Riprap

Updated September, 1997

Definition

Riprap is a permanent cover of rock used to stabilize streambanks, provide in-stream channel stability, and provide a stabilized outlet below concentrated flows.

This BMP addresses using riprap to stabilize streambanks, line channels and provide stable outlets. For purposes of this BMP, "rock" can be used interchangeably with "stone". For information on designing various types of stream liners (including vegetation and riprap), see the Stormwater Conveyance Channel BMP.

All work conducted below the ordinary high water mark of a lake or stream, or in a floodplain or wetland will require permits from the Michigan Department of Environmental Quality, Land and Water Management Division. This includes the placement of riprap. (See Exhibit 1 for a definition of ordinary high water mark).

Other Terms Used to Describe

Armoring
Energy Dissipator

Pollutants Controlled and Impacts

The use of riprap in channels and below concentrated flows protects stream banks and discharge channels from higher erosive flow velocities. This reduces downcutting and lateral cutting, which in turn decreases sediment input to a watercourse.

Application

Land Use
All land uses.

Soil/Topography/Climate
The rock to be used as riprap must be capable of withstanding freezing and thawing and the flow or wave action of the water where it is used. The soil texture on the site and whether seepage is occurring are factors in determining the need and thickness of filters beneath the riprap.

When to Apply
Riprap used at outlets should be in place before the outlet is discharging. Streambank grading should be done when it is most feasible to bring stone to the site. Riprap should be placed as soon after grading as possible.

Where to Apply
Riprap is most often used in streambanks, on slopes, and at outlets.

Relationship With Other BMPs

Riprap is often used in making Stabilized Outlets, in Streambank Stabilization (including bioengineering techniques), and Slope/Shoreline Protection. Filters should be used underneath riprap to help stabilize the soils.

Specifications

General Considerations:

Riprap structures should be designed by licensed professional engineers or other persons qualified in the design of such structures.

Stone Type

The material used for riprap should be fieldstone or rough unhewn quarry stone. Stone should be hard, angular, and of such quality that it will not disintegrate on exposure to water or weathering. It should also be chemically stable, capable of withstanding freezing and thawing, and suitable in all other respects for the intended use.

Because it is not as aesthetically pleasing as rock, broken concrete is a less favorable riprap alternative. If concrete is used, it should be clean and otherwise meet design criteria. Asphalt should *not* be used as riprap.

Riprap Size

Riprap comes in a variety of sizes. The appropriate size to use primarily depends on the intended use of the structure. For example, the size of riprap used to stabilize streambanks depends on the velocity of the water.

Structural design is usually based on the diameter of stone in the mixture for which a percentage, by weight, will be smaller. For example, D_{50} indicates a mixture of stones in which 50 percent of the stone by size would be larger than the diameter specified, and 50% would be smaller than the stone size specified. In other words, the design is based on the average size of stone in the mixture.

Table 1 lists some typical riprap by weight, spherical diameter and corresponding rectangular dimensions. These stone sizes are based on an assumed specific weight of 165 lbs./ft^3.

Table 1

Size of Typical Riprap Stones

Weight (lbs)	Mean Spherical Diameter (in)	Typical Rectangular Shape Length (in)	Width, Height (in)
50	10	18	6
100	13	21	7
150	14	24	8
300	18	30	10
500	22	36	12
1000	27	45	15
1500	31	52	17
2000	34	57	19
4000	43	72	24
6000	49	83	28
8000	54	90	30

Source: USDA Soil Conservation Service

Gradation

Riprap should be composed of a well-graded mixture down to the one-inch size particle such that 50 percent of the mixture by weight is larger than the D_{50} size as determined from the design procedure. For the purposes of this BMP, a well-graded mixture is defined as a mixture composed primarily of the larger stone sizes but with a sufficient mixture of other sizes to fill the progressively smaller voids between the stones. The diameter of the largest stone size in such a mixture should not be more than 1.5 times the D_{50} stone size.

After determining the riprap size that will be stable under the flow conditions, the designer should consider that size to be a minimum size and then, based on riprap gradations actually available in the area, select the size or sizes that equal or exceed the minimum size.

Riprap structures for **streambank stabilization** should be designed to be stable for bank-full flows in the reach of the channel being stabilized.

Thickness

For both streambank stabilization and outlets, the minimum thickness of the riprap layer should be 1.5 times the D_{50} diameter, or 6 inches, whichever is greater. **A geotextile or stone filter must be placed under the riprap to prevent water from removing the underlying soil material through the voids in the riprap.** (Removal of the soil material leaves cavities behind the riprap and failure of the riprap may result). The filter may consist of smaller sized stone (usually 2"), a geotextile material, or a combination of both. Stone filters should be a minimum of 6 inches thick, and greater if the area has high seepage pressures. Follow the specifications below.

Granular (Stone) Filter Blanket. For dumped riprap, a filter ratio of 5 or less between successive layers will result in a stable condition. The filter ratio is defined as the ratio of D_{15} size of the coarser layer to the D_{85} size of the finer layer. An additional requirement for stability is that the ratio of the D_{15} size of the coarse material to the D_{15} size of the fine material should exceed 5 and be less than 40. A further requirement is that the ratio of the D_{50} size of the coarse material to the D_{50} size of the fine material not exceed 40. These requirements can be stated as follows:

$$\frac{D_{15}\text{ (coarser layer)}}{D_{85}\text{ (finer layer)}} < 5 < \frac{D_{15}\text{ (coarser layer)}}{D_{15}\text{ (finer layer)}} < 40$$

$$\frac{D_{50}\text{ (coarser layer)}}{D_{50}\text{ (finer layer)}} < 40$$

The filter requirements apply between the bank material and the filter blanket, between successive layers of filter blanket material if more than one layer is used, and between the filter blanket and the stone cover.

If a single layer of filter material will not satisfy the filter requirements, one or more additional layers of filter material must be used. In addition to the filter requirements, the grain size curves for the various layers should be approximately parallel to minimize the infiltration of the fine material into the coarser material. Not more than 5 percent of the filter material should pass the No. 200 sieve.

The minimum thickness of each layer of granular filter material shall be 6 inches, or 3 times the D_{50} size of the filter, whichever is greater.

Synthetic (Geotextile) Filter Fabric. The Filters BMP includes information on geotextile materials which may be used may be used in place of or in conjunction with granular filters. Always check manufacturer's specifications to ensure that the filter fabric selected meets the tensile strength and

durability requirements for the determined rock size. Some guidance in selecting filter fabric is given below.
The following particle size relationships must exist:

For filter fabric adjacent to granular materials containing 50 percent or less (by weight) of fine particles (less than 0.075 mm):

a) $\frac{D_{85} \text{ base (mm)}}{\text{EOS* filter fabric (mm)}} > 1$

b) Total open area of filter fabric is less than 36 percent.

For filter fabric adjacent to all other soils:

*Equivalent Opening Size to a US Standard Sieve Size

a) EOS less than U.S. Standard Sieve No. 70.

b) Total open area of filter is less than 10 percent.

No filter fabric should be used with less than 4 percent open area or an EOS smaller than U.S. Standard Sieve No. 100.

Stream Bank Protection and Channel Lining

See Exhibit 1 for applications.

General Planning Considerations:

1. Slopes on which riprap is used to stabilize streambanks should be no steeper than 1.5:1.

2. All bare soil on the slope above the riprap should be stabilized with seed and mulch, or sod. See the Vegetative BMPs.

3. When riprap is used in conjunction with other vegetative practices or bioengineering, the riprap should extend 1 foot above the ordinary high water mark. When only riprap is being used for bank stabilization, the top of the riprap should extend 3 feet above the ordinary high water mark. See Exhibit 1 for an explanation of the ordinary high water mark.

4. Determine a means of accessing the site before designing any riprap structure.

5. Determine how the riprap will be placed on the site. If the rock is to be dumped, it must be done in a manner which will not cause separation of the small and large stones. If rock is to be dumped over a bank and placed by hand, it must be done so that it does not create more erosion. Consider using aluminum or wooden shutes to roll rock down a bank to the waters' edge.

6. If riprap placement requires re-configuring banks or slopes, the filter should be placed as soon after the banks are prepared as possible. Placement of riprap should follow immediately after the placement of the filter.

7. The finished surface should not have pockets of finer materials which would flush out and

weaken the structure. Some hand placing should be done to provide a stable surface.

8. Riprap used both at the outlet of storm sewers <u>and</u> to protect an eroding bank, should be designed to accommodate both uses. Riprap used as outlet protection should be constructed before the pipe or channel begins to operate.

Design:

Stone Size Selection for Streambank Stabilization:

The design method described below is adapted from *Design of Stable Channels with Flexible Linings, Hydraulic Engineering Circular No. 15* of the Federal Highway Administration. It is applicable to both straight and curved sections of channel where the flow is not perpendicular to the bank of the channel.

A. Straight Sections of Channel.

This design method determines a stable rock size for straight and curved sections of channels. It is assumed that the shape, depth of flow, and slope of the channel are known. A stone size is chosen for the maximum depth of flow. If the sides of the channel are steeper than 3:1, the stone size must be increased accordingly. The final design size will be stable on both sides of the channel and the bottom.

1. Enter Exhibit 3 with the maximum depth of flow (feet) and channel slope (feet/foot). Where the two lines intersect, choose the d_{50} size of stone.

2. If channel side slopes (z) are steeper than 3:1, continue with step 3, if not, the procedure is complete.

3. Enter Exhibit 4, with the side slope and the base width to maximum depth ratio (B/d). Where the two lines intersect, move horizontally left to K1. Record K1.

4. Determine from Exhibit 5, the angle of repose (Ar) for the d_{50} size of stone. The angle of repose is the angle in which the rocks will lay in relation to the bank. Banks should be designed so that the natural angle of repose of the stone mixture is greater than the slope of the bank being stabilized. (Use Ar=42° for d_{50} greater than 1.0 ft. Do not use riprap on slopes steeper than the angle of repose for the size of stone.)

5. Enter Exhibit 6, with the side slope (z) of the channel and the angle of repose (Ar) for the d_{50} size of stone. Where the two lines intersect, move vertically down to read K2. Record K2.

6. Compute $d'_{50} = d_{50} \times K1/K2$, where d'_{50} is to determine the correct size stone for the bottom and side slopes of straight sections of channel.

B. Curved Sections of Channel

1. Compute the radius of the curve (Ro), measured at the outside edge of the bottom.

2. Compute the ratio of the top width of the water surface (Bs) to the radius of the curve (Ro), Bs/Ro.

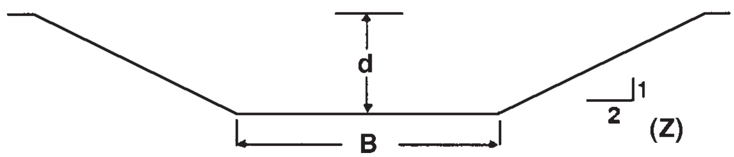
3. Enter Exhibit 7, with the ratio Bs/Ro. Move vertically until the curve is intersected.

Move horizontally left to read K3.

4. Compute $d_{50c} = d'_{50} \times K3$, where d_{50c} is the correct size stone for bottom and side slopes of curved sections of channel.

C. <u>Design Example Problems</u>:

Problem #1
Given: A trapezoidal channel 3 feet deep (d), with an 8-foot bottom (B), 2:1 side slopes (z), and a 2 percent slope. **Calculate**: A stable riprap size for the bottom (B) and side slopes (z) of the channel.



Solution:

1. From Exhibit 3, for a 3-foot deep channel on a 2 percent grade: d_{50} = 0.75 feet or 9 inches.

2. Since the side slopes (z) are steeper than 3:1, continue with Step 3.

3. From Exhibit 4 for B/d = 2.67 and z = 2; K1 = 0.8

4. From Exhibit 5 for d_{50} = 9 inches; Ar = 41°

5. From Exhibit 6 for z = 2 and Ar = 41°; K2 = 0.75

6. $d'_{50} = d_{50} \times K1/K2 = 0.75 \times 0.8/0.75 = 0.8$ feet

   0.8 ft x 12 inches = 9.6 inches

   Use d'_{50} = 10 inches

Problem #2
Given: The preceding channel in Problem #1 has a curved section with a radius of 50 feet at the outside edge of the bottom. **Calculate**: A stable riprap size for the bottom and side slopes of the curved section of channel.

Solution:

1. Radius of curvature, Ro = 50 feet

2. Top width at water surface,

   Bs = 8 +(2 x 3 x 2) = 20 feet

   Bs/Ro = 20/50=0.40

3. From Exhibit 7 for Bs/Ro = 0.40; K3 = 1.1

4. $d_{50c} = d'_{50} \times K3 = 0.84 \times 1.1 = 0.92$ feet

   Use d_{50c} = 1.0 ft = 12 inches

Length/Thickness/Height of Streambank Area to be Riprapped
Refer back to page RIP-3 for specifications on the proper thickness.

Length: The appropriate length of channel in which rock should be placed should be at least the entire eroded section that is being protected, plus a minimum of 10 feet upstream and downstream of the eroded area. Be sure that the stone on the upstream and downstream ends are trenched in to prevent dislodging.

Where riprap is used only for slope or bank protection and does not extend across the bottom at the channel, riprap should be “keyed in” as shown in Exhibit 2.

Height: Install riprap to a height of three feet above the ordinary high water mark, or 1 foot above the ordinary high water mark if used in conjunction with bioegineering techniques. All exposed soil above the riprap should be stabilized according to the vegetative BMPs.

Design Example Problem:
A streambank has an ordinary high water mark of 3 feet, an 8 foot bottom width, 2:1 side slopes and a two percent slope. There is a 75 foot long curved bank that is eroding. Determine the proper rock size, appropriate stone gradation, and dimensions of the riprap.

1. Refer to example Problems #2 to solve for the proper stone size. Use a D_{50} stone size of 12 inches.

2. This riprap will be placed to a height of 6 feet (3 feet above the ordinary high water mark). The depth will be 24 inches: [1.5 x (stone size of 12 inches) = 18 inches + 0.5 foot granular stone = total of 24 inches].

3. The length of area covered with riprap will be the eroded area (75 feet) + 10 feet upstream and downstream = 95 feet.

4. A geotextile fabric will be installed beneath the riprap.

Construction:
1. Where grading is required, grade the site according to the grading plan. Grade only when stone is ready to be placed.

2. Compact gravel subgrades according to design. Any fill that is used should be compacted to a density approximating that of the surrounding undisturbed area.

3. Install geotextile filter fabrics according to the manufacturer’s specification. Always bury both the upper-most and toe of the geotextile fabric to prevent unravelling. (Basic installa-

tion techniques are discussed in the Filters BMP. Spread granular filters in uniform layers according to the design.

4. Install riprap. If riprap is dumped, hand place any rocks that need to be moved to fit the design.

Maintenance of Riprap on Stream Banks

Inspections should be made of all sites immediately after the first rainfall following installation of riprap. This is particularly important in areas where riprap that is displaced during the storm would impact culverts. Thereafter, riprapped sites should be checked following large storms, especially those which are near or exceed the storm frequency used in the design. Displaced riprap should be removed from its downstream location and new riprap placed according to the specifications above.

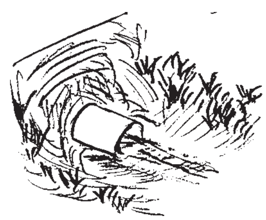
Outlets

General Considerations for Outlets

1. How and when to use a riprapped outlet should be made based on criteria given in the Stabilized Outlets BMP.

2. The outlet structure should be designed in conjunction with the conveyance system (i.e. pipe, outlet of a Sediment Basin, etc.) from which the water is outletted. There should be no overfall from the end of the pipe/outlet to the outlet structure (i.e. the pipe/outlet should not be suspended above the outlet structure).

overfall



no overfall

3. The outlet structure should be in place before water is released from the conveyance system.

4. Additional protection may be required on the opposite bank or downstream to prevent in-stream erosion.

5. There should be no overfall from the end of the apron to the receiving channel streambed.

Stone Size Selection for Outlets

1. The median stone diameter, d_{50}, in feet, shall be determined from the formula:

$$d_{50} = \frac{0.02}{TW}\left(\frac{Q}{D_o}\right)^{4/3}$$

Where TW is tailwater depth above the invert of the culvert in feet, Q is the pipe discharge in cfs for the conduit design storm, or the 25-year storm, whichever is greater, and

D_o is the maximum inside culvert width in feet.

2. Fifty percent by size of the riprap mixture should be larger than the median size stone designated as d_{50} and 50% should be smaller. The largest stone size in the mixture should be 1.5 times the d_{50} size. The riprap should be reasonably well-graded.

<u>Outlet Dimensions</u>
Refer to Exhibit 8.

1. **Length**: The length of the apron, L, should be determined using the following formula:

$$L_a = \frac{1.7\,Q}{D_o^{3/2}} + 8D_o$$ for culverts flowing up to 1/2 full.

$$L_a = \frac{3.0\,Q}{D_o^{3/2}}$$ for culverts flowing at or above 1/2 full

Where Q and D_o are as described above.

2. **Width**: Where there is a well-defined channel downstream of the apron, the bottom width of the apron should be at least equal to the bottom width of the channel. The structural lining should extend at least one foot above the tailwater elevation, but no lower than two-thirds of the vertical conduit dimension above the conduit invert.

Where there is *no* well-defined channel immediately downstream of the apron (i.e. as may apply to <u>Sediment Basins</u>) width, W, of the outlet end of the apron should be as follows:

For tailwater elevation greater than or equal to the elevation of the center of the pipe:

$$W = 3D_o + 0.4L_a$$

For tailwater elevation less than the elevation of the center of the pipe:

$$W = 3D_o + L_a$$

Where L_a is the length of the apron determined from the formula above and D_o is the culvert width.

The width of the apron at the culvert outlet should be at least three times the culvert width.

3. The side slopes should be 2:1 or flatter.

4. The bottom grade should be level (0.0%).

5. There should be no overfall from the end of the apron to the receiving channel streambed.

6. There should be no overfall at the end of the apron or at the end of the culvert.

7. There should be no bends or curves at the intersection of the conduit and apron.

<u>Stone Size and Gradation</u>

1. The median stone diameter, D_{50}, in feet shall be determined from the formula,

$$D_{50} = \frac{0.02}{TW}\left(\frac{Q}{D_o}\right)^{4/3}$$

   Where Q and D_o are as defined under apron dimensions and TW is tailwater depth above the invert of culvert in feet.

2. The largest stone size in the mixture shall be 1.5 times the D_{50} size. The riprap shall be reasonably well graded.

3. Gabions or precast cellular blocks may be substituted for riprap if the D_{50} size calculated above is less than or equal to the thickness of the gabions or concrete revetment blocks. See the <u>Shoreline/Slope Stabilization</u> BMP.

<u>Design Example Problem:</u>

Given: a maximum inside culvert width, D_o of 1.5 ft., a flow (Q) of 14/5 cfs, and a tailwater elevation, TW, of 0.7 feet, determine the appropriate design dimensions of the apron (h_a and W), and the D_{50} stone size.

<u>Solution</u>:

Using $$L_a = \frac{1.7Q}{D_o^{3/2}} + 8D_o$$

$$= \frac{1.7\,(14.5)}{(1.5)^{3/2}} + 8(1.5)$$

L_a = 25.4 feet, rounded up = 26 feet

Since TW < 0.5 D_o , use W = $3D_o + L_a$

= 3(1.5) + 26

W = 30.5 feet, rounded up = 31 feet

Using $$D_{50} = \frac{0.02}{TW}\left(\frac{Q}{D_o}\right)^{4/3}$$

$$= \frac{0.02}{0.7}\left(\frac{14.5}{1.5}\right)^{4/3}$$

D_{50} = 0.58 feet, converted and rounded = 7 inches

Maintenance

Inspections should be made of all sites immediately after the first rainfall following installation of riprap. This is particularly important in areas where riprap that is displaced during the storm would impact culverts. Thereafter, riprapped sites should be checked following large storms, especially those which are near or exceed the storm frequency used in the design. Displaced riprap should be removed from its downstream location and new riprap placed according to the specifications above.

Exhibits

Formulas included in this BMP were taken from the Rhode Island Soil Erosion and Sediment Control Handbook, Rhode Island Dept. of Env. Mgt., 1989.

Exhibit 1: Streambank stabilization using Riprap. MDNR Construction Project Evaluation Manual, 1987, and Rhode Island Soil Erosion and Sediment Control Handbook, as adopted from Connecticut Guidelines for Soil Erosion and Sediment Control, Connecticut Council on Soil and Water Conservation, 1985.

Exhibit 2: Length and Height of Riprap. MDEQ, Surface Water Quality Division.

Exhibit 3: Maximum depth of Flow for Riprap-lined Channels. “Design of Stable Channels with Flexible Linings”, Hydraulic Engineering Circular No. 15, Federal Highway Administration, 1975.

Exhibit 4: Distribution of Boundary Shear Around Wetted Perimeter of Trapezoid Channels. “Design of Stable Channels with Flexible Linings”, Hydraulic Engineering Circular No. 15, Federal Highway Administration, 1975.

Exhibit 5: Angle of Repose for Riprap Stone. Virginia Erosion and Sediment Control Handbook, Virginia Soil and Water Conservation Commission, 1980.

Exhibit 6: Ratio of Critical Shear on Sides to Critical Shears on Bottom. “Design of Stable Channels with Flexible Linings”, Hydraulic Engineering Circular No. 15, Federal Highway Administration, 1975.

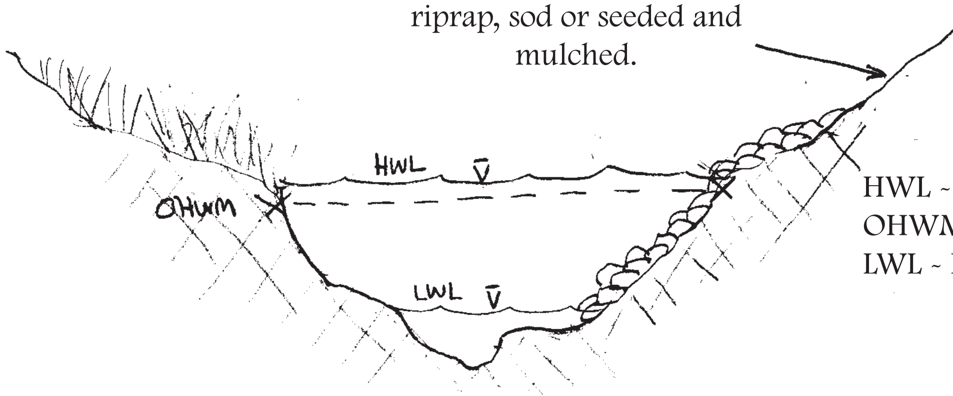
Exhibit 7: Ratio of Maximum Boundary Shear in Bends to Maximum Bottom Shear in Straight Reaches. Virginia Erosion and sediment Control Handbook, Virginia Soil and Water Conservation Commission, 1980.

Exhibit 8: Configuration of Conduit Outlet Protection where there is no well defined channel downstream. Standards for Soil Erosion and Sediment Control in New Jersey, New Jersey Soil Conservation Committee, 1980.

Exhibit 1

Ordinary High Water Mark

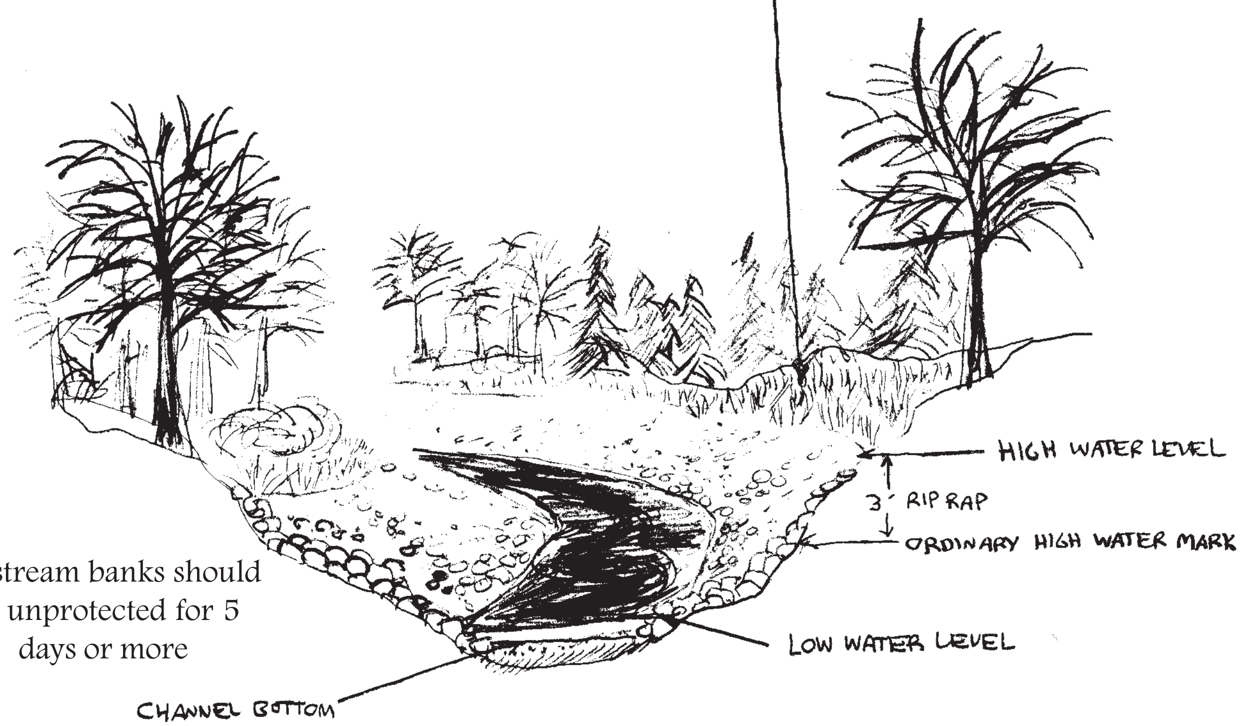
All raw soil above permanent riprap should be covered with riprap, sod or seeded and mulched.



HWL - High Water Level
OHWM - Ordinary High Water Mark
LWL - Low Water Mark

The ordinary high water mark is the normal water level, which on a river is where the grass stops and the bare soil starts.

All raw soil above permanent riprap should be covered with riprap, sod or seeded and mulched.

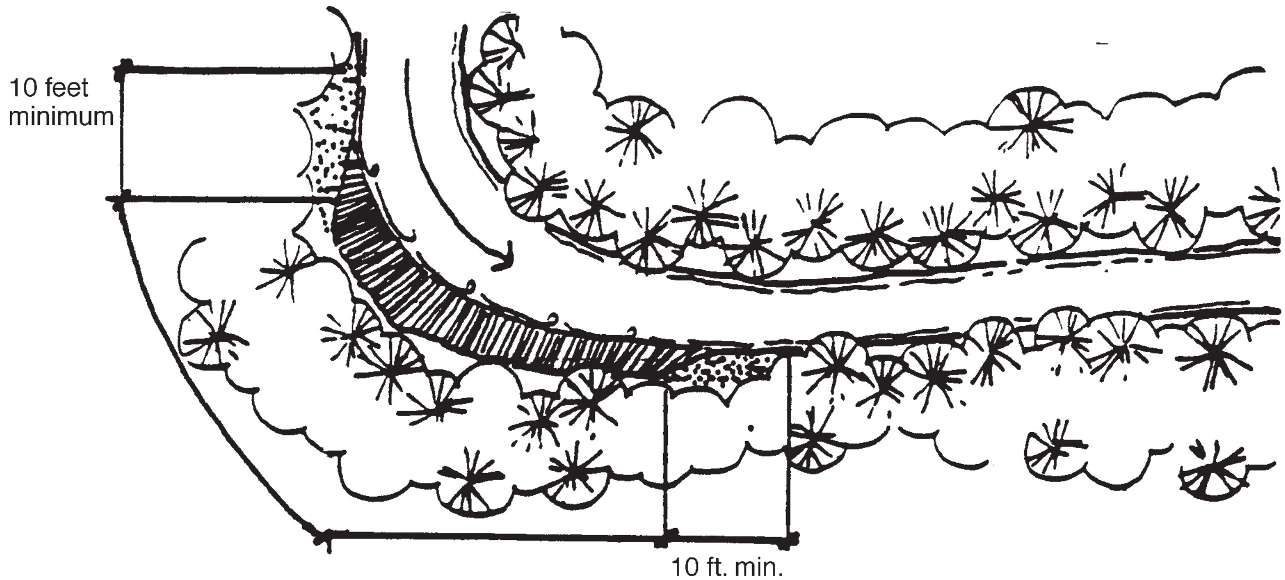


No stream banks should be unprotected for 5 days or more

Source: Michigan Department of Environmental Quality, Land and Water Management Division, 1997.

Exhibit 2

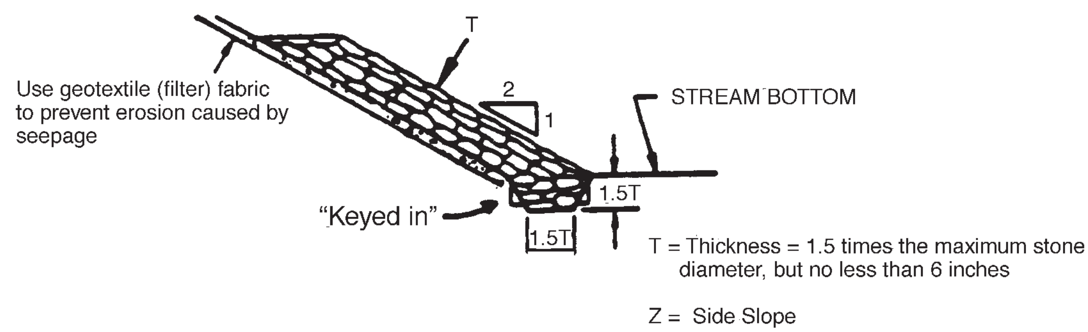
Riprap Placement: Length, Thickness, Height



Length to stabilize: cut bank, plus a minimum of 10 feet on both sides.

Height to stabilize: usually three feet above the Ordinary High Water Mark; can be less on hydrologically stable streams.

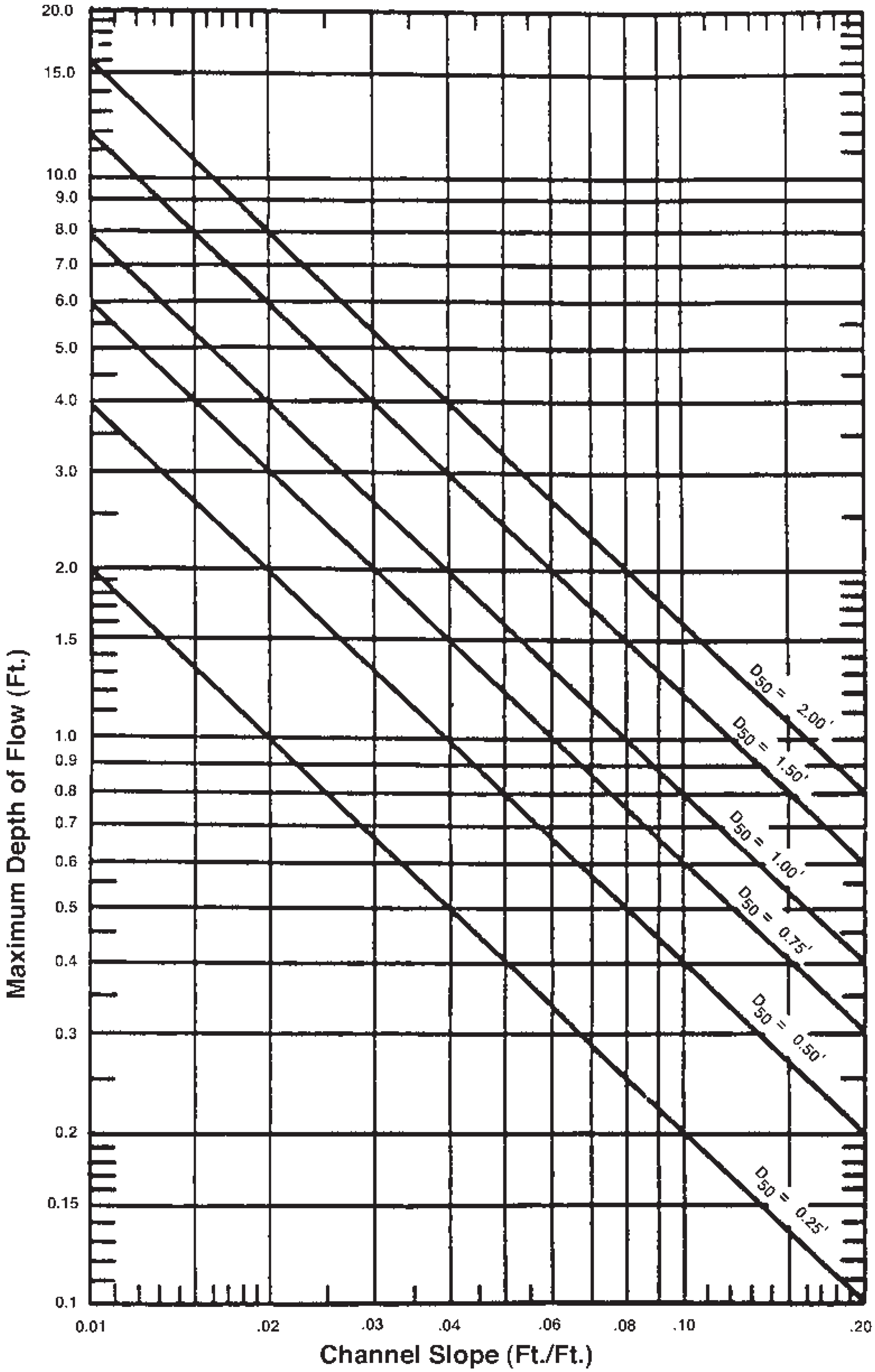
"Keying in"



Sources: Top: Construction Project Evaluation Manual. Michigan Department of Environmental Quality, Land and Water Mangement Division. Redrawn 1997. Bottom: Rhode Island Soil Erosion and Sediment Control Handbook, as adopted from the Connecticut Guidelines for Soil Erosion and Sediment Control, Connecticut Council of Soil and Water Conservation, 1985. Redrawn 1997 by MDEQ.

Exhibit 3

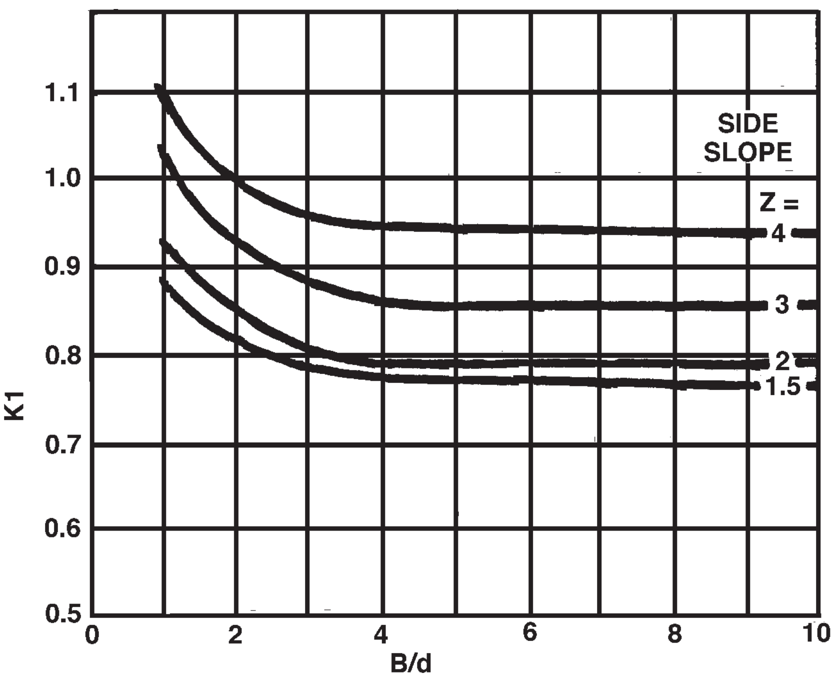
Maximum Depth of Flow for Riprap-Lined Channels



Source: Design of Stable Channels with Flexible Linings, Hydraulic Engineering Circular No. 15, Federal Highway Administration, 1975, as copied from the Rhode Island Soil Erosion and Sediment Control Handbook.

Exhibit 4

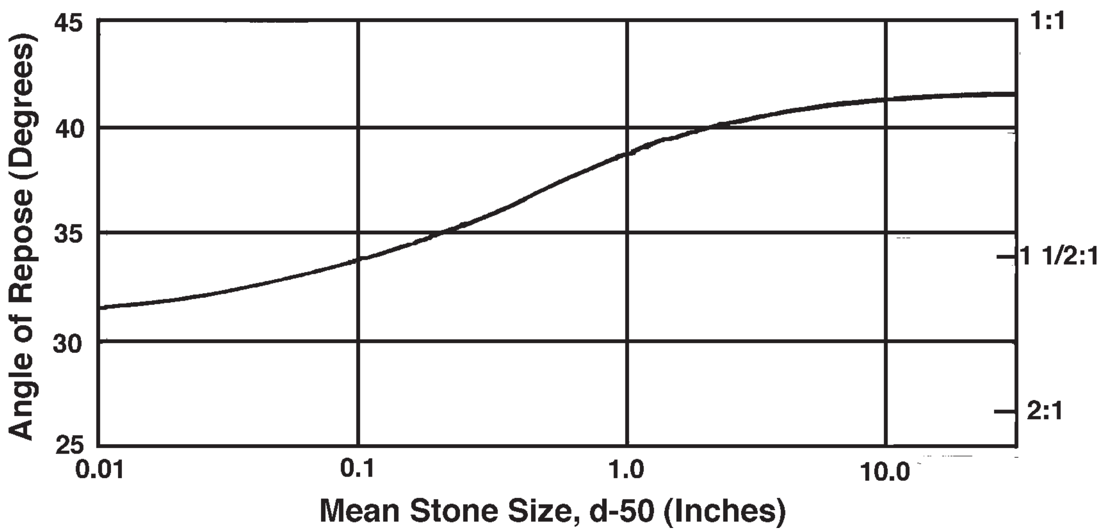
Distribution of Boundary Sheer Around Wetted Perimeter of Trapezoidal Channels



Source: Design of Stable Channels with Flexible Linings, Hydraulic Engineering Circular No. 15, Federal Highway Administration, 1975, as copied from the Rhode Island Soil Erosion and Sediment Control Handbook.

Exhibit 5

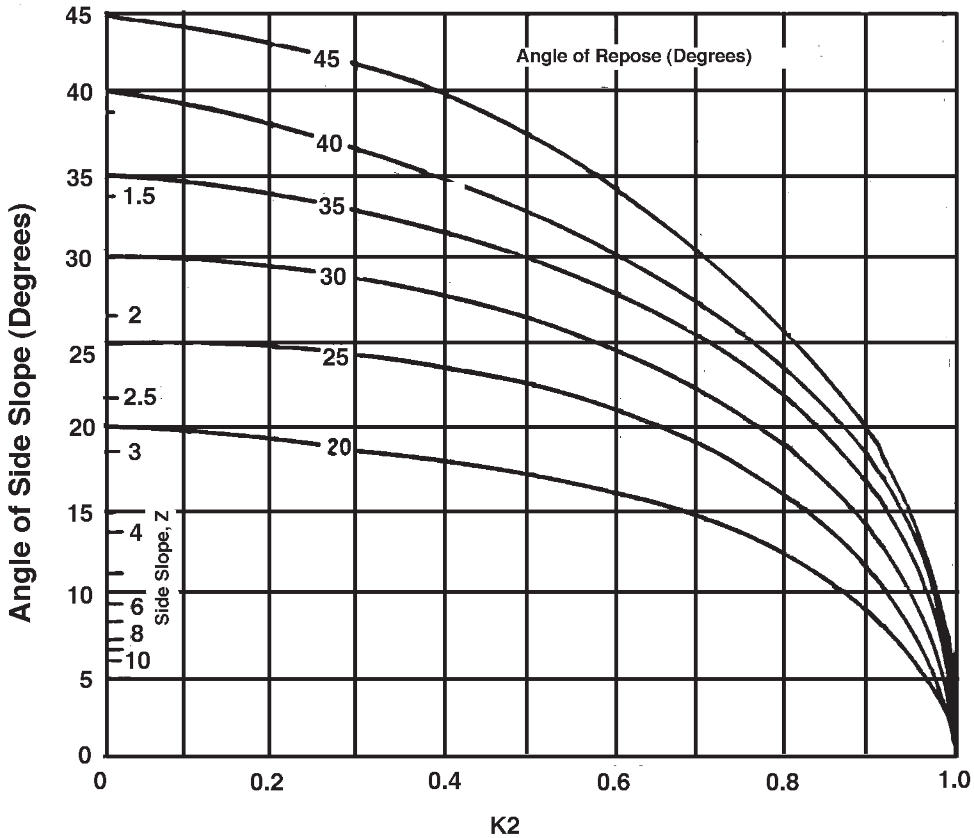
Angle of Repose for Riprap Stones



Source: Virginia Erosion and Sediment Control Handbook, Virginia Soil and Water Conservation Commission, 1980, as copied from the Rhode Island Soil Erosion and Sediment Control Handbook.

Exhibit 6

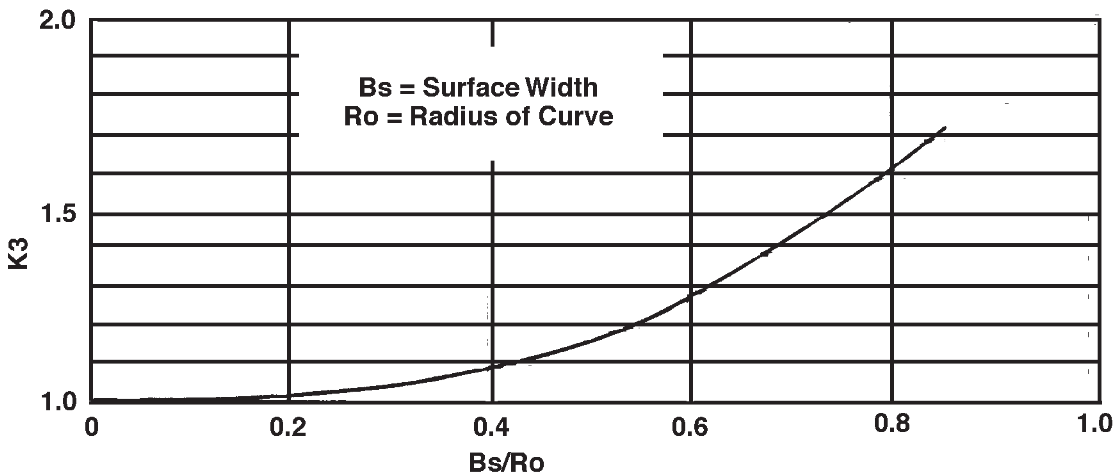
Ratio of Critical Shear on Sides to Critical Shear on Bottom



Source: Design of Stable Channels with Flexible Linings, Hydraulic Engineering Circular No. 15, Federal Highway Administration, 1975, as copied from the Rhode Island Soil Erosion and Sediment Control Handbook.

Exhibit 7

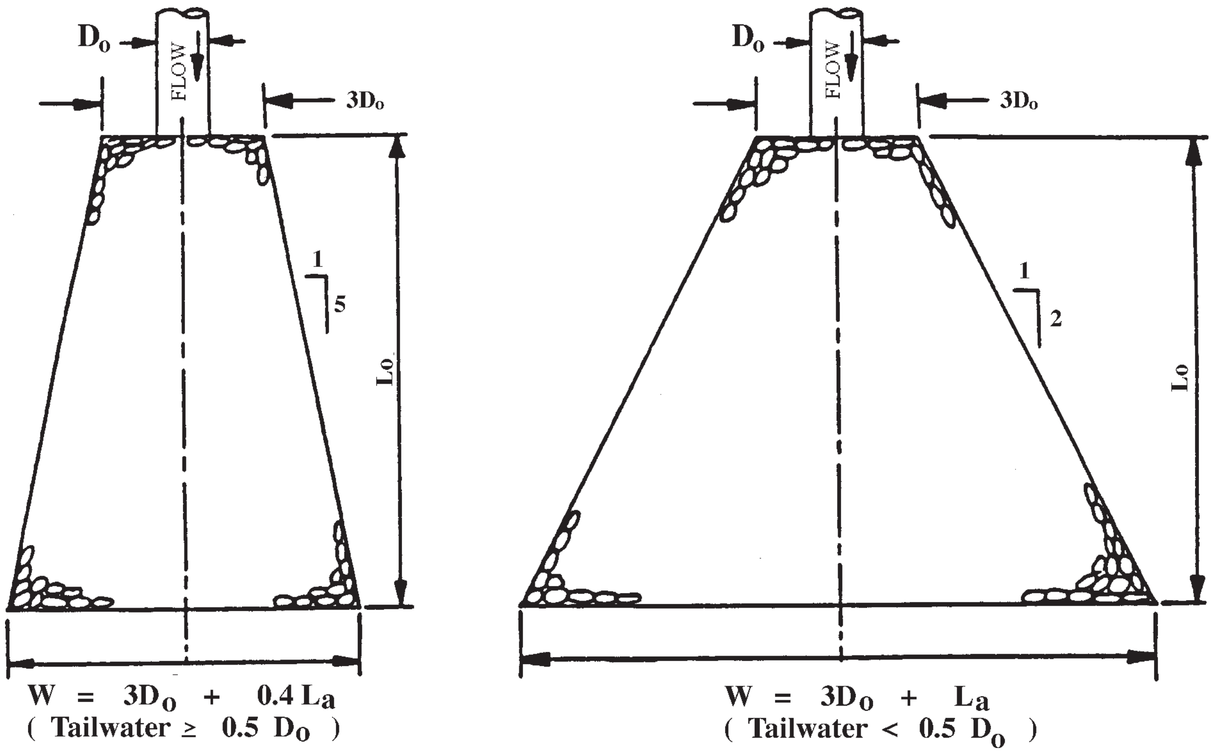
Ratio of Maximum Boundary Shear in Bends to Maximum Bottom Shear in Straight Reaches



Source: Virginia Erosion and Sediment Control Handbook, Virginia Soil and Water Conservation Commission, 1980, as copied from the Rhode Island Soil Erosion and Sediment Control Handbook.

Exhibit 8

Configuration of Conduit Outlet Protection Where There is no Well-Defined Channel Downstream



Source: Standards for Soil Erosion and Sediment Control in New Jersey, New Jersey Soil Conservation Committee, 1980, as copied from the Rhode Island Soil Erosion and Sediment Control Handbook.