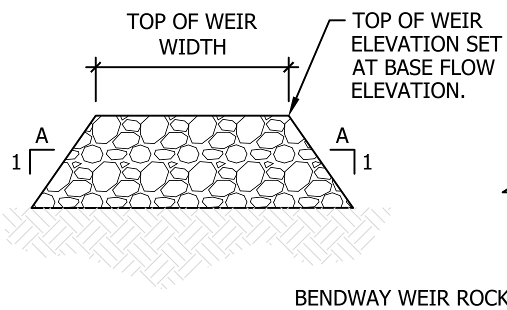
2.3.5 Photographs

Photograph 1: Bendway weir during construction at Whitaker Avenue, Philadelphia, PA. Source: PWD.

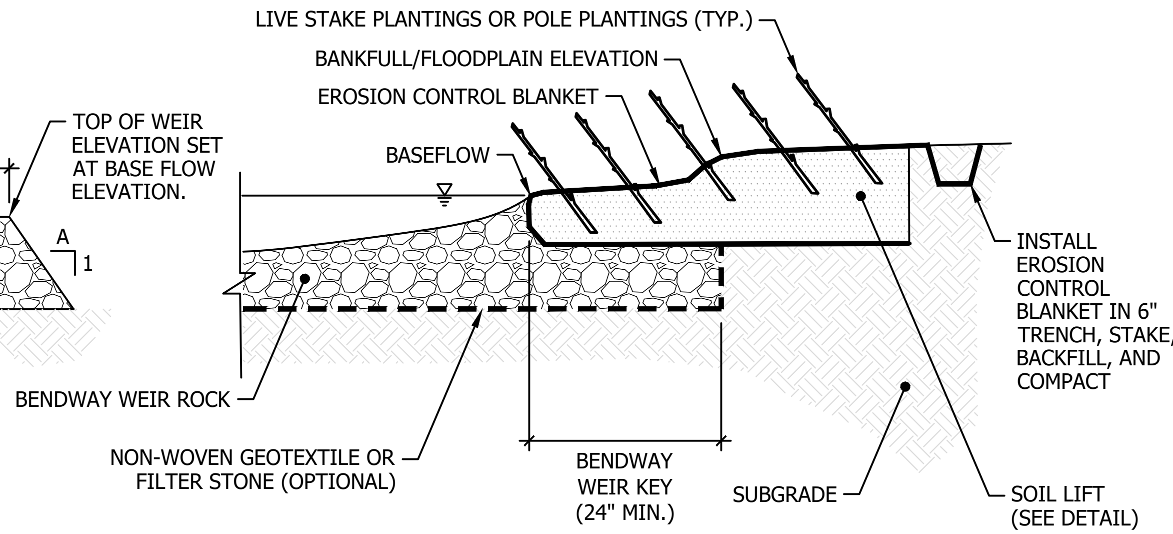
Photograph 2: Bendway weir following construction at Whitaker Avenue, Philadelphia, PA. Source: PWD.



PLAN VIEW



SECTION VIEW A-A



SECTION VIEW B-B

STRUCTURE ID	WEIR SPACING (FT)	TOP OF WEIR ELEVATION (FT)	TOP OF WEIR WIDTH (FT)	WEIR SIDE SLOPE (A)	ROCK SIZE (R-_)

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

BENDWAY WEIR

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S3

2.4 Erosion Control Blanket

Erosion control blanket is a biodegradable and heavy-weight matting intended for use as a long-term temporary erosion and sediment control measure for stabilizing streambanks, bankfull/floodplain benches, and side slopes. These areas may experience stream and flood flows – during and immediately after construction – until permanent vegetation is established.

2.4.1 Components

Erosion control blanket consists of the following components:

- A machine-produced mat of wood fibers, wood excelsior, or other biodegradable natural fibers.
- Wood stakes for securing and anchoring erosion control blanket to the seeded soil surface beneath.

2.4.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Most suitable for installation on freshly graded streambanks, bankfull/floodplain benches, and side slopes where shear stress typically does not exceed 3 – 5 lb/sf or the manufacturer specified maximum permissible velocity and shear stress values for the specific product used.	Not recommended for use on slopes exceeding 2(H):1(V) or the manufacturer specified maximum slopes for the specific product used.
If properly designed, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.4.3 Computations

- Erosion control blanket shall be designed according to the manufacturer's specified maximum permissible velocity, shear stress, and slope values for the specific product used.
- Calculations for the maximum permissible velocity and shear stress are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations for open channel flow using Manning's Equation are recommended for use in determining velocity and shear stress for worst-case geomorphic conditions up to and including the 100-year design storm event.
  - Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.

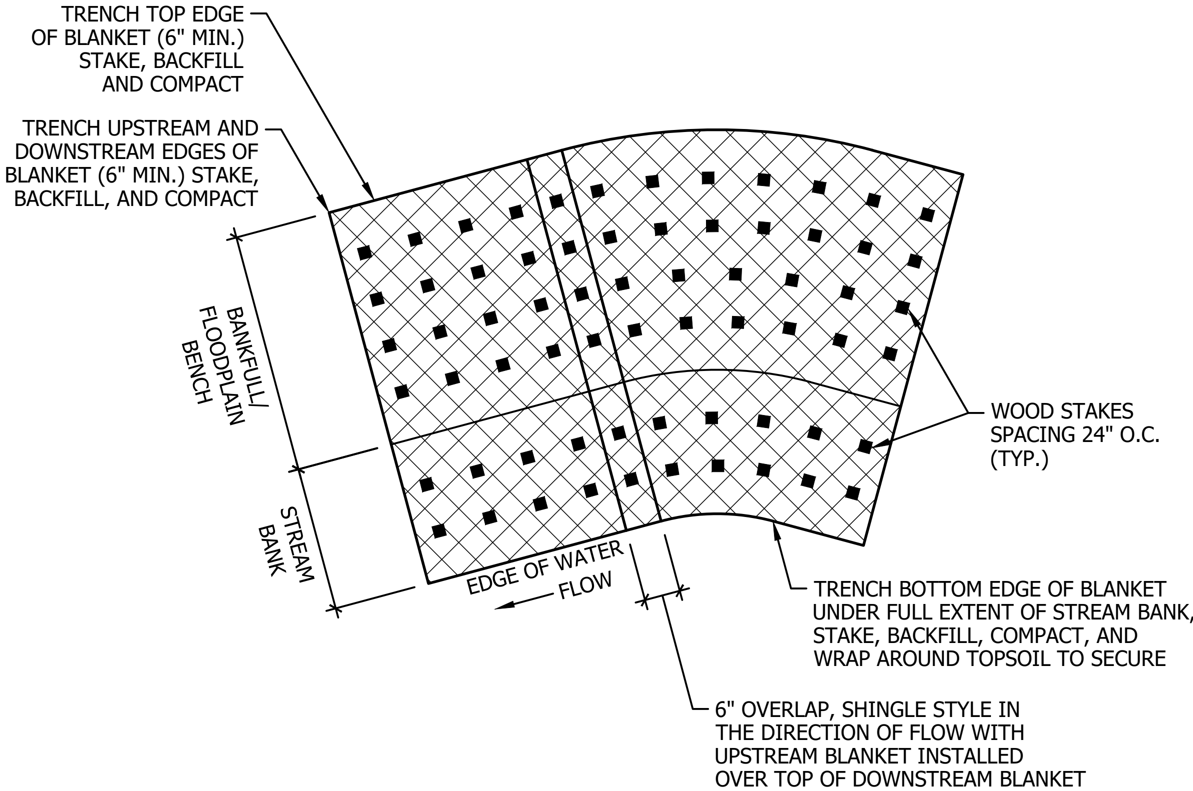
2.4.4 Notes to Designers

- Wood stake spacing for side slope installation shall be based upon the manufacturer's recommendations for the specific product used and the slope at which the erosion control blanket is being installed. Wood stake spacing for stream bank installation is recommended to be 2 feet on-center. At a maximum, wood stakes shall be spaced no further than 4 feet on-center.
    - The designer should revise the standard detail and specification to **add** reference to the specific wood stake spacing required.

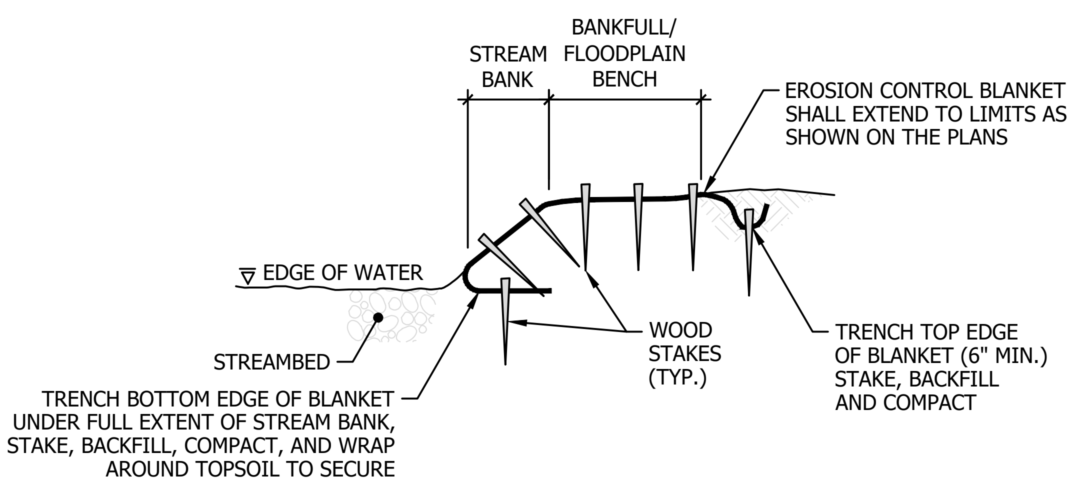
2.4.5 Photographs

Photograph 1: Erosion control blanket during construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.

Photograph 2: Erosion control blanket following construction at Bear Branch, Anne Arundel County, MD. Source: JMT.



STREAM BANK INSTALLATION (PLAN VIEW)



STREAM BANK INSTALLATION (SECTION VIEW)

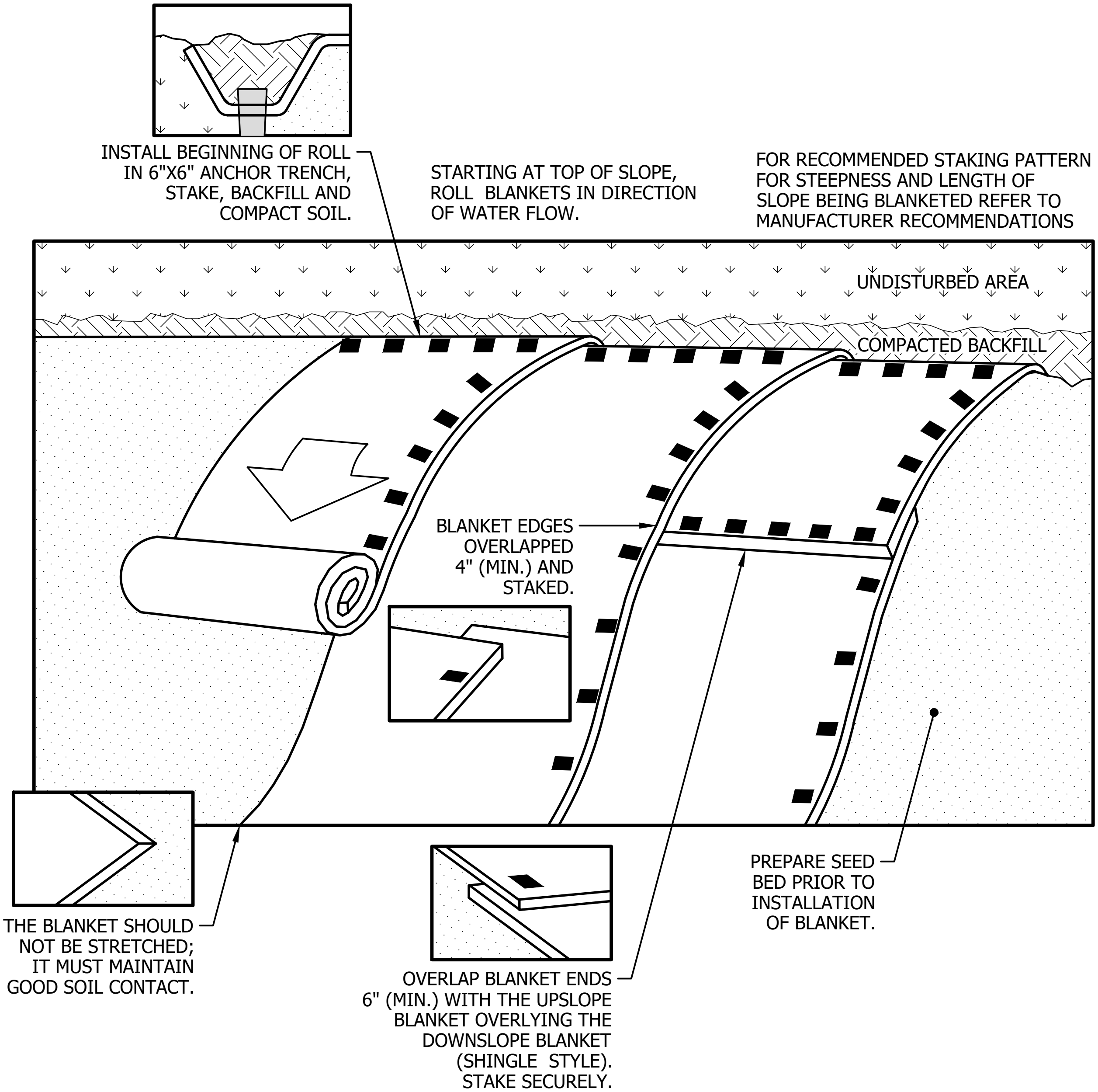
PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

EROSION CONTROL BLANKET FOR STREAM BANKS

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S4.1



SIDE SLOPES INSTALLATION (ISOMETRIC VIEW)

PHILADELPHIA WATER DEPARTMENT

1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

EROSION CONTROL BLANKET FOR SIDE SLOPES

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S4.2

2.5 Live Stake Plantings

Live stakes are live, dormant plant cuttings of selected native species of shrub/tree material. They are self-rooting when planted in moist soils and provide more robust vegetative stability and rooting structure for constructed streambanks, bankfull/floodplain benches, and other channel/floodplain/wetland areas with higher energy flow conditions.

They differ from pole plantings in that they are typically smaller cuttings that grow more robustly than the older/larger poles. Live stakes are typically no less than 3 feet long with diameters up to 1.5 inches. Live stake plantings should be selected over pole plantings for areas requiring shallower planting depths in order to provide groundwater connectivity.

2.5.1 Components

Live stake plantings consist of the following components:

- Cut, dormant branches of selected native species of shrub/tree material. The term "dormant" used here is to describe live cuttings taken in the late fall to early spring (approximately November 1 to April 15) after the trees have lost their leaves or before their buds emerge.

2.5.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Most suitable for installation on freshly graded streambanks, bankfull/floodplain benches, and other channel/floodplain/wetland areas where velocity and shear stress typically do not exceed 10 ft/s and 3 lb/sf, respectively.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.
Complimentary to other stabilization practices, such as soil lifts and erosion control blanket, and associated in-stream structures.	Highest chance of survival when installed in areas which have groundwater connectivity to keep them moist.

2.5.3 Computations

- Not Applicable.

2.5.4 Notes to Designers

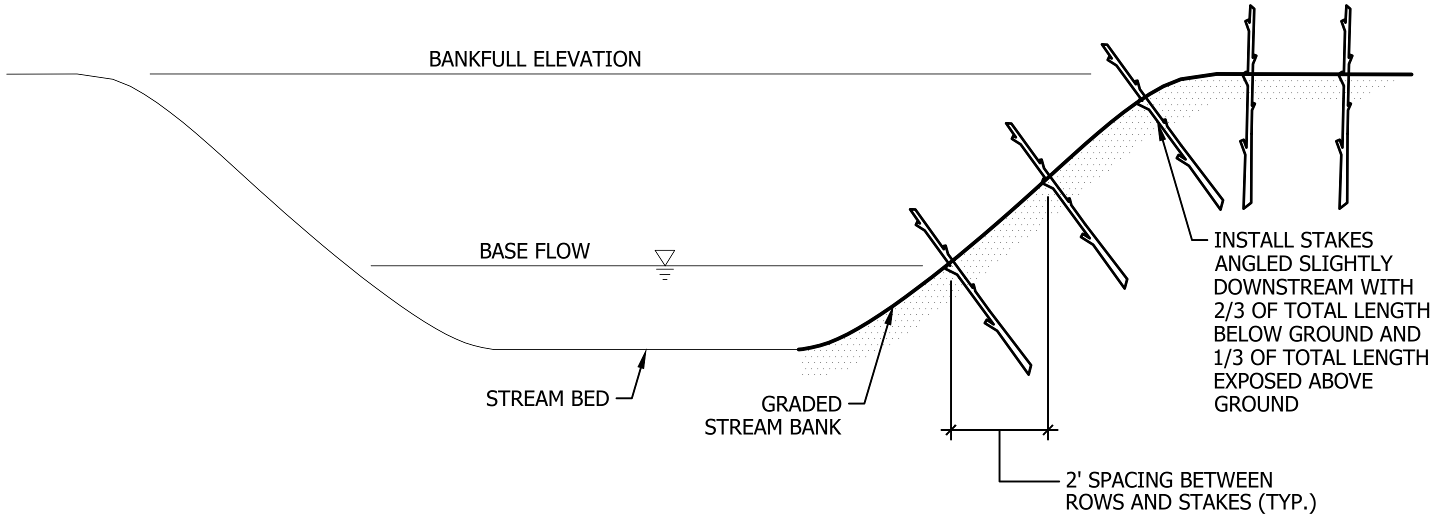
- Live stake length shall be based upon site specific conditions to ensure that installed plantings have groundwater connectivity to keep them moist.
    - The designer should revise the standard detail and specification to **add** reference to the specific live stake length.

- The following native species are recommended by Philadelphia Parks and Recreation for live stakes:
    - Salix nigra – Black Willow
    - Salix discolor – Pussy Willow
    - Salix interior – Sandbar Willow
    - Cornus sericea – Red-osier Dogwood
    - Cornus racemose – Gray Dogwood
    - Cornus amomum – Silky Dogwood
    - Plantanus occidentalis – American Sycamore
    - Sambucus canadensis – Elderberry
    - Alnus incana – Speckled Alder
    - Physocarpus opulifolius – Ninebark
    - Cephalanthus occidentalis – Buttonbush
    - Lindera benzoin – Spicebush
    - Viburnum dentatum – Arrowwood Virburnum

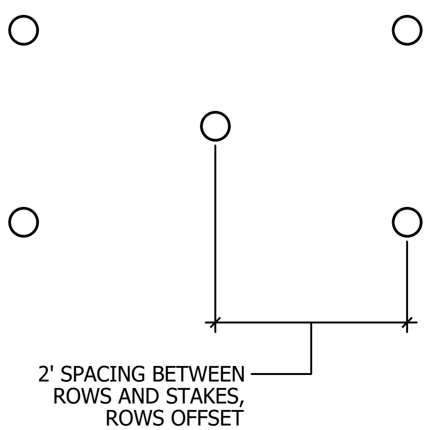
2.5.5 Photographs

Photograph 1: Live stake plantings during construction. Source: JMT.

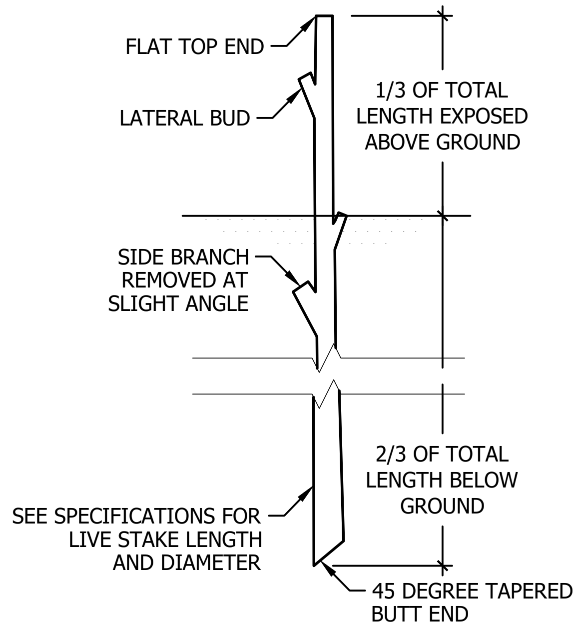
Photograph 2: Live stake plantings following construction at Kitten Branch, Anne Arundel County, MD. Source: JMT.



STREAM BANK INSTALLATION (SECTION VIEW)



LIVE STAKE LAYOUT



LIVE STAKE DETAIL

NOTE

1. SEE CONTRACT SPECIFICATIONS FOR THE MINIMUM NUMBER OF SPECIES TO BE RANDOMLY DISTRIBUTED WITHIN EACH PLANTING ZONE TO PROMOTE BIODIVERSITY.

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LIVE STAKE PLANTINGS

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S5

2.6 Pole Plantings

Pole plantings are live, dormant plant cuttings of selected native species of shrub/tree material. They are self-rooting when planted in moist soils and provide more robust vegetative stability and rooting structure for constructed streambanks, bankfull/floodplain benches, and other channel/floodplain/wetland areas with higher energy flow conditions.

They differ from live stakes in that they are typically larger, more woody species, which provide more rigid structure during plant establishment than the smaller live stake plantings. Pole plantings are typically 4 to 8 feet long with diameters up to 10 inches. Pole plantings should be selected over live stakes for areas requiring deeper planting depths in order to provide groundwater connectivity.

2.6.1 Components

Pole plantings consists of the following components:

- Cut, dormant branches of selected native species of shrub/tree material. The term "dormant" used here is to describe live cuttings taken in the late fall to early spring (approximately November 1 to April 15) after the trees have lost their leaves or before their buds emerge.

2.6.2 Effective Uses and Limitations

<table>
<tr><th>EFFECTIVE USES</th><th>LIMITATIONS</th></tr>
<tr><td>Most suitable for installation on freshly graded streambanks, bankfull/floodplain benches, and other channel/floodplain/wetland areas where velocity and shear stress typically do not exceed 10 ft/s and 3 lb/sf, respectively.</td><td rowspan="2">Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.</td></tr>
<tr><td>May be installed in void spaces of soil-filled riprap or other riprap areas where soil has been filtered into the voids for higher energy flow conditions.</td></tr>
<tr><td>Complimentary to other stabilization practices, such as soil lifts and erosion control blanket, and associated in-stream structures.</td><td>Most effective when installed in areas which have groundwater connectivity to keep them moist.</td></tr>
</table>

2.6.3 Computations

- Not Applicable.

2.6.4 Notes to Designers

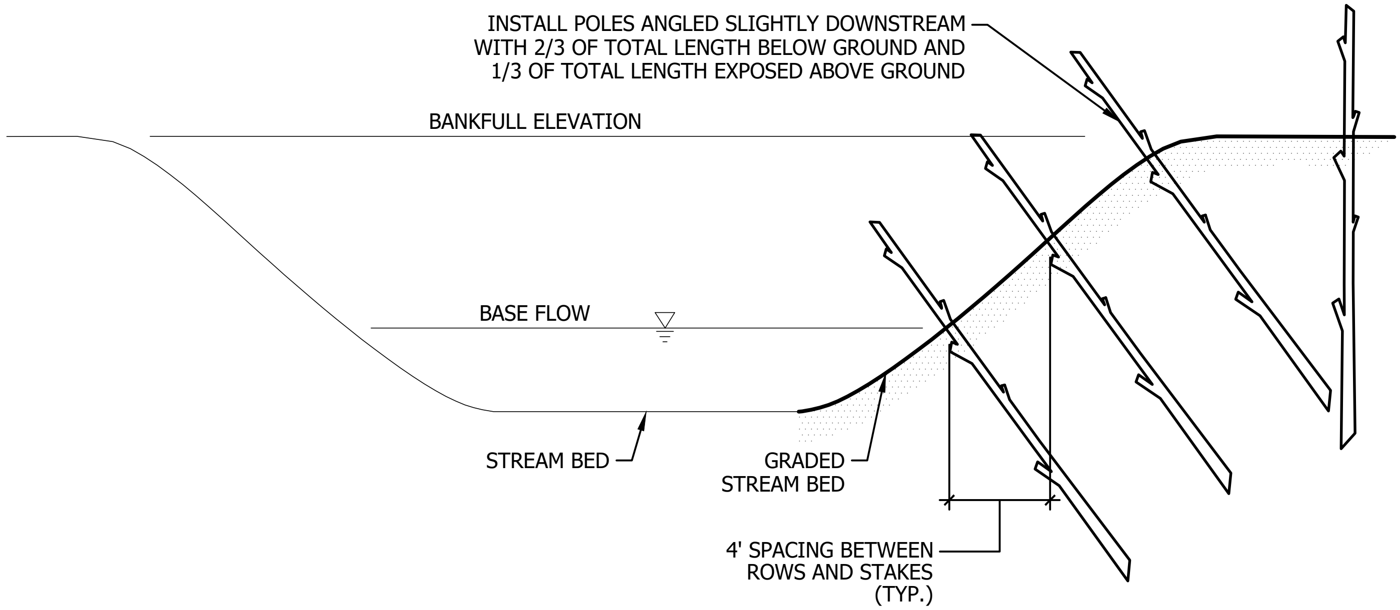
- Pole length shall be based upon site specific conditions to ensure that installed plantings have groundwater connectivity to keep them moist. At a minimum, pole plantings shall be 4 feet in length.
    - The designer should revise the standard detail and specification to **add** reference to the specific pole length.

- The following native species are recommended by Philadelphia Parks and Recreation for pole plantings:
    - Salix nigra – Black Willow
    - Salix discolor – Pussy Willow
    - Salix interior – Sandbar Willow
    - Cornus sericea – Red-osier Dogwood
    - Cornus racemose – Gray Dogwood
    - Cornus amomum – Silky Dogwood
    - Plantanus occidentalis – American Sycamore
    - Sambucus canadensis – Elderberry
    - Alnus incana – Speckled Alder
    - Physocarpus opulifolius – Ninebark
    - Cephalanthus occidentalis – Buttonbush
    - Lindera benzoin – Spicebush
    - Viburnum dentatum – Arrowwood Virburnum

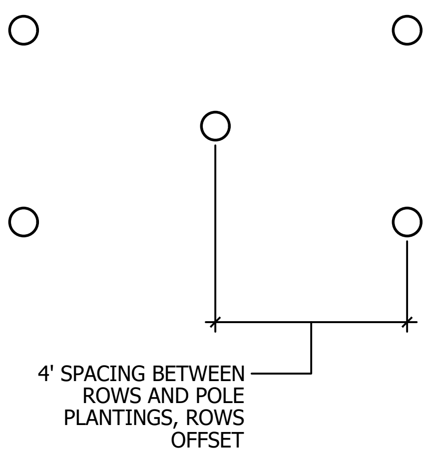
2.6.5 Photographs

Photograph 1: Pole planting during construction. Source: JMT.

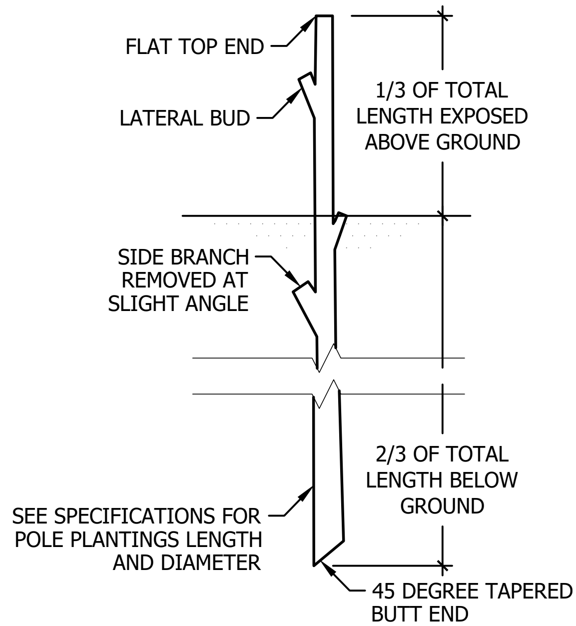
Photograph 2: Pole plantings following construction at Kitten Branch, Anne Arundel County, MD. Source: JMT.



STREAM BANK INSTALLATION (SECTION VIEW)



POLE LAYOUT



POLE DETAIL

NOTE

1. SEE CONTRACT SPECIFICATIONS FOR THE MINIMUM NUMBER OF SPECIES TO BE RANDOMLY DISTRIBUTED WITHIN EACH PLANTING ZONE TO PROMOTE BIODIVERSITY.

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1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

POLE PLANTINGS

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER: S6

2.7 Soil Lifts

Soil lifts are a bioengineering practice used to create stable, vegetated earthen fill slopes that are subject to frequent flow conditions within stream channels and bankfull/floodplain bench areas. Erosion control blanket is wrapped around lifts of soil, which are seeded and planted with live stakes and/or pole plantings to create a dense, erosion resistant soil/root mass.

2.7.1 Components

Soil lifts consist of the following components:

- Furnished or salvaged topsoil, seeded and wrapped in erosion control blanket, and planted with live stakes or pole plantings.
- Wood stakes for securing and anchoring erosion control blanket to the seeded soil surface beneath.

Soil lifts may contain the following **optional** components based upon site specific conditions:

- Additional toe protection structures (i.e., boulder toe revetment, riprap revetment) may be used in conjunction with soil lifts as needed based upon site specific conditions.
- Reinforced soil lifts utilizing turf reinforcement mat (or similar) may be used in lieu of erosion control blanket for slopes steeper than 2(H):1(V), if required and based upon site specific conditions.

2.7.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Most suitable for installation on freshly graded streambanks, bankfull/floodplain benches, and side slopes where shear stress typically does not exceed 3 – 5 lb/sf or the manufacturer specified maximum permissible velocity and shear stress values for the erosion control blanket used.	Not recommended for use on slopes exceeding 2(H):1(V). Reinforced soil lifts may be used for steeper slopes, if necessary.
If properly designed, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.7.3 Computations

- Soil lifts shall be designed for temporary and permanent stabilization conditions according to the ***Computations*** section for **Erosion Control Blanket**. The designer should consult with their Geotechnical Engineer to determine if soil lifts are appropriate for site conditions.

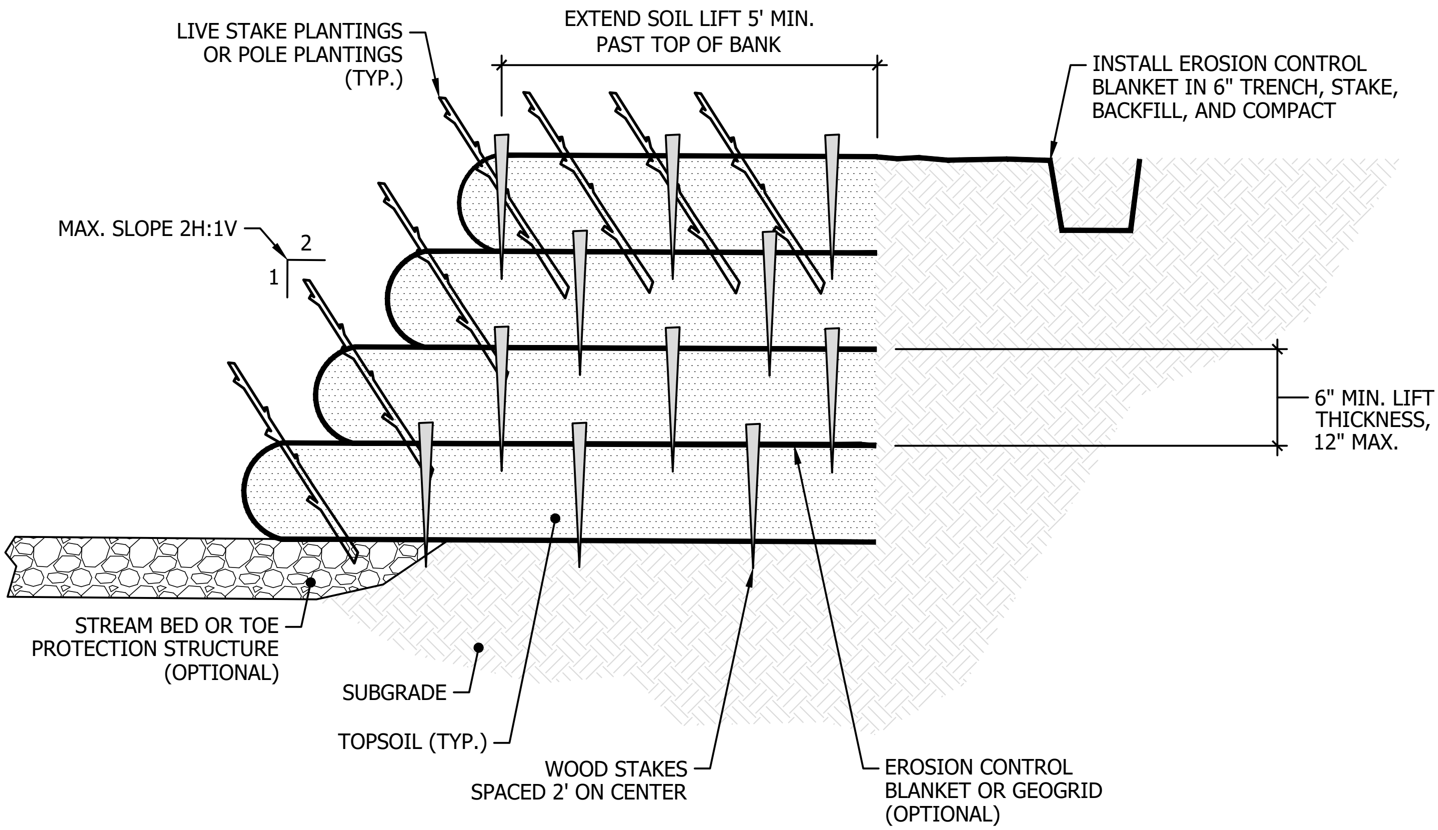
2.7.4 Notes to Designers

- Additional toe protection structures (i.e., boulder toe revetment, riprap revetment) may be used in conjunction with soil lifts as needed based upon site specific conditions. The designer should consult with their Geotechnical Engineer to determine if additional toe protection is necessary.
    - The designer should revise the standard detail and specification to **add** reference to the specific toe protection structure required.
- Reinforced soil lifts utilizing turf reinforcement mat (or similar) may be used in lieu of erosion control blanket for slopes steeper than 2(H):1(V), if required and based upon site specific conditions. The designer should consult with their Geotechnical Engineer to determine if reinforced soil lifts are appropriate for site conditions.
    - The designer should revise the standard detail and specification to **add** reference to the specific reinforced soil lift product and **remove** reference to erosion control blanket.
- Each lift shall have a minimum thickness of 6 inches and maximum thickness of 12 inches.
- At a minimum, the soil lifts should be extended 5 feet past the top of bank.

2.7.5 Photographs

Photograph 1: Soil lifts during construction at Gorgas Run, Philadelphia, PA. Source: PWD.

Photograph 2: Soil lifts following construction at Gorgas Run, Philadelphia, PA. Source: PWD.



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1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

SOIL LIFTS

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER:

S7

2.8 Preformed Scour Hole

A preformed scour hole is an excavated depression lined with rock constructed at the outlet of a pipe or culvert to provide energy dissipation and prevent localized scour at the outfall. Preformed scour holes can also be used at the transition from an existing high-energy entrenched stream channel condition to a proposed low-energy bankfull channel condition with a restored floodplain or bankfull bench.

2.8.1 Components

A preformed scour hole consists of the following components:

- A layer of angular rock, formed to the dimensions of the depression, and sized to resist the erosive forces of water exiting the structure.

A preformed scour hole may contain the following **optional** components based upon site specific conditions:

- A filter layer created by non-woven geotextile or filter stone to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. The filter layer also allows for fine sediments from the outfall to naturally fill in void spaces within the rock.

2.8.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Method of providing rapid energy dissipation for water exiting a pipe or culvert within the stream channel and/or providing a stable starting point for conveyance of flows from outfalls to the restored or stabilized channel.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.
Stable starting point of a stream restoration or stabilization project.	

2.8.3 Computations

- Calculations for the preformed scour hole dimensions and minimum required size of rock are based on the following guidelines:
    - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
    - Hydraulic calculations utilizing the empirical relationships for Preformed Scour Hole Calculations – provided in the ***General Literature*** section – are recommended for use in determining preformed scour hole dimensions and properly sized rock to resist the outfall forces, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.
        - If the rock size is too large according to the calculations for a Type 1 Preformed Scour Hole, the designer may consider a Type 2 Preformed Scour Hole.

- Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.

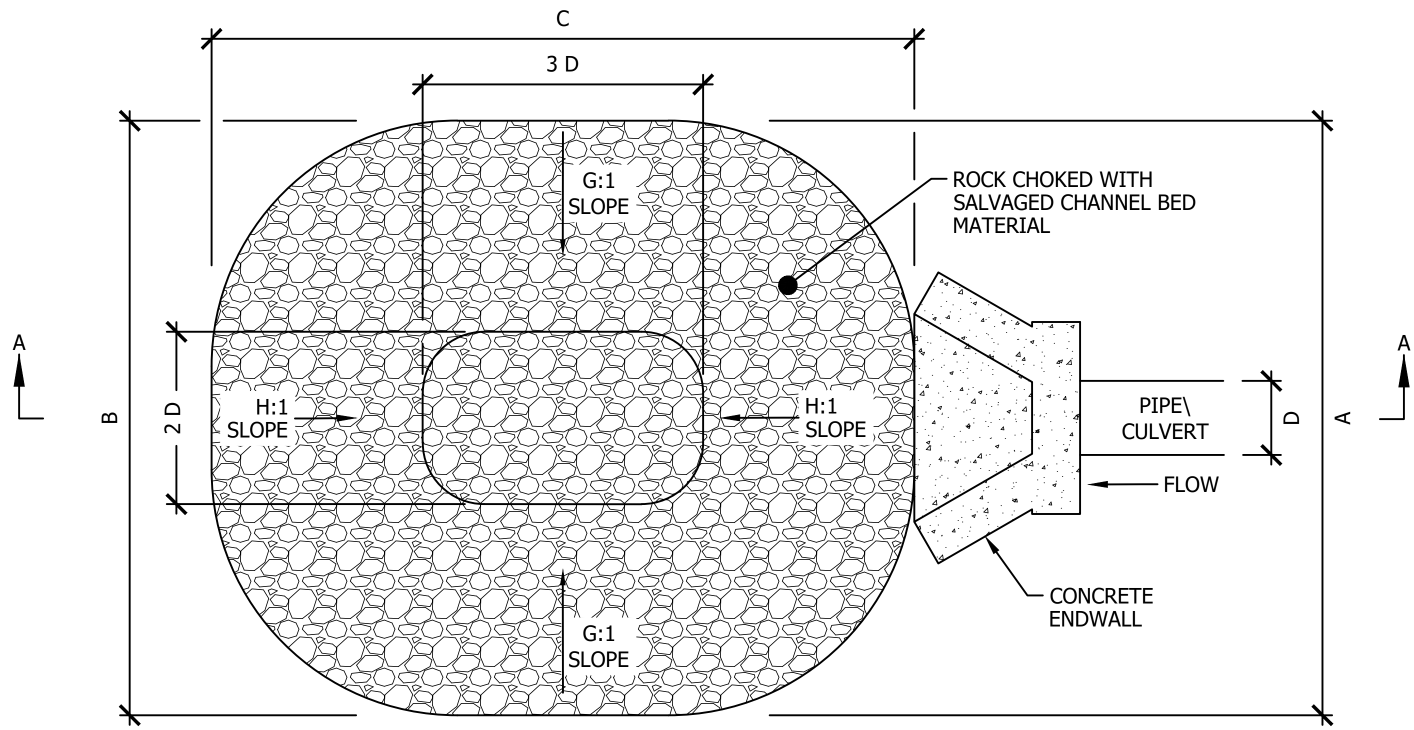
2.8.4 Notes to Designers

- Non-woven geotextile or filter stone layer between subgrade and structure is optional based upon site specific conditions. Conditions that may warrant non-woven geotextile or filter stone layer include but are not limited to: non-cohesive streambed material (such as sand) or construction of a preformed scour hole placed in fill. The designer should consult with their Geotechnical Engineer to determine if an underlayment is necessary.
  - The designer should revise the standard detail and specification to **remove** reference to non-woven geotextile or filter stone if it is not warranted.
- At a minimum, rock used for construction of preformed scour holes should be R-5 riprap or larger. The minimum placement thickness of the rock should be at least 2x the D50 of the selected riprap size.

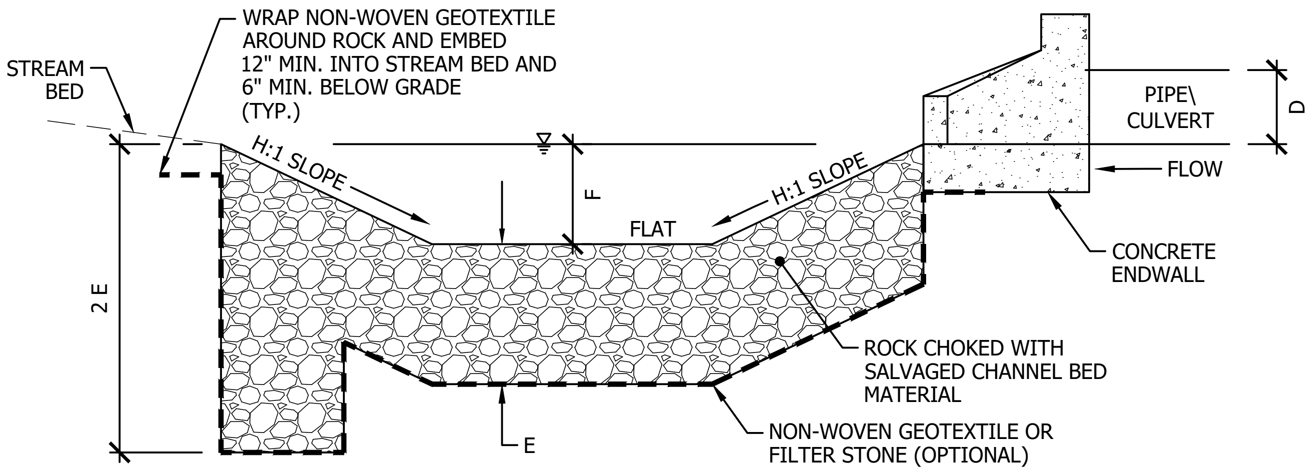
2.8.5 Photographs

Photograph 1: Preformed scour hole during construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.

Photograph 2: Preformed scour hole following construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.



PLAN VIEW



SECTION VIEW A-A

STRUCTURE ID	A (FT)	B (FT)	C (FT)	D (FT)	E (FT)	F (FT)	G	H	ROCK SIZE (R-_)

PHILADELPHIA WATER DEPARTMENT
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PHILADELPHIA, PA, 19107

PREFORMED SCOUR HOLE

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S8

2.9 In-Stream Log Sill

An in-stream log sill is the installation of logs – harvested from the trunks of trees removed within the permitted limit of disturbance – within the stream channel to provide vertical grade control. The log is buried within the stream channel and the top of the structure set flush with the existing or proposed streambed elevation. Log sills are a natural, semi-permanent grade control solution created from the repurposing of a renewable resource.

An in-stream log sill can be used in conjunction with floodplain log sills to provide immediate vertical grade control to both the stream channel and adjacent bankfull/floodplain bench.

2.9.1 Components

An in-stream log sill consists of the following components:

- Logs, harvested from the trunks of trees, that are trimmed to be smooth and free of branches and/or roots.
- Soil lifts to restore the stream channel and bankfull/floodplain bench above the buried log structure.

An in-stream log sill may contain the following **optional** components based upon site specific conditions:

- A filter layer created by non-woven geotextile anchored to the upstream end of the log sill to prevent subgrade soil migration and pumping of fine sediments through the structure, while still allowing water to freely drain through.
- Boulders – or other anchoring components based upon the designer's professional judgement – may be used where buoyancy calculations require additional resisting forces.

2.9.2 Effective Uses and Limitations

<table>
<tr><th>EFFECTIVE USES</th><th>LIMITATIONS</th></tr>
<tr><td>Method of providing vertical grade control within the stream channel using natural materials most effective in low gradient stream systems.</td><td rowspan="2">Can be used as vertical grade control in higher gradient stream systems accompanied by anchor stones.</td></tr>
<tr><td>Footer logs may be used to provide protection for a greater vertical depth near bridge/culvert structures or other areas that may be prone to severe bed scour.</td></tr>
<tr><td>Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.</td><td>Not recommended for installation in severely eroded and incised stream conditions.</td></tr>
</table>

2.9.3 Computations

- Calculations for the minimum required size of logs are based on the following guidelines:
  - Buoyancy Calculations – provided in the ***General Literature*** section – are recommended for use in determining minimum required log dimensions to resist the uplifting forces of stream flow, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

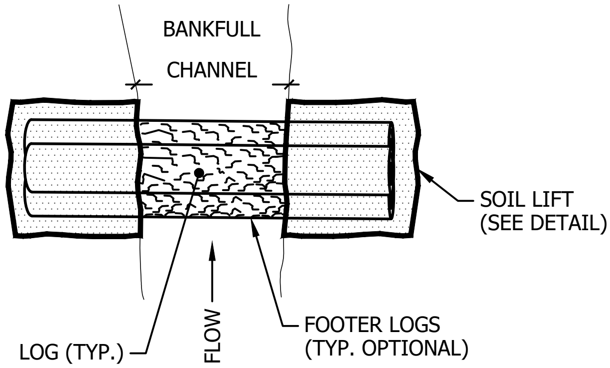
2.9.4 Notes to Designers

- Non-woven geotextile anchored to the upstream end of the structure is optional based upon site specific conditions. Conditions that may warrant non-woven geotextile include but are not limited to: non-cohesive streambed material (such as sand) or construction of a streambed underlayment (rock lining) with a placement depth that extends below the bottom of the log sill structure. The designer should consult with their Geotechnical Engineer to determine if non-woven geotextile is necessary.
  - The designer should revise the standard detail and specification to **remove** reference to non-woven geotextile if it is not warranted.
- Footer logs are optional based upon site specific conditions. Conditions that may warrant footer logs include but are not limited to: non-cohesive streambed material (such as sand) and/or areas that may be prone to severe bed scour (i.e., contraction/expansion zones up and downstream of bridges or culverts). The use of footer logs protects the streambed for a greater vertical distance.
  - The designer should revise the standard detail and specification to **remove** reference to footer logs if they are not warranted.
- Boulders – or other anchoring components based upon the designer's professional judgement – may be used where buoyancy calculations require additional resisting forces.
  - The designer should revise the standard detail and specification to **add** reference to the specific anchoring components to be used if necessary.
- At a minimum, the in-stream log sill should be extended 5 feet past the top of bank on both sides of the channel.

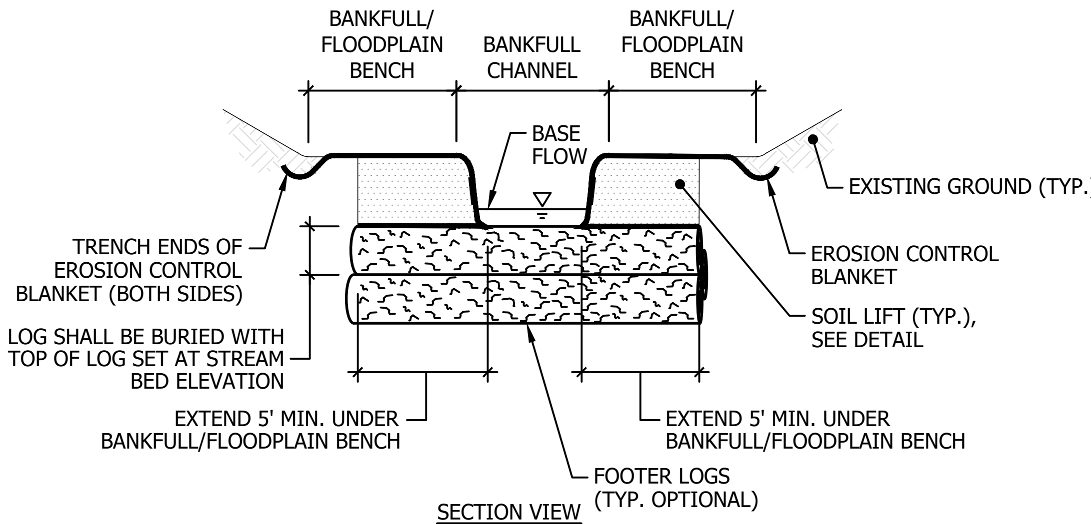
2.9.5 Photographs

Photograph 1: In-stream log sill during construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.

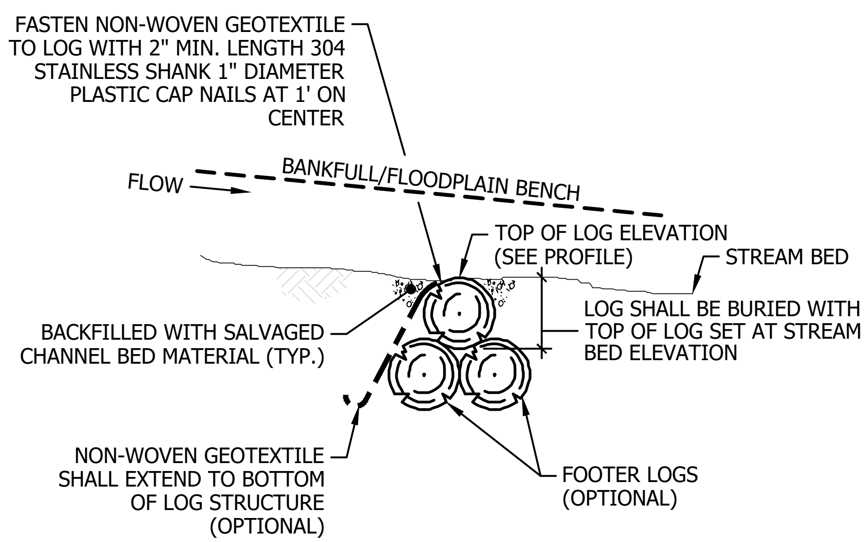
Photograph 2: In-stream log sill following construction at Little Catoctin Creek, Frederick County, MD. Source: JMT.



PLAN VIEW



SECTION VIEW



PROFILE VIEW

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

IN-STREAM LOG SILL

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S9

2.10 Floodplain Log Sill

A floodplain log sill is the installation of logs – harvested from the trunks of trees removed within the approved project site limit of disturbance – within the bankfull/floodplain bench area adjacent to the stream channel to provide vertical grade control. The log is buried within the bankfull/floodplain bench and the top of the structure set flush with the existing or proposed bankfull/floodplain elevation. Log sills are a natural long-term temporary (or semi-permanent) grade control solution created from the repurposing of a renewable resource.

A floodplain log sill can be used in conjunction with an in-stream log sill to provide immediate vertical grade control to both the stream channel and adjacent bankfull/floodplain bench.

2.10.1 Components

A floodplain log sill consists of the following components:

- Logs, harvested from the trunks of trees, that are trimmed to be smooth and free of branches and/or roots.

A floodplain log sill may contain the following **optional** components based upon site specific conditions:

- Boulders – or other anchoring components based upon the designer's professional judgement – may be used where buoyancy calculations require additional resisting forces.

2.10.2 Effective Uses and Limitations

<table>
<tr><th>EFFECTIVE USES</th><th>LIMITATIONS</th></tr>
<tr><td>Method of providing immediate vertical grade control within bankfull/floodplain bench areas using natural materials most effective in low gradient stream systems.</td><td rowspan="5">Not recommended for use in higher gradient stream systems or in areas where bedrock is at, or very near, the surface.</td></tr>
<tr><td>Method for preventing the down-valley migration or short-cutting of stream channels and maintaining plan for geometry of the stream channel.</td></tr>
<tr><td>Footer logs may be used to provide protection for a greater vertical depth near bridge/culvert structures or other areas that may be prone to severe bed scour.</td></tr>
<tr><td>May be used to create subsurface blockage of ground and/or surface water in certain locations, to repurpose on-site materials and add a future carbon source vital to the denitrification process, and to create varied local hydrology, topography and habitat.</td></tr>
<tr><td>Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.</td></tr>
</table>

2.10.3 Computations

- Calculations for the minimum required size of logs are based on the following guidelines:
    - Buoyancy Calculations – provided in the ***General Literature*** section – are recommended for use in determining minimum required log dimensions to resist the uplifting forces of stream flow, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

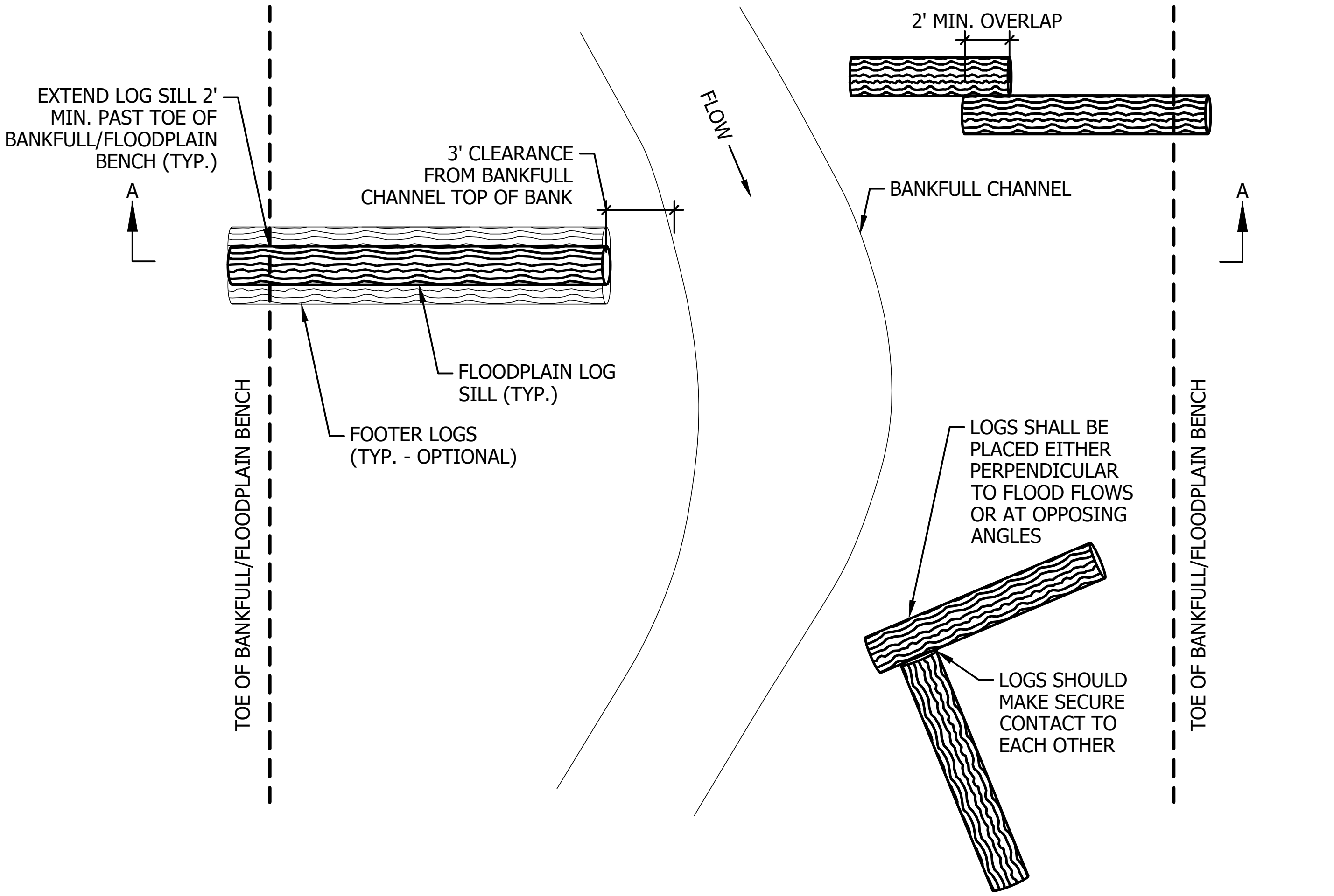
2.10.4 Notes to Designers

- Footer logs are optional based upon site specific conditions. Conditions that may warrant footer logs include but are not limited to: non-cohesive subgrade material (such as sand) and/or areas that may be prone to severe floodplain scour (i.e., contraction/expansion zones up and downstream of bridges or culverts). The use of footer logs protects the floodplain for a greater vertical distance.
    - The designer should revise the standard detail and specification to **<u>remove</u>** reference to the footer logs if they are not warranted.
- Boulders – or other anchoring components based upon the designer's professional judgement – may be used where buoyancy calculations require additional resisting forces.
    - The designer should revise the standard detail and specification to **<u>add</u>** reference to the specific anchoring components to be used if necessary.
- At a minimum, the in-stream log sill should maintain a 3-foot clearance from the top of bank and should be extended 2 feet into the side slope.

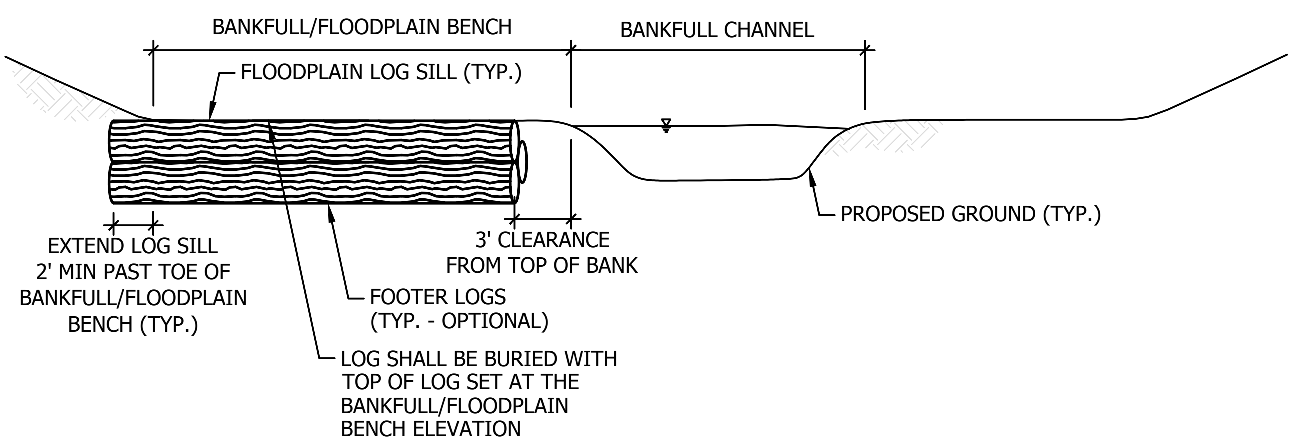
2.10.5 Photographs

Photograph 1: Floodplain log sill during construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.

Photograph 2: Floodplain log sill during construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.



PLAN VIEW



SECTION VIEW A-A

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

FLOODPLAIN LOG SILL

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S10

2.11 Rock Sill

A rock sill is the installation of large, rectangular, blocky rocks spanning across both the stream channel and bankfull/floodplain bench. The rocks are buried within the stream channel and bankfull/floodplain bench with the top of the structure set flush with existing ground or proposed grade. Rock sills provide immediate vertical grade control to both the stream channel and adjacent bankfull/floodplain bench as one continuous structure.

2.11.1 Components

A rock sill consists of the following components:

- Large, rectangular, blocky rocks sized to resist the erosive forces of water being conveyed through the structure.
- A choking layer incorporated into the rocks, consisting of gravels and cobbles (furnished or salvaged), to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. May also help to promote expression of base flow conditions above channel grade.

2.11.2 Effective Uses and Limitations

<table>
<tr><th>EFFECTIVE USES</th><th>LIMITATIONS</th></tr>
<tr><td>Method of providing immediate vertical grade control within bankfull/floodplain bench areas in both low and high gradient stream systems; stable starting or ending point for a stream restoration or stabilization project.</td><td rowspan="4">Not recommended for use in stream systems with non-cohesive sediments (i.e., sand bed systems) as settling of the rock may prevent effectiveness.</td></tr>
<tr><td>Method for preventing the down-valley migration or short-cutting of stream channels and maintaining plan for geometry of the stream channel; effective in localized areas of high shear stress and/or velocity due to flow convergence or contraction/expansion of flows on bankfull/floodplain benches.</td></tr>
<tr><td>In-stream footer rocks may be used to provide protection for a greater vertical depth near bridge/culvert structures or other areas that may be prone to severe bed scour.</td></tr>
<tr><td>May be used to create subsurface blockage of ground and/or surface water in certain locations.</td></tr>
<tr><td>Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.</td><td>Not recommended for installation in severely eroded and incised stream conditions.</td></tr>
</table>

2.11.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event. The following Rock Sizing Calculations – provided in the ***General Literature*** section – are recommended for use, but other relationships may be used based upon site specific conditions and/or designer's professional judgement:
    - Shields Entrainment Function
    - Leopold, Wolman, and Miller (1964) Entrainment Function
    - Rosgen (or Regionally Developed) Rock Sizing and Mobility Curves
    - Andrews Methodology
    - Ishbash Equation
  - Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

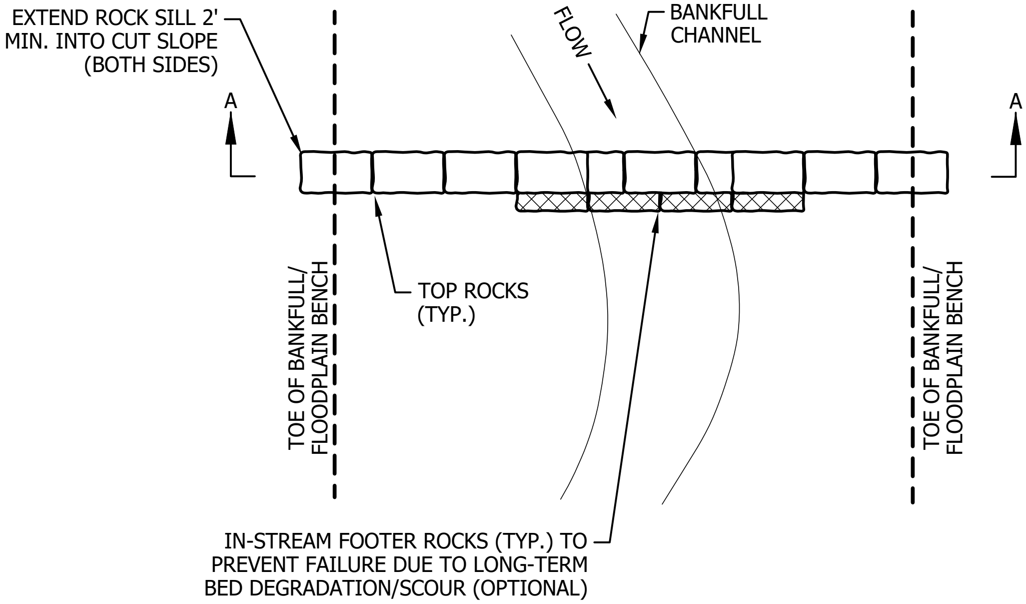
2.11.4 Notes to Designers

- In-stream footer rocks are optional based upon site specific conditions. Conditions that may warrant footer rocks include but are not limited to areas that may be prone to severe bed scour (i.e., contraction/expansion zones up and downstream of bridges or culverts). The use of footer rocks protects the streambed for a greater vertical distance.
- At a minimum, the rock sill should be extended 2 feet into the valley wall/side slope.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

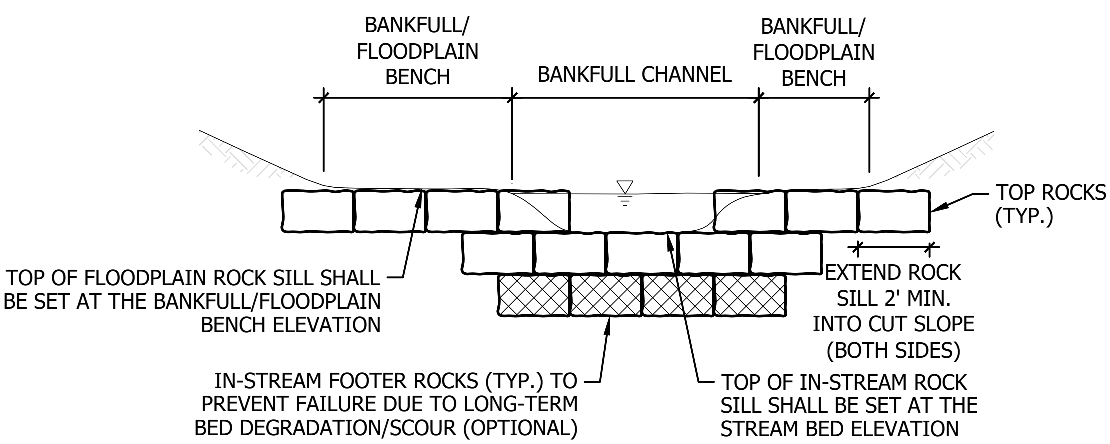
2.11.5 Photographs

Photograph 1: Rock sill during construction at Bear Branch, Anne Arundel County, MD. Source: JMT.

Photograph 2: Rock sill following construction at Bear Branch, Anne Arundel County, MD. Source: JMT.

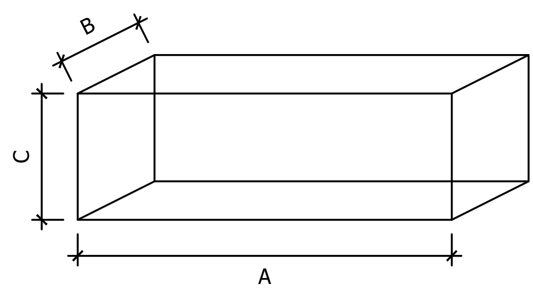


PLAN VIEW



SECTION VIEW A-A

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



BOULDER SIZING DETAIL

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

ROCK SILL

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S11

2.12 Toe Wood

A toe wood structure is used to reduce the width-depth ratio of over-widened stream channels, stabilize eroded streambanks – especially on the outside of meander bends – and provide cover, habitat, and food chain sources for numerous aquatic species.

2.12.1 Components

A toe wood structure consists of the following components:

- Foundation logs installed at the base of the structure that remain permanently submerged below low flow; foundation logs are the largest logs used in the structure and shall remain free of all limbs, branches, and snags.
- Cantilevered logs installed on top of the foundation logs that remain permanently submerged below base flow; cantilevered logs should be slightly smaller than the foundation logs and shall have roots, limbs, branches, and snags protruding into the stream channel.
- Brush and live cuttings installed on top of the cantilevered logs to form a dense, woody, vegetative mat. Brush and live cuttings will be exposed to water above base flow conditions of the stream. The mat will consist of both dead branches, limbs and tree tops, as well as live cuttings from select native species adapted to a wet hydrology.
- Floodplain log sills installed at the upstream and downstream limits of the structure to provide a border for packing the brush and live cuttings layer.
- Soil lifts installed on top of the brush and live cuttings layer to provide immediate vegetative stability to the exposed surface of the toe wood structure. Topsoil will be installed and compacted as backfill within the voids of the brush layer to create a level surface for subsequent installation of the soil lifts.
- Live stake plantings will be installed through the erosion control blanket of the soil lifts and will extend into the groundwater. The live stakes will provide a permanent dense root mat for the surface of the toe wood structure upon establishment.
    - Wood stakes will be installed temporarily in lieu of the live stake plantings during periods outside of the dormant planting season. The wood stakes will then be replaced with live stake plantings during the dormant planting season.

A toe wood structure may contain the following **optional** components based upon site specific conditions:

- Sod mats harvested within the permitted limit of disturbance or furnished from an approved source. The sod mats wrapped in erosion control blanket will be used in lieu of the soil lifts to provide immediate vegetative stability to the exposed surface of the toe wood structure.

2.12.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Method of providing immediate stabilization of eroded streambanks and over-widened stream channels; primarily on the outside of meander bends, but may be used along any portion of the channel subject to erosion.	Not recommended for use near bridge/culvert structures or other areas that may be prone to severe bed scour.
May serve to imitate natural streambanks through the use of natural materials for construction; replicate undercut banks; provide cover, habitat and food sources for fish and other aquatic species as well as organic matter trapping for macroinvertebrate processing.	Not recommended for use immediately adjacent to critical infrastructure requiring long-term protection.
Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.	Not recommended for use on actively incising stream channels, as channel incision may undermine the structure.

2.12.3 Computations

- Calculations for the minimum required size of logs are based on the following guidelines:
    - Buoyancy Calculations – provided in the ***General Literature*** section – are recommended for use in determining minimum required log dimensions to resist the uplifting forces of stream flow, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

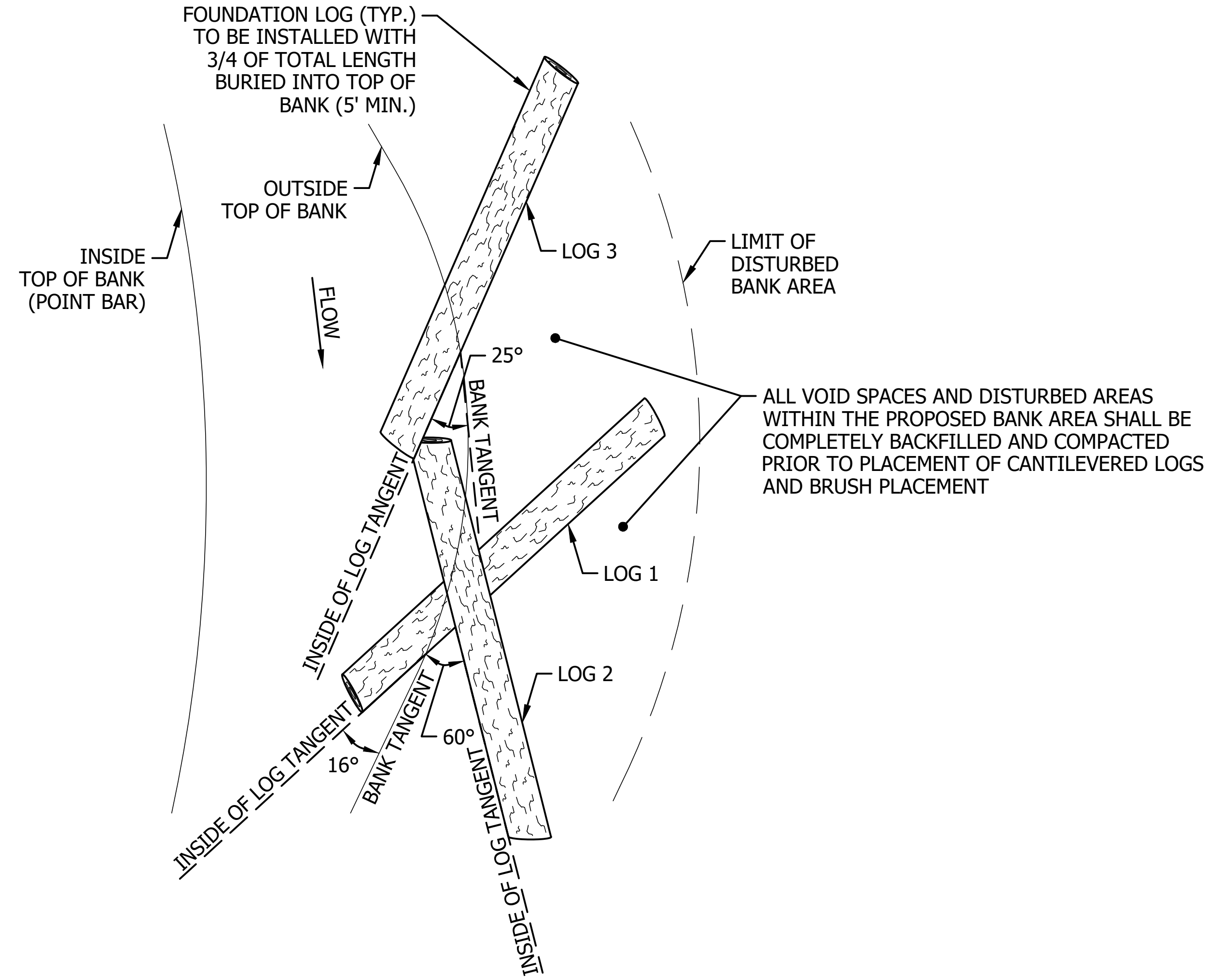
2.12.4 Notes to Designers

- Sod mats wrapped in erosion control blanket are optional as an alternative to the soil lifts for providing improved vegetative stability immediately following construction. Sod mats should only be used when it is possible to keep mats consistently wet and protected from extreme heat and cold.
    - The designer should revise the standard detail and specification to **add** reference to the sod mats and **remove** reference to the soil lifts.

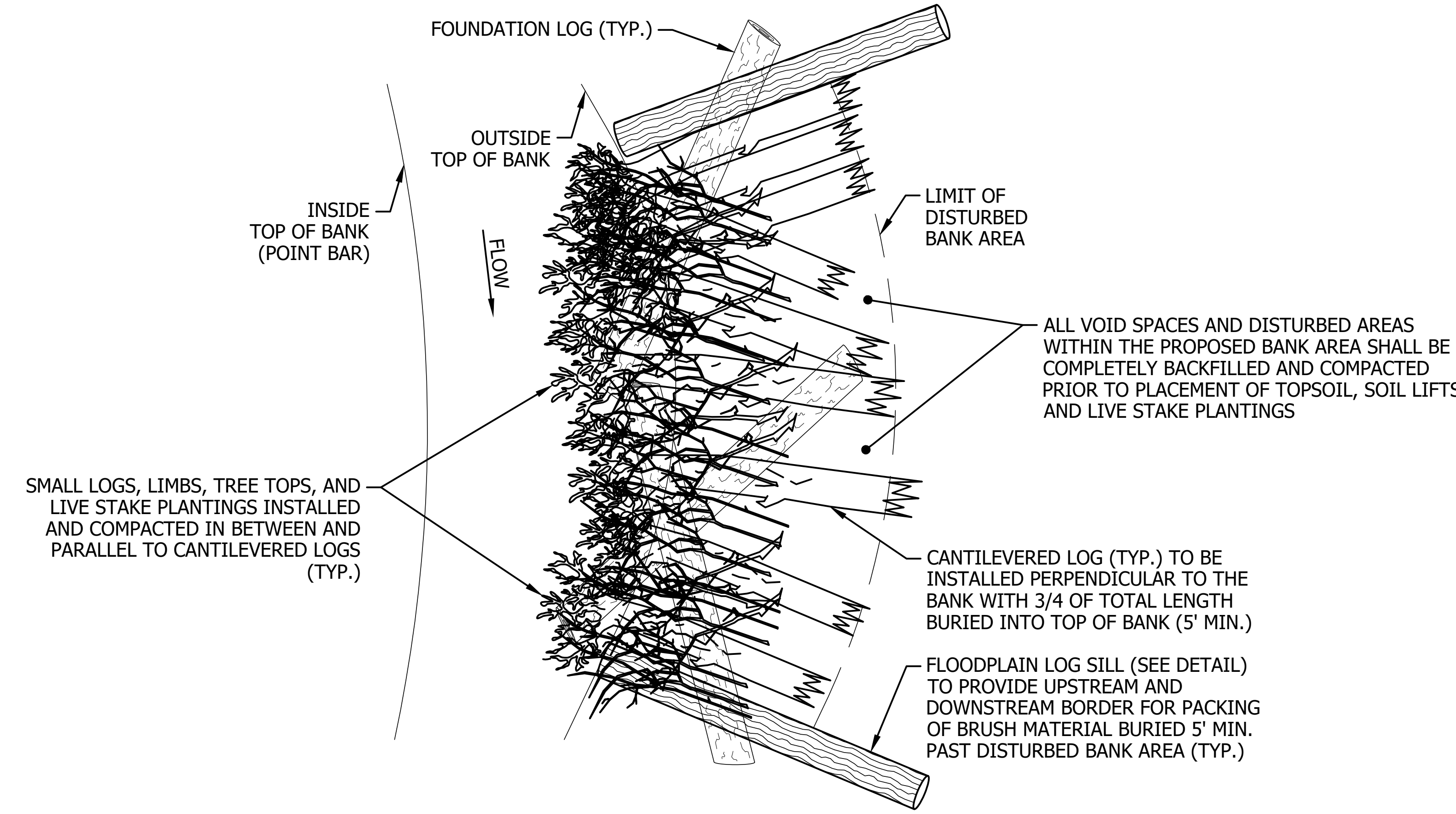
2.12.5 Photographs

Photograph 1: Toe wood during construction at UNT to Jones Falls, Baltimore County, MD. Source: JMT.

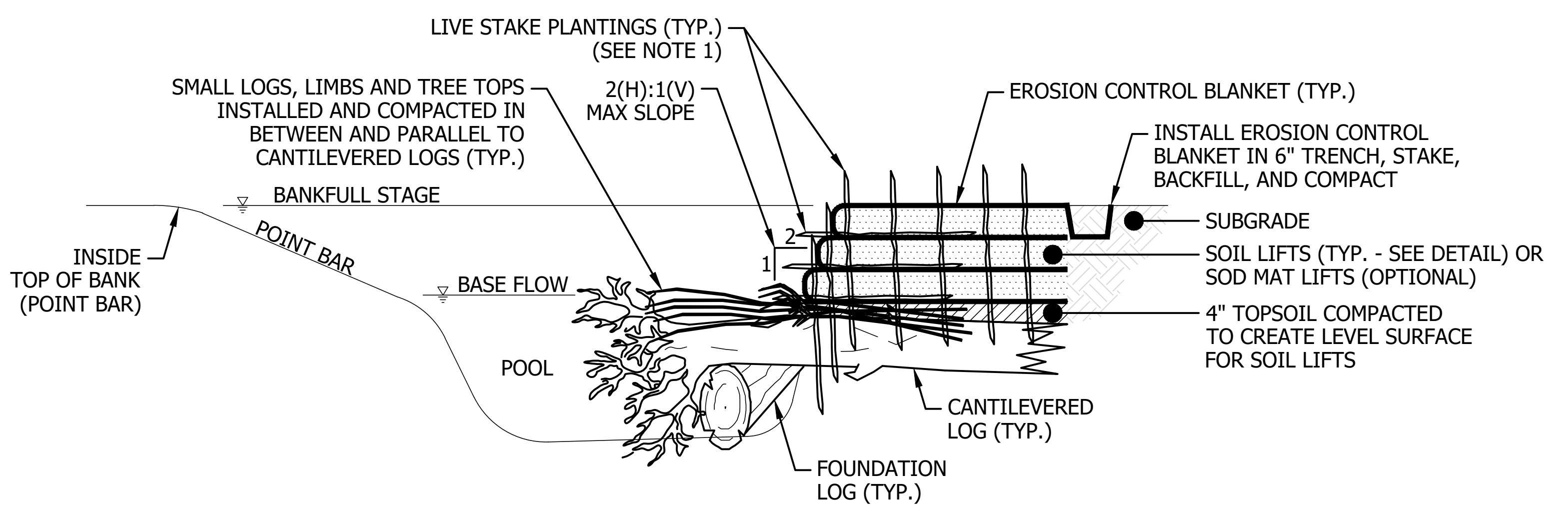
Photograph 2: Toe wood following construction at Jones Falls, Baltimore County, MD. Source: JMT.



STEP 1 - FOUNDATION LOGS (PLAN VIEW)

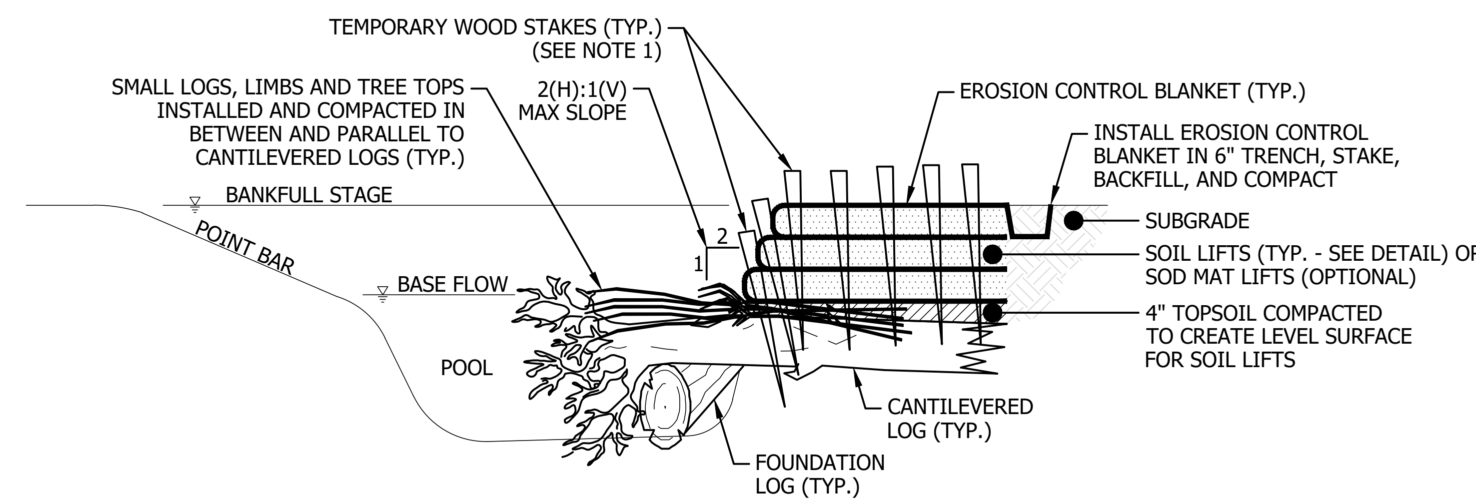


STEP 2 - CANTILEVERED LOGS AND BRUSH PLACEMENT (PLAN VIEW)



NOTES:
1. LIVE STAKE PLANTINGS SHALL BE INSTALLED IN ACCORDANCE WITH THE CONTRACT SPECIFICATIONS DURING THE DORMANT PLANTING SEASON.

STEP 3 - SOIL LIFTS AND LIVE STAKE PLANTINGS DURING DORMANT PLANTING SEASON (SECTION VIEW)



NOTES:
1. TEMPORARY WOOD STAKES SHALL BE INSTALLED FOR PERIODS OUTSIDE OF THE DORMANT PLANTING SEASON. TEMPORARY WOOD STAKES SHALL BE REPLACED WITH LIVE STAKE PLANTINGS IN ACCORDANCE WITH THE CONTRACT SPECIFICATIONS DURING THE DORMANT PLANTING SEASON.

STEP 3 - SOIL LIFTS AND TEMPORARY WOOD STAKES OUTSIDE OF THE DORMANT PLANTING SEASON (SECTION VIEW)

PHILADELPHIA WATER DEPARTMENT

1101 MARKET ST.
4TH FLOOR
PHILADELPHIA, PA
19107

TOE WOOD

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S12

2.13 Engineered Habitat Boulder Placement

Engineered habitat boulder placement is used to reduce flow velocity and provide secondary flow currents and habitat for fish or other aquatic species within the riffle section(s) of a stream channel. This is achieved through the installation of large, rectangular, blocky rocks protruding above the streambed elevation.

2.13.1 Components

Engineered habitat boulder placement consists of the following components:

- Large, rectangular, blocky rocks sized to resist the erosive forces of water within the riffle section(s) of a stream channel.
- Salvaged and/or furnished channel bed material backfilled around the placed boulders to restore channel bed stability.

2.13.2 Effective Uses and Limitations

<table>
<tr><th>EFFECTIVE USES</th><th>LIMITATIONS</th></tr>
<tr><td>Method for providing small scour pools and eddies which are utilized by fish and other aquatic species as rearing areas.</td><td>Not recommended for use in stream systems with a large supply of bedload materials being delivered to the project reach, as the rocks may act more like a trapping mechanism leading to aggradation and lateral migration of the channel.</td></tr>
<tr><td>May be utilized to deflect channelized flow and provide additional channel bed roughness to protect streambanks from erosion.</td><td>Not recommended for use at meander bends where energy may be directed in non-uniform flow directions towards the streambanks.</td></tr>
<tr><td>Method for creating streambed diversity and roughness in areas where larger homogeneous streambed materials are present.</td><td rowspan="2">Not recommended for use in stream systems with non-cohesive sediments (i.e., sand bed systems) as settling of the rock may prevent effectiveness.</td></tr>
<tr><td>Most effective in wide and shallow streams – that are subject to higher velocities – with coarse streambed materials such as large gravel and cobbles, and where pool density is very limited.</td></tr>
</table>

2.13.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - o Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - o Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions

up to and including the 100-year design storm event. The following Rock Sizing Calculations – provided in the ***General Literature*** section – are recommended for use, but other relationships may be used based upon site specific conditions and/or designer's professional judgement:

- Shields Entrainment Function
- Leopold, Wolman, and Miller (1964) Entrainment Function
- Rosgen (or Regionally Developed) Rock Sizing and Mobility Curves
- Andrews Methodology
- Ishbash Equation

- Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.

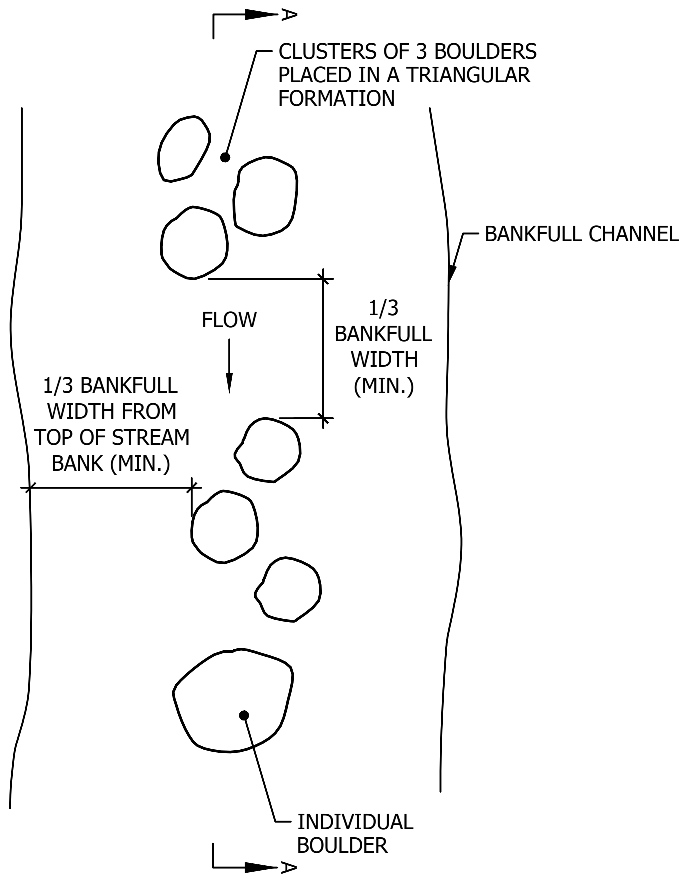
2.13.4 Notes to Designers

- Footer rocks are optional based upon site specific conditions. Conditions that may warrant footer rocks include but are not limited to areas that may be prone to severe bed scour (i.e., contraction/expansion zones up and downstream of bridges or culverts). The use of footer rocks protects the streambed for a greater vertical distance.
  - The designer should revise the standard detail and specification to **remove** reference to the footer rocks, if they are not warranted.
- At a maximum, the protrusion depth above the streambed elevation shall be no more than 1/3 of the bankfull depth.
  - The designer should revise the standard detail and specification to **add** reference to the specific protrusion depth.
- Top boulders should be placed on the footer boulder such that a minimum 75% of the top boulder surface overlaps the footer boulder surface.
  - The designer should revise the standard detail and specification to **add** reference to the specific offset distance.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

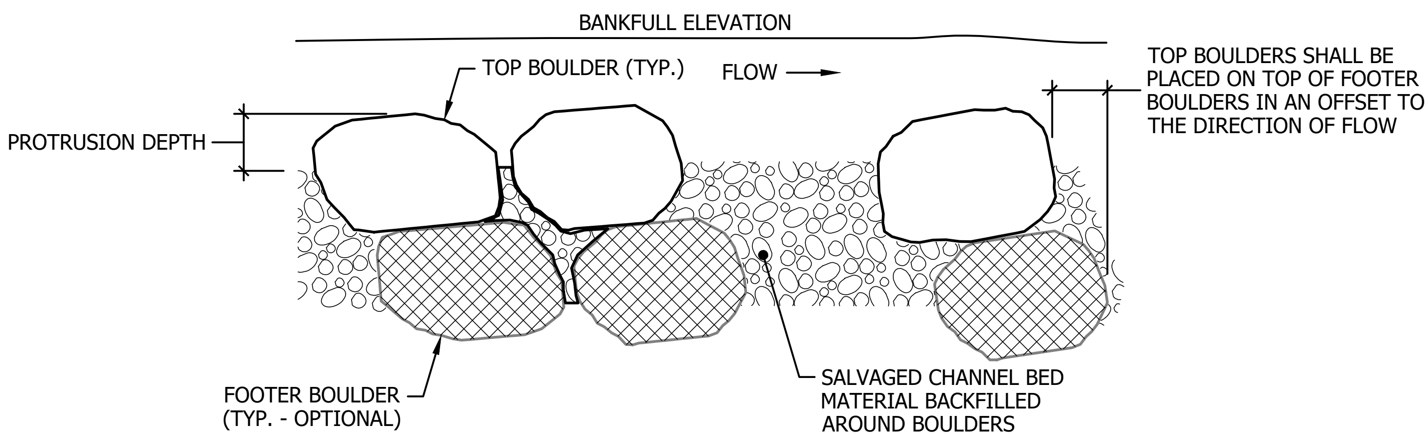
2.13.5 Photographs

Photograph 1: Engineered habitat boulder placement during construction at Elklick Run, Allegany County, MD. Source: JMT.

Photograph 2: Engineered habitat boulder placement following construction at Elklick Run, Allegany County, MD. Source: JMT.

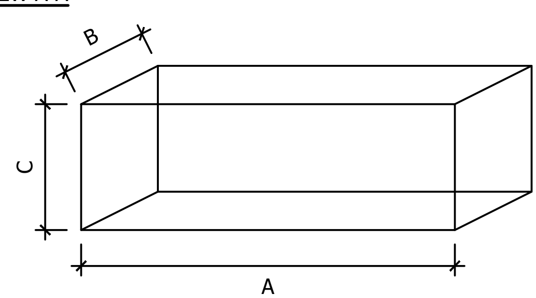


PLAN VIEW



SECTION VIEW A-A

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



PHILADELPHIA WATER DEPARTMENT

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ENGINEERED HABITAT BOULDER PLACEMENT

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S13

2.14 Typical Riffle and Pool Cross Sections

Typical riffle and pool cross sections are intended to provide the designer, reviewer, and construction manager and contractor with specific information related to the proposed channel cross section dimensions and shape of the proposed channel for construction. The typical sections will provide the general morphological features of these stream facets that are typically associated with a natural channel design approach for stream and floodplain restoration type projects.

2.14.1 Components

Typical riffle and pool cross sections consist of the following components:

- Information to identify the various geomorphic features of a typical cross section for construction, including cross sectional area, width, mean depth, and maximum depth.

2.14.2 Effective Uses and Limitations

- Not Applicable.

2.14.3 Computations

- Hydrologic calculations to determine relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

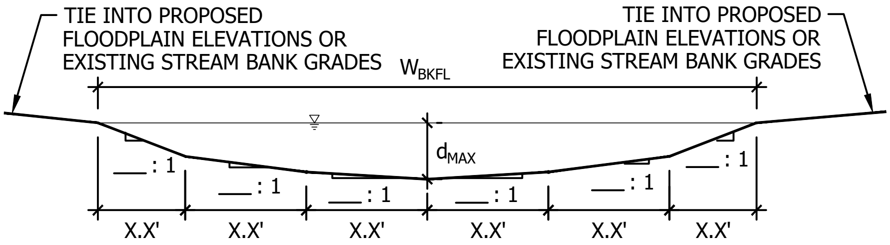
2.14.4 Notes to Designers

- Not Applicable.

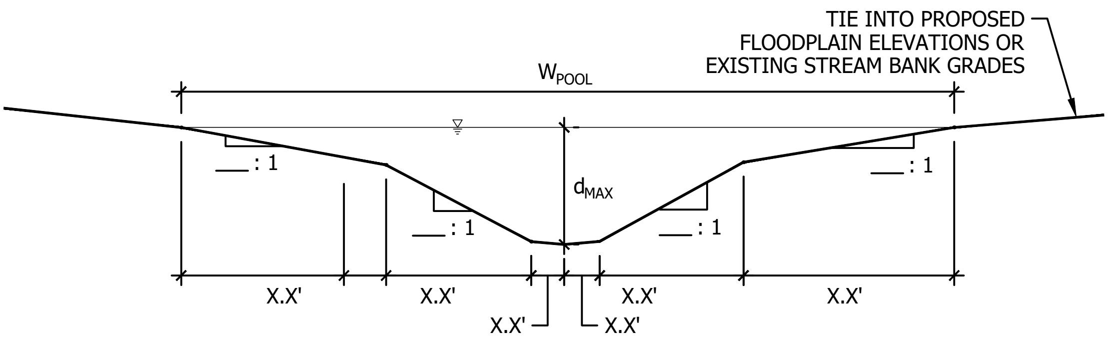
2.14.5 Photographs

Photograph 1: Typical riffle cross section following construction at Stickney Creek, Cuyahoga County, OH. Source: JMT.

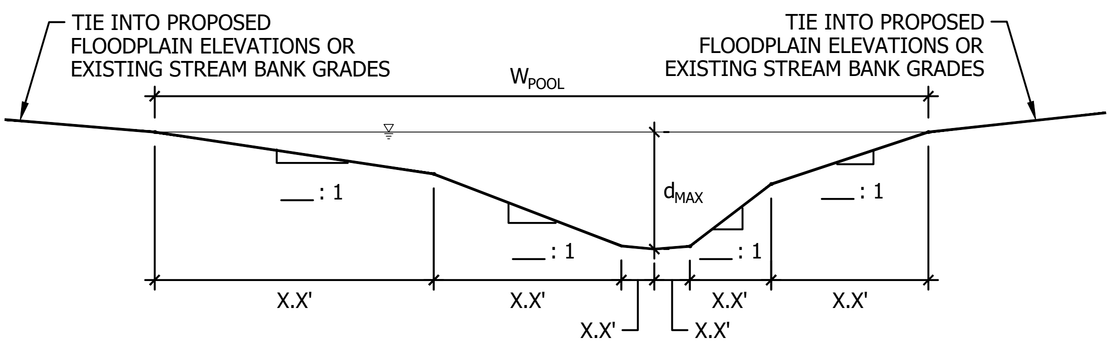
Photograph 2: Typical pool cross section following construction at Stickney Creek, Cuyahoga County, OH. Source: JMT.



TYPICAL RIFFLE - CROSS SECTION



TYPICAL POOL - CROSS SECTION



TYPICAL POOL (RIGHT) - CROSS SECTION

NOTES:

1. TYPICAL POOL (LEFT) IS A MIRRORED CONDITION OF TYPICAL POOL (RIGHT)

CROSS SECTION TYPE	BANKFULL AREA (SQ. FT.)	BANKFULL WIDTH (FT.)	MEAN DEPTH (FT.)	MAXIMUM DEPTH (FT.)
RIFFLE				
POOL				

CROSS SECTION SCHEDULE

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

TYPICAL RIFFLE AND POOL CROSS SECTIONS

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S14

2.15 Root Wad

A root wad structure is used to reduce the width-depth ratio of over-widened stream channels, stabilize eroded streambanks, and provide cover, habitat, and food chain sources for numerous aquatic species.

2.15.1 Components

A root wad structure consists of the following components:

- Root wad from a tree, consisting of the main mass of roots and bottom portion of the trunk (free from limbs, branches, and snags). The root wad is installed into and along the streambank and set at an elevation where approximately 85% - 90% of the roots are submerged during base flow conditions.
- Anchor and footer boulders, consisting of large, rectangular, blocky rocks that are stackable to create a uniform and stable surface that will resist the erosive forces of channelized stream flow.
- Erosion control blanket secured with wood stakes will be installed and secured on top of the root wad structure to provide temporary stability to the exposed surface until permanent vegetation is established.

2.15.2 Effective Uses and Limitations

<table>
<tr><th>EFFECTIVE USES</th><th>LIMITATIONS</th></tr>
<tr><td>Best suited for stable stream systems that require varying habitat and minor bank protection; may be installed in series to create root wad revetment along the streambank.</td><td>Placement in narrow stream channels could result in scour along the opposite bank/inside of meander bend; Streambanks on the opposite side of the channel should be monitored for excessive erosion.</td></tr>
<tr><td>May serve to imitate natural streambanks through the use of natural materials for construction; replicate undercut banks; provide cover, habitat and food sources for fish and other aquatic species as well as organic matter trapping for macroinvertebrate processing.</td><td>The top of the structure can be subject to local scour due to non-uniform flow conditions and should be monitored following storm events exceeding bankfull conditions.</td></tr>
<tr><td rowspan="2">Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.</td><td>Not recommended for use immediately adjacent to critical infrastructure requiring long-term protection.</td></tr>
<tr><td>Not recommended for use on severely eroding, actively incising, and/or entrenched or unstable stream channels, as erosion and channel incision may undermine the structure.</td></tr>
</table>

2.15.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

    Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized rock for the anchor and footer rocks, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.
- Calculations for the minimum required size of logs are based on the following guidelines:
  - Buoyancy Calculations – provided in the ***General Literature*** section – are recommended for use in determining minimum required log dimensions to resist the uplifting forces of stream flow, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

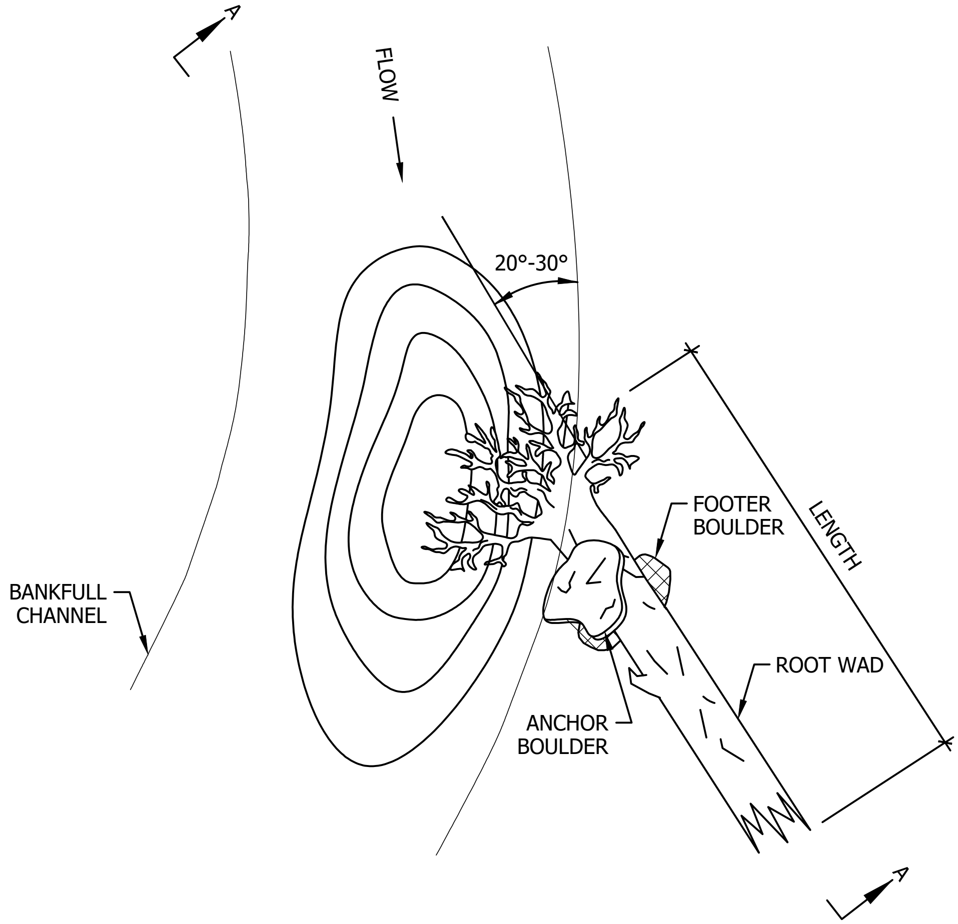
2.15.4 Notes to Designers

- Additional streambank protection measures should be considered for installation in conjunction with root wad structures based upon site specific conditions. Additional in-stream structures may not be required where bankfull/floodplain benches will be constructed.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

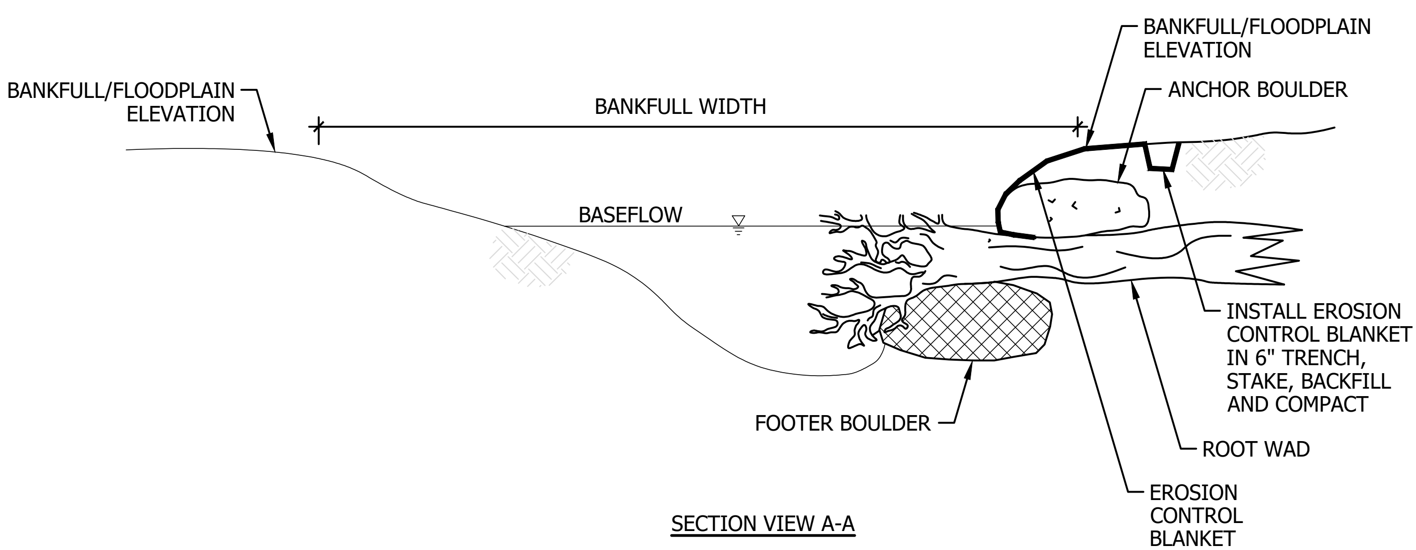
2.15.5 Photographs

Photograph 1: Root wad during construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.

Photograph 2: Root wad following construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.



PLAN VIEW



SECTION VIEW A-A

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

ROOT WAD

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER: S15

2.16 Log Vane

A log vane is a single arm, low profile wooden structure that directs flow away from the streambank. Log vanes are typically installed along meander bends to decrease shear stress and velocity in the near-bank region while promoting the development of scour pools for habitat. This structure will reduce bank erosion while maintaining sediment transport capacity and sediment competence.

Log vanes can be installed in pairs or with other in-stream habitat and stabilization structure (refer to **Log Vane-Root Wad**) in order to direct flow away from streambanks until vegetation is established.

2.16.1 Components

A log vane consists of the following components:

- Logs, harvested from the trunks of trees, that are trimmed to be smooth and free of branches and/or roots. The log is partially embedded into the streambed and streambank such that it is submerged during base flow conditions.
- Anchor and footer boulders, consisting of large, rectangular, blocky rocks that are stackable to create a uniform and stable surface that will resist the erosive forces of channelized stream flow.
- Salvaged and/or furnished channel bed material backfilled around the installed structure to restore channel bed stability and match the elevation of the log vane.
- Erosion control blanket secured with wood stakes will be installed and secured on top of the log vane structure to provide temporary stability to the exposed surface until permanent vegetation is established.

2.16.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Best suited for stable stream systems that require varying habitat and minor bank protection; can promote pool development.	Streambanks on the opposite side of the channel should be monitored for excessive erosion.
	Not recommended for use on stream systems where bedrock is at, or very near, the surface due to limitations for scour pool development.
Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.	Not recommended for use immediately adjacent to critical infrastructure requiring long-term protection.
	Not recommended for use on severely eroding, actively incising, and/or entrenched or unstable stream channels, as erosion and channel incision may undermine the structure.

2.16.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - o Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and

threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.

  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

    Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized rock for the anchor and footer rocks, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

- Calculations for the minimum required size of logs are based on the following guidelines:
  - Buoyancy Calculations – provided in the ***General Literature*** section – are recommended for use in determining minimum required log dimensions to resist the uplifting forces of stream flow, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

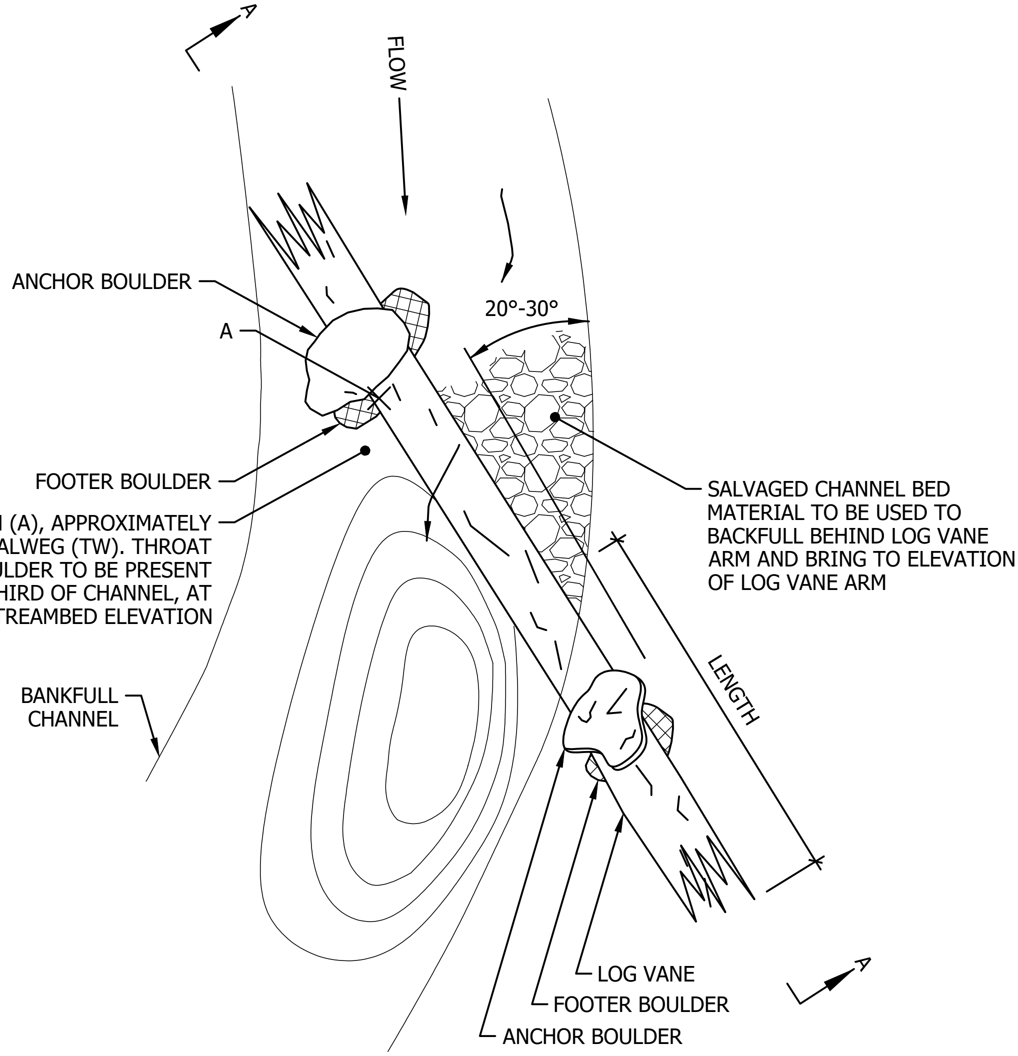
2.16.4 Notes to Designers

- Additional streambank protection measures should be considered for installation in conjunction with log vanes based upon site specific conditions; refer to **Log Vane-Root Wad**. Additional in-stream structures may not be required where bankfull/floodplain benches will be constructed.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

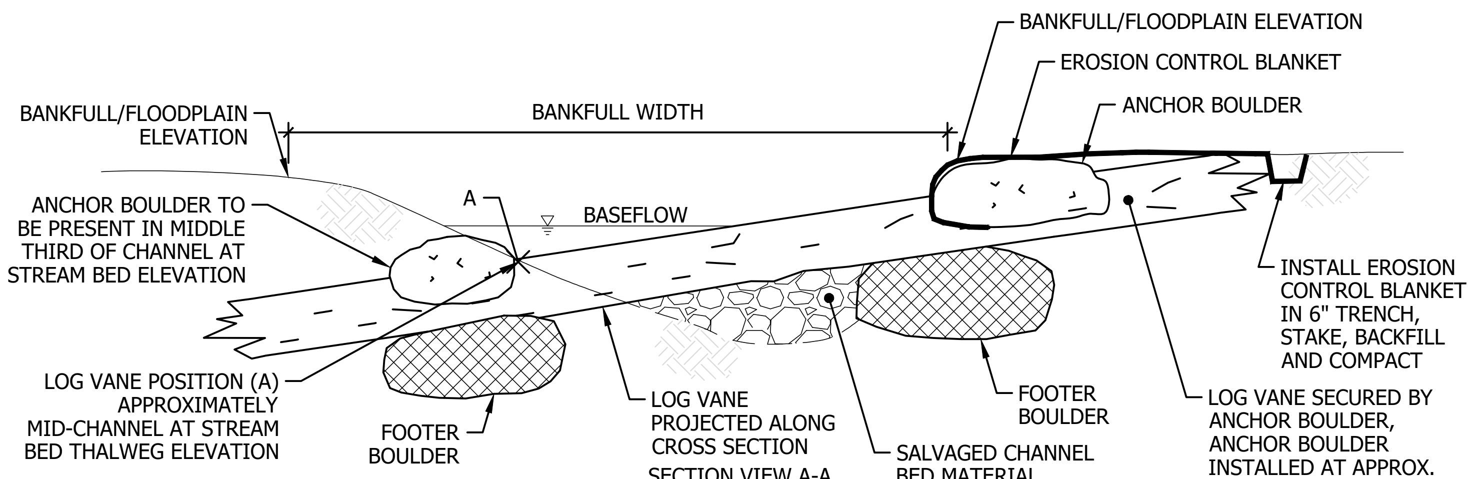
2.16.5 Photographs

Photograph 1: Log vane during construction at UNT to Jones Falls, Baltimore County, MD. Source: JMT.

Photograph 2: Log vane following construction at UNT to Jones Falls, Baltimore County, MD. Source: JMT.



PLAN VIEW



SECTION VIEW A-A

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

LOG VANE

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S16

2.17 Log Vane-Root Wad

A log vane-root wad is a single arm, low profile wooden structure that directs flow away from the streambank. Log vane-root wads are typically installed along meander bends to decrease shear stress and velocity in the near-bank region while promoting the development of scour pools for habitat. This structure will reduce bank erosion while maintaining sediment transport capacity and sediment competence.

Log vane-root wads differ from log vanes by combining the log vane and root wad structures to better direct flow away from streambanks and provide more stability until vegetation is established.

2.17.1 Components

A log vane-root wad consists of the following components:

- Logs, harvested from the trunks of trees, that are trimmed to be smooth and free of branches and/or roots. The log is partially embedded into the streambed and streambank such that it is submerged during base flow conditions.
- Root wad from a tree, consisting of the main mass of roots and bottom portion of the trunk (free from limbs, branches, and snags). The root wad is installed into and along the streambank and set at an elevation where approximately 85% - 90% of the roots are submerged during base flow conditions.
- Anchor and footer boulders, consisting of large, rectangular, blocky rocks that are stackable to create a uniform and stable surface that will resist the erosive forces of channelized stream flow.
- Salvaged and/or furnished channel bed material backfilled around the installed structure to restore channel bed stability and match the elevation of the log vane.
- Erosion control blanket secured with wood stakes to provide temporary stability to the exposed surface until permanent vegetation is established.

2.17.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Best suited for stable stream systems that require varying habitat and minor bank protection; can promote pool development.	Streambanks on the opposite side of the channel should be monitored for excessive erosion.
	Not recommended for use on stream systems where bedrock is at, or very near, the surface due to limitations for scour pool development.
May serve to imitate natural streambanks through the use of natural materials for construction; replicate undercut banks; provide cover, habitat and food sources for fish and other aquatic species as well as organic matter trapping for macroinvertebrate processing.	The top of the structure can be subject to local scour due to non-uniform flow conditions and should be monitored following storm events exceeding bankfull conditions.
Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.	Not recommended for use immediately adjacent to critical infrastructure requiring long-term protection.
	Not recommended for use on severely eroding, actively incising, and/or entrenched or unstable stream channels, as erosion and channel incision may undermine the structure.

2.17.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

    Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized rock for the anchor and footer rocks, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.
- Calculations for the minimum required size of logs are based on the following guidelines:
  - Buoyancy Calculations – provided in the ***General Literature*** section – are recommended for use in determining minimum required log dimensions to resist the uplifting forces of stream flow, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

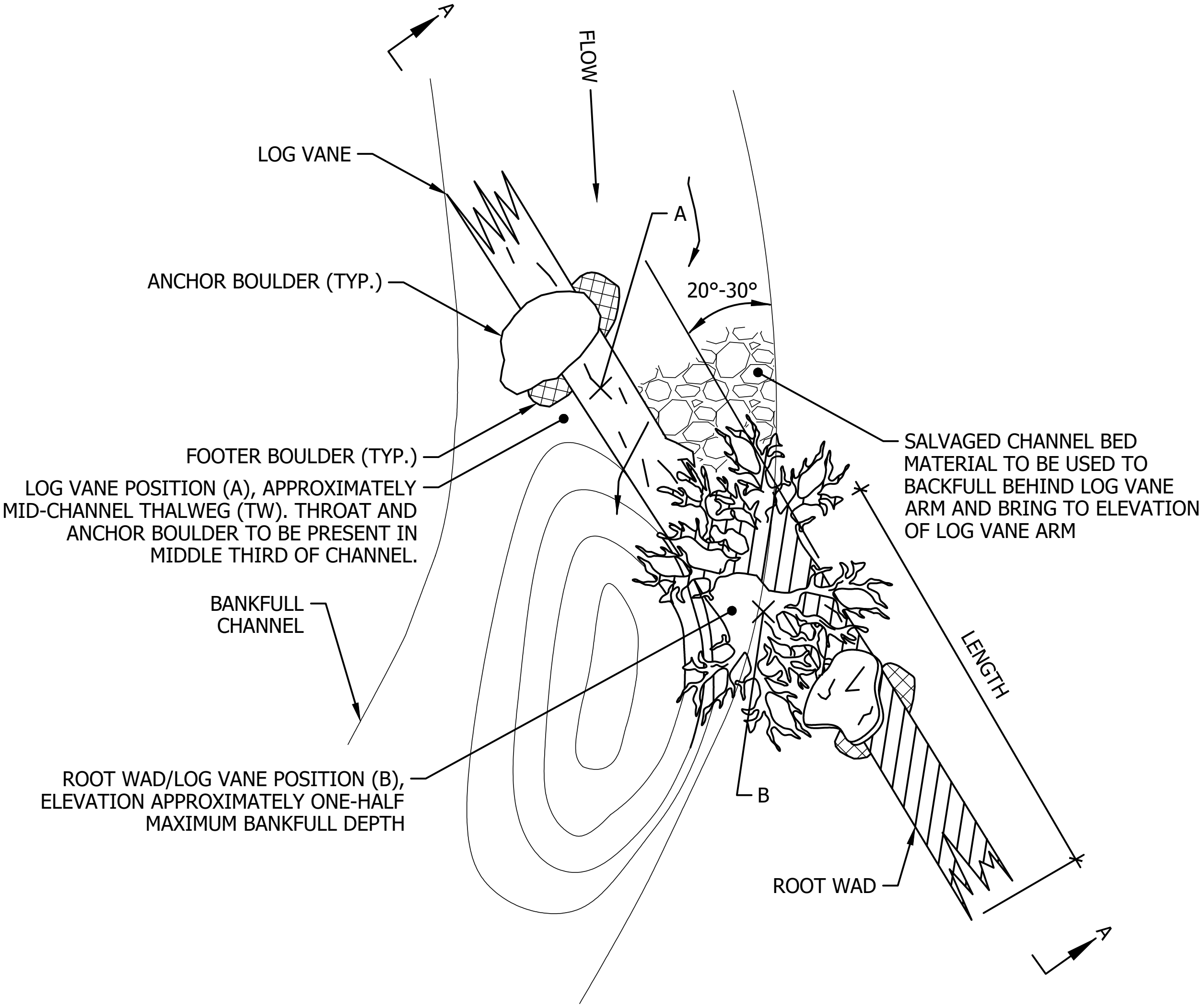
2.17.4 Notes to Designers

- Additional streambank protection measures should be considered for installation in conjunction with log vane-root wad structures based upon site specific conditions. Additional in-stream structures may not be required where bankfull/floodplain benches will be constructed.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

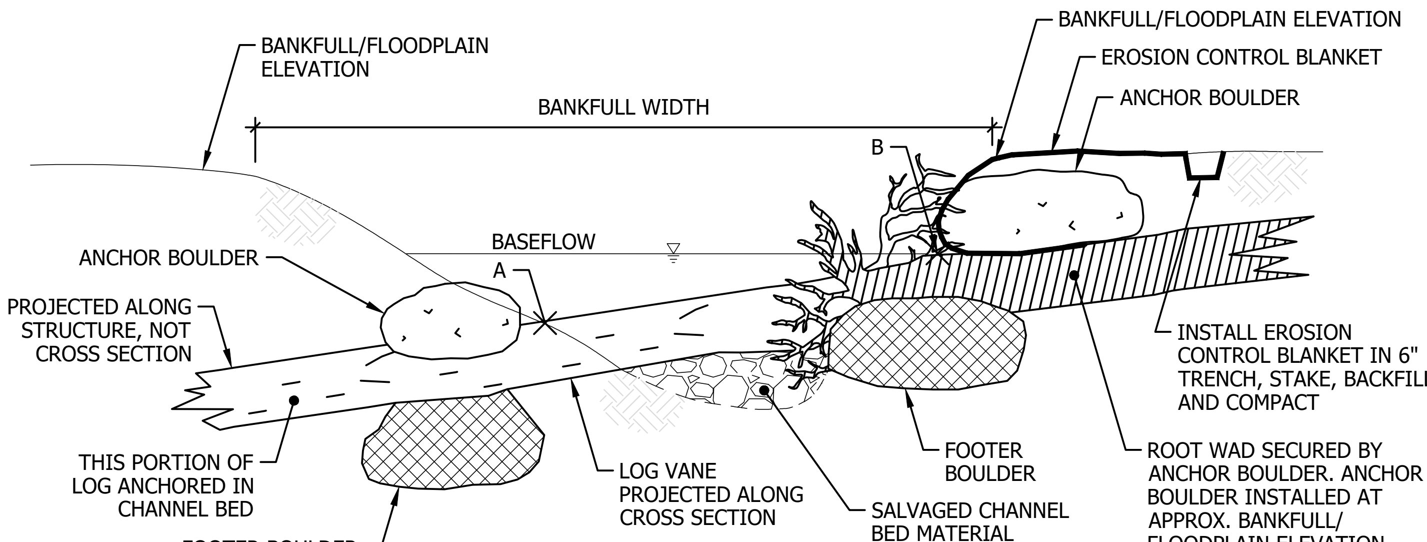
2.17.5 Photographs

Photograph 1: Log vane-root wad during construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.

Photograph 2: Log vane-root wad following construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.



PLAN VIEW



SECTION VIEW A-A

PHILADELPHIA WATER DEPARTMENT

1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

LOG VANE-ROOT WAD

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S17

2.18 Cross Rock Vane

A cross rock vane is a double arm, low profile rock structure that provides vertical grade control and directs flow away from the streambanks. Cross rock vanes decrease shear stress and velocity at the streambanks while increasing energy in the center of the channel to promote the development of scour pools for habitat. This structure will establish vertical grade control and reduce bank erosion while maintaining sediment transport capacity and sediment competence.

Cross rock vanes can be installed with various throat configurations based upon specific site conditions.

2.18.1 Components

A cross rock vane consists of the following components:

- Large, rectangular, blocky top and footer boulders sized to resist the erosive forces of water being conveyed through the structure.
- A choking layer incorporated into the boulders, consisting of gravels and cobbles (furnished or salvaged), to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. May also help to promote expression of base flow conditions above channel grade.

A cross rock vane may contain the following **optional** components based upon site specific conditions:

- A secondary throat sill to provide additional pool development and habitat.

2.18.2 Effective Uses and Limitations

<table>
<tr><th>EFFECTIVE USES</th><th>LIMITATIONS</th></tr>
<tr><td>Best suited for stable stream systems that require varying habitat and minor bank protection; can promote riffle-pool features.</td><td rowspan="2">Not recommended for use on stream systems where bedrock is at, or very near, the surface due to limitations for scour pool development.</td></tr>
<tr><td>Best suited for higher gradient stream systems, but can be implemented on lower gradient stream systems.</td></tr>
<tr><td>Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.</td><td>Not recommended for use on severely eroding, actively incising, and/or entrenched or unstable stream channels, as erosion and channel incision may undermine the structure.</td></tr>
</table>

2.18.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
    - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
    - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

      Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized vane and footer rocks, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

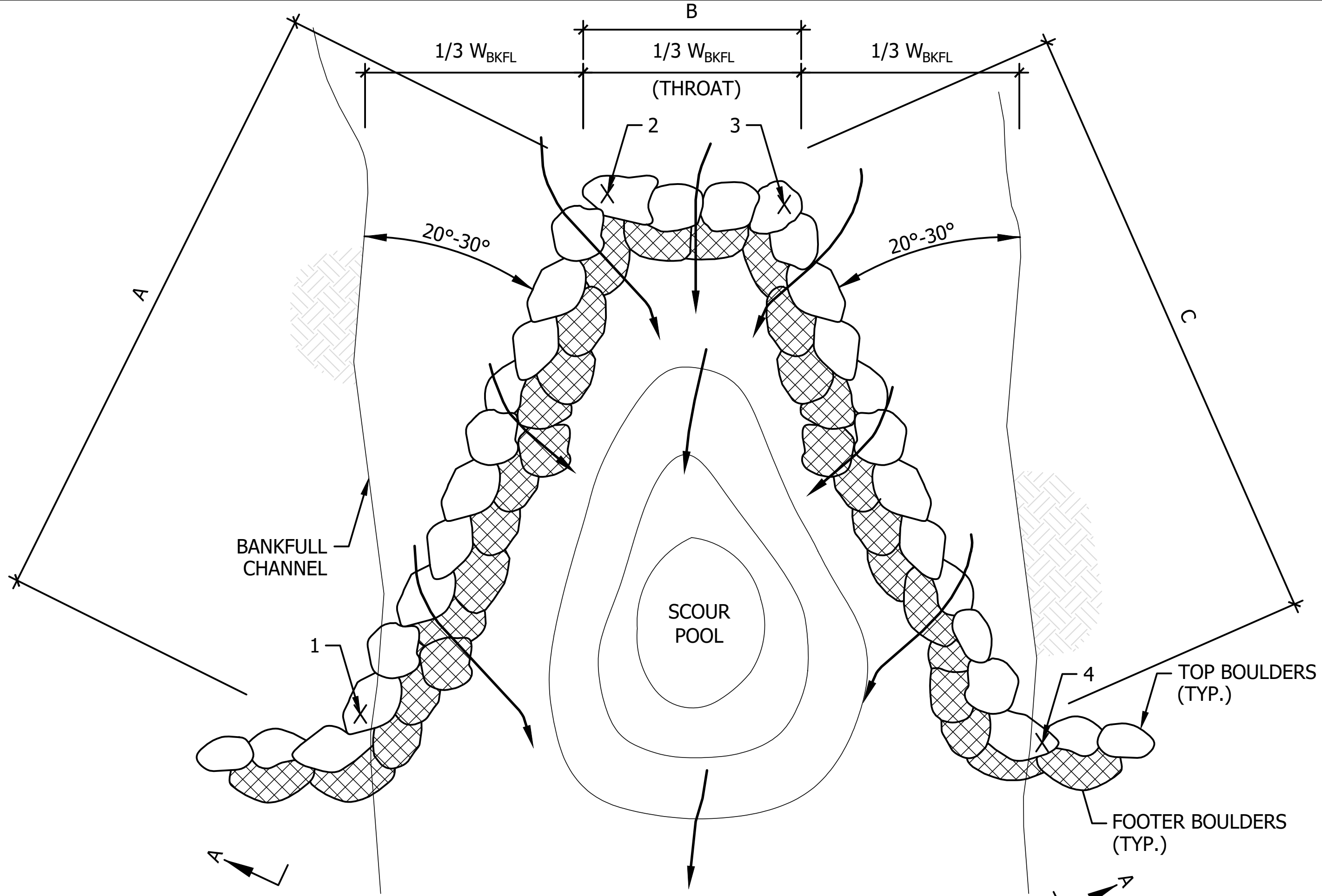
2.18.4 Notes to Designers

- Cross rock vanes can be installed with various throat configurations based upon specific site conditions.
    - The designer should revise the standard detail and specification to **remove** reference to any throat configurations that are not to be utilized.
- At a minimum, the vane arms should be extended 5 feet into the streambank.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

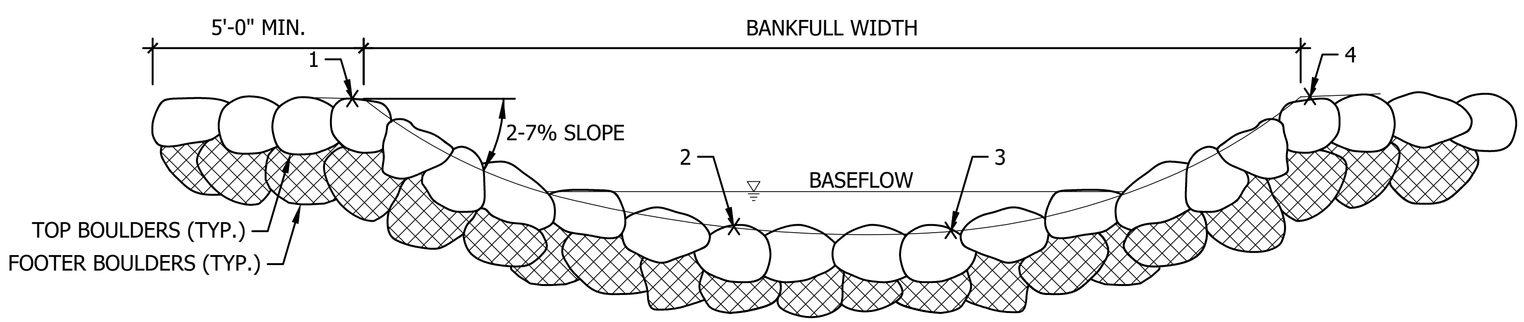
2.18.5 Photographs

Photograph 1: Cross rock vane during construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.

Photograph 2: Cross rock vane following construction at Kitten Branch, Anne Arundel County, MD. Source: JMT.



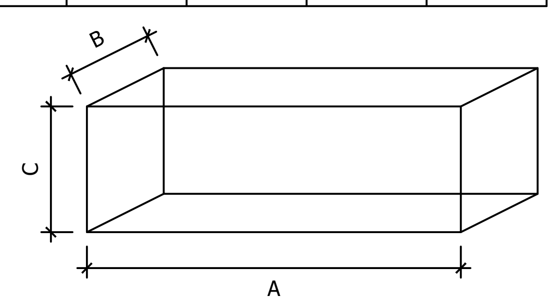
PLAN VIEW



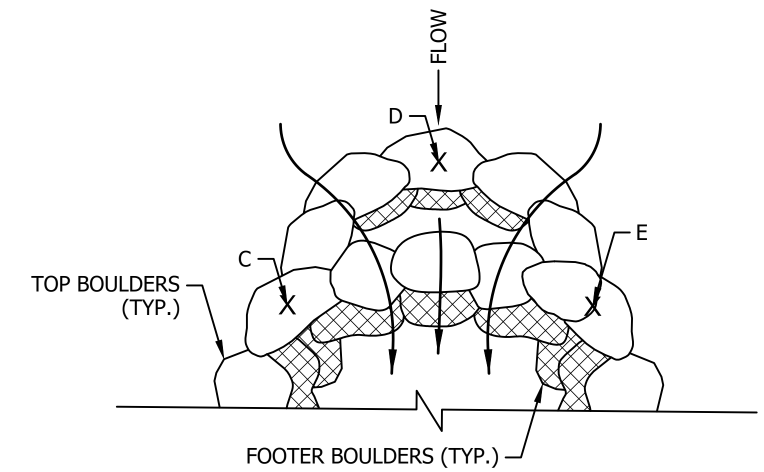
SECTION VIEW A-A

STRUCTURE SCHEDULE							
STRUCTURE ID	LENGTHS (FT)			INVERT ELEVATIONS (FT)			
	A	B	C	1	2	3	4

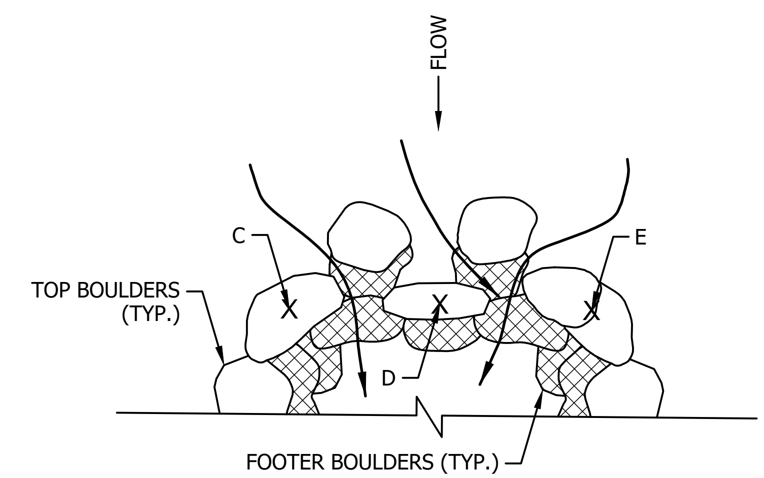
BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



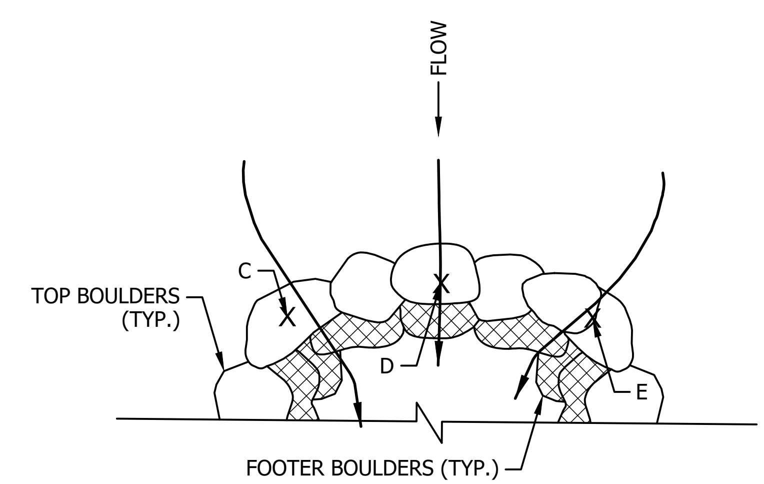
BOULDER SIZING DETAIL



STEPPED THROAT DETAIL



OPEN THROAT DETAIL



CLOSED-GAP THROAT DETAIL

PHILADELPHIA WATER DEPARTMENT

1101 MARKET ST.
4TH FLOOR
PHILADELPHIA, PA
19107

CROSS ROCK VANE

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER: S18

2.19 Offset Cross Rock Vane

An offset cross rock vane – similar to a cross rock vane – is a double arm, low profile rock structure that provides vertical grade control and directs flow away from the streambanks. This structure includes an offset vane arm on the inside of the meander bend to prevent short-circuiting of the stream flow. Offset cross rock vanes decrease shear stress and velocity at the streambanks while increasing energy in the center of the channel to promote the development of scour pools for habitat. This structure will establish vertical grade control and reduce bank erosion while maintaining sediment transport capacity and sediment competence.

Offset cross rock vanes can be installed with various throat configurations based upon site specific conditions.

2.19.1 Components

An offset cross rock vane consists of the following components:

- Large, rectangular, blocky top and footer boulders sized to resist the erosive forces of water being conveyed through the structure.
- A choking layer incorporated into the boulders, consisting of gravels and cobbles (furnished or salvaged), to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. May also help to promote expression of base flow conditions above channel grade.

An offset cross rock vane may contain the following **optional** components:

- A log vane arm to replace the rock vane arm on the outside of the meander bend. This optional feature can help limit the amount of boulders required for construction.

2.19.2 Effective Uses and Limitations

<table>
<tr><th>EFFECTIVE USES</th><th>LIMITATIONS</th></tr>
<tr><td>Best suited for stable stream systems that require varying habitat and minor bank protection; can promote riffle-pool features.</td><td rowspan="2">Not recommended for use on stream systems where bedrock is at, or very near, the surface due to limitations for scour pool development.</td></tr>
<tr><td>Best suited for higher gradient stream systems, but can be implemented on lower gradient stream systems.</td></tr>
<tr><td>Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.</td><td>Not recommended for use on severely eroding, actively incising, and/or entrenched or unstable stream channels, as erosion and channel incision may undermine the structure.</td></tr>
</table>

2.19.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

  Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized vane and footer rocks, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

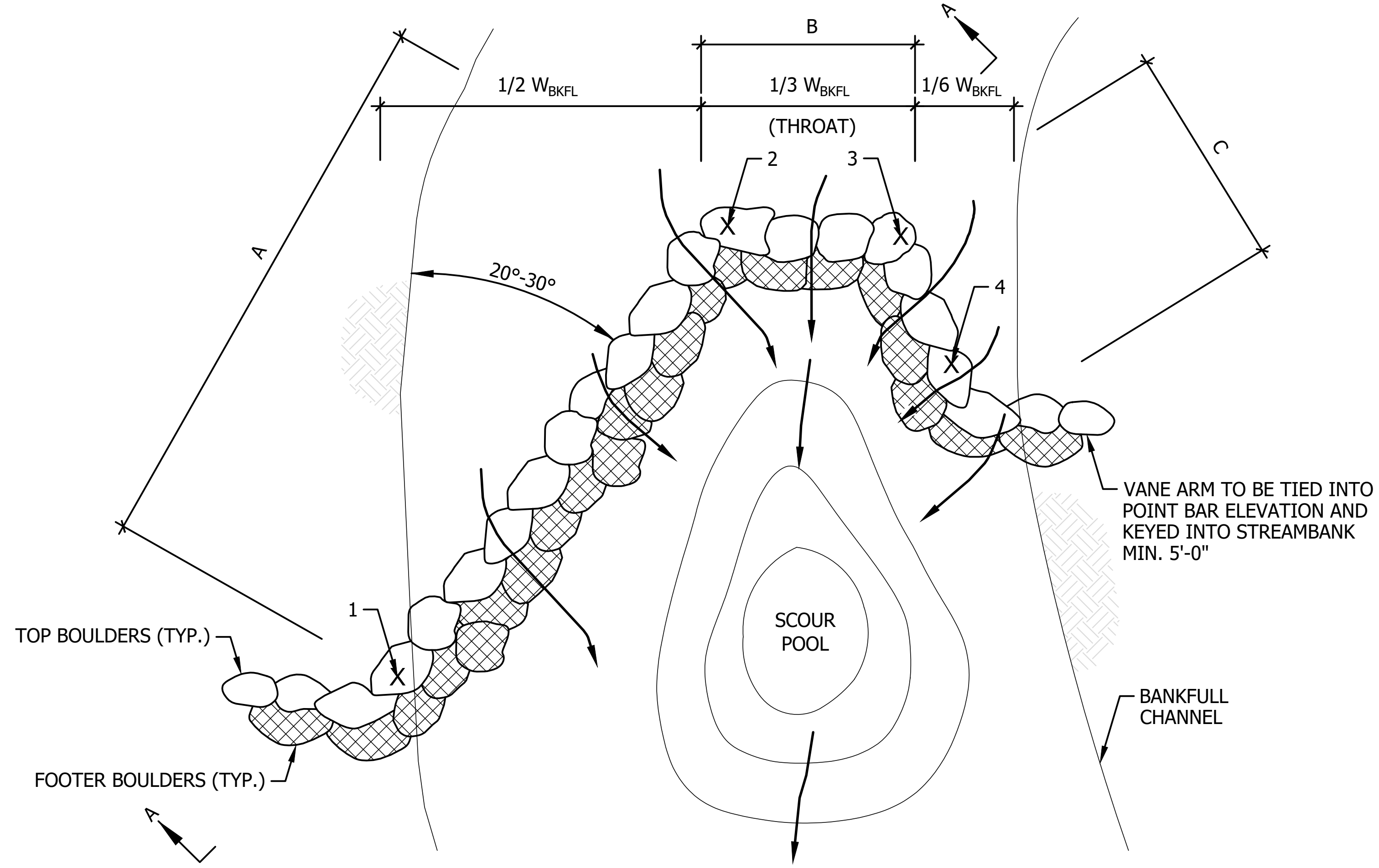
2.19.4 Notes to Designers

- Offset cross rock vanes can be installed with various throat configurations based upon site specific conditions.
  - The designer should revise the standard detail and specification to **remove** reference to any throat configurations that are not to be utilized.
- At a minimum, the vane arms should be extended 5 feet into the streambank.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

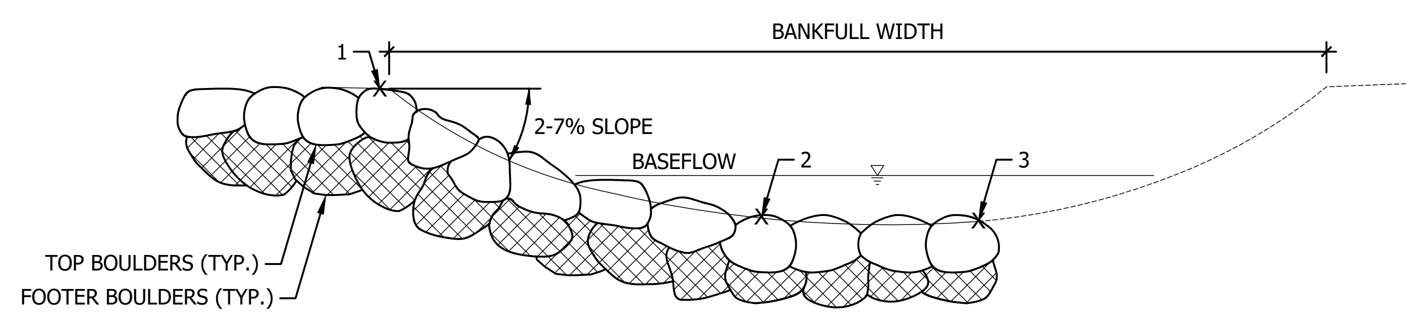
2.19.5 Photographs

Photograph 1: Offset cross rock vane during construction at UNT to Patapsco River, Baltimore County, MD. Source: JMT.

Photograph 2: Offset cross rock vane following construction at Jones Falls, Baltimore County, MD. Source: JMT.



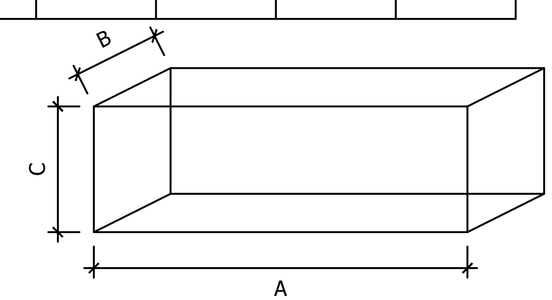
PLAN VIEW



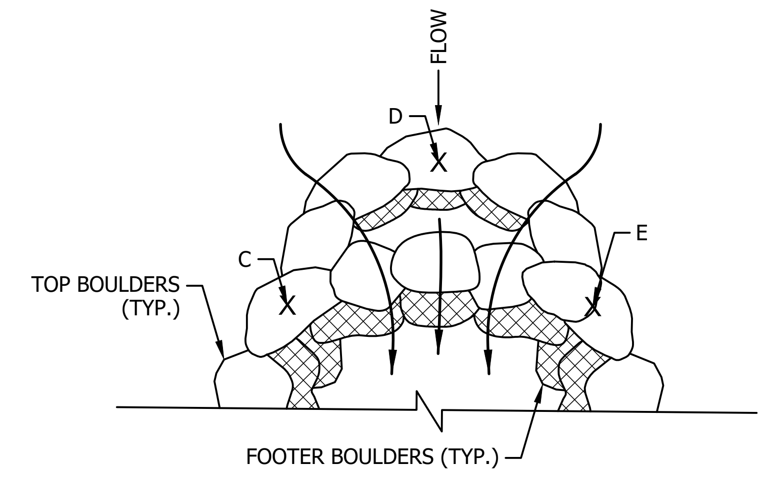
SECTION VIEW A-A

STRUCTURE SCHEDULE							
STRUCTURE ID	LENGTHS (FT)			INVERT ELEVATIONS (FT)			
	A	B	C	1	2	3	4

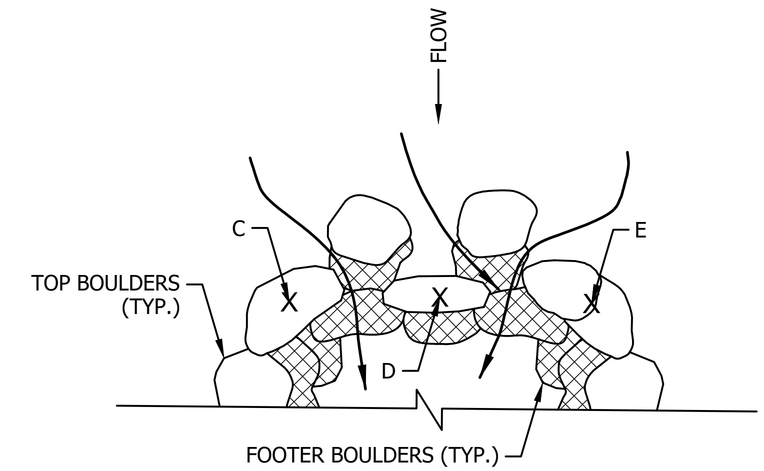
BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



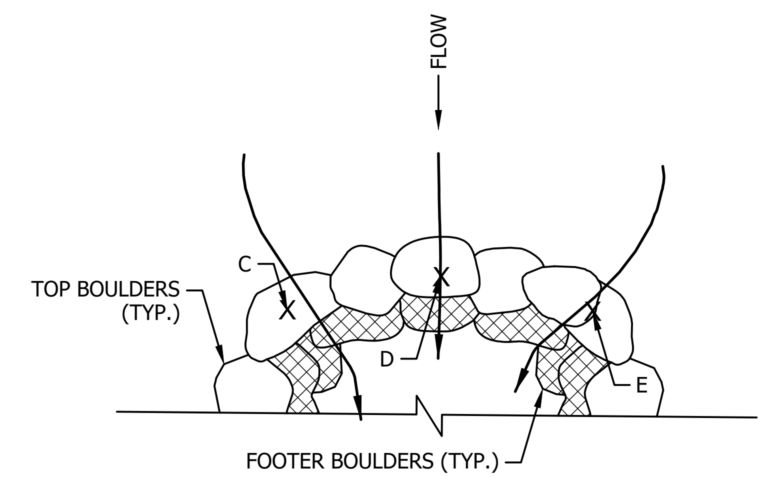
BOULDER SIZING DETAIL



STEPPED THROAT DETAIL



OPEN THROAT DETAIL



CLOSED-GAP THROAT DETAIL

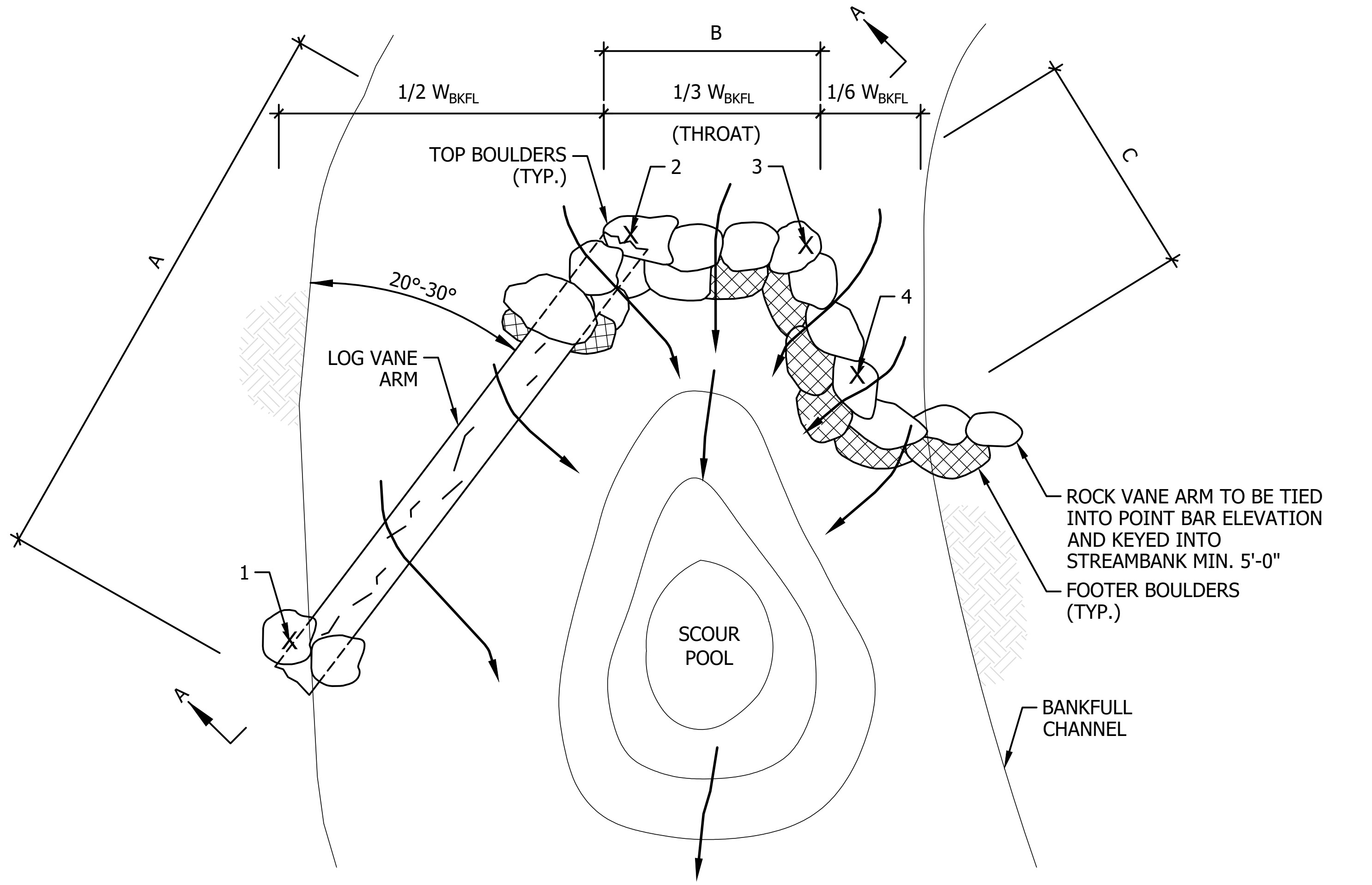
PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST.
4TH FLOOR
PHILADELPHIA, PA
19107

OFFSET CROSS ROCK VANE

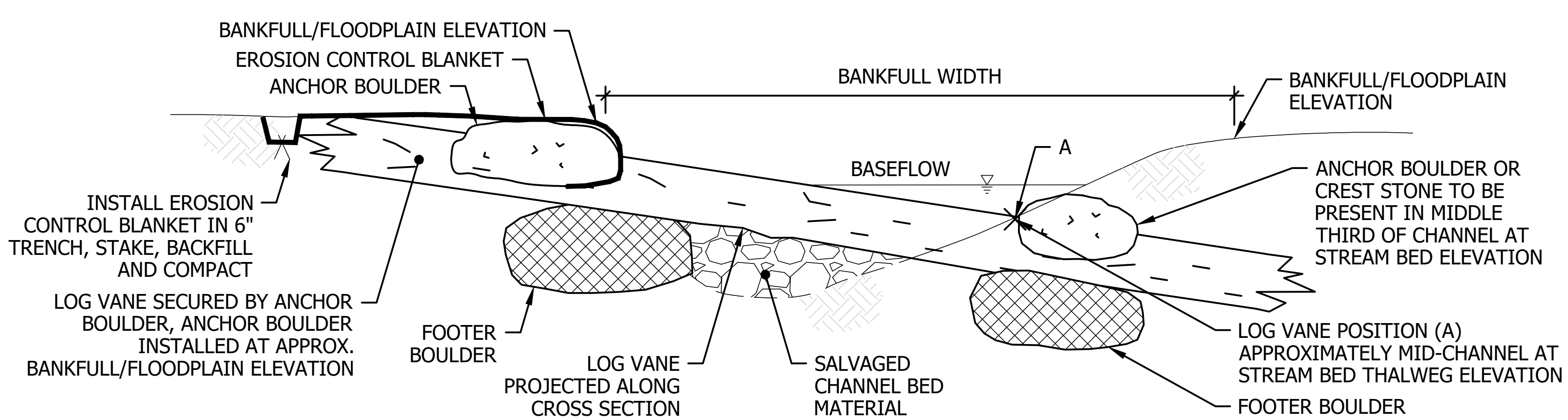
VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S19.1

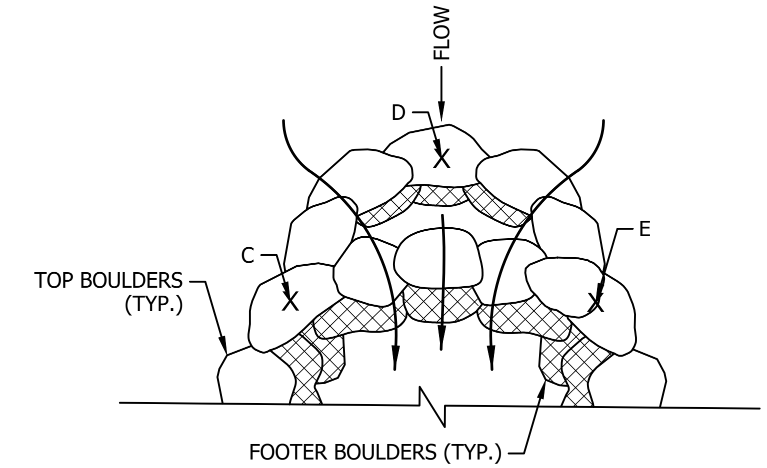


PLAN VIEW

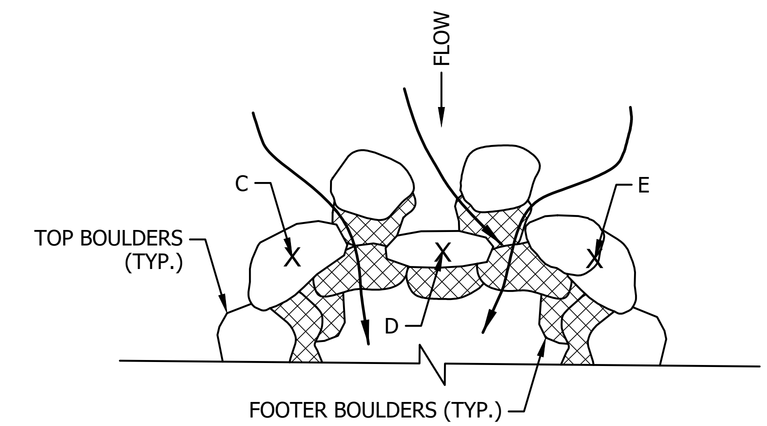


SECTION VIEW A-A

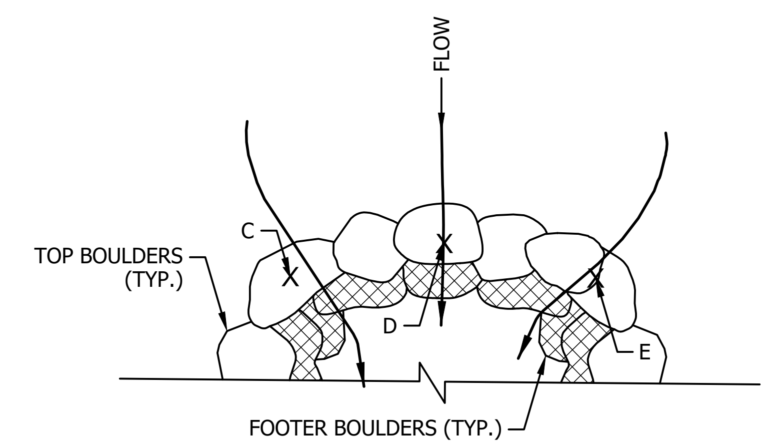
STRUCTURE SCHEDULE							
STRUCTURE ID	LENGTHS (FT)			INVERT ELEVATIONS (FT)			
	A	B	C	1	2	3	4



STEPPED THROAT DETAIL



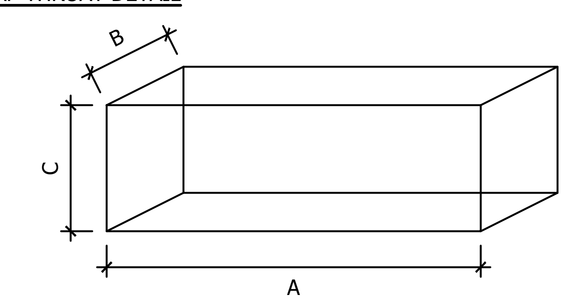
OPEN THROAT DETAIL



CLOSED-GAP THROAT DETAIL

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			

BOULDER SIZING DETAIL



PHILADELPHIA WATER DEPARTMENT

1101 MARKET ST.
4TH FLOOR
PHILADELPHIA, PA
19107

OFFSET CROSS ROCK LOG VANE

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER: S19.2

2.20 Rock Vane

A rock vane is a single arm, low profile rock structure that directs flow away from the streambanks. Rock vanes decrease shear stress and velocity in the near-bank region while increasing energy in the center of the channel to promote the development of scour pools for habitat. This structure will reduce bank erosion while maintaining sediment transport capacity and sediment competence.

2.20.1 Components

A rock vane consists of the following components:

- Large, rectangular, blocky top and footer boulders sized to resist the erosive forces of water being conveyed through the structure.
- A choking layer incorporated into the boulders, consisting of gravels and cobbles (furnished or salvaged), to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. May also help to promote expression of base flow conditions above channel grade.

2.20.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Best suited for stable stream systems that require varying habitat and minor bank protection; can promote pool development.	Streambanks on the opposite side of the channel should be monitored for excessive erosion.
Best suited for lower gradient stream systems, but can be implemented on higher gradient stream systems.	Not recommended for use on stream systems where bedrock is at, or very near, the surface due to limitations for scour pool development.
Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.	Not recommended for use on severely eroding, actively incising, and/or entrenched or unstable stream channels, as erosion and channel incision may undermine the structure.

2.20.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - o Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - o Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

    Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized vane and footer rocks, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

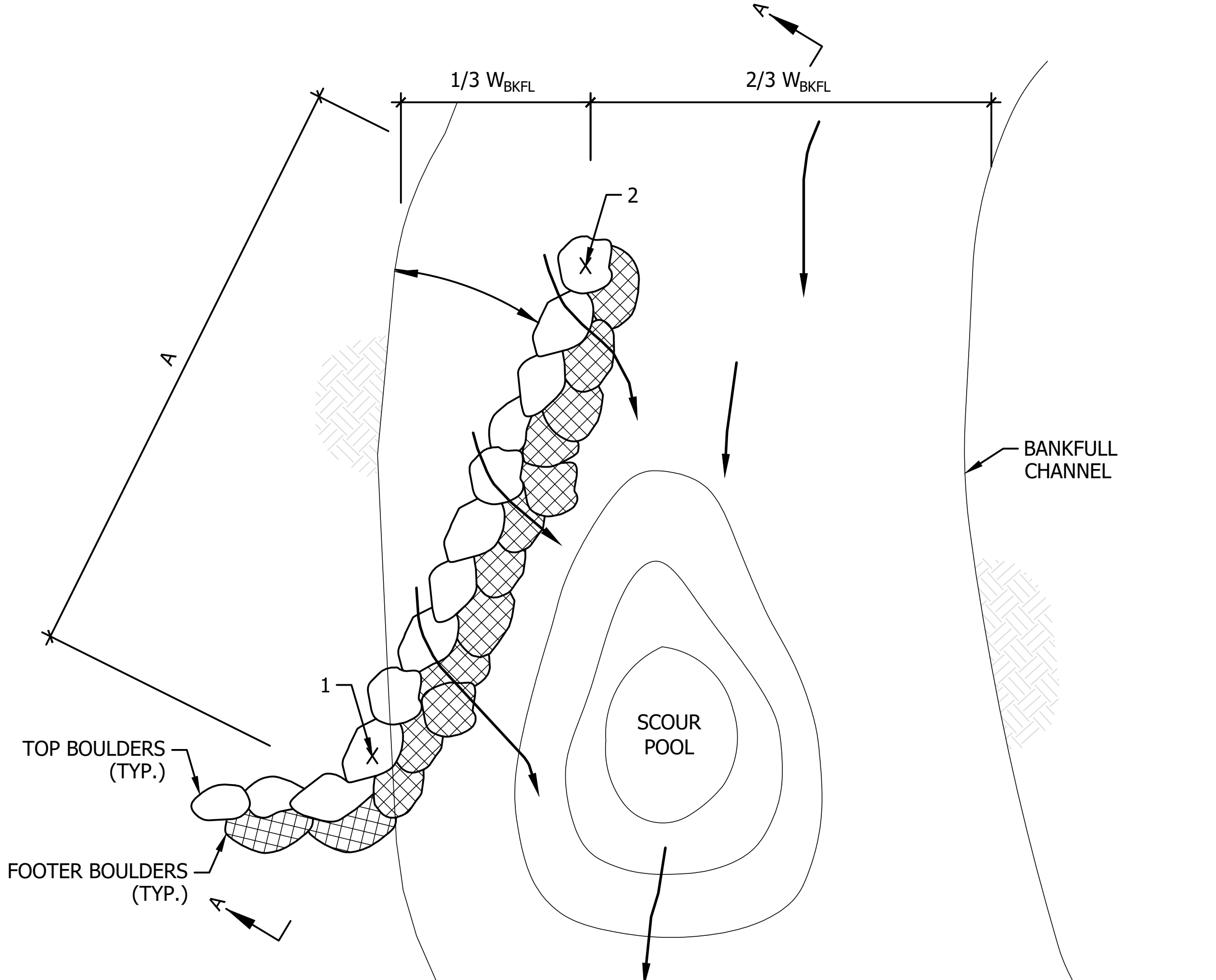
2.20.4 Notes to Designers

- At a minimum, the vane arms should be extended 5 feet into the streambank.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

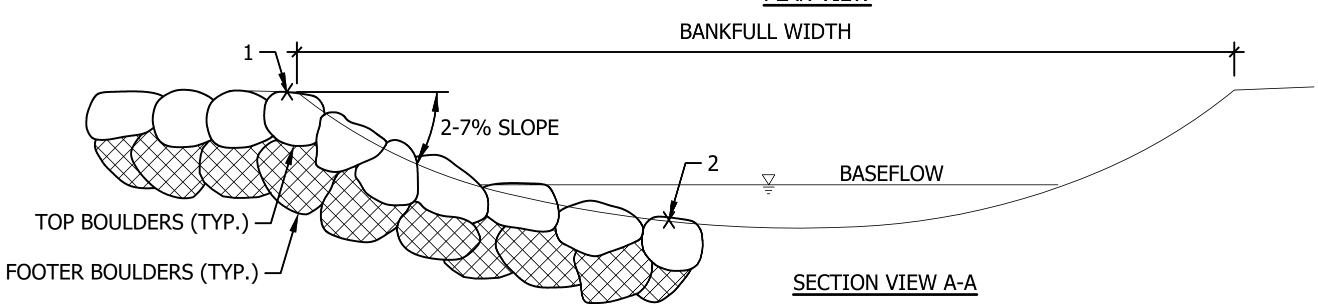
2.20.5 Photographs

Photograph 1: Rock vane during construction at Middle Creek, Frederick County, MD. Source: JMT.

Photograph 2: Rock Vane following construction at Middle Creek, Frederick County, MD. Source: JMT.



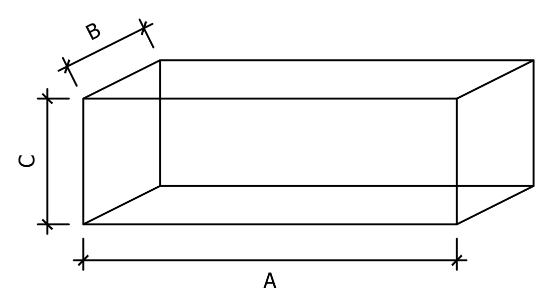
PLAN VIEW



SECTION VIEW A-A

STRUCTURE SCHEDULE							
STRUCTURE ID	LENGTHS (FT)			INVERT ELEVATIONS (FT)			
	A	B	C	1	2	3	4

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



BOULDER SIZING DETAIL

PHILADELPHIA
WATER
DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

ROCK VANE

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER:
S20

2.21 Boulder Wall

A boulder wall is used for infrastructure protection and streambank stabilization within a high-stress or entrenched channel condition, and typically encompasses the entire height of the streambank.

2.21.1 Components

A boulder wall consists of the following components:

- Large, rectangular, blocky boulders that are stackable to create a uniform and stable wall that will resist the erosive forces of channelized stream flow.
- A footer boulder designed to a depth based upon site-specific conditions to prevent failure due to long-term bed degradation and/or localized scour.
- Rock toe protection constructed of appropriately sized riprap choked with salvaged channel bed material – and conforming to the footer boulder depth – to resist the tractive forces of channelized stream flow at the interface between the wall and streambed.
- A filter stone (free-draining) backfill wrapped in non-woven geotextile to prevent soil movement into and through the boulder wall – which could undermine its footing or fill void spaces in the backfill – while allowing water to freely drain through the structure to avoid failure from freeze/thaw processes and/or the build-up of hydrostatic pressure.
- Backfill slope consisting of topsoil, seeded and stabilized with erosion control blanket.

2.21.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Method of providing resistance to tractive forces (shear stress and velocity) where streambank stabilization and/or infrastructure protection is required for utilities located adjacent to and parallel to the channel.	For actively incising stream channels and/or utility crossings (perpendicular to channel), consider implementing a streambed vertical grade control structure in conjunction with the boulder wall.
If properly designed, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.21.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

    Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized rock for the boulder wall, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

    The following Rock Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized rock for the rock toe protection, but other relationships may be used based upon site specific conditions and/or designer's professional judgement:

    - Shields' Entrainment Function
    - Leopold, Wolman, and Miller (1964) Entrainment Function
    - Rosgen (or Regionally Developed) Rock Sizing and Mobility Curves
    - Andrews Methodology
    - Ishbash Equation
  - Footer boulder depth – and corresponding rock toe protection depth – shall be designed to a depth based upon site-specific conditions to prevent failure due to long-term bed degradation and/or localized scour.
    - The Federal Highway Administration, Hydraulic Engineering Circular No. 23 Bridge Scour and Stream Instability Countermeasures method for Scour at Longitudinal Structures – Scour Depth Calculations provided in the ***General Literature*** section – is recommended for use in determining the localized scour depth, but other methods may be used based upon site specific conditions and/or designer's professional judgement.
  - Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

2.21.4 Notes to Designers

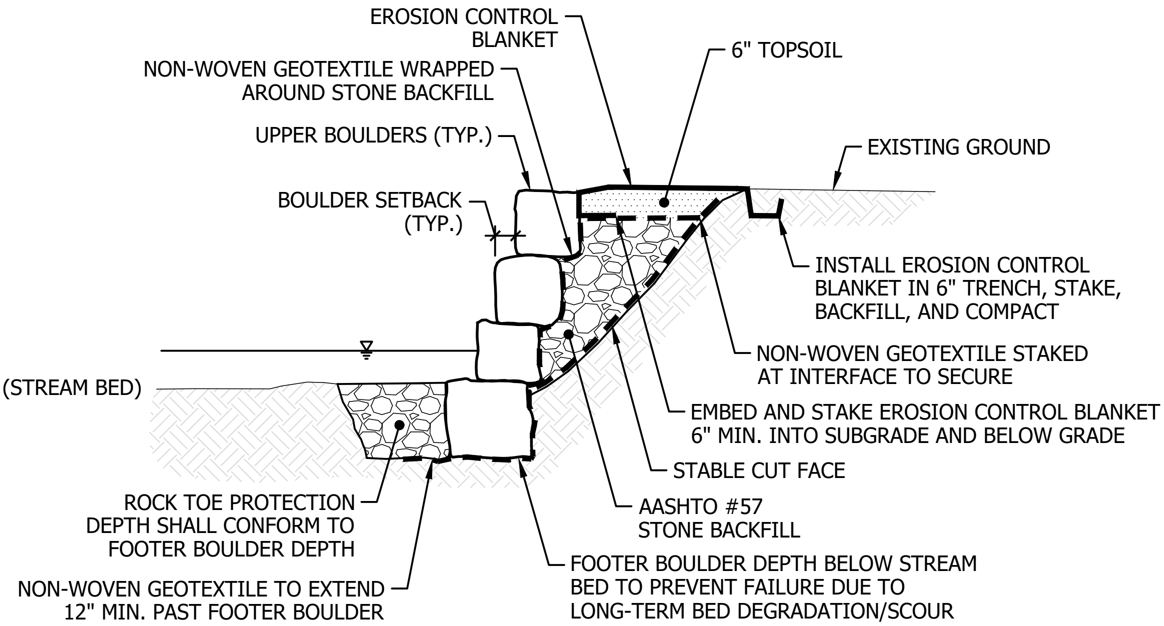
- The designer should consult with their Geotechnical Engineer for the design of boulder walls based upon site specific conditions, height and use.
    - Geotechnical design calculations must be provided for wall heights exceeding 10 feet maximum height (from bottom of footer boulder to top of wall).
    - Geotechnical consultation – and calculations if necessary based upon site specific conditions, height and use – should be performed for all other walls not exceeding the maximum height.
    - Soil borings should be performed as part of the Geotechnical Investigative Testing and Reporting efforts.
- The length of the longest axis of each rock used to construct the boulder wall should be the greater of 1/3 the total height of the boulder wall or the size necessary to resist the tractive forces as described under the ***Computations*** section above.
- At a minimum, rock used for construction of rock toe protection should be R-4 riprap or larger.
- The footer boulder and rock toe protection depths shall be designed to a depth based upon site specific conditions to prevent failure due to long-term bed degradation and/or localized scour as described under the ***Computations*** section above.
    - The designer should revise the standard detail and specification to **add** reference to the site-specific footing depth.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

2.21.5 Photographs

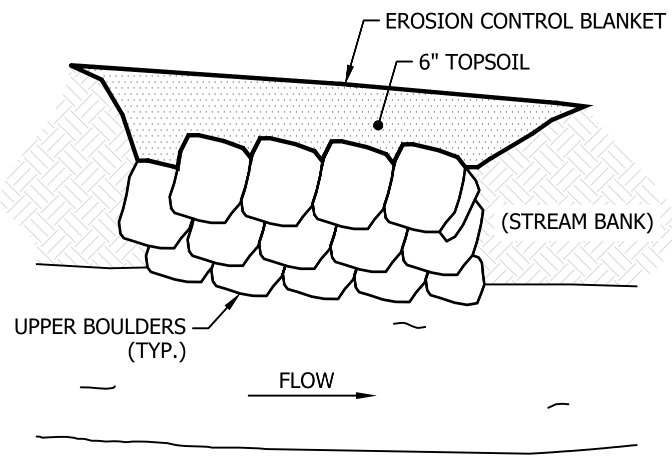
Photograph 1: Boulder wall during construction at UNT Middle Patuxent River, Howard County, MD; showing preparation of non-woven geotextile and beginning of filter stone backfill installation. Source: JMT.

Photograph 2: Boulder wall during construction at UNT Middle Patuxent River, Howard County, MD; showing installation of filter stone backfill to be wrapped in non-woven geotextile. Source: JMT.

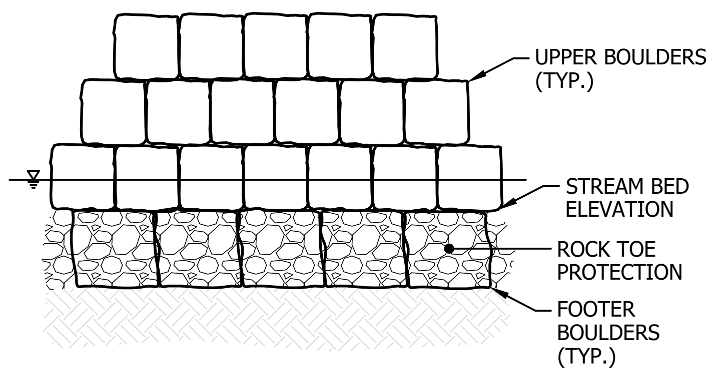
Photograph 3: Boulder wall following construction at UNT Middle Patuxent River, Howard County, MD. Source: JMT.



SECTION VIEW

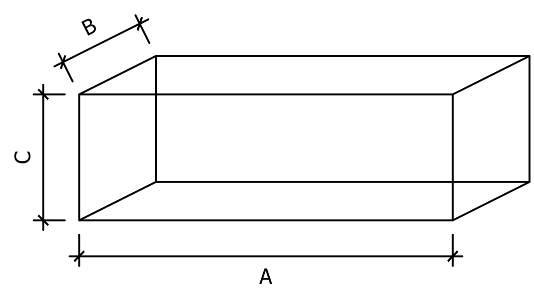


PLAN VIEW



ELEVATION VIEW

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



BOULDER SIZING DETAIL

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

BOULDER WALL

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S21

2.22 Rock Step Pool with Boulder Toe Revetment

A rock step pool with boulder toe revetment consists of constructing a step pool facet for use on higher gradient stream systems for grade control and the creation of pools for habitat; this structure is combined with boulder toe revetment to provide streambank protection and creating a bankfull/floodplain bench for shear stress relief within a high-stress or entrenched channel condition.

This structure consists of a series of steps (vertical grade changes) formed by large, rectangular, blocky rocks followed by pool features used to dissipate energy in the system from supercritical flow tumbling over the steps to subcritical flow in the downstream pool.

2.22.1 Components

A rock step pool with boulder toe revetment consists of the following components:

- Step and footer boulders constructed of large, rectangular, blocky rocks that are stackable to create a uniform and stable step that will resist the erosive forces of channelized stream flow.
- Low boulder wall with footer boulders constructed of large, rectangular, blocky rocks that are stackable to create a uniform and stable wall that will resist the erosive forces of channelized stream flow.
- A choking layer incorporated into the boulders, consisting of gravels and cobbles (furnished or salvaged), to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. May also help to promote expression of base flow conditions above channel grade.
- Filler rock consisting of salvaged and/or furnished channel bed material (large gravels and cobbles) used to restore channel bed stability within the pools.

A rock step pool with boulder toe revetment may contain the following **optional** components based upon site specific conditions:

- A filter layer created by non-woven geotextile to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. The filter layer also allows for fine sediments from upstream to naturally fill in void spaces within the rock.

2.22.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Stream flow conveyance down gradient through relatively straight reaches of stream and higher gradient stream systems. Typically used as part of a step-pool facet sequence, promoting vertical grade control.	Not recommended for low gradient stream systems as planform and profile geomorphic conditions provide for proper distribution of energy conditions within these types of systems.
If properly sized, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.22.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

    Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized rock for the boulder toe revetment, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.
  - Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.
  - Pool-to-Pool Spacing Calculations – provided in the ***General Literature*** section – are recommended for use in determining appropriate pool-to-pool spacing and rock step heights for the rock step pool with boulder toe revetment, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

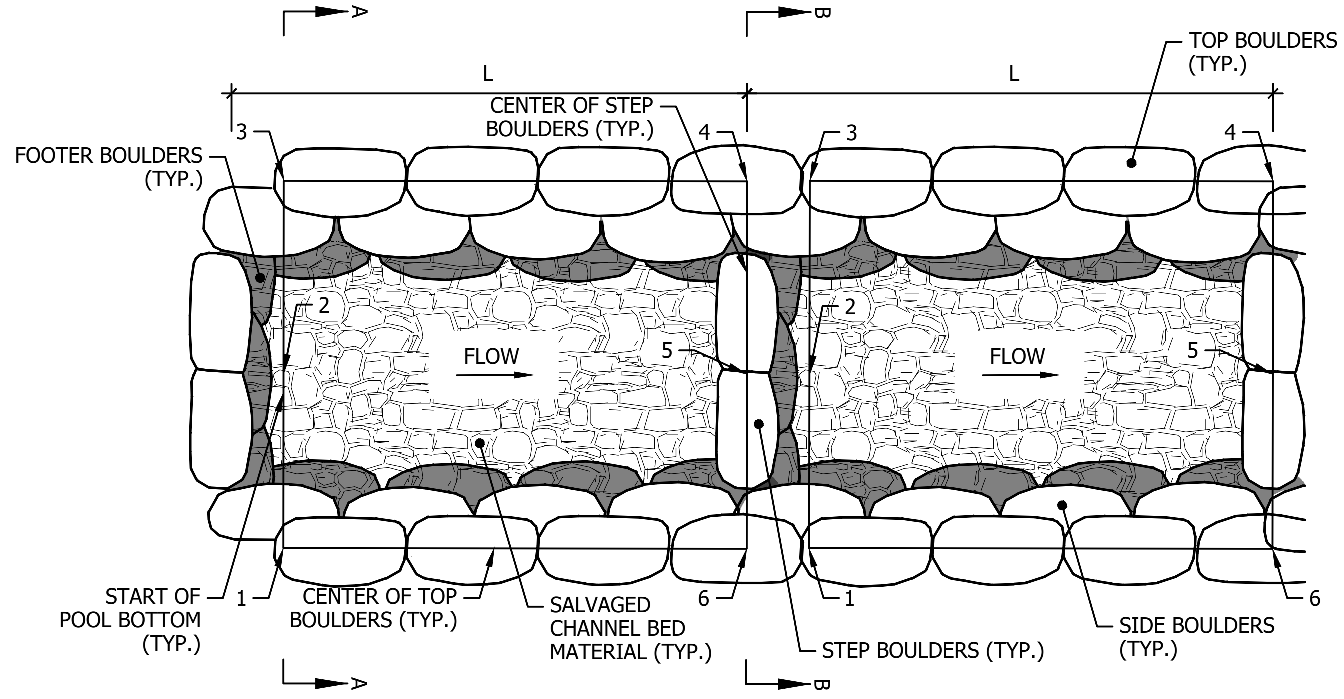
2.22.4 Notes to Designers

- Non-woven geotextile between subgrade and structure is optional based upon site specific conditions. Conditions that may warrant non-woven geotextile or filter stone layer include but are not limited to: non-cohesive bank material (such as sand or gravel) or construction of a rock step pool with boulder toe revetment placed in fill. The designer should consult with their Geotechnical Engineer to determine if an underlayment is necessary.
  - The designer should revise the standard detail and specification to **<u>remove</u>** reference to non-woven geotextile if it is not warranted.
- The length of the longest axis of each rock used to construct the boulder toe revetment should be the greater of 1/3 the total height of the boulder wall or the size necessary to resist the tractive forces as described under the ***Computations*** section above.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

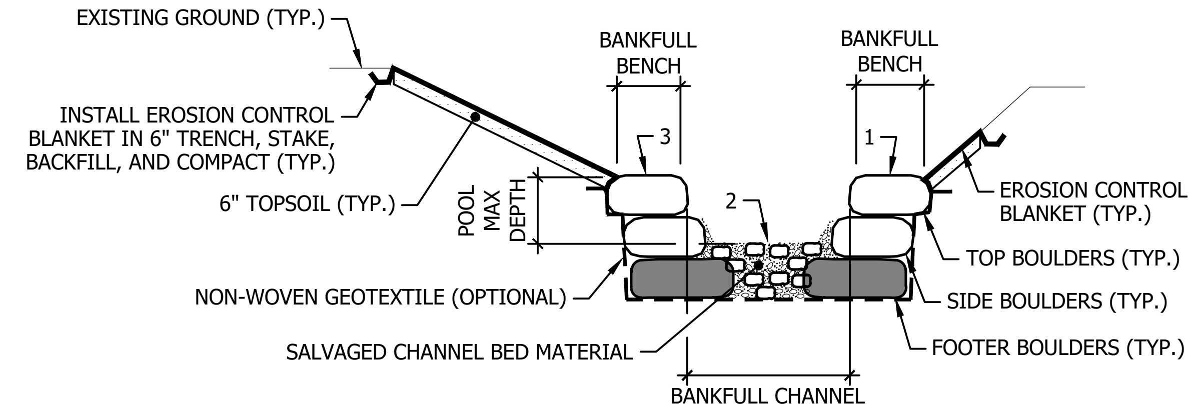
2.22.5 Photographs

Photograph 1: Rock step pool with boulder toe revetment following construction at West Branch Indian Creek, Philadelphia, PA. Source: PWD.

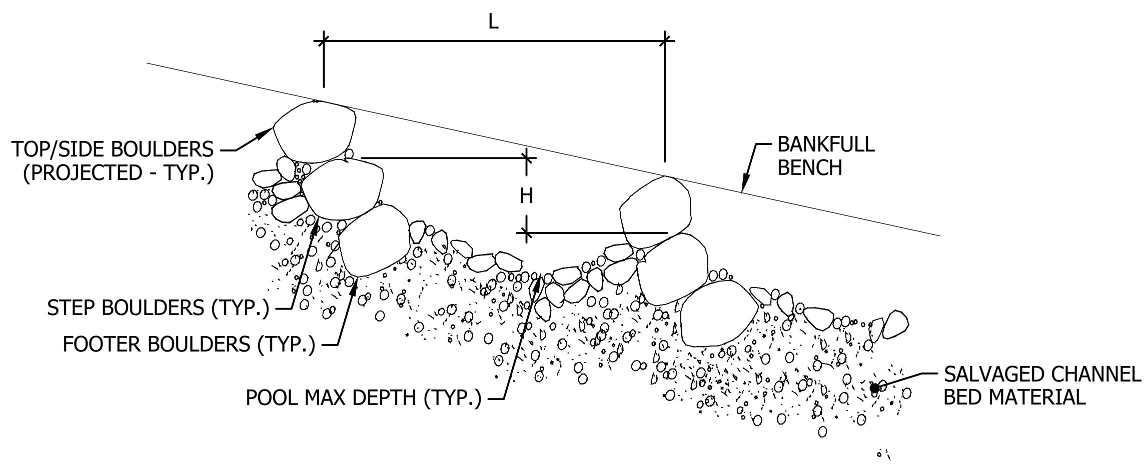
Photograph 2: Rock step pool with boulder toe revetment following construction at West Branch Indian Creek, Philadelphia, PA. Source: PWD.



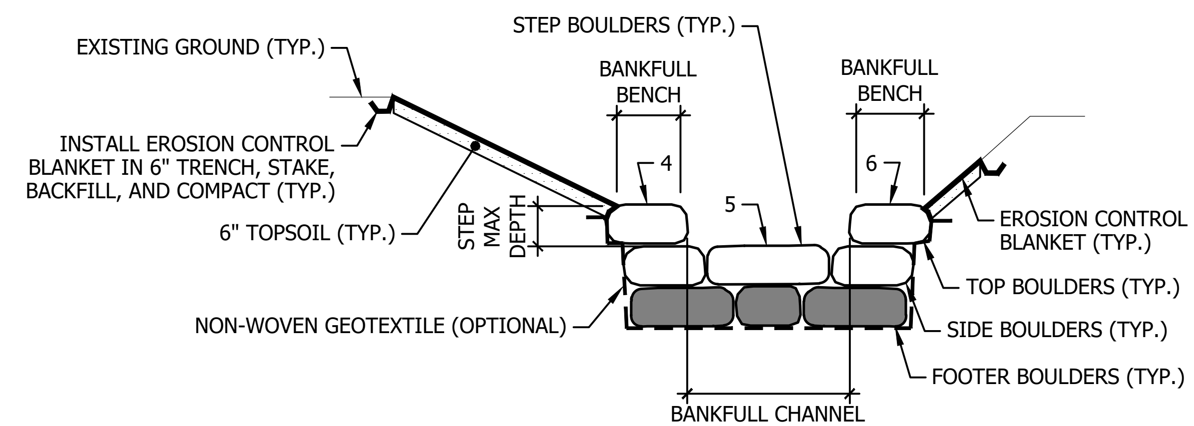
PLAN VIEW



SECTION VIEW A-A

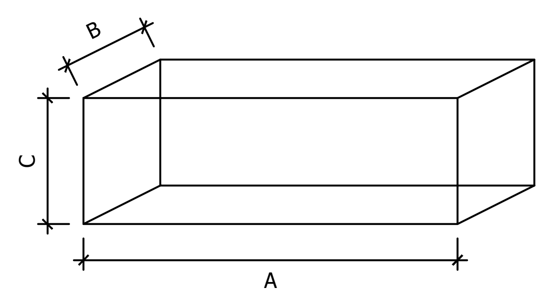


PROFILE VIEW



SECTION VIEW B-B

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



BOULDER SIZING DETAIL

PHILADELPHIA WATER DEPARTMENT

1101 MARKET ST.
4TH FLOOR
PHILADELPHIA, PA
19107

ROCK STEP POOL WITH BOULDER TOE REVETMENT

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S22

2.23 Riprap Revetment

Riprap revetment is rock slope protection used to protect and stabilize eroded streambanks, typically in entrenched and/or confined stream channels. Riprap revetment may also be used to protect embankments at roadway crossings that are prone to high energy conditions within contraction/expansion zones.

2.23.1 Components

Riprap revetment consists of the following components:

- A layer of angular rock sized to resist the erosive forces of channelized flow conditions.
- A filter layer created by non-woven geotextile or filter stone to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. The filter layer also allows for fine sediments from upstream to naturally fill in void spaces within the rock.

2.23.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Method of providing resistance to tractive forces (shear stress and velocity) where turbulent flow conditions are present and vegetation is absent, can be used where infrastructure protection is required. Example includes sewer or other utilities located adjacent to and parallel to the channel and/or roadway embankments.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.
If properly sized, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Not recommended for use on severely eroding and/or actively incising stream channels, as erosion and channel incision may undermine the structure.

2.23.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.
    - The National Cooperative Highway Research Program, Report 568 Riprap Design Criteria, Recommended Specifications, and Quality Control, Appendix C: Guidelines for the Design and Specification of Rock Riprap Installations, Section 2: Revetment Riprap, Part 2.1: Sizing the Riprap – Riprap Revetment Sizing provided in the ***General Literature*** section – is recommended for use in determining the

required rock size, but other methods such as Lane's Method (1955) may be used based upon site specific conditions and/or designer's professional judgement.

- Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.

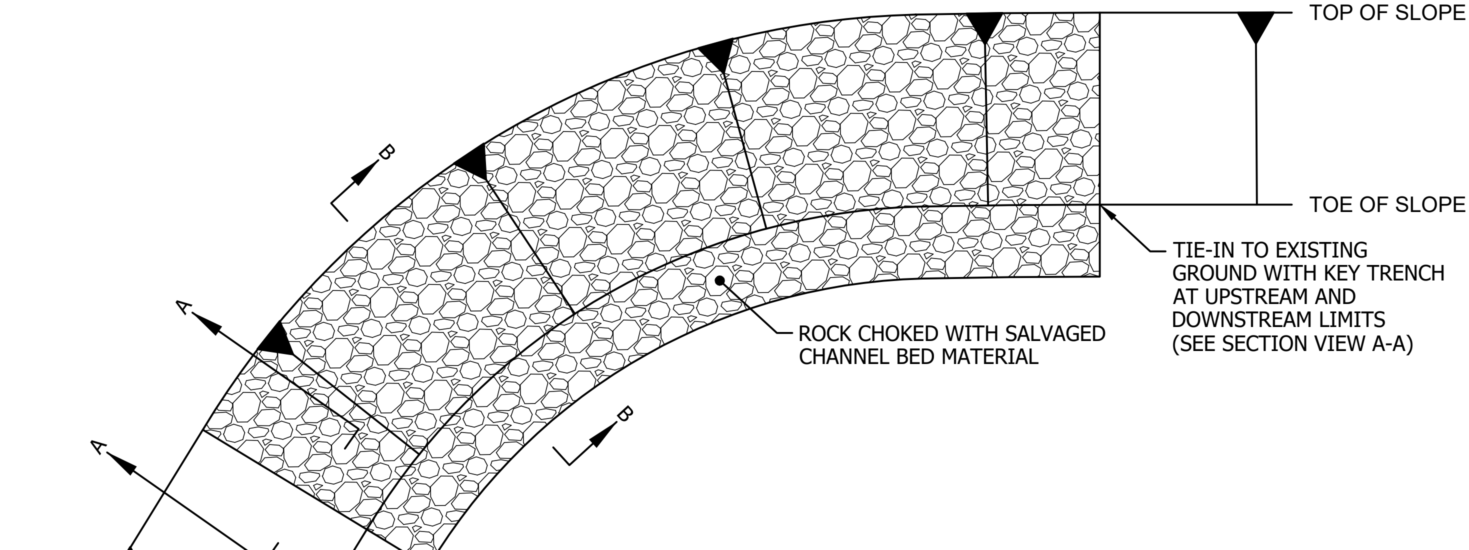
2.23.4 Notes to Designers

- A filter layer of non-woven geotextile should only be used when the bank material is non-cohesive (such as sand or gravel). Otherwise the filter layer shall be constructed using a filter stone layer between subgrade and structure. The designer should consult with their Geotechnical Engineer to determine the appropriate type of underlayment.
  - The designer should revise the standard detail and specification to **remove** reference to the filter layer that is not selected for construction.
- Riprap revetment should be installed on slopes 2(H):1(V) or flatter.
- At a minimum, rock used for construction of riprap revetment should be R-5 riprap or larger. The minimum placement thickness of the rock should be at least 2x the D50 of the selected riprap size.

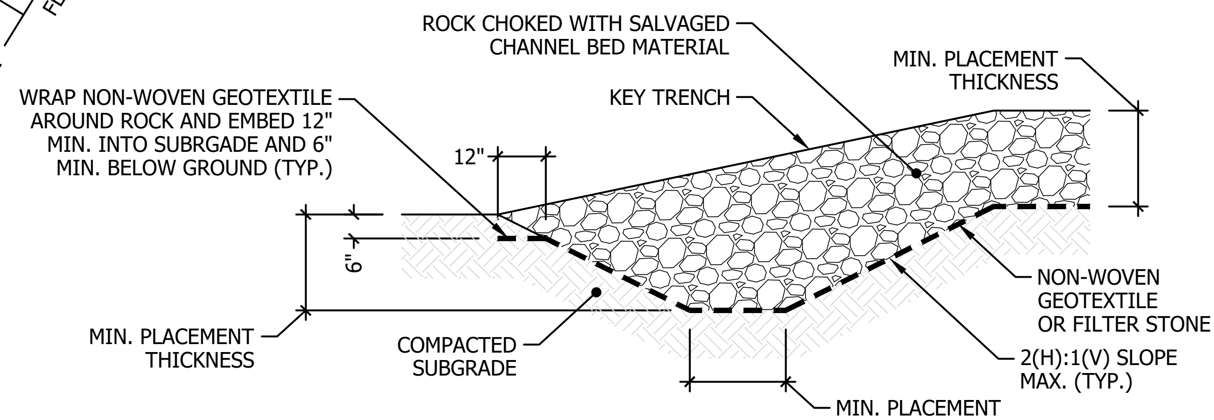
2.23.5 Photographs

Photograph 1: Riprap revetment following construction at Nash Run, Washington, DC. Source: JMT.

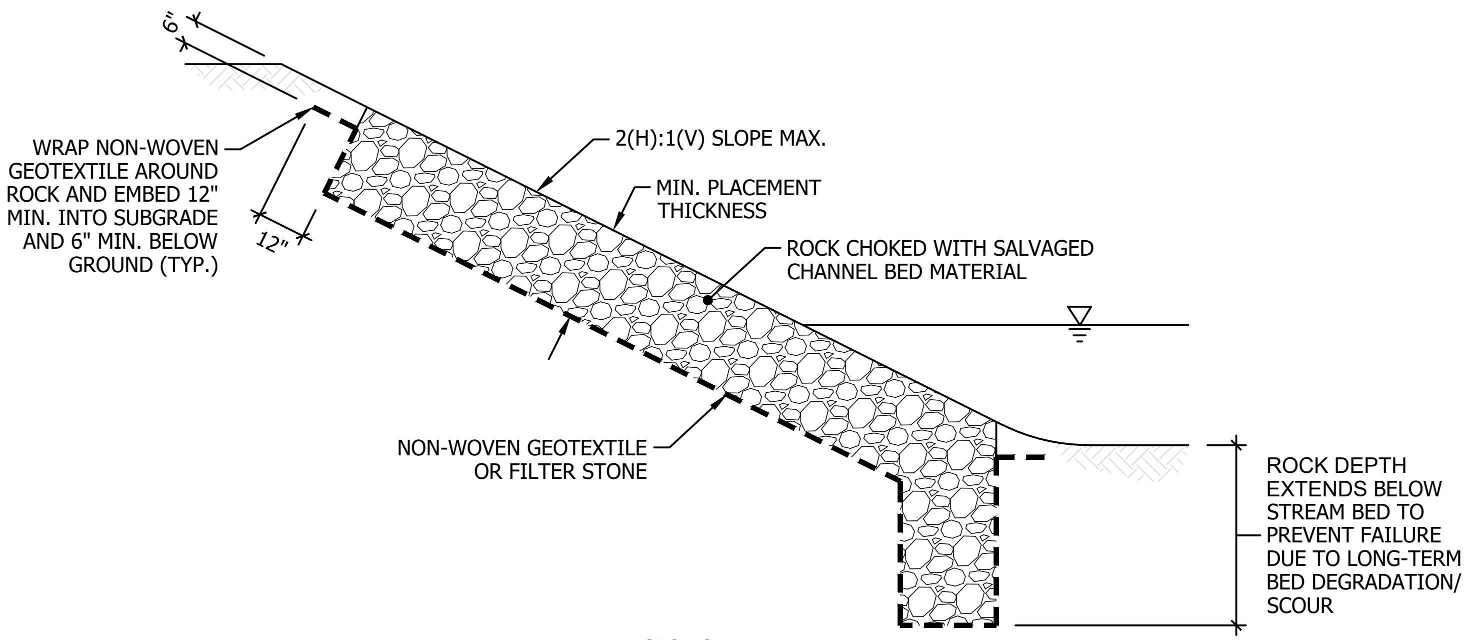
Photograph 2: Riprap revetment following construction at Nash Run, Washington, DC. Source: JMT.



PLAN VIEW



SECTION VIEW A-A



SECTION VIEW B-B

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

RIPRAP REVETMENT

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER: S23

2.24 Boulder Toe Revetment

Boulder toe revetment is a low boulder wall – similar to boulder terraces – used for infrastructure protection, streambank protection, and creating a bankfull/floodplain bench for shear stress relief. Boulder toe revetment provides the ability to maintain appropriate bankfull and base flow channel dimensions within a high-stress or entrenched channel condition.

2.24.1 Components

Boulder toe revetment consists of the following components:

- Low boulder wall constructed of large, rectangular, blocky rocks that are stackable to create a uniform and stable wall that will resist the erosive forces of channelized stream flow.
- A footer boulder designed to a depth based upon site-specific conditions to prevent failure due to long-term bed degradation and/or localized scour.
- Rock toe protection constructed of appropriately sized riprap choked with salvaged channel bed material – and conforming to the footer rock depth – to resist the tractive forces of channelized stream flow at the interface between the wall and streambed.
- Vegetated bankfull/floodplain bench consisting of topsoil, seeded and stabilized with erosion control blanket, and planted with live stakes or pole plantings.

Boulder toe revetment may contain the following **optional** components based upon site specific conditions:

- A non-woven geotextile filter layer to prevent soil movement into and through the boulder toe revetment – which could undermine its footing – while allowing water to freely drain through the structure to avoid failure from freeze/thaw processes and/or the build-up of hydrostatic pressure.
- A key trench constructed of large, rectangular, blocky rocks that are stackable to create a uniform and stable tie-in to existing subgrade based upon site-specific conditions. The key trench is intended to prevent soil movement behind the structure due to the erosive forces of channelized stream flow and/or piping.

2.24.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Method of providing resistance to tractive forces (shear stress and velocity) where streambank stabilization and/or infrastructure protection is required for utilities located adjacent to and parallel to the channel.	For actively incising stream channels and/or utility crossings (perpendicular to channel), consider implementing a streambed vertical grade control structure in conjunction with the boulder toe revetment.
If properly designed, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.24.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
    - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
    - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

      Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized boulders for the boulder toe revetment, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

      The following Rock Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized rock for the rock toe protection, but other relationships may be used based upon site specific conditions and/or designer's professional judgement:
        - Shields Entrainment Function
        - Leopold, Wolman, and Miller (1964) Entrainment Function
        - Rosgen (or Regionally Developed) Rock Sizing and Mobility Curves
        - Andrews Methodology
        - Ishbash Equation
    - Footer boulder depth – and corresponding rock toe protection depth – shall be designed to a depth based upon site specific conditions to prevent failure due to long-term bed degradation and/or localized scour.
        - The Federal Highway Administration, Hydraulic Engineering Circular No. 23 Bridge Scour and Stream Instability Countermeasures method for Scour at Longitudinal Structures – Scour Depth Calculations provided in the ***General Literature*** section – is recommended for use in determining the localized scour depth, but other methods may be used based upon site specific conditions and/or designer's professional judgement.
    - Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

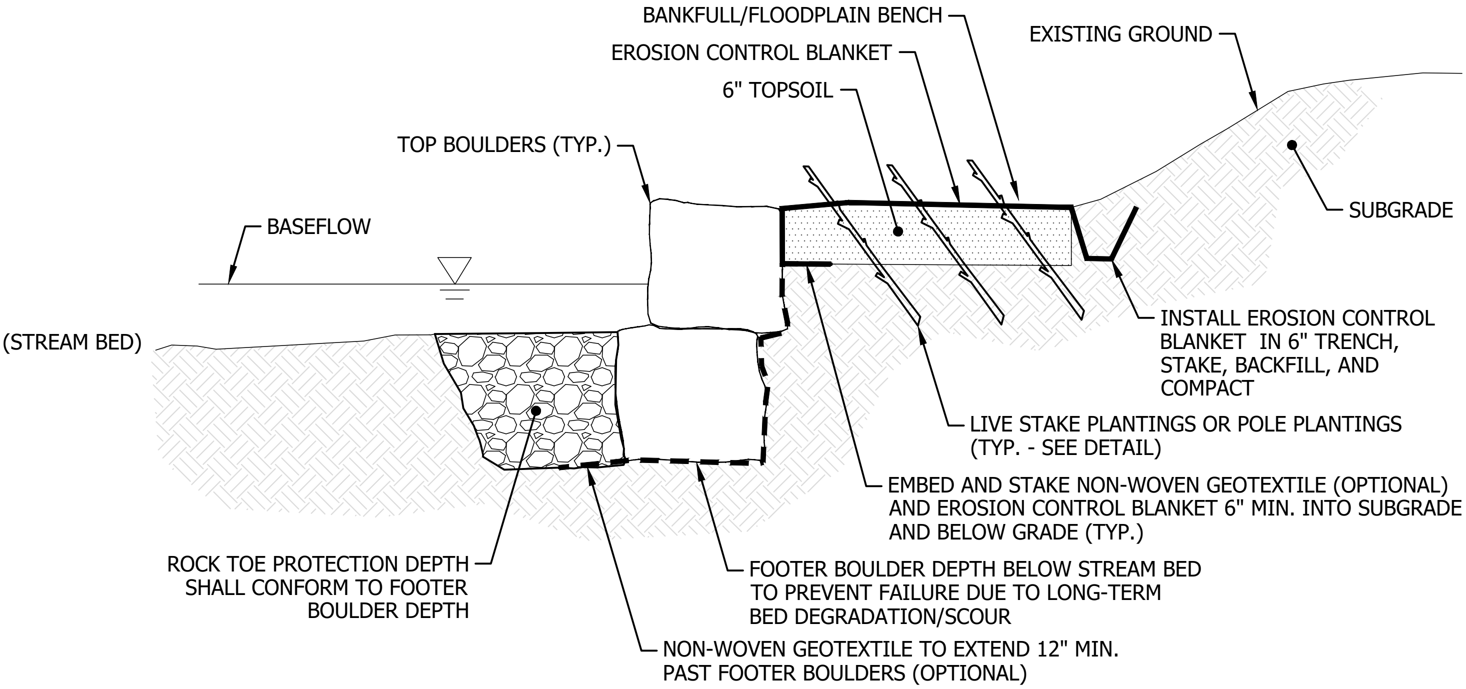
2.24.4 Notes to Designers

- Non-woven geotextile filter layer between subgrade and structure is optional based upon site specific conditions. Conditions that may warrant non-woven geotextile include but are not limited to: non-cohesive bank material (such as sand or gravel) or construction of boulder toe revetment placed in fill. The designer should consult with their Geotechnical Engineer to determine if non-woven geotextile is necessary.
    - The designer should revise the standard detail and specification to **remove** reference to non-woven geotextile if it is not warranted.
- The length of the longest axis of each rock used to construct the boulder toe revetment should be the greater of 1/3 the total height of the boulder wall or the size necessary to resist the tractive forces as described under the ***Computations*** section above.
- At a minimum, rock used for construction of rock toe protection should be R-4 riprap or larger.
- The footer boulder and rock toe protection depths shall be designed to a depth based upon site specific conditions to prevent failure due to long-term bed degradation and/or localized scour as described under the ***Computations*** section above.
- The designer should revise the standard detail and specification to **add** reference to the site-specific footing depth.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

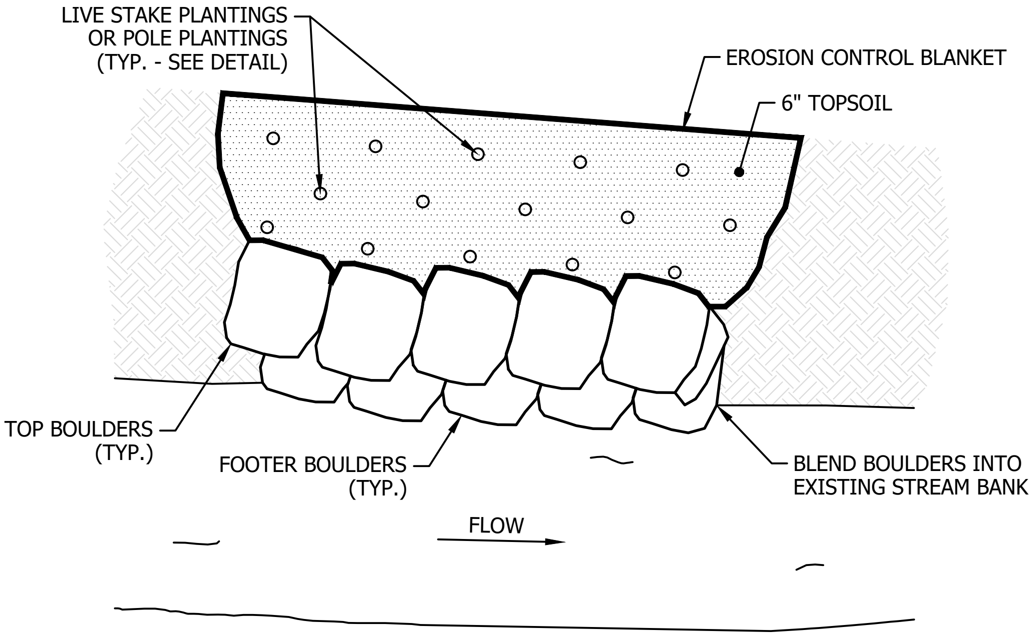
2.24.5 Photographs

Photograph 1: Boulder toe revetment during construction at Saw Mill Run, Allegheny County, PA. Source: JMT.

Photograph 2: Boulder toe revetment following construction at Saw Mill Run, Allegheny County, PA. Source: JMT.

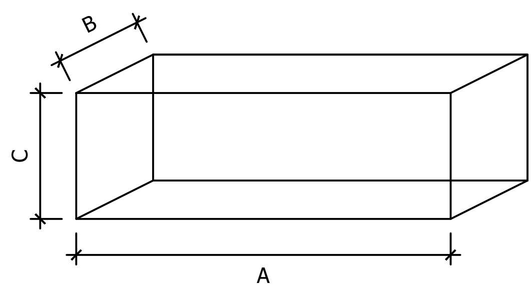


SECTION VIEW



PLAN VIEW

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



BOULDER SIZING DETAIL

PHILADELPHIA WATER DEPARTMENT

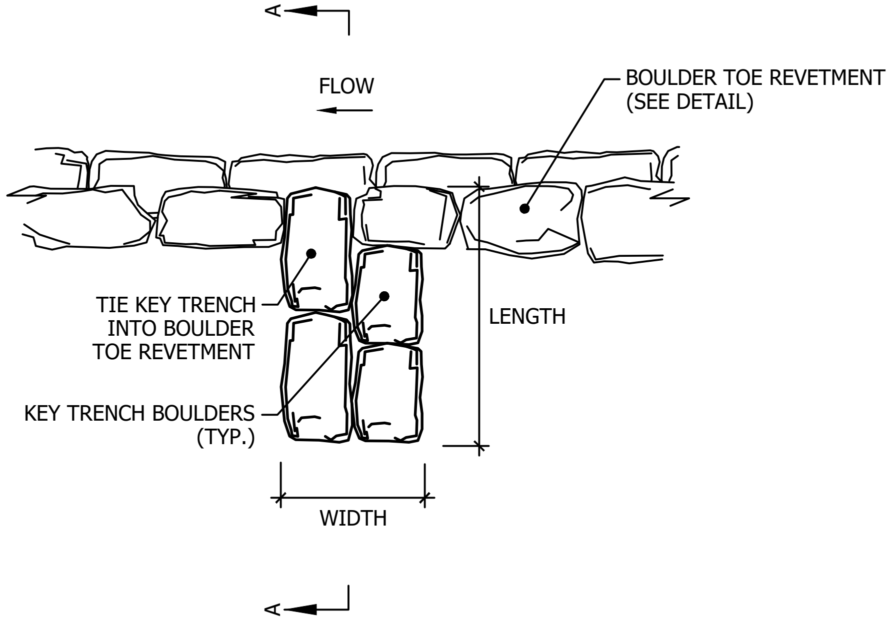
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

BOULDER TOE REVETMENT

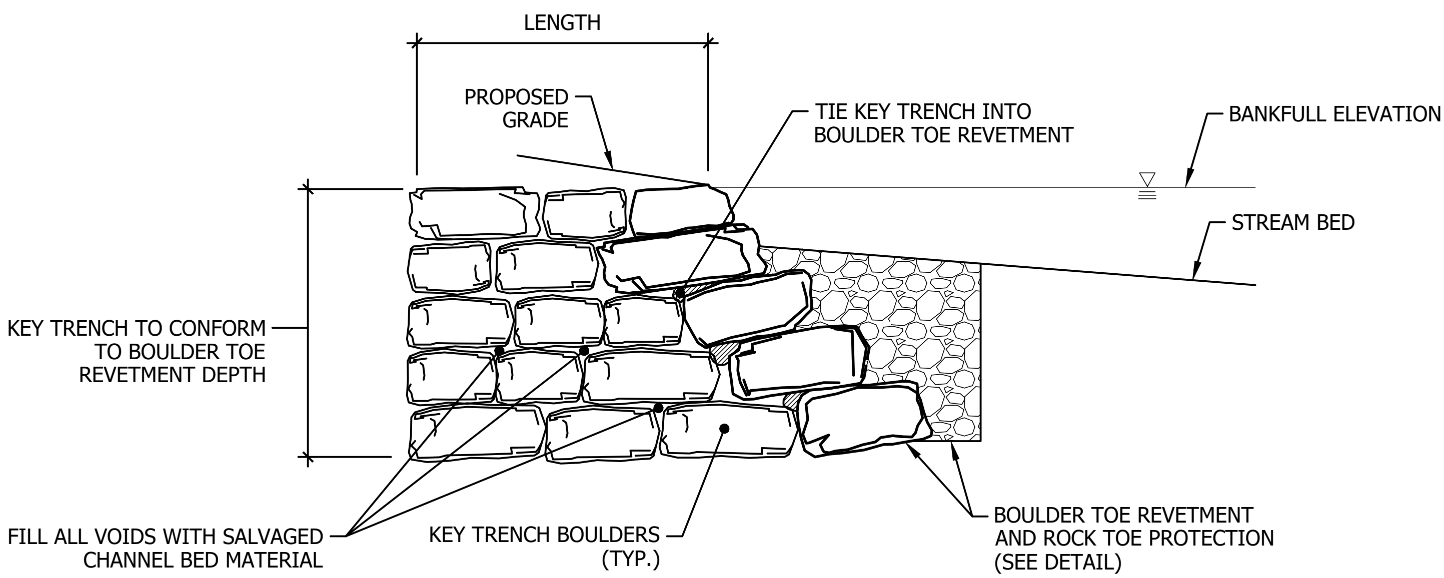
VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

SCALE: N.T.S.

DRAWING NUMBER: S24.1



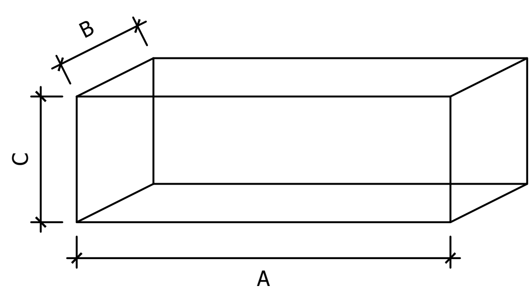
PLAN VIEW



SECTION VIEW A-A

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			

BOULDER SIZING DETAIL



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KEY TRENCH

VS.	DATE	INITIALS	REASON
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SCALE: N.T.S.

DRAWING NUMBER: S24.2

2.25 Boulder Cascade

A boulder cascade is a constructed channel facet feature intended to mimic the geomorphic functions of a boulder-bed stream system. It is a means of conveying stream flow down very steep gradients via a rock-lined channel segment, and typically used for vertical grade control application.

2.25.1 Components

A boulder cascade consists of the following components:

- A layer of large, rectangular, blocky rock formed to the dimensions of the channel, and sized to resist the erosive forces of water being conveyed through the structure.
- An infill layer incorporated between the boulders, consisting of angular rock choked with sands and gravels (furnished or salvaged), to promote expression of base flow conditions above channel grade.

A boulder cascade may contain the following **optional** components based upon site specific conditions:

- A filter layer created by non-woven geotextile or filter stone to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. The filter layer also allows for fine sediments from upstream to naturally fill in void spaces within the rock.

2.25.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Stream flow conveyance down gradient through relatively straight reaches of stream and higher gradient stream systems.	Not recommended on lower gradient stream systems.
Stable starting or ending point of a stream restoration or stabilization project.	Consider hydraulic influences directly upstream or downstream and size rock accordingly.
Method of providing resistance to tractive forces (shear stress and velocity) where infrastructure protection is required. Example includes sewer or other utility crossings (perpendicular to channel).	For utilities located adjacent to and parallel to the channel, consider implementing a streambank stabilization structure in conjunction with the engineered riffle.
If properly sized, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.25.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event. The following Rock Sizing Calculations – provided in the ***General Literature*** section – are recommended for use, but other relationships may be used based upon site specific conditions and/or designer's professional judgement:
    - Shields Entrainment Function
    - Leopold, Wolman, and Miller (1964) Entrainment Function
    - Rosgen (or Regionally Developed) Rock Sizing and Mobility Curves
    - Andrews Methodology
    - Ishbash Equation
  - Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

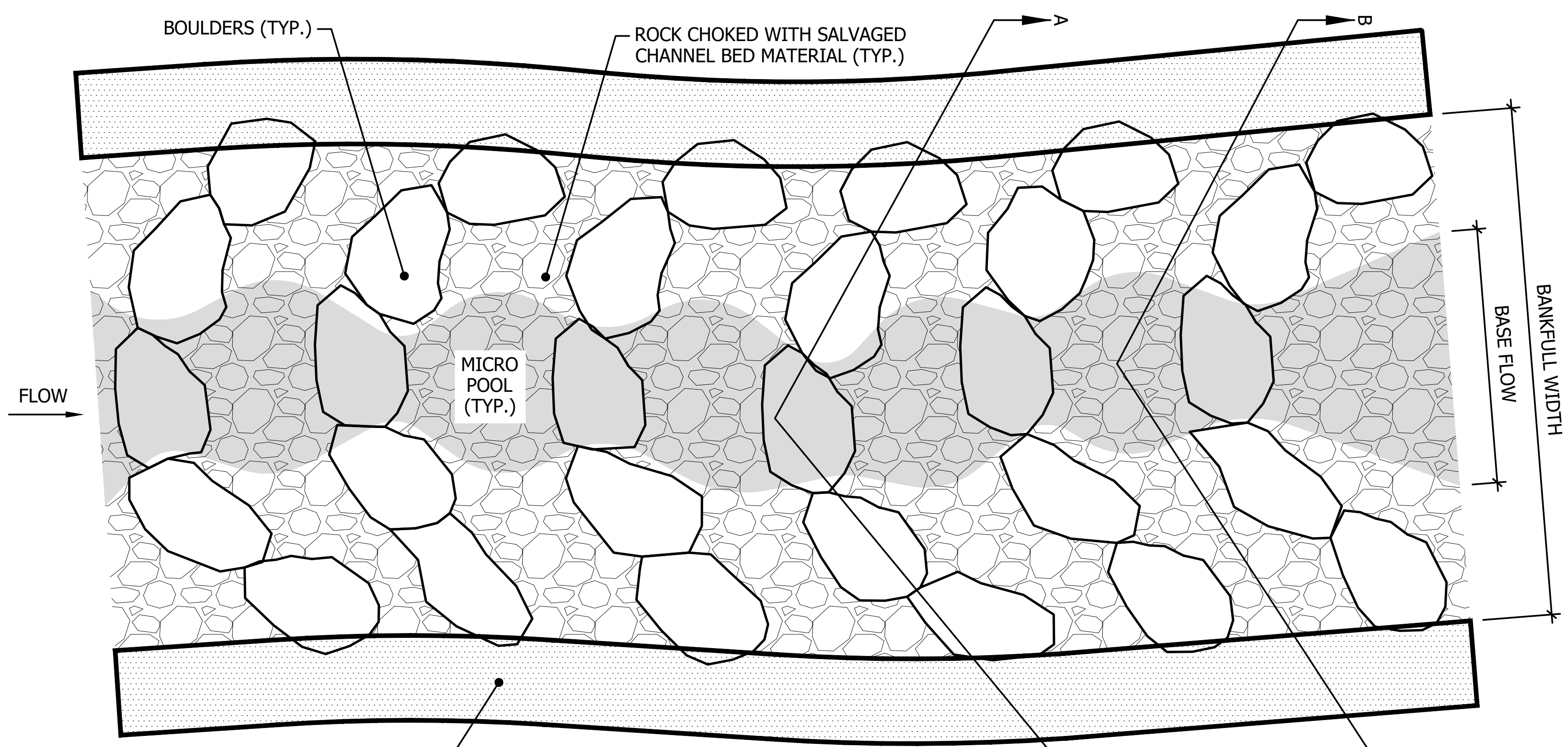
2.25.4 Notes to Designers

- Non-woven geotextile or filter stone layer between subgrade and structure is optional based upon site specific conditions. Conditions that may warrant non-woven geotextile or filter stone layer include but are not limited to: non-cohesive streambed material (such as sand) or construction of a boulder cascade placed in fill. The designer should consult with their Geotechnical Engineer to determine if an underlayment is necessary.
  - The designer should revise the standard detail and specification to **remove** reference to non-woven geotextile or filter stone if it is not warranted.
- Boulder cascades should only be used to traverse grades between 5% and 50% slopes. At a maximum, the vertical drop of the boulder cascade should be 5 feet or less for cascades with a 50% slope. Multiple cascades may be required along the length of stabilization in order to traverse steeper grades.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

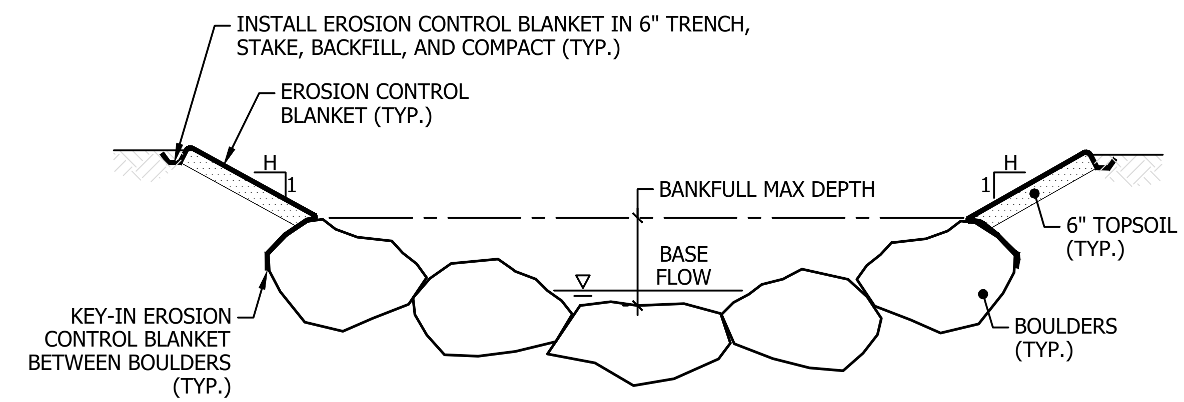
2.25.5 Photographs

Photograph 1: Boulder cascade during construction at Cresheim Creek, Philadelphia, PA. Source: PWD.

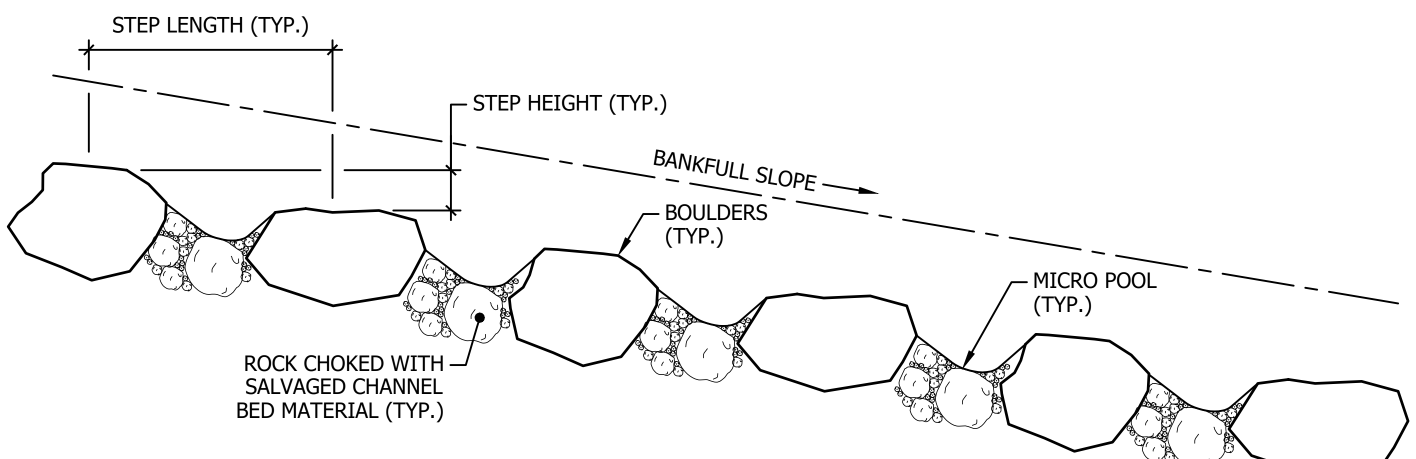
Photograph 2: Boulder cascade following construction at White Marsh Run Tributary, Baltimore County, MD. Source: JMT.



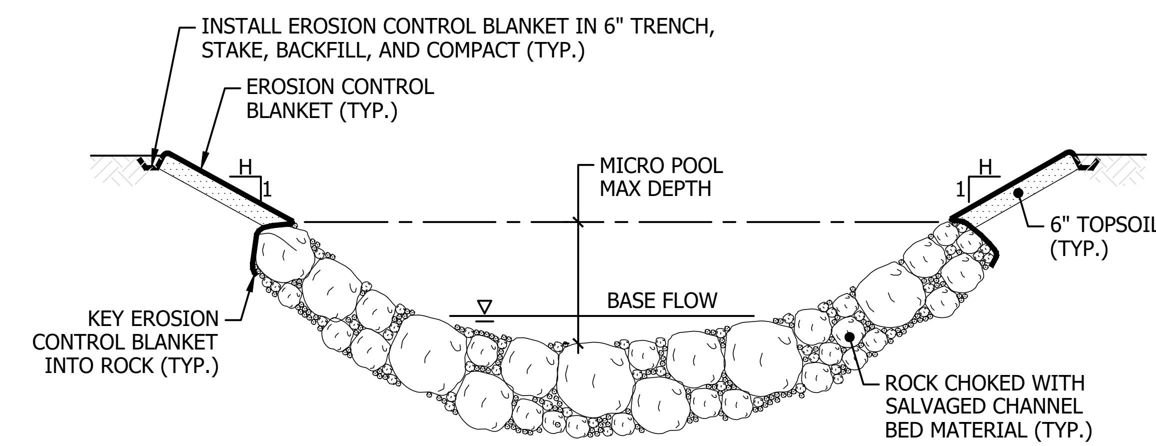
PLAN VIEW



SECTION VIEW A-A (BOULDER STEP)

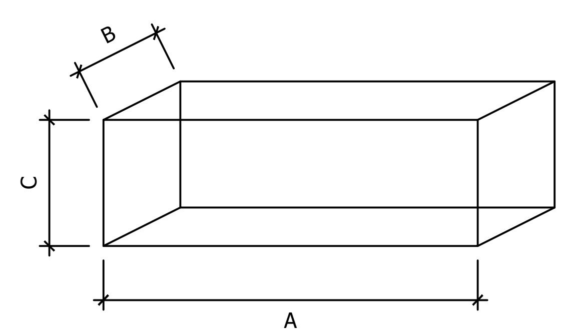


PROFILE VIEW



SECTION VIEW B-B (MICRO POOL)

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



BOULDER SIZING DETAIL

STRUCTURE ID	BANKFULL SLOPE (%)	BANKFULL WIDTH (FT)	BANKFULL MAX DEPTH (FT)	MICRO POOL MAX DEPTH (FT)	STEP LENGTH (FT)	STEP HEIGHT (FT)	SIDE SLOPE (H)	ROCK SIZE (R- _)	MINIMUM PLACEMENT THICKNESS (FT)

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BOULDER CASCADE

VS.	DATE	INITIALS	REASON
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SCALE: N.T.S.

DRAWING NUMBER: S25

2.26 Regenerative Step Pool Storm Conveyance

A regenerative step pool storm conveyance system is a step pool facet for use on higher gradient stormwater outfall systems for grade control and the creation of pools for habitat.

This structure consists of a series of riffle grade controls with steps formed by large, rectangular, blocky rocks followed by pool features – all connected to a subsurface sand seepage filter – used to dissipate energy in the system from supercritical flow tumbling over the steps to subcritical flow in the downstream pool. These stormwater outfall systems can provide water quality benefit through the conversion of surface flow to groundwater flow within the sand seepage filter.

2.26.1 Components

A regenerative step pool storm conveyance system consists of the following components:

- A layer of angular rock, formed to the dimensions of the channel, to construct riffle facets and sized to resist the erosive forces of water being conveyed through the structure.
- Step boulders constructed of large, rectangular, blocky rocks that are stackable to create a uniform and stable step that will resist the erosive forces of channelized stream flow.
- A choking layer incorporated into the rocks, consisting of gravels and cobbles (furnished or salvaged), to prevent subgrade soil migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. May also help to promote expression of base flow conditions above channel grade.
- A layer of sand (furnished or salvaged) to construct the subsurface filter bed.

A regenerative step pool storm conveyance system may contain the following **optional** components based upon site specific conditions:

- A filter layer created by non-woven geotextile to prevent subsurface filter bed material migration and pumping of fine sediments into and through the structure, while still allowing water to freely drain through. The filter layer also allows for fine sediments from upstream to naturally fill in void spaces within the rock.
- Boulder cascades should be used in lieu of riffle grade controls to traverse the grade for 5% or greater slopes.

2.26.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Storm flow conveyance down gradient through relatively straight stormwater gullies and higher gradient stormwater outfall systems. Typically used as part of a step-pool facet sequence, promoting vertical grade control.	Not recommended for low gradient systems as planform and profile geomorphic conditions provide for proper distribution of energy conditions within these types of systems.
	Not recommended for use on perennial stream systems greater than first order.
If properly sized, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.26.3 Computations

- Regenerative step pool storm conveyance systems may be designed utilizing the Anne Arundel County Government, Department of Public Works, Bureau of Engineering, Design Guidelines for Step Pool Stormwater Conveyance or other similar guidelines based upon site specific conditions and/or designer's professional judgement.
- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

    Boulder Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized rock for the step boulders, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

    The following Rock Sizing Calculations – provided in the ***General Literature*** section – are recommended for use in determining properly sized rock for the riffles, but other relationships may be used based upon site specific conditions and/or designer's professional judgement:

    - Shields Entrainment Function
    - Leopold, Wolman, and Miller (1964) Entrainment Function
    - Rosgen (or Regionally Developed) Rock Sizing and Mobility Curves
    - Andrews Methodology
    - Ishbash Equation
  - Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

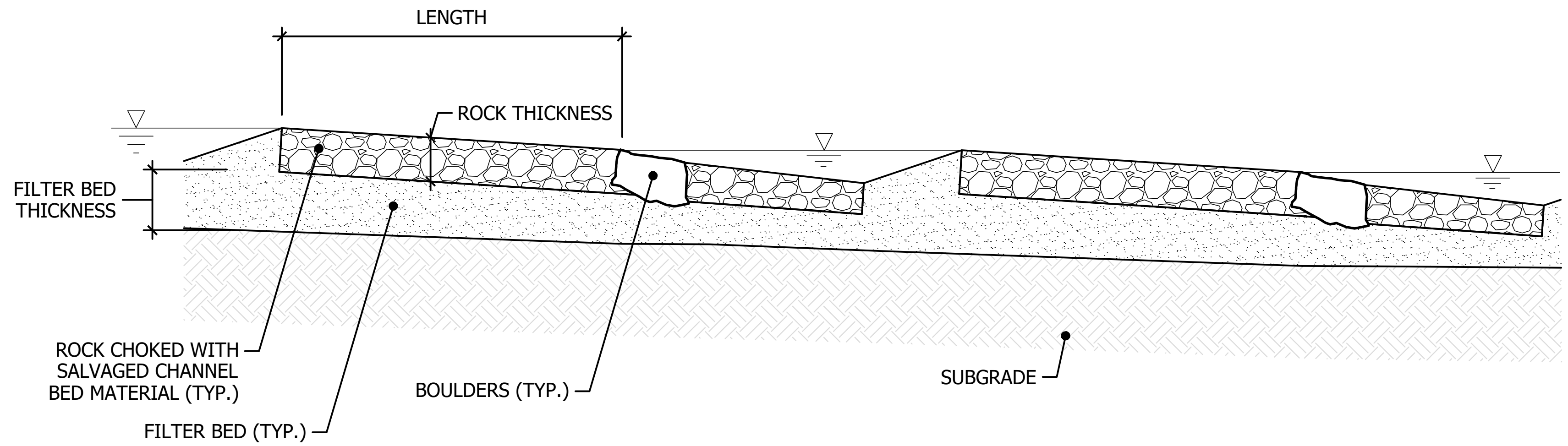
2.26.4 Notes to Designers

- Bankfull channel side slopes should be 2(H):1(V) or flatter; erosion control blanket shall be required for any slopes steeper than 3(H):1(V).
    - The designer should revise the standard detail and specification to **add** reference to erosion control blanket if it is required.
- At a minimum, rock used for construction of regenerative step pool storm conveyance should be R-4 riprap or larger. The minimum placement thickness of the rock should be at least 2x the D50 of the selected riprap size.
- The designer should consider the increased demand and limited availability of large, rectangular, blocky boulders as a major limitation for this structure when developing design alternatives.

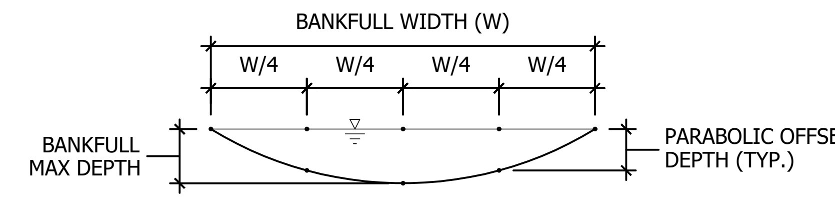
2.26.5 Photographs

Photograph 1: Regenerative step pool storm conveyance during construction. Source: JMT.

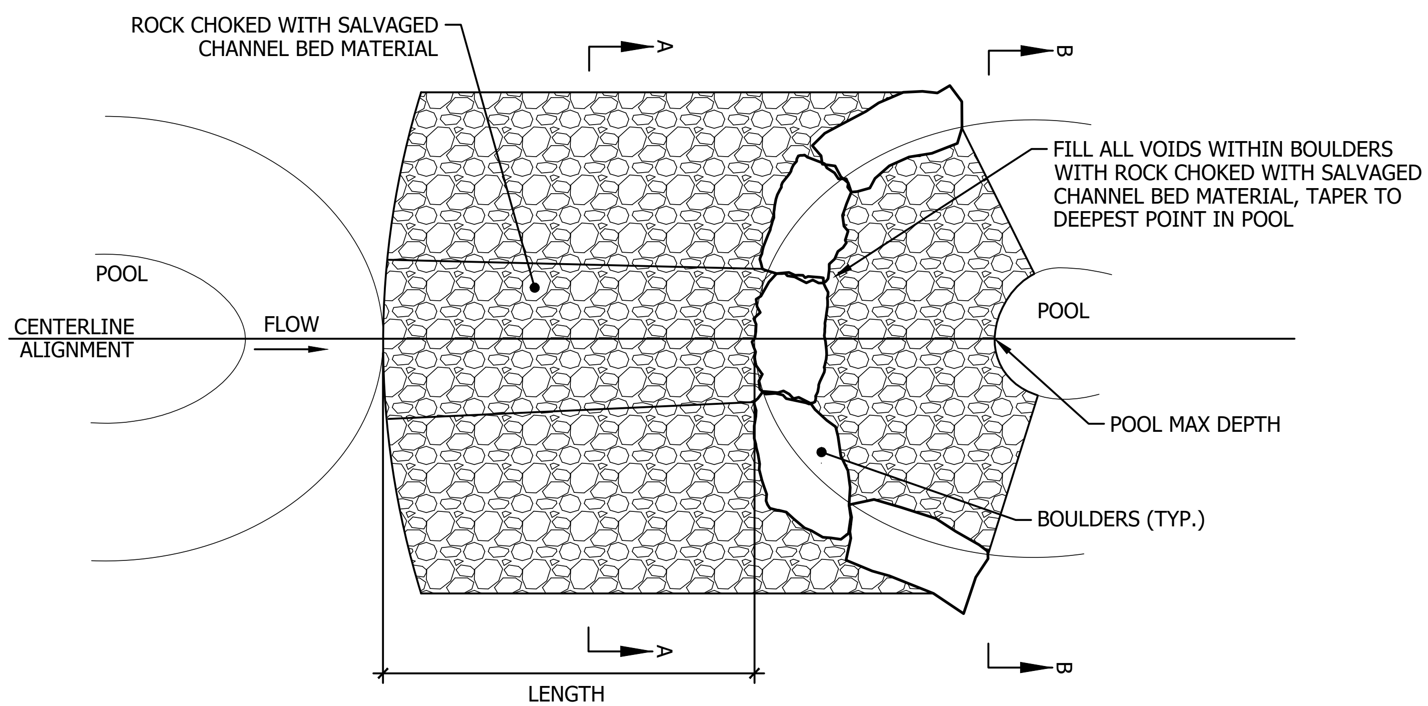
Photograph 2: Regenerative step pool storm conveyance following construction at White Marsh Run Tributary, Baltimore County, MD. Source: JMT.



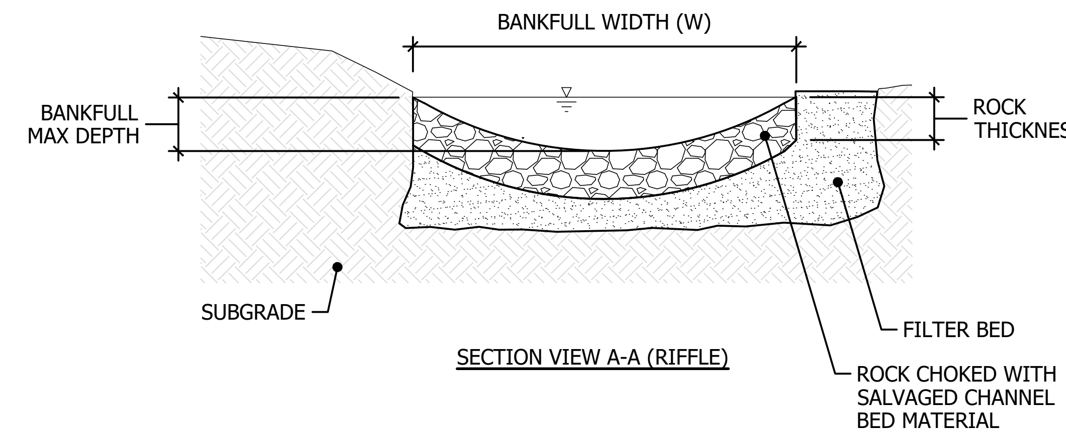
PROFILE VIEW



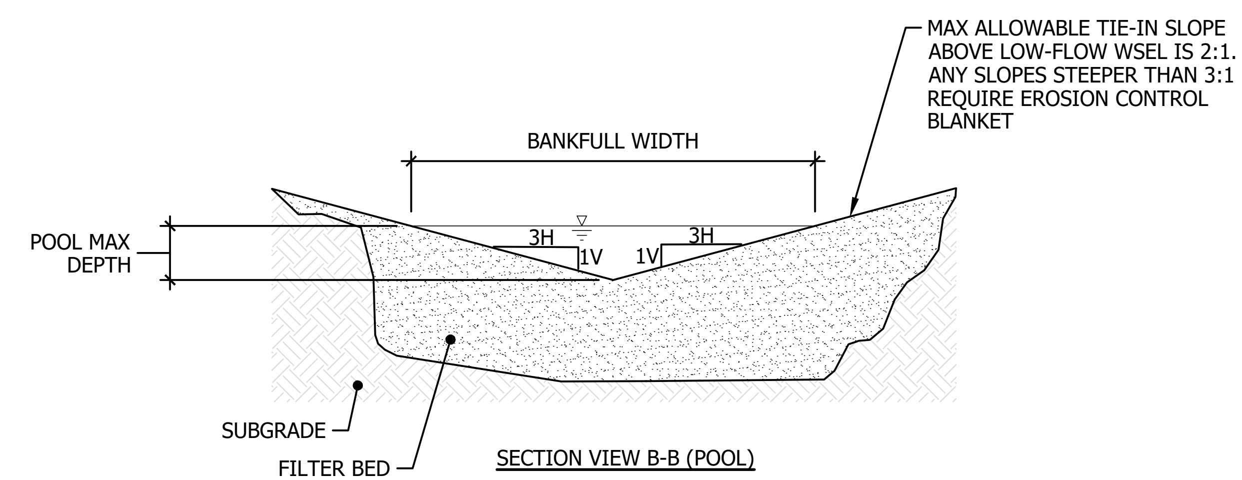
PARABOLIC SECTION DIMENSIONS



PLAN VIEW

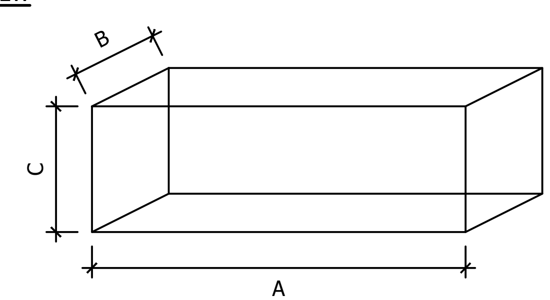


SECTION VIEW A-A (RIFFLE)



SECTION VIEW B-B (POOL)

BOULDER SIZE TABLE			
BOULDER SIZE	A	B	C
MIN. SIZE (FT)			
MAX. SIZE (FT)			



BOULDER SIZING DETAIL

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REGENERATIVE STEP POOL STORM CONVEYANCE

VS.	DATE	INITIALS	REASON
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SCALE: N.T.S.

DRAWING NUMBER: S26

2.27 Beaver Dam Analog

A beaver dam analog replicates natural beaver activity through the construction of check dams using wooden posts and live stake weaves to promote deposition of sediment within the stream channel – providing transient grade control and reconnecting the stream channel to the surrounding floodplain or terrace.

Beaver dam analogs are not considered permanent structures; however, when implemented correctly they can promote natural processes that will be self-sustaining for the long-term.

2.27.1 Components

A beaver dam analog consists of the following components:

- Log posts from hardwood species – free of rot and evidence of pests – sharpened to a point on one end, and having a minimum length of 6 feet and minimum diameter of 6 inches.
- Live stake plantings – at least 4 feet in length – woven into the log posts and planted adjacent to the structure.
- Salvaged and/or furnished channel bed material used as backfill for the upstream end of the structure.

2.27.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Provides transient grade control which promotes the reconnection of a channelized system with the surrounding floodplain or terrace without requiring disturbance to the surrounding natural areas (i.e., trees, wetlands, etc.).	Not considered permanent grade control structures and are not recommended for use immediately adjacent to critical infrastructure requiring long-term protection.
In urban settings, they are most effective when implemented on headwater tributaries and/or erosional gullies in lower-gradient, unconfined valleys.	In urban settings, not recommended for use on highly incised systems located in higher-gradient, confined valleys.
	In urban settings, not recommended for second order or higher stream systems.

2.27.3 Computations

- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning’s Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD’s infrastructure.

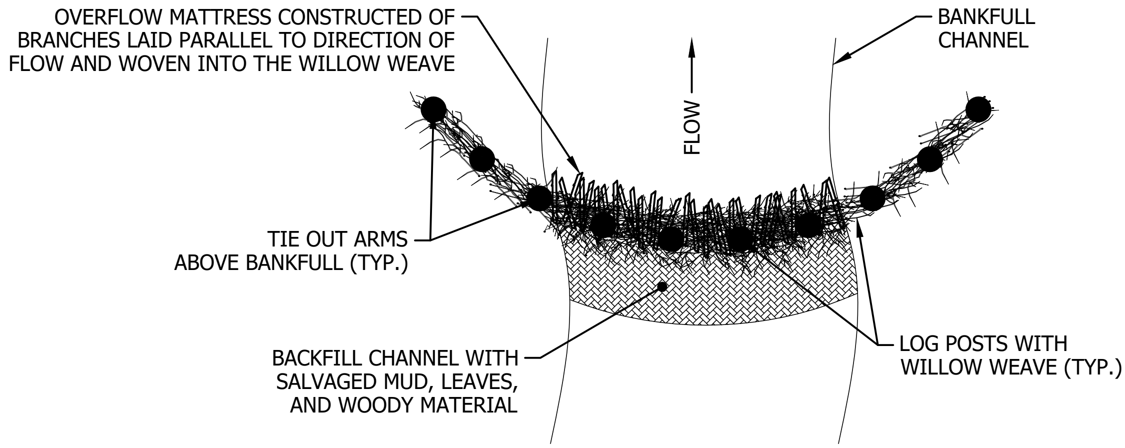
2.27.4 Notes to Designers

  - At a minimum, the log posts and live stake weave should be extended at least 1/4 of bankfull width past top of bank. In the event of a vertical bank, log posts should only be extended up to the top of bank.

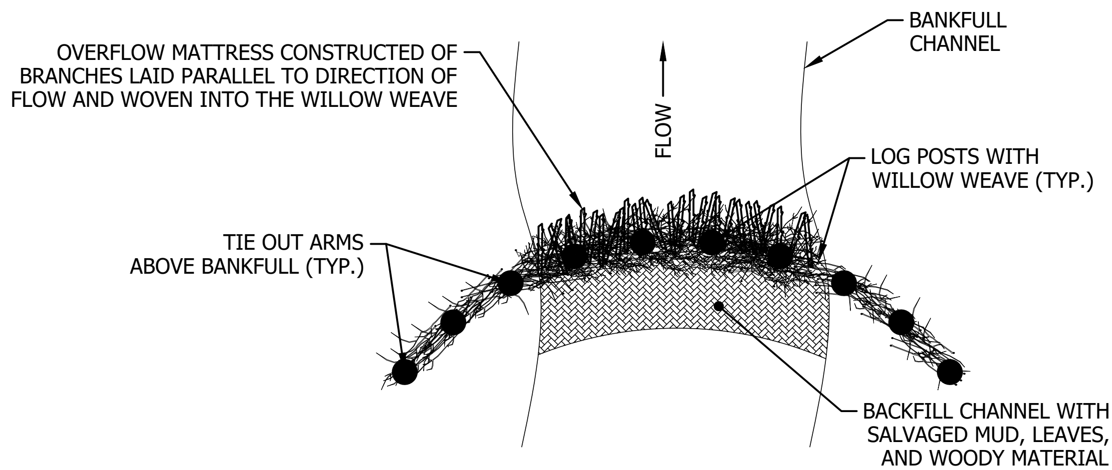
2.27.5 Photographs

Photograph 1: Beaver dam analogs during construction at Beaver Creek, Washington County, MD. Source: JMT.

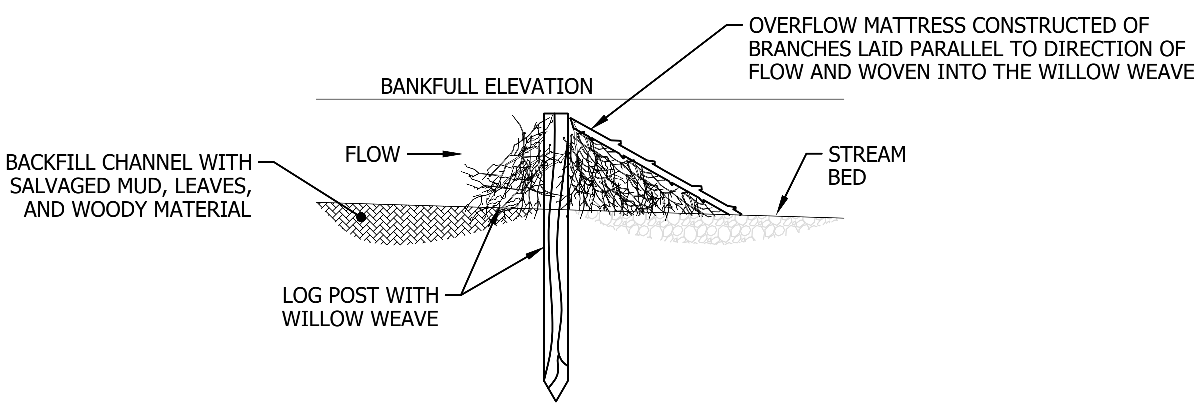
Photograph 2: Beaver dam analogs during a storm event following construction at Big Spring Run, Lancaster County, PA. Source: JMT.



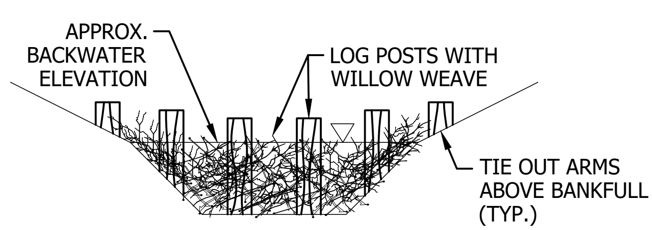
BEAVER DAM ANALOG VANE (PLAN VIEW)



CONCAVE BEAVER DAM ANALOG (PLAN VIEW)



PROFILE VIEW



SECTION VIEW

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BEAVER DAM ANALOG

VS.	DATE	INITIALS	REASON
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SCALE: N.T.S.

DRAWING NUMBER: S27

2.28 Rock and Roll Logs

Rock and roll logs consist of constructing a step pool facet for use on moderate gradient stream systems for grade control and the creation of pools for habitat; this structure may be considered as an alternative for rock step pools in certain instances, primarily when dealing with lower shear stress conditions and for areas where critical infrastructure is not located in the immediate vicinity.

This structure consists of a series of steps (vertical grade changes) formed by angled logs followed by micro pool features used to dissipate energy in the system from supercritical flow tumbling over the logs to subcritical flow in the downstream pool.

2.28.1 Components

Rock and roll logs consist of the following components:

- Logs, harvested from the trunks of trees, that are trimmed to be smooth and free of branches and/or roots.
- Salvaged and/or furnished soil material used as backfill above the installed structure
- Erosion control blanket secured with wood stakes will be installed and secured to provide temporary stability to the exposed backfill soil surface until permanent vegetation is established.

2.28.2 Effective Uses and Limitations

<table>
<tr><th>EFFECTIVE USES</th><th>LIMITATIONS</th></tr>
<tr><td>Stream flow conveyance down gradient through relatively straight reaches of stream and low/moderate gradient stream systems. Typically used as part of a step-pool facet sequence, promoting vertical grade control.</td><td rowspan="2">Not recommended for use on stream systems where bedrock is at, or very near, the surface due to limitations for scour pool development.</td></tr>
<tr><td>Best suited for stable stream systems that require varying habitat and minor bank protection; can promote pool development.</td></tr>
<tr><td rowspan="2">Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.</td><td>Not recommended for use immediately adjacent to critical infrastructure requiring long-term protection.</td></tr>
<tr><td>Not recommended for use on severely eroding, actively incising, and/or entrenched or unstable stream channels, as erosion and channel incision may undermine the structure.</td></tr>
</table>

2.28.3 Computations

- Calculations for the minimum required size of logs are based on the following guidelines:
  - Buoyancy calculations – provided in the ***General Literature*** section – are recommended for use in determining minimum required log dimensions to resist the uplifting forces of stream flow, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

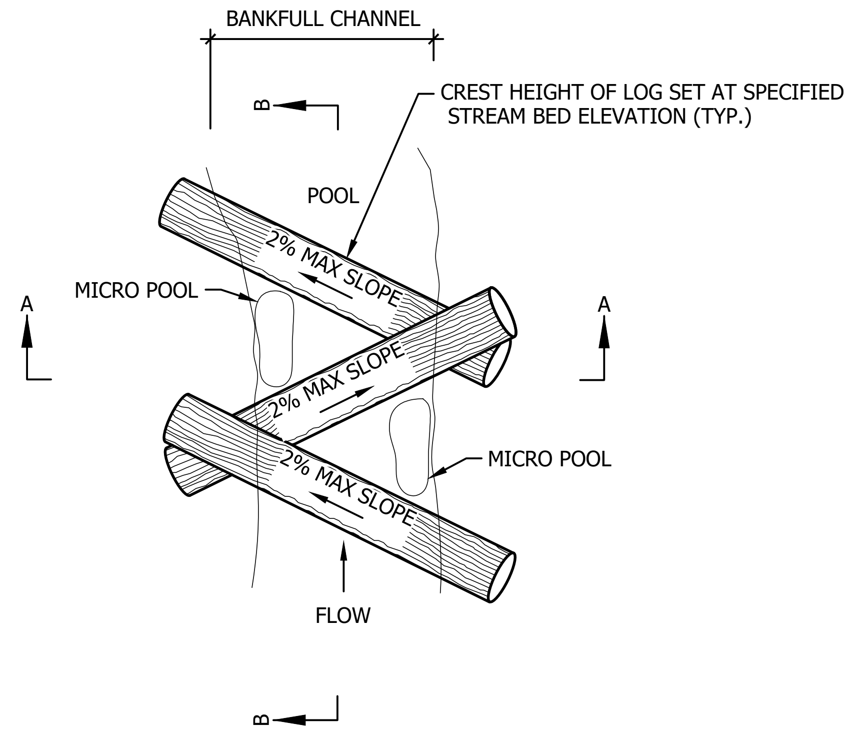
2.28.4 Notes to Designers

- At a minimum, the logs should be extended 5 feet past the top of bank on both sides of the channel.

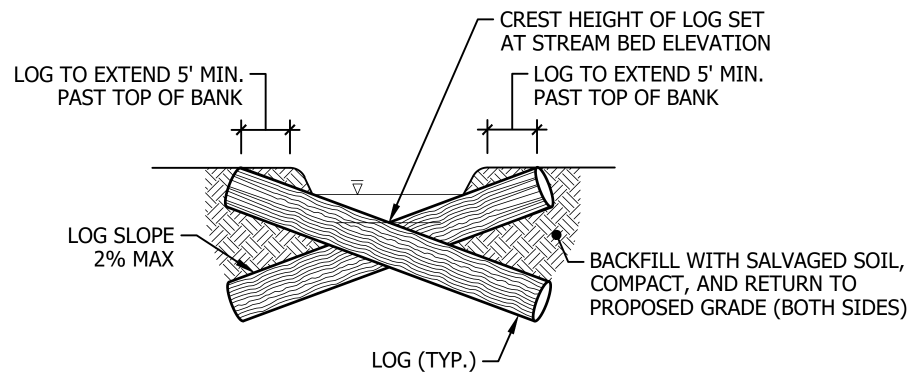
2.28.5 Photographs

Photograph 1: Rock and roll logs during construction at UNT to Jones Falls, Baltimore County, MD. Source: JMT.

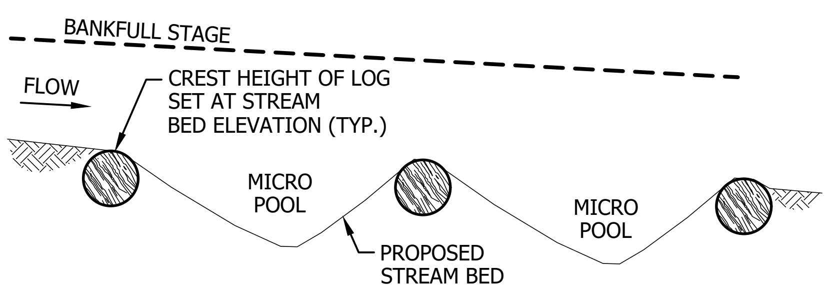
Photograph 2: Rock and roll logs following construction at UNT to Jones Falls, Baltimore County, MD. Source: JMT.



PLAN VIEW



SECTION A-A



SECTION B-B

PHILADELPHIA WATER DEPARTMENT
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ROCK AND ROLL LOGS

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER: S28

2.29 Soil-Filled Riprap Floodplain Bench

A soil-filled riprap floodplain bench provides for a more robust bankfull/floodplain bench in certain instances, primarily dealing with higher shear stress conditions and/or for areas where critical infrastructure will be re-buried by the bankfull/floodplain bench.

This structure consists of a bankfull/floodplain bench constructed from rock that has been mixed with topsoil to fill the void spaces, and is then planted with a native seed mix and live stake plantings.

2.29.1 Components

A soil-filled riprap floodplain bench consists of the following components:

- A layer of angular rock, formed to the dimensions of the bankfull/floodplain bench, and sized to resist the erosive forces of water being conveyed through the structure.
- A choking layer incorporated into the rock, consisting of topsoil (furnished or salvaged), to provide a growing medium for the establishment of permanent vegetative cover.
- Vegetated bankfull/floodplain bench consisting of topsoil, seeded and stabilized with erosion control blanket, and planted with live stakes or pole plantings.

2.29.2 Effective Uses and Limitations

EFFECTIVE USES	LIMITATIONS
Method of providing resistance to tractive forces (shear stress and velocity) where streambank stabilization and/or infrastructure protection is required for utilities located adjacent to and parallel to the channel.	For actively incising stream channels and/or utility crossings (perpendicular to channel), consider implementing a streambed vertical grade control structure in conjunction with the boulder toe revetment.
If properly designed, can resist shear forces in entrenched channels, within narrow floodplains, and/or at other channel restrictions/blockages.	Most effective when a proposed design incorporates a bankfull bench or floodplain where all energy is not concentrated into the main channel.

2.29.3 Computations

- Calculations for the minimum required size of rock are based on the following guidelines:
  - Hydrologic calculations to determine peak flow rates, including: 1-, 2-, 5-, 10-, 25-, 50-, and 100-year discharges; as well as other relevant design discharges such as base flow and threshold or bankfull flows. Consideration should be given for the use of stream gauge data (if available) to further refine or validate hydrologic calculations.
  - Hydraulic calculations to determine properly sized rock to resist the tractive forces utilizing empirical relationships for shear stress and velocity for worst-case geomorphic conditions up to and including the 100-year design storm event.

    The following Rock Sizing Calculations – are recommended for use in determining properly sized rock for the soil-filled riprap floodplain bench, but other relationships may be used based upon site specific conditions and/or designer's professional judgement:

    - Shields Entrainment Function

        - Leopold, Wolman, and Miller (1964) Entrainment Function
        - Rosgen (or Regionally Developed) Rock Sizing and Mobility Curves
        - Andrews Methodology
        - Ishbash Equation
    - Consideration should be given to utilizing a detailed 1D or 2D hydraulic model to validate these designs based upon site specific conditions and/or designer's professional judgement.
- Channel dimensions are dictated by reference reach parameters and/or hydraulic equations for open channel flow using Manning's Equation. The bankfull channel should be evaluated for base flow and threshold or bankfull discharge to meet the general principles of fluvial geomorphology and support ecological uplift while providing stability to PWD's infrastructure.

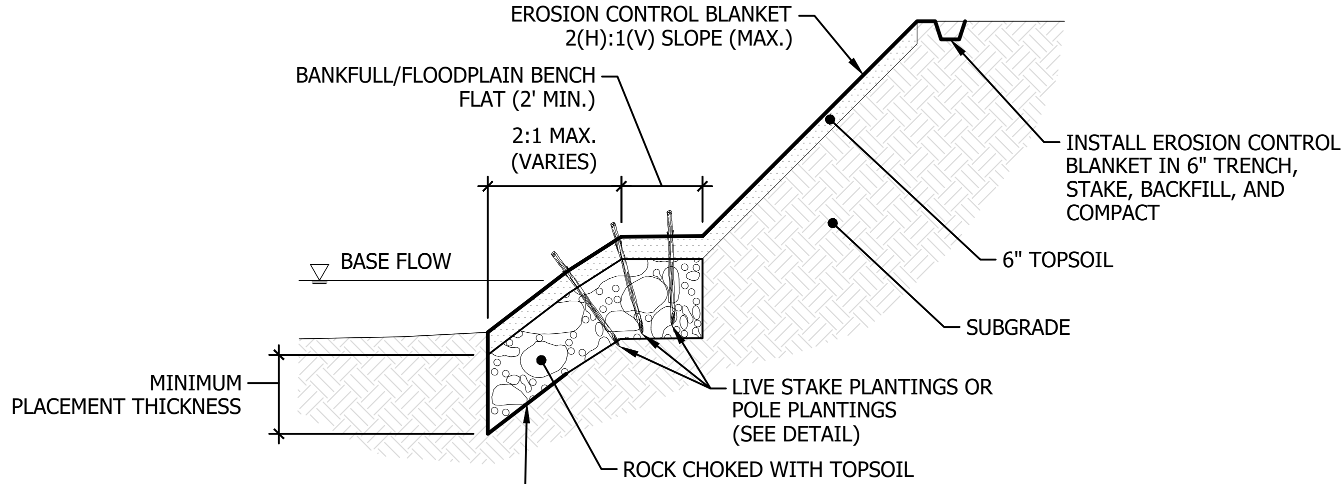
2.29.4 Notes to Designers

- Bankfull channel side slopes should be 2(H):1(V) or flatter.
- At a minimum, the bankfull/floodplain bench should be 2 feet wide.
- At a minimum, rock used for construction of soil-filled riprap floodplain benches should be R-4 riprap or larger. The minimum placement thickness of the rock should be at least 2x the D50 of the selected riprap size.

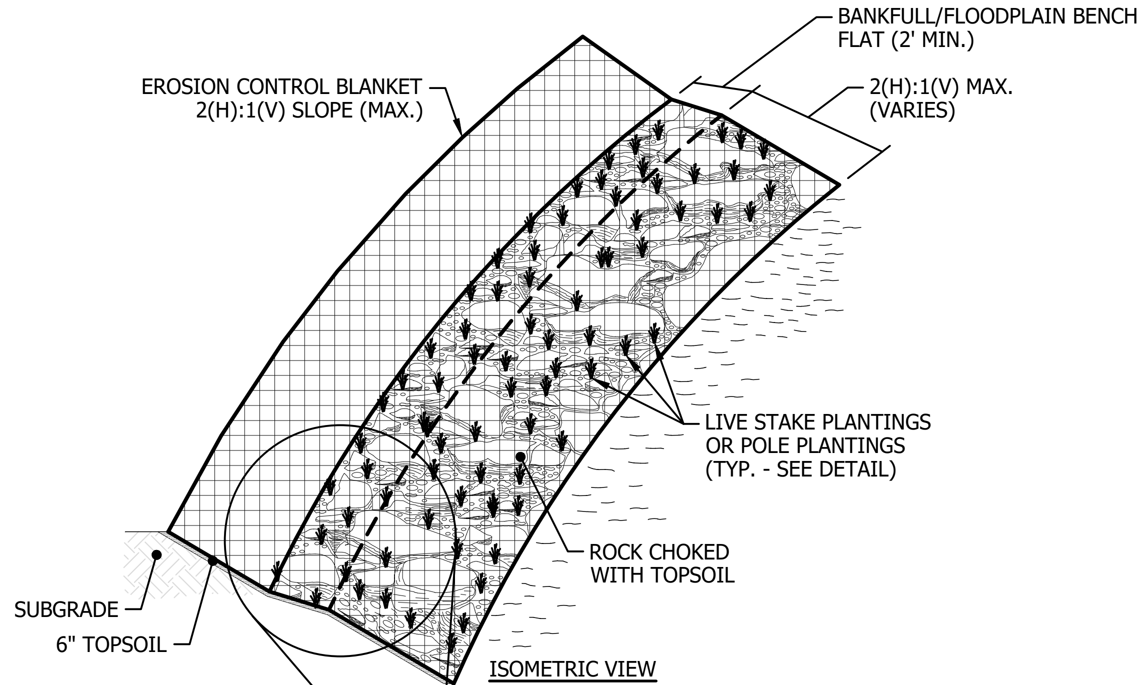
2.29.5 Photographs

Photograph 1: Soil-filled riprap floodplain bench – installed in front of a boulder wall – during construction at Deer Creek, Harford County, MD. Source: JMT.

Photograph 2: Soil-filled riprap floodplain bench – installed in front of a boulder wall – following construction at Deer Creek, Harford County, MD. Source: JMT.



SECTION VIEW



ISOMETRIC VIEW

INSET VIEW

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

SOIL-FILLED RIPRAP FLOODPLAIN BENCH

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER:
S29

2.30 Log Planting Terrace

A log planting terrace provides minor grade changes around existing trees and other at-grade features that are intended to be preserved during construction. This structure may also be used at significant grade breaks to reduce the potential for erosion. Log planting terraces are auxillary structures primarily used on side slopes and areas adjacent to the stream channel.

2.30.1 Components

A log planting terrace consists of the following components:

- Logs, harvested from the trunks of trees, that are trimmed to be smooth and free of branches and/or roots.
- Salvaged and/or furnished topsoil used as backfill behind the structure.
- Mulch to provide temporary stabilization for the topsoil backfill.

2.30.2 Effective Uses and Limitations

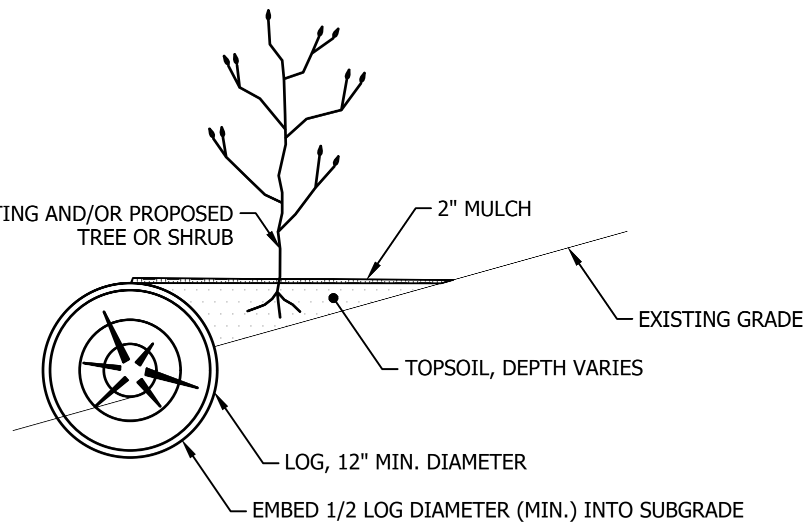
EFFECTIVE USES	LIMITATIONS
Method of providing minor grade changes around existing trees and other at-grade features to be preserved.	Not recommended for use in channelized flow paths.
May be used at significant grade breaks to reduce the potential for erosion.	Not recommended for vertical drops exceeding two feet.

2.30.3 Computations

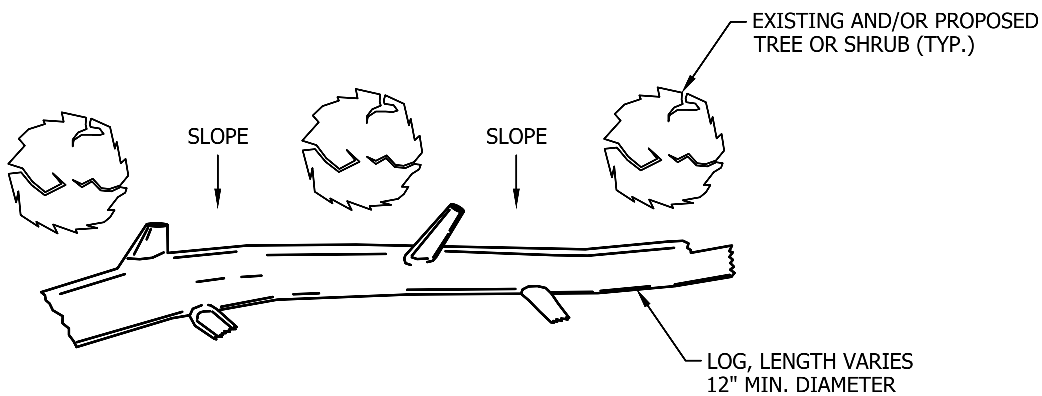
- Not Applicable.

2.30.4 Notes to Designers

- Not Applicable.



SECTION VIEW



PLAN VIEW

PHILADELPHIA WATER DEPARTMENT
1101 MARKET ST, 4TH FLOOR
PHILADELPHIA, PA, 19107

LOG PLANTING TERRACE

SCALE: N.T.S.

VS.	DATE	INITIALS	REASON
2	06/01/2024	TJC	VERSION UPDATE

DRAWING NUMBER: S30

3.0

General Literature

3.1 Rock Sizing Calculations

The following equations are recommended for use in determining properly sized rock for in-stream structures, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

3.1.1 Shields Entrainment Function

$$D_s = \frac{\tau}{(\rho_s - \rho) \times \theta \times g}$$

Where:

D_s = diameter of the largest sediment particle that is mobilized (ft)

τ = shear stress (lb/ft^2)

ρ_s = density of sediment (5.15 $slugs/ft^3$)

ρ = density of water (1.94 $slugs/ft^3$)

θ = Shields parameter (typically selected as 0.06)

g = gravitational acceleration (32.2 ft/s^2)

3.1.2 Leopold, Wolman, and Miller (1964) Entrainment Function

$$D_s = \frac{77.97 \times \tau^{1.042}}{304.8}$$

Where:

D_s = diameter of the largest sediment particle that is mobilized (ft)

τ = shear stress (lb/ft^2)

304.8 = conversion factor from mm to ft

3.1.3 Rosgen (Colorado) Field Data Function

$$D_s = \frac{152.02 \times \tau^{0.7355}}{304.8}$$

Where:

D_s = diameter of the largest sediment particle that is mobilized (ft)

τ = shear stress (lb/ft^2)

304.8 = conversion factor from mm to ft

3.1.4 Andrews Methodology

$$D_s = \frac{\tau}{\tau^{*} \times (s-1) \times \gamma}$$

Where:

D_s = diameter of the largest sediment particle that is mobilized (ft)

τ = shear stress (lb/ft^2)

τ* = dimensionless shear stress

s = specific gravity of sediment (typically selected as 2.65)

γ = specific weight of water (62.4 lb/ft^3)

AND

$$\tau^{*} = 0.0834\left(\frac{D_s}{D_{50}}\right)^{-0.872} \quad (1984)$$

OR

$$\tau^{*} = 0.0384\left(\frac{D_s}{D_{50}}\right)^{-0.887} \quad (1994)$$

OR

$$\tau^{*} = 0.0376\left(\frac{D_s}{D_{50}}\right)^{-0.994} \quad (1995)$$

Where:

τ* = dimensionless shear stress

D_s = diameter of the largest sediment particle that is mobilized (ft)

D_{50} = mean diameter of riffle particles (ft)

3.1.5 Ishbash Equation

$$D_{50} = \left[\frac{V}{C \times \left(2 \times g \times \frac{\gamma_s - \gamma_w}{\gamma_w}\right)^{0.5}}\right]^2$$

Where:

D_{50} = median stone diameter (ft)

V = velocity (ft/s)

C = Ishbash constant (0.86 for high turbulence flow and 1.20 for low turbulence flow)

g = gravitational acceleration (32.2 ft/s^2)

γ_s = specific weight of stone (typically selected as 160 lb/ft^3)

γ_w = specific weight of water (62.4 lb/ft^3)

3.1.6 Riprap Revetment Sizing

$$d_{30} = y \times (S_f \times C_s \times C_v \times C_t) \times \left[\frac{V_d}{\sqrt{K_1 \times (S_g - 1) \times g \times y}}\right]^{2.5}$$

AND

$$d_{50} = 1.20 \times d_{30}$$

Where:

d_{30} = 30th percentile stone diameter (ft)

d_{50} = median stone diameter (ft)

y = local depth of flow above particle (ft)

S_f = safety factor (must be > 1.0)

C_s = stability coefficient (equals 0.30 for angular rock and 0.375 for rounded rock)

C_v = velocity distribution coefficient

= 1.0 for straight channels or inside of bends

= 1.283 – 0.2log(R_c/W) for the outside of bends (1 for R_c/W > 26)

= 1.25 downstream from concrete channels

= 1.25 at the end of dikes

C_t = blanket thickness coefficient given as a function of the uniformity ratio d_{85}/d_{15}

= 1.0 is recommended because it is based on very limited data

V_d = characteristic velocity for design, defined as the depth-averaged velocity at a point 20% upslope from the toe of the revetment (ft/s)

= V_{avg}(1.74 – 0.52log(R_c/W)) for natural channels

= V_{avg}(1.71 – 0.78log(R_c/W)) for trapezoidal channels

V_{avg} = channel cross-sectional average velocity (ft/s)

K_1 = side slope correction factor

$$K_1 = \sqrt{1 - \left(\frac{\sin\theta - 14°}{\sin 32°}\right)^{1.6}}$$

AND

θ = bank angle in degrees

R_c = centerline radius of curvature of channel bed (ft)

W = width of water surface at upstream end of channel bed (ft)

S_g = specific gravity of riprap (typically selected as 2.65)

g = gravitational acceleration (32.2 ft/s^2)

3.1.7 Lane's (1955) Method

$$D_{75} = \frac{3.5}{C \times K} \times \gamma_w \times D \times S_f$$

Where:

D_{75} = 75th percentile stone diameter (in)

C = correction for channel curvature

K = correction for side slope

S_f = channel friction slope (ft/ft)

D = depth of flow (ft)

γ_w = specific weight of water (62.4 lb/ft^3)

AND

R_c/W	C	Side Slope	K
4-6	0.6	1.5H:1V	0.52
6-9	0.75	1.75H:1V	0.63
9-12	0.90	2H:1V	0.72
straight channel	1.0	2.5H:1V	0.80
		3H:1V	0.87

Where:

R_c = radius of curvature (ft)

W = water surface width (ft)

3.2 Boulder Sizing Calculations

The following calculations are recommended for use in determining properly sized boulders for in-stream structures, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

3.2.1 Minimum Boulder Size as a Function of Bankfull Shear Stress

$$D_{min} = [0.5656 \times \ln(\tau)] + 2.9799$$

Where:

D_{min} = minimum boulder size (ft)

τ = bankfull shear stress (lb/ft^2)

3.3 Scour Depth Calculations

The following equations are recommended for use in determining the localized scour depth at longitudinal structures, but other methods may be used based upon site specific conditions and/or designer's professional judgement.

3.3.1 Method for Scour at Longitudinal Structures with Flow Parallel to a Vertical Wall

$$y_s = y_1 \times [0.73 + (0.14 \times \pi \times F_r^2)]$$

Where:

y_s = equilibrium depth of scour, measured from mean bed level to bottom of the scour hole (ft)

y_1 = average upstream flow depth in the main channel (ft)

F_r = upstream Froude number

3.3.2 Method for Scour at Longitudinal Structures with Flow Impinging at an Angle on a Vertical Wall

$$y_s = y_1 \times \left[[0.73 + (0.14 \times \pi \times F_r^2)] \cos\theta + 4\,F_r^{0.33} \sin\theta\right]$$

Where:

y_s = equilibrium depth of scour, measured from mean bed level to bottom of the scour hole (ft)

y_1 = average upstream flow depth in the main channel (ft)

F_r = upstream Froude number

θ = angle between the impinging flow direction and the vertical wall in degrees

3.4 Outfall Stabilization Calculations

The following equations are recommended for use in determining properly sized rock for Preformed Scour Holes, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

3.4.1 Type 1 Preformed Scour Hole

$$D_{50} = \left(\frac{0.0125 \times d^2}{Tw}\right) \times \left(\frac{Q}{d^{2.5}}\right)^{4/3}$$

Where:

D_{50} = median stone diameter (ft)

d = culvert diameter or span (ft)

Tw = tailwater depth (ft)

Q = design flow rate (ft^3/s)

3.4.2 Type 2 Preformed Scour Hole

$$D_{50} = \left(\frac{0.0082 \times d^2}{Tw}\right) \times \left(\frac{Q}{d^{2.5}}\right)^{4/3}$$

Where:

D_{50} = median stone diameter (ft)

d = culvert diameter or span (ft)

Tw = tailwater depth (ft)

Q = design flow rate (ft^3/s)

3.4.3 Preformed Scour Hole Dimensions

Preformed Scour Hole Inlet and Outlet Width (ft) A and B = (2 X D) + (G X F)

Preformed Scour Hole Length (ft) C = (3 X D) + (H X F)

Pipe Diameter or Culvert Span (ft) = D

Preformed Scour Hole Rock Thickness (ft) E = 2 X D_{50}

Preformed Scour Hole Depression (ft) F = 0.5 X D (Type 1) or D (Type 2)

Horizontal Side Slope for Preformed Scour Hole Width (ft) = G

Horizontal Side Slope for Preformed Scour Hole Length (ft) = H

3.5 Buoyancy Calculations

The following equations are recommended for use in determining minimum required log dimensions to resist the uplifting forces of stream flow, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

3.5.1 Buoyancy Equations for Wood Structures

$$F_{\mathrm{BL}} = L \times \frac{\pi \times D_{\mathrm{L}}^2}{4} \times \rho \times g \times (1 - S_{\mathrm{L}})$$

Where:

F_{BL} = net buoyant force (lbs)

L = log length (ft)

D_L = log diameter (ft)

ρ = density of water (1.94 slugs/ft^3)

g = gravitational acceleration (32.2 ft/s2)

S_L = specific gravity of log (typically selected as 0.40)

AND

$$F_{\mathrm{s}} = V_{\mathrm{s}} \times \gamma_{\mathrm{DS}}$$

Where:

F_s = downward force of soil (lbs)

V_s = volume of soil over log (ft3)

γ_{DS} = dry density of soil (typically selected as 115 lbs/ft^3)

3.6 Pool-to-Pool Spacing Calculations

The following figures are recommended for use in determining appropriate pool-to-pool spacing and rock step heights for Rock Step Pool with Boulder Toe Revetment, but other relationships may be used based upon site specific conditions and/or designer's professional judgement.

3.6.1 Ratio of Pool-to-Pool Spacing to Bankfull Width as a Function of Channel Slope

$$\frac{Pool\ to\ Pool\ Spacing\ (ft)}{Bankfull\ Width\ (ft)} = 8.2513 \times S^{(-0.9799)}$$

Where:

S = channel slope (%)

3.6.2 Pool Spacing Guidelines as a Function of Channel Slope

Approximate channel slope: >0.065	Typical Pool Spacing: <1 channel width	Average step height $1 \le \{(H/L)ave\ /slope\} \le 2$

Approximate channel slope: 0.030-0.065	Typical Pool Spacing: 1–4 channel width	Average step height $1 \le \{(H/L)ave\ /slope\} \le 2$

Where:

H = step height (ft)

L = step length (ft)

(H/L)ave = mean steepness of steps (ft/ft)

slope = channel slope (ft/ft)

4.0

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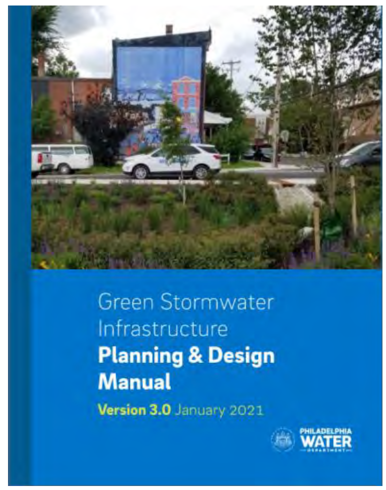
4.2 Other Resources

Kindly refer to the links below to other PWD Resources and Standard drawings for reference:

- Resource Directories:
    - Ecological Restoration: https://water.phila.gov/contractors/ecological-restoration/
    - GSI: https://water.phila.gov/gsi/planning-design/resources/

- Design Manuals:

URL:
https://water.phila.gov/design/manual



URL:
https://water.phila.gov/gsi/planning-design/manual/

4.3 Glossary

Stream Restoration is the process of converting an unstable, altered, or degraded stream corridor, including adjacent riparian zone and flood-prone areas to its natural or referenced, stable conditions considering recent and future watershed conditions. The process also involves restoring the geomorphic characteristics, such as the dimension, pattern, and profile as well as the biological and chemical integrity, including the transport of water and sediment produced by the stream's watershed in order to achieve dynamic equilibrium.

Stream Stabilization is defined as the in-place stabilization of severely eroded streambanks and streambed to improve water quality, biologic and chemical processes, and uplift of ecological functions. Stabilization techniques may include both "soft" and "hard" engineering methods along with in-stream structures with the long-term goal of improving the aquatic resource.

In-Stream Grade Control is a parameter identified to evaluate the capacity of a best management practice to maintain the vertical stability of a stream's longitudinal profile.

Vertical Stability is a direct measure of a stream's degradation (down cutting).

Horizontal Stability is a direct measure of a stream's ability to maintain its existing pattern.

Streambank Protection is a parameter identified to evaluate the capacity of a best management practice to reduce channel erosion through mass wasting and near bank stress processes.

Floodplain Protection is a parameter identified to evaluate the capacity of a best management practice to reduce velocity and shear stress on the floodplain surface of a stream in order to reduce erosion of fine sediment, deposit fine sediments from flood flows, and thereby reduce the shear stress on infrastructure and natural habitats in floodplain areas.

In-Stream Habitat Improvement is a parameter identified to evaluate the capacity of a best management practice to promote stable and diverse benthic and aquatic habitats for a variety of fish, herpetofauna, and macro invertebrates.

Riparian Habitat Improvement is a parameter identified to evaluate the capacity of a best management practice to promote stable and diverse riparian habitats, including floodplain wetland habitat, upland buffer habitats, and the birds, mammals, herpetofauna, and invertebrate species that utilize them. This is a direct measure of the capacity of a best management practice to promote improvements and maintain stability in riparian habitats.

Water Quality Improvement is a parameter identified to evaluate the capacity of a best management practice for source reduction, removal, sequestration or conversion of sediment and nutrients. Reduction of sediment sources, treatment of nutrients, denitrification processes, and practices which enhance hyporheic exchange are included in this parameter.

The following terms are included throughout the In-Stream Structures section and are provided for general understanding of common terms used by stream restoration professionals. This list has been adapted from the Iowa Department of Natural Resources, River Restoration Toolbox (2018) and is not considered exhaustive or comprehensive:

Bankfull is the elevation on the bank where flow begins to spill out onto the active floodplain. This elevation may or may not correspond to the existing/proposed top of bank elevation. Bankfull is frequently equated with a 1 to 2-year recurrence interval.

Bankfull Mean Depth is the mean distance from the bottom of the channel to bankfull elevation. The bankfull depth can be measured for any cross-section but for the purposes of stream classification is measured at a riffle.

Bankfull Maximum Depth is the distance from the deepest part of the channel (thalweg) to the bankfull elevation.

Bankfull Bench is a flat area adjacent to the stream at bankfull elevation, either naturally occurring or constructed to create an area for flows above bankfull to spread out and dissipate energy.

Bedrock is a stream substrate consisting of solid rock rather than mobile particles.

Capacity is the total amount of sediment a stream can transport under given flow conditions.

Competence is the ability of a stream to transport a particular size of particle, often expressed as the maximum size of sediment a stream can transport.

D50/D84 is the particle size that 50%/84% of the samples area equal to or smaller than in a given sediment size characterization using the Wolman Pebble Count procedure.

Degradation is the long-term removal of sediment occurring through increased erosion from the channel bed, causing downcutting or channel deepening (NRCS, 2007).

Facet is a distinct morphological segment of a longitudinal profile (NRCS, 2007). Stream bed features, defined by the channel plan form and gradient, and used to describe the channel configuration, including riffles, runs, pools, glides, and steps (Rosgen).

Floodplain is an area of low-lying ground adjacent to a river or stream, formed mainly of sediments and subject to flooding.

Floodplain Bench is an area of low-lying ground adjacent to a river or stream, constructed to allow out of bank flows in areas with limited or non-existing active floodplain.

Low-Flow Channel is the portion of the stream channel wetted during base flow.

Near Bank Stress is an index that rates the erosive force on the streambank, used in estimating bank erosion rates. Near bank stress is influenced by energy distribution in the stream channel and varies with cross section width and radius of curvature. Disproportionate energy distribution in the near bank region accelerates streambank erosion.

Perennial Stream has flowing water year-round during a typical year. The water table is located above the stream bed for most of the year. Groundwater is the primary source of water for stream flow. Runoff from rainfall is a supplemental source of water for stream flow (USACE).

Pool is the area in a natural channel deeper and somewhat narrower than the average channel section (NRCS, 2007).

Pool-to-Pool Spacing is the distance between the mid-point of two adjacent pools. Pool-to-pool spacing can be expressed as a length, or ratio by dividing the length by the bankfull width measured as a riffle.

Protrusion is an indicator of bed roughness. Protrusion height is a measure of the height that a particle extends above the bed surface.

Reference Reach is a river or stream that exists in a state of dynamic equilibrium (maintains dimension, pattern and profile without significant aggrading or degrading (Rosgen, 1996)). The profile facets of a reference reach area also in phase with the meander pattern (i.e., pools exist at meander bends and riffles occur within the cross-over section of the channel). A reference reach should also have attributes that are favorable to replicate in a restoration project. In order to obtain sufficient data from a reference reach, the stream should exhibit favorable characteristics for a distance of 2 meander wavelengths or 20 to 30 bankfull widths.

Restoration the manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning natural/historic functions to a former or degraded aquatic resource (USACE, 2017).

Riffle is the area in a natural channel that is wider and shallower than the average channel section (NRCS, 2007).

Riparian Areas are lands next to streams, lakes, and estuarine-marine shorelines, which provide a variety of ecological functions and services (USACE, 2017).

Sediment is weathered soil and rock particles transported by water or wind.

Shear Stress is the product of energy slope, hydraulic radius, and unit weight of water. Spatial and temporal variation may result in a higher or lower point value for shear stress (NRCS, 2007).

Soil Bioengineering is the use of live and dead plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment (NRCS, 2007).

Streambed is the substrate of the stream channel between the ordinary high water marks. The substrate may be bedrock or inorganic particles that range in size from clay to boulders (USACE, 2017).

Structure Arm is the section of an in-stream structure that extends up from the thalweg and intercepts the bank at the bankfull elevation.

Thalweg is the “flow line” or deepest point of the channel cross section.

Top of Bank is the channel bank slope break point at which the existing and/or proposed channel cross section intercepts the adjacent ground/floodplain.