CONSTRUCTION GUIDANCE

FIRST EDITION

ALLIANCE
for the Chesapeake Bay

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TABLE OF CONTENTS

PREFACE

This Regenerative Stream Conveyance (RSC) Construction Guidance for the regenerative restoration of streams and stormwater conveyances was prepared to present conceptual information on constructing regenerative projects and implementation techniques for common features. Past efforts have generated checklists, guidance documents and manuals focused specifically on designing RSC projects. Contractors, however, play a crucial role in translating two dimensional engineered plans into restoring fully functional three-dimensional natural ecosystems.

This construction guidance aims to support contractors' efforts to advance regenerative stream restoration by setting the foundation for constructing successful regenerative stream restoration projects. Although contractors are the main audience, the information presented in the guidance can help bridge the gap in translation between design, construction and maintenance phases of projects by serving as a common reference for water resource and ecological engineers, permit reviewers, contractors, construction inspectors, construction managers and watershed restoration practitioners.

REGENERATIVE STREAM CONVEYANCE

WHAT IS RSC?

Regenerative Stream Conveyance (RSC) is a restoration approach that re-establishes conditions necessary for healthy, natural stream ecosystems by freeing stream flows from incised channels (Figure 1) to hydrologically reconnect with the floodplain, enabling robust interaction between groundwater and surface water, and re-establishing native vegetation (Figure 2). The key term is "regenerative"; RSC aims to re-establish lost hydrologic conditions critical to reversing the degrading trend and resetting it into a regenerative mode.

RSC, referred to as Regenerative *Stormwater* Conveyance, is recognized as a Best Management Practice (BMP), demonstrated to be effective by the U. S. Environmental Protection Agency's Chesapeake Bay Program's Expert Panel on Stream Restoration to Define Removal Rates for Individual Stream Restoration Projects (US Environmental Protection Agency, 2012). Efforts to refine the term RSC have resulted in iterations of the term including Regenerative Stormwater Conveyance and Regenerative Stream Channel and encompass pseudonyms such as Coastal Plain Outfalls constructed in ravines at the end of storm pipes and Sand Seepage Wetlands constructed near the tidal interface.

RSC aims to reset the stream ecosystem from a degenerative mode into a regenerative mode.

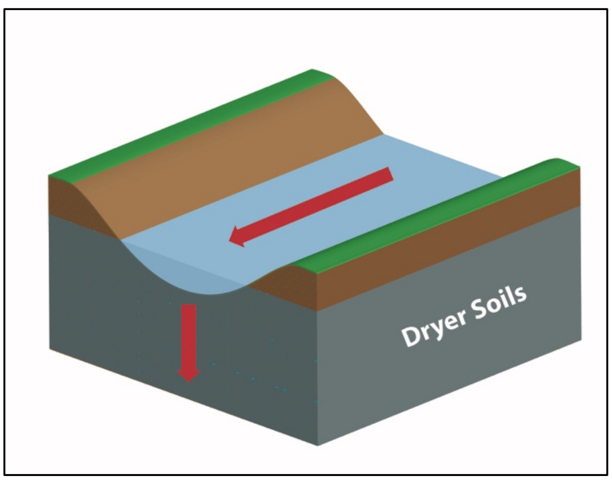


Figure 1. Incised streams that are disconnected from the floodplain contain flow in channels that result in excessive velocities during storm events (straight arrows pointing downstream). Soils surrounding the incised channel are drained by the incised stream, which essentially functions as a ditch (brown and grey soil layer) and are unable to support native riparian vegetation. Because water cannot overflow onto the floodplain, soils remain dehydrated and groundwater and surface interaction is limited in area and volume (arrow down).

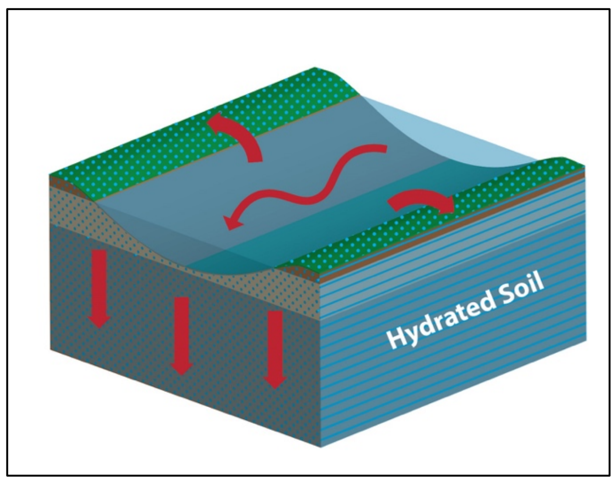


Figure 2. Wide, shallow streams regularly overflow onto the floodplain during storm events (curved arrows pointing onto floodplain), thereby reducing volume within the channel (thin, sinuous arrow pointing downstream). Water stays on site longer over a larger surface area, which hydrates soils and re-establishes robust groundwater and surface interaction (three thick down arrows) and establishes hydrated soil conditions to feed baseflow during dry periods (blue striped soil layers).

To replace or recreate these functions, true RSC designs create the most stable distribution, duration and timing of flooding (hydroperiod) to hydrate the floodplain with stream overflows, recharge ground water through infiltration and create seepage through exfiltration. The re-established hydrologic conditions, especially reconnecting surface water to groundwater, are necessary to kickstart the complex biogeochemical processes critical to healthy regeneration of the native ecosystem. This approach is a change from modern stormwater management practices that aimed to shunt water from the source to a distant waterway as quickly as possible through a network of channels, storm drains and pipes. The contemporary RSC approach on the other hand, slows down and spreads out the water higher on the landscape and closer to its source thereby allowing it to slowly soak in and seep its way down to receiving waters. Functionally, this is achieved by constructing a series of weirs, riffles and associated pools and berms.

Slow It Down – Spread It Out – Soak It In

Slow it Down: Riffle-weirs serve as check points that slow and redirect flow at designed elevations (Figure 30). Weirs are mini grade control structures that hold back streamflow and direct water to the adjacent floodplain where it infiltrates into the ground. In RSCs, weirs are generally constructed with native boulders and/or rock, incorporate a riffle and are paired with a pool. When the area behind a weir fills, water begins to flow over the boulders and rocks and continues downstream into a pool before flowing over the next weir.

A riffle is a seamless upstream extension of the weir that conveys streamflow. It is a shallow, gravel and rock bedded section that withstands fast and turbulent flows. In RSC, it is an integral part of the weir and, therefore, the complete structure is referred to as “riffle-weir”. Riffles introduce roughness by non-uniform placement of gravel and rock, which slows flow. The longer, rougher and wider the riffle, the slower the flow.

Pools receive water from the upstream weir and riffle and hold it until they fill and water flows over the next weir. During storms, pools reduce energy and slow down flow by holding water and, therefore, the wider and deeper the pool, the slower the flow.

The combination of these features form the riffle-pool or step pool sequence that effectively serve to slow down flow.

Spread It Out: Berms are landward extensions of riffle-weirs used to tie riffle-weirs into existing grade and serve to spread water laterally onto the floodplain and direct flow to the riffle-weir so that it does not cut around the weir (Figure 45). They are constructed of sandy soils and form low embankments that hold water back during high flows. In RSC, berms are often constructed of sandy soils to establish seepage conditions that enable water to slowly filter back into the stream after storm events, as well as encourage the growth of wetland vegetation and development of a fibric root mat that supports geochemical processes.

Soak It In: Pools and floodplains hold water and allow time for water to slowly seep into the ground. After storm events and during dry periods, the saturated floodplain feeds the ecosystem slowly draining into the stream, thereby prolonging baseflow conditions. Wet conditions in the floodplain and perennial baseflow provide a more stable habitat for diverse communities of aquatic and riparian organisms, which in turn aid in the filtration of water and processing of nutrients. Therefore, our goal in constructing RSC is to maximize the amount of water we can store in our pools and on the floodplain.

WHY RSC?

Retaining water on site is a significant change from past civil and water resource engineering approaches, which aimed to shunt water as far and quickly off site as possible. However, RSC practice builds on past restoration approaches, such as in-stream game fish habitat designs from the late 1800s and Natural Channel Design (NCD) from the 1990s, which stabilized rapidly degrading streams by reducing erosive forces of stream flows while creating in-stream fish habitat. (See Appendix A, Brief History of Land Use and Stream Restoration)

Many streams today are incised and/or channelized from receiving heightened volumes, velocity and concentrations of water diverted from developed land through manmade storm drain and pipe networks (see Appendix A for history of land use). During storm events, concentrated flows from pipes erode stream beds and banks and carry turbid waters into receiving waterbodies. Deep and straight channels disconnect streams from their floodplain, rendering them unable to regularly hydrate the floodplain and store water for drier times. Over time, the disconnected floodplains convert into "drought plains", or terraces, fail to support higher levels of stream functions and succumb to degradation. The "drought" sets off a domino effect; poor habitat for native plants open the way for invasive plant species, animals that depended on native plants for food and habitat diminish and soils that depended on native flora and fauna for physical aeration and biogeochemical processes become depleted and compacted (Table 1). Negative impacts of land use changes include:

1. High volume flows that flush the stream, causing banks and streams to erode and prohibiting the sustainability of diverse in-stream habitat such as riffles, pools and coarse woody debris.
2. Incised and channelized streams that move water quickly out of the system in one concentrated direction and cannot deliver overbank overflows onto the floodplain.
3. Turbid waters that result from sediment laden runoff and stream bank erosion smother aquatic species and fill downstream waterbodies.
4. Polluted waters that bypass the floodplain do not have a chance to filter through soils and wetlands. Nutrient laden runoff from the streams to tidal waters stimulates excessive phytoplankton growth and subsequent die-off, which creates low dissolved oxygen and degraded aquatic environments downstream.
5. A disconnected and dry floodplain that cannot reciprocate to nourish the stream during dry periods.

Stream restoration science shows proper hydrologic and hydraulic functions serve as the foundation for restoring a stream ecosystem (Harman, 2012) (Figure 3). RSC is a holistic approach that considers the hydrological, hydraulic, geomorphological, physical, chemical and biological needs of the stream ecosystem and sets conditions for these processes to re-establish.

To build a robust foundation, RSC seeks to restore the full three-dimensional movement of water that natural stream systems depend upon (Levels 1 and 2 of the Functional Pyramid) by creating:

1. Longitudinal flow that moves water downslope from the watershed, to the stream and to the next receiving water body;
2. Lateral flow out onto the vegetated riparian zone and hydrated floodplain; and
3. Vertical flow down into and up out of the ground that enables interactions between surface water and groundwater.

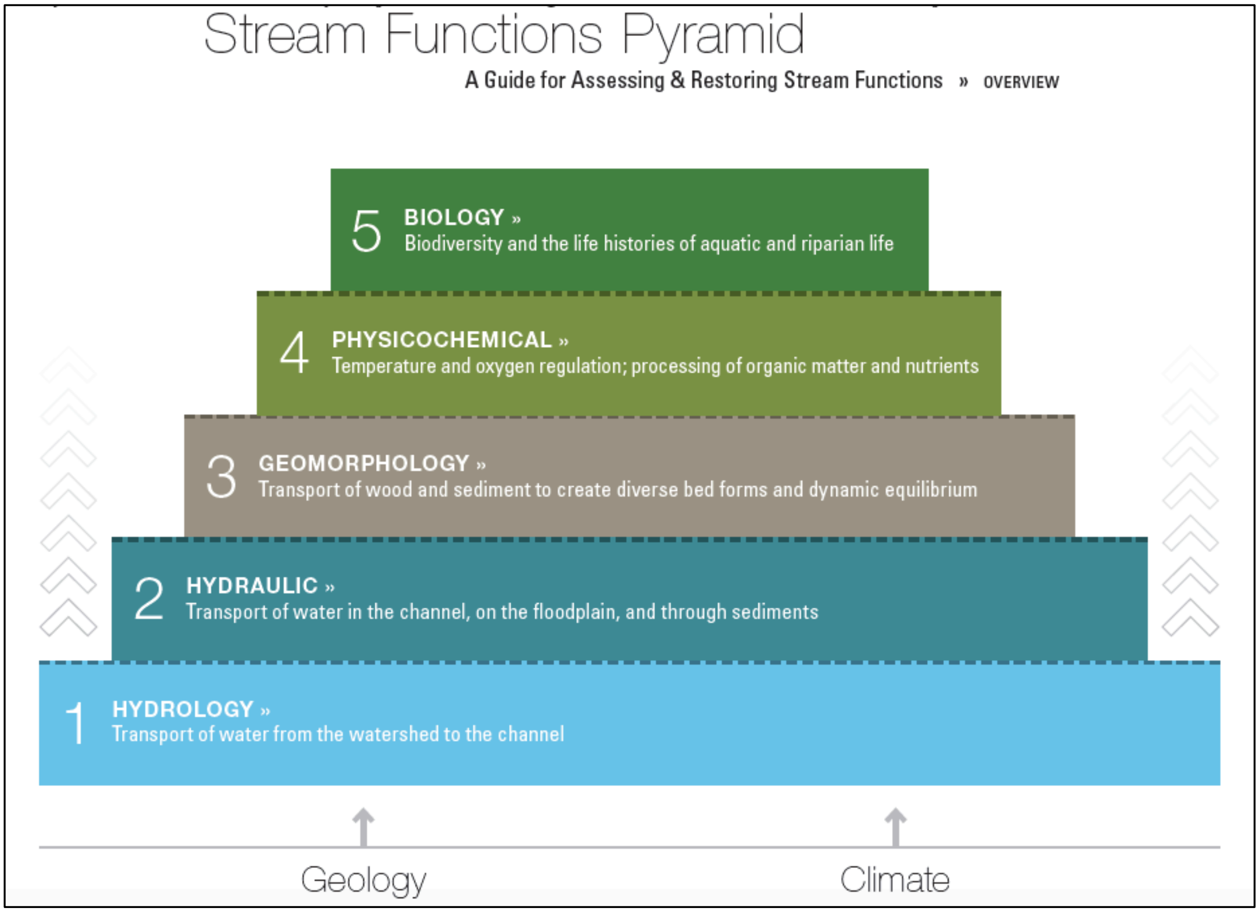


Figure 3. Functional pyramid indicates that hydrologic and hydraulic functions provide the foundation for higher level stream functions. US Fish and Wildlife Service. A Function-Based Framework. May 2012.

To enable the system to regenerate itself upon the restored foundation, RSC aims to set the stage to propel hydraulic, geomorphology, physicochemical and biological processes (Levels 2, 3, 4 and 5 of Stream Functions) by integrating:

1. Prevented erosion (Level 2 Hydraulic);
2. Retention of woody material/carbon and addition of aggregates of various gradations, e.g., fine sands, coarse sand, gravel, river rock and boulders, to support natural stream channel processes through self-organization of stream bed material (Level 3 Geomorphology);
3. Reconnection of stream and floodplain and re-establishment of surface and groundwater interaction to help remove nitrogen phosphorus and settle out sediment (Level 4 Physiochemical); and
4. Establishment of robust vegetative community to create habitat, support physiochemical processes and replenish carbon (Level 5 Biology).

Recognizing this critical connection with the floodplain, properly designed and constructed RSC projects maximize opportunities to firmly establish the hydrologic and hydraulic foundation by retaining as much water on site for as long as possible by slowing down the longitudinal flow, spreading out through lateral flow, and soaking into the ground through vertical flow. Provided stresses to the system are kept in check, these exchanges of flow between the stream and its floodplain consistently nourish and replenish the ecosystem and dramatically improve the stream's chances of regenerating itself into a fully functioning ecosystem.

Table 1. Comparison of sample functional characteristics between a healthy and degraded stream.

STREAM FUNCTIONS	HEALTHY STREAM	DEGRADED STREAM
Hydrology	• Healthy baseflow continuously fed by seeping groundwater from hydrated soils	• Low and/or intermittent baseflow due to dehydrated soils and lower groundwater levels
Hydraulic	• Flow tops banks and dissipates energy throughout the floodplain	• Flow restricted within channel picks up energy and erodes channel
Geomorphology	• Replenishes the system by sustainably transporting sediment and woody debris to establish dynamic equilibrium and create diverse in-stream features	• Flushes the system with excessive transport of sediment and woody debris and strips system of diversity resulting in a straight and denuded channel
Physicochemical	• Cooler temperature that support fisheries • Higher oxygen levels • Abundant and diverse sources of organic matter that replenishes seasonally and supports biological processes • Maintains complex processes that breakdown and take up nutrients	• Warmer temperature that inhibit fisheries • Lower oxygen levels • Stripped of organic material which limits biological processes • Simply transports nutrients to downstream waterbodies
Biology	• Diverse flora and fauna including sensitive species • Supports native species	• Fewer flora and fauna dominated by tolerant species • Susceptible to non-native species

WHERE CAN RSCs BE APPLIED?

RSCs have successfully been applied throughout the watershed from a down spout to and beyond confluences where streams meet tidal waterbodies. RSCs are applicable in perennial as well as ephemeral systems and in natural as well as manmade systems. For example, Step Pool Stormwater Conveyance (SPSC) is an RSC practice applied specifically to manage stormwater through an open channel stream-like feature rather than a stormdrain and underground pipe (Figure 4). The various pseudonyms for RSC, such as SPSC, coastal plain outfall, and regenerative *stormwater* conveyance, reflect the broad applicability of RSCs throughout the watershed. They can be applied in any waterway, stormwater conveyance or landscape that has potential to detain, infiltrate and/or spread water on site. Therefore, RSCs can be successfully applied in small headwater wetlands at the top to gently sloped streams below, in stormwater ponds (Figure 5), at outfalls (Figure 6), in steep gullies (Figure 7), and down to tidal confluences where streams meet tidal waterbodies (Figure 8). RSCs can successfully be used in both small and large drainage areas and waterbodies (Figure 9).

RSCs can be applied to sites that can detain and infiltrate water and support native vegetation.

1. *Range of locations from top to bottom of watersheds*
2. *Range of slope from steep to flat*
3. *Perennial as well as ephemeral*
4. *To replace or repair outfalls and other stormwater conveyances*
5. *Small to large drainage areas*

Step Pool Stormwater Conveyance (SPSC)

Figure 4. Example of a step pool stormwater conveyance capturing water from rooftop and surrounding fields with compacted soils to filter through sand and woodchip chamber before stormwater drains into a fragile freshwater bog. This was an excavation project.

Stormwater Pond Retrofit

Figure 5. Example of a dry pond retrofit that created sand and woodchip berms and filter beds to increase time of stormwater detention and decrease volume and velocity entering the stream immediately below. This was a fill project.

Outfall

Figure 6. Example of deeply incised outfalls (streams at end of stormwater pipe) that were restored with sand and woodchip filter bed, riffle-weirs, pools and cascades. These are fill projects that raise the stream bed to reconnect with the floodplain.

Steep Gully/Ravine

Figure 7. Example of a steep gully and exposed utilities restored with a step pool stormwater conveyance to capture stormwater (flowing down boulder) at the end of a dead end street and non-erosively convey and improve water quality before it enters a stream.

Tidal Confluence/Flat Valley Bottom

Figure 8. Example of just completed RSC restoration of a small stream near the mouth of a tidal river. Increased stormwater runoff from roads and parking lot eroded the wetland and stream complex, causing sediment to flow into the river.

Large Drainage Area and Waterbodies

Figure 9. Example of dam removal and regenerative restoration of a stream with a 13-square mile drainage area. This was a fill project to improve water quality and fish passage.

Throughout various locations, slope and hydrology, the same principles apply: slow it down, spread it out and soak it in. Due to the smaller construction footprint, RSCs can be constructed by mostly working in-stream. Therefore, it is also a useful approach in areas where property boundaries or limits of disturbance (LOD) are severely limited as is often the case in ultra-urban streams.

HOW DO YOU CONSTRUCT SUCCESSFUL RSC PROJECTS?

For decades, stream restoration projects have benefited from an interdisciplinary team approach. RSC practice builds on this by demanding more of design engineers and contractors. **An interdisciplinary construction team** with knowledge of sensitive ecosystems and understanding of basic hydrology, hydraulics and ecosystem functions is optimal. Leading up to the construction phase, design and permit teams can set the stage for success by:

1. Proficiently applying their knowledge of natural and water resources to RSC designs;
2. Familiarizing themselves with the site and its unique characteristics;
3. Paying attention to the needs of contractors for accurate estimating and informed construction of RSC features;

4. Allotting sufficient time for team members to be available during construction in anticipation of field modifications and quantify materials; and
5. Being cognizant of standard construction practices that may need to be modified to preserve and amplify existing regenerative conditions.

In addition to interpreting engineering plans and operating heavy equipment, contractors must enable the creation of and be able to create the complex three-dimensional realm that streams need to thrive. Contractors must recognize that software limitations relegate engineering plans to straight lines and proportional curves and, therefore, engineers often cannot accurately represent natural features. Hence, a box symbol for a weir should not be interpreted to mean a weir with angled corners and clean, straight edges but rather an indication of the placement and minimum dimensions of the structure.

Contractors should aim to estimate and construct features to blend in with the natural setting, use sufficient material to facilitate dynamic equilibrium through natural movement of bedload material and reintroduce abundant organic, aggregate and vegetative materials to successfully establish regenerative conditions. Designers can support this practice by:

1. Incorporating sufficient and varied material in calculation of quantities by recognizing that structures should not be distinct geometric shapes with sharp edges but rather blended into the landscape with a diverse range of materials and sizes;
2. Factoring in settlement of aggregates over time, voids that need to be filled, expansion during excavation, loss of materials during the first few storms as the system seeks dynamic equilibrium; and
3. Working closely with the contractor and maintaining a presence on site to support and facilitate interpretation of plans and review of material and quantity needs.

The next section provides more detail about specific construction practices, tools and techniques specific to successfully constructing RSC projects.

RSC CONSTRUCTION

The Anne Arundel County Department of Public Works' Design Guidelines for Step Pool Storm Conveyance (SPSC) (revision anticipated in 2019) includes details and specifications on SPSC design elements and includes guidance and specifications on proper installation (Flores, 2012). This section provides supplemental guidance on construction team, practices, key construction equipment and tools, and select techniques to fine tune RSC construction and ensure successful establishment of regenerative conditions.

A. CONSTRUCTION TEAM

A.1 Ecological Specialist

As stream restoration advances to more fully restore ecological function, it is imperative to have a team member who possesses proficient ecological knowledge. This member must maintain a presence on site and commit to bilateral exchange of knowledge with the crew to further the team's multifaceted goals. A background in disciplines such as hydrology, stream or wetland ecology, natural or aquatic resources management and/or restoration science would strengthen the construction team's ability to recognize the restoration potential on site, understand the nuances of construction activities and their impacts to the restoration goal and collectively overcome challenges and seize opportunities.

A.2 Restoration Manager

A construction manager who is not only knowledgeable of construction practices but also possesses basic understanding of, and appreciation for, stream ecosystem functions and processes is instrumental to establishing regenerative conditions, especially in the absence of an Ecological Specialist. Such a Restoration Manager will be able to construct the engineering designs, which are firmly based on hydrologic and hydraulic models, in a manner that also establishes the necessary geomorphic (Level 3 Function), physicochemical (Level 4 Function) and complex biological (Level 5 Function) conditions necessary to restore and support those functions. To be able to direct construction activities in a manner that consistently supports the restoration of intended ecological function(s), basic knowledge in hydrology, hydraulics, geomorphology, biogeochemistry and botany is optimal.

A.3 Restoration Crew

The crew of operators and laborers are the foot soldiers of stream restoration and, therefore, are equally critical to the success of the project as any other team member. It is imperative that the crew understands the goals of restoration projects, give deference to the fragility of the ecosystem and adopt practices that avoid unnecessary impacts. A crew that is mindful of the delicate balance that exists between the impacts of construction and ability of a system to regenerate will be able to ensure a functionally successful project.

B. CONSTRUCTION PRACTICES

B.1 Impact Minimization

Successful RSC projects adopt a practice of avoidance within the LOD. The area within the LOD should not be interpreted by the contractor as freedom to disturb the entire area but rather to further avoid and minimize disturbance and to protect existing features beneficial to the regeneration of the system. Degraded systems are not completely devoid of native materials and functional conditions. Often, the system is degraded simply because the functional parts are buried, disconnected and overwhelmed by stressors such as silt, erosive hydraulic energies and invasive plant species. A minimally invasive approach can successfully remove or reduce stressors to establish regenerative conditions. Familiarity with the project site increases at each successive stage from project site survey, conceptual design, final design, permitting, estimating and construction to adaptive management. As the last practitioner in line, the contractor has the responsibility to capture opportunities to further reduce impact and enhance regenerative conditions. The degree and extent to which a contractor avoids and minimizes disturbance, especially in the riparian area, will set apart the project that merely appears successfully constructed from one that is truly functional under the surface.

CODE OF REGENERATIVE CONSTRUCTION

1. ***Avoid tree removal throughout project site***
2. ***Minimize land and soil disturbance in riparian areas***
3. ***Preserve existing micro-topography and re-establish diverse topography in disturbed areas***
4. ***Maintain and enhance groundwater interactions when appropriate***
5. ***Adopt an iterative approach to construction***

The remainder of this guidance provides instruction on the careful planning, measured actions and tools and techniques necessary to construct in adherence to the Code of Regenerative Construction.

B.2 Adaptive Management

Adaptive management is a deliberative and iterative process that is implemented sequentially over time. The feedback between learning from the system and helping to inform decision making is a defining feature of adaptive management and is often applied in managing systems that are subject to uncertainties (Williams, 2011). Stream restoration projects are subject to numerous uncertainties, such as environmental variation and structural or process uncertainty, and, therefore, should be managed adaptively over time rather than treated as turn-key projects. In essence, informed interventions are experimental "treatments" with the subsequent learning seen as a means to an end, namely effective management, and not an end in itself (Walters, 1986). The National Research Council uses the phrase "flexible decision making that can be adjusted in the face of uncertainties" at the heart of its definition of adaptive management, which differs from trial and error because it is structured through articulation of objectives, identification of management alternatives, predictions of management consequences, recognition of key uncertainties and monitoring (National Research Council, 2004).

Adaptive management is critical to stream restoration in order to establish and maintain a high-functioning ecosystem. Restoration begins at a very high level and goes through an iterative process to fine tune the most appropriate design for the site. Project sponsors, e.g., resource management agencies, nonprofit organizations, property owners, etc., identify restoration needs through watershed level assessments. Once streams are identified for restoration, engineers and permit reviewers efficiently analyze and design projects through site survey and desktop modeling that produce designs that capture a two-dimensional snapshot of the project site at a singular point in time, which is used to guide the next phase – construction.

Just as design engineers cannot assess and predict all variables of the system and its drainage area, contractors cannot fully anticipate how specific site characteristics and complex forces shape the system. Constructing in a degraded yet sensitive system is complex and layered with uncertainties. Features and conditions that could not be identified, or anticipated, during the design phase, e.g., differing soil conditions, unique site hydrology, unexpected bedrock, valuable native plant community or seed bank, undocumented stormwater networks, illicit discharges, constructability of certain features or sequences, etc., are some of the uncertainties and design limitations encountered during the construction phase.

As the last practitioner in line, the contractor also has the responsibility to construct at the microscale level to achieve the intended goals with a design, construction budget and schedule based on the mesoscale design and estimates. Recognizing that it is difficult to identify, nevertheless address, microscale characteristics during design and permitting phases due to limited resources and the mesoscale in which design functions, contractors should actively engage project sponsors, engineers and permit reviewers to adaptively manage the project. Securing adequate flexibility, time, collaboration and resources from the full team will enable the contractor to further fine tune the project to more fully realize project objectives and reduce risk for all parties.

To maximize ecological benefit, restoration teams must be able to make timely and functionally appropriate modifications ("treatments") based on the team's collective expertise, project objectives, site specific observations and consideration of alternatives during the construction phase. It is prudent to develop a decision-making process with all parties involved that facilitates timely implementation of adaptive actions both during and after construction. Examples of responsive decisions include but are not limited to:

- Enabling access to site to repair damage, replant areas or treat invasive plants;
- Response to post storm observations during construction that highlight opportunities to increase hydrologic and hydraulic function such as to modify grade control or shift structures to better manage actual flow patterns created by the site specific characterstics that could not be captured in modeling; and
- In extreme cases, possible consideration of a change in original layout due to severely changed conditions in the project site or in the drainage area.

To facilitate adaptive management, project stakeholders may want to include certain scope of work features and practices into their contracts and designs, such as:

1. Design Engineer's close collaboration with contractor and permitting agency during construction;
2. Maintenance access to the site post construction;
3. Incorporation of additional materials on the project site for easy access to materials for repairs and adaptive amendment of materials to the system as it seeks a dynamic equilibrium post construction; and
4. Inclusion of an adaptive management/maintenance phase in the project contract with a defined budget and general scope of work.

C. CONSTRUCTION EQUIPMENT

C.1 Wide Tracked, Limited/Zero Tail Swing Excavator with Hydraulic Thumb

It is common knowledge that wide steel tracks are necessary to minimize compaction and maneuver through wet conditions. Not only do wide steel tracks distribute weight more evenly than rubber tracks but they can also keep soil layers intact unlike knobbed rubber tracks that tend to dig into and churn the soil, which is detrimental to creating and maintaining conditions for infiltration and seeps. Last, wide steel tracks are necessary to:

- Crush and blend woodchips into the project site;
- Press and lock materials such as woodchip, sand, gravel and rock in place as they are placed in an additive process; and
- Help form the parabolic shape of large weirs.

The agility, range and power of an excavator and its bucket are necessary to:

- Firmly and securely push and/or pound boulders into the soil; and
- Cast, rather than methodically place, smaller aggregates, e.g., pea gravel, ¾ gravel and 2-inch stone throughout structures for stream flow to "self-organize", i.e., distribute material with flow velocities and energies.

A limited tail swing or zero tail swing excavator is critical to reduce or eliminate unintentional damage to surrounding plants and trees.

A thumbed excavator on stream restoration projects is a must and a hydraulic thumb is optimal for deftly moving materials, picking through boulders for the right size and shape and accurately setting boulders to create a stable structure.

C.2 Rotating Tracked Dump Truck

Tracked dump trucks allow the operator to deliver large quantities of material to the worksite via low ground pressure steel tracks. The ability of the truck to rotate 360 degrees allows the precise placement of material as well as exiting the location in the same footprint as its entrance. This alone limits its area of impact and ground compaction by eliminating the area that most equipment needs to turn around. Within their footprint, tracks yield less pressure per inch than wheels and, therefore, reduce compaction.

Figure 10. Smooth bucket creates smears (left vertical side of left photo) impeding subsurface flow; whereas toothed bucket "fluffs" the soils (bottom and right vertical sides of excavated area in left photo, and right photo) and allow movement of water vertically and laterally.

C.3 Toothed Bucket

Toothed buckets are necessary to avoid creating slick, impervious surfaces while excavating and grading (Figure 10). Excavated areas for installation of grade control structures and pools must remain as porous as possible to allow infiltration and exfiltration. Smooth buckets in soils with any clay content smear the surface and create conditions that impede movement of water into surrounding soils.

C.4 Rubber Treaded Skid Steer/Mini Tracked Loader

Skid steers are strongly recommended for the installation of perforated pipe and gravel under-drain, construction of haul road and weirs and shaping of weirs. Again, toothed buckets should be utilized.

C.5 Hand Tools

Successful RSC relies on both heavy equipment and hand tools such as shovels and rakes. Once structures are installed and site is graded, use of heavy equipment should be minimized to keep the area from becoming overly compacted. The crew should switch from a heavy equipment construction to landscaping with shovels, rakes and wheelbarrow to put the final stabilization touches on slopes, fill crevices and rake tracked surfaces. This switch ensures less compacted top layers that will allow infiltration, seepage and plant establishment, which cannot be accomplished by smoothing (and smearing as discussed in C.3 Toothed Bucket) with the back of the bucket.

D. SITE PREPARATION

D.1 Preserve Microtopography and Soil Layers

Figure 11. Microtopography of a seepage wetland.

Fence Off Natural Features Within the LOD

Natural features that pock mark the floodplain with depressions, hummocks, seeps, oxbows, etc. are integral to ecological processes such as nutrient cycling and energy flows that connect the living and non-living components of the ecosystem. Like the seepage wetland shown in Figure 11, these systems are fragile yet provide critical habitat for native species. Preserving as much of these features as possible is beneficial to the restoration effort and, therefore, should be fenced off before equipment is transported onto the site, and ideally during construction stakeout, to keep from filling and grading (Figures 12, 13 and 14).

Figure 12. A small depression along the base of a hill and perpendicular to the stream was present on site. The depression captured water seeping out of the slope (to the left of depression). It is potential habitat for amphibians and other aquatic animals. It was too small to be captured on plans with one-foot contours but the contractor fenced off the area when it was discovered to prevent construction activity.

Figure 13. During haul road construction along the edge of the stream, this contractor minimized the width, avoided tree removal and preserved the existing depression on the floodplain (wet areas at the bottom and right side of the photo). Clean sand was used to bridge the haul road across the depression to allow drainage and the depression was not filled or levelled to preserve a diverse topography. Logs were used to keep sand from spilling into the depression, which was kept intact throughout and post construction as seen in the next figure.

Figure 14. Depression shown in Figure 12 remains post construction. Hydrology was slightly altered due to the haul road that remained on site to serve as a footpath, but the depression continues to receive seepage from the slope and drain into the stream through the sand and woodchip filter.

Three Phases of Grading

As discussed in Section C.3 Toothed Bucket, smearing the ground chokes soils and reduces ability to infiltrate. Extensive smooth grading with the bottom of the bucket can also create this condition and is discouraged. Rough grading and final grading should focus on getting proper elevations and grades. As discussed in Section C.4 Hand Tools, equipment use after completion of structures should be avoided. Therefore, fine grading by hand raking to achieve smooth out surfaces, e.g., track ruts, teeth marks, is encouraged.

Limit Excavation

On fill projects, excavation should be limited to the footprint of grade control structures where excavation is necessary for achieving subgrade for boulder placement. On cut projects that require extensive excavation to remove legacy sediment or other undesirable material such as urban fill, it is important to keep native soil layers intact where sand or gravel lenses that facilitate subsurface flow may be present.

D.2 Minimize Tree Removal

Figure 15. Both larger and smaller trees are left in place during the construction of the haul road and iteratively removed or incorporated into the project during weir and pool construction. Trees removed during construction are used as coarse woody debris in addition to imported stumps, logs and branches.

As restoration practitioners, contractors should take responsibility for protecting trees and avoid excessively clearing riparian areas. As prescribed in the Code of Regenerative Construction, avoid tree removal during clearing and grubbing operations to limit disturbance, preserve soil structure, retain carbon on site and maintain a canopy.

Conservative and Iterative Decision Making

Permitted removal should not be interpreted to mean necessary tree removal but rather flexibility to facilitate construction if tree removal is necessary. It also does not mean tree removal can only be done during clearing and grubbing. Therefore, decisions to remove trees should be made conservatively, in stages and iteratively (Figure 15), and techniques, such as boulder walls and tree wells, for savings trees should be explored and implemented (Figure 16). For example, the initial clearing and grubbing effort should be limited to accessing the site and continued in stages as construction of haul roads proceeds into the project. Haul road construction should skirt around trees within the LOD rather than strictly following survey stakes and clearing every tree in the path. Usually during design, only "specimen" trees that are a minimum of 30-inch diameter at breast height are surveyed. Therefore, 29-inch trees may be on the side of the haul road and should be saved if possible even if they are not marked for protection. Removal should be the last option after avoiding drip line, working within root zones and partially impacting roots and inundation.

An impacted tree (as opposed to an absent tree) provides long-term ecological value. Trees that gradually die from prolonged periods of inundation or root impacts continue to seed, hold soils in place, provide shade, serve as a snag for habitat and supply carbon after its death and is preferred over immediate removal. If the project is in a recreational area, measures such as pruning dead limbs to ensure public safety should take priority.

Compensation for Saved Trees

Often, plans identify and contracts enumerate trees to be removed. Payment is based on the number of trees removed or removal of all marked trees, so the more marked trees the contractor removes the higher the payment. Therefore, there is no financial incentive to save trees. However, saving trees and working around these trees also involves a level of effort during construction and there is long-term ecological value of saved trees that outweigh cost savings from easing construction by clearcutting a path. In keeping with the restoration goal to regenerate the system, and until a line item for Tree Preservation or Lump Sum value with specifications to minimize tree removal is adopted by design engineers and project sponsors, contractors should advocate for saving trees and negotiate compensation for minimized tree removal.

Figure 16. To avoid removal of trees that are close to the haul road, tree wells and boulder walls are available techniques. Rather than remove a tree that is on the edge of the haul road, keep the tree while ensuring that a tree well is created and maintained to avoid burying the trunk.

D.3 Minimize Riparian Footprint

Figure 17. Construction of in stream haul road with sand and woodchip. Contractor backs trucks to the edge, as evidenced by tire tracks, and dumps material in place.

RSC designs for incised channels raise the stream bed up closer to the floodplain by filling the eroded channel with a sand and woodchip filter bed (Figure 17 and 27). This RSC feature is purposefully designed to minimize riparian impacts by serving dual functions:

1. Haul road that enables in-stream construction and reduces need to utilize the riparian area for trucks and equipment; and
2. Restored RSC element critical to re-establishing active interaction between surface and groundwater.

Contractors should take steps to contain heavy equipment traffic to the sand and woodchip in-stream haul road to minimize compaction of soils and tree removal in the riparian area. Operating heavy equipment in the riparian zone creates a domino effect that begins with compacted soils and leads to degraded riparian ecosystems due to dryer soils (Figure 18 and 19).

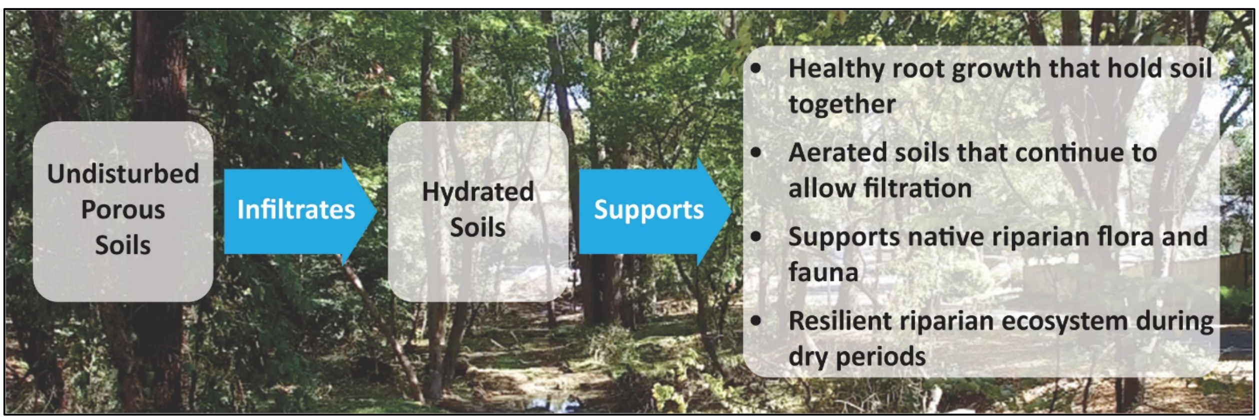


Figure 18. Conditions supported by undisturbed riparian zone, the interface between land and stream.

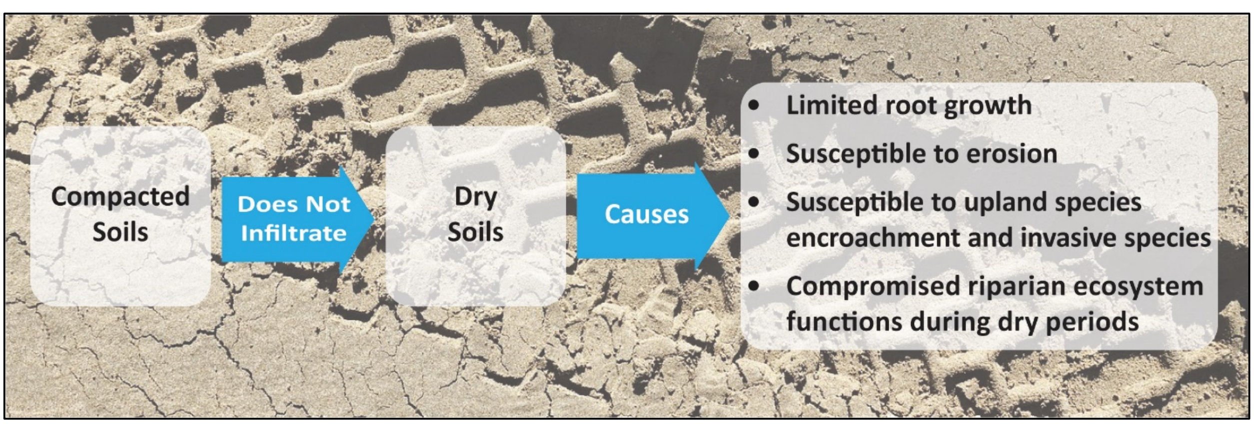


Figure 19. Conditions caused by compacted soils in the riparian zone versus undisturbed soils.

E. CONSTRUCTION METHODS AND TECHNIQUES

Transitioning from estimating with engineering plans to constructing in the field is the final step in realizing a restoration project. It affords an opportunity to fine-tune features and quantities that is not possible to achieve through desktop designing and estimating with short site visits before bid due dates. However, contractors have the responsibility to adjust each designed structure and feature to create the most stable and functional installation and often face a wide range of existing conditions and dimensions that differ from engineering plans.

All parties must fully recognize that stream restoration is subject to the constant, complex and minimally controllable forces of nature to a greater degree than constructing static structures in more controlled environments. To ensure a functionally successful project, contractors, engineers and project sponsors must recognize the inherent uncertainty and inaccuracy in estimating material quantities with computer aided design and engineering plans that cannot adequately account for true quantities necessary to construct three-dimensional features, ensure integrated placement of structures and fully assure constructability during the design phase. Contractors should advocate for contingencies and field modification protocols. Otherwise, contractors are relegated to construct with insufficient quantities, precarious placement of structures and simplified practices that do not establish regenerative conditions.

E.1 Slotted Pipe and Gravel Underdrain

Figure 20. Slotted underdrain system functions as a french drain to help keep haul road dry and convey baseflow during construction. Sections of pipe must be removed during sequential construction of pools to restore surface flow.

In general, stream restoration designs rely solely on pumping water around the stream and is referred to as clear water diversion and pump around. The diversion of surface water suffices for most stream designs because the haul road is on the dryer riparian area and installation of grade control and habitat structures is approached from the side. Reconnecting the stream to the floodplain is usually not the restoration goal of such projects. Therefore, some baseflow in the channel does not greatly hinder construction because there is no need to continuously fill the channel to replace the eroded streambed.

A key goal of RSC, on the other hand, is to reconnect the stream to its floodplain. This can be achieved by lowering the floodplain to the channel through legacy sediment removal or replenishing the channel with porous fill material to raise the stream bed. As explained in Section D.3 Minimize Riparian Footprint, the sand and woodchip filter bed in RSC also serves as a haul road during construction and becomes the stream bed at completion. To facilitate dry haul road conditions in channel fill projects, experienced practitioners have successfully devised and used a perforated underdrain system to drain the road (Figures 20 and 26). The underdrain functions like a French drain and must be used in tandem with a pump around practice properly sized for the drainage area (Figure 25).

Figure 21. Slotted pipe is inserted into pipe and capped. For smaller drainage areas, haul road can begin immediately downstream as seen in the bottom left of photo. Small pumps can be used to dewater if necessary.

Figure 22. Slotted pipe is inserted into outfall and capped. For large drainage areas, sandbag dikes should be installed sufficiently downstream to create pooling area, as seen in the photo, for clean water diversion.

Figure 23. Slotted pipes must be secured with sand bags and stakes to prevent buckling during pea gravel seam installation.

KEY STEPS

- ***Lay pipe along centerline.***
- ***Secure pipes with series of staked sandbags.***
- ***Place gravel over pipe.***
- ***Simultaneously extend haul road.***
- ***Remove sections of underdrain perforated pipe during pool construction.***

Function

When the haul road becomes saturated after storm events, water filters down through the sand and wood chip medium. The gravel placed around the perforated pipe drains the saturated haul road/filter bed and pool water at the bottom of the existing stream bed. The perforations in the pipe allows water to seep into the pipe and drain downstream.

Materials and Supplies

- Slotted or perforated (high-density polyethylene) pipe sized and configured according to existing saturation level of riparian area and baseflow (e.g., 4-inch, 6-inch, or two rows)
- Wooden stakes
- Wire ties
- Sand and sandbags
- Pea gravel

Installation Method

1. Lay pipes along the entire length of the center line of the stream bed and/or designed in-stream haul road location following water flow, which indicates the lowest elevation of the stream bed. If it is an excavation project, excavate to achieve subgrade before laying pipes.
   1.1. For projects that begin at an outfall pipe (Figures 21 and 22):
      1.1.1. Insert perforated pipe far into the storm drain pipe.
      1.1.2. Cap the end. The underdrain functions as a filter drain by draining water through slots/perforations. Its purpose is not an extension of an outfall pipe and, therefore, the end should be capped. Cap also prevents debris from clogging up the pipe.
      1.1.3. If the outfall has severely eroded the streambed and is no longer at a similar elevation as the streambed, start the underdrain at the end of the pipe in the stream.
   1.2. For projects that begin mid-reach of a stream:
      1.2.1. Install perforated pipe from sandbag dams specified for clear water diversion, with a section extending upstream into the ponded area behind sandbags.
      1.2.2. Cap pipe.
2. Secure entire length of perforated pipe every 10-15 feet with sandbags, stakes and wire ties to keep pipe in place as the channel is filled (Figure 23). For the portion that is inserted into a stormwater pipe, secure with continuously stacked sandbags over the entire length of the inserted pipe.
3. Starting sufficiently downstream of perforated pipe, place pea gravel over the secured pipe to begin the gravel seam (Figure 24). Size the seam from 3-feet by 3-feet for 4-inch pipes to wider and deeper for larger diameter pipes. Keep the section of pipe extending into the outfall pipe or upstream of the sandbag exposed to allow ponded water to continuously drain.
4. Simultaneously construct the in-stream sand and woodchip haul road over gravel underdrain. Seasoned practitioners dump materials in place rather than stock pile.
5. Actively maintain the pump around (clear water diversion) practice throughout the duration of in-stream construction. Systems with large drainage areas or flashy systems should install automatic pumps to ensure continuous diversion during unmanned periods.
6. Sections of slotted pipe must be removed during construction of pools to restore surface flow and avoid dry streams.

Figure 24. Placement of pea gravel seam over secured slotted pipe and construction of sand and woodchip haul road over the underdrain.

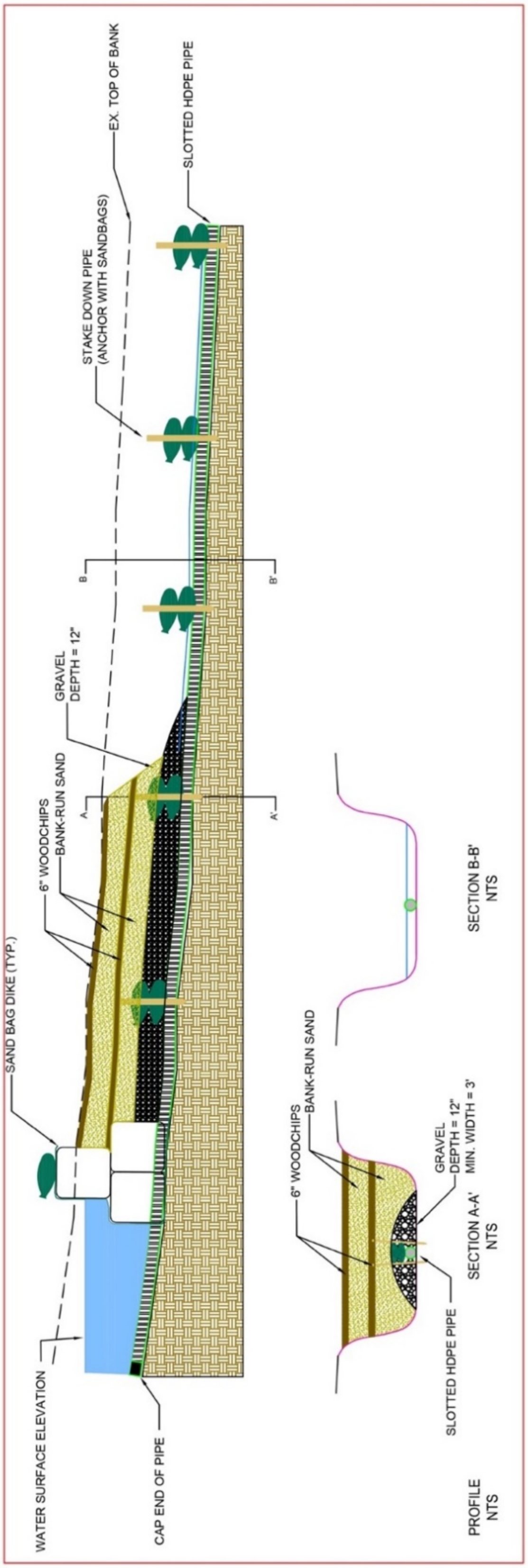
Figure 25. Slotted pipe underdrain must be used in conjunction with a pump around practice that is sized to handle the volumes of the drainage area.

KEY STEPS

- ***Lay pipe along centerline.***
- ***Secure pipes with series of staked sandbags.***
- ***Place gravel over pipe.***
- ***Simultaneously extend sand as the haul road.***
- ***Remove sections of underdrain perforated pipe during pool construction.***

It is important to secure the perforated pipe with sandbags and stakes to keep pipe flush to the stream bed during installation (Figure 23). To function properly, the pipe must remain at the lowest part of the stream bed. This system helps to dry out the haul road to enable continued work after average rain events and throughout the construction period.

Sample Photos, Plans and Details



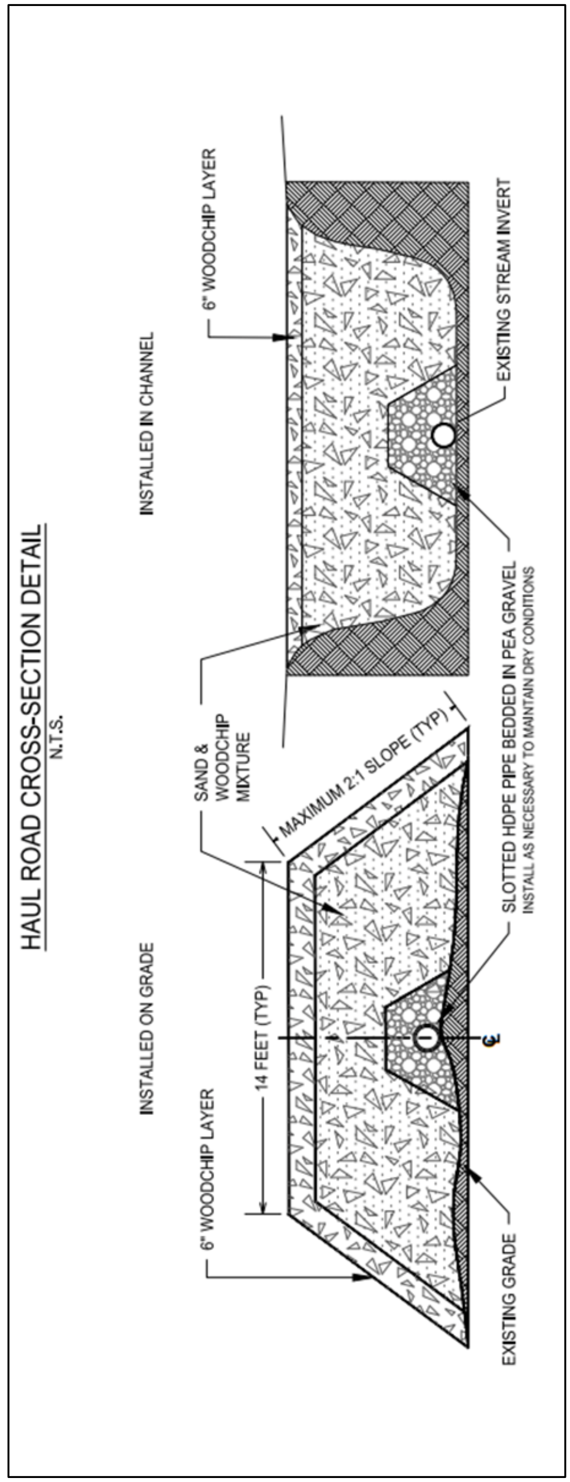


Figure 26. Profile and cross section of slotted pipe and gravel underdrain used to dewater the haul road. The underdrain pipe must be removed during pool excavation.

E.2 Construction Entrance and Haul Road

Figure 27. Woodchip and sand haul road constructed in stream to raise the stream bottom and to minimize impacts to riparian area.

RSC designs specify sand and woodchip construction entrance and haul roads, rather than aggregate (Figure 27). Again, this is to utilize the channel fill as the haul road to minimize impacts to the riparian zone. Other stream restoration designs typically call for removal of the haul road at the end of the project. In RSC, the haul road that is in-stream becomes the stream bed. The parts that are outside of the stream are left in place to naturalize into the landscape as sloughs and provide access to enable adaptive management activities post construction. Most importantly, the sand and woodchip medium sustains appropriate vegetation and habitat post construction.

RSC designs that are ideal for constructing in stream begin haul road construction at the upstream end. This enables the construction team to work themselves out of in-stream structures from downstream to upstream and, more importantly, ensures continuous and stable construction of riffle-weir-pool sequences (see Section E.4 Riffle-weir).

Function

The dual purpose and function of a sand and woodchip haul road was presented in Sections D.3 Minimize Riparian Footprint and E.1 Slotted Pipe and Gravel Underdrain. Specifically, during construction, the haul road provides access for trucks and equipment and serves as erosion and sediment control. The mixture of sand and woodchip helps keep the road dry and stable. Runoff created from the haul road is minimal due to the sand that passes water and woodchip that absorbs precipitation. Woodchip also helps to trap sediment from runoff from other parts of the project site.

During cold weather, woodchip maintains the ground in a workable condition by providing a cover.

Post construction, the organic carbon is an energy source for microbes and, therefore, the foundation of the aquatic food web, which streams depend on for the biogeochemical processes that improve water quality by fixing nitrogen.

Materials and Supplies*

- Clean sand
- Woodchip
- Temporary stabilization seed

**Note: geotextile is not used in RSC haul roads because sand and woodchip haul road is left in place to naturalize into the landscape.*

Installation Method

1. Place loads of sand over the perforated pipe and gravel underdrain to cover the gravel and to the edges of stream bank.
2. Spread woodchip over sand.
3. Constantly track and dress haul road to thoroughly incorporate woodchip into the sand bed.
4. Continue to build haul road up to the level of banks or close to finished grade by using one load of woodchip to three or four loads of sand, depending on size of loads.
5. Continuously add sand and woodchip throughout construction duration to keep road dry and functional as wet weather necessitates and to blend woodchip into the soil.
6. Repeatedly seed with temporary seed throughout construction duration and throughout the site to establish a sufficient seed bank on site in the top 12-inches of the haul road and other chipped areas. Seeding with a spreader after each fresh layer of woodchip is highly recommended.

KEY STEPS

- ***Cover underdrain with sand.***
- ***Constantly add and track woodchip into sand haul road/channel fill.***
- ***Repeatedly seed the site.***

This method helps to:

1. Replenish organic carbon lost from clearing and grubbing and tree removal;
2. Consolidates the sand and woodchip mixture to form a more uniform and stable medium on which to build that also allows water to filter and flow through; and
3. Enables the site to revegetate and stabilize after storms, post construction and beyond. Small rills or eroded patches from washed out woodchip will quickly germinate seed that has been blended into the woodchip.

Pre-mixing woodchip and sand for one-time placement creates uniformity throughout the system that does not achieve the same regenerative conditions as layering sand and woodchip then tracking, which creates diverse layers. Areas where layers of sand are intact will seep water through differently than areas where sand and woodchip are mixed, which may become an area of higher microbial activity. Therefore, layering sand and woodchips is recommended.

E.3 Stratified Lenses

Figure 28. Glacial deposits (gravel) buried under organic soils (dark band) from presettlement wetlands and silty legacy sediment (light band) from deforestation post European settlement.

RSC aims to create sand and gravel layers that mimic the form and function of interstratified lenses inherent in intact soils. Often, porous lenses of sand and gravel are sandwiched between other material such as clay, organics or bedrock (Figure 28). In degraded systems, these functions have been lost due to streambed erosion that broke the stratified lenses and/or sedimentation that choked the material. These features are difficult to detail in engineered plans because the existing gravel layers on every stream vary in depth, thickness and location. However, contractors should strive to restore the connection to broken and disconnected layers.

Function

Stratified lenses of sand, gravel and other material enable storage and movement of groundwater and important materials processes to take place. When saturated, top soil layers drain into sand and gravel layers that are remnants from the glacial period. These gravel layers move water underground like the gravel underdrain presented in Section E.1 Slotted Pipe and Gravel Underdrain. Wherever these lenses daylight at a stream bank or a depression in the floodplain, a seep or spring occurs. Seeps, springs and the subsurface movement of water feeding them are critical to establishing and maintaining wetland conditions, regulating stream temperatures and supporting geochemical processes. This interaction between groundwater and surface water is an important part of a robust hydrologic cycle but one that is often overlooked in stream restoration. It is a difficult condition to design and achieve but not impossible if the contractor is able to identify the restoration opportunities.

Materials and Supplies

- Sand
- Range of gravel sizes
- Woodchip

Installation Method

1. Observe eroded banks throughout the entire length of the stream to identify sand and/or gravel seams, which are often exposed on the sides of the eroded banks (Figure 29).
   1.1. Install sand and/or gravel layers in a manner that connects the imported material to existing gravel substrate.
   1.2. Ensure full connection, in depth and bank to bank width, to the native sand and/or gravel layer.
2. Avoid mixing silt into sand and gravel material as this impedes movement of water through the soils.
3. Avoid excavating unless it is for installing grade control structures or pools. Digging into soils will break lenses, which may be a fine layer of sand and organic soils indistinguishable to the eye.
4. Place pea gravel on the slopes of pools to create opportunities for lenses to daylight. Place on the side that has a higher ground in the riparian area, which is more likely to drain water underground toward the stream.

Figure 29. Installation of pea gravel under-drain and seam starting to connect to the native gravel seam (darker gravel on the right side of photo beneath the layer of soil) that has been broken and exposed by bank erosion.

E.4 Riffle-Weir

Design specifications with basic weir construction guidance can be found in the Anne Arundel County Department of Public Works' Design Guidelines for Step Pool Storm Conveyance (SPSC), December 2012, (revision anticipated in 2019). Techniques to fine tune construction and suggested modifications to optimize function are presented in this section. As mentioned in Section D.2 Construction Access and Haul Road, it is ideal to construct structures from downstream to upstream. The haul road remains open to facilitate materials transport and equipment fueling throughout the construction of each structure and enable the crew "zip up" the stream by stacking material as they work upstream and out of the site, exiting through the same upstream entrance that was created to build the in-stream haul road.

Figure 30. Weirs are placed to form a parabolic shape that is continued onto the bank. Footer boulders are submerged during wet period with downstream apron of river rock seen at water surface.

Function

Hydraulically, weirs hold back water and riffles deflect water. In RSC, riffle-weirs are one continuous structure where the riffle is an extension of the weir and they function together to convey stream flow from pools to the next weir in a stable manner (Figure 30). Structurally, properly designed and constructed riffle-weirs control the grade in a manner that allows fish passage. In gently sloped systems, there is sufficient length in the stream to extend the riffle significantly before a one-foot change in elevation necessitates another pool-riffle-weir sequence. The anatomy of a riffle-weir are footer boulders, weir boulders or weir rock, apron and riffle (Figure 33 and 34).

Materials and Supplies

- Concrete sand and/or sandy fill
- Range of gravel sizes
- Specified stone (river rock is preferred)
- Specified boulder
- Geotextile and pins

Installation Method

<u>Footer Boulder</u>: Footer boulders anchor the grade control structure and keep the parabolic shape intact. In weirs, unlike cascades, these boulders do not necessarily serve as footing for stacking boulders but rather as stoppers to keep the weir boulders from slipping downstream (Figures 33 and 44).

1. Excavate subgrade for footer boulder placement.
2. Cut and place geotextile for the footer boulder to keep boulders in place (Figure 31).
3. Place footer boulders sufficiently into soil over pinned geotextile, tilt downstream, press and pound into ground with the back of the excavator bucket (Figure 31).
   3.1. Most of the footer boulder should be below the water surface elevation and where the apron starts (explained below). The upper 3- to 6-inches should break the water surface. This is particularly important in cobble weirs in which weirs are constructed of river rock over footer boulders (Figure 32). The extruding portion of the footer boulder is a fail-safe measure to provide some grade control until repairs can be made should an extreme storm event wash out the cobble.
   3.2. It is optimal to place a single layer of footer boulders and no more than two layers (Figure 43). Stacking introduces instability and unnecessarily adds height to the weir.
   3.3. If stacking is necessary to make up elevation in steep sequences, set the first layer sufficiently downstream to make room for a second layer that partially overlaps rather than stacks directly on top of the underlying boulder. Also, adequately bury the first layer. Do not create a stacked wall. Continue overlapping layers upstream.

Figure 31. Footer boulder and weir boulder placed over geotextile (photo on left). Firmly press or pound boulders into place with the back of an excavator bucket (photo on right).

3.4. Stagger seams of boulders between each layer. Setting a boulder on the crevice of two boulders is more stable than stacking one on top of another.
3.5. During wet periods, water should submerge footer boulders (Figure 36).

Figure 32. "Cobble weir" with footer boulders submerged and river rocks (cobble) used to hold the grade. It was constructed with sufficient gravel in pools, riffle-weir and along edges to enable formation of diverse flow characteristics, stream bed and habitat.

Apron: The apron carries flow from the weir down into the pool in a non-erosive manner.

4. Place small boulders and river rock along the downstream edge along footer boulders and down the pool slope. The footer boulder is the beginning of the apron and extends into the pool.
   4.1. Place larger river rock in the center third of the width of the weir where flow is most concentrated and aim to create an organic shape rather than a perfect rectangle (Figure 33 and 34).
   4.2. Placement of a few larger-sized river rocks scattered in the apron disrupts concentrated flow and is encouraged.
   4.3. Expect movement of gravel and river rock as the stream dynamically adjusts post construction to find its equilibrium.

Weir Boulders/River Rock: Weir boulders/rocks establish the grade that controls flow. Some designs specify boulders for the weir (Figure 33). Others specify large river rock for the construction of weirs on top of footer boulders and are sometimes called "cobble weirs" (Figures 32 and 35).

5. Moving upstream, set weir boulders and river rock behind the footer boulder to finished elevation. Working upstream with the gradient allows the most stable overlapping of boulders and structurally sound weirs.
   5.1. Geotextile may not be necessary in gently sloped areas unless specified.
   5.2. Create a one-foot drop from top (upstream side) to bottom (downstream side) of the weir by tilting boulders downstream or placing river rock to create a sloped plane rather than a step (Figure 35 and 44).
   5.3. For cobble weirs, start over the footer boulders and continue upstream so that half the cobble is over the footer boulder.
      5.3.1. Set boulders to achieve finished elevation (invert) at the center of the weir on the upstream edge.

Figure 33. Riffle-weir constructed with weir boulders. From downstream to upstream (right side of photos to left), features are pool, river rock apron (submerged), footer boulder (exposed during baseflow conditions on left photo) anchoring the weir boulders that are controlling grade, riffle and pool. Note that the weir boulders are not stacked on top of footer boulders.

5.3.2. Tilt boulders 10% to create a smooth one-foot drop in elevation by following the general slope of the stream bed.

5.3.2.1. Creating the one-foot drop in elevation by tilting boulders enables weir to convey flows from larger storms in a stable manner. Minimizing fall (steps) reduces force hitting boulders (sheer stress). Weirs cannot handle as much force as cascades, which are constructed slightly differently and explained in Section E.6.

5.3.2.2. Use large river rock (erratics) scattered around the weir and riffle or irregularly shaped boulder surfaces to disrupt and slow flow rather than tilting boulders upstream to achieve the same effect, unless specified otherwise (Figure 40). Upstream tilt could compromise the structure from excessive backsplashing.

5.3.2.3. While ensuring drops are not excessive, ensure sufficient drop within the weir structure because without it, lateral flow will increase and cut around the weir.

5.4. Form a gently curved rack (broad crescent shape with opening facing downstream) to encourage a broader flow rather than a concentrated flow in the center (Figure 35). Again, ensuring sufficient drop within the weir is important to keep lateral flow in check to maintain the broad flow over weir boulders.

5.5. Create a parabolic shape (crescent shape with opening facing skyward) by tilting boulders 5 degrees toward the centerline and form arms into the banks (Figure 36).

5.6. The one-foot drop and parabolic shape will deflect flow into the center of the pool.

5.7. A construction sequence of constructing pools and riffles from downstream to upstream stages a more seamless process that results in a well-integrated series of pools, weirs and riffles.

5.8. Avoid tree removal (Figure 37 and 38).

6. Add sand and gravel to fill voids. Supplying the system with a range of gravel sizes is key to establishing desired flow characteristics as the stream self-organizes and stabilizes.

6.1. Observe during and after storms to note flow over weirs.

6.2. Supply more sand and gravel in strategic locations, e.g., gravel and small cobble along upstream edge of weir and sand and gravel on pool slopes for next storm to naturally fill in voids. River rock and small boulders may also be needed to supplement material or adjust structures.

6.3. Avoid moving material already in the system to adjust structures or flow characteristics as they have already been "installed" by natural storm flows. If a structure is no longer accessible to a skid steer, use wheelbarrows to bring in new material.

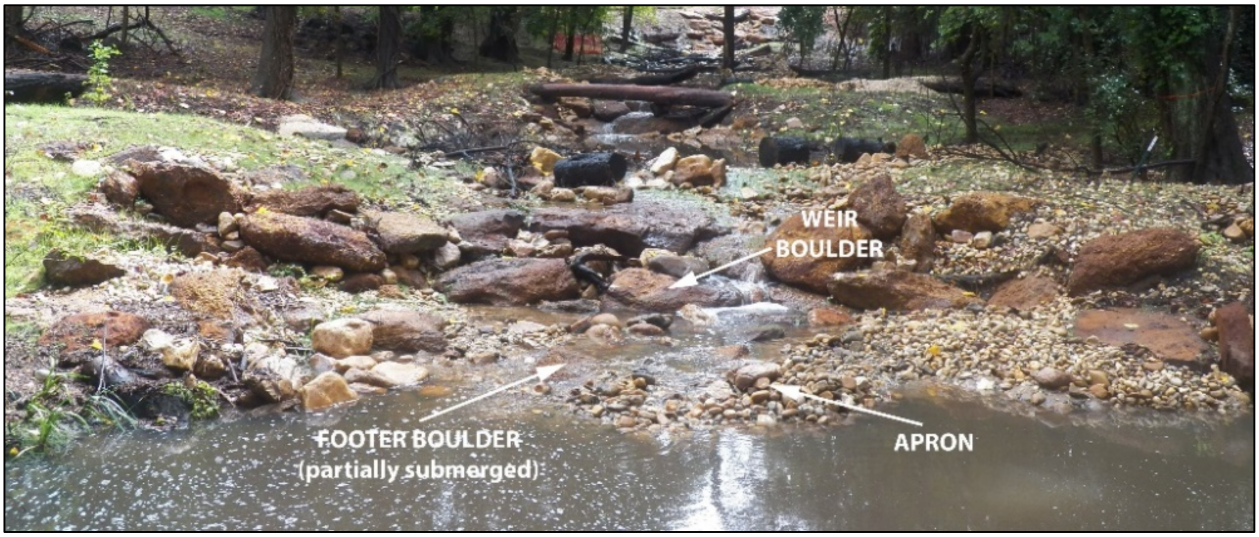


Figure 34. Upstream view of riffle-weir with submerged footer border, apron and weir boulders.

Figure 35. Riffle-weirs constructed with one-foot difference in elevation between the top and bottom edges to avoid sheer drops and safely convey large storm flows. Photo on left is an example of a riffle-weir constructed with weir boulders. Photo on right is an example of a "cobble weir" constructed with footer boulders and river rock (cobble). In both cases, boulders are tilted downstream to convey flow to pool without increased force on stream bed (sheer stress) and a gentle curve is formed to broaden flow.

Figure 36. Large trees voluntarily marked with orange construction fencing to avoid removal before haul road construction. Smaller trees saved by the contractor until weir construction before determining need for removal. The contractor successfully constructed the weir per plans without removing the trees (red circles show same trees pre, during and post construction).

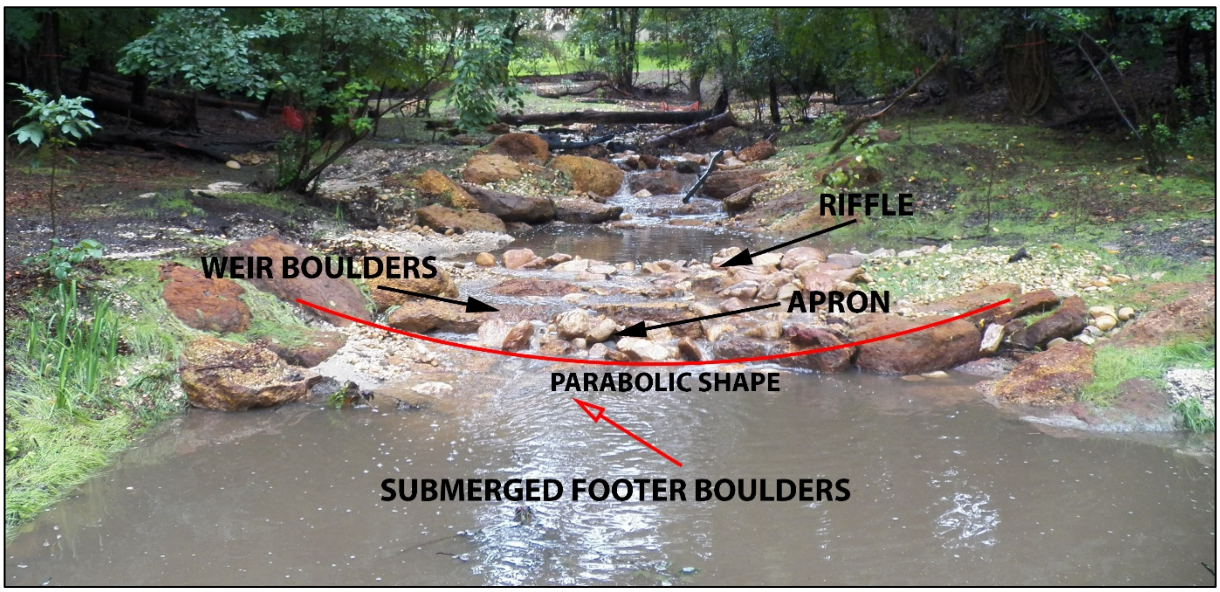


Figure 37. Illustration of parabolic shape and the anatomy of a weir that consists of apron, footer boulders, weir boulders/rocks and riffle.

Figure 38. Large trees were saved during boulder wall construction (left). Weirs were constructed without removing tree (above and right), which will continue to stabilize the soil and provide habitat, shade and organic carbon.

Riffle: Riffles stably convey and slow down flow and provide habitat and are an integral part of the whole weir, hence the name riffle-weir.

7. Place river rock upstream of weir boulders with some overlap to create a blended transition and continue to the edge of the upstream pool (Figures 39 and 40).
   7.1. Longer riffle lengths increase flow path and create more friction. Working with the design engineer, efforts should be made to maximize riffle lengths within the stream's gradient to increase roughness.
   7.2. Over time, the stream will extend the apron downstream as it adjusts so it is important to supply the riffle with excess river rock.
   7.3. Flows are most concentrated in the center and, therefore, larger river rocks should be placed in the middle third of the riffle width.
8. Geotextile under river rock should be avoided if possible. The smooth surface tends to cause erosive movement of materials rather than the desired natural self-sorting of bedload material and incorporation of gravel and rocks into the stream. It also compromises the desired three-dimensional stream flow characteristics that RSC aims to establish.
9. Track the weir with a skid steer to lock materials into the parabolic shape.
   9.1. If a skid steer is not available, use the bucket of an excavator to firmly pack placed material into place without flattening the sides of the parabolic shape.
   9.2. This simple but essential step helps to minimize excessively large bumps and embed the structure into the soil to lock in the rocks, thereby increasing stability in the early periods post construction. It does not suffice to simply sprinkle rock onto the surface with a bucket as the final step in constructing a riffle-weir.
10. Randomly cast mixed size gravel into the riffle and around the edges.
    10.1. A full range of particle size is necessary to adjust to the range of velocity and volume. Therefore, once the backbone of the structures has been constructed with specified sizes, a broader range of gravel and river rock sizes should be added to and around the structure.
    10.2. Casting these aggregates, rather than placing them neatly or premixing them, is encouraged. It introduces randomness that creates a more gradual transition between the sized rock in the riffle and finer existing soils.
11. Liberally cast sand and gravel over each finished structure before continuing to the next structure to fill in voids and to supply material for the wash-in step.
12. After the wash-in step is complete, leave excess material at the riffle-weir and pool edges for touch ups and to allow natural features to form and diversify stream bed morphology and habitat (Figure 31). Sands and gravel throughout the system also help to create varied flow, which is also important to habitat diversity.

Chink and Wash-In: Voids between boulders and rocks must be sufficiently filled to achieve proper flow over and through the weirs and is achieved by washing sand and gravel through the system which also provides the contractor opportunity to observe and adjust structures or grades.

13. Place small boulders and rock in cracks and openings between weir boulders. This is often referred to as chinking. If possible, choose shapes and place in a manner that continues the lines of the boulders (Figure 51).
14. Use a dewatering pump to wash structures to create movement of smaller particles into and over riffle-weirs at end of construction once stream is stabilized (Figure 41).
    14.1. Start at top most weir.

Figure 39. Riffle with scattered erratics extending upstream from weir boulders. Apron of river rock extends downstream from weir boulders and into the pool.

Figure 40. Riffle leading up to one-foot weir contains scattered erratic rocks that reduces energy by disrupting flow. Weir boulders are submerged under streamflow after storm event. Gentle parabolic shape of weir both spreads stream flow with-in the riffle and weir as well as prevents flow from cutting around the weir.

14.2. Place sufficient wash in material, e.g., mix of sand, pea gravel and ¾-inch gravel (also referred to as bank run gravel) throughout structures.
14.3. Use 2-inch pump and hose to wash structures using clean water from pools and/or behind sandbag dikes.
14.4. Observe flows over weirs and cascades and adjust addition of sand, gravel and river rock accordingly.
14.5. Repeat multiple times.
14.6. Leave additional sand and gravel upstream and edge of weir for storms to wash in.

Figure 41. Wash in structures with sand and gravel to fill voids. This should be repeated to sufficiently fill voids, observe flow paths and adjust, if necessary, with more gravel and cobble.

Sample Plans and Details

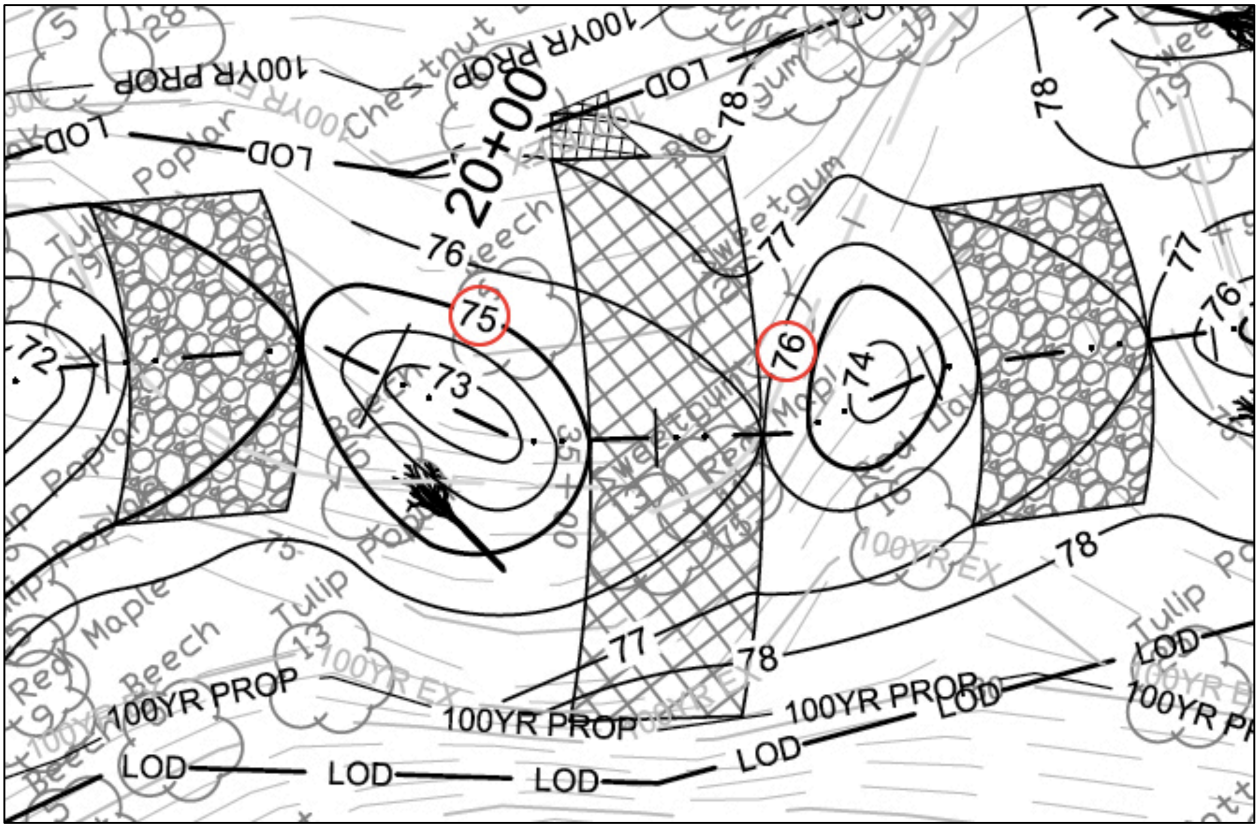


Figure 42. One-foot drop between upstream and downstream edges of a weir.

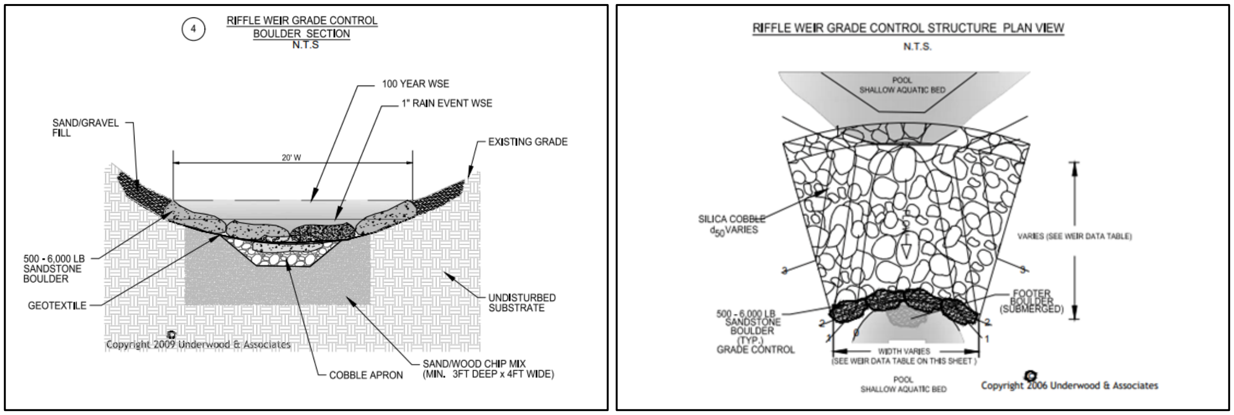
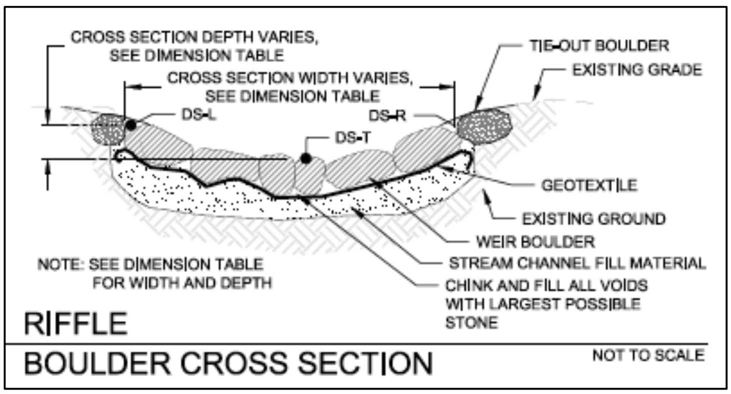
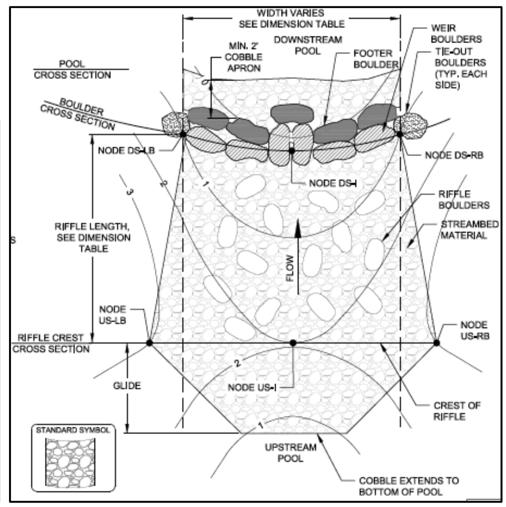


Figure 43. Sample plan view and cross sections of one-foot riffle-weir. Note that weir boulders are not stacked on top of footers.





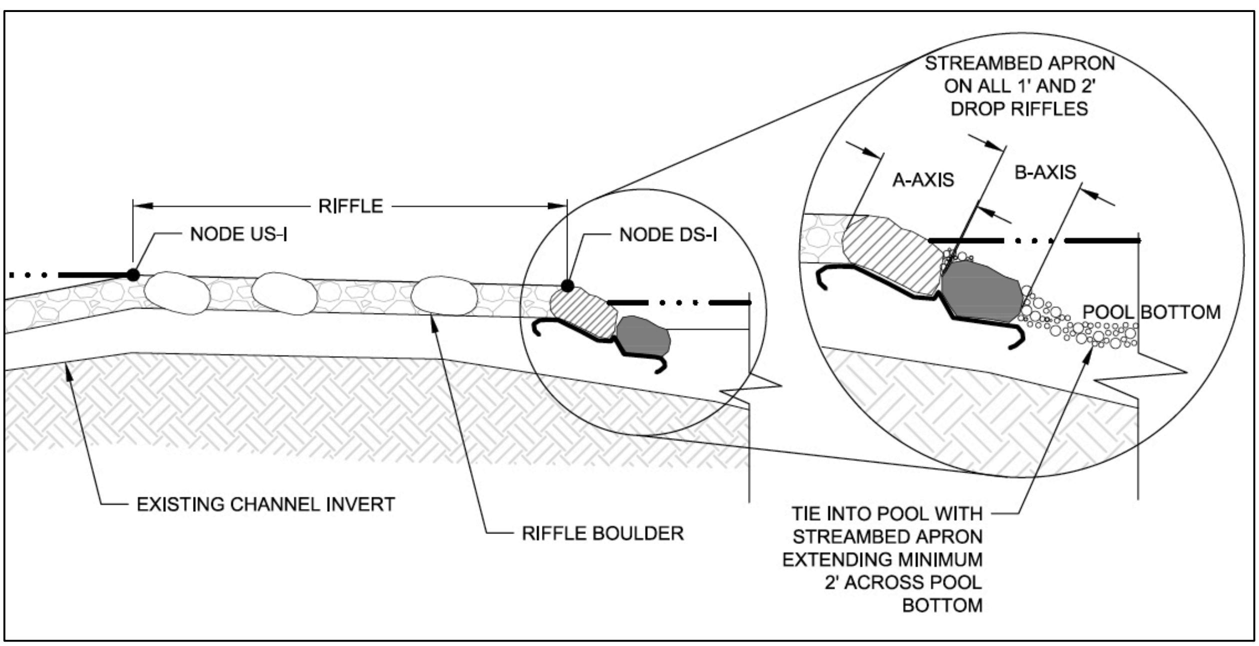


Figure 44. Sample profile of riffle-weir illustrating the footer boulder (hatched boulder) anchoring the weir boulder and beginning the apron (grey boulder).

E.5 Berms

Figure 45. Berms holding water to keep flow from cutting around the weir, spreading water out, increasing exchanges of surface and groundwater and filtering water through their medium.

Function

Berms are landward extensions of weirs and serve multiple functions (Figure 45). Structurally, they connect the weir to the landscape by extending the height of the weir edges to the same height (grade) in the existing topography. Hydraulically, berms hold and spread water out laterally onto the floodplain, keeping flow from cutting around the weir and eroding the banks during large storm events. Hydrologically, berms increase saturated periods to allow surface and groundwater (vertical) interaction that supports baseflow conditions. Also, water filtering through the berm often creates seeps on the downstream edge of berms. Seeps contribute to biological diversity and health as they provide a different habitat and filter water. Chemically, berms help improve water quality by slowly filtering and cooling ponded water through their medium as well as floodplain soils.

Materials and Supplies

- Sandy fill
- Woodchip

Installation Method

1. Place sand to extend the edge of weir onto the floodplain. Maintain the same elevation (level) until it connects with same elevation on the existing landscape (Figures 46, 47 and 48).
   1.1. Generally, a flat, 3-foot width at the top of the berm and gentle side slopes function best and enable plants to establish.
   1.2. Avoid shaping berms like A dikes (too steep and not wide enough at the top) with pointed ridges because they are prone to failure in stream systems.
   1.3. Avoid using silty material as it is prone to causing piping and internal erosion.
   1.4. Properly tie in to high ground to avoid breach.
   1.5. Track over berms to uniformly compact and ensure proper elevation to avoid low spots and depressions that can allow water to overtop and form a breach.
2. Place woodchip over berm.

Figure 46. Berm extended out to tie into same grade in the landscape. Plantings on berm left access path for future adaptive management activities.

Sample Plans and Details

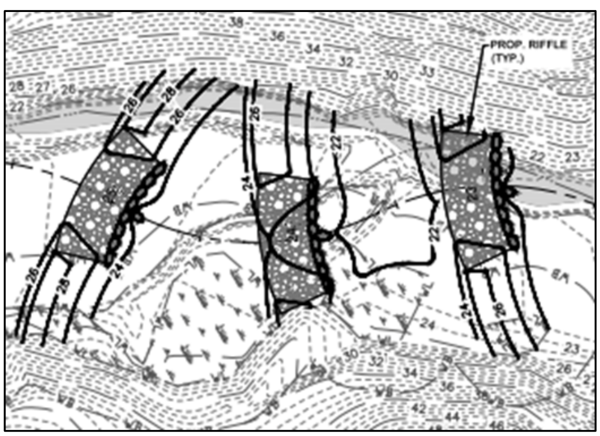


Figure 47. Plan view of proposed condition showing grade lines that extend from constructed weir onto existing floodplain to form berms that tie into existing grade. Dark line showing elevation 28 on Weir 25 (left) connects with the existing elevation 28 indicated by dotted line.

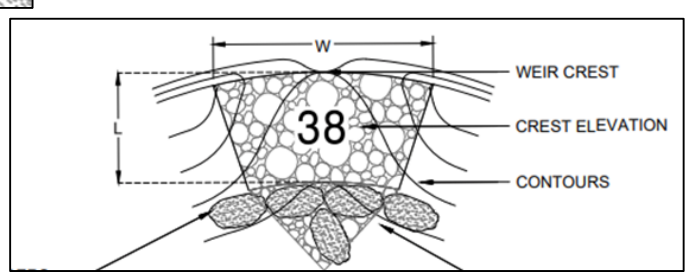


Figure 48. Detail of a weir instructing it to be constructed to 38 feet at crest of the weir and grade lines extending from the weir to indicate that weirs must be tied into existing grade.

E.6 Cascades

Design specifications with basic cascade construction guidance can also be found in the Anne Arundel County Department of Public Works' Design Guidelines for Step Pool Storm Conveyance (SPSC), December 2012, (revision anticipated in 2019). Techniques to fine tune construction and appropriate interpretations of plans and details to optimize function are presented in this section.

Figure 49. Gentle parabolic shape to keep flow from cutting around. Curved rack to widen flow. Flat placement of boulders to break flow. Tie in boulders extending into the berm and existing ground.

Function

Cascades, when sized correctly, can safely transport stream flow over a greater drop than weirs and, therefore, are used to convey water through changes in elevations that are greater than two feet (Figure 49 and 53). Generally, weirs safely control and convey water for a fall in elevation of one (optimal) to two feet. Flow velocity and sheer stress (force of water pushing on the bed) increases dramatically for each one-foot drop in elevation and require a more robust structure. One seasoned practitioner likened cascades to "Rosgen Cross Vanes on steroids". Cross vanes redirect flow away from the banks and to the center of the thalweg (Figure 50). Cascades allow a broader flow over the width of the shoulders.

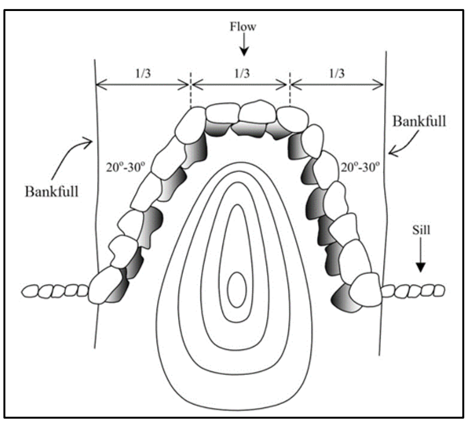


Figure 50. Plan view of Rosgen cross vane that directs flow to the center.

Materials and Supplies

- Sandy fill
- Range of gravel sizes
- Range of river rock sizes
- Boulders
- Geotextile and pins
- Woodchip

Installation Method

1. Excavate subgrade for footer boulder placement. Footer boulder(s) keep the grade control structure intact and truly function as a footer onto which next layer of boulder will be stacked. It is recommended to bury cascade footer boulders three feet deep.
2. Cut and place geotextile over the entire footprint of the cascade, including the side slopes. Fold back upstream portions to sit excavator without puncturing geotextile while constructing downstream portions.
   - 2.1. For longitudinal placement, overlap geotextile so the upstream piece covers the downstream one to maintain continuous flow over the top and keep water from going under the fabric.
   - 2.2. For vertical placement, overlap geotextile so the top piece covers the bottom.
   - 2.3. To avoid unnecessary seams, be sure to cut geotextile to a size much wider than the proposed structure width (in some cases 25% or more). Due to the irregularity of the rock

material and structure shape, fabric is consumed by the structure in the form of wrinkles, sags, depressions, etc.

2.4. Geotextile must extend all the way out and slightly beyond sides of finished structure.
2.5. Trim any excess geotextile upon completion.

3. Secure footer boulders, generally three feet deep, into soil over pinned geotextile.
   3.1. Place boulders flat (unlike weirs, in which they are tilted).
   3.2. Press and pound into the ground with the back of the excavator bucket (Figure 31).
4. Form a gently curved rack to spread water laterally (ends of curve point downstream).
5. Form a gentle parabolic shape to keep flow within the thalweg and shoulders (Figure 51).
6. Continue stacking boulders to designed elevation by stepping each layer upstream with a slight overlap of layers. Carefully interpret details, keeping in mind that engineering software is limited in representing natural, three-dimensional features, to ensure stability (Figure 53).
   6.1. Place boulders flat, unlike weirs in which boulders are tilted downstream, to break flow and reduce energy (Figure 52).
   6.2. Do not create a chute.
   6.3. Cascades should be three boulders deep (into the upstream slope) rather than one stacked row.
7. Liberally cast sand and gravel over each finished structure before continuing to the next structure to fill in voids and to supply material for the wash-in stage.
8. Wash in smaller particles into the structure at the end of construction.
   8.1. Start at top pool or pooled water behind sandbag dike.
   8.2. Use 2-inch pump and hose to wash structures.
   8.3. Repeat multiple times. Supply more sand and gravel at top weirs to continue supplying material to fill voids in subsequent storms and washes.
9. Chink (add large rocks and small boulders to crevices) larger voids between boulders.

Preventing Common Failures and Issues

1. Water erodes a path adjacent and/or around boulders where it ties into the existing ground.
   1.1. Do not spare sub-surface "key-in" boulders beyond the visible footprint (secured into the bank).
   1.2. Carry the parabolic shape into the bank as boulders are "keyed in."
   1.3. Observe drainage patterns carefully to characterize surface flow from sheet drainage arriving at the structure. Water often arrives from adjacent properties, over curbs and across the landscape.
2. Excessive velocity and scour downstream.
   2.1. Do not tilt boulders downstream which creates smooth chute.
   2.2. Create roughness and turbulence in the structure by using flat and irregular surfaces to break flow.
3. Cascades unravel.
   3.1. Boulders must be three boulders deep into the upstream slope.

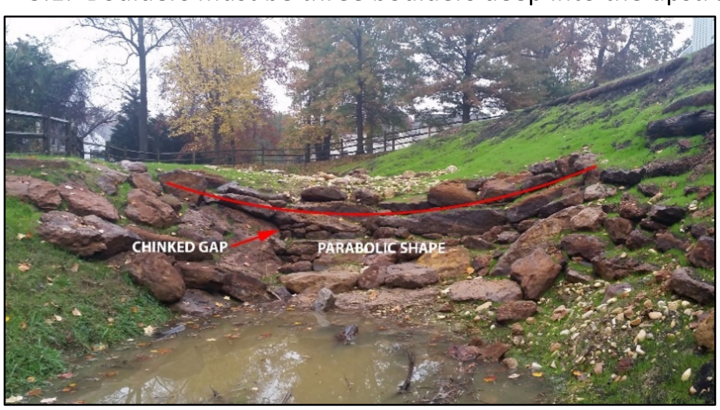


Figure 51. Subgrade is excavated to support a parabolic shape necessary to keep flow in the center and shoulders. Boulders are placed flat to create falls from top boulder to next rather than continuous surface in a chute. Gaps between boulders have been filled by hand-placing smaller boulders and rock (chinking) in a manner that maintains the general line of the boulders. Range of gravel and cobble sizes have been randomly cast throughout the cascade to allow self-organization throughout time. Spaces between boulders are planted and seed is cast over entire structure to stabilize and naturalize over time.

Figure 53. Gentle curved rack spreads flow across the cascade. Flat and alternating placement of boulders breaks flow. Tie in boulders extend into the berm or existing ground with many buried.

Sample Plans and Details

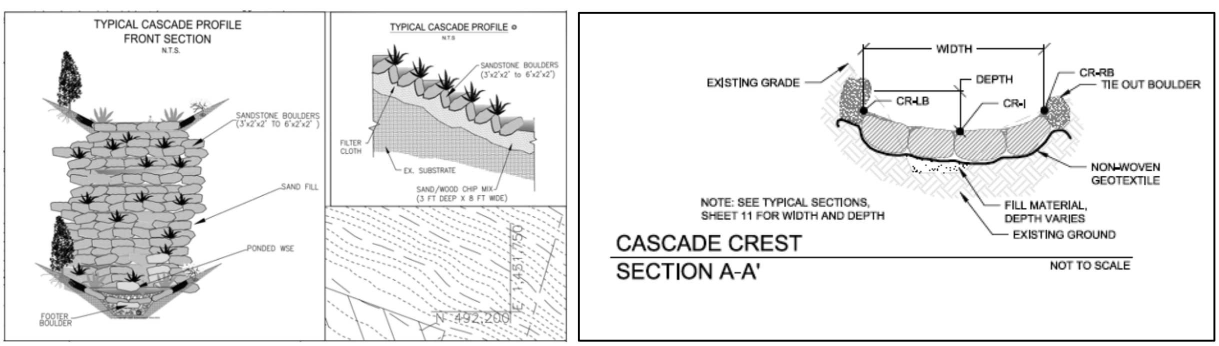


Figure 52. Details are symbols generated by graphic or engineering programs that are limited to two-dimensional geometric shapes and serve as a guide for construction. To create optimally functional three-dimensional structures, contractors must translate the two-dimensional symbols to construct the intended feature. The cascade profile front section on the left, if strictly interpreted, would result in a stacked boulder wall. If constructed per the side profile with boulders installed vertically, the cascade would not be stable. It illustrates the drops and break in fall that need to be created during construction of a cascade. In Section A-A, the number of boulders illustrated do not strictly mean each cascade must have four boulders and one tie out boulder on each side. The width of the stream at the location will determine the numbers of boulders.

E.7 Pool

Efforts should be made to maximize pool width while minimizing removal of existing trees. Again, plan details are symbols so contractors should aim to create organic shapes, e.g., kidney bean shaped rather than perfect circles or ovals. Irregularly shaped edges, as opposed to uniform and smooth edges, will further dissipate energy by introducing friction and disrupting to flow. Hydraulically, pools need to be at least as wide as the weir (Figure 54).

Figure 54. A pool that was widened to further dissipate energy. Edges supplemented with gravel and river rock to create roughness, support diverse geomorphology and provide habitat.

Function

Pools dissipate energy of stream flow and provide deep water habitat. Many streams are or were once spawning grounds for fish. Therefore, contractors should be mindful to minimize sheer drops in height between weirs and pools that prohibit fish passage.

Materials and Supplies

- Concrete sand
- Masonry sand (for adaptive management to adjust infiltration if necessary)
- Clay (for adaptive management to adjust flow if necessary)
- Pea gravel
- Coarse woody debris

Installation Method

1. Excavate within the footprint of the pool to remove sections of underdrain pipes. To restore healthy surface flow, perforated/slotted pipes must be removed to prevent stream flow from remaining underground.
2. Grade to designed pool depth.
3. Shape pool working with surrounding grade. Minimize tree removal, create organic shapes (Figure 55) and widen pools wherever possible.
4. Adaptively manage riffle-weirs and pools to achieve optimal conditions, including the rate of infiltration and drainage.
   - 4.1. Place a 1- to 2-inch layer of concrete sand over the pool bottom to encourage infiltration.
   - 4.2. If the pool is infiltrating too fast, spread the bottom with masonry sand (next smaller particle size).
   - 4.3. If the weir is draining the pool too fast, supplement with masonry sand. If that does not sufficiently slow the draining, propose constructing a clay curtain, also referred to as an irrigation curtain, between the pool edge and weir. This may need to be done during the adaptive management phase after multiple field observations have been made and will need to be done during a dry period.

Sample Plans and Detail

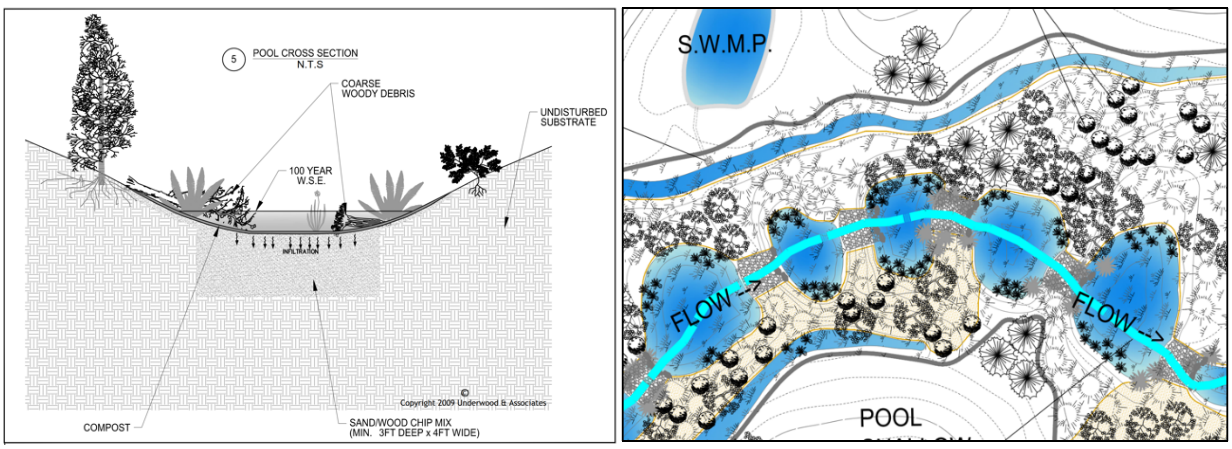


Figure 55. Cross section of pool illustrating typical shape and elements. Ensuring contact with sand and woodchip mix is critical to achieving infiltration. Dense plantings and coarse woody debris are critical components to supporting multiple stream functions. Together, plantings and coarse woody debris stabilize slope, break up flow, trap sediment, supply organic carbon, process nutrients, and provide habitat.

E.8 Coarse Woody Debris

Replenish the site with abundant organic material necessary to support stream functions and processes that depend on diverse material and organic carbon.

Figure 56. Abundant supply of woodchip, brush, branches and logs added to riffle-weirs, pools and riparian areas replenish some of the organic material lost to construction and help support multiple stream functions.

Function

Incorporated coarse woody debris (CWD) supports the full range of processes.

1. Microbial processes that depend on organic carbon as source of energy;
2. Chemical processes that build soil over time through decomposition;
3. Hydraulic conditions that transport woody debris to redistribute throughout the system;
4. Morphological processes that move debris to break flow and stabilize channels and banks; and
5. Habitat and food (biological) to support robust native flora and fauna.

Materials and Supplies

- Woodchip
- Leaves
- Brush and branches
- Logs and tree stumps with roots intact (root wad)
- Tree tops with branches intact

Installation Method

1. Place brush and secure logs in the riparian area, along pool edges and in pools (Figures 55 and 56).
2. Place tree tops with branches along the pool edge to break up flow and provide habitat.
3. For root wads, turn root side up and pile the trunk securely into the bottom of the pool. Seed roots with permanent seed.
4. Leave leaf litter on site and if possible, supplement with leaf litter during first year after construction.
5. In RSC inspired projects that create limited (not full) connection to its floodplain and in projects that are close to roads and culverts, scale and modify CWD installation accordingly.

F. RESPONSIVE STABILIZATION AND MAINTENANCE

Streams are dynamic systems that respond to their environment in a constant search for equilibrium. The movement of material and succession of plants are responses to changing water volume and velocity dictated by weather and upstream land use practices. After construction, it is critical to minimize interference as the restored system begins this dynamic process.

F.1 Seed Bank

To provide the newly constructed site with means to regenerate, an important and inexpensive technique is to leave the site with sufficient seed bank. As described in Section E.2 on Construction Entrance and Haul Road, a site with abundant temporary stabilization seed bank within the top 12-inch layer of the soil will self-stabilize eroded areas.

Function

Overseeding and successive seeding of permanent seeds increases probability of continued stabilization as well as establishment of native vegetation, which will decrease chances of non-native and/or invasive plants from taking over the site. Bid tabulations often calculate one application of permanent seeding to cover the designed area. Although design specifications generally do not account for multiple permanent seedings, contractors are encouraged to account for additional seed for permanent stabilization as well as maintenance stages.

Materials and Supplies

- Temporary seed for multiple applications
- Permanent seed for two applications

Installation Method for Seed Bank

1. Repeatedly and thoroughly seed the entire site with temporary seed, including weirs, cascades, haul roads and any disturbed area throughout the duration of construction period.
2. Towards the end of construction, thoroughly seed the site with permanent seed multiple times.

F.2 Material Movement and Rills

Figure 57. Rills filled to grade with pea gravel to allow water flow to continue in the path it has carved into the newly constructed landscape.

Post construction, it is natural for materials to move and rills to form as the newly restored stream settles and stormwater travels downhill through the newly graded surface. This process creates dendritic patterns as water flows through the landscape. Smoothing out the rills is counterproductive and other rills will continue to form as water continues to search for the lowest path with the least resistance. The contractor must respond, not react, to the process by amending the rill with diverse sizes of material and supporting the site's settling and regenerative processes.

Function

In essence, rills are active formation of miniature tributaries that hydrologically connect the surrounding uplands to the project area. Again, rather than fight against forces of nature and treat this feature as erosion to be restored, the contractor should help establish and preserve these miniature tributaries during the adaptive management and maintenance periods. The dendritic pattern distributes energy over a larger area and longer total flow length. Therefore, only a light touch is needed.

Materials and Supplies

- Temporary and permanent seed
- Concrete sand
- Pea gravel
- River rock

Installation Method

After the initial formation of rills, supply aggregates in an iterative process that replenishes the washed-out woodchip and sand/sandy fill and ends with a cap of pea gravel to transport water without eroding the sand layer below (Figure 57). If sufficient material was used during the construction while integrating the structures into the landscape, rills will simply expose the sand, gravel and rocks under the woodchip. If this is the case, no action needs to be taken as the aggregates are stabilizing the slopes.

1. For deep rills on steeper slopes:
   - 1.1. Fill part of the rill with concrete sand.
   - 1.2. Fill with river rock sufficiently sized for the flow so it is almost flush with surrounding grade.
   - 1.3. Add pea gravel to fill voids without raising the grade above the surrounding area, which would direct flow away from rill.
2. For shallow rills on gentle slopes, fill with a layer of sand capped by a layer of pea gravel that is one-gravel thick.
3. Seed with temporary or permanent seed.
4. If possible, plant sphagnum moss along the edges in shady areas to further stabilize and improve regenerative conditions.

G. PLANTING

Figure 58. Dense planting is critical to keeping invasive species in check and propagating native plant species. Insufficient planting will compromise establishment of regenerative conditions.

Dense planting of native trees, shrubs and herbaceous species across zones, including edges of pool and riffle-weirs, is as critical to restoring and regenerating a degraded site as the construction of grade control structures is to the establishment of groundwater and surface water connection (Figure 58). A healthy native plant community is an indication of a robust stream that supports biodiversity and corresponds to Level 5 of Functional Pyramid (Figure 3). Volunteer planting is an excellent way to engage the neighbors, schools, and area businesses, which often fosters community ownership of the stream and interest in protecting its future (Figure 59).

Function

An established native plant community is not only critical to the biological functions of the stream but equally important to supporting the other four functions – hydrologic, hydraulic, geomorphic and physicochemical. Dense native vegetation help to moderate water temperature, provide detritus (energy for microbes and organic material for soil development), attenuate flood velocities, stabilize banks and riparian areas, increase infiltration through roots and stem flow and form critical habitat. Plants are an integral part of hydrologic cycle. They increase infiltration by directing water into the ground through stem flow and aerating the soils with their roots, reduce runoff through leaf interception and return moisture to the atmosphere through transpiration.

Materials and Supplies

Figure 59. Volunteer planting with project sponsors and community members.

- Auger
- Dibber (for marsh plantings)
- Trowel
- Shovels, rakes and pitch forks
- Compost
- Concrete sand
- Organic fertilizer
- Native seeds and plants specified on plans (sample list provided in Table 2)
- Stakes
- Wire ties
- Hardware cloth, welded mesh or other specified supplies for deer fencing, if necessary

Installation Method

1. Continuously seed site with temporary seed during construction and overseed permanent seed to quickly establish disturbed sites and preclude invasive species from taking hold.
2. Observe stream flow during the last stages of construction and within the designated planting zones to differentiate saturated, hydric, mesic and dry zones.
3. List and separate plants for the micro zones: pool areas (saturated), edge of pool (wet), slope of pool (mesic), riparian areas (mesic), depressions in lowlands (hydric), uplands and ridges (dry).
4. Mix compost, sand and fertilizer to specifications. If there are no specifications, then use a 2:1 ratio of compost to sand with 5% of the mixed planting soil volume of fertilizer.
5. For trees and shrubs, hand dig or use an auger to prepare a hole that is at least twice the width of the pot.
   - 5.1. Do not create wells or excessive mounds around trees.
   - 5.2. Fill soil to slightly above the level of the existing grade and allow planting soil to settle.
   - 5.3. Place plantings randomly. Avoid planting in straight rows.
6. For herbaceous species, use shovels, trowel or dibbers.
   - 6.1. Plant in clusters of at least three to five plants.
   - 6.2. Plant larger crevices in boulders with appropriate ferns, e.g., cinnamon fern (Figure 60).
   - 6.3. Fill smaller crevices of boulders with planting soil and seed.
   - 6.4. Densely plant aquatic plants and pool edges, which will help to hold the soil and introduce roughness to slow flow and trap sediment.
7. Do not plant in the haul road to keep it accessible for light machines for adaptive management. Plant along haul road.
8. It is recommended to conduct planting in stages and iteratively to allow the system to settle and enable the contractor to observe the microzones to appropriately place plants. Spring plantings allow a full growing season and are optimal. Hot, dry periods such as August in the Northeast, should be avoided.
9. Adaptive management should include invasives species management, especially in the first few years following construction. Herbicides should be used sparingly and sprays should be timed and targeted.
   - 9.1. Spray the underside of the leaves where the stomata (pores) are present.
   - 9.2. Time sprays to treat emerging plants before they fully leaf out, which reduces the amount of herbicide needed.

9.3. If applications were not made in the spring, herbicide should be applied before the plants go to seed.

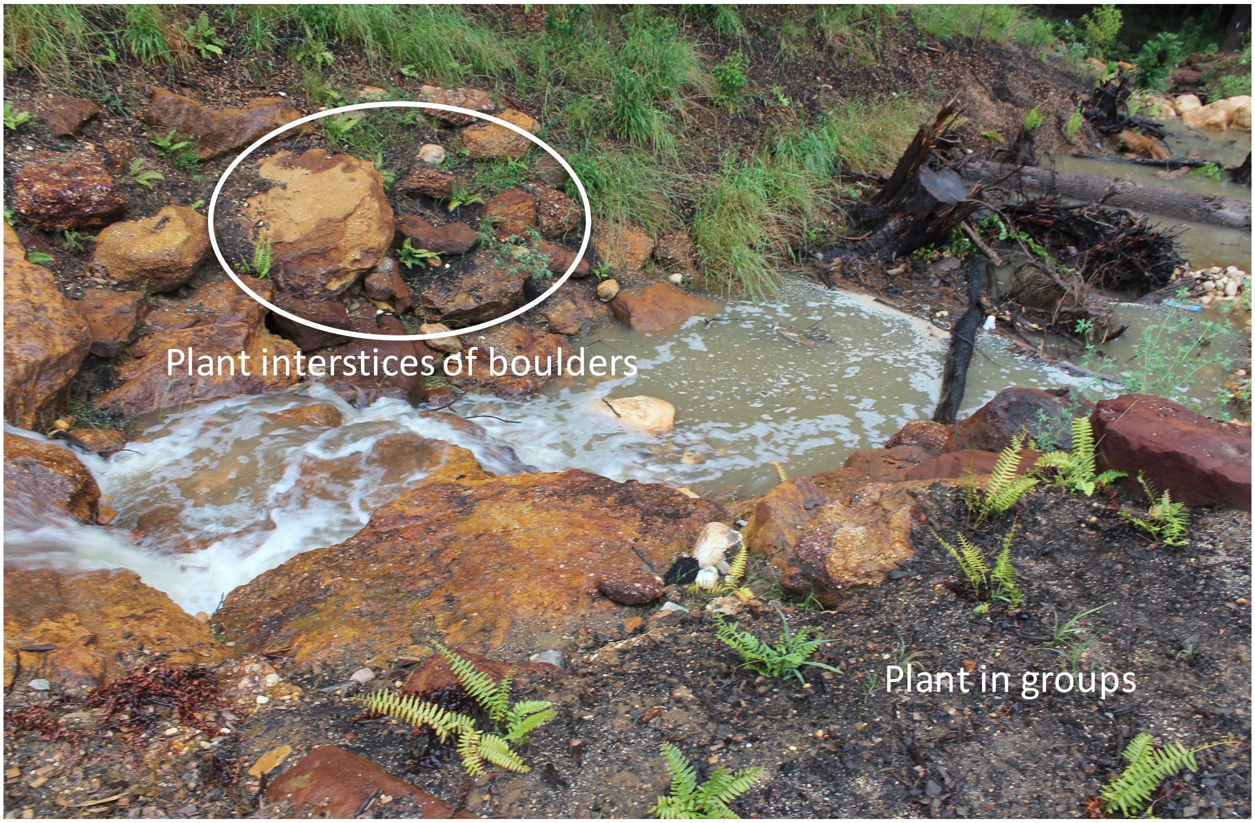


Figure 60. Plant herbaceous in crevices of boulders and group plants rather than uniform lines.

The following is a sample, abbreviated list of native plants modified from The Anne Arundel County Department of Public Works' Design Guidelines for Step Pool Storm Conveyance (SPSC), December 2012.

Table 2. Select native plant species and general planting areas within restored sites.

ABBREVIATED NATIVE PLANT LIST FOR RSC RESTORATION SITES		
Common Name	**Latin Name**	**Planting Areas**
American Holly	*Ilex opaca*	Riparian areas
American Hornbean	*Carpinus caroliniana*	Throughout site
Atlantic White Cedar	*Chamaecyparis thyoides*	Water's edge
Bald Cypress	*Taxodium distichum*	Water's edge
Bayberry	*Myrica pensylvanica*	Throughout site
Black Gum	*Nyssa sylvatica*	Wet to moderately moist areas
Blue Flag Iris	*Iris virginica or versicolor*	Water's edge
Blueberry *(Lowbush)*	*Vaccinium anguaticolium*	Wet to moderately moist areas with sandy soils
Blueberry (Highbush)	*Vaccinium corymbosium*	Edge of water and pool slopes
Broomsedge Bluestem	*Adropogon virginicus*	Dry upland and edge of weirs
Bushy Bluestem	*Andropogon glomeratus*	Dry upland and edge of weirs
Christmas Ferns	*Polystichum acrostichoides*	Boulder crevices, shady pool slopes
Cinnamon Fern	*Osmunda cinnamomea*	Pool slope to moderately moist areas
Cranberry	*Vaccinium macrocarpon*	Wet to moderately moist areas with sandy soils
Eastern Redcedar	*Juniperus virginiana*	Dry open uplands
Fringe Tree	*Chionanthus virginiana*	Water's edge to moderately moist areas
Golden Club	*Orontium aquaticum*	In pools and quiet sloughs
Inkberry	*Ilex glabra*	Water's edge to moderately moist areas
Little Bluestem	*Schizachyrium scoparium*	Riparian areas
Mountain Laurel	*Kalmia latifolia*	Moderately moist areas to dryer upland
Pitch Pine	*Pinus rigida*	Dry upland with sandy soils
Redhead Grass	*Potamogeton perfoliatus*	In pools
River Birch	*Betula Nigra*	Water's edge to riparian areas
Royal fern	*Osmunda regalis*	In pools and quiet sloughs
Serviceberry	*Amelanchier canadensis*	Dry upland
Smooth Alder	*Alnus serrulata*	Wet areas
Summersweet	*Clethra alnifolia*	Moderately moist areas

Swamp Azalea	*Rhododendron viscosum*	Moderately moist areas in part shade
Sweetbay Magnolia	*Magnolia virginiana*	Moderately moist areas
Switchgrass	*Panicum virgatum*	Dry upland
Tussock Sedge	*Carex stricta*	In pools or edges of weirs
Virginia Chain Fern	*Woodwardia virginica*	Wet areas
Virginia Sweetspire	*Itea virginica*	Wet to moderately moist areas
Water Lily	*Nymphea odorata*	In pools
Wax Myrtle	*Morella cerifera*	Wet to moderately moist areas
Winterberry (Common)	*Ilex laevigata*	Moderately moist areas
Woodland Fern	*Dryoperis marginalis*	Dry, rocky areas

APPENDIX A

BRIEF HISTORY OF LAND USE AND STREAM RESTORATION

Across the United States and most temperate regions, broad and shallow surface water flow existed prior to settlement, allowing water to remain on the landscape for extended periods. Historically, low-lying areas were a mosaic of braided streams, depressions and hummocks that remained saturated. Flowpaths were not distinct like the stream channels we see today. Rather, the entire floodplain served as a saturated sponge that fed streams and rivers. The extensive and expansive interaction between groundwater and surface water created complex and diverse aquatic ecosystems, retained high volumes of precipitation on the landscape and facilitated biogeochemical processes. Human settlement dramatically altered the landscape, frequently causing detrimental changes to streams.

Post European Settlement

Starting in the 18th century, the first major impairment to the health of our rivers and streams was caused by large scale deforestation of land for settlement and farming, poor farming practices and mill dams. Deforestation significantly diminished absorption of rainfall and floodwaters, eroded soils, and destroyed terrestrial habitat. Draining wetlands eliminated the perennial water source for creeks and streams and destroyed high quality aquatic habitat. Construction of thousands of mills and dams in streams and rivers to transport timber caused sedimentation behind the dams and floodplains and the channelization of streams. The incised channels characterized by a cliff above a fast-flowing stream and below a wide floodplain that we are accustomed to are significantly altered conditions that resulted from the combination of fast flowing streams and sedimentation brought on by deforestation and mill dams (Walter & Merritts, 2008).

The slow deposition of sediments led to a buildup of what are known as legacy sediments. Profiles of these sediments show sediments that date back to the settlement period of the 18th through early 20th centuries.

Land Development and Hard Engineering

The second major impairment to the health of our rivers and streams was caused by ditches, swales, pipes and levees. Throughout history, settlement and growing population necessitated controlling water to keep it off the land. As suitable land became scarce, floodplains and wetlands were ditched and drained for farming and building. As volumes of stormwater increased on the denuded yet densely developed land, water was piped underground and quickly carried away from development as it was deemed a nuisance and often hazardous. However, away from farms and development, water provided a source of energy and was held back with dams. As mill dams phased out, hydro dams continued altering rivers and streams.

Expansion of Impervious Surfaces

Poor land use practices did not stop with mass deforestation. Economic development also brought about expansions of highways, roads, parking lots and buildings. The growing area of impervious surfaces continued the degradation of our waterways. Streams and rivers carried the burden of the massive growth spurt. They have had to convey larger discharges of stormwater at greater velocities. As a result, many streams and rivers washed out, downstream flooding increased and loads of sediment stripped from the land and streams filled in rivers and bays and reduced navigability.

Creation of Game Fish Habitat

In the late 19th century, stream restoration was initially undertaken by wealthy landowners and focused on improving game fish habitat that had been lost due to deforestation and overfishing. The idea that took hold was that humans can reduce the inefficiencies of natural systems to maximize benefits such as trout habitat. Carl L. Hubbs of University of Michigan was the first to study the use of in-stream structures and was responsible for widespread use of this method in the 1930s. "He declared that the aim of instream structures was to shorten the time between bites and reduce the long walks between successive pools so 'fishing would bear less resemblance to golf'" (Thompson D. M., 2005).

The human-centered view of streams did not stop with increasing game fisheries habitat or on private land. After the New Deal era and for most of the 20th century, federal policies focused on publicly managing rivers for greater economic benefits. To improve trade and commerce, agencies embarked on numerous projects to improve flood control, harness hydropower, expand irrigation and facilitate navigability. By the 1970s, the Army Corps of Engineers and Natural Resource Conservation Corps and channelized 33,353 kilometers (20,724 miles) of rivers and streams and constructed 9,490 kilometers (5,897 miles) of levees. The Bureau of Land Management alone built more than 600 dams (Lave, 2012).

Stream Stabilization

In the 1990s, Natural Channel Design (NCD) brought about an interdisciplinary approach to stream restoration design and construction and marked the reversal of economically focused river management. NCD is founded on strong understanding of hydrology and hydraulics of stream and river systems and advanced construction of stream restoration projects by providing standardized engineering details and specified guidance on materials and installations.

NCD enhances fish habitat by stabilizing rapidly eroding rivers and streams with rock structures such as j-hook vanes, cross vanes, "W" weirs and engineered riffles. If designed for habitat, it can create habitat conditions favorable to fish. NCD has been widely adopted and augmented by an intensive stream hydrology training and certification program. It is the stream restoration approach that most practitioners are familiar with and continues to be widely practiced today.

Stream Regeneration

In the 2000s, the reversal trend gained momentum and efforts focused on re-establishing conditions necessary for healthy natural stream ecosystems by reconfiguring sites to "free streams" from channels and re-establish hydrologic connections with associated floodplains.

1. **Legacy Sediment Removal** is a restoration approach that reconnects the floodplain to the stream by removing the layers of legacy sediments that have deposited on the floodplain over the centuries. The approach lowers the floodplain to reconnect with the incised channel. It is particularly well suited in open landscapes but can be applied where sufficient room exists for the necessary excavation and grading and streams restored in this manner are capable of handling increased flows by utilizing the floodplains for overflows.

> ***Legacy Sediment Removal***
>
> - ***Reconnects floodplain to stream***
> - ***Removes sediment to lower the floodplain to meet stream***
> - ***Restore hydro-logic function through sand and gravels***

Creating a lowered floodplain leads to increased native plants and animal species returning to the floodplain as well as a reduction in the nutrient load When legacy sediments are properly removed, much of the preexisting seed bank and native marsh soil preserved in the soil germinate and re-establish a robust, native plant community (US Environmental Protection Agency, 2015).

2. **Regenerative Stream Conveyance (RSC)** is a restoration approach that reconnects the stream to the floodplain by filling the stream that has eroded and cut through legacy sediment. The approach raises the channel to reconnect with the thirsty floodplain. It is particularly well suited in stream systems with broad valleys but can be applied throughout the watershed to reconnect the stream to the floodplain. It is also well suited for streams with tight construction areas because much of the construction can be done in stream while filling in the channel. Grade control structures hold back increased volumes, withstand concentrated velocity of flow and utilize the additional storage capacity on the floodplain.

Regenerative Stream Conveyance (RSC)

- ***Reconnects floodplain to stream***
- ***Fills channel to raise stream to meet floodplain***
- ***Restore hydrologic function through sand and gravels***

Filling the stream channel with sand enables infiltration and re-establishes active interaction between surface and groundwater. The reconnected floodplain supports native wetland and lowland plant species as well as amphibians once again.

APPENDIX B

FREQUENTLY ASKED QUESTIONS (FAQ) ABOUT REGENERATIVE STREAM CONVEYANCE (RSC) CONSTRUCTION

1. **Why are stockpile areas often not designated in RSC designs?**

   Well thought out RSC designs set the stage for the contractor to receive material in place and work in-stream. A committed contractor will develop the means, methods and techniques to construct with minimal impact including establishing good working relationships with hauling companies and their drivers to drive in-stream and dump in place whenever possible and a designated crew member to guide trucks in-stream. This is entirely feasible and more efficient for haul road construction because the sand and woodchip haul road is a continuous fill operation that creates a maneuverable surface for trucks and moving sand, gravel and woodchip within the site after delivery is inefficient.

   Once the haul road is constructed and the crew is ready to construct structures that require rocks and boulders, there is generally sufficient room throughout the site and within the LOD, e.g., at the top of the haul road, at turns, or along the side of the haul road, for placing material closer to the structures. Because rocks and boulders are not erodible materials, it is generally an accepted practice to store material without a silt fence and temporary stabilization measures.

2. **Do RSCs utilize conventional stabilized construction entrances?**

   Each site varies and some may need stone structures to ensure a safe and sediment free entrance. However, sand and woodchip haul roads that are continuously replenished with sand and woodchip generally function well in supporting heavy equipment and truck traffic, keeping tires clean and reducing runoff from the entrance by filtering stormwater. Also, the sand and woodchip entrance is seeded, readily blends into the natural landscape and can be left in place to provide future access for adaptive management.

3. **How do these projects hold up long-term, and what maintenance do they require?**

   The structural features of these projects – the riffles, weirs and cascades – can be designed and built to convey the 100-year storm while simultaneously maximizing baseflow. With recent increases in frequencies and intensities of storms and anticipated climate change, constructing projects to fully manage 100-year storms will increase long-term stability. Like many environmental restoration projects, they require some adaptive management, particularly in the years immediately following installation and before planted vegetation becomes established. Mass movement of materials (e.g., cobble) and encroachment of invasive plants should be monitored in the immediate years following completion and managed adaptively by supplementing larger sized material, targeted herbicide applications and supplemental plantings.

4. **How do you plant in weirs and cobble?**

   Planting on the edge of riffle-weirs and cascades is a challenge. However, if properly budgeted and constructed with sufficient sand filling the voids, it is possible. Christmas ferns do well when planted in between boulders on the sides of cascades. Other herbaceous species take root between river rock on the edges of weir where moisture is more constant. Permanent seed establishes quickly in between river rock and boulders in weirs and cascades.

GLOSSARY

Aggregate	Material formed from a loosely compacted mass of fragments or particles.[1]
Baseflow	Typical low-flow discharge in streams drawn from natural storage sources in contrast to stormflow that occurs in response to precipitation events; groundwater discharge drives baseflow.[2]
Bedload material	Portion of the total sediment load with sediments of a size found in the stream bed.[3]
Berm	In RSC, earthen mound built *perpendicular* to the stream bank and designed to hold flood flows *on* the adjacent flood plain. In certain stream restorations, earthen mound often built *parallel* to the stream bank and designed to hold flood flows *from entering* the adjacent flood plain.[4]
Biological diversity	The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.[5]
Cascade	A short, steep drop in stream bed elevation often marked by boulders and agitated white water.[6]
Exfiltration	Process by which infiltrated water in the unsaturated zone reaches the soil surface and creates runoff or a spring/seep.[7]
Geomorphology	A branch of both physicography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and in the buildup of erosional debris.[8]
Hydrology	Of or relating to the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle.[9]
Hydroperiod	Seasonal pattern of surface and sub-surface water levels.
Hydraulic	Of or relating to water flowing down a vertical distance.[10]
Infiltration	Movement of water through the soil surface into the soil.
Mesic	Moderately wet.
Physicochemical Function	The physical and chemical processes that create baseline water chemistry, breakdown organic matter and transform nutrients.[11]

Riffle A stream reach characterized by shallow, fast moving water broken by the presence of rocks and boulders.[12]

Thalweg The line of lowest elevation along the axial part of a valley or stream channel.[13]

Weir A structure to control water levels in a stream.

1 Fischenich, 2000

2 Easton, 2015

3 Fischenich, 2000

4 Fischenich, 2000

5 Secretariat of the Convention on Biological Diversity, 2015

6 Fischenich, 2000

7 Easton, 2015

8 Fischenich, 2000

9 US Geological Service, 2016

10 Fischenich, 2000

11 Harman, 2012

12 Fischenich, 2000

13 Fischenich, 2000

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