Appendix

Miscellaneous reports or publications

MINNESOTA DEPARTMENT OF NATURAL RESOURCES

Limited/Amended

Public Waters Work General Permit

Expiration Date: 11/27/2018

General Permit Number

2004-0001

Pursuant to Minnesota Statutes, Chapter 103G, and on the basis of statements and information contained in the permit application, letters, maps, and plans submitted by the applicant and other supporting data, all of which are made part hereof by reference, **PERMISSION IS HEREBY GRANTED** to the applicant to perform actions as authorized below. This permit supersedes the original permit and all previous amendments.

Project Name:	**County:**	**Watershed:**	**Resource:**
MNDOT Statewide General Permit	All counties in Minnesota	All watersheds in Minnesota	All waters shown on the Public Waters Inventory

Purpose of Permit:	**Authorized Action:**
Bridge, culvert, or stormwater outfall repair or replacement.	Upon notification of approval by the DNR Transportation Hydrologist or Area Hydrologist, replace or repair of bridges, culverts, riprap, or stormwater outfalls on Public Waters, where all conditions and provisions specified herein are met.

Permittee:	**Authorized Agent:**
MN DEPARTMENT OF TRANSPORTATION CONTACT: CLARKOWSKI, LYNN, (651) 366-3602 OFFICE OF ENVIRONMENTAL STEWARDSHIP 395 JOHN IRELAND BLVD, MS 620 ST. PAUL, MN 55155 (651) 366-3600	N/A

Property Description (*land owned or leased or where work will be conducted*):

The Permittee or its authorized agent must own, control, or have permission to access and use all lands affected by the project.

Authorized Issuer:	**Title:**	**Issued Date:**	**Effective Date:**	**Expiration Date:**
Tom Hovey	Water Regulations Unit Supervisor	11/27/2013	11/27/2013	11/27/2018

This permit is granted **subject to** the following **CONDITIONS**:

APPLICABLE FEDERAL, STATE, OR LOCAL REGULATIONS: The permittee is not released from any rules, regulations, requirements, or standards of any applicable federal, state, or local agencies; including, but not limited to, the U.S. Army Corps of Engineers, Board of Water and Soil Resources, MN Pollution Control Agency, watershed districts, water management organizations, county, city and township zoning.

NOT ASSIGNABLE: This permit is not assignable by the permittee except with the written consent of the Commissioner of Natural Resources.

NO CHANGES: The permittee shall make no changes, without written permission or amendment previously obtained from the Commissioner of Natural Resources, in the dimensions, capacity or location of any items of work authorized hereunder.

SITE ACCESS: The permittee shall grant access to the site at all reasonable times during and after construction to authorized representatives of the Commissioner of Natural Resources for inspection of the work authorized hereunder.

TERMINATION: This permit may be terminated by the Commissioner of Natural Resources at any time deemed necessary for the conservation of water resources of the state, or in the interest of public health and welfare, or for violation of any of the conditions or applicable laws, unless otherwise provided in the permit.

(MPARS revision 10/07/2013, Permit Issuance ID 10959, printed 11/27/2013)

CONDITIONS continued on next page...

GENERAL PERMIT CONDITIONS (*Continued from previous page*)

COMPLETION DATE: Construction work authorized under this permit shall be completed on or before the date specified above. The permittee may request an extension of the time to complete the project by submitting a written request, stating the reason thereof, to the Commissioner of Natural Resources.

WRITTEN CONSENT: In all cases where the permittee by performing the work authorized by this permit shall involve the taking, using, or damaging of any property rights or interests of any other person or persons, or of any publicly owned lands or improvements thereon or interests therein, the permittee, before proceeding, shall obtain the written consent of all persons, agencies, or authorities concerned, and shall acquire all property, rights, and interests needed for the work.

PERMISSIVE ONLY / NO LIABILITY: This permit is permissive only. No liability shall be imposed by the State of Minnesota or any of its officers, agents or employees, officially or personally, on account of the granting hereof or on account of any damage to any person or property resulting from any act or omission of the permittee or any of its agents, employees, or contractors. This permit shall not be construed as estopping or limiting any legal claims or right of action of any person other than the state against the permittee, its agents, employees, or contractors, for any damage or injury resulting from any such act or omission, or as estopping or limiting any legal claim or right of action of the state against the permittee, its agents, employees, or contractors for violation of or failure to comply with the permit or applicable conditions.

EXTENSION OF PUBLIC WATERS: Any extension of the surface of public waters from work authorized by this permit shall become public waters and left open and unobstructed for use by the public.

INVASIVE SPECIES - EQUIPMENT DECONTAMINATION: All equipment intended for use at a project site must be free of prohibited invasive species and aquatic plants prior to being transported into or within the state and placed into state waters. All equipment used in designated infested waters, shall be inspected by the Permittee or their authorized agent and adequately decontaminated prior to being transported from the worksite. The DNR is available to train inspectors and/or assist in these inspections. For more information refer to the "Best Practices for Preventing the Spread of Aquatic Invasive Species" at http://files.dnr.state.mn.us/publications/ewr/invasives/ais/best_practices_for_prevention_ais.pdf. Contact your regional Invasive Species Specialist for assistance at www.mndnr.gov/invasives/contacts.html. A list of designated infested waters is available at http://files.dnr.state.mn.us/eco/invasives/infested_waters.pdf. A list of prohibited invasive species is available at www.mndnr.gov/eco/invasives/laws.html#prohibited.

APPLICABLE PROJECTS: This permit applies only to the replacement, reconstruction, or repair (including associated minor channel or shoreline work) of existing bridges, culverts, stormwater outfalls, or riprap in Public Waters that are designed under the supervision of a registered professional engineer. A project not meeting applicable conditions of this permit or a project the DNR identifies as having the potential for significant resource impacts, is not authorized herein. Rather, such projects will require an individual permit application.

PROJECT AUTHORIZATION: This permit provides conditions to aid project planning and facilitate initial design to streamline DNR regulatory approval. A project must be reviewed by the DNR Transportation Hydrologist through the MnDOT Early Notification Memo (ENM) process in order for it to qualify for authorization under this permit. The existing framework of MnDOT environmental review by the applicable DNR personnel will be utilized to review projects at the earliest possible stage for permit needs and additional conditions. Additional design information may be required of MnDOT during this process. If a project can not meet the conditions of this permit, a separate individual permit will be required. If emergency or unforeseen projects arise that can not include the framework of the ENM process, the permittee shall contact the DNR Transportation Hydrologist or Area Hydrologist immediately to provide details and discuss project design and applicable standards for authorization under this permit. Work shall not commence until written approval that the project will meet these (and any additional written) permit conditions is received from the applicable DNR Hydrologist.

RESPONSIBILITY: The permittee is responsible for satisfying all terms and conditions of this permit. When a project is awarded to a said third party (contractor) for work to be completed, the permittee may notify the DNR in order to administratively amend the project authorization form to include the said third party as a co-permittee for joint responsibility in compliance with this permit.

ENVIRONMENTAL REVIEW: If the bridge/culvert construction is part of a road project that requires mandatory environmental review pursuant to MN Environmental Quality Board rules, then this permit is not valid until environmental review is completed.

DNR NOTIFICATION: The permittee shall notify the DNR Transportation Hydrologist or Area Hydrologist at least five days in advance of the commencement of the work. An email notification of the pre-construction meeting will suffice for this notification.

CONDITIONS continued on next page...

GENERAL PERMIT CONDITIONS (*Continued from previous page*)

PHOTOS AND AS-BUILTS: Upon completion of the authorized work, the permittee may be required to submit a copy of established benchmarks, representative photographs, and may be required to provide as-built surveys of Public Watercourse crossing changes.

STATE & FEDERAL LISTED SPECIES PROHIBITION: If there are unresolved concerns regarding impacts to federally or state listed species (endangered, threatened, or special concern), this general permit is not applicable, and the project must be submitted as a separate permit application. Compliance with DNR and federal guidelines established for a listed species (e.g. Topeka Shiner conditions) would constitute a resolved concern.

PRELIMINARY ENGINEERING: This permit authorizes preliminary engineering studies in the water associated with bridge planning (e.g., core sampling). All core holes must be sealed in accordance with Department of Health well sealing requirements. On designated infested waters, all equipment in contact with the water must be decontaminated per the Invasive Species condition.

HYDROLOGIC/HYDRAULIC DATA REPORTING: Unless waived by the DNR Transportation Hydrologist or Area Hydrologist, hydrologic modeling to show the impacts of the structure(s) on the 100-yr (1% chance) flood elevation is required. Calculations showing calculated velocities through the structures at 2-year peak flows may also be required.

NAVIGATION MAINTAINED OR IMPROVED: The structure's final design will not obstruct reasonable public navigation, as determined by the DNR. For bridges, three feet above the calculated 50-year flood stage ordinarily satisfies navigational clearance requirements. For culverts, three feet of clearance above the ordinary high water level (top of the bank) ordinarily satisfies navigational requirements.

STATE TRAILS: Projects proposed near an existing or proposed state trail system should be consistent therewith.

FLOWLINE/GRADIENT NOT CHANGED: Replacement of culverts or crossings are to follow (or be restored to) the natural alignment and profile of the stream. Changes from the existing flowline, gradient or alignment must be consistent with the Water Level Control and Fish Passage conditions and authorized by the DNR Transportation Hydrologist or Area Hydrologist.

FLOOD STAGES/DAMAGES NOT INCREASED: A. No approach fill for a crossing shall encroach upon a DNR approved community designated floodway. When a floodway has not been designated or when a floodplain management ordinance has not been adopted and approved, increases in flood stage in the regional flood of up to one-half of one foot shall be approved if they will not materially increase flood damage potential. Additional increases may be permitted if: a field investigation and other available data indicate that no significant increase in flood damage potential would occur upstream or downstream, and any increases in flood stage are reflected in the floodplain boundaries and flood protection elevation adopted in the local floodplain management ordinance as determined by the applicable DNR Hydrologist; B. If the existing crossing has a swellhead of one-half of one foot or less for the regional flood, the replacement crossing shall comply with the provisions for new crossings in (A). If the existing crossing has a swellhead of more than one-half of one foot for the regional flood, stage increases up to the existing swellhead may be allowed if field investigation and other available data indicate that no significant flood damage potential exists upstream from the crossing based on analysis of data submitted by the applicant. The swellhead for the replacement crossing may exceed the existing swellhead if it complies with the provisions found in (A) above.

WATER LEVEL CONTROL: Permittee is responsible for maintaining existing water level control elevations.

FISH PASSAGE: Bridges, culverts and other crossings shall provide for fish movement unless the structure is intended to impede rough fish movement, aquatic invasive species movement, or the stream has negligible fisheries value as determined by the Transportation Hydrologist or Area Hydrologist in consultation with the Area Fisheries Manager. The accepted practices for achieving these conditions include: A. Where possible a single culvert or bridge shall span the natural bankfull width adequate to allow for debris and sediment transport rates to closely resemble those of upstream and downstream conditions. A single culvert shall be recessed in order to pass bedload and sediment load. Additional culvert inverts should be set at a higher elevation. All culverts should match the alignment and slope of the natural stream channel, and extend through the toe of the road side slope. "Where possible" means that other conditions may exist and could take precedence, such as unsuitable substrate, natural slope and background velocities, bedrock, flood control, 100-yr (1% chance) flood elevations, wetland/lake level control elevations, local ditch elevations, and other adjacent features. B. Rock Rapids or other structures may be used to retrofit crossings to mimic natural conditions.

TERRESTRIAL SPECIES MOVEMENT: Structures shall not be detrimental to significant wildlife habitat. If the crossing is located at a significant wildlife travel corridor as determined by DNR Wildlife or Ecological & Water Resources staff, the

CONDITIONS continued on next page...

GENERAL PERMIT CONDITIONS (*Continued from previous page*)

crossing shall be designed to minimize concerns. Typically this is accomplished with the presence of a walkable surface (dry ground) at normal flow conditions. For bridges this is known as a 'Passage Bench', which is incorporated into bridge abutment riprap. On multiple culvert installations, outer culvert inverts can be set at an elevation higher than normal flow to allow terrestrial species use during non-flood conditions. A Passage Bench design is incorporated into MnDOT Standard sheet (Figure 5-397.309) and available at http://www.dot.state.mn.us/bridge/cadd/files/bdetailspart2/pdf/fig7309e.pdf. Also see 'Passage Bench Design' as well as other species protection measures in Chapter 1 of the collection of "Best Practices for Meeting DNR General Public Waters Work Permit GP 2004-0001" http://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/gp_2004_0001_manual.html.

RESTORATION OF VEGETATION: On areas of disturbed soil adjacent to Public Waters, final vegetation plans should include native species suitable to the local habitat. This may include trees, shrubs, grasses, and/or forbs. Also see MnDOTs "Native Seed Mix Design for Roadsides" http://www.dot.state.mn.us/environment/erosion/pdf/native-seed-mix-dm.pdf.

TEMPORARY IMPACTS DURING CONSTRUCTION: Construction methods not finalized at the time of project review shall be submitted for review and approval at a later date. Temporary work below the Ordinary High Water (OHW) elevation, such as channel diversions, placement of temporary fill, structures for work pads/dock walls, bypass roads, coffer dams, or staging areas to aid in the demolition or construction of any authorized structure shall be submitted for review and approval in writing by the DNR Transportation Hydrologist or Area Hydrologist prior to beginning work. This is normal procedure for bridge or culvert projects as we recognize that final project designs are often posted for bid without final construction/ demolition plans. The following conditions must be met:

A. AQUATIC INVASIVE SPECIES - EQUIPMENT DECONTAMINATION: All equipment intended for use at a project site must be free of prohibited invasive species and aquatic plants prior to being transported into or within the state and placed into state waters. All equipment used in designated infested waters, shall be inspected by the Permittee or their authorized agent and adequately decontaminated prior to being transported from the worksite. The DNR is available to train inspectors and/or assist in these inspections. For more information refer to the "Best Practices for Preventing the Spread of Aquatic Invasive Species" at http://files.dnr.state.mn.us/publications/ewr/invasives/ais/best_practices_for_prevention_ais.pdf. Contact your regional Invasive Species Specialist for assistance at www.mndnr.gov/invasives/contacts.html. A list of designated infested waters is available at http://files.dnr.state.mn.us/eco/invasives/infested_waters.pdf. A list of prohibited invasive species is available at www.mndnr.gov/eco/invasives/laws.html#prohibited.

B. WORK EXCLUSION DATES FOR FISH SPAWNING AND MOVEMENT: Work within Public Waters may be restricted due to fish spawning and migration concerns. Dates of fish spawning and migration vary by species and location throughout the state. Specific dates for each DNR Region may be found on page 3 of Chapter 1 of the manual: Best Practices for Meeting DNR General Waters Work Permit GP2004-0001. http://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/gp_2004_0001_manual.html. Work in the water is not allowed within these dates. The DNR Transportation Hydrologist, Area Hydrologist, or Area Fisheries Supervisor shall be contacted about waiving work exclusion dates where work is essential or where MnDOT demonstrates that a project will minimize impacts to fish habitat, spawning, and migration.

C. HYDROLOGIC MODELING: Hydrologic modeling of temporary fill or temporary structures may be required by DNR Transportation Hydrologist or Area Hydrologist in order to evaluate impacts to the 100-yr (1% chance) flood elevation. Contingency plans may also be required to ensure all construction equipment and unsecured construction materials are moved out of the floodplain to prevent impacts to the 100-yr (1% chance) flood elevation or from being swept away by flood waters.

D. TEMPORARY FILL: If approved, temporary fill shall be free of organic material or any material that may cause siltation or pollute the waterbody. All such material shall be removed and the area restored to pre-existing profiles prior to project completion.

E. WETLAND PROTECTION: Should MnDOT or its contractors chose to do work in association with this project that is outside MnDOT project area right-of-way (EG excavation, grading, fill, vegetation alterations, utility installations, etc), they must obtain a signed statement from the property owner stating that permits required for work have been obtained or that a permit is not required, and mail a copy of the statement to the regional DNR Enforcement office where the proposed work is located. The Landowner Statement and Contractor Responsibility Form can be found at: http://www.bwsr.state.mn.us/wetlands/wca/index.html#general

F. STORAGE/STOCKPILES: Project materials must be deposited or stored in an upland area, in a manner where the

CONDITIONS continued on next page...

GENERAL PERMIT CONDITIONS (*Continued from previous page*)

materials will not be deposited into the public water by reasonably expected high water or runoff.

G. NAVIGATION: All work on navigable waters shall be so conducted that free navigation of waterways will not be interfered with, except as allowed by permits issued by the proper public authority. See MnDOT Standard Specifications for Navigable Waters (spec #1709) of MnDOT Standard Specifications for Construction, 2005 edition, or its successor: http://www.dot.state.mn.us/pre-letting/spec/2014/2014-Std-Spec-for-Construction.pdf.

H. EROSION PREVENTION AND SEDIMENT CONTROL: In all cases, erosion prevention and sediment control methods that have been determined to be the most effective and practical means of preventing or reducing sediment from leaving the worksite shall be installed in areas that are within 200 feet of the water's edge and drain to these waters, and on worksite areas that have the potential for direct discharge due to pumping or draining of areas from within the worksite (EG coffer dams, temporary ponds, stormwater inlets). These methods, such as mulches, erosion control blankets, temporary coverings, silt fence, silt curtains or barriers, vegetation preservation, redundant methods, isolation of flow, or other engineering practices, shall be installed concurrently or within 24 hours after the start of the project, and shall be maintained for the duration of the project in order to prevent sediment from leaving the worksite. DNR requirements may be waived in writing by the authorized DNR staff based on site conditions, expected weather conditions, or project completion timelines.

I. MPCA WATER QUALITY REQUIREMENTS: MPCA administers the requirements of the National Pollutant Discharge Elimination System and the State Disposal System (NPDES/SDS) requirements. To ensure state water quality standards during construction are not violated, check with the MPCA Stormwater Program www.pca.state.mn.us/stormwater for permit application requirements, pollution prevention guidance documents, and additional measures required for work in Special or Impaired Waters. For questions on MPCA requirements, contact the MPCA-MnDOT Liaison (Dan Sullivan at Dan.Sullivan@state.mn.us or 651-366-4294).

J. TEMPORARY DEWATERING: A separate water use permit is required for withdrawal of more than 10,000 gallons of water per day or 1 million gallons per year from surface water or ground water. GP1997-0005 (temporary water appropriations) covers a variety of activities associated with road construction and should be applied if applicable. An individual appropriations permit may be required for projects lasting longer than one year or exceeding 50 million gallons. Information is located at: http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/permits.html .

K. PROTECTION OF VEGETATION: If DNR Ecological & Water Resources staff determine that Native Plant Communities, Sites of Biodiversity Significance, other Areas of Environmental Sensitivity are present in or adjacent to Public Waters, precautions must be implemented to ensure protection and restoration of vegetation. MnDOT Standard Specifications for Protection and Restoration of Vegetation (spec #2572) of MnDOT Standard Specifications for Construction, 2005 edition, or its successor must be followed to minimize disturbance to such areas, see http://www.dot.state.mn.us/pre-letting/spec/2014/2014-Std-Spec-for-Construction.pdf. This may include, but is not limited to, the following: (1) During the project, parking, placement of temporary structures or material shall not be allowed outside the existing road right-of-way; (2) Place temporary fence at the construction limits and at other locations adjacent to vegetation designated to be preserved; (3) Minimize vehicular disturbance in the area (no unnecessary construction activities); (4) Leave a buffer of undisturbed vegetation between the critical resource and construction limits; (5) Precautions should be taken to ensure that borrow and disposal areas are not located within native plant communities; and (6) Revegetate disturbed soil with native species suitable to the local habitat.

L. NESTING BIRDS: MnDOT adherence to existing federal migratory bird protection programs will suffice for DNR concerns. Should active nests be encountered on the project (including swallow nests attached to bridges or culverts), contact MnDOT Office of Environmental Stewardship (Jason.Alcott@state.mn.us, ph; 651-366-3605), for specific guidance relating to Federal Threatened and Endangered Species and U.S. Fish and Wildlife Service coordination.

BEST PRACTICES - MNDOT: Please refer to the collection of "Best Practices for Meeting DNR General Public Waters Work Permit GP 2004-0001" for guidance to meeting the conditions of this General Permit. A PDF version is available at: http://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/gp_2004_0001_manual.html.

MESBOAC Guidance as often referred to by DNR in NE Minnesota

'MESBOAC' CRITERIA FOR DESIGNING A CULVERT TO ALLOW FISH PASSAGE AND MAINTAIN STREAM STABILITY

Undersized culvert.

Properly sized and placed culverts.

1. **M**atch culvert width to bankfull width (minimum). Minimum height should be at least 1/3 the bankfull width. Where multiple culverts are used, non-thalweg culverts may be 1 foot shorter than thalweg culverts so top elevations can match.
2. **S**et culvert at same slope as riffle slope as measured in the thalweg.
3. **B**ury culvert(s) to 1/6th the bankfull width of the stream (up to 2 feet), 1/5th for steeper streams with larger cobble substrate.
4. **O**ffset elevation of multiple culverts, with thalweg culvert buried according to permit requirements and centered on the thalweg; other culvert(s) set one foot higher.
5. **A**lign culvert with stream alignment.
6. **C**heck for potential headcuts. Provide grade control above and/or below where there is potential for head-cuts that could degrade the channel.

Note:

A. If the existing culvert has a lateral erosion or is perched, it is likely that the culvert is undersized. Care should be taken in re-design, as it is also possible that the stream has aggraded on the upstream side. An improperly re-designed culvert can lead to head cutting and destabilizing stream conditions, potentially adversely effecting upstream or downstream property.

B. Culvert sizing for matching bankfull width can be adjusted to utilize the nearest standard culvert sizes.

C. Be aware that culvert widths that add up to 10feet or more are considered a 'bridge' by MnDOT and such crossings are subject to MnDOT's bridge inspection and maintenance requirements.

(Much of the information contained within this section was developed and provided by Sandy Verry, retired U.S. Forest Service Hydrologist and currently geomorphology consultant with Ellen River Partners.) Photo source: Karl Koller

MESBOAC Guidance as often referred to by DNR in NE Minnesota

Bankfull Width Determination

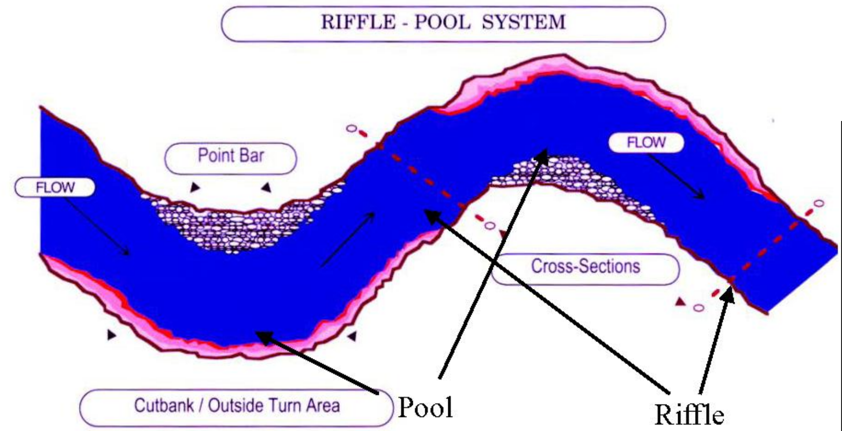
BANKFULL ELEVATION Stage of flow at which water has filled the principal channel and just begins to flow onto the floodplain.

BANKFULL DISCHARGE Bankfull flow is usually associated with about the 1 - 2 year event. Over the long term, bankfull flows shape the channel because bankfull flow is the most prevalent flow that is fast enough to entrain the channel bottom and transport bedload as well as suspend bedload.

When possible, calibration should be done using field determined bankfull stage elevations and corresponding channel dimensions compared to known recurrence intervals at gaging stations. Where gaging station data is not available, approximate calibration can be done through hydraulic modeling. Be sure not to measure bankfull width near culverts or bridges.

It is important that culvert width matches bankfull width to provide stability to the channel. By matching bankfull width, velocity through the culvert will more likely match channel velocity for the bankfull discharge.

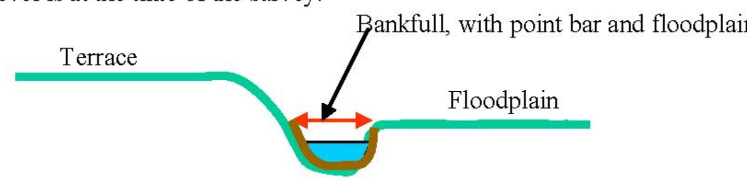
Reference: Rosgen, David L. 1994. A Classification of Natural Rivers. Catena. June, 1994.



DETERMINING BANKFULL ELEVATION Bankfull width can be fairly easy to determine in streams with little to moderate entrenchment (streams with wide, accessible floodplains). In streams that are highly entrenched, determining bankfull width may be difficult (see next page).

The flats on top of the depositional features such as point bars are the best indication of bankfull elevation. To measure bankfull width, measure the width of the stream across the riffles (straight sections) from bankfull elevation to bankfull elevation. This measurement should be taken in the narrowest part of the stream. The riffles are the hydraulic control points on the stream, so the cross-sectional area in riffles is the minimum area needed to maintain stream stability.

Measure at the bankfull or floodplain elevation regardless of where the water level is at the time of the survey.



Be careful not to interpret a terrace, when present, as the bankfull elevation. A terrace is a remnant geomorphic feature.

MESBOAC Guidance as often referred to by DNR in NE Minnesota

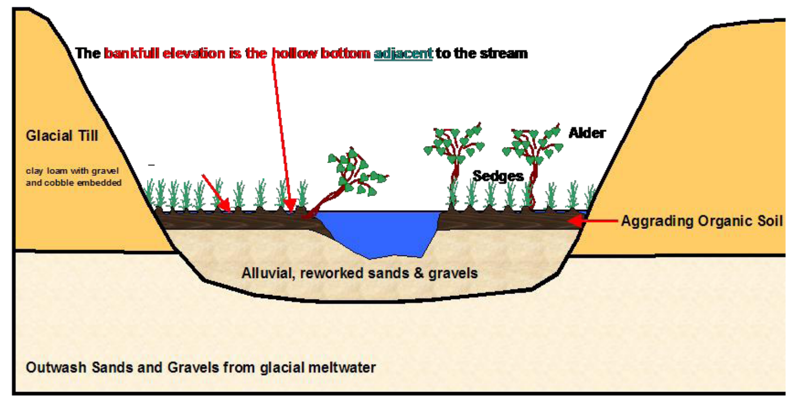
Bankfull Width Determination (cont.)

Determining Bankfull Elevation in Difficult Circumstances or Stream Types

Stream with low, wetland floodplain

(E and C Channel)

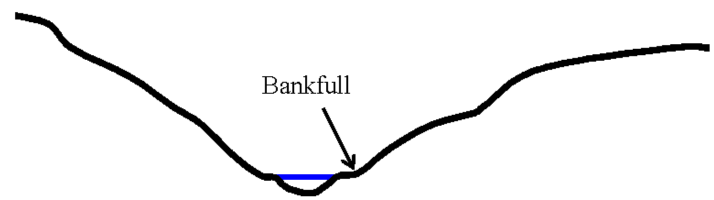
The majority of the stream channels will be type C and E channels, which are low gradient (<2%), highly meandered streams with wide floodplains (low entrenchment). Identifying bankfull elevation is relatively easy in these channel types. Many channels will flow through wetland areas, with hummocky sedge growth and perhaps alder. In this case, the low points (hollows), between the hummocks will be the bankfull elevation.



Moderately Entrenched Stream Types

(B Channel)

In areas with higher slopes moderately entrenched channels are more common. Small flats adjacent to the stream can often be identified. B channels are typically of moderate gradient (2 -4%), have narrow floodplains (moderately entrenched), have low sinuosity and are usually dominated by step/pool sequence.

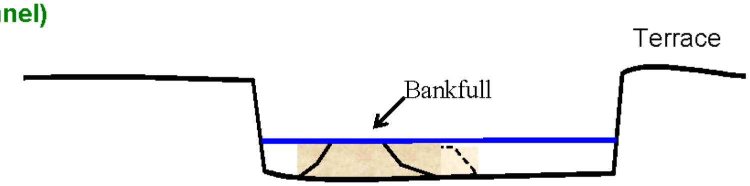


Look for small, footprint-sized floodplain flats adjacent to the channel in B stream types

Highly Entrenched Stream Types (Wide and shallow channel)

(F Channel)

In Minnesota, F channels are often unstable sections of stream that have become overwide and are in an intermediate stage of channel evolution in reaction to a past or current disturbance to hydrology or sediment load. F channels have little or no floodplain (highly entrenched), are wide and shallow and are low gradient with moderate sinuosity. The tops of mid-channel bars may be the only indicator of bankfull elevation.



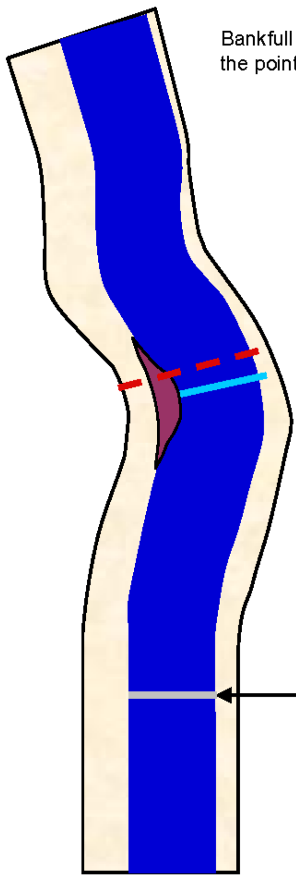
The highest mid-channel bar is the elevation of the bankfull stage.

Bankfull Width Determination (cont.)

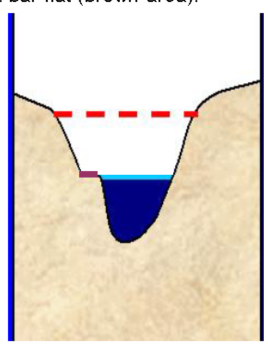
Determining Bankfull Elevation in Difficult Circumstances or Stream Types (Cont.)

Highly Entrenched Stream Types (Narrow and deep channel)

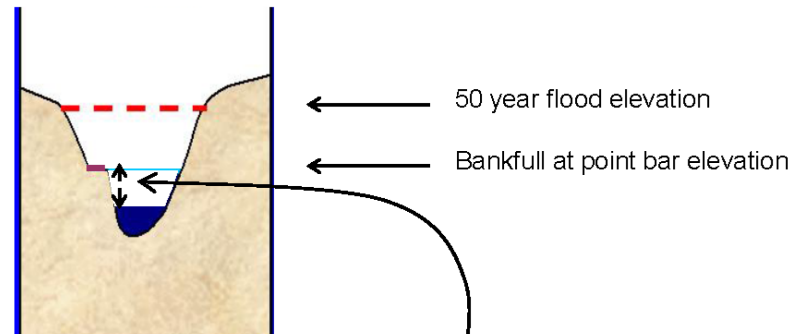
(G Channel)



Bankfull stage and flow showing the forming of the point bar flat (brown area).



Bankfull depositional flat and distance above water on the day measurements are made.



G channel types (gulleys) are moderately steep with slopes between 2% and 4%.
They are relatively straight, but nearly always have some bends in the entrenched valley.
They are so entrenched, the 50-year flood (red, dashed line) can not get out of the valley.
The bankfull elevation occurs about 2 out of 3 years (1.5-yr storm).
This bankfull flow forms rudimentary point bars on the inside of bends.

To estimate bankfull height where it is not evident, measure the distance between the water surface and he top of the point bar flats.

Move up or downstream to the narrowest width of the bankfull channel.

Measure bankfull width at bankfull/point bar elevation (distance measured above water surface) At the elevation of the point bar flat (distance above water) measure the bankfull width.
This bankfull width will pass the bankfull discharge at the channel bankfull flow velocity.
In the steeper G channels the bankfull velocity will likely be in the 3 to 5 feet per second range because of the steeper channels.

Highly Entrenched Stream Types (Narrow and deep channel- steep slopes)

(A Channel)

A (and A+) channels are high gradient (>4% slope), entrenched channels that are relatively narrow and deep. There is no easy, reliable way to determine bankfull elevation on these types of stream channels. Because A channel segments are rare and likely short in Minnesota, the best technique would be to go upstream or downstream of the A channel and measure bankfull width at that location.

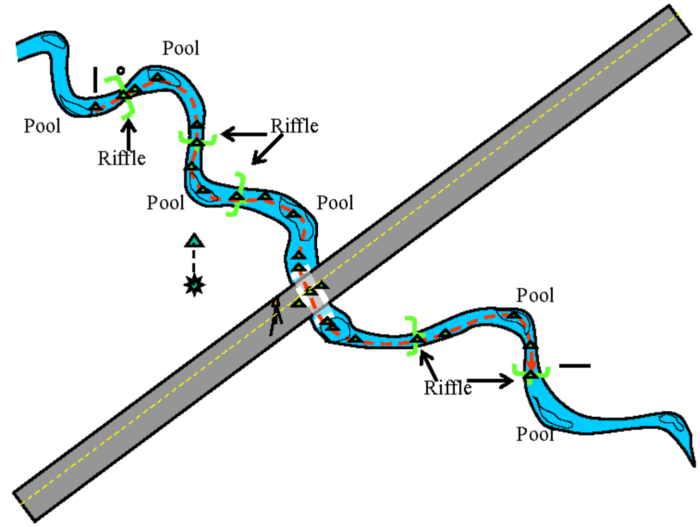
MESBOAC Guidance as often referred to by DNR in NE Minnesota

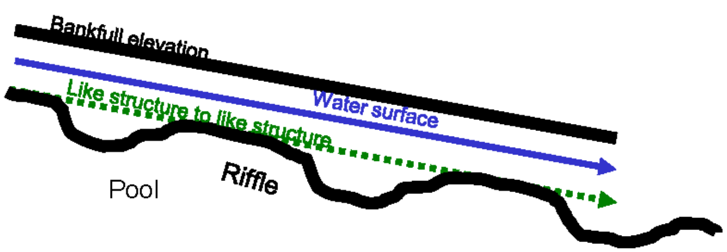
Determining Slope and Elevation

Unaltered streams follow a predictable pattern with pools forming along the outsides of bends and riffles (shallowest points in the longitudinal profile of the stream) forming within the straight sections. Riffles control the elevation and slope of the stream; therefore, the riffle elevations (as measured in the thalweg*) should be used to determine culvert elevation and slope. Culverts are usually set in riffles because it is easier to cross a stream in a straight stretch than in a bend and the banks tend to be more stable.

SURVEYING RIFFLES
The easiest way to determine culvert invert elevations is to measure a minimum of two riffles elevations upstream and two downstream of the crossing (avoid the riffle immediately downstream of the culvert). (Every effort should be made to increase the length of your longitudinal profile to get as many riffle elevations as possible.) Elevations should be measured at least at every change in depth, ensuring that all riffles are measured. Measure the stream distance between each reading so slope (elevation vs. distance) can be calculated and note station distance of each existing or proposed culvert invert. Three elevations should be measured at each location; 1. Streambed elevation in thalweg * 2. water surface and 3. bankfull elevation (although not necessary, recording bankfull elevations when possible can help in the analysis).

▲ Location of elevation readings for longitudinal profile





There are three ways to measure stream slope. Water surface, bankfull and like structure slopes will be the same in stable streams. Culvert elevation determination, is based on riffle elevations (like structure to like structure), as measured in the thalweg.

If you are not confident you can identify pools and riffles, record thalweg elevations frequently through at least three bends both upstream and downstream of the crossing.

Remember to establish a benchmark to tie all your readings together and to use when setting the culvert at the proper elevation.

*Thalweg = Deepest point in a channel cross-section, usually found near the center of the channel in riffles and near the outside of the bend in pools.

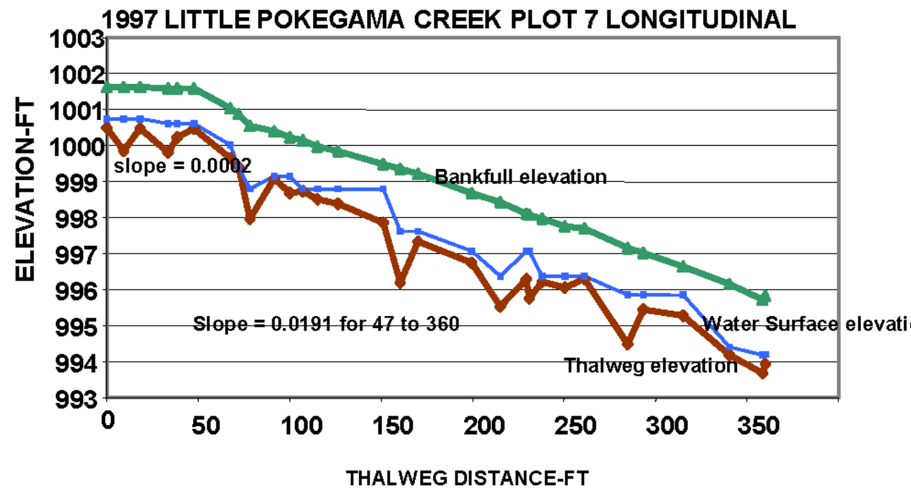
Determining Slope and Elevation (Cont.)

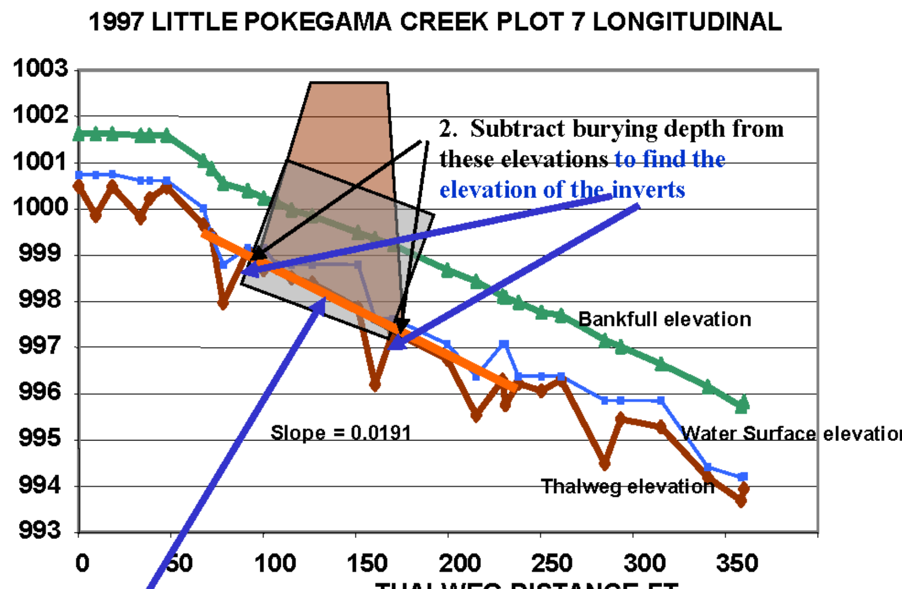
PLOTTING

Once longitudinal profile elevations have been collected, plot the elevations versus distance to calculate the slope (regress). Thalweg, water surface and bankfull slopes should be similar. It should become evident which points are riffles, which are pools and which are intermediate points. To calculate riffle slope and determine elevations of culvert inverts, regress only the riffle points. The invert distances can be inserted into the regression to calculate the stream bottom elevation at the inverts. Once this is done, subtracting 1/6th the bankfull width (1/5th in higher gradient, large substrate streams) from this elevation will yield the proper invert elevation.

If there was an obvious scour pool immediately downstream of the culvert, then there will often be an unusually high riffle immediately downstream of the scour pool. This is likely an indication that the current culvert is undersized and/or set too high. In this case, disregard this riffle when calculating riffle slope and culvert invert elevations.

When installing multiple culverts, remember to bury the culvert closest to thalweg to proper depth and place other culvert(s) about a foot higher. Also, when working with small or lightweight culverts (CMP), dig channel for culverts approximately 6 inches deeper than design elevation to account for culvert pushing up during backfilling.

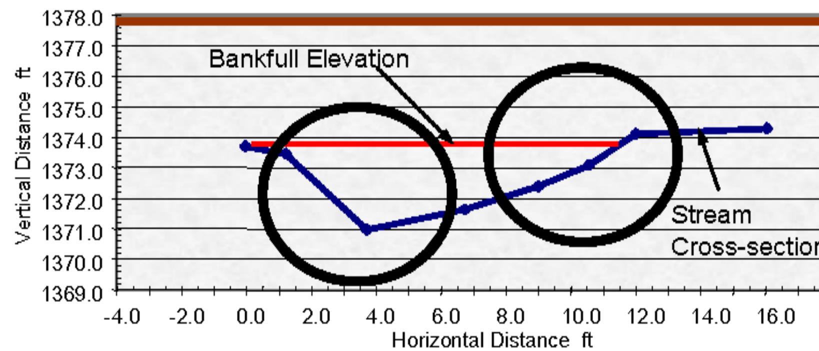




1. A line connecting the thalweg riffle points from above and below the crossing site is the most accurate estimate of stream bottom

Burying and Offsetting

Determining proper elevations of culvert inverts is described in previous pages. When installing multiple culverts, one culvert should be buried to 1/6th the bankfull width as determined by using the longitudinal riffle slope elevation and should be centered on the thalweg (deepest part of the channel cross section). The remaining culvert(s) should be placed one foot higher. Every effort should be made to minimize the number of culverts to maximize capacity and sediment transport.

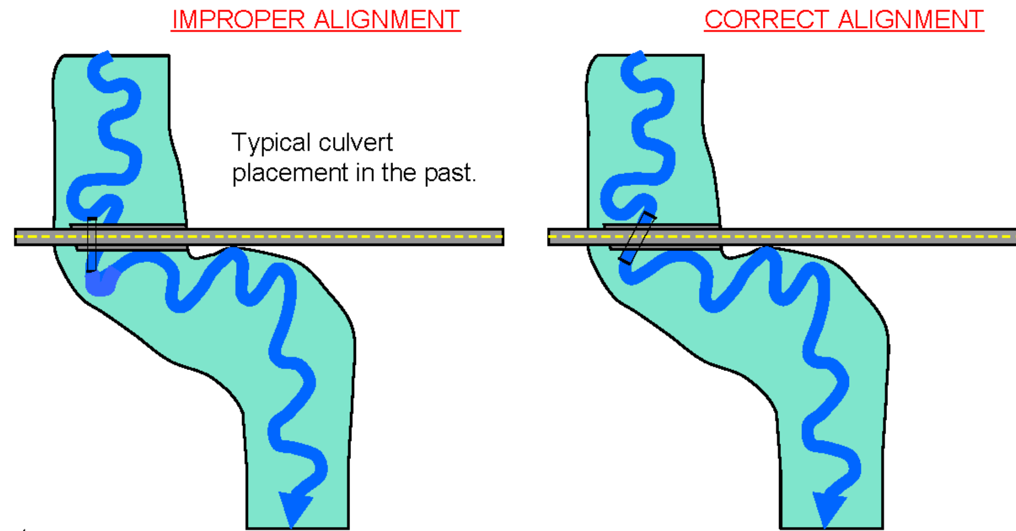


Note; This is the design installation based on a measured cross-section. The stream will adjust its cross-section and will look different after installation. The stream will maintain its cross-sectional area through the culverts, thus resulting in less sediment in the culverts than appears in this diagram.

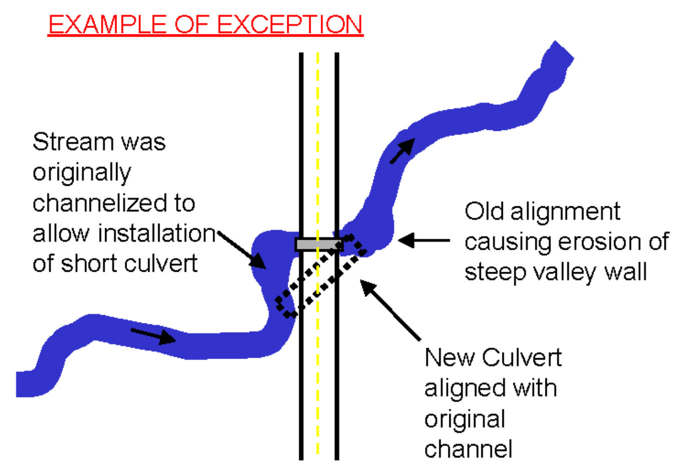
MESBOAC Guidance as often referred to by DNR in NE Minnesota

Alignment

In the past, culverts were typically placed perpendicular to the road, regardless of stream alignment, to minimize the length of the culvert. This saved money in the short term by allowing the shortest possible culvert and was believed to have less impact on fish passage because the distance fish had to swim through the culvert was minimized. However, shortening the stream length increases slope locally, which can destabilize the stream. In addition, the outlets of such culverts often direct the outflow into a bank, rather than down the channel, thus causing bank erosion. These concerns are alleviated by following the channel alignment and other requirements of the permit. By matching bankfull width with culvert width, and burying to allow the culvert to fill with native substrate, fish passage should not be impacted by a longer culvert, and designing for a stable stream will reduce maintenance costs over the long run.



Exceptions to the requirement of following existing stream alignment include replacing culverts that were not in alignment when first installed or situations where the stream is naturally directed into a steep valley wall leading to erosion of the valley wall. An example of the first situation is shown to the right, where a channelized section of stream was restored with a natural meander pattern. When the stream is being directed into a valley wall at the outlet of a culvert, it may be beneficial to redirect the channel away from the valley wall, although each situation is unique and should be looked at individually. Longitudinal slope data must support the proposed change in alignment and plans should be approved by the DNR. Benefits of realigning the channel should be balanced with the impact of installing a longer culvert. Culverts exceeding 100 feet should be avoided.

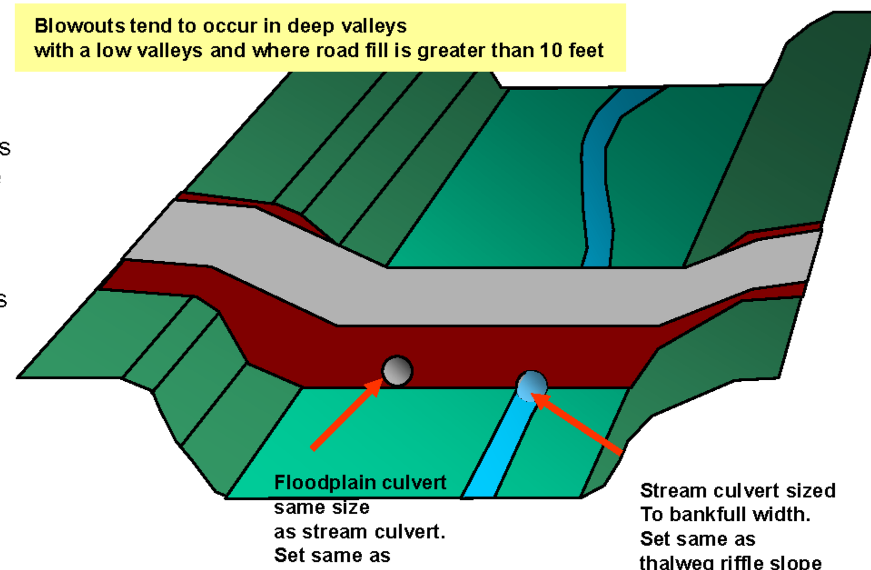


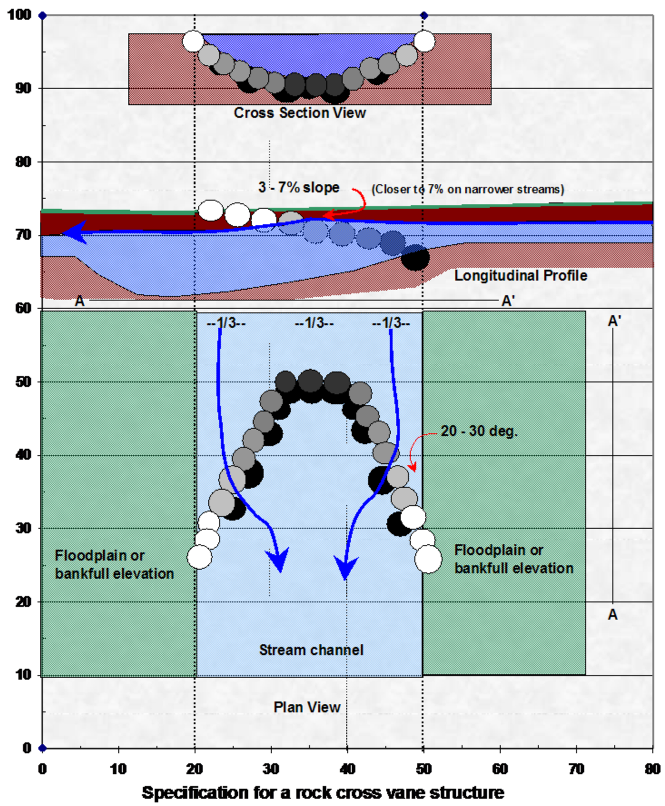
Another exception to consider in replacing existing culverts: There are site conditions where a replacement culvert can be placed adjacent to the existing culvert. Installation is done in the dry, and then the stream is redirected to the new culvert. In many cases this is reverse of how the existing culvert was placed. It is also a good option where there are other resource concerns such as sediment and flow regime during construction.

Always consult with the DNR when considering alignment.

Other Considerations

FLOODPLAIN CULVERTS (See diagram to right)
The requirements in this permit are minimum design specifications. There are circumstances that may require additional design. A healthy stream has full use of its floodplain to release the energy of floods and fish also use the slower velocities in floodplains as refuge during extreme floods. In deep valleys, especially narrow, entrenched ones, adding floodplain culverts not only increases stream stability and aids in fish passage, but reduces the likelihood of road washout. Always consider floodplain culverts in crossings with a history of washouts, or where fish passage is especially critical.





GRADE CONTROL
Grade control structures may be beneficial to add to a stream crossing design. They can be used to protect: a) single span bridge pilings from scour, b) provide grade control to prevent head-cutting where past undersized and/or perched culverts have caused upstream aggradation and downstream degradation, c) create slower velocity backwater type habitat for fish passage, or d) direct flow away from a bank (See www/wildlandhydrology.com/assets/cross-vane.pdf for design specifications). W-weirs can be used to protect instream bridge pilings from scour. If grade control greater than about one foot is needed, a rock arch rapids will need to be installed. Design assistance can be provided by the Department of Natural Resources.

Transportation Research Record: Journal of the Transportation Research Board
Stream Simulation for Aquatic Organism Passage at Road-Stream Crossings
Volume 2203, Page 36- 45, Date 2011-12-01
Link - http://trb.metapress.com/content/G59K30783680W45M

Stream Simulation for Aquatic Organism Passage at Road–Stream Crossings

Daniel A. Cenderelli, Kim Clarkin, Robert A. Gubernick, and Mark Weinhold

Historically, road–stream crossing structures were designed on the basis of the hydraulic capacity of the structure for a specific design flood without consideration of aquatic species or the swimming and jumping abilities of a single target fish species and life stage during its migration, and ignored the movement needs of other adult fish, juvenile fish, and aquatic organisms occupying the stream. Hydraulic designs typically constrict the channel, create flow hydraulics and channel conditions that are markedly dissimilar from those in the natural channel, and impede the movement of most other nontarget fish and aquatic organisms along the stream corridor. The stream simulation approach for designing road–stream crossing structures was recently adopted by the U.S. Department of Agriculture Forest Service as a pragmatic and sustainable long-term solution to maintain passage for all aquatic organisms at all life stages at road–stream crossings while meeting vehicle transportation objectives. This study shows how the stream simulation design process integrates fluvial geomorphology concepts with engineering principles to design a natural and dynamic channel through the road–stream crossing structure. The premise of stream simulation is that the creation of channel dimensions and characteristics similar to those in the adjacent natural channel will enable fish and other aquatic organisms to experience no greater difficulty moving through the structure than if there were no crossing. Stream simulation channels are designed to adjust laterally and vertically to a wide range of floods and sediment or wood inputs without compromising the movement needs of fish and other aquatic organisms or the hydraulic capacity of the structure.

Migration barriers such as dams, irrigation diversions, and road–stream crossings are one of the primary reasons the populations of many aquatic species throughout the world are decreasing in number or are at risk of extinction (*1, 2*). Movement is essential for fish and many other types of aquatic species to gather food, escape poor habitat conditions or predators, and complete phases of their life-cycle such as spawning and rearing (*3*). Recolonization of stream areas by aquatic species after a local extirpation also depends on barrier-free stream movement corridors. Aquatic species isolated by barriers have lower genetic diversity and may be less able to adapt to changing environmental conditions (*4*). Recent movement studies have found that resident salmonid movements are more wide ranging and common than formerly thought, and even small warm-water fish species can no longer be considered sedentary (*5*).

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Transportation Research Record: Journal of the Transportation Research Board, No. 2203, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 36–45.
DOI: 10.3141/2203-05

The National Forest Management Act directed the U.S. Department of Agriculture Forest Service to preserve the diversity of aquatic communities and maintain viable populations of native species on streams within National Forest System lands. The Endangered Species and Clean Water Acts also require that essential behavioral patterns of aquatic species, including their movement, not be disrupted or obstructed. Beginning in the 1970s, the Forest Service began to respond to the issue of road culverts that blocked spawning migrations of salmon and steelhead trout in the Pacific Northwest. Blockages associated with undersized culverts were generally due to high water velocities, excessive turbulence, and shallow water depths in culverts; debris accumulation at the culvert inlet; or high perches of the culvert outlet above the scoured downstream channel (Figure 1; note the distinct perch of the culvert outlet above the channel bed, lack of sediment in the culvert, or aggraded sediment at the culvert inlet).

The Forest Service began replacing older undersized culverts with larger ones designed to provide hydraulic conditions that allowed for passage of adult fish. Hydraulic design has been used for decades to design fish-passable culverts at road–stream crossings along with fishways and other types of passage structures. The objective of a hydraulic design is to create flow conditions through the structure that decrease velocities, decrease turbulence, and increase flow depths for the range of flows in which a particular target species has been shown to be moving. Culvert size, slope, length, and material roughness along the culvert bottom are factored into the hydraulic design method. Baffles, weirs, and rock substrate can be used to increase roughness, decrease flow velocity, and increase flow depth to achieve the design criteria for the target species. However, culverts designed by using the hydraulic method are generally much narrower than the width of the adjacent natural channel.

In the late 1980s, engineers using the hydraulic design approach to design culverts identified several concerns with the method: (*a*) fish swimming performance criteria were lacking for a large number of species, (*b*) the timing and magnitude of flows when fish migrated were uncertain, (*c*) juvenile salmonids could not necessarily navigate the culverts designed for adults of the same species, and (*d*) designing for passage of multiple species that migrate at different times of year and at different flows was impractical. In addition, fish biologists and ecologists began to express the importance that all aquatic species, at all life stages, need to be able to move freely along the stream corridor for the range of flows in which they typically are moving in the natural channel. Moreover, observations that juvenile salmonids were not able to pass through engineered fishways identified the importance of channel substrate and bank heterogeneity in providing critical pathways and resting areas for fish as they moved along the channel (K. K. Bates, Consultant, unpublished data, March 2010).

FIGURE 1 Effects of undersized culverts on channel morphology and fluvial processes: (*a*) upstream view of 6-ft (1.8-m) diameter culvert on Save Creek (Olympic National Forest, Washington), (*b*) downstream view of 3-ft (0.96-m) diameter culvert on North Thompson Creek (White River National Forest, Colorado), (*c*) upstream view of 6-ft (1.8-m) diameter culvert on unnamed stream (White Mountain National Forest, New Hampshire), and (*d*) upstream view of 9-ft (2.7-m) diameter culvert on Peavine Creek (Tahoe National Forest, California).

In addition to the impacts on the movement of fish and other aquatic organisms, culverts smaller than bankfull width are prone to backwatering of the culvert inlet during high flows, causing sediment and debris to accumulate at the inlet. This accumulation of material at the inlet can result in increased maintenance or even failures that disrupt the transportation system, reduce water quality, and degrade channel conditions. In an assessment of the numerous road–stream crossings that failed in the Pacific Northwest from floods between 1996 and 1998, Furniss et al. found that plugging of the culvert by sediment and wood was the primary factor that caused many road–stream crossings to fail (*6*). They concluded that culverts presenting the least change to channel cross section, slope, and alignment through the crossing were most likely to pass sediment and debris, substantially reducing the risk for failure of those crossings. Thus, for both biological and physical reasons, a new paradigm of culvert design, stream simulation, began to evolve.

The concept of stream simulation was first introduced by the Washington Department of Fish and Wildlife in 1999 (*7*). The basic premise of stream simulation is that creation of a structure with channel dimensions and characteristics similar to those in the adjacent natural channel would cause fish and other aquatic organisms to experience no greater difficulty moving through the structure than if there were no crossing. Although the concepts and overarching goals of stream simulation are easily understood, technical guidelines for collecting and interpreting channel data in the vicinity of the road–stream crossing and integrating those data to design a stream simulation channel and structure or roadway had not been thoroughly developed. A 2008 Forest Service publication expands the concept of stream simulation as an ecosystem-based approach to road–stream crossing design and provides detailed guidelines for developing and implementing a stream simulation design (*8*).

Stream simulation designs have a continuous channel through the structure with dimensions and characteristics similar to those in the adjacent natural channel (Figure 2). Water depths, velocities, and pathways in a stream simulation channel are designed to be as similar and diverse as those encountered in the adjacent natural channel, providing for unimpeded passage of fish and other aquatic organisms at all life stages through the structure (*8*). Unlike hydraulic designs, stream simulation designs are not subject to the uncertainties associated with fish swim performance data and migration flows, nor do they depend on the questionable assumption that providing for a target fish species accommodates the needs of other fish and aquatic organisms.

(a) (b) (c) (d)

FIGURE 2 Road–stream crossings: (*a*) culvert built in late 1950s with diameter of 6 ft (1.83 m), length of 90 ft (27.4 m), and gradient of 2.1% before replacement along tributary to Middle Fork Salmon River, Washington; (*b*) same site as in (*a*) after the culvert was replaced using stream simulation design approach with open-bottom arch built in late 2005 with span of 18 ft (5.5 m), height of 9 ft (2.7 m), length of 95 ft (28.9 m), and gradient of 4.0%; (*c*) culvert built in late 1960s with diameter of 3 ft (0.96 m), length of 48 ft (14.6 m), and gradient of 2.0% before replacement along North Thompson Creek, Colorado; and (*d*) same site as in (*c*) after culvert was replaced using stream simulation design approach with pipe-arch culvert built in late 2008 with span of 12.2 ft (3.7 m), height of 8.5 ft (2.6 m), length of 48 ft (14.6 m), and gradient of 2.5%.

The various components of the assessment, design, and construction process used in stream simulation are briefly summarized here. Examples of road–stream crossings that were designed using the stream simulation approach are presented along with a brief discussion of site conditions where stream simulation is not appropriate. A more in-depth discussion and list of references on stream simulation may be found elsewhere (*8*).

STREAM SIMULATION DESIGN APPROACH

Stream simulation integrates fluvial geomorphology with engineering principles to design a road–stream crossing that contains a natural and dynamic channel through the structure. This approach requires measurements of site-specific channel characteristics in the adjacent natural channel to ensure that an appropriate reference reach can be identified. Identifying a reference reach is a key component of stream simulation as it provides the natural template for designing a channel through the crossing and determining the size and embedment depth of the replacement structure. The reference reach is typically located in a section of channel that is in close proximity to but not affected by the existing undersized crossing structure and is in the same geomorphic setting as the crossing. The reference reach characterizes channel and floodplain dimensions, channel features and bedforms, and sediment characteristics along a stable, representative reach of the channel. By developing a design channel through a road–stream crossing structure with a gradient, a cross-section shape, bedforms, and sediment size characteristics that are similar to those of the stable nearby reference reach, natural fluvial processes will function through the structure and provide unimpeded aquatic organism passage. The replacement structure, either a bridge or a culvert, is designed around and over the stream simulation channel so that the design channel dimensions determine the dimensions of the structure.

Natural channels constantly adjust their dimension in response to a range of floods and sediment and wood inputs. A stream simulation channel responds similarly to the natural channel and should provide long-term, sustainable geomorphic continuity through the structure and along the stream corridor. To allow for such channel adjustment, flows that transport sediment and wood along the channel should not be constrained by or accelerated inside the crossing structure. The width of a stream simulation design structure is equivalent to or exceeds the bankfull width of the natural channel, which reduces or eliminates backwatering or ponding at the inlet during moderate floods and makes those areas less prone to sediment and debris accumulation. Flow velocities through and exiting the stream simulation structure are similar to those in the downstream channel during a range of floods, preventing excessive scour and degradation of the channel immediately downstream of the structure. In addition, stream simulation structures are less susceptible to damage by high flows and debris blockage because flows are not constricted until they substantially exceed bankfull flow conditions.

Stream simulation design is an interdisciplinary approach requiring those skilled in engineering, hydrology, geomorphology, biology, and construction contract administration. The approach is a multiple-step process that involves (*a*) conducting a watershed and initial reach review, (*b*) conducting a site assessment, (*c*) developing a stream simulation design channel and selecting an appropriate structure, (*d*) finalizing the design and preparing a design contract, and (*e*) constructing the design.

Watershed and Initial Reach Review

Geomorphic processes need to be considered at the watershed scale because channel characteristics and fluvial processes at the local scale are strongly tied to the supply of water and sediment from the upstream watershed and to base-level controls downstream. The interaction and integration of watershed-scale processes control the hydrologic regime (discharge magnitude, duration, and frequency) and sediment regime (quantity and size of sediment supplied) at a given location along the channel, which in turn influence channel characteristics such as channel-bed composition and structure, channel width and depth, channel gradient, sediment transport, and sediment deposition. If watershed-scale processes are not considered in the road–stream crossing channel design, the replacement structure may not adequately handle the temporal variability of water and sediment that passes through the crossing from natural and anthropogenic disturbances, potentially causing unintended passage issues to fish and other aquatic organisms.

By using existing information and data resources, the watershed review identifies (*a*) large-scale natural processes (e.g., landslides, floods, wildfire) and management activities that can influence, have influenced, or will influence channel conditions and geomorphic processes at the crossing; (*b*) the value of aquatic resources at the crossing within a broader, watershed-scale context; and (*c*) current and future transportation requirements, potential roadway constraints, and past road maintenance issues at the crossing.

Once this watershed information is obtained, the interdisciplinary team performs a site reconnaissance at the road–stream crossing. During the site reconnaissance the team gathers preliminary information about the road–stream crossing and qualitatively describes channel characteristics upstream and downstream of the crossing. The team evaluates the alignment of the channel with the current structure and roadway, determines if the crossing can be relocated to a more favorable location, assesses current channel conditions and stability, identifies important geomorphic features of the stream that will need to be surveyed in subsequent phases of the stream simulation process, and identifies potential construction constraints and challenges at the site.

From the information obtained from the watershed review and site reconnaissance, the interdisciplinary team develops preliminary project objectives for replacing the road–stream crossing. Project objectives will become more clearly defined as the team learns more about site conditions and constraints during the site assessment. Preliminary project objectives should address both ecological and transportation needs at the site, reflecting both the risks and resource values associated with the project.

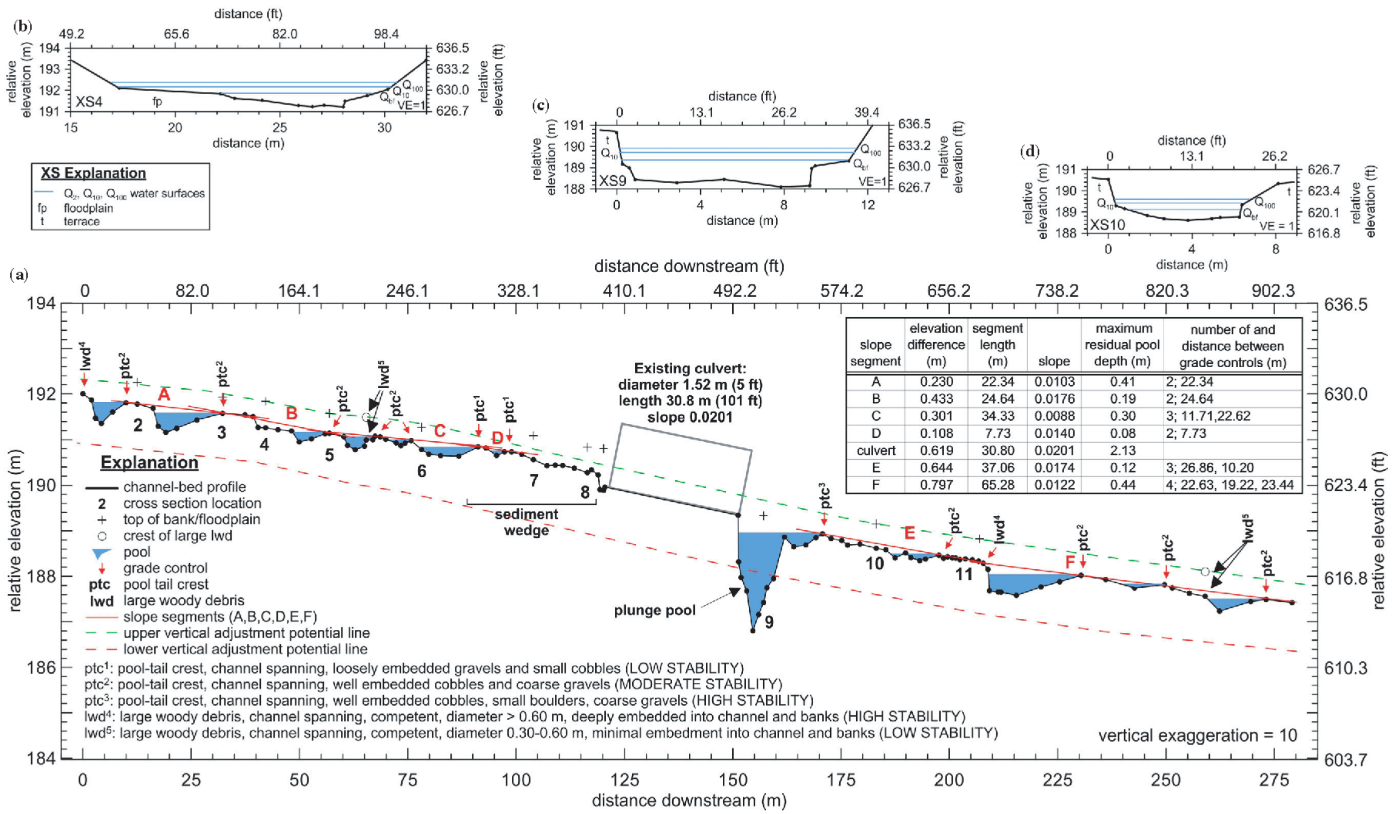
Site Assessment

After preliminary project objectives to replace the road–stream crossing structure have been defined, a detailed site assessment is conducted. During the site assessment, the interdisciplinary team collects data and information to characterize channel features and interpret geomorphic processes 20 to 30 channel widths upstream and downstream from the road–stream crossing. At the crossing, the team also evaluates road travel-way alignment and approaches, right-of-way and property boundary issues, and the presence of utilities.

Data collection for the site assessment requires a site survey to characterize channel, valley, and road topography as well as important geomorphic and road features observed at the site. A longitudinal profile survey of the channel is the most valuable data collected and interpreted in the stream simulation design process because it characterizes the range of channel gradients, type and stability of grade controls, range of pool scour depths, spacing and length of channel units, and potential aggradation surfaces upstream and downstream of the road–stream crossing, as shown in Figure 3*a*. In Figure 3*a*, note the differences between the depth and spacing of pools upstream and downstream of the crossing. The dashed red and green lines bracket the potential range of bed elevations along the channel in response to floods and inputs of sediment and debris over the service life of the structure. The effects of the undersized culvert are illustrated by the sediment wedge upstream of the inlet and the deep plunge pool downstream of the outlet.

Surveying representative cross sections upstream and downstream of the road–stream crossing provides important data on bankfull flow width, flood-prone width, bank height and stability, channel entrenchment, and valley confinement along the channel (Figure 3*b*–*d*).

The site assessment includes interpreting the natural channel pattern through the road–stream crossing, collecting sediment data along the channel bed, and conducting a preliminary geotechnical investigation. Interpreting the original natural channel location and pattern through the road–stream crossing is necessary to determine how the existing crossing structure has affected the length and slope of the channel through the crossing. Characterizing channel-bed composition is important for understanding of bed mobility along the channel, the stability of key feature particle sizes in the channel, and sediment supply to the channel and for determining the size and range of sediment sizes for the design channel through the crossing (Figure 4). A geotechnical field investigation is performed to assess the presence of bedrock, unstable soils, and shallow groundwater at the road–stream



slope segment	elevation difference (m)	segment length (m)	slope	maximum residual pool depth (m)	number of and distance between grade controls (m)
A	0.230	22.34	0.0103	0.41	2; 22.34
B	0.433	24.64	0.0176	0.19	2; 24.64
C	0.301	34.33	0.0088	0.30	3; 11.71,22.62
D	0.108	7.73	0.0140	0.08	2; 7.73
culvert	0.619	30.80	0.0201	2.13	
E	0.644	37.06	0.0174	0.12	3; 26.86, 10.20
F	0.797	65.28	0.0122	0.44	4; 22.63, 19.22, 23.44

FIGURE 3 Longitudinal profile and cross sections: (*a*) longitudinal profile showing range of channel gradients, spacing and length of channel units (pools, riffles, wood-forced small steps), type and stability of grade controls, distribution and distance between grade controls, and range of pool scour depths along a channel upstream and downstream of a road–stream crossing; (*b*) representative cross section upstream of road–stream crossing characterizing channel dimensions at various flows; (*c*) cross section at plunge pool showing channel dimensions at various flows; and (*d*) representative cross section downstream of road–stream crossing characterizing channel dimensions at various flows.

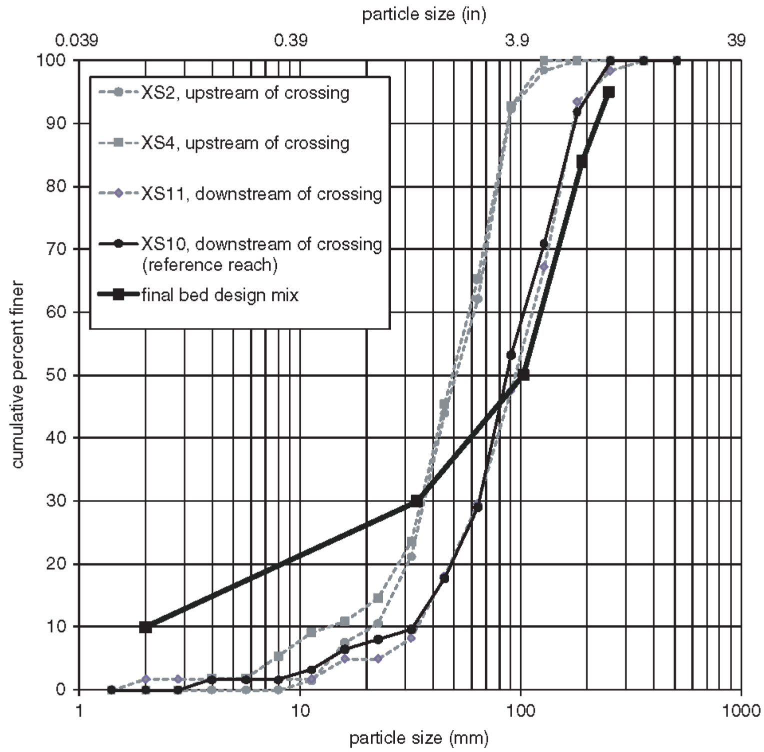


FIGURE 4 Particle-size distributions collected at four cross sections along channel upstream and downstream from road–stream crossing site described in Figures 3 and 5. Solid line represents final bed design mix for design based on bed mobility analysis and inclusion of fines to reflect presence of fines in subsurface. For design channel to have similar mobility as reference reach channel, particles larger than D50-percentile particle size were increased by factor of 1.2 in design channel when compared with reference reach particle sizes.

crossing and to determine if a more in-depth subsurface investigation is necessary.

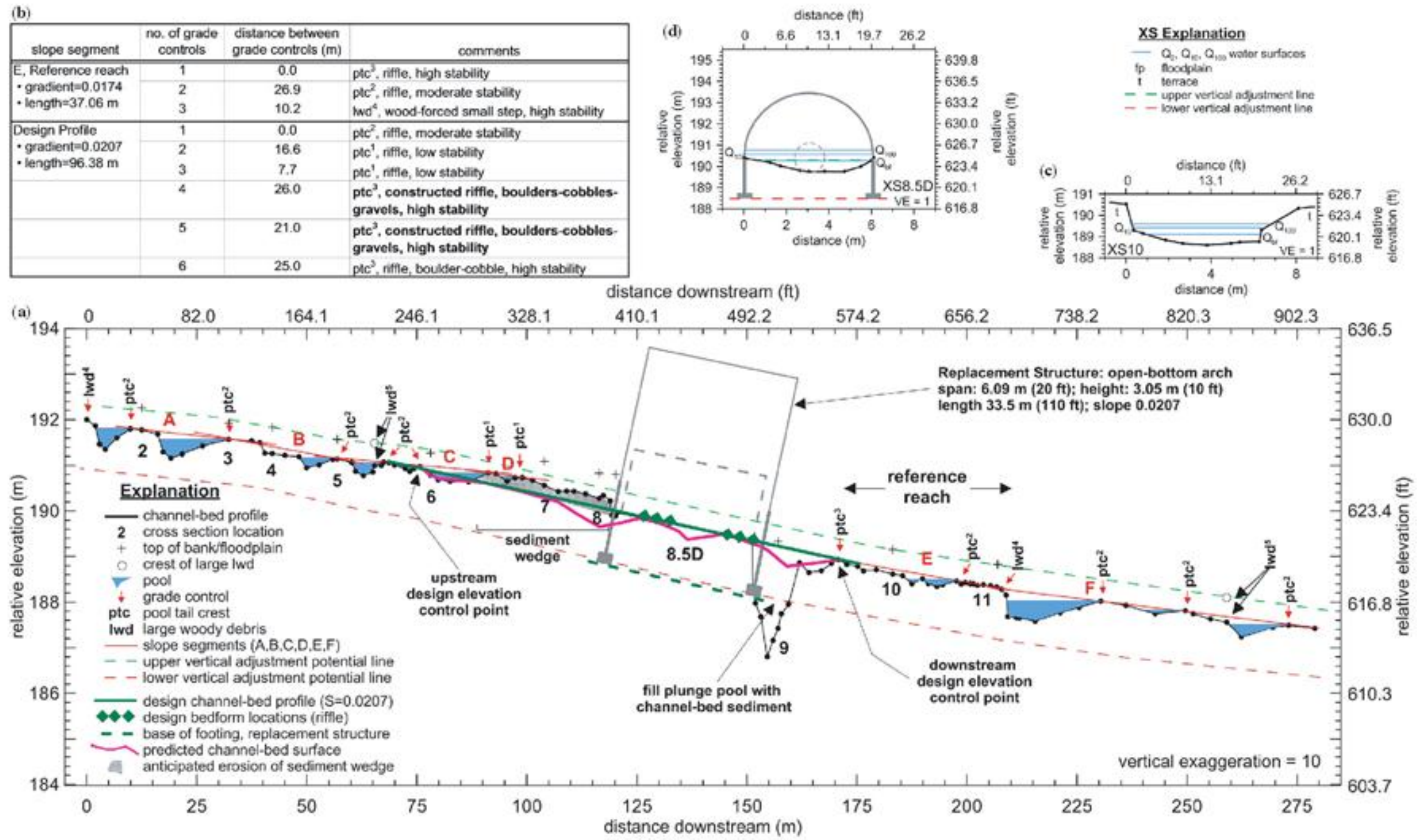
On the basis of the analyses and interpretations of the various site assessment data, potential channel responses and risks are predicted when the existing structure is replaced. Channel responses and site risks that need to be addressed at the road–stream crossing include the stability or instability of the channel, floodplain-conveyance issues, and the potential for headcutting, vertical channel adjustments, lateral channel adjustments, and debris loading.

Stream Simulation Design

During the stream simulation design phase, the information and data obtained during the site assessment are used to develop a stream simulation channel through the road–stream crossing that is based on a reference reach in the adjacent natural channel. The key components of the stream simulation design process include optimizing horizontal alignment relative to the road, developing a longitudinal profile of the design channel through the crossing, developing the cross-section shape of the design channel, and developing the size and arrangement of bed material for the design channel.

On the basis of the interpreted natural channel pattern through the crossing, the structure orientation and road alignment are evaluated to determine if they can be modified to improve the hydraulic transition between the channel and the structure. Special design options such as headwalls or dips in the road that shorten the length of the replacement structure should be considered and used to develop the best alignment between the structure and the channel.

Developing the design longitudinal profile through the road–stream crossing is the most important step in the stream simulation design process (Figure 5*a*, *b*). The design profile in Figure 5 shows the proposed structure and embedment depth, that the plunge pool is to be filled with channel-bed sediment, that the sediment wedge surface will be eroded and lowered by natural flood processes, and the predicted channel-bed surface after a period of adjustment (see Figure 3*a* for additional information about prereplacement conditions). The design longitudinal profile represents the surface that will be constructed through the project reach so that geomorphic continuity is provided between the upstream and downstream channels. This process involves (*a*) developing a design channel gradient that is anchored to stable grade controls upstream and downstream of the crossing, (*b*) identifying a reference reach in an adjacent natural channel that is similar in gradient and length to the design channel,



slope segment	no. of grade controls	distance between grade controls (m)	comments
E, Reference reach • gradient=0.0174 • length=37.06 m	1	0.0	ptc³, riffle, high stability
	2	26.9	ptc², riffle, moderate stability
	3	10.2	lwd⁴, wood-forced small step, high stability
Design Profile • gradient=0.0207 • length=96.38 m	1	0.0	ptc², riffle, moderate stability
	2	16.6	ptc¹, riffle, low stability
	3	7.7	ptc¹, riffle, low stability
	4	26.0	**ptc³, constructed riffle, boulders-cobbles-gravels, high stability**
	5	21.0	**ptc³, constructed riffle, boulders-cobbles-gravels, high stability**
	6	25.0	ptc³, riffle, boulder-cobble, high stability

FIGURE 5 Longitudinal profile and cross sections: (*a*) stream simulation design profile at crossing (solid green line) tied to stable elevation grade controls upstream and downstream of crossing; design profile is similar in gradient to reference reach channel segment, and diamond symbols on design profile are grade controls (constructed riffles) similar in dimension and characteristics to those in reference reach; (*b*) summary of type, stability, and spacing of bedforms in reference reach and design channel; (*c*) representative cross section from reference reach characterizing channel dimensions at various flows downstream of road–stream crossing; and (*d*) representative cross section of design channel and replacement structure.

(*c*) determining the spacing and dimensions of bedforms in the design channel that are similar to those measured in the reference reach, (*d*) ensuring that the design channel provides geomorphic continuity between the upstream and downstream channel, (*e*) determining the structure embedment depth based on pool scour depths measured along the channel and interpreted scour depths at the crossing, and (*f*) interpreting the potential ranges of channel-bed surface elevations that may occur over the service life of the structure.

The cross-section shape for the stream simulation design channel is based on finding a shape that best fits the shape of cross sections in the reference reach (Figure 5*c*) and is feasible to describe in a contract and to construct. This shape is used later in the design process to determine the size and type of structure that are best suited for the site.

The particle-size mix for the stream simulation design channel is initially determined by using the particle-size distribution of the channel bed in the reference reach. Typically, the percentage of smaller particles is increased in the particle-size distribution to reflect the presence of those sediment sizes in the subsurface that fill the voids between the larger particles (Figure 4). The particle sizes needed to construct key features in the stream simulation design channel (e.g., grade controls, bedforms, banks, large roughness elements) are initially determined from measurements of the 10 to 25 largest particles of key features in the reference reach channel. Later in the stream simulation design process, the initial particle sizes selected may be modified on the basis of bed mobility and stability analyses, site risk factors, and site conditions.

Final Design and Contract Preparation

The final design and contract preparation phase of the stream simulation design process involves

1. Selecting a structure,
2. Analyzing the mobility of the stream simulation design channel bed,
3. Analyzing the stability of key pieces and bedforms in the design channel bed for the design flood,
4. Evaluating the hydraulic capacity of the selected structure for the design flood,
5. Developing final bed material specifications for the stream simulation design channel,
6. Developing erosion control and dewatering plans, and
7. Preparing the documents necessary for soliciting construction bids.

After the shape and dimensions of the stream simulation design channel are determined (width, depth, range of potential vertical bed changes, bank geometry), the replacement structure is selected and the roadway is designed. The type and size of crossing structure selected are determined by fitting them around the design channel and allowing for additional space to accommodate potential vertical and lateral adjustments over the service life of the structure (Figure 5*d*). A wide variety of structures such as circular culverts, arch culverts, concrete or metal open-bottom arches, and bridges may be suitable at the road–stream crossing. Engineering considerations at the crossing (right-of-way and property boundary issues, limitations on changing the road travel-way alignment and approach, limitations on moving utilities) combined with economic costs, materials and equipment available, value of the aquatic resource, and funds available will influence the type and size of the structure selected at a given site.

After the structure type and its dimensions have been selected, the mobility of the design bed material, stability of key particles in grade controls, and hydraulic capacity of the proposed structure are analyzed. The purpose of the bed mobility analysis is to determine if the initial bed material sizes selected are mobilized at the same flows as those in the reference reach. If they are not, the initial bed material sizes are increased until similar bed mobility between the design channel and reference reach channel is obtained (Figure 4). Bed mobility in the stream simulation design channel needs to be similar to that of the reference reach during low and moderate floods to ensure that excessive aggradation and degradation do not occur in the design channel.

The purpose of the bed stability analysis is to determine if the initial key feature particle sizes selected for the stream simulation design channel are stable for the design flood. Key pieces for features such as steps, riffles, and banks that are used to control channel form and flow hydraulics need to be stable for the design flood. This stability is important since the particle sizes of key features in the design channel are not easily replenished or replaced if mobilized. Banks for both low- and high-gradient channels are designed to be permanent for the design life of the structure. The stability of most natural banks is a function of the root structure of bank vegetation, the particle sizes and stratigraphy of the banks, and cohesive nature of the banks. Because vegetation growth inside the structure is not attainable, bank material must be sized appropriately to emulate the function of vegetation for bank stability in the design channel during the design flood discharge. From the results of the bed mobility and stability analyses, a final bed material gradation for the overall bed and the key pieces is determined and specified in the contract.

The proposed design structure is then evaluated to determine if it has sufficient hydraulic capacity and debris clearance during the design flood. Stream simulation design structures are required to have headwater-to-depth ratios less than 0.80. This requirement reduces the likelihood that pressurized flow will occur at the inlet and provides clearance for debris being transported during large-magnitude floods. Observations and analyses of stream simulation structures show that the headwater-to-depth ratio for the 100-year design flood discharge is typically less than 0.60.

Finalizing the engineering design for the contract includes specifying the road reconstruction and fill requirements, providing documentation outlining special contract provisions needed to control the size of bed material used and how it is placed in the design channel, providing details on how to protect aquatic species and water quality during construction activities, and specifying dewatering and pollution control plans.

Construction

The long-term success of a stream simulation project depends on the effective implementation of the design during construction. Successful implementation requires that those involved in construction have a solid understanding of the project objectives and critical design elements. Construction for a stream simulation design is somewhat different from other road–stream crossing design approaches because it involves building a three-dimensional channel bed. Precision in determining channel elevation control can be crucial to the success of the project, especially on steeper channels.

Installation of the physical structure of a stream simulation design is the same as that for any other road–stream crossing design and must be in accordance with the installation specifications of the selected structure. The most critical aspects of stream simulation construction are the placement and arrangement of the bed material, grade control features (e.g., steps, riffles), and banks (Figures 2*b*, *d*, and 5*a*). The material used to construct the stream simulation channel bed is built in multiple lifts or layers. The thickness of the lifts is a function of the larger particles in the bed gradation (D84- to D95-percentile particle sizes) since those sizes affect placement and compaction. The large particles used to construct the key features should be incorporated and embedded into the surrounding bed material. The bed material is compacted around the key features to help lock them in place. Proper channel-bed construction techniques include keying in the base of structural elements (steps, riffles, banks), interlocking and packing key particles against each other to maximize the stability of those features, incorporating smaller particles between the voids of larger particles to reduce bed permeability and achieve a dense interlocking channel bed, and conducting quality control measurements to ensure that the sediment sizes specified in the design are being used. Bed material must be well graded and contain a sufficient quantity of fines (generally between 5% and 10%) so that the voids between larger rocks can be filled. As lifts are compacted, fines can be jetted into the surface of the channel to effectively fill the voids throughout the constructed bed. If the bed material does not include enough fines, flows can infiltrate into the bed, unnaturally drying sections of the channel during critical low flow periods when aquatic species need to move. Experience has shown that the voids between large particles do not necessarily fill naturally over time.

Dewatering the construction area is an important step, and it can be challenging because some structures can take weeks or months to build. The dewatering system must accommodate any high flows that may occur during the construction period. Also, projects in habitat occupied by threatened, endangered, or other critical species often require special care in removing organisms that would otherwise be killed during construction. Dewatering of the channel needs to be done slowly to allow crews to catch and move aquatic species out of the construction area. Slow rewatering of the channel after construction is necessary to avoid releasing a pulse of sediment that could bury habitats and harm aquatic organisms downstream of the construction site.

Proper and successful construction of key features requires adequate oversight at multiple times to ensure that materials meet gradation requirements, particles are properly packed and interlocked, and voids are sufficiently filled with fines. Other critical aspects of construction that require oversight and inspection include foundation preparation, dewatering of the site, and material development. In addition, erosion and pollution control measures, traffic control, and public safety measures need to be in place at all times during construction.

LIMITATIONS AND CHALLENGES

Although the stream simulation approach can be used to assess and design most road–stream crossings where aquatic organism passage is an issue, there are environments that make achieving the objectives of stream simulation unlikely. These environments include

1. Unstable, incised channels downstream of road–stream crossings;
2. Road–stream crossings located on active alluvial fans;
3. Road-impounded wetlands that form sediment sinks upstream of road–stream crossings; and
4. Roads that cross channels prone to debris flows or other mass wasting events.

These types of environments are identified during the watershed review and site reconnaissance of the stream simulation design process. In these cases, the physical differences between the design channel and reference-reach channel may be too great to achieve the objectives of stream simulation. However, the collection of channel data and analyses performed during site assessment of the stream simulation process can be used to develop an alternative, geomorphic-based channel design that reconnects the upstream and downstream channel while meeting the needs of most fish and other aquatic organism movement.

Stream simulation requires critical inspection of the design channel when it is being built. The actual process of constructing a channel bed with bedforms, banks, and key features is new to many contractors and Forest Service personnel. In some instances, this lack of familiarity has resulted in improperly built design channels that are dissimilar to those in the adjacent natural channel and are possibly not providing passage for fish and other aquatic organisms at all life stages. Contract administrators and inspectors may require additional training to ensure that critical elements of the stream simulation design channel are built as specified in the contract.

Road–stream crossing structures designed with the stream simulation approach initially cost about 20% to 30% more than those designed with hydraulic design methods because the structures are wider and placed deeper below the channel bed, and a channel with bedforms and banks is built through the structure. However, stream simulation structures are anticipated to require little or no maintenance and last longer than structures designed using the hydraulic design methods, resulting in lower total costs over the service life of the structure. Monitoring and anecdotal information provided by field offices reports that stream simulation road–stream crossing designs have lower maintenance needs than the culverts they replaced.

SUMMARY

The stream simulation approach for designing road–stream crossing structures is applied on all Forest Service roads where restoring ecological continuity along the stream corridor is an objective. Since the turn of the century, the Forest Service has successfully designed and installed hundreds of road–stream crossings on national forests using the stream simulation approach. Although more time is needed to evaluate the long-term effectiveness of stream simulation designs, the Forest Service believes that the approach is a pragmatic and sustainable long-term solution to maintain passage for all aquatic organisms at all life stages at road–stream crossings while meeting vehicle transportation objectives. Moreover, the stream simulation design approach to road–stream crossings allows the Forest Service to meet requirements of not disrupting or obstructing the movement and habitat needs of aquatic species as outlined in the National Forest Management Act, the Endangered Species Act, and the Clean Water Act.

The stream simulation design approach at road–stream crossings integrates fluvial geomorphology concepts with engineering principles to design a natural and dynamic channel through the road–stream crossing structure. By using reference reach metrics in the stream simulation design channel, the morphology and hydraulic characteristics of the design channel should provide no greater obstacle to the movement needs of fish and other aquatic organisms occupying the stream. Because the dimensions and characteristics of stream simulation channels through the road–stream crossing are similar to those in the natural channel, stream simulation channels are capable of laterally and vertically adjusting to a wide range of floods and sediment or wood inputs without compromising the movement needs of fish and other aquatic organisms or hydraulic capacity of the structure. In addition, stream simulation structures are less susceptible to damage by high flows and debris blockage because they do not constrict the channel until flows substantially exceed bankfull flow conditions. More details and discussion on the stream simulation assessment, design, and construction process may be found in the 2008 Forest Service technical guide (*8*).

ACKNOWLEDGMENTS

The authors thank the many individuals who helped develop the stream simulation assessment, design, and construction techniques described in the Forest Service technical guide (*8*) on this subject. Specifically, the authors acknowledge the efforts of Kozmo Bates, Kim Johansen, and Scott Jackson, who made significant contributions to the Forest Service technical guide (*8*) and to the authors' understanding of the stream simulation concept and how to practically apply that concept at road–stream crossings. The authors also thank the reviewers of the original version of this manuscript, whose thoughtful comments helped improve the paper.

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The Committee for the 10th International Conference on Low-Volume Roads peer-reviewed this paper.

Citation reference only. Permission for re-printing has been applied for, though not yet received.

Fisheries

Volume 39, Issue 2, 2014

Flood Effects on Road-Stream Crossing Infrastructure: Economic and Ecological Benefits of Stream Simulation Designs

Preview: http://www.tandfonline.com/doi/pdf/10.1080/03632415.2013.874527#preview

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DOI:10.1080/03632415.2013.874527

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pages 62-76

Publishing models and article dates explained
Published online: 26 Feb 2014

ABSTRACT
Stream simulation design is a geomorphic, engineering, and ecologically based approach to designing road–stream crossings that creates a natural and dynamic channel through the crossing structure similar in dimensions and characteristics to the adjacent natural channel, allowing for unimpeded passage of aquatic organisms, debris, and water during various flow conditions, including floods. A retrospective case study of the survival and failure of road–stream crossings was conducted in the upper White River watershed and the Green Mountain National Forest in Vermont following record flooding from Tropical Storm Irene in August 2011. Damage was largely avoided at two road–stream crossings where stream simulation design was implemented and extensive at multiple road–stream crossings constructed using traditional undersized hydraulic designs. Cost analyses suggest that relatively modest increases in initial investment to implement stream simulation designs yield substantial societal and economic benefits. Recommendations are presented to help agencies and stakeholders improve road–stream crossings, including increasing coordination to adopt stream simulation design methodology, increasing funding and flexibility for agencies and partners to upgrade failed crossings for flood resiliency, and expanding training workshops targeting federal, state, and local stakeholders.

REDUCING LOCALIZED IMPACTS TO RIVER SYSTEMS THROUGH PROPER GEOMORPHIC SIZING OF ON-CHANNEL AND FLOODPLAIN OPENINGS AT ROAD/RIVER INTERSECTIONS

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November, 2013

DNR Stream Habitat Program website: http://www.dnr.state.mn.us/eco/streamhab/index.html
Publication: http://files.dnr.state.mn.us/eco/streamhab/geomorphology/reducing-rior.pdf

This guidance, one of several 2013 Permit fact sheets, is available at MPCA website:
http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/construction-stormwater/index.html

Perimeter control

National Pollutant Discharge Elimination System/State Disposal System Permit Guidance on the use of perimeter control

Silt fence used as perimeter control

Perimeter control is a method of sediment control best management practices (BMPs) that acts as a barrier to retain sediment on a construction site. Sediment control BMPs are intended to slow and hold flow, filter runoff, and promote the settling of sediment out of runoff, via ponding behind the sediment control BMP.

What is required by the National Pollutant Discharge Elimination System/State Disposal System Construction Stormwater Permit?

The National Pollutant Discharge Elimination System/State Disposal System (NPDES/SDS) Construction Stormwater Permit (Permit) requires that certain sediment control BMPs are utilized to minimize sediment from leaving a construction site. Some sediment controls, such as ditch checks, may be needed to promote sheet flow and prevent rills and gullies from forming on steeper slopes or ditch bottoms. The Permit also requires additional sediment controls to be utilized at the base of soil piles to contain sediment. Sediment controls located at down gradient boundaries of the construction site are referred to as "perimeter controls". The location and type of perimeter control BMPs, along with other sediment control BMPs required by the Permit, must be identified in the site's Stormwater Pollution Prevention Plan (SWPPP).

The perimeter sediment control BMPs must be established on all down gradient perimeters and up-gradient of buffer zones before any land disturbing activities begin. These BMPs shall remain in place until final stabilization has been established. If the down gradient perimeter controls are overloaded, additional up gradient controls may be necessary to prevent further overloading. The selection of perimeter control BMPs is the permittee's decision, but it must be effective at keeping sediment on the site. If it is determined through inspection that the selected method is not effective, then the BMP must be upgraded to a method that is effective at keeping sediment on the site.

The timing of the perimeter control installation may be adjusted to accommodate short term activities such as clearing and grubbing, and passage of vehicles. This means these BMPs may be taken down as necessary to allow vehicle on and off areas of the site or to allow work such as utilities to be installed through the perimeter BMP. These short term activities must be completed as quickly as possible and the perimeter control BMPs must be reinstalled immediately after the activity is finished. All perimeter control BMPs, however, must be in place before the next precipitation event, even if the activity is not complete. For full details of the Permit requirements, a copy of the NPDES/SDS Permit can be found at www.pca.state.mn.us/water/stormwater/stormwater-c.html.

Types of perimeter sediment control

Silt fence is a commonly known method of perimeter control. However, other types of perimeter controls exist that can be equally or even more effective depending on the construction site circumstances. The following sediment control BMPs are commonly used as perimeter control on construction sites of all sizes:

- ditch checks
- rock logs
- compost berms, logs, and rolls
- biorolls
- sand bags
- vegetated or stabilized soil berms
- geotextile wrapped jersey barriers
- existing vegetation
- silt fence
  - super duty
  - heavy duty
  - preassembled

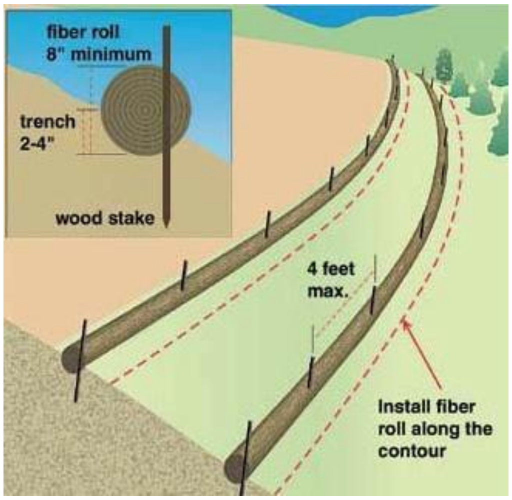
Planning perimeter sediment control

Perimeter controls should be planned as a system, taking the entire site into consideration and installed prior to any land disturbing activity, and only need to be installed in locations down gradient of the construction. The design of a site's perimeter control system should anticipate ponding that will occur up gradient of the controls and provide sufficient storage and deposition areas and stabilized outlets to prevent flows from over topping the controls. The SWPPP must account for the following factors in designing the temporary erosion prevention and sediment control BMPs including perimeter controls:

1. The expected amount, frequency, intensity, and duration of precipitation.
2. The nature of stormwater runoff and run-on at the site, including factors such as expected flow from impervious surfaces, slopes, and site drainage features.
3. If any stormwater flow will be channelized at the site, the Permitte(s) must design BMPs to control both peak flow rates and total stormwater volume to minimize erosion at outlets and to minimize downstream channel and stream bank erosion.
4. The range of soil particle sizes expected to be present on the site.

Flows should be strategically directed to specified deposition areas through appropriate positioning of the perimeter controls and site grading. Sometimes additional perimeter controls need to be added or moved to different locations on a project as conditions change. For example, perimeter control is installed above street curbs once the curb and gutter system is installed to keep sediment out of the water conveyance. Some perimeter controls can be relocated as needed, such as biorolls, rock logs, sand bags, and triangular silt dikes. Keeping a vegetated buffer between disturbed areas on a construction site and the down gradient perimeter control BMP can help the BMP perform better and need less maintenance.

Perimeter control BMPs serve no function along ridges or drainage divides where there is little movement of water. Perimeter controls should be installed on the contour of slopes, and the ends of the BMP should bend up slope forming a crescent shape or a "J- hook" rather than a straight line. This will prevent runoff from flowing around the ends of the controls.



Install biorolls or other sediment controls along the contour of the slope.

"J-hooked" silt fencing

Maintenance considerations

The NPDES/SDS Permit requires that all BMPs are inspected once every seven days or within 24 hours of a rainfall event greater than 0.5 inches in 24 hours. All non-functioning BMPs must be replaced, repaired or supplemented with functional BMPs within 24 hours of discovery or as soon as field conditions allow access. Generally, sediment controls must be repaired, replaced, or supplemented when they become nonfunctional, or sediment reaches 1/3 the height of the control.

After the contributing drainage area has been stabilized, all sediment controls and the associated sediment build up must be removed and disposed of properly. Care should be taken to dispose of sediment in a location that is not susceptible to erosion.

Cold weather considerations

It is important to consider winter conditions when planning a perimeter control system. All construction sites must remain in compliance with the NPDES/SDS Permit throughout the winter even if no construction is occurring. It is imperative that properly functioning sediment controls are in place during minor thaws and for the large spring snowmelt to prevent transport of sediment to area surface waters. For this reason, the BMPs must be installed and functional prior to winter freeze up. The BMPs must be inspected and maintained immediately following intermittent snow melt or rainfall that occurs in winter months. If construction resumes during the winter, then the weekly inspection schedule must also resume.

Regular maintenance is needed to ensure that a site's perimeter control is functioning properly.

The best way to ensure proper functioning of perimeter controls throughout the winter is to have all sediment controls installed prior to the first freeze. Stakes needed for some sediment control BMPs will be difficult, if not impossible to install into frozen ground. The site's SWPPP should clearly outline the strategy to prepare the site for the winter months.

If construction is going to continue during the winter and new areas will be disturbed that requires new sediment controls; materials such as compost berms, logs and rolls, fiber rolls, rock bags and rock filters can be installed over the snow cover. These installations will need extra care and frequent inspections to assure continued effectiveness.

Use of down gradient perimeter sediment control for work in or near open water

It is critical to ensure down gradient perimeter controls are utilized during work on stream banks and lake shores to keep sediment from washing into open water. Sediment discharges resulting from this type of construction can result in enforceable water quality violations.

Sites that include work in public waters permits from the Department of Natural Resources (DNR) that also have coverage under the Minnesota Pollution Control Agency's (MPCA) general construction stormwater permit are required to comply with the conditions in both permits, including the use of down gradient perimeter controls to minimize sediment discharges.

More specialized types of sediment control BMPs may be needed to protect surface waters during construction that extends below the water surface. Whenever possible, work below the Ordinary High Water table (OHW) should be done in a manner that keeps water out of the work area, or separated from flowing water. For example, coffer dams made of sheet pilings or other materials to isolate the work from the water or water diversions to divert water around the work area may be the best choices during bridge construction or any work that encroaches into open water.

Coffer dams made of sheet metal to isolate the work area from the surface water.

Biorolls, rock logs, sand bags, triangular silt dikes, geotextile wrapped jersey barriers or stabilized soil berms that can easily be relocated may be best during stream bank restoration work. The perimeter control method may need to change as work changes at the site. Therefore, multiple perimeter control methods may be employed at one site at different times or at the same time.

If the work is conducted on an MPCA designated special water, such as a trout stream or scenic and recreational river segment, redundant BMPs must be employed when an existing 100 foot buffer is encroached. In this case, more than one method of perimeter control is employed or a super duty perimeter control method may be required to adequately protect the surface water.

Protection of wildlife

Perimeter controls have been known to trap amphibians, reptiles, and small mammals within a construction area. Of concern is the inadvertent harm to rare species. Inspectors of perimeter controls should move rare species out of harm's way if they appear trapped or are in imminent danger. If not in danger, they should be left alone. In areas of known rare species populations, silt fence may also be helpful in keeping these animals out the construction area. In all cases it is critical that silt fencing be removed after the area has been re-vegetated. More information on Minnesota's rare species can be found on the DNR website: http://www.dnr.state.mn.us/ets/index.html.

Floating curtain is not perimeter control

Frequently, floating silt curtains are employed during work in water. However, it is important to note that floating curtains will not satisfy MPCA's NPDES/SDS Permit requirement for down gradient

Relying on floating curtain as down gradient perimeter control will result in permit violations for failure to install sediment control and in most cases will result in water quality violations.

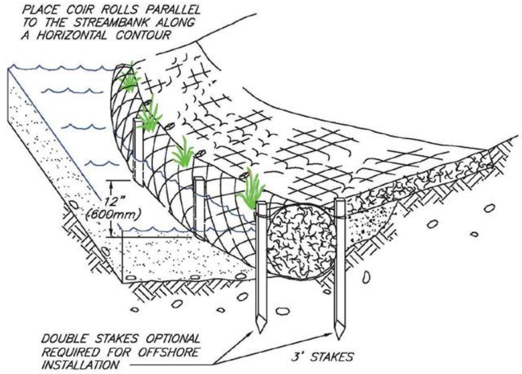
perimeter control. Even if a floating curtain is utilized, down gradient perimeter control must still be installed between the work and the surface water to prevent sediment from entering the surface water. A nuisance condition (as described in Minn. R. 7050.0210 sub. 2) caused by allowing sediment runoff into the water body is a water quality violation.

Floating silt curtain is not designed to prevent sediment from entering surface water. It is designed to help contain suspended sediment within the water column until it has settled to the bottom of the water body. Therefore, floating curtain's only use may be for work that cannot be done outside the water or as a secondary containment to minimize the impact of a water quality violation and keep the damage to the water body near the shore and the sediment recoverable.

Use floating silt curtain for work in the water as secondary containment to contain sediment close to the work area.

Proper placement of perimeter sediment controls near water

Perimeter controls need to be installed before upgradient work begins. The perimeter control should be placed at the water's edge during work on the bank or shoreline. If possible, vegetation should be left between disturbed areas and the sediment control BMP. As work is completed on the bank and the bank is fully stabilized, the perimeter controls can be moved upward away from the water's edge above the vegetated or rip rapped areas.



Fiber roll installation at shoreline.

Move perimeter controls up the bank as the bank is stabilized.

Additional resources

Additional information on the use of perimeter controls; including use of floating silt curtain, water diversions, coffer dams and other perimeter control BMPs for work in or near waters as well as all other applications can be found in the *MPCA Protecting Water Quality in Urban Areas – Manual* http://www.pca.state.mn.us/index.php/view-document.html?gid=7157.

Minnesota DNR species protection information http://files.dnr.state.mn.us/waters/watermgmt_section/pwpermits/gp_2004_0001_chapter1.pdf.

MPCA Stormwater Construction Inspection Guide http://www.pca.state.mn.us/publications/wq-strm2-10.pdf.

United States Environmental Protection Agency NPDES Menu of BMPs –Construction Site Sediment Control – *Silt Fences* http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=56&minmeasure=4.

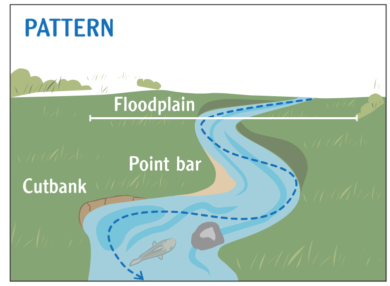
Understanding Our Streams and Rivers

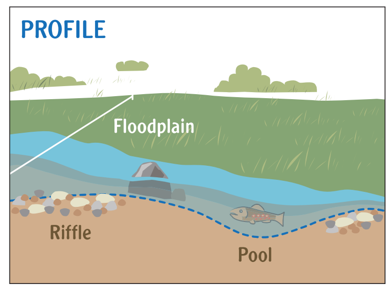
Are Minnesota Streams Healthy?

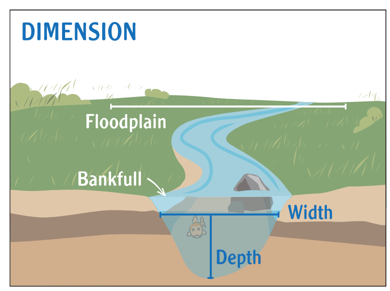
Just as our human health is determined by the factors that influence our bodies, including environment, lifestyle, and healthcare, so too is stream health determined by the combined factors of the stream's configuration, environment, resilience, and our stewardship. A stream, like the human body, has several interdependent features that indicate health of the stream. These features can be grouped into the following **five** components: *shape*, *flow*, *connectivity*, *biology*, and *water quality*.

1. Stream shape

A stream's shape is formed over time through the continuous interaction between water and the watershed, including its size, climate (wet or dry), topography, soil types, and vegetation. The channel is shaped by the predominant floodflow, known as *bankfull* flow, in which the water fills the banks and just begins to overflow onto the floodplain. Natural streams of all types and sizes have a tendency toward a balanced, stable state. In this state, streams transport water and sediment and dissipate the water's energy while maintaining over time their shape: pattern, profile, and dimension (see graphics at right). In other words, when erosion and deposition and scour and fill are balanced, the channel does not widen or narrow, nor does the streambed rise (*aggrade*) or deepen (*degrade*).



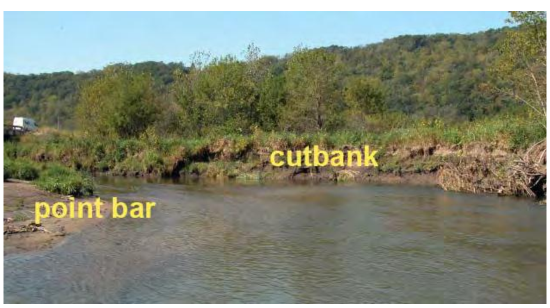




This does not mean a stream channel's position is permanent; instead, the channel is able to adjust over time as the bends, or meanders, of the channel slowly migrate down the valley. Naturally shaped streams provide aquatic organisms a variety of habitats, like *riffles* (shallow, rocky rapids), pools, sandbars, and backwaters, because of variations in stream depth, width, water currents, and streambed materials.

2. Streamflows

Streamflows vary seasonally and interannually depending on snow melt, rain-on-snow events, growing season rains, drought, and climatic changes such as increasing temperatures. Variations in seasonal and annual precipitation yield a range of flows that are fundamental to sustaining river ecosystems. Aquatic organisms such as spawning fish have evolved to these seasonal cues. Streamflows are also altered by land-use changes, from agriculture and urbanization to timber harvest. These changes generally inhibit infiltration of precipitation into the ground. Reduced infiltration increases runoff, which increases the volume of water that streams must transport, resulting in stream instability and excessive erosion.



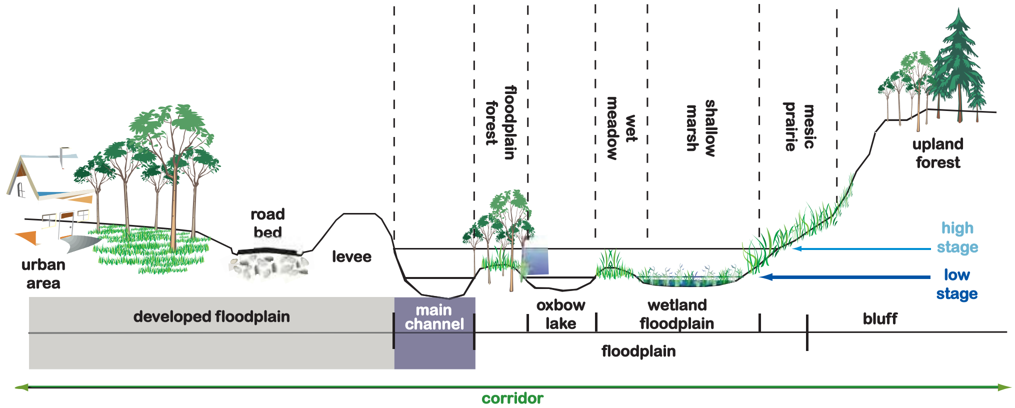
Streamflow is faster along the outer bend of a stream and will erode a streambank lacking stabilizing native vegetation, creating a cutbank. Excessive erosion increases the sediment load of the stream. Streamflow is slower on the inside of the bend, which allows sediment to settle and form a point bar.

In the stream channel, flows vary because of stream features such as *sinuosity* (curving shape), width, depth, and bed and bank materials (e.g., sand, gravel, boulders, vegetation). For example, flows are faster along the outside of bends and slower along the inside of bends. Consequently, strong erosional forces along outside bends form pools, or scours, and cutbanks if the banks are weak; slower flows along inside bends deposit sediment, forming point bars (see photo at left). Streams create bends to reduce the speed of the flows just as a downhill skier carves from side to side down the hillside. Also like a skier gaining speed, the tighter the turns, the deeper the scours or pools left by the streamflow. The strongest streamflow generally follows the *thalweg* (deepest part of the channel), travels from pool to pool or bend to bend, and crosses from one side of the channel to the other depositing sediment, which creates riffles.

3. Stream connectivity

Fragmenting streams with dams and culverts disrupts the *longitudinal connectivity* of a stream. Uninterrupted flow along the entire length of the stream is essential for the proper flow and exchange of water, energy, sediments, nutrients, and organisms. Structures that fragment streams disrupt the progression of stream habitats from small, shaded, rocky, steep headwater streams to large, sandy, flat, warm, slow-flowing valley streams.

Lateral connectivity between the stream channel and its floodplain is crucial to stream health and stability. Floodplains play an important role because this land reduces the floodwater's energy with plants and trees and provides temporary storage space for floodwaters and sediment. Floodplains also provide habitat for various plant and wildlife communities, some of which depend on flood events to reproduce and grow. Floodwaters nourish floodplains with sediments and nutrients and provide temporary aquatic habitat for invertebrate communities, amphibians, reptiles, and spawning fish.



Lateral connectivity: The stream is connected to its floodplain on the right but is disconnected on the left by development. At various stream stages, the stream and its floodplain provide a range of habitat settings.

4. Stream biology

Streams are complex networks of terrestrial and aquatic communities. Streams and their floodplains provide diverse habitats including uplands, riparian zones (streambanks), floodplain forests, marshes, fens, oxbow lakes, riffles and pools. The diverse habitats and their plant and animal species are key to maintaining healthy ecosystems.

Terrestrial plants, aquatic plants, and aquatic animals in the stream are important to the stream's health. Terrestrial plants in the floodplain and riparian zones strengthen and stabilize the soil; intercept runoff; filter out nutrients, sediment, and other pollutants; and provide habitat. Similarly, aquatic plants protect the shoreline, stabilize the streambed, are a food source, provide refuge, absorb nutrients and contaminants from the water, and produce oxygen. Aquatic animals such as freshwater mussels are important to aquatic systems because they stabilize the streambed by anchoring themselves into the sediment, clean the water of particles and chemicals during their feeding process, and are a source of food and habitat for fish and invertebrates. They also use fish as hosts for their larvae, relying on fish health, abundance, and migration for dispersal. This demonstrates the interconnections of aquatic systems.

5. Water quality

Water quality includes the chemical, biological, and physical characteristics of water. Good water quality is maintained by natural channel shapes and flows, naturally vegetated riparian zones, a healthy biological community, and proper stewardship. The most common pollution sources in Minnesota are sediment, herbicides, insecticides, industrial chemicals, sewage effluent (outflow), and fertilizers. Some of these sources such as industrial and sewage effluent are point sources, which are identifiable, local sources that are relatively easy to monitor and regulate. Others are nonpoint sources such as herbicides and fertilizers, which are contaminants from sources that are much harder to assess and regulate.

Healthy stream systems ensure good water quality and are paramount to human and ecological health. This crucial resource provides drinking water from lakes and rivers for many cities, in addition to habitat for wildlife, fish, and aquatic organisms, some of which are valuable food sources.

Freshwater mussels are sedentary, long-lived (some more than 100 years) mollusks that nestle in sediments while filtering particles and oxygen from the water to feed and breathe. Mussels are vulnerable to stream habitat disturbances (dams, channelization, pollution, exotics) and are good biological indicators of stream health. They are one of the most endangered animals in North America.

Naturally vegetated streambanks protect streams and stream organisms. Desirable woody vegetation includes willow, cottonwood, and dogwood. Beneficial forbs and grasses include monkey flower, blue vervain, fox sedge, swamp milkweed, and river bulrush.

How do stream alterations affect the five components of stream health?

Structures in a stream, such as dams and culverts, and some land use practices in a watershed can significantly affect the five components of natural, healthy streams: shape, flow, connectivity, biology, and water quality.

How structures affect stream health

1. **Shape**: Dams, culverts, and handmade structures alter the natural stream pattern, dimensions, and profile. The water flowing over a dam is "sediment hungry," leading to scouring or down cutting the streambed and erosion of streambanks. Dams also create unnatural reservoirs upstream that slowly fill with settling sediment.
2. **Flow**: Dams and improperly sized or placed culverts limit the flow of water, energy, sediments, and nutrients downstream. These structures also lock the channel in place, which restricts the stream from adjusting to maintain stability.
3. **Connectivity**: Dams and perched culverts create barriers that disrupt the flow downstream and prevent fish migration upstream to spawning, over-wintering, or other habitat areas. Levees and dikes disconnect the channel from the floodplain, forcing the channel to carry floodflows.
4. **Biology**: Dams create reservoirs or impoundments that initially flood and eventually bury critical wildlife habitat. Dams and levees also disrupt the flow and exchange of material longitudinally and laterally on which biological communities depend.
5. **Water quality**: In the upstream reservoirs, contaminants and nutrients accumulate, which ultimately degrades water quality.

Dams and culverts: (above) A handmade dam disconnects fish from upstream migration and alters the stream flow. (below) A perched culvert also inhibits fish passage and disrupts the longitudinal connectivity of the stream.

How land use practices affect stream health

1. **Shape**: Digging ditches converts headwater streams into unstable straight trenches and increases the stream slope. This leads to excessive erosion upstream and sediment deposition downstream of the ditched area. Removal and degradation of natural riparian vegetation weakens streambanks, resulting in excessive erosion and ultimately a change in stream shape.
2. **Flow**: Irrigation from streams can lower stream flows to potentially critical levels, especially during dry periods when water levels are low and aquatic communities need refuge. Urbanization and tiling on farmland funnel excess rainwater directly into streams, forcing the streams to carry higher, flashier flows.
3. **Connectivity**: Connection to the floodplain is commonly degraded or removed. Floodplains converted to farmland, pasture, or developments do not effectively dissipate or store floodwaters. Riparian zones that are farmed, mowed, grazed, deforested, or developed replace natural and diverse vegetation with crops, lawns, bare soil, and pavement.
4. **Water quality, and 5. Biology**: Excessive erosion of topsoil commonly degrades water quality, primarily by decreasing water clarity. Field and lawn fertilizer and manure inputs add excess nutrients to streams, causing extreme plant and algal growth followed by decomposition that extracts oxygen from the water. Pesticides, herbicides, and insecticides have been found at dangerous levels in streams. Research indicates that these chemicals kill aquatic organisms, inhibit reproduction, and upset hormones in animals in addition to a multitude of adverse physiological effects.

Land use: (above) Parking lot runoff, (below left) eroded fields, and (below right) unvegetated ditches transport pollutants and excess sediment to streams.

To what extent have we disturbed Minnesota streams and watersheds?

Reconnecting the Red River: Since the early 1800s, more than 500 dams have been built on the Red River of the North and its tributaries. Lake sturgeon could no longer migrate to critical spawning habitat in the higher gradient tributaries. By the mid-1900s, the sturgeon were gone, victims of a fragmented river that no longer provided the habitat the fish needed to reproduce. The DNR is working with local communities to "reconnect the Red" by removing or modifying dams into artificial rapids. This has successfully opened hundreds of miles of streams to migrating fish.

Minnesotans take great pride in and enjoy the state's 92,000 miles of large and small streams. However, throughout our history, humans have had a growing impact on our streams and watersheds due to a booming population and technological advancements. The following are a few examples of the extreme changes that have degraded stream health in Minnesota:

- Nearly one-third of the streams have been converted to ditches.
- Nearly 18,000 miles of tile are added to farmland in Minnesota every year. That is nearly three-fourths of the circumference of the earth.
- More than 900 dams greater than 6 feet in height and hundreds of smaller (low-head) dams have been built on Minnesota streams.
- More than 56 percent of the landscape has been converted from native prairies, wetlands, and forests to farmland and urban areas.

These land-use changes and resulting changes in stream shape lead to excessive streambank or streambed erosion and degraded stream health. These impacts, in addition to climate change, lead to increased erosion and deposition, altered hydrology, more frequent and destructive flooding, degradation of aquatic and riparian habitat, and decrease in species diversity. Moreover, these effects have huge economic impacts. In the deep loess soils (highly erodible, windblown fine sediments) of western Iowa there has been an estimated $1.1 billion in damage to private and public infrastructure due to channelization and ditching. In Minnesota, flowing water carries off more than 60 million tons of upland topsoil each year. That amount would fill the Metrodome with topsoil 21 times every year. Consequently, stream stability is crucial to our environment and our own well being.

(above) *Buffered*: The vegetated buffer along the Pelican River decreases the contaminants and sediment carried by runoff to the stream. (below) *Unbuffered*: The South Branch of the Buffalo River lacks such protection from runoff.

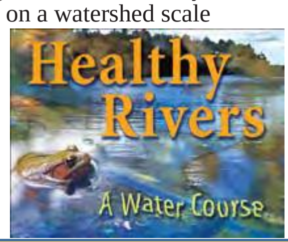
How can you and the community correct stream disturbances and improve stream health?

As individuals, riparian landowners can restore, protect, and maintain naturally vegetated riparian buffers and floodplains realizing that rivers are dynamic. However, many stream health problems are the result of widespread land use issues. In these cases, communitywide efforts are needed for recovery to begin.

Watershed planning engages citizens, landowners, businesses, local governments, interest organizations, and other agencies. Watershed protection and planning becomes effective through cooperation toward long-term goals like improving water quality, reducing surface runoff, reducing soil loss, improving habitat, restoring natural biodiversity, and allowing for sustainable development. Furthermore, focusing on a watershed scale makes it easier to integrate social, economic, and cultural factors into planning and implementation efforts.

Additional information

The Healthy Rivers instructional CD and resource sheets on stream health, such as techniques to stabilize a streambank, are on the DNR web site. Research sources are available on request.



DNR Contact Information

DNR Stream Habitat Program is described on the Ecological Services website:
http://mndnr.gov/eco/streamhab
The DNR Waters website:
http://mndnr.gov/waters

DNR address in St. Paul:
500 Lafayette Road
St. Paul, MN 55155
DNR Ecological Services: (651) 259-5100
DNR Waters: (651) 259-5700

DNR Information Center

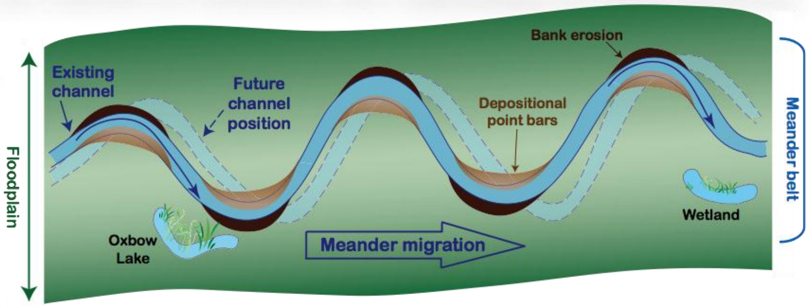
Twin Cities: (651) 296-6157
Minnesota toll free: 1-888-646-6367
Telecommunication device for the deaf (TDD): (651) 296-5484
TDD toll free: 1-800-657-3929

Stream Habitat Program

Resource Sheet 1: Streambank Erosion and Restoration

Why is my streambank eroding?

In order to determine why a streambank is eroding and to develop a restoration approach, it is necessary to understand stream behavior. All streams are dynamic, gradually changing shape as they erode, transport, and deposit sediment. A natural stream will have slowly eroding banks, developing sandbars, migrating meanders, and channels reshaped by flood flows. They are in a state of *dynamic equilibrium*, where the stream is able to maintain a stable shape (dimension, pattern, and profile) over time without excessive erosion or sedimentation even as natural changes or artificial changes occur in the watershed (see informational sheet Understanding Our Streams and Rivers). A stream system maintains this dynamic equilibrium when its natural flexibility and a functional connection to the floodplain are preserved (see figure).



A natural, healthy stream channel meanders from bend to bend within a *meander belt*. This meandering (seen here from above) is known as the stream's *pattern*.

Many streams are artificially confined; consequently, they cannot adjust or regain their equilibrium within their meander belt or floodplain after a disturbance. Streams are increasingly confined by agriculture, infrastructure, and development in the floodplain. When ditches and levees, roads, bridges and culverts, rock revetments, and other structures are placed in the floodplain, the state of dynamic equilibrium is interrupted. Confined streams can no longer self-mend, which results in instability where bed and bank erosion is a common consequence.

Land use change and channelization: The floodplain and stream corridor are impinged by agricultural fields. The meanders are disconnected after straightening by channelization.

Common causes of stream instability

Land use changes

Land use activities throughout the watershed lead to stream instability by changing the watershed's *hydrology*. Land use changes force a stream to adjust to changes in *discharge*, water *velocities*, or *sediment load*. For example, both urban storm drains and agricultural tile funnel rainfall quickly and directly into streams. These practices dramatically increase the peak discharge and water velocity of a stream. Additionally, this direct flow is low-sediment or "sediment-hungry" runoff and is very erosive. Another land use change that impacts hydrology is draining wetlands. By removing natural water storage, streams are further burdened with water that is no longer retained on the landscape. Consequently, affected streams are unstable, usually degraded and incised, and must eventually adjust their shape to accommodate the flashy discharge events with un-naturally high peak flows.

Vegetation changes

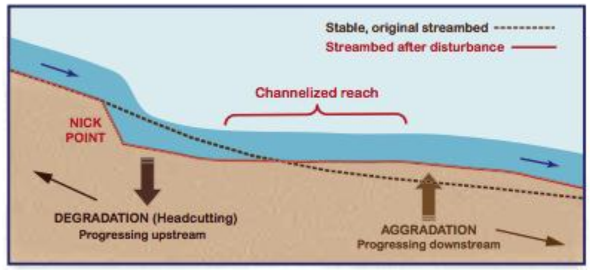
Streambank instability, erosion, and bank failure also result from a lack or loss of natural vegetation along streambanks. Deep, dense-rooting, and flood-tolerant native plants strengthen and stabilize the banks and slow floodwaters. (See additional benefits explained in Resource Sheet #2.) The loss or degradation of natural riparian vegetation can be caused by livestock overgrazing, row crops without vegetative buffers, herbicide applications, deforestation, or development. Once streambanks are degraded the potential for accelerated erosion is greatly increased because the banks are weak and unstable. Common practices of repairing banks with riprap are expensive, less stable, and lack the biological benefits of a vegetated bank.

Definitions:
aggradation*: rising streambed, sedimentation*
degradation*: lowering streambed, erosion*
discharge*: volume of water carried by a stream per unit time*
headcut*: downcutting of streambed in upstream direction*
hydrology*: movement of water through the hydrologic cycle*
nickpoint*: sudden change in the slope of the streambed*
sediment load*: amount of sediment carried by a stream*
slumping*: block(s) of bank slips down*
velocity*: speed of flow*

Resource Sheet 1: Streambank Erosion and Restoration

In-channel changes

In-channel alterations of stream shape directly disrupt stream balance resulting in *aggradation* and *degradation*. For instance, ditching or channelizing a stream replaces a long, sinuous stream reach with a short, straight, smooth channel. Such a change steepens the slope and removes roughness from the streambed. The sudden increase in speed and erosive energy of the streamflow will degrade the streambed within the straightened reach. Upstream the channel will begin to incise at the *nickpoint*. This forms an active *headcut* that migrates upstream (referred to as headcutting). Over time, the streambed continues to deepen and the entire stream reach becomes incised and disconnected from its floodplain.



In-channel changes: As shown in this side view, channelizing a stream may cause headcutting upstream and aggradation downstream.

The effects of channelization are widespread and impact the entire stream network. A headcut can initiate headcuts in the tributaries. This leads to excessive erosion and instability upstream into the basin. As excessive sediment is released into the stream system, the instability will extend downstream as the newly eroded sediment aggrades in flatter valley reaches.

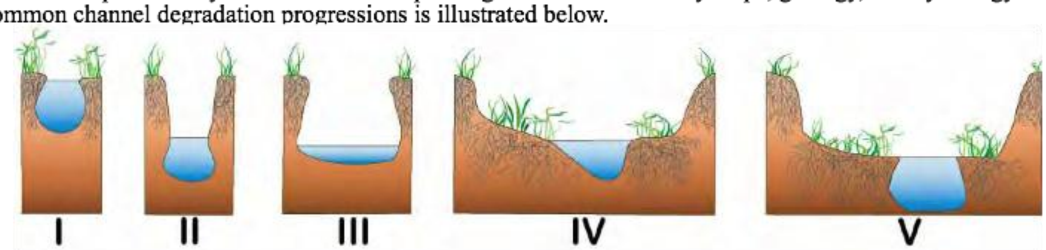
In-channel structures such as dams, bridges, and culverts interrupt the natural stream shape by creating unnatural reservoirs or passageways. For instance, culverts are commonly too small, set improperly, and do not emulate the natural channel pattern. Stream instability is the result as demonstrated by flooding upstream and erosion downstream of these structures.

Headcut & nickpoint: An active headcut degrades the bed of an Illinois stream.

Stream responses to disturbances

A disturbance such as ditching, development, or deforestation that changes the hydrology, stream shape, or riparian vegetation causes a stream to lose its equilibrium. When a stream is in disequilibrium, the stream channel actively adjusts toward a more stable form by going through transitional phases. Channel evolution can progress through many phases, where each phase could persist for years to centuries depending on stream and valley slope, geology, and hydrology. One of the more common channel degradation progressions is illustrated below.

Channel evolution



I. A properly shaped stream in **equilibrium** and connected to its floodplain prior to disturbance.
II. Channel incision from ditching or by a headcut originating in a channelized reach due to increased slope and flow.
III. Channel widening as the channel begins to meander again.
IV. A more properly shaped stream as it evolves to re-establish equilibrium and rebuild a new floodplain.
V. A new, properly shaped channel in equilibrium with a lowered floodplain.

The first section below describes an undisturbed stream in equilibrium. The next three sections describe common responses to stream instability after a disturbance. These responses vary greatly in extent and duration depending on the disturbance and the channel's recovery potential.

Equilibrium

A stream in equilibrium (Stage I in Channel evolution figure above) can transport water and sediment and dissipate the water's energy while maintaining its shape over time without excessive degradation or aggradation. A stream channel in equilibrium has these shape features:

- Pattern: a sinuous pattern that increases the stream's length, thereby decreasing its gradient and stream flows
- Profile: an alternation between riffles that help control stream gradient and pools that absorb the water's energy
- Dimension: the proper width and depth to effectively transport water and sediment supplied by the watershed

Furthermore, the channel is connected to the floodplain during high flows, the riparian zone is well vegetated, and the channel is not confined throughout the meander belt. As a result, channel movement (meander migration) and streambed and streambank erosion are minimal.

Channel incision

When a channel is incising (Stage II in Channel evolution figure), the streambed is actively eroding, downcutting, or degrading in response to disturbances such as:

- changes in the watershed (urban stormwater drains, ditching, tiling, draining wetlands) that introduce higher volumes of water or low-sediment ("sediment hungry") runoff,
- erosion by low-sediment water flowing over a dam or out of a reservoir,
- improperly sized or placed bridges or culverts that constrict flow and effectively act as dams,
- increased streamflow velocities because of disturbances such as channelization or urbanization, or
- a headcut that originated downstream.

An incised channel is disconnected from its floodplain. During high flows, the channel must transport the total volume of water because it cannot access the floodplain that, under natural conditions, could store and slow down the floodwaters. The banks of an incised channel are actively eroding (see Channel widening, below). Consequently, excessive erosion of the streambed and streambanks occurs and often results in long-term instability. As degradation continues, streambank heights and angles increase, which further reduces bank stability resulting in weak banks prone to failure and *slumping*.

Channel widening

Channel widening is lateral erosion of the streambanks (Stage III in Channel evolution figure). It can be caused by one or more of the following: channel incision; scour below culverts, bridges, or dams; flood flows in incised channels; weakened banks; increased streamflows due to watershed changes; aggradation; or construction of over-wide channels.

Channel widening occurs in an incised or scoured stream reach that attempts to find a new equilibrium by reforming and amplifying meanders to decrease the slope of the streambed and stream velocities. Also during this process, developing point bars establish a new floodplain that corresponds to the channel's new, lower streambed elevation. (For more detail, refer to the MN DNR website for the brochure, "The Shape of Healthy Rivers.")

Restoration philosophy

Incision is a common stream channel condition in Minnesota due to the prevalence of activities such as ditching and draining wetlands. It is also a systemic problem that results in stream instabilities throughout the watershed. During this response stage the channel will continue to unwind (degrade) until a new equilibrium is established. To reach equilibrium, the channel will go through successional stages that erode the banks to develop meanders, rebuild a new floodplain, and develop a properly sized channel that can effectively transport water and sediment. This process can be advanced artificially by constructing a properly shaped channel with a new lowered floodplain. Another method involves installing riffles and rock weirs that incrementally elevate the streambed to reconnect the channel to the original floodplain. These structures, unlike check dams, maintain sediment transport and are submerged during a bankfull event.

Widening is a successional stage following incision or aggradation when the channel is in disequilibrium. Restoration approaches depend on the cause, the extent of incision or aggradation, and future impacts. A restoration design could include the following:

- address upstream impacts by restoring upstream reaches (e.g. replace improperly placed culverts),
- restoring riparian vegetation,
- installing woody material and structures to add roughness, narrow the channel, and protect the banks,
- reshaping cutbanks with a bankfull bench,
- installing tree or rootwad revetments,
- excavating a properly shaped channel, or
- excavating a new floodplain.

Aggradation in Minnesota most commonly occurs downstream of channelized reaches. To re-establish equilibrium, an aggraded stream reach must develop a properly shaped channel (sinuous, deep, and narrow) through the aggraded sediment, which becomes the new floodplain. A restoration approach would be similar to that described above for an over-wide channel and similarly would depend on the cause, the extent of aggradation, recovery potential, and future circumstances.

(left) *Incision*: Extreme field erosion and an active headcut resulting from unbuffered runoff. (right) *Aggradation*: Downstream of the headcut, the flow of water slowed where the terrain flattened and deposited sediment, forming a delta.

Channel aggradation

Channel aggradation is the raising of the streambed elevation as sediment is deposited from upstream erosion along the flatter valley reaches, making the channel too shallow or over-wide. An aggraded stream reach will continue to fill and widen because the channel dimensions are out of balance with the amount of sediment that needs to be transported by the stream. More sediment settles out, further aggrading the stream bed. The channel becomes increasingly shallow, water extends laterally and erodes the banks, and stream flows more readily cause flooding.

Resource Sheet 1: Streambank Erosion and Restoration

What are the steps to address streambank erosion?

Extreme streambank erosion indicates an unstable, unhealthy stream. The instability stems from a change in the stream's shape, flow, or connectivity (see info sheet Understanding Our Streams and Rivers). These changes can be direct (ditching, dredging, straightening, dams) or the results of land use changes within the watershed (degradation of natural riparian vegetation, urbanization, logging, agriculture). Explained below are the recommended steps for restoring an eroding streambank with naturally designed approaches.

Identify the underlying cause

The first step is to determine the cause of stream instability. Are there disturbances in or along the stream; or are there destabilizing activities in the watershed? Individual landowners may not be able to control activities in a watershed that affect a stream, but landowners and citizens can have a voice in promoting and advocating natural channel design. In any situation, restoration and protection of natural riparian zones is a positive step for landowners to take to prevent or reduce streambank erosion and promote good stewardship of the watershed.

Additional adverse impacts to stream health

Channel incision, widening, and aggradation not only affect stream **shape** and **flow** but also degrade the other components of stream health:

- **Biology.** Loss and degradation of aquatic and riparian habitat (e.g. sedimentation in riffles and pools, degraded riparian vegetation).
- **Water quality.** Higher turbidity and nutrient concentrations from erosion and land inputs. Warmer water temperatures in aggraded reaches and in reservoirs.
- **Connectivity.** Disconnection from floodplain habitat (lateral) in incised streams. Disconnection from upstream and downstream reaches (longitudinal) due to dams and culverts. Increased flood risk in aggraded streams.

Adopt a natural design approach

Below is a list of recommended designs and approaches that can be used in combination to stabilize the soils in a streambank, protect the banks and floodplain, accelerate recovery, and ultimately restore stream stability. The keys to a successful bank stabilization project are:

- Allow the stream to maintain its dynamic equilibrium by not confining the channel.
- Design streambank structures to temporarily protect the banks while they stabilize.
- Consider future watershed conditions in a project design to assess how the stream will need to adjust with time.

The structures and materials listed in the box below are explained in more detail in following resource sheets.

Natural design approaches

Landscape scale
- Preserve and re-establish natural riparian and floodplain vegetation buffers
- Re-establish and protect the floodplain with compatible land use practices

Streambank stabilization and protection *(Resouce Sheet #2)*
- Vegetation: seed or plant native, deep-rooting vegetation on banks
- Biodegradable erosion-control blankets or hydroseeding
- Brush mattresses
- Biologs, wattles, or fiber rolls
- Tree revetments
- Toe wood-sod mat

In-stream bank protection
- Root wad revetments
- Bankfull bench
- J-hooks and rock vanes

Grade control (to decrease slope and reconnect channel to floodplain)
- Riffles and rock weirs

Large-scale restoration
- Re-meander straightened reach
- Remove or modify dams or improperly place culverts
- Excavate properly shaped channel
- Excavate new floodplain
- Reestablish and protect a functional floodplain with compatible land use practices
- Promote best management practices for runoff including: wetland restoration; minimum tillage; grassed waterways on agricultural land; and rain gardens and pervious pavement in urban areas

These approaches are described in following resource sheets in this ***Understanding Our Streams*** *series (in development).*

Consult with a professional and determine what permits you need

Contact a representative of the Stream Habitat Program from DNR Ecological Resources, your Area Hydrologist from DNR Waters, or your local soil and water conservation district to discuss what you can do on your streambank and within the watershed to minimize or correct streambank erosion. Before attempting any stabilization project, obtain the applicable permits from the DNR or other agencies. The permits you need can be identified when you contact your DNR Area Hydrologist and representatives from other agencies.

Contact Information

DNR Ecological Resources in St. Paul: 500 Lafayette Road, Box 25, St. Paul, MN 55155, (651) 259-5900

Stream Habitat Program website: http://mndnr.gov/eco/streamhab

DNR Waters in St. Paul: 500 Lafayette Road, Box 32, St. Paul, MN 55155, (651) 259-5700

DNR Waters website: http://mndnr.gov/waters

(http://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/gp_2004_0001_manual.html)

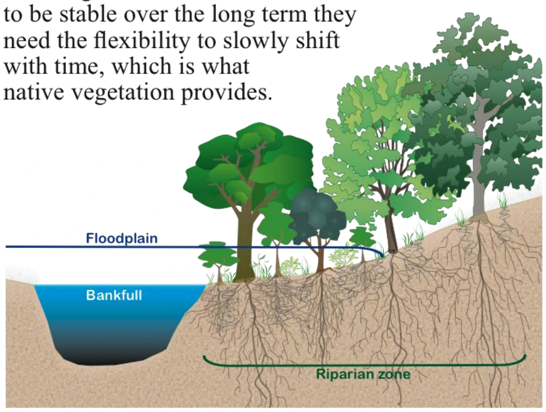
Stream Habitat Program

Resource Sheet 2: The Value and Use of Vegetation

Why is vegetation so important?

Naturally vegetated stream banks, riparian zones, and floodplains are crucial to streambank and channel stability, stream condition and function, water quality, and overall ecosystem health. Healthy streams provide, among many things, clean drinking water and a diversity of fish. The loss and degradation of native riparian vegetation through human activities is a common cause of streambank erosion and failure. These activities include cultivation, deforestation, watershed development, livestock overgrazing, herbicide application, and streambank armoring.

The most simple, inexpensive, and valuable form of streambank stabilization is the preservation and restoration of native riparian and floodplain vegetation. Vegetation, in addition to natural materials and structures, are rudiments of the natural channel design approach that naturally stabilize and protect streambanks. Larger materials such as logs and root wads provide strength and structure and gradually decompose giving streambanks time to re-vegetate and stabilize. For channels to be stable over the long term they need the flexibility to slowly shift with time, which is what native vegetation provides.



The benefits of streambank vegetation

Riparian zones, or buffers, along the banks naturally consist of deep-rooting, flood-tolerant plants and trees that provide multiple benefits:

Streambank stabilization

- Native riparian vegetation has dense, deep, intertwined root systems that physically strengthen soils.
- Riparian root systems remove excess moisture from the soil, making banks more resistant to erosion or slumping.
- Exposed root systems provide roughness that dissipates the water's erosive energy along the banks while the plant stems and leaves provide roughness during flood flows.

Water quality protection

- Vegetated buffers intercept and filter out much of the overland flow of water, nutrients, sediment, and pollutants; accordingly, wider corridors are more effective at protecting water quality and promoting ground-water recharge.

Riparian habitat benefits

- Diverse riparian vegetation provides shade, shelter, leafy or woody debris, and other nutrients needed by fish and other aquatic organisms.
- Wide, continuous, vegetated floodplains help dissipate flood flows, provide storage for floodwaters, retain sediment and nutrients, and provide shelter, forage, and migration corridors for wildlife.

Natural channel design fundamentals

Restoring and conserving native vegetation in the riparian zone and throughout the floodplain and meander belt is fundamental to bank stability and stream health because of the many benefits provided (see text box above). In situations where erosion is not severe and the grade is not too steep, restoring vegetation may be the only step required. In cases where erosion is more severe (e.g. cutbanks, incised channel), re-vegetation remains an essential component of a restoration involving more complex methods and structures, which are explained in following resource sheets.

Prior to planting native vegetation, non-native and nuisance species must be completely removed and the bank may need to be re-graded if the bank slope is too steep or unstable. Re-vegetation techniques include planting seeds, seedlings/saplings, live cuttings, and shrubs and hydroseeding. Live cuttings are branches cut from readily sprouting tree species, such as black willow or dogwood, preferably from nearby vegetation that is adapted to the site. These species will grow and root quickly, thereby providing immediate soil strength and erosion protection. The seeds, plants, disturbed soil, and bank toe should be protected from runoff and stream flow during the rooting process. Such erosion control products and methods are described next.

Disadvantages of hard armoring

Hard armoring banks with rock (riprap), timber walls, sheet piling, or waste concrete (which is not allowed) is a common bank protection approach; however, there are many disadvantages and undesirable impacts.

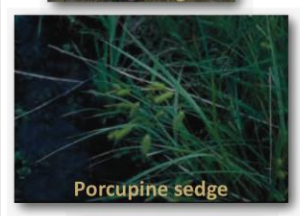
- Hard armored banks transfer the problem downstream by strengthening and redirecting stream flows downstream of the armor and into the next bend or meander resulting in bank erosion and failure, particularly along downstream bend(s).
- From an ecological standpoint, armoring does not provide aquatic or terrestrial habitat (shade, shelter, food) and has no ability to filter or process nutrients and sediments, which negatively impacts stream health.
- Armored banks can negatively affect long-term stability because they lock the channel into place preventing it from adjusting to changes in the watershed.
- Lastly, riprap is expensive to install and looks unnatural.

Resource Sheet 2: The Value and Use of Vegetation

In choosing suitable native plant species, consider local habitat type (e.g. forest, prairie, wetland) and habitat components such as shade, soil type, moisture, and climate. Resources available to identify plant species suitable for various habitat types and desired purposes, such as erosion control, aesthetics, and wildlife habitat include: local nurseries, extension offices, soil and water conservation districts, the "Restore Your Shore" CD-ROM (info at http://mndnr.gov/restoreyourshore) and MN DNR website http://mndnr.gov/gardens/nativeplants. Vegetative stabilization has all the benefits of restoring native vegetation (strengthen and stabilize stream banks, runoff buffer, provide habitat, aesthetic value) in addition to low cost, low maintenance, lack of structural complexity, and endurance. Below is a list of plant species native to Minnesota that are recommended for streambank restorations.

Common name	Scientific name	Life form	Habitat
Blue vervain	*Verbena hastata*	F	W, UM
Canada anemone	*Anemone canadensis*	F	W, UM
Golden alexanders	*Zizia aurea*	F	W, UM
Grass-leaved goldenrod	*Euthamia graminifolia*	F	W, UM
Monkey flower	*Mimulus ringens*	F	W
Obedient plant	*Physostegia virginiana*	F	W, UM
Swamp milkweed	*Asclepias incarnata*	F	W, UM
Fowl manna grass	*Glyceria striata*	G	W
Fox sedge	*Carex vulpinoidea*	G	W, UM
Hardstem bulrush	*Scirpus acutus*	G	A, W
Porcupine sedge	*Carex hystericina*	G	W
River bulrush	*Scirpus fluviatilis*	G	A, W
Softstem bulrush	*Scirpus validus*	G	A, W
Tall manna grass	*Glyceria grandis*	G	W
Virginia wild-rye	*Elymus virginicus*	G	W
Basswood	*Tilia americana*	T	UM, UD
Black willow	*Salix nigra*	T	W
Red-osier dogwood	*Cornus sericea (stolonifera)*	T	W, UM, UD
Silver maple	*Acer saccharinum*	T	W, UM

Native Minnesota plant species recommended for stream bank restorations throughout the state (sorted by Life form then Common name).
***F**: forb (flower)* ***G**: grass or grass-like* ***T**: woody vegetation*
***A**: aquatic* ***W**: wet/transitional* ***UM**: upland moist* ***UD**: upland dry*



Natural materials and structures

Natural materials and structures can be used in addition to native vegetation to:

- ☆ protect seed & plantings from overland and stream flows,
- ☆ protect the toe of the streambank,
- ☆ prevent erosion on slopes,
- ☆ promote trapping of sediment,
- ☆ quickly develop dense roots and sprouts, & provide habitat.

The following six techniques are effective on small to medium streams. They are of moderate cost and can be installed by most landowners with a bit of direction. Landowners should consult an area hydrologist as project approval or a permit is required by the DNR and other agencies.

Biodegradable erosion control blankets (ECBs)

» Biodegradable ECBs are made of: jute (a vegetable fiber) mesh (*in photo*), coconut/coir fiber, straw, or excelsior (fine wood fiber) that are woven into a fiber matrix. ECBs are designed to temporarily provide erosion protection and assist with vegetation establishment as they degrade over 1-3 years leaving a vegetated bank. Products with polypropylene materials are not recommended because they do not degrade and can entangle wildlife in the rigid knitting.

× ECBs are placed over re-graded and re-seeded streambanks (use more durable netting for steeper banks). Wood stakes or live cuttings are used to secure the fabric in place (instead of metal anchor pins). Blankets should be installed promptly after the restoration to provide immediate erosion protection.

Resource Sheet 2: The Value and Use of Vegetation

Broadcast seeding and hydroseeding

» Broadcast seeding is the scattering of native seed mixes by hand or mechanically over prepared soil. Good seed to soil contact, protection (ECBs, mulch, oats or rye as a cover crop), and watering are important.

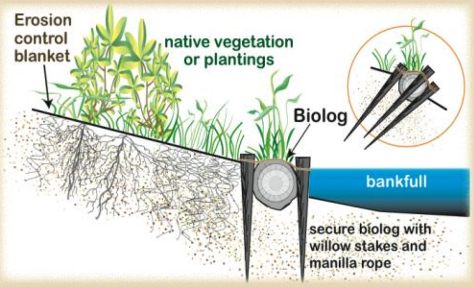
» Hydroseeding is a planting process that uses a mixture of water, seed, fertilizer, mulch, and tackifiers that is sprayed over renovated banks or slopes. Native seeds that are suitable to the habitat should be used in the mix. This mixture can be applied to the upper slopes, even on steeper slopes. The mixture should not be applied too close to the channel to avoid fertilizer from polluting the stream or seed from being washed away.

Staking and live cuttings

» Stakes and live cuttings from readily sprouting, local, healthy tree species such as black willow, dogwood, and alder are used to quickly vegetate restored streambanks. Staking can be applied on all types of banks and in addition to other techniques.

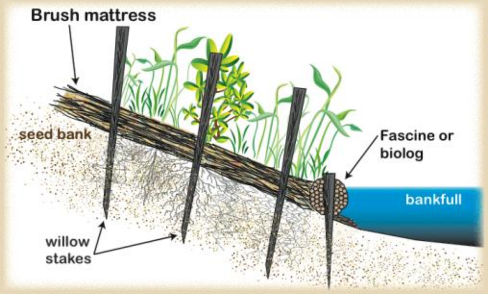
× The cuttings or stakes (branch sections without twigs or leaves) are cut and planted while dormant, late fall through early spring. Stakes are 2'+ in length and ½ - 3" in diameter with one end cut at a 45° angle. Stakes are planted 1 - 2' deep in soft soils or into a pilot hole in harder soils ensuring the stake is deep enough to reach permanently wet soils. Stakes are planted 1 - 2' apart depending on the size of the stakes to ensure successful survival and sufficient cover.

Biologs, coir fiber rolls, wattles, fascines



» Biologs and coir fiber rolls are made of coconut fiber, straw, or excelsior fiber. Wattles and fascines are cylindrical bundles of wheat or rice straw or cuttings. They are strong, flexible rolls (8-10' long, 8-12" diameter) of biodegradable material used to protect the toe of banks and to stabilize slopes . These structures work best where scour is not too severe and where flows will infrequently flow over the toe protection.

× The logs, rolls, or bundles are staked and tied into a shallow trench along the toe of the streambank to deflect flows and wave energy, retain sediment, and provide a stable structure for plant growth (substrate). Native vegetation is planted on and around the structures, then as the vegetation or cuttings becomes established, the natural materials will degrade in 2 to 6 years leaving a vegetated bank.



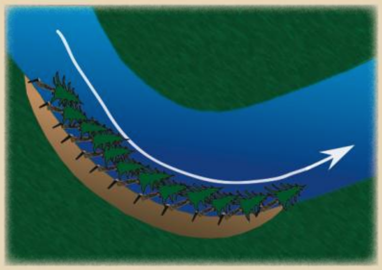
× Additional rows can be installed (placed in shallow trenches secured by wood stakes) upslope parallel to the toe of the bank for additional bank stabilization.

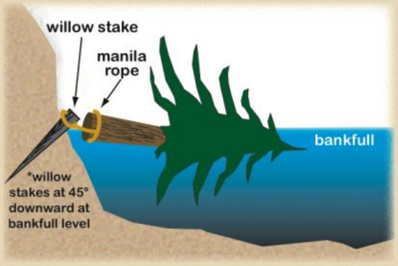
Brush mattresses

» Brush mattresses consist of a layer of interlaced dormant cuttings (e.g. willow, dogwood, alder) that are laid perpendicular to the toe and staked over a gently sloped streambank, often with a fascine or biolog at the base as toe protection.

× These structures work on most banks. They require good soil contact to support brush growth; base flows to keep the basal ends of the cuttings moist; and installation during the non-growing season, preferably early spring.

Tree revetments





» Tree revetments involve anchoring coniferous (such as Christmas trees) or hardwood trees along an outside bend where erosion is excessive.

× The trees are tied by the trunks with natural filament rope to wooden stakes placed at the bankfull level with the treetops pointing downstream. Tree revetments dissipate outside meander flows and collect sediment, thereby reducing erosion and promoting deposition.

× Tree revetments work best in small to medium streams with high sand or gravel loads because sediment deposition is important to the long-range goal of rebuilding and protecting the bank.

⇨ These structures provide habitat and as they degrade and accumulate sediment they become a natural, structural part of the bank.

Resource Sheet 2: The Value and Use of Vegetation

Root wad revetments

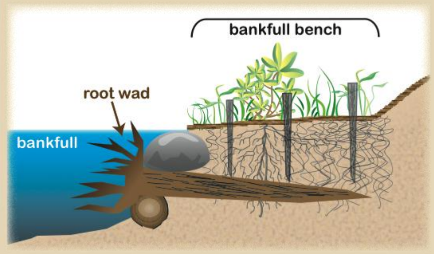
» Root wad revetments are more complex structures built into exposed cutbanks where erosion is actively cutting away the bank. These revetments commonly involve the construction of a bankfull bench to help accommodate and dissipate flood flows. This design is especially useful where there is infrastructure on the bank that needs to be protected from bank loss or slumping. These revetments can be scaled to the size of the stream (e.g., root wads can be stacked in large streams). They are not recommended in sandy soils where it is difficult to drive the trunks into the bank and the sand is more erodible.

× Large tree trunks with root wads are driven into a renovated cutbank so that the trunks angle upstream and the root wads are positioned below bankfull level directed into the flow. The trunks are secured with large boulders and a matrix of logs. Live cuttings are staked, natural vegetation planted or seeded, and erosion control fabric is staked on the bankfull bench and restored bank.

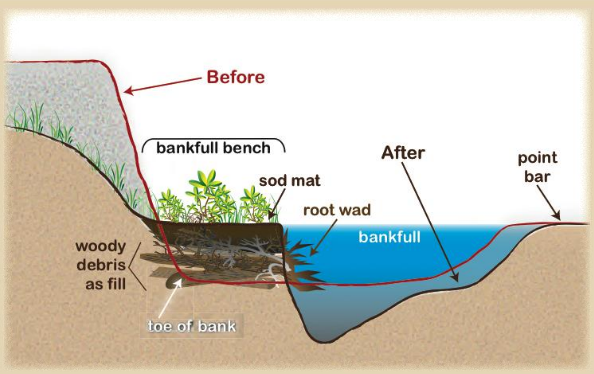
⇨These revetments protect the banks over a range of flows, provide substrate for invertebrates and refuge for fish, and will slowly degrade while becoming a natural part of the streambank.

Installation of root wads using an excavator to drive tree trunks into the bankfull bench (looking upstream).

**Variations of this design have been used through the years. For more specific design details see Applied River Morphology by Dave Rosgen, 1996.*



Root wad revetment and a revegetated bankfull bench built to stabilize a cutbank encroaching on Interstate 94, two years after construction (looking downstream).



Toe wood-sod mats *(see fact sheet for more details)*

» Toe wood-sod mats involve similar design elements to the root wad revetments. This approach can be scaled to all stream sizes.

× Cutbanks are renovated with a bankfull bench consisting of layers of logs, branches, brush, roots, and fill. Root wads can be incorporated to provide additional roughness and habitat. These layers are then covered with sod mats, willow cuttings, and transplants set at bankfull stage.

⇨ This structure design restores the connection to the floodplain with a bankfull shelf, restores channel dimensions, protects a once vulnerable and unstable cutbank, provides habitat (both aquatic and terrestrial), and is relatively inexpensive.

**Variations of this design have been used through the years. General design details are credited to Dave Rosgen of Wildland Hydrology.*

Review and advanced restoration designs

Bank restorations utilizing vegetation, erosion-control blankets, biologs, wattles, revetments, and mats or combinations thereof, can effectively protect and rebuild banks if properly placed and established. These approaches utilize all natural materials that do not artificially confine the channel, they are relatively inexpensive, and can be applied to all stream varieties (forested, prairie, steep, gentle, rocky, sandy). As explained in Resource Sheet #1, the cause(s) of stream instability and future watershed conditions should be considered. Most projects will need permits and professional assistance.

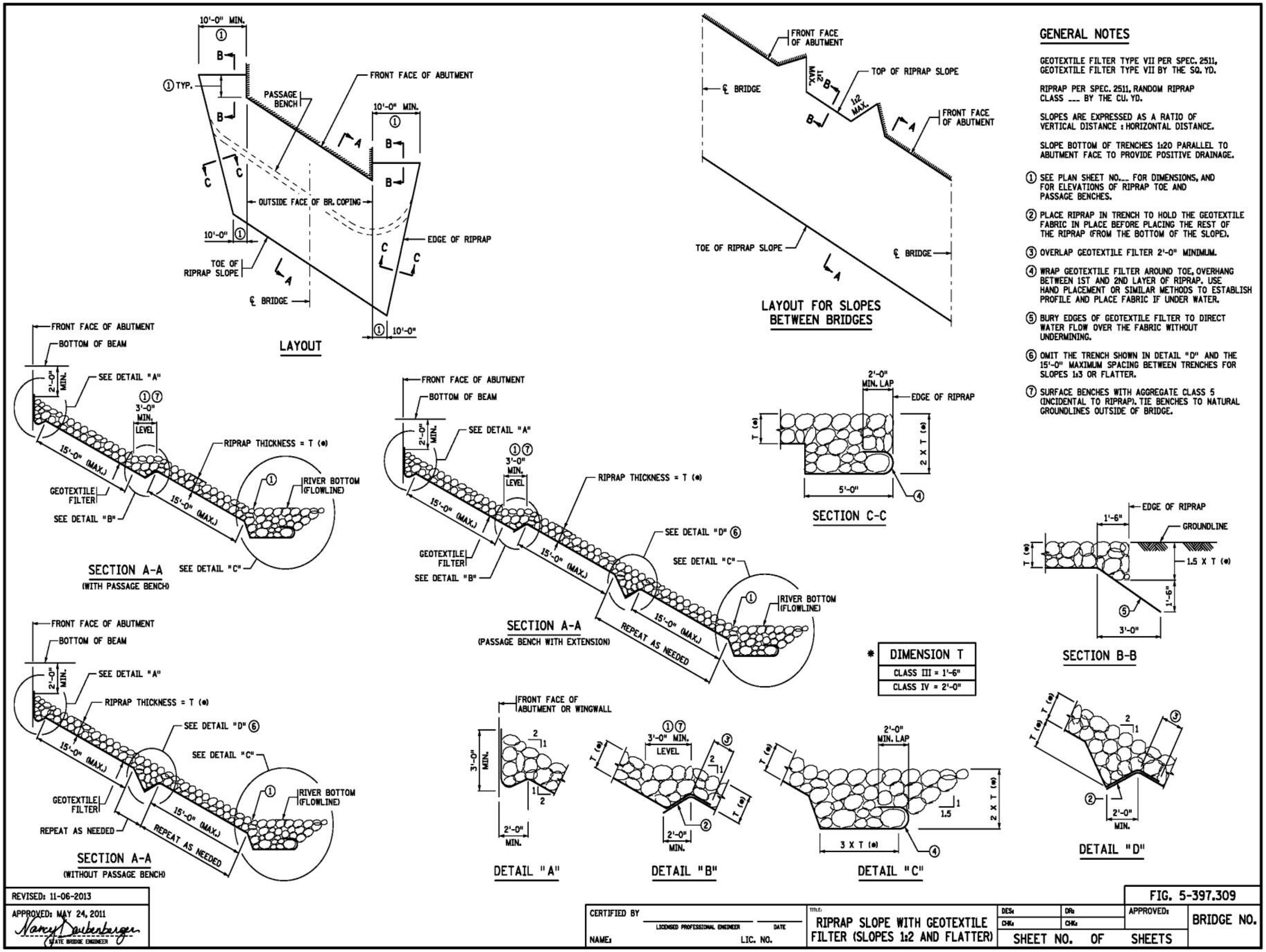
In some cases in-channel structures can also be used to protect restored or unstable banks. These include rock structures such as rock vanes, J-hooks, and riffles that are effective at properly slowing and deflecting flows from the streambanks. Installation of these structures requires professional assistance because proper placement is absolutely essential for successful streambank protection and restoration. This requires stream and watershed monitoring and assessments. These in-channel structures are explained in more detail in the following resource sheets.

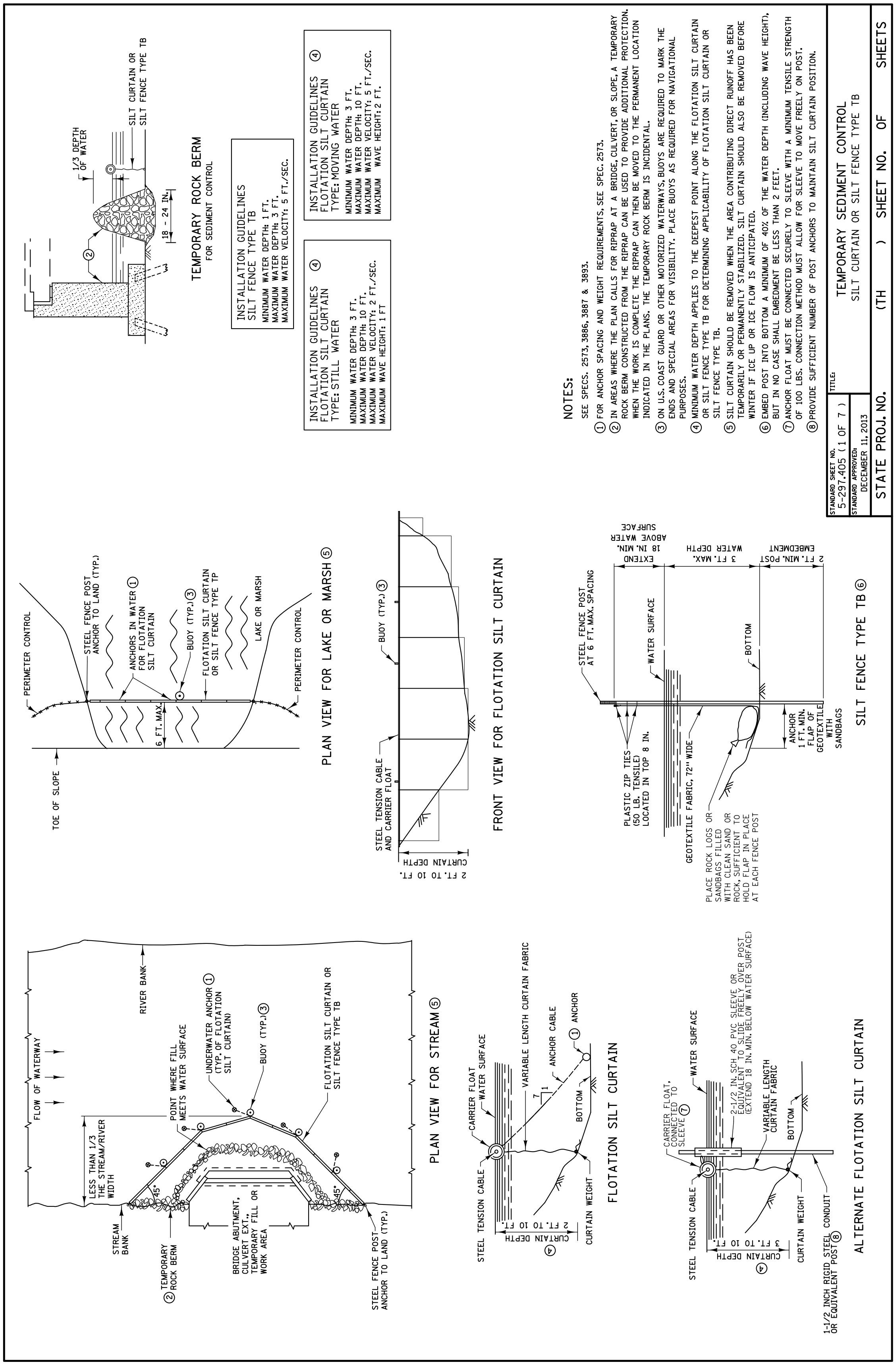
Contact Information

DNR Ecological Resources:
Stream Habitat Program
Ecosystem Restoration
500 Lafayette Road, Box 25
St. Paul, MN 55155
(651) 259-5900

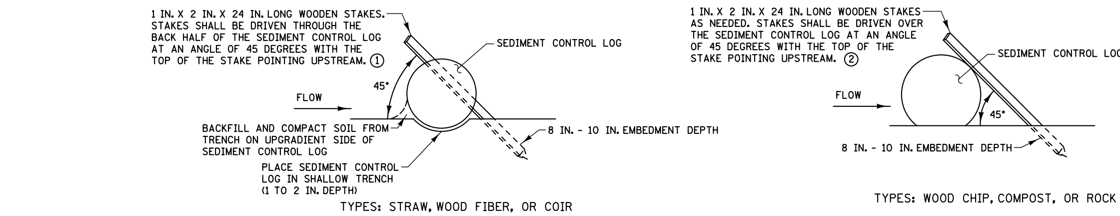
DNR Waters:
Public Water Permit Requirements
500 Lafayette Road, Box 32
St. Paul, MN 55155
(651) 259-5700

DNR website:
http://mndnr.gov

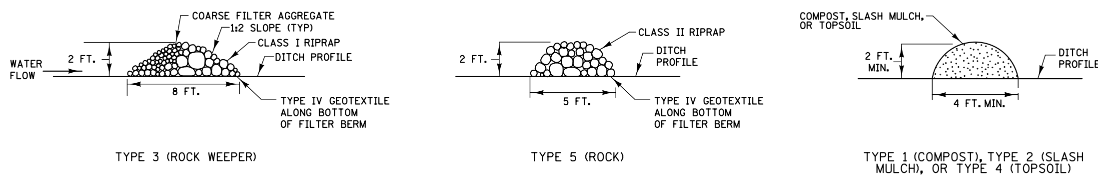

GENERAL NOTES
GEOTEXTILE FILTER TYPE VII PER SPEC. 2511, GEOTEXTILE FILTER TYPE VII BY THE SQ. YD.
RIPRAP PER SPEC. 2511, RANDOM RIPRAP CLASS ___ BY THE CU. YD.
SLOPES ARE EXPRESSED AS A RATIO OF VERTICAL DISTANCE : HORIZONTAL DISTANCE.
SLOPE BOTTOM OF TRENCHES 1:20 PARALLEL TO ABUTMENT FACE TO PROVIDE POSITIVE DRAINAGE.
① SEE PLAN SHEET NO.___ FOR DIMENSIONS, AND FOR ELEVATIONS OF RIPRAP TOE AND PASSAGE BENCHES.
② PLACE RIPRAP IN TRENCH TO HOLD THE GEOTEXTILE FABRIC IN PLACE BEFORE PLACING THE REST OF THE RIPRAP (FROM THE BOTTOM OF THE SLOPE).
③ OVERLAP GEOTEXTILE FILTER 2'-0" MINIMUM.
④ WRAP GEOTEXTILE FILTER AROUND TOE, OVERHANG BETWEEN 1ST AND 2ND LAYER OF RIPRAP. USE HAND PLACEMENT OR SIMILAR METHODS TO ESTABLISH PROFILE AND PLACE FABRIC IF UNDER WATER.
⑤ BURY EDGES OF GEOTEXTILE FILTER TO DIRECT WATER FLOW OVER THE FABRIC WITHOUT UNDERMINING.
⑥ OMIT THE TRENCH SHOWN IN DETAIL "D" AND THE 15'-0" MAXIMUM SPACING BETWEEN TRENCHES FOR SLOPES 1:3 OR FLATTER.
⑦ SURFACE BENCHES WITH AGGREGATE CLASS 5 (INCIDENTAL TO RIPRAP). TIE BENCHES TO NATURAL GROUNDLINES OUTSIDE OF BRIDGE.
LAYOUT
FRONT FACE OF ABUTMENT
PASSAGE BENCH
OUTSIDE FACE OF BR. COPING
EDGE OF RIPRAP
TOE OF RIPRAP SLOPE
℄ BRIDGE
10'-0" MIN.
① TYP.
LAYOUT FOR SLOPES BETWEEN BRIDGES
TOP OF RIPRAP SLOPE
1:2 MAX.
SECTION A-A (WITH PASSAGE BENCH)
SECTION A-A (PASSAGE BENCH WITH EXTENSION)
SECTION A-A (WITHOUT PASSAGE BENCH)
BOTTOM OF BEAM
SEE DETAIL "A"
SEE DETAIL "B"
SEE DETAIL "C"
SEE DETAIL "D" ⑥
RIPRAP THICKNESS = T (*)
GEOTEXTILE FILTER
RIVER BOTTOM (FLOWLINE)
15'-0" (MAX.)
3'-0" MIN.
LEVEL
REPEAT AS NEEDED
SECTION C-C
2'-0" MIN. LAP
5'-0"
2 X T (*)
SECTION B-B
GROUNDLINE
1'-6"
1.5 X T (*)
3'-0"
* DIMENSION T
CLASS III = 1'-6"
CLASS IV = 2'-0"
DETAIL "A"
FRONT FACE OF ABUTMENT OR WINGWALL
DETAIL "B"
DETAIL "C"
3 X T (*)
DETAIL "D"
2'-0" MIN.
REVISED: 11-06-2013
APPROVED: MAY 24, 2011
STATE BRIDGE ENGINEER
CERTIFIED BY
LICENSED PROFESSIONAL ENGINEER
DATE
NAME:
LIC. NO.
RIPRAP SLOPE WITH GEOTEXTILE FILTER (SLOPES 1:2 AND FLATTER)
FIG. 5-397.309
BRIDGE NO.
SHEET NO. OF SHEETS



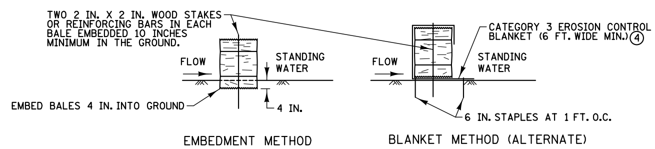
DECEMBER 11, 2013 5-297.405 (1 OF 7)



SEDIMENT CONTROL LOGS



FILTER BERMS



BALE BARRIERS ③

NOTES:

SEE SPECS. 2573, 3149, 3874, 3882, 3886, & 3897.

① SPACE BETWEEN STAKES SHALL BE A MAXIMUM OF 1 FOOT FOR DITCH CHECKS OR 2 FEET FOR OTHER APPLICATIONS.

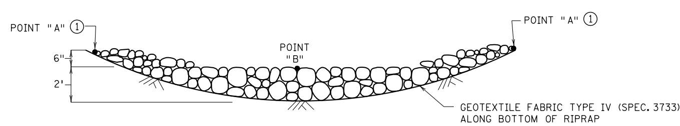
② PLACE STAKES AS NEEDED TO PREVENT MOVEMENT OF SEDIMENT CONTROL LOGS PLACED ON SLOPES OR AS NEEDED DUE TO OTHER FACTORS. STAKES SHALL BE INCIDENTAL.

③ TO BE USED FOR CRITICAL PERIMETER CONTROL AREAS WHERE STANDING WATER OCCURS (6 INCH MAX. DEPTH). BALES SHALL CONSIST OF TYPE 1 MULCH OF APPROXIMATELY 14 IN. X 18 IN. X 36 IN. LONG. BALES SHALL BE PLACED ON EDGE AND BUTTED TIGHT TO ADJACENT BALES.

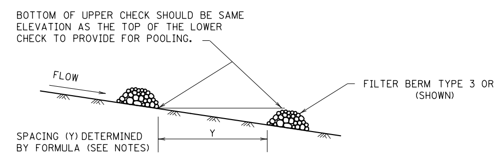
④ INSTEAD OF TRENCHING, PLACE BALE ON THE BLANKET AND WRAP BLANKET AROUND THE BALE. PLACE STAKE THROUGH BALE AND BLANKET.

STANDARD SHEET NO. 5-297.405 (2 OF 7) STANDARD APPROVED: DECEMBER 11, 2013	TEMPORARY SEDIMENT CONTROL FILTER BERMS, SEDIMENT CONTROL LOGS, AND BALE BARRIERS
STATE PROJ. NO.	(TH) SHEET NO. OF SHEETS

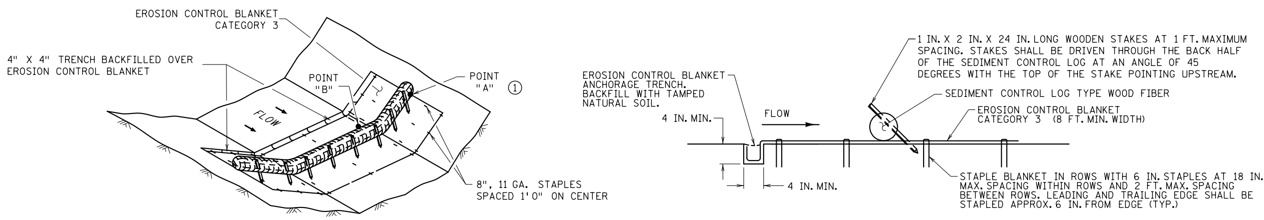
DECEMBER 11, 2013 5-297.405 (2 OF 7)



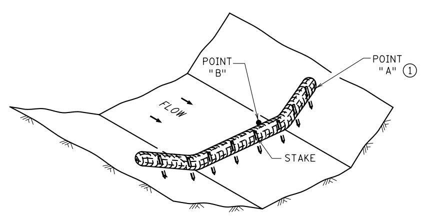
ROCK DITCH CHECKS
FILTER BERMS TYPE 3 (ROCK WEEPER) OR FILTER TYPE 5 (ROCK) ② ③
(FOR USE ON ROUGH GRADED AREAS)



DITCH CHECK SPACING
(FOR ALL FILTER BERM TYPES)



SEDIMENT CONTROL LOG TYPE BLANKET SYSTEM ④



SEDIMENT CONTROL LOG TYPE WOOD FIBER, OR TYPE COMPOST ⑤
(FOR USE ON ROUGH GRADED AREAS)

NOTES:

SEE SPECS. 2573, 3601, 3733, 3885, 3886 & 3889.

FOR DITCH CHECKS, PLACE SEDIMENT CONTROL LOG PERPENDICULAR TO FLOW AND IN A CRESCENT SHAPE WITH THE ENDS FACING UPSTREAM.

APPROXIMATE SPACING BETWEEN EACH DITCH CHECK SHOULD BE DETERMINED FROM THE FOLLOWING SPACING FORMULA:

$$\text{APPROXIMATE SPACING OF DITCH CHECKS (FT.)} = Y = \frac{\text{DITCH CHECK HEIGHT (FT)}}{\text{\% CHANNEL SLOPE}} \times 100$$

① POINT "A" MUST BE A MINIMUM OF 6 INCHES HIGHER THAN POINT "B" TO ENSURE THAT WATER FLOWS OVER THE DIKE AND NOT AROUND THE ENDS.

② PERMANENT ROCK DITCH CHECKS PLACED WITHIN THE CLEAR ZONE ARE TO BE 18" OR LESS IN HEIGHT. A 1:6 APPROACH AND DEPARTURE SLOPE SHALL BE PROVIDED.

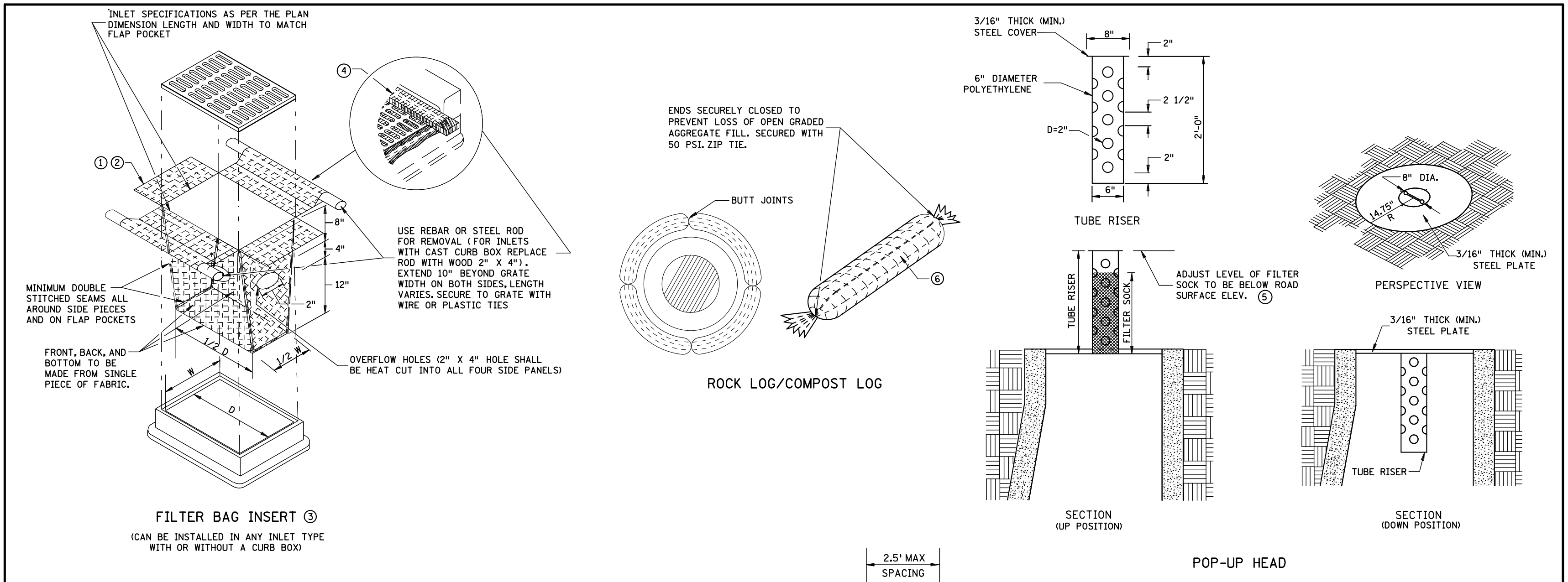
③ DITCH GRADE 3% - 5%, MAX. FLOW VELOCITY 12 FT./SEC..

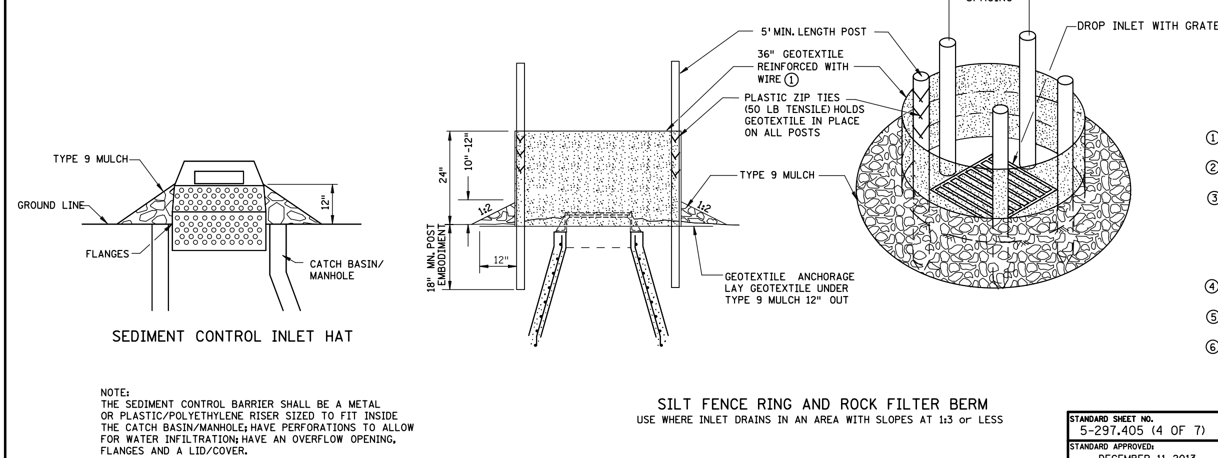
④ DITCH GRADE 1.5% - 3%, MAX. FLOW VELOCITY 4.5 FT./SEC..

⑤ DITCH GRADE 1.5% - 3%, MAX. FLOW VELOCITY 1.5 FT./SEC..

STANDARD SHEET NO. 5-297.405 (3 OF 7) STANDARD APPROVED: DECEMBER 11, 2013	TEMPORARY SEDIMENT CONTROL DITCH CHECK
STATE PROJ. NO.	(TH) SHEET NO. OF SHEETS

DECEMBER 11, 2013 5-297.405 (3 OF 7)





NOTES:

SEE SPECS. 2573, 3137, & 3886.

DEVICES MUST BE ADJUSTED ACCORDINGLY AS TO NOT CAUSE FLOODING ON ROADWAY THAT WOULD IMPEED TRAFFIC FLOW.

① ALL GEOTEXTILE USED FOR INLET PROTECTION SHALL BE MONOFILAMENT IN BOTH DIRECTIONS, MEETING SPEC. 3886.

② FINISHED SIZE, INCLUDING POCKETS WHERE REQUIRED SHALL EXTEND A MINIMUM OF 10 INCHES AROUND THE PERIMETER TO FACILITATE MAINTENANCE OR REMOVAL.

③ INSTALLATION NOTES:
DO NOT PLACE FILTER BAG INSERT IN INLETS SHALLOWER THAN 30 INCHES, MEASURED FROM THE BOTTOM OF THE INLET TO THE TOP OF THE GRATE. THE PLACED BAG SHALL HAVE A MINIMUM SIDE CLEARANCE OF 3 INCHES BETWEEN THE INLET WALLS AND THE BAG, MEASURED AT THE BOTTOM OF THE OVERFLOW HOLES. WHERE NECESSARY THE CONTRACTOR SHALL CLINCH THE BAG, USING PLASTIC ZIP TIES, TO ACHIEVE THE 3 INCH SIDE CLEARANCE.

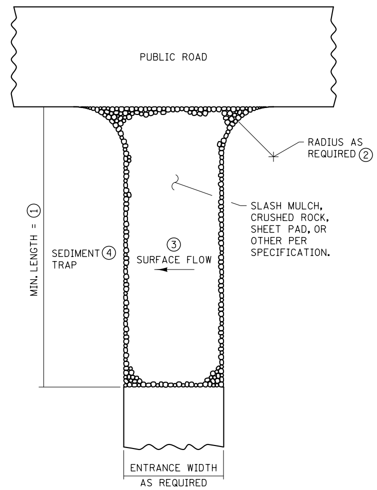
④ FLAP POCKETS SHALL BE LARGE ENOUGH TO ACCEPT WOOD 2 INCH X 4 INCH OR USE A ROCK SOCK OR SAND BAGS IN PLACE OF THE FLAP POCKETS.

⑤ SOCK HEIGHT MUST NOT BE SO HIGH AS TO SLOW DOWN WATER FILTRATION TO CAUSE FLOODING OF THE ROADWAY.

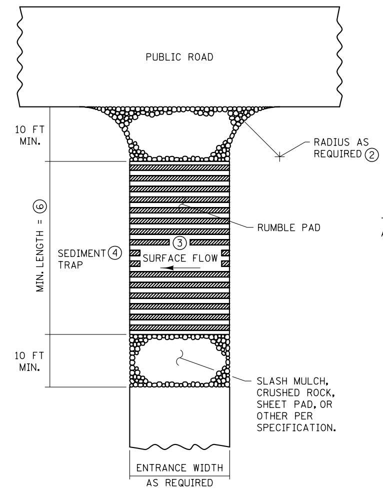
⑥ GEOTEXTILE SOCK BETWEEN 4-10 FEET LONG AND 4-6 INCH DIAMETER. SEAM TO BE JOINED BY TWO ROWS OF STITCHING WITH A PLASTIC MESH BACKING OR PROVIDE A HEAT BONDED SEAM (OR APPROVED EQUIVALENT). FILL ROCK LOG WITH OPEN GRADED AGGREGATE CONSISTING OF SOUND DURABLE PARTICLES OF COARSE AGGREGATE CONFORMING TO SPEC. 3137 TABLE 3137-1; CA-3 GRADATION.

STANDARD SHEET NO. 5-297.405 (4 OF 7) STANDARD APPROVED: DECEMBER 11, 2013	TITLE: TEMPORARY SEDIMENT CONTROL STORM DRAIN INLET PROTECTION
STATE PROJ. NO.	(TH) SHEET NO. OF SHEETS

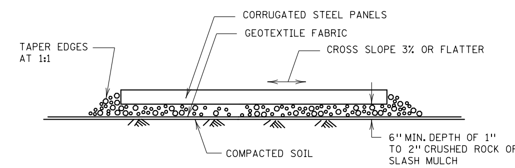
DECEMBER 11, 2013 5-297.405 (4 OF 7)



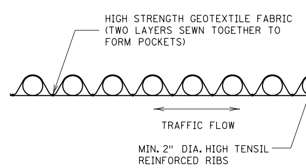
SLASH MULCH, CRUSHED ROCK, OR SHEET PAD CONSTRUCTION EXIT ⑤⑦



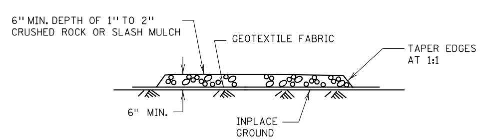
RUMBLE PAD CONSTRUCTION EXIT ⑤⑦



RUMBLE PAD



SHEET PAD



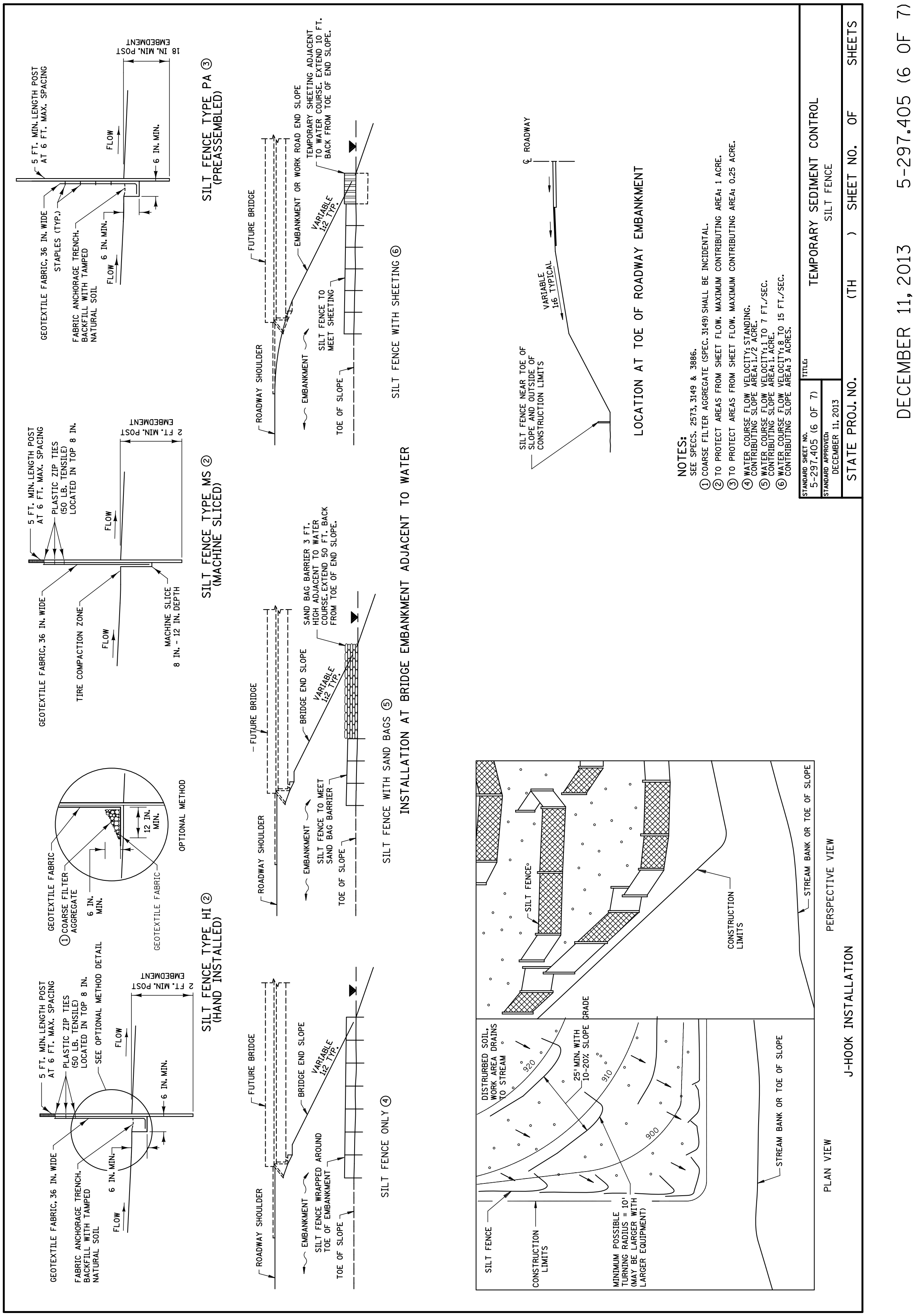
SLASH MULCH OR CRUSHED ROCK

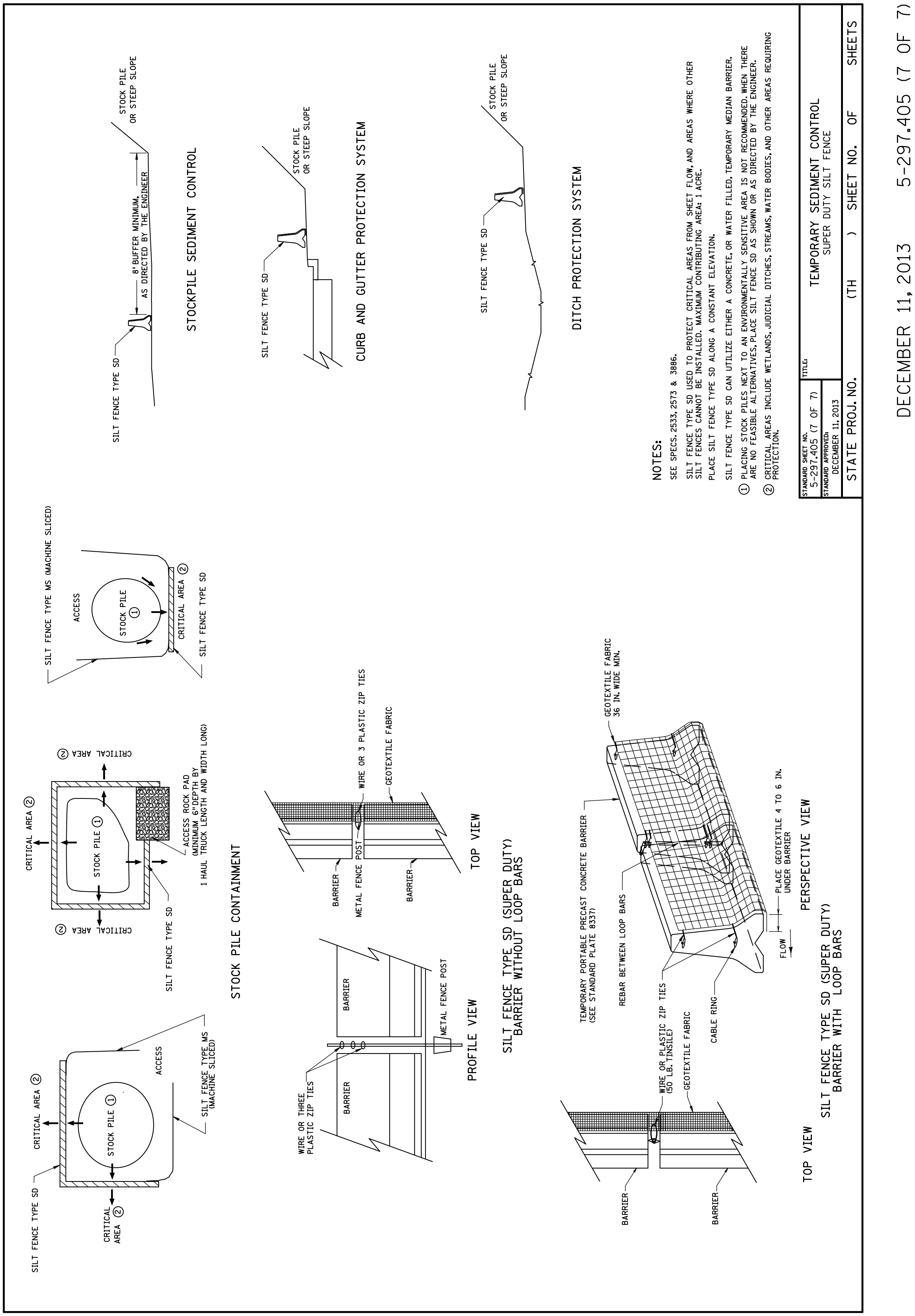
NOTES:
SEE SPECS. 2573 & 3882.

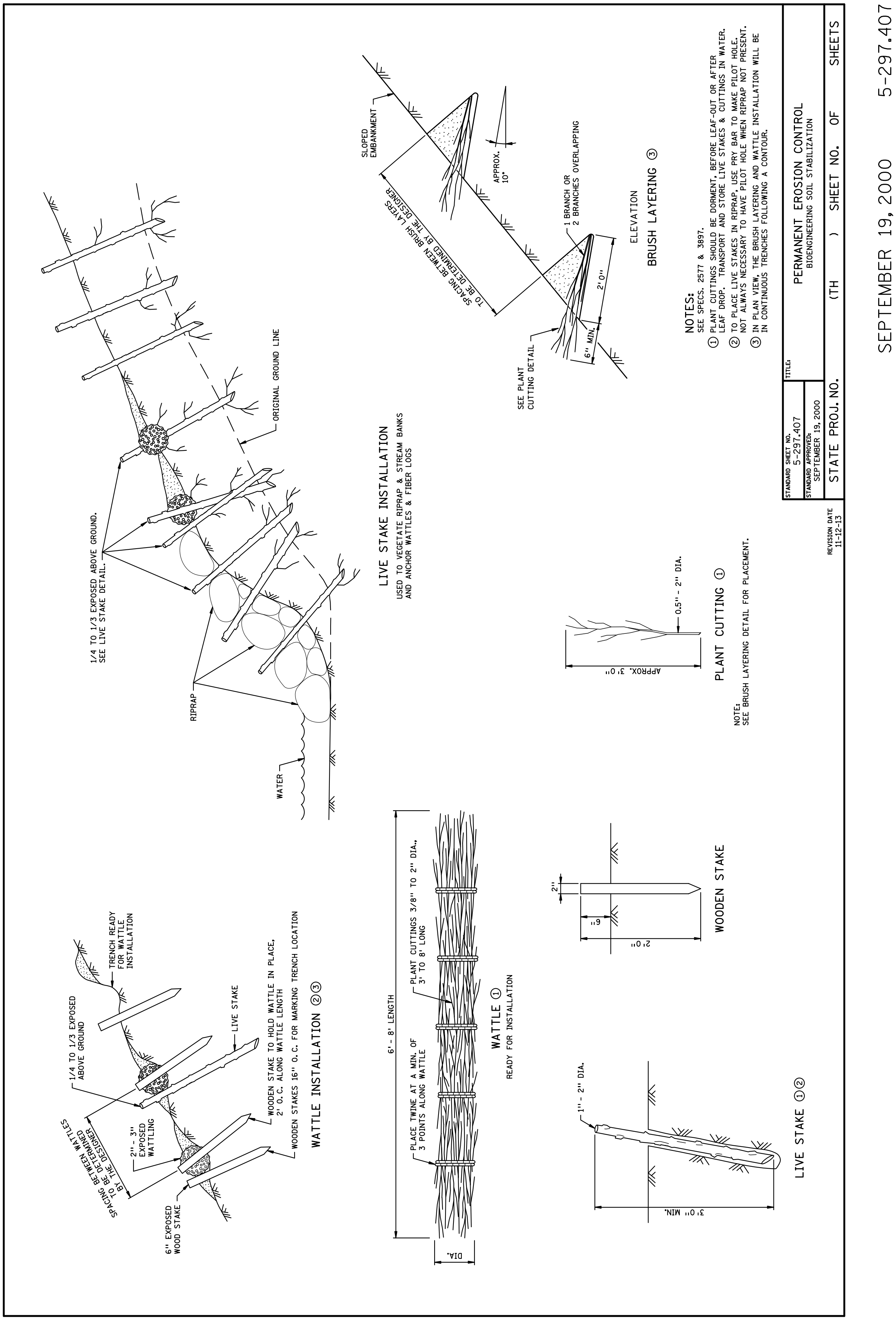
1. MINIMUM LENGTH SHALL BE THE GREATER OF 50 FEET OR A LENGTH SUFFICIENT TO ALLOW A MINIMUM OF 5 TIRE ROTATIONS ON THE PROVIDED PAD. MINIMUM LENGTH SHALL BE CALCULATED USING THE LARGEST TIRE WHICH WILL BE USED IN TYPICAL OPERATIONS.
2. PROVIDE RADIUS OR WIDEN PAD SUFFICIENTLY TO PREVENT VEHICLE TIRES FROM TRACKING OFF OF PAD WHEN LEAVING SITE.
3. IF RUNOFF FROM DISTURBED AREAS FLOWS TOWARD CONSTRUCTION EXITS, PREVENT RUNOFF FROM DRAINING DIRECTLY TO PUBLIC ROAD OVER CONSTRUCTION EXIT BY CROWNING THE EXIT OR SLOPING TO ONE SIDE. IF SURFACE GRADING IS INSUFFICIENT, PROVIDE OTHER MEANS OF INTERCEPTING RUNOFF.
4. IF RUNOFF FROM CONSTRUCTION EXITS WILL DRAIN OFF OF PROJECT SITE, PROVIDE SEDIMENT TRAP WITH STABILIZED OVERFLOW.
5. IF A TIRE WASH OFF IS REQUIRED THE CONSTRUCTION EXITS SHALL BE GRADED TO DRAIN THE WASH WATER TO A SEDIMENT TRAP.
6. MINIMUM LENGTH OF RUMBLE PAD SHALL BE 20 FEET, OR AS REQUIRED TO REMOVE SEDIMENT FROM TIRES. IF SIGNIFICANT SEDIMENT IS TRACKED FROM THE SITE, THE RUMBLE PAD SHALL BE LENGTHENED OR THE DESIGN MODIFIED TO PROVIDE ADDITIONAL VIBRATION. WASH-OFF LENGTH SHALL BE AS REQUIRED TO EFFECTIVELY REMOVE CONSTRUCTION SEDIMENT FROM VEHICLE TIRES.
7. MAINTENANCE OF CONSTRUCTION EXITS SHALL OCCUR WHEN THE EFFECTIVENESS OF SEDIMENT REMOVAL HAS BEEN REDUCED. MAINTENANCE SHALL CONSIST OF REMOVING SEDIMENT AND CLEANING THE MATERIALS OR PLACING ADDITIONAL MATERIAL (SLASH MULCH OR CRUSHED ROCK) OVER SEDIMENT FILLED MATERIAL TO RESTORE EFFECTIVENESS.

STANDARD SHEET NO. 5-297.405 (5 OF 7) STANDARD APPROVED: DECEMBER 11, 2013	TITLE: TEMPORARY SEDIMENT CONTROL CONSTRUCTION EXITS
STATE PROJ. NO.	(TH) SHEET NO. OF SHEETS

DECEMBER 11, 2013 5-297.405 (5 OF 7)


SILT FENCE TYPE HI ②
(HAND INSTALLED)
SILT FENCE TYPE MS ②
(MACHINE SLICED)
SILT FENCE TYPE PA ③
(PREASSEMBLED)
GEOTEXTILE FABRIC, 36 IN. WIDE
5 FT. MIN. LENGTH POST AT 6 FT. MAX. SPACING
PLASTIC ZIP TIES (50 LB. TENSILE) LOCATED IN TOP 8 IN.
SEE OPTIONAL METHOD DETAIL
FABRIC ANCHORAGE TRENCH. BACKFILL WITH TAMPED NATURAL SOIL
FLOW
6 IN. MIN.
2 FT. MIN. POST EMBEDMENT
18 IN. MIN. POST EMBEDMENT
① COARSE FILTER AGGREGATE
GEOTEXTILE FABRIC
12 IN. MIN.
OPTIONAL METHOD
TIRE COMPACTION ZONE
MACHINE SLICE 8 IN. - 12 IN. DEPTH
STAPLES (TYP.)
ROADWAY SHOULDER
FUTURE BRIDGE
BRIDGE END SLOPE
VARIABLE 1:2 TYP.
EMBANKMENT
SILT FENCE WRAPPED AROUND TOE OF EMBANKMENT
TOE OF SLOPE
SILT FENCE ONLY ④
SILT FENCE TO MEET SAND BAG BARRIER
SAND BAG BARRIER 3 FT. HIGH ADJACENT TO WATER COURSE. EXTEND 50 FT. BACK FROM TOE OF END SLOPE.
SILT FENCE WITH SAND BAGS ⑤
EMBANKMENT OR WORK ROAD END SLOPE
TEMPORARY SHEETING ADJACENT TO WATER COURSE. EXTEND 10 FT. BACK FROM TOE OF END SLOPE.
SILT FENCE TO MEET SHEETING
SILT FENCE WITH SHEETING ⑥
INSTALLATION AT BRIDGE EMBANKMENT ADJACENT TO WATER
SILT FENCE NEAR TOE OF SLOPE AND OUTSIDE OF CONSTRUCTION LIMITS
VARIABLE 1:6 TYPICAL
℄ ROADWAY
LOCATION AT TOE OF ROADWAY EMBANKMENT
NOTES:
SEE SPECS. 2573, 3149 & 3886.
① COARSE FILTER AGGREGATE (SPEC. 3149) SHALL BE INCIDENTAL.
② TO PROTECT AREAS FROM SHEET FLOW. MAXIMUM CONTRIBUTING AREA: 1 ACRE.
③ TO PROTECT AREAS FROM SHEET FLOW. MAXIMUM CONTRIBUTING AREA: 0.25 ACRE.
④ WATER COURSE FLOW VELOCITY: STANDING. CONTRIBUTING SLOPE AREA: 1/2 ACRE.
⑤ WATER COURSE FLOW VELOCITY: 1 TO 7 FT./SEC. CONTRIBUTING SLOPE AREA: 1 ACRE.
⑥ WATER COURSE FLOW VELOCITY: 8 TO 15 FT./SEC. CONTRIBUTING SLOPE AREA: 3 ACRES.
SILT FENCE
CONSTRUCTION LIMITS
MINIMUM POSSIBLE TURNING RADIUS = 10' (MAY BE LARGER WITH LARGER EQUIPMENT)
DISTURBED SOIL, WORK AREA DRAINS TO STREAM
25' MIN. WITH 10-20% SLOPE GRADE
920
910
900
STREAM BANK OR TOE OF SLOPE
PLAN VIEW
PERSPECTIVE VIEW
J-HOOK INSTALLATION
STANDARD SHEET NO. 5-297.405 (6 OF 7)
STANDARD APPROVED: DECEMBER 11, 2013
TITLE: TEMPORARY SEDIMENT CONTROL
SILT FENCE
STATE PROJ. NO.
(TH)
SHEET NO. OF SHEETS
DECEMBER 11, 2013
5-297.405 (6 OF 7)


SILT FENCE TYPE SD
CRITICAL AREA ②
STOCK PILE ①
ACCESS
SILT FENCE TYPE MS (MACHINE SLICED)
SILT FENCE TYPE SD
ACCESS ROCK PAD (MINIMUM 6" DEPTH BY 1 HAUL TRUCK LENGTH AND WIDTH LONG)
SILT FENCE TYPE MS (MACHINE SLICED)
CRITICAL AREA ②
SILT FENCE TYPE SD
STOCK PILE CONTAINMENT
WIRE OR THREE PLASTIC ZIP TIES
BARRIER
METAL FENCE POST
PROFILE VIEW
WIRE OR 3 PLASTIC ZIP TIES
GEOTEXTILE FABRIC
TOP VIEW
SILT FENCE TYPE SD (SUPER DUTY) BARRIER WITHOUT LOOP BARS
TEMPORARY PORTABLE PRECAST CONCRETE BARRIER (SEE STANDARD PLATE 8337)
REBAR BETWEEN LOOP BARS
WIRE OR PLASTIC ZIP TIES (50 LB. TENSILE)
GEOTEXTILE FABRIC
CABLE RING
GEOTEXTILE FABRIC 36 IN. WIDE MIN.
PLACE GEOTEXTILE 4 TO 6 IN. UNDER BARRIER
FLOW
PERSPECTIVE VIEW
SILT FENCE TYPE SD (SUPER DUTY) BARRIER WITH LOOP BARS
STOCK PILE OR STEEP SLOPE
8' BUFFER MINIMUM, AS DIRECTED BY THE ENGINEER
STOCKPILE SEDIMENT CONTROL
CURB AND GUTTER PROTECTION SYSTEM
DITCH PROTECTION SYSTEM
NOTES:
SEE SPECS. 2533, 2573 & 3886.
SILT FENCE TYPE SD USED TO PROTECT CRITICAL AREAS FROM SHEET FLOW, AND AREAS WHERE OTHER SILT FENCES CANNOT BE INSTALLED. MAXIMUM CONTRIBUTING AREA: 1 ACRE.
PLACE SILT FENCE TYPE SD ALONG A CONSTANT ELEVATION.
SILT FENCE TYPE SD CAN UTILIZE EITHER A CONCRETE, OR WATER FILLED, TEMPORARY MEDIAN BARRIER.
① PLACING STOCK PILES NEXT TO AN ENVIRONMENTALLY SENSITIVE AREA IS NOT RECOMMENDED. WHEN THERE ARE NO FEASIBLE ALTERNATIVES, PLACE SILT FENCE SD AS SHOWN OR AS DIRECTED BY THE ENGINEER.
② CRITICAL AREAS INCLUDE WETLANDS, JUDICIAL DITCHES, STREAMS, WATER BODIES, AND OTHER AREAS REQUIRING PROTECTION.
STANDARD SHEET NO. 5-297.405 (7 OF 7)
STANDARD APPROVED: DECEMBER 11, 2013
TITLE: TEMPORARY SEDIMENT CONTROL
SUPER DUTY SILT FENCE
STATE PROJ. NO. (TH) SHEET NO. OF SHEETS
DECEMBER 11, 2013 5-297.405 (7 OF 7)


PERMANENT EROSION CONTROL
BIOENGINEERING SOIL STABILIZATION
STANDARD SHEET NO. 5-297.407
STANDARD APPROVED: SEPTEMBER 19, 2000
REVISION DATE 11-12-13
STATE PROJ. NO. (TH) SHEET NO. OF SHEETS
SEPTEMBER 19, 2000
5-297.407
NOTES:
SEE SPECS. 2577 & 3897.
① PLANT CUTTINGS SHOULD BE DORMANT, BEFORE LEAF-OUT OR AFTER LEAF DROP. TRANSPORT AND STORE LIVE STAKES & CUTTINGS IN WATER.
② TO PLACE LIVE STAKES IN RIPRAP, USE PRY BAR TO MAKE PILOT HOLE. NOT ALWAYS NECESSARY TO HAVE PILOT HOLE WHEN RIPRAP NOT PRESENT.
③ IN PLAN VIEW, THE BRUSH LAYERING AND WATTLE INSTALLATION WILL BE IN CONTINUOUS TRENCHES FOLLOWING A CONTOUR.
SLOPED EMBANKMENT
APPROX. 10°
SPACING BETWEEN BRUSH LAYERS TO BE DETERMINED BY THE DESIGNER
1 BRANCH OR 2 BRANCHES OVERLAPPING
2'0"
6" MIN.
SEE PLANT CUTTING DETAIL
ELEVATION
BRUSH LAYERING ③
1/4 TO 1/3 EXPOSED ABOVE GROUND. SEE LIVE STAKE DETAIL.
ORIGINAL GROUND LINE
RIPRAP
WATER
LIVE STAKE INSTALLATION
USED TO VEGETATE RIPRAP & STREAM BANKS AND ANCHOR WATTLES & FIBER LOGS
APPROX. 3'0"
0.5" - 2" DIA.
PLANT CUTTING ①
NOTE:
SEE BRUSH LAYERING DETAIL FOR PLACEMENT.
TRENCH READY FOR WATTLE INSTALLATION
1/4 TO 1/3 EXPOSED ABOVE GROUND
LIVE STAKE
SPACING BETWEEN WATTLES TO BE DETERMINED BY THE DESIGNER
2" - 3" EXPOSED WATTLING
6" EXPOSED WOOD STAKE
WOODEN STAKE TO HOLD WATTLE IN PLACE, 2' O.C. ALONG WATTLE LENGTH
WOODEN STAKES 16" O.C. FOR MARKING TRENCH LOCATION
WATTLE INSTALLATION ②③
6' - 8' LENGTH
PLACE TWINE AT A MIN. OF 3 POINTS ALONG WATTLE
PLANT CUTTINGS 3/8" TO 2" DIA., 3' TO 8' LONG
DIA.
WATTLE ①
READY FOR INSTALLATION
2"
6"
2'0"
WOODEN STAKE
1" - 2" DIA.
3'0" MIN.
LIVE STAKE ①②