CHAPTER DR-05
CHANNELS AND DITCHES

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DR-05.900 EXHIBITS

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DR-05.100 FUNDAMENTALS
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DR-05.100 Open Channel Flow

An open channel is defined as any conduit in which liquid flows with a free surface such as a stream, roadside ditch, depressed median, slope flume, or pipe flowing part full.

Open channel flow includes all types of flow, especially in natural channels. The various types of flow are:

1. Laminar or streamline flow - all particles move parallel to each other
2. Turbulent flow - swirls and eddies are prevalent
3. Steady flow - the quantity of water passing a cross section is constant
4. Uniform flow - the velocity is the same at all cross sections
5. Non-uniform flow - variable velocity
6. Steady uniform flow - the quantity and velocity are the same at all points along the channel. For this condition the cross section of flow must be constant, such as ditches and excavated channels with unvarying cross sections.
7. Steady non-uniform flow - the quantity of flow is constant at any point, but the velocity varies. This type of flow is most common in natural streams. By subdividing the channel reach, the available flow formulas, which assume steady uniform flow, may be used to analyze the reach.

DR-05.120 Equation of Continuity

If steady flow exists throughout a reach of any channel there is a continuity of discharge or, as commonly stated, continuity of flow. The mean velocities at all cross sections having equal areas are equal. If the areas are not equal, the velocities are inversely proportional to the areas of the respective cross sections.

Thus, A_1V_1 and A_2V_2 are the respective products of area and mean velocity at any two cross sections in an open channel where continuity of flow exists.

$$A_1V_1 = A_2V_2 \quad \text{and} \quad V_1/V_2 = A_2/A_1$$

DR-05.130 Hydraulic Radius

Area, a single numerical value, is insufficient to characterize a cross section. The measure generally used is the hydraulic radius, which is the quotient of the area divided by the wetted perimeter. The hydraulic radius has a dimension of depth, and for very wide channels with shallow depths, the value approaches average depth.

$$R = A/P$$

R = hydraulic radius
A = area of cross section of flow
P = length of wetted perimeter

The most efficient cross section of an open channel would be one having a maximum capacity for a given slope, area, and roughness factor. This cross section is the one having the smallest wetted perimeter and is the half circle. A rectangular cross section has the highest efficiency when the depth equals one half the width.

DR-05.140 Specific Head

According to Bernoulli's energy theorem, flowing water contains the same total energy at all points, neglecting energy loss due to friction. Energy of the water may be of two forms: potential energy due to depth of the water and elevation above some zero datum plane and kinetic energy due to velocity. Potential energy is represented by potential head depth plus height ($d + Z$), above the zero datum plane, in feet; and kinetic energy is represented by the velocity head ($V^2/2g$), in feet. In Exhibit 5.930, the total head at point 1 in a stream is equal to the total head at point 2 in the stream plus head losses occurring between the two points:

$$d_1 + V_1^2/2g + Z_1 = d_2 + V_2^2/2g + Z_2 + h_f$$

It is often convenient to consider the energy content with respect to the channel bottom. This is called the specific energy, or specific head, and is equal to the depth of the water plus the velocity head ($d + V^2/2g$). The slope of the energy line is a measure of the friction slope or rate of energy head lost due to friction($S = h_f/L$).

For small channels, the specific energy is constant. Thus the friction loss, h_f is equal to the elevation difference between the two points in the channel (Z_1 - Z_2). The friction slope is used in the Manning's equation below to determine the flow conditions.

For large channels, the specific energy can not be assumed constant and a Standard Step Backwater procedure must be used. By trial and error, the above energy equation is balanced using the Manning's equation below.

DR-05.150 Manning's Equation

Manning's formula for computing flow in open channels is widely used because of its simplicity:

$$V = (1.486/n)(R^{0.67})(S^{0.5})$$

Where: V = velocity, ft./sec.
R = hydraulic radius, ft.
S = slope of channel, ft. per foot
n = roughness coefficient

The roughness coefficient, n, accounts for the character of:

a. Stream or channel bed
b. Banks or side slopes
c. Vegetation both in channel and on banks

Values of n for use in Manning's formula are given in Exhibit 05.901.

DR-05.160 Critical Flow

Relative values of potential energy (depth) and kinetic energy (velocity head) are important in that channels may be at various slopes thus causing various depths and velocities for a specific discharge. There will be a specific slope for which the total energy content, in order to maintain a specific discharge, will be minimum. This slope is known as critical slope (Sc), and the velocity and depth of flow at this slope are known as critical velocity and critical depth. Flow at slopes steeper than critical is termed supercritical and at slopes flatter than critical is termed subcritical. When flow is supercritical, downstream changes in channel slope or roughness will not be reflected upstream; whereas, in subcritical flow, downstream channel changes will be reflected upstream and affect the flow in the upstream channel.

DR-05.170 Depth of Flow

Depth of flow in an open channel depends upon 4 factors:

1. Quantity of flow, Q
2. Slope of channel, S
   a. Longitudinal grade when flow is at normal depth. Water surface will be parallel to channel bed.

   b. Normal depth is approached in long reaches of uniform sections. This is difficult to find on many small streams where cross sections are irregular. When this occurs, average cross sections for reach will do.
3. Roughness of channel,n
4. Shape of cross section as reflected in hydraulic radius, R

For given values of Q, S, n, and R, the normal depth, dn, may be found by applying the Manning formula.

For given values of Q, n, and R, and a varying slope, the depth will vary:

1. When the slope is flat:
   a. Normal depth, dn, is large
   b. Flow is controlled by conditions downstream

2. As the slope increases:
   a. Normal depth decreases
   b. Velocity increases

3. When the slope reaches a certain value, control passes from downstream to upstream:
   a. Slope is critical slope, Sc
   b. Normal depth, dn, equals critical depth, dc
   c. Critical depth, dc, will vary with different channels or flow discharges

4. As the slope increases beyond critical:
   a. Normal depth decreases
   b. Velocity increases

Critical depth, dc, and critical velocity, Vc, are:

1. Dependent upon:
   a. Discharge
   b. Size of area
   c. Shape of channel

2. Independent of:
   a. Roughness of channel

   Critical slope, S_c, is:

1. Dependent upon:
   a. Discharge
   b. Size of area
   c. Roughness of channel

NOTES AND COMMENTS

DR-05.200 HIGHWAY DITCHES

DR-05.210 General

This section discusses various types of ditches and channel changes used in highway applications. The ditches have been named based on their general use and location. Roadway ditches refer to ditches that are constructed in conjunction with roadway cut sections.

Interceptor ditches are also associated with cut sections, but they are constructed at the top of cuts to prevent excess water from ever reaching the roadway ditch. They are also used at the top of cuts where the soil may be highly erodible. Surface ditches are associated with fill sections. Usually a berm is constructed near the toe of a fill to deflect surface water from the fill into the ditch. These ditches are formed by excavating the ditch shape into the existing groundline surface. Median ditches are located in depressed medians between the opposing traffic flow lanes of what is usually a multi-lane highway facility.

Special ditches are those roadway ditches in cuts where the geometry varies from the normal typical section. If a roadway ditch is constructed wider, deeper, or is shaped differently than the typical roadway section, then it is classified as a special ditch.

The term "channel change" usually refers to a change in the location of a channel or stream. The new channel should be designed to duplicate the old channel as nearly as possible. Do not confuse short inlet and outlet ditches to and from pipes or culverts with channel changes.

The term "channel improvement" refers to that work in a stream where perhaps one side of the channel is reconstructed, or excess sediment is removed to improve flow. The widening of a channel to improve flow is not a good engineering practice. Attempting to improve hydraulics in a localized area through channel widening produces only a temporary cosmetic improvement. The widened channel will eventually fill itself to the extent of the pre-construction conditions. Therefore, channel widening should be avoided.

DR-05.220 Normal Roadway Ditches

Normal roadway ditches are defined as open channels alongside and parallel to the highway in cuts which carry runoff from the roadway and adjacent areas. These ditches are to be of sufficient depth as to allow the seepage of water from the subgrade into the ditch to insure permanency.

Normal roadway ditches usually have a "V" shape. They can also have a flat-bottom shape, or be part of a rock cut ditch bench. The geometry of normal roadway ditches is determined by the category of highway. The category of highway is based on: (1) the purpose of the highway and (2) the traffic volume.

Normal roadway ditch dimensions for Interstate highways and projects designed with full safety shall be an 18 foot ditch on a 6:1 side slope from the edge of the shoulder. This will give a usable ditch depth of 1.5 feet.

The hydraulic design of roadway ditches consists of: (a) determining whether the normal roadway ditch is sufficient to carry the design flow without encroaching on the highway shoulder, and (b) determining the lining necessary to prevent scour or undesirable sedimentation in the ditch. The general procedure for obtaining the Rational Discharge is to subdivide the ditch into sections by stations. For each section the area contributing runoff should be determined as well as the weighted value of "C." A 10 -Year Return Interval shall be used to determine the Rainfall Intensity for the Rational Formula: $Q = CIA$. The discharge for any section shall be determined by totaling the CA's and calculating the longest Time-of-Concentration for the area.

The capacity of the ditch will vary with its cross-section, the longitudinal slope, roughness, and hydraulic radius; and may be determined by the Manning Formula. In the event the normal roadway ditch exceeds the allowable depth of flow and there is no outlet for disposal of the water, it will be permissible to resort to a special ditch as needed to carry the flow. See 5-230.

In sections on steep grades and unstable soils, it is desirable to use a widener ditch to control velocity. When this cannot be accomplished a ditch lining should be designed to fit that situation.

When depressed medians are used on divided highways, the side ditches shall be designed to carry additional runoff in the event water from the median must be cross drained to the side ditch. This will require a larger side ditch. A comparison between the cost of larger ditches and the cost of storm sewers should be made to determine the best alternative.

DR-05.230 Median Ditches

Median ditches are associated with multi-lane facilities which have depressed medians. These ditches intercept the surface drainage from the pavement area and the inside shoulders. They also collect seepage from the subgrade. The typical median ditch is V-shaped. Its geometry is based on the median width established for the project.

A minimum median ditch grade of 0.5% should be maintained if at all possible. In cut sections with flat roadway grades use special ditches to adjust the ditch to obtain the minimum ditch grade. In fill sections the surface ditches can usually be designed to accommodate the minimum grade. There are, however, areas in Kentucky where the surrounding terrain is flat enough to prevent the use of the minimum grade. Where those situations arise, use the best engineering judgement in determining the minimum slopes.

DR-05.240 Special Ditches

When roadway or median ditches are designed to exceed the geometrics as described on a typical section, they shall be known as "special ditches." They may be deeper or wider or both deeper and wider than the prescribed geometrics for roadway or median ditches.

Special ditches should be shown on the cross sections and the quantities included with those computed for the regular typical section.

All special ditches should be shown on the Plan and Profile Sheets whether or not the cross sections are a part of the plans. When cross sections are included, special ditches shall be detailed in accordance with Exhibit 5.902(a).

DR-05.250 Interceptor Ditches

Interceptor ditches are used on all categories of highways to intercept surface water at the top of cuts. Interceptor ditches may be used when erodible soils are encountered. The ditch is used in this situation to stabilize the problem by eliminating erosive actions of surface water. Interceptor ditches should also be used when one or more existing drains are undercut. This surface water should be ditched on top of the cut to eliminate icing or water problems which could occur.

Care must be exercised in the positioning of these ditches. They should be a minimum of 10 feet back from the top of the cut and of sufficient depth and width to accommodate the volume of water intercepted. For an example of interceptor ditch placement, see Standard Drawings RDD-001-02 and RDD-002-03 for details regarding the paving of interceptor ditches.

Interceptor ditches are to be shown on the cross sections and quantities shown as a separate item when plotted manually. This is to show the Contractor that the quantities have been included and not overlooked. When the computer method is used in lieu of cross sections, the volume of the ditch will not be shown. This item will be shown on the final construction plans and paid for as Roadway Excavation.

Interceptor ditches are to be shown on the Plan and Profile Sheets whether or not the cross sections are a part of the plans. When cross sections are included, interceptor ditches shall be detailed in accordance with Exhibit 5.902(b).

Interceptor ditches should be designed using the same procedure developed for normal roadway ditches. An alignment and grade should be developed to eliminate abrupt changes. Juncture points should be radiused toward the downstream flow. These measures are intended to streamline the flow and lesson the erosive forces acting at points of adverse turns.

DR-05.260 Surface Ditches

Surface ditches are those ditches cut in the original ground which, more or less, parallel the toe of a fill to protect the fill from the surface water washing against and eroding it. They also intercept water from the pavement and fill slope and transport this water to safe disposal areas. A flat-bottom shaped ditch is generally used for surface ditches because of ease of construction.

Surface ditches shall be placed outside and away from the toe of fill as shown in Exhibit 5.902(c). They shall be designed for a depth and width that will efficiently accommodate and transport the surface water.

The designer should attempt to develop an alignment for the surface ditch which is fairly straight, whenever practical. For ditches with substantial volumes of water and steep gradients, severe horizontal breaks in alignment will create maintenance problems and impair the hydraulic efficiency of the ditch downstream.

Surface ditches are to be shown on the cross sections and quantities shown as a separate item. Channel lining should be plotted below the ditches.

Surface ditches are to be shown, on the Plan view, as two parallel solid lines, indicating the flat-bottom shape. The flow line of the ditches shall be plotted in the profile as a single continuous line. The slopes of the ditch segments should be indicated or the elevation at each break in grade provided.

Surface ditches should be designed using rainfall intensity for a 10 - Year storm. An alignment and grade should be developed to eliminate abrupt changes. Juncture points should be radiused toward the downstream flow. These measures are intended to stream-line the flow and lesson the erosive forces acting at points of adverse turns.

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DR-05.300 CHANNEL DESIGN
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DR-05.310 General

This section will outline a process for assessing a natural stream channel and a more specific design procedure for roadside channels.

DR-05.320 Stream Channels

The analysis of a stream channel in most cases is in conjunction with the design of a highway hydraulic structure such as a culvert or bridge. In general, the objective is to convey the water along or under the highway in such a manner that will not cause damage to the highway, stream, or adjacent property. An assessment of the existing channel is usually necessary to determine the potential for problems that might result from a proposed action. The detail of studies necessary should be commensurate with the risk associated with the action and with the environmental sensitivity of the stream and adjoining flood plain.

Although the following step-by-step procedure may not be appropriate for all possible applications, it does outline a process which will usually apply.

<u>STEP 1</u>

Assemble site data and project file.

A. Data Collection (see Data Collection, Chapter 3)

- Topographic, site, and location maps
- Roadway profile
- Photographs
- Field reviews
- Design data at nearby structures
- Gaging records

B. Studies by other agencies

- Flood insurance studies
- Floodplain studies
- Watershed studies

C. Environmental constraints

- Floodplain encroachment
- Floodway designation
- Fish habitat
- Commitments in review documents

D. Design criteria

STEP 2

Determine the project scope.

A. Determine level of assessment

- Stability of existing channel
- Potential for damage
- Sensitivity of the stream

B. Determine type of hydraulic analysis

- Qualitative assessment
- Single-section analysis
- Step-backwater analysis

C. Determine additional survey information

- Extent of streambed profiles
- Locations of cross sections
- Elevations of flood-prone property
- Details of existing structures
- Properties of bed and bank materials

STEP 3

Evaluate hydrologic variables.

A. Compute discharges for selected frequencies.

B. Consult Hydrology Section, Chapter 4.

STEP 4

Perform hydraulic analysis.

A. Single-section analysis

- Select representative cross section.

- Select appropriate "n" values (Exhibit 05.901).
- Compute stage-discharge relationship.

B. Step-backwater analysis

C. Calibrate with known high water.

STEP 5

Perform stability analysis.

A. Geomorphic factors

B. Hydraulic factors

C. Stream response to change

STEP 6

Design countermeasures.

A. Criteria for selection

- Erosion resistance
- Stream characteristics
- Construction and maintenance requirements
- Vandalism considerations
- Cost considerations

B. Types of countermeasures

- Meander migration countermeasures
- Bank stabilization countermeasures
- Bend control countermeasures
- Channel braiding countermeasures
- Degradation countermeasures
- Aggradation countermeasures

C. For additional information

- HEC-20 Stream Stability
- Highways in the River Environment
- See Reference List

STEP 7

Documentation

- Prepare report and file with background information.
- See Site Specific Documentation, Chapter 3.

DR-05.330 Channel Changes

Channel changes are artificially created trenches which replace sections of natural channels. These man-made channels should be of sufficient depth and width to carry the flow without creating a potential hazard to either the roadway or surrounding property. Positioning the channel change to provide uninterrupted flow is important in eliminating a potential damage factor.

The potential adverse environmental effects of channel changes underscore the importance of evaluating reasonable alternatives. Consideration of prime farmland, floodplain encroachment, and wetlands further restrict the use of channel changes. Estimates of cost for various alternatives to avoid channel changes shall be prepared and included in the documentation of the final recommendation. The emphasis is on avoiding channel changes whenever possible, but it must be understood that other factors may result in highways being located where channel changes are unavoidable.

Inlet and/or outlet ditches associated with Blue-Line Streams shall be classified as channel changes when the Ditch Disturbances are over 200 feet long. Otherwise they are just inlet and/or outlet ditches as applicable.

Channel changes are grouped into two categories - small channels and large channels. For the basic evaluation of channel changes each is defined as follows:

Small Channel- Stream having an average flow of 5 cfs or less. Flow can be intermittent.

Large Channel- Stream having an average flow of more than 5 cfs.

The first step in the evaluation process is to review proposals at the Preliminary Line and Grade Inspection. Channel changes greater than 100 feet in length on "large channels" must be outlined on the preliminary plans. Plans may be furnished to the Department of Fish and Wildlife Resources and the Division of Environmental Analysis for their use in evaluating potential impacts. An invitation to attend the inspection may also be extended. The designer may prepare preliminary cost estimates for alternative proposals at this point.

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A decision concerning channel changes must be made at this stage. Unavoidable channel changes must be documented and the Division of Environmental Analysis requested to prepare a Water Quality and Aquatic Ecosystem Study if one has not been prepared already. Plans depicting the affected areas will be submitted to that office as an attachment.

The P L G I report must include a discussion of recommended channel changes. At this stage, special plan and profile sheets for channel changes longer than 500 feet on "large channels" will be required. The plan shall be on a scale of 1" = 100'. Horizontal alignment data and the relationship of the proposed channel to the highway will be included. Design controls such as houses or other structures shall be located and critical elevations shown for each. The profile shall show both the proposed stream profile with existing ground as well as the existing stream profile. Highwater profiles and normal water surface profiles will be shown.

Whenever feasible, the design of a channel change should incorporate the following measures:

1. Adding curvature and meanders to channel change alignment to minimize loss of length

2. Varying bottom slope in individual channel changes to create variations in velocity and depth of flow

3. Approximating natural stream width with channel change width

4. Approximating natural stream bank slope with channel change bank slopes

5. Revegetating banks of the channel change with trees indigenous to the area in concentrations conforming with the cover on the natural stream

6. Refraining from unnecessary rip-rapping above the high flow level on the bank because this practice retards the rate of revegetation and succession of the stream bank

7. Approximating the natural riffle-pool ratio by using gabion riffle structures and non-uniform placement of bottom materials (i.e. placing large boulders, etc.)

8. Designing channels to have adequate depth of flow during dry weather to maintain habitats for aquatic life. This might

include side pools, slanting streambeds to provide a shallow side and a deep side, and using a small channel within the main channel to carry this flow.

Cross sections for the channel changes may be handled in one of two ways. One way would be to use separate sections for the channel, which is desirable since the channels will normally be at variable distances from the highway centerline. Another means would be to use cross section extensions from the highway, which may be used for "small channels" or "large channels" where less than 500 feet is changed. Hydraulic sections spaced approximately 500 feet apart, which depict at least the 100 year floodplain (500 Year floodplain if in a Regulatory Floodway), must be plotted and included with the special plan and profile sheet. These sections will be used to evaluate the need for a detailed floodplain encroachment study.

The final joint inspection should be a time for discussing measures to mitigate the effect of proposed channel changes. The Department of Fish and Wildlife Resources again will receive plans and be invited to the inspection. On most channel changes, the Department of Fish and Wildlife Resources and the Department of Transportation will have reached an agreement on mitigation measures in compliance with the Fish and Wildlife Coordination Act. On other locations, mitigation measures such as riffle pool structures, habitat improvement deflectors, rip-rap, and stream meanders will be considered by the designer. Final selection of appropriate measures will be left to the inspection party.

Acceptance of the final channel change plan will be requested from the Department of Fish and Wildlife Resources. A final cost estimate for alternatives will be submitted by the designer to the Drainage Section. The normal assessment for projects which have no formal Environmental Impact Statement will be prepared by the designer and supplemented by the addition of a Water Quality Aquatic Ecosystem Report prepared by the Division of Environmental Analysis. Documentation pertinent to the final decision to adopt the channel change will be submitted as part of the Section 404 permit application.

Small channels normally do not require a permit, but care in recommending channel changes should still be exercised. Because of the requirement of the Fish and Wildlife Coordination Act, many of these small channels will have mitigation recommendations agreed to in the planning stage. Additional coordination will not be required but alternatives must be analyzed and mitigation employed where possible.

Channel changes for culverts are undesirable. The designer should locate structures on skews of 0, 15, 30 or 45 with the inlet and outlet in the natural channel. No more than 200 feet of channel change in most situations will be approved. An exception to this will be for those designs complementing proposed channelization by other agencies.

Channel cleanout, or other such measures proposed at bridge crossing, will be avoided unless a significant obstruction is present. Rip-rap will be used on the banks only when there is a stability problem or at the recommendation of the Division of Materials. Uniform bank slopes above and below the stream crossing should be left undisturbed.

The positioning of channel changes relative to the highway embankment should be done as detailed in Exhibit 05.903. If it is not possible to attain the minimum berm distance, the side of the channel adjacent to the roadway may be lined with rip-rap or other suitable material.

When a channel change is required in the proximity of fill slopes, an accurate highwater elevation is important. In the case of fills constructed of earth or other easily erodible materials, saturation and/or scour could occur if the known highwater elevation exceeds that of the toe of the fill. This could result in slipping or sloughing conditions resulting in fill deterioration. If such conditions are anticipated, special precautions must be taken. This may be done by constructing a rock berm against the face of the fill to an elevation above the known highwater. The rock berm should be at least 10 feet horizontally to facilitate construction. If suitable rock fill material is not available, Cyclopean Stone Rip-Rap may be used. The standard use of rip-rapping is a 2 foot thickness. For cases of extreme erosive conditions, the thickness should be 3 to 4 feet (see Exhibit 05.903).

The construction of channel changes involves excavating areas originally used for some other function. Soil conditions may vary from those where the original channel was located. The channel slopes are nearly always cleaner, thus resulting in a velocity increase. Erosion can become a serious maintenance problem unless input is obtained from the Division of Materials.

Channel side slopes are an important factor for consideration. The type of soil or rock should ultimately determine the side slope but the following list can be used as a guide:

Earth slope - 2:1, preferably 3:1
Shale slope - 1/2:1, preferably 1 1/2:1
Solid rock - 1/4:1, if deemed necessary

DR-05.340 Design Procedure

Each project is unique, but the following six basic design steps are normally applicable:

STEP 1

Establish a roadside channel plan.

A. Collect available site data.

B. Obtain or prepare existing and proposed plan/profile layout, including highway, culverts, bridges, etc.

C. Determine and plot on the plan the locations of natural basin divides and roadside channel outlets. An example of a roadside channel plan/profile is shown in Exhibit 5.940.

D. Plot the layout of the proposed roadside channels to minimize diverted flow lengths.

STEP 2

Obtain or establish cross section data.

A. Provide channel depth adequate to drain the subbase and minimize freeze/thaw effects.

B. Choose channel side slopes based on geometric design criteria including safety, economics, soil, aesthetics, and access.

C. Establish bottom width of trapezoidal channel.

D. Identify features which may restrict cross-sectional design:

- right-of-way limits
- trees or environmentally-sensitive areas
- utilities
- existing drainage facilities

STEP 3

Determine initial channel grades.

A. Plot initial grades on plan/profile layout. Slopes in roadside ditches, in cuts, are usually controlled by highway grades.

B. Provide minimum grade of 0.5% to minimize ponding and sediment accumulation.

C. Consider influence of type of lining on grade.

D. Where possible, avoid features which may influence or restrict the grade, such as utility locations.

STEP 4

Check flow capacities and adjust as necessary.

A. Compute the design discharge at the downstream end of a channel segment (see Hydrology Section, Chapter 4).

B. Set preliminary values of channel size, roughness coefficient, and slope.

C. Determine maximum allowable depth of channel including freeboard.

D. Check flow capacity using Manning's Equation and single section analysis.

E. If capacity is inadequate, possible adjustments are as follows:

- increase bottom width
- make channel side slopes flatter
- make channel slope steeper
- provide smoother channel lining
- install drop inlets and a parallel storm drain pipe beneath the channel to supplement channel capacity

F. Provide smooth transitions at changes in channel cross sections.

G. Provide extra channel storage where needed to replace floodplain storage and/or to reduce peak discharge.

STEP 5

Determine channel lining/protection needed (HEC-15).

A. Select a lining and determine the permissible shear stress (τ_p), in lbs/ft^2, from Table 5-2 and/or Table 5-3.

B. Estimate the flow depth, and choose an initial Manning's "n" value from Table 5-4 or from Exhibits 5.950 through 5.955.

C. Calculate normal flow depth (y_o), in ft, at design discharge using Manning's Equation and compare with the estimated depth. If they do not agree, repeat steps 5B and 5C.

D. Compute maximum shear stress (τ_d), in lbs/ft^2, at normal depth as: $\tau_d = 62.4\ y_o\ S$

E. If $\tau_d < \tau_p$ then lining is acceptable. Otherwise consider the following options:

- choose a more resistant lining
- use concrete, gabions, or other more rigid lining either as full lining or composite
- decrease channel slope
- decrease slope in combination with drop structures
- increase channel width and/or flatten side slopes

STEP 6

Analyze outlet points and downstream effects.

STEP 7

Fill out the ditch analysis forms or provide computer output containing appropriate information.

A. Identify any adverse impacts to downstream properties which may result from any of the following at the channel outlet:

- increase or decrease in discharge
- increase in velocity of flow
- confinement of sheet flow
- change in outlet water quality
- diversion of flow from another watershed

B. Mitigate any adverse impacts identified in 6A. Possibilities include:

- enlarge outlet channel and/or install control structures to provide detention of increased runoff in channel
- install velocity control structures
- increase capacity and/or improve lining of downstream channel
- install sedimentation/infiltration basins
- install sophisticated weirs or other outlet devices to redistribute concentrated channel flow
- eliminate diversions which result in downstream damage and which cannot be mitigated in a less expensive fashion

In order to obtain the optimum roadside channel system design, it may be necessary to make several trials of the previous procedure before a final design is achieved.

More details on channel lining design may be found in HEC-15 including consideration of: channel bends, steep slopes, and composite linings.

Table 5-2 Classes of Vegetal Covers as to Degrees of Retardancy

Retardance	Cover	Condition
A	Weeping Lovegrass	Excellent stand, tall (ave. 30")
	Yellow Bluestem Ischaemum	Excellent stand, tall (ave. 36")
B	Kudzu	Very dense growth, uncut
	Bermuda grass	Good stand, tall (ave. 12")
	Native grass mixture little bluestem, blue gamma other short and long stem midwest grasses	Good stand, unmowed
	Weeping lovegrass	Good stand, tall (ave. 24")
	Laspedeza sericea	Good stand, not woody, tall (ave. 19")
	Alfalfa	Good stand, uncut (ave. 11")
	Weeping lovegrass	Good stand, uncut (ave. 13")
	Kudzu	Dense growth uncut
	Blue gamma	Good stand, uncut (ave. 13")
C	Crabgrass	Fair stand, uncut (10"-48")
	Bermuda grass	Good stand, Mowed (ave. 6")
	Common lespedeza	Good stand, uncut (ave. 11")
	Grass-legume mixture: summer (orchard grass redtop, Italian ryegrass, and common lespedeza	Good stand, uncut (6"-8")
	Centipedegrass	Very dense cover (ave. 6")
	Kentucky bluegrass	Good stand,(6"-12")
D	Bermuda grass	Good stand,cut to 2.5"
	Common lespedeza	Excellent stand, uncut (ave. 4.5")
	Buffalo grass	Good stand,uncut (3-6")
	Grass-legume mixture: fall, spring (orchard grass, redtop Italian ryegrass, and common lespedeza	Good stand, uncut (4"-5")
	Lespedeza serices	After cutting to 2" (very good before cutting)
E	Bermuda grass	Good stand, cut to 1.5"
	Bermuda grass	Burned stubble

[Note: Covers classified have been tested in experimental channel. Covers were green and generally uniform.]

Table 5-3 Summary Of Shear Stress For Various Protection Measures

Protective Cover	Underlying Soil		τ_p (lb/ft^2)
Class A Vegetation	Erosion	Resistant	3.7
		Erodible	3.7
Class B Vegetation	Erosion	Resistant	2.1
		Erodible	2.1
Class C Vegetation	Erosion	Resistant	1.0
		Erodible	1.0
Class D Vegetation	Erosion	Resistant	0.60
		Erodible	0.60
Class E Vegetation	Erosion	Resistant	0.35
		Erodible	0.35
Bare Soil (See Exhibits 05.910 and 05.920)			
Hydroseeded			0.10
Woven Paper			0.15
Jute Net			0.45
Single Fiberglass			0.60
Double Fiberglass			0.85
Straw W/Net			1.45
Curled Wood Mat			1.55
Synthetic Mat			2.00
Plain Grass, Good Cover	Clay		N/A
Plain Grass, Average Cover	Clay		N/A
Plain Grass, Poor Cover	Clay		N/A
Grass, Reinforced W/Nylon	Clay		N/A
Dycel W/Grass	Clay		N/A
Petraflex W/Grass	Clay		N/A
Armorflex W/Grass	Clay		N/A
Dymex W/Grass	Clay		N/A
Grasscrete	Clay		N/A
Gravel			
D_{50} = 1 in			0.40
D_{50} = 2 in			0.80
Rock			
D_{50} = 6 in			2.50
D_{50} = 12 in			5.00
6 in Gabions		Type I	35
4 in Geoweb		Type I	10
Soil Cement (8%) Cement)		Type I	>45
Dycel W/O Grass	Type I		>7.0

Table 5-3 Summary Of Shear Stress For Various Protection Measures

Protective Cover	Underlying Soil	τ_p (lb/ft^2)
Petraflex W/O Grass	Type I	>32
Armorflex W/O Grass	Type I	12-20
Erikamat w/3 in Asphalt	Type I	13-16
Erikamat w/1 in Asphalt	Type I	<5
Armorflex Class 30 with longitudinal and lateral cables, no grass	Type I	>34
Dycell 100, longitudinal cables, cells filled with mortar	Type I	<12
Concrete construction blocks, granular filter underlayer	Type I	>20
Wedge-shaped blocks with drainage slot	Type I	>25

[Note: ft/s x 0.03048 = m/s
lb/ft^2 x 47.87 = N/M^2]

Source: FHWA-RD-89-110, HEC-15

Table 5-4 Manning's Roughness Coefficients (HEC-15)
"n" Values
Depth Ranges

Category	Type	0 - 0.5 ft	0.5 - 2.0 ft	> 2.0 ft
Rigid	Concrete	0.015	0.013	0.013
	Grouted Riprap	0.040	0.030	0.028
	Stone Masonry	0.042	0.032	0.030
	Soil Cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil	0.023	0.020	0.020
	Rock Cut	0.045	0.035	0.025
Temp.*	Woven Paper	0.016	0.015	0.015
	Jute Net	0.028	0.022	0.019
	Fiberglass Roving	0.028	0.022	0.019
Straw	w/ Net	0.065	0.033	0.025
Curled Wood Mat		0.066	0.035	0.028
Synthetic Mat		0.036	0.025	0.021
Gravel	1-inch D_{50}	0.044	0.033	0.030
	2-inch D_{50}	0.066	0.041	0.034
Riprap	6-inch D_{50}	0.104	0.069	0.035
	12-inch D_{50}	--	0.078	0.040

[Note:Values listed are representative values for the respective depth ranges. Manning's roughness coefficients "n" vary with the flow depth.]

* Some "temporary" linings become permanent when buried

NOTES AND COMMENTS

DR-05.400 CHANNEL LININGS

DR-05.410 General

The selection of an adequate channel lining is an important part of the overall channel design process. Several types of lining are available and each should be reviewed to determine the most suitable, based on the channel requirements. The available linings (grass, aggregate and paving) and the design process will be discussed in the following material.

DR-05.420 Grass Lining

Grass Lining can be accomplished either by seeding or by sodding. Seeding provides a grass lining at a low cost but has a limited range of applicability. This method allows for the channel lining to be applied at the same time normal seeding operations take place. Protective methods such as hydroseeding or excelsior matting will hold the seeds in place. Sodding allows for an immediate application of grass lining at a higher cost than seeding. Sodding expands the use of grass lining and also serves to transition into more rigid linings. Composite linings using sodding are desirable in some applications and should be studied carefully.

DR-05.430 Aggregate Lining

Three types of aggregate lining are available, and these are described in Section 703 of the Department's current Standard Specifications. Class II Aggregate Lining has stones ranging in size from 5 inches to 9 inches. Class III Aggregate Lining has stones ranging in size from 1/4 cubic feet to 1 1/2 cubic feet. Each successive class allows for more erosion prevention capability. Another type of aggregate lining can be obtained by using a wire mattress filled with 1 1/2 inch to 5 inch stone. This aggregate lining is also covered in Section 703 of the Department's current Standard Specifications and is shown as Class I-A. Aggregate-filled mattresses have a wide range of use and can offer a competitive alternate to paving on steep grades.

An alternate to the quarry run stone specified for the above classes is Channel Lining Class IV. This aggregate lining, Class IV, is comprised of stone from or near the project site and will vary in size with the rock at the site. This stone is most commonly used as an alternate to Channel Lining Class III.

DR-05.440 Paved Lining

Paved lining takes the form of a trapezoidal reinforced con-crete ditch (Paved Ditch Type 1) or circular-shaped reinforced concrete ditch (Paved Ditch Type 2). Rigid linings prevent infiltration but contribute to high velocities which cause scour at the end. The high cost of this type of lining demands that the situation be analyzed adequately to ensure that this lining type will function as designed. Flow undercutting the lining, head-cutting, or hydrostatic pressure behind the walls or floor lead to the failure of rigid linings. Due to the high failure rate of paved lining channels, paved lining will be used only in extreme cases under the approval of the Division of Design.

The type of soil to be encountered during construction requires consideration in determining the type of lining. Soils containing fine sand, sandy loam, or silt loam may require protection by a rigid lining. Consultation with the Division of Materials will assist in defining problem areas.

PAVED DITCH TYPES

Two types of concrete paved ditches are detailed in the RDD-Series of the Standard Drawings.

Paved Ditch Type 1 has a flat bottom and 2:1 side slopes. The depth and width are variable except that the two feet wide flat bottom and 1 foot of depth are minimum dimensions. The normal applications of this type of lining are roadside ditches, surface ditches and special ditches; occasionally, this lining is needed on interceptor ditches. This type of paved ditch, with the minimum dimensions, often provides more paved area than is needed, particularly on steep slopes. Sizes greater than the minimum dimensions should be justified by hydraulic design.

Paved Ditch Type 2 is used primarily on interceptor ditches. It can also be used to pave just the flowline of larger ditches where occasional flow, higher than the paved ditch, will not be damaging. The Paved Ditch Type 2 has approximately a third of the area of the Paved Ditch Type 1; therefore, the Paved Ditch Type 2 is a more economical ditch lining when it is used properly.

PAVED DITCH JUNCTIONS

Paved ditches should not be shown on plans to junction at right angles. A 45 degree angle or less between two ditch lines is desirable. If a paved ditch on a steep slope junctions with one on a mild slope, the side opposite where the steeper ditch joins may need to be widened for a short distance in order to contain the flow. The design of junctions should be done by the design engineer with the flow data at hand rather than by construction personnel, who often do not have this information.

PAVED DITCH TERMINALS

Wherever paved ditches are terminated on soil, erosion is certain to occur. The erosion can be minimized by ending the ditch on as flat of a slope as possible. For instance, paved ditches should not be ended at the top of a stream bank but ended in the stream flow-line. Generally, some rip-rapping should be placed at the end of any paved ditch which ends on soil.

OTHER PAVED DITCH APPLICATIONS

Paved Ditches on Minimum Slopes - Sometimes it is advantageous to pave ditches which are on very flat slopes in order to lessen sedimentation and reduce flow depth. Hydraulic analysis is necessary for this determination. Another possible application of paved ditches is when the prevention of surface flow from entering sinkholes is important.

Special Paved Ditches - If a standard paved ditch will not satisfactorily fit the needs of a certain condition, the designer should require a specially designed paved ditch. If the cross sectional dimensions of a paved ditch do not conform to either of the paved ditches in the Standard Drawings, then a detailed drawing, including reinforcement, shall be included in the roadway plans. When a specially designed paved ditch is necessary, the design and application shall be approved by the Drainage Section of the Division of Design before being incorporated into the plans.

Traffic Safety - The potential road hazard of concrete paved ditches near the traveled lanes should be recognized. Abrupt changes between ditch surfaces should be eliminated if the ditch is within or near the clear zone. The 2:1 side slopes of the Paved Ditch Type 1 should be modified in such cases to a 4:1 side slope, if feasible, or a Paved Ditch Type 2 substituted.

DR-05.450 Lining Geometry

Aggregate lined channels shall be a minimum of two feet wide, one foot deep, with 3:1 side slopes desirable (2:1 maximum). Minimum thickness of lining shall be the mattress thickness for Class IA, 15 inches for Class II, and 24 inches for Class III.

Minimum depth for the channel lining should be designed using a recurrence interval of 10 years. Use the Channel Design portion of this chapter to determine a stable lining design.

Quantity of channel lining necessary can be estimated at 0.5 ton/sq yd/foot depth. This assumes 60-70% solid density for the aggregate.

The unit pay item for Classes IA, II and III is per ton. And the unit pay item for Channel Lining Class IV is per cubic yard.

DR-05.460 Design Limitations

The above procedures to not take into account the stability of an existing stream. Review of the existing stream upstream and downstream may reduce (or increase) the stability requirements.

DR-05.470 Design Procedures

Exhibit 03.924 shows a calculation sheet for ditch analysis.

DR-05.480 Soils Investigation

The gradation of the aggregate lining and the underlying soil must be obtained. Leaching of the underlying soil will be a problem if the following relationships do not hold:

$$\frac{d15\ filter}{d85\ base} < 5 < \frac{d15\ filter}{d15\ base} < 40$$

and :

$$\frac{d50\ filter}{d50\ base} < 40$$

The term "base" implies the material which is underlying the interface between two materials. The term "filter" implies the overlying material of the two.

If aggregate is used as a filter material, the equations must be valid between the underlying soil and the filter aggregate, and between the filter aggregate and the channel lining material. The following chart presents the gradation data for the aggregate channel lining necessary for the selection of a filter blanket (if aggregate):

Class of Aggregate Lining	d50	d15
IA	0.20′	0.12′
II (IV)	0.50′	0.40′
III (IV)	1.00′	0.70′

There are cloth filters available which may replace the aggregate filter blanket.

The designer shall determine the location, geometrics, and class of aggregate lining for the open channel. This information shall be transmitted to the Division of Materials, Soil Section, requesting determination of need for a filter blanket. The Soil Section will establish specifications for the blanket when required.

NOTES AND COMMENTS

DR-05.500 Stream Morphology

DR-05.510 General

The form assumed by a natural stream, which includes its cross-sectional shape as well as its plan form, is a function of many variables for which cause-and-effect relationships are difficult to establish. The stream may be graded or in equilibrium with respect to long time periods, which means that on the average it discharges the same amount of sediment that it receives; although, there may be short term adjustments in its bedforms in response to flood flows. On the other hand, the stream reach of interest may be aggrading or degrading as a result of deposition or scour in the reach, respectively. The plan form of the stream may be straight, braided, or meandering. These complexities of stream morphology can be assessed by inspecting aerial photographs and topographic maps for changes in slope, width, depth, meander form, and bank erosion with time.

A qualitative assessment of the river in response to proposed highway facilities is possible through a vast knowledge of river mechanics and an accumulation of engineering experience.

Equilibrium sediment load calculations can be made by a variety of techniques and compared from reach to reach to detect an imbalance in sediment inflow and outflow and thus identify an aggradation/degradation problem. The BRI-STARS model is recommended as a tool to quantify the expected scour and/or sedimentation of potential problem locations. References (FHWA, 1990 and Molinas, 1990) should be consulted to evaluate the problem and propose mitigation measures. Finally, the proposed methodology should be approved by the Chief Drainage Engineer.

The natural stream channel will assume a geomorphological form which will be compatible with the sediment load and discharge history that it has experienced over time. To the extent that a highway structure disturbs this delicate balance by encroaching on the natural channel, the consequences of flooding, erosion, and deposition can be significant and widespread. The hydraulic analysis of a proposed highway structure should include a consideration of the extent of these consequences.

DR-05.520 Levels Of Assessment

The analysis and design of a stream channel will usually require an assessment of the existing channel and the potential for problems as a result of the proposed action. The detail of studies necessary should be commensurate with the risk associated with the action and with the environmental sensitivity of the stream. Observation is the best means of identifying potential locations for channel bank erosion which will require channel stabilization. Analytical methods for the evaluation of channel stability can be classified as either hydraulic or geomorphic. It is important to recognize that these analytical tools should only be used to substantiate the erosion potential anticipated through observation. A brief description of the three levels of assessment are as follows:

Level 1

Qualitative assessment involving the application of geomorphic concepts to identify potential problems and alternative solutions. Data needed may include historic information, current site conditions, aerial photographs, old maps and survey notes, bridge design files, maintenance records, and interviews with long time residents.

Level 2

Quantitative analysis combined with a more detailed qualitative assessment of geomorphic factors. Generally includes water surface profile and scour calculations. This level of analysis will be adequate for most locations if the problems are resolved and relationships between different factors affecting stability are adequately explained. Data needed will include Level 1 data and information needed to establish the hydrology and hydraulics of the stream.

Level 3

Complex quantitative analysis based on detailed mathematical modeling and possibly physical hydraulic modeling. This Level 3 analysis is necessary only for high risk locations, extraordinarily complex problems, and after the fact analyses where losses and liability costs are high. This level of analysis may require professionals experienced with mathematical modeling techniques for sediment routing and/or physical modeling. Data needed will require the data obtained in Levels 1 and 2 as well as field data on bed load and suspended load transport rates and properties of bed and bank materials such as size, shape, gradation, fall velocity, cohesion, density, and angle of repose.

DR-05.530 Factors That Affect Stream Stability

Factors that affect stream stability and, potentially, bridge and highway stability (at stream crossings) can be classified as geomorphic factors and hydraulic factors.

Geomorphic Factors.

- Stream size
- Valley setting
- Natural levees
- Sinuosity
- Width variability
- Bar development
- Flow variability
- Flood plains
- Apparent incision
- Channel boundaries
- Degree of braiding
- Degree of anabranching

Exhibit 5.960 depicts examples of the various geomorphic factors.

Hydraulic Factors.

- Magnitude, frequency and duration of floods
- Bed configuration
- Resistance to flow
- Water surface profiles

Exhibit 5.970 depicts the changes in channel classification and relative stability as related to hydraulic factors.

Rapid and unexpected changes may occur in streams in response to man's activities in the watershed such as alteration of vegetative cover. Changes in perviousness can alter the hydrology of a stream, sediment yield, and channel geometry. Channelization, stream channel straightening, stream levees and dikes, bridges and culverts, reservoirs, and changes in land use can have major effects on stream flow, sediment transport, channel geometry, and location. Knowing that man's activities can influence stream stability can help the designer anticipate some of the problems that can occur.

Natural disturbances such as floods, droughts, earthquakes, landslides, volcanoes, and forest fires can also cause large changes in sediment load, thus causing major changes in the stream channel. Although difficult to plan for such disturbances, it is important to recognize that when natural disturbances do occur, it is likely that changes will also occur to the stream channel.

DR-05.540 Stream Response to Change

The major complicating factors in river mechanics are: 1) the large number of interrelated variables that can simultaneously respond to natural or imposed changes in a stream system; and 2) the continual evolution of stream channel patterns, channel geometry, bars, and forms of bed roughness with changing water and sediment discharge. In order to better understand the responses of a stream to the actions of man and nature, a few simple hydraulic and geomorphic concepts are presented herein.

The dependence of stream form on slope, which may be imposed independently of other stream characteristics, is illustrated schematically in Exhibit 5.980.

Any natural or artificial change which alters channel slope can result in modifications to the existing stream pattern. For example, a cutoff of a meander loop decreases channel sinuosity and increases channel slope. Referring to Exhibit 5.980, this shift in the plotting position to the right could result in a shift from a relatively tranquil, meandering pattern toward a braided pattern that varies rapidly with time, has high velocities, is subdivided by sandbars, and carries relatively large quantities of sediment. Conversely, it is possible that a slight decrease in slope could change an unstable braided stream into a meandering one.

The different channel dimensions, shapes, and patterns associated with different quantities of discharge and amounts of sediment load indicate that as these independent variables change, major adjustments of channel morphology can be anticipated. Further, a change in hydrology may cause changes in stream sinuosity, meander wave length, and channel width and depth. A long period of channel instability with considerable bank erosion and lateral shifting of the channel may be required for the stream to compensate for the hydrologic change.

Exhibit 5.990 illustrates the dependence of river form on channel slope and discharge. It shows that when $SQ^{1/4} \leq .0017$ in a sandbed channel, the stream will meander. Similarly, when $SQ^{1/4} \geq .010$, the stream is braided.

In these equations, S is the channel slope (in ft/ft) and Q is the mean discharge (in cfs). Between these values of $SQ^{1/4}$ is the transitional range.

Many U.S. rivers plot in this zone between the limiting curves defining meandering and braided streams. If a stream is meandering but its discharge and slope border on a boundary of the transitional zone, a relatively small increase in channel slope may cause it to change, in time, to a transitional or braided stream.

DR-05.550 Countermeasures

A countermeasure is defined as a measure incorporated into a highway crossing of a stream to control, inhibit, change, delay, or minimize stream and bridge stability problems. The countermeasure may be installed at the time of highway construction or retrofitted to resolve stability problems at existing crossings.

In many locations, it may be necessary to retrofit a countermeasure because the magnitude, location, and nature of potential stability problems are not always discernible at the design stage, and indeed, may take a period of several years to develop.

The selection of an appropriate countermeasure for a specific bank erosion problem is dependent on factors such as the erosion mechanism, stream characteristics, construction and maintenance requirements, potential for vandalism, and costs.

Below is a brief discussion of possible countermeasures for some common river stability problems.

DR-05.560 Meander Migration

The best countermeasure against meander migration is to locate the bridge crossing on a relatively straight reach of stream between bends. Other countermeasures include: the protection of an existing bank line, the establishment of a new flow line or alignment, and the control and constriction of channel flow. Countermeasures identified for bank stabilization and bend control are bank revetments, spurs, retardance structures, longitudinal dikes, vane dikes, bulkheads, and channel relocations. Measures may be used individually or a combination of two or more measures may be used to combat meander migration at a site (FHWA, 1990; and HEC-20, 1991).

DR-05.570 Channel Braiding

Countermeasures used at braided streams are usually intended to confine the multiple channels to one channel. This tends to increase sediment transport capacity in the principal channel and encourage deposition in secondary channels.

The measures usually consist of dikes constructed from the limits of the multiple channels to the channel over which the bridge is constructed. Spur dikes at bridge ends used in combination with revetments on highway fill slopes, riprap on highway fill slopes only, and spurs arranged in the stream channels to constrict flow to one channel have also been used successfully.

DR-05.580 Degradation

Degradation in streams can cause the loss of bridge piers in stream channels, and piers and abutments on caving banks. A check dam, which is a low dam or weir constructed across a channel, is one of the most successful techniques for halting degradation on small to medium streams.

Longitudinal stone dikes placed at the toe of channel banks can be effective countermeasures for bank caving in degrading streams. Precautions to prevent outflanking, such as tiebacks to the banks, may be necessary where installations are limited to the vicinity of the highway stream crossing. In general, channel lining alone is not a successful countermeasure against degradation problems (HEC-20).

Longitudinal stone dikes placed at the toe of channel banks can be effective countermeasures for bank caving in degrading streams. Precautions to prevent outflanking, such as tiebacks to the banks, may be necessary where installations are limited to the vicinity of the highway stream crossing. In general, channel lining alone is not a successful countermeasure against degradation problems (HEC-20).

DR-05.590 Aggradation

Current measures in use to alleviate aggradation problems at highways include: channelization, bridge modification, continued maintenance, or combinations of these.

Channelization may include excavating and cleaning channels, constructing cutoffs to increase the local slope, constructing flow control structures to reduce and control the local channel width, and constructing relief channels to improve flow capacity at the crossing. Except for relief channels, these measures are intended to increase the sediment transport capacity of the channel, thus reducing or eliminating problems with aggradation.

Another technique which shows promise is the submerged vane technique developed by the University of Iowa. The studies suggest that the submerged vane structure may be an effective, economic, low maintenance, and environmentally acceptable sediment control structure with a wide range of applications (HEC-20, Odgaard and others, 1986).

DR-05.5100 Stream Classification Scheme

An expert system for stream classification was developed by Dr. Albert Molinas as part of the NCHRP Project No. 15-11, BRI-STARS. (Molinas, 1986 and 1990) The purpose of the stream classification system is to assist the users in assessing stream stability and in choosing the appropriate sediment transport equation. The methods utilized in the expert system are predicated on bed material sediment size and stream channel slope. Stream morphology and related channel patterns are directly influenced by the width, depth, velocity, discharge, slope, roughness of channel material, sediment load, and sediment size. Changes in any of these variables can result in altered channel patterns. As stream morphology is a result of these mutually adjustable variables, those most directly measurable were incorporated into Rosgen's criteria for stream classification. This criteria was selected for use in the expert system as it is a detailed analysis of hundreds of streams over many hydrophysiographic regions and from portions of other existing classification schemes. Stream channel patterns are classified based upon bed material size, channel gradients, and channel entrenchment and confinement.

NOTES AND COMMENTS

CHAPTER DR-05
CHANNELS AND DITCHES

DR-05.900 CHAPTER 5 EXHIBITS

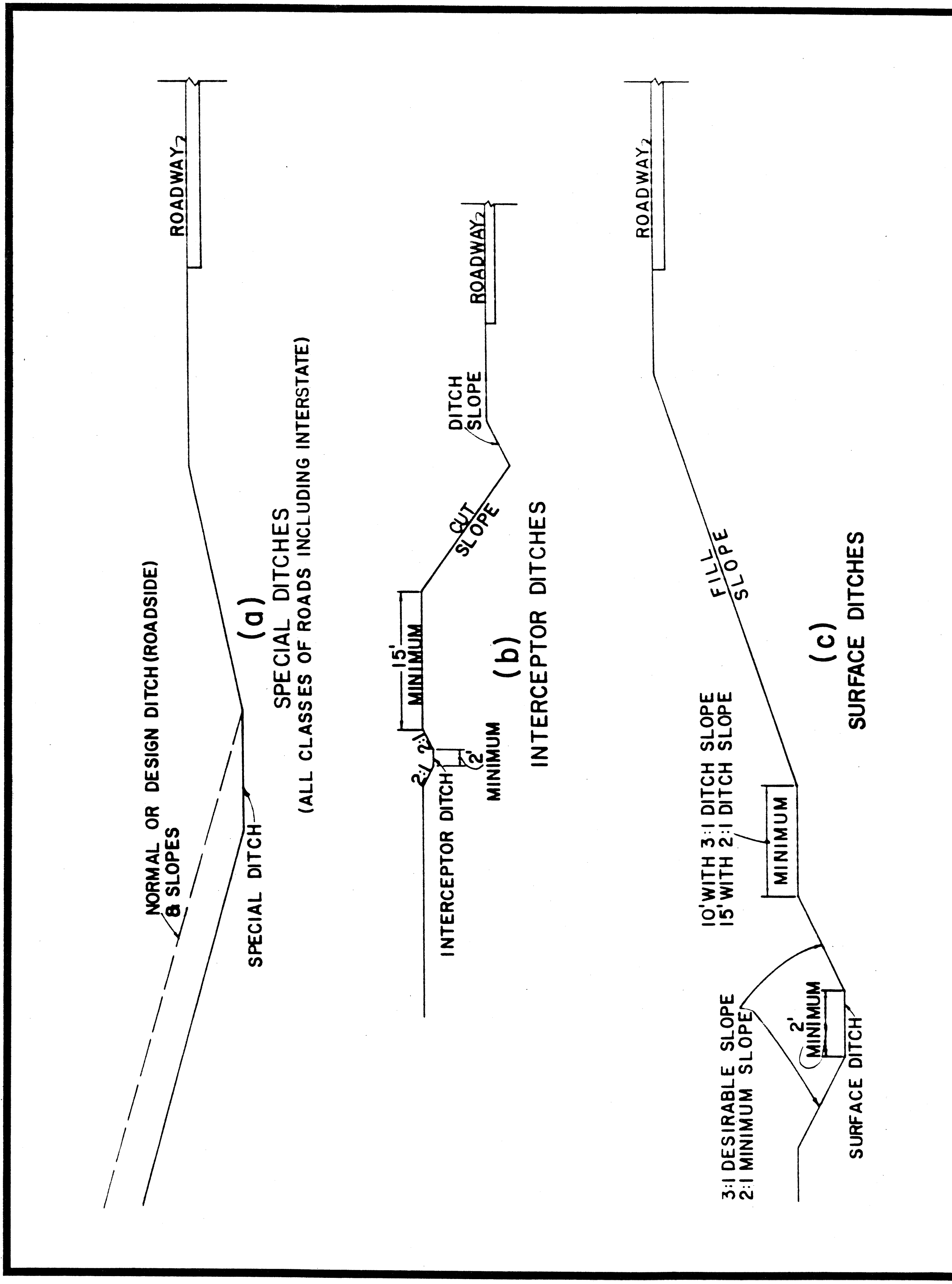
05.901	Manning's Roughness Coefficients
05.902	Types of Ditches
05.903	Embankments adjacent to Channel Changes
05.910	Permissible Shear Stress - Non-cohesive Soils
05.920	Permissible Shear Stress - Cohesive Soils
05.930	Terms in the Energy Equation
05.940	Sample Roadside Ditches
05.950	Manning's N vs. Relative Roughness for Selected Lining Types
05.951	Manning's N vs. Hydraulic Radius,R, for Class A Vegetation
05.952	Manning's N vs. Hydraulic Radius,R, for Class B Vegetation
05.953	Manning's N vs. Hydraulic Radius,R, for Class C Vegetation
05.954	Manning's N vs. Hydraulic Radius,R, for Class D Vegetation
05.955	Manning's N vs. Hydraulic Radius,R, for Class E Vegetation
05.960	Geomorphic Factors That Affect Stream Stability
05.970	Channel Classification and Relative Stability As Hydraulic Factors are Varied
05.980	Sinuosity vs. Slope with Constant Discharge
05.990	Slope - Discharge for Braiding or Meandering Bed Streams

UNIFORM FLOW

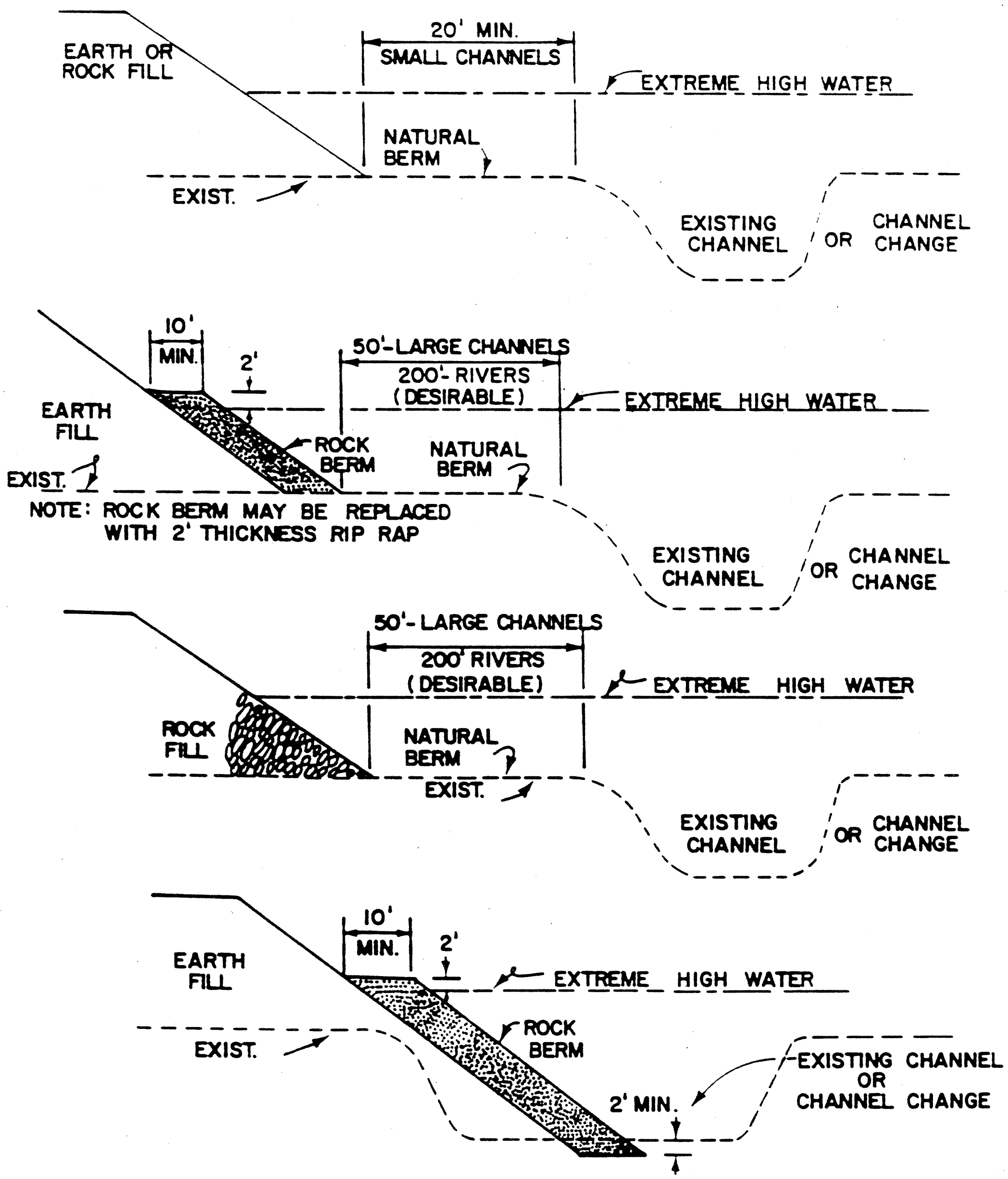
Values of Roughness Coefficient "n"

Type Of Channel and Description	Minimum	Normal	Maximum
EXCAVATED OR DREDGED			
A. Earth, straight and uniform	0.016	0.018	0.020
1. Clean, recently completed	0.018	0.022	0.025
2. Clean, after weathering	0.022	0.025	0.030
3. Gravel, uniform section, clean	0.022	0.027	0.033
B. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense Weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.025	0.030	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
6. Cobble bottom and clean sides	0.030	0.040	0.050
C. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
D. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
E. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
NATURAL STREAMS			
A. Minor streams (top width at flood stage < 100 ft)			
1. Streams on Plain			
a. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as 4, more stones	0.045	0.050	0.060
g. Sluggish rches, wdy, deep pools	0.050	0.070	0.080
h. Very wdy rches, deep pools, floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

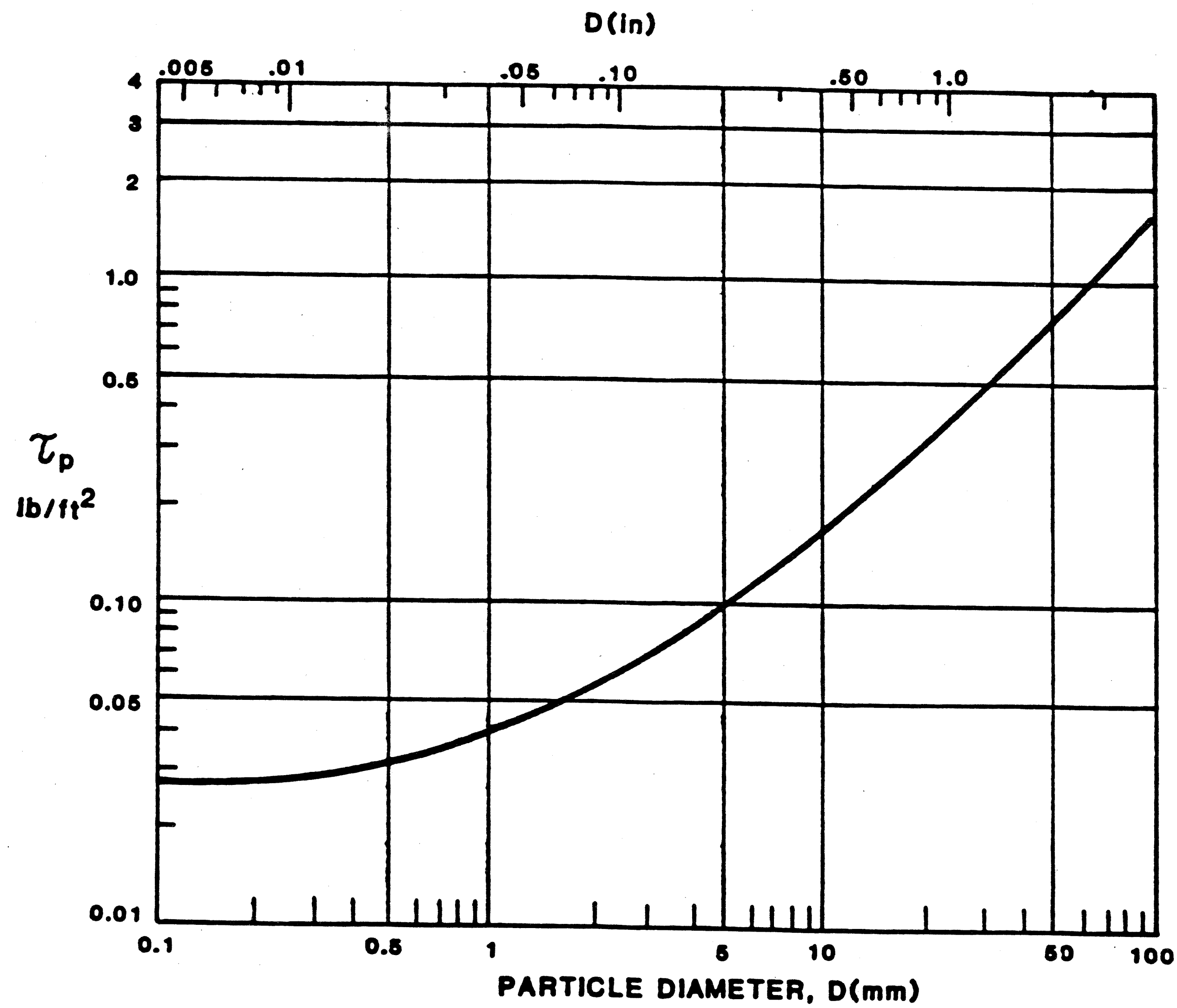
Type Of Channel and Description	Minimum	Normal	Maximum
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. Btm: gravels, cobbles, few boulders	0.030	0.040	0.050
b. Bottom: cobbles with large boulders	0.040	0.050	0.070
B. Flood Plains			
1. Pasture, no brush			
a. Short grass	0.025	0.030	0.035
b. High grass	0.030	0.035	0.050
2. Cultivated area			
a. No crop	0.020	0.030	0.040
b. Mature row crops	0.025	0.035	0.045
c. Mature field crops	0.030	0.040	0.050
3. Brush			
a. Scattered brush, heavy weeds	0.035	0.050	0.070
b. Light brush and trees in winter	0.035	0.050	0.060
c. Light brush and trees, in summer	0.040	0.060	0.080
d. Med. to dense brush, in winter	0.045	0.070	0.110
e. Medium to dense brush, in summer	0.070	0.100	0.160
4. Trees			
a. Dense Willows, summer, straight	0.110	0.150	0.200
b. Cleared land w/ stumps, no sprouts	0.030	0.040	0.050
c. Same as b., with heavy growth of spouts	0.050	0.060	0.080
d. Heavy timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
e. Same as d., with flood stage reaching branches	0.100	0.120	0.160
C. Major Streams (top width at flood stage > 100 ft). The n value is less than that for minor streams of similar description, because banks offer less effective resistance.			
1. Regular section with no boulders or brush	0.025	.....	0.060
2. Irregular and rough section	0.035	.....	0.100

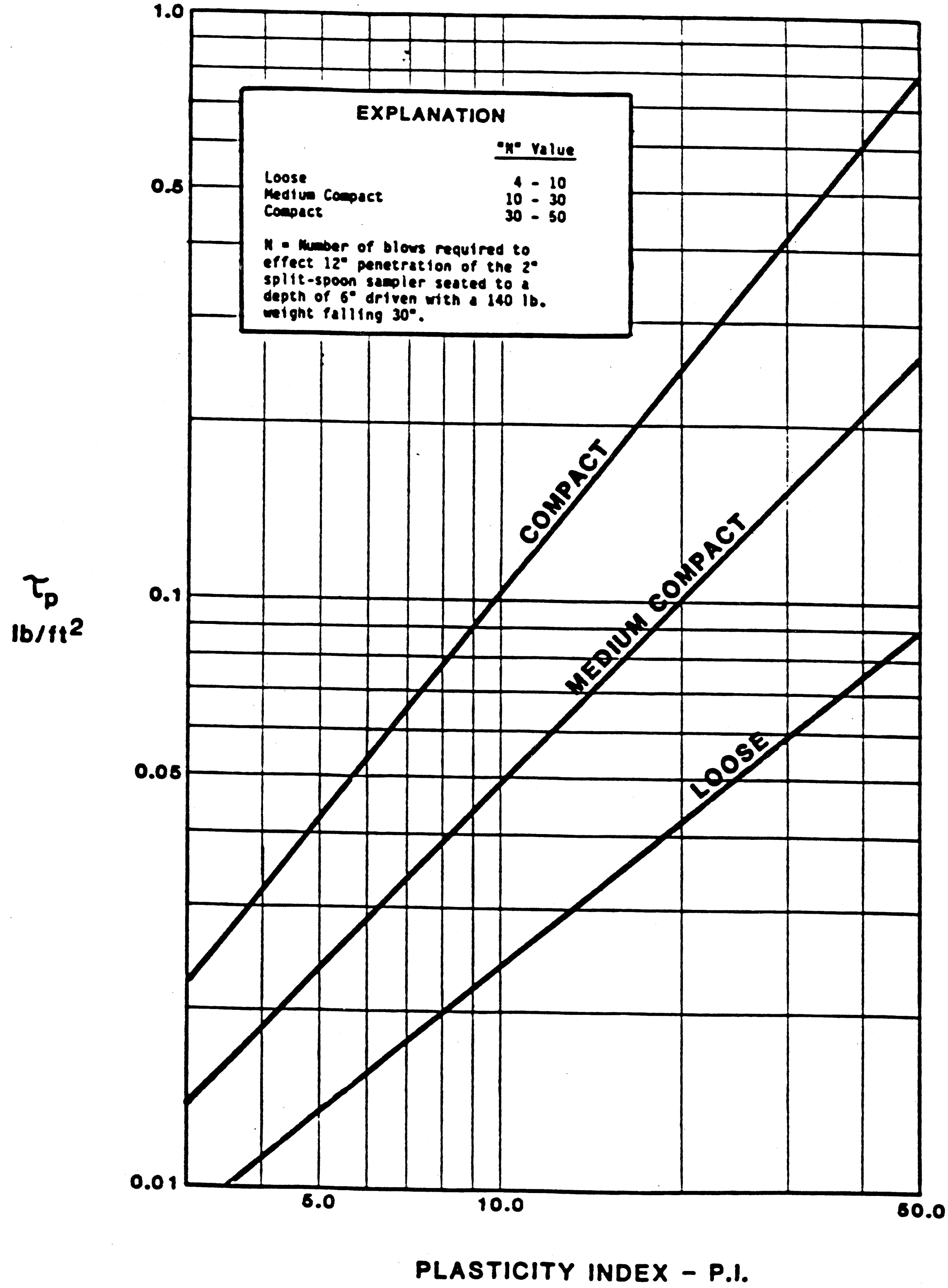

ROADWAY ℄
NORMAL OR DESIGN DITCH (ROADSIDE) & SLOPES
SPECIAL DITCH
(a)
SPECIAL DITCHES
(ALL CLASSES OF ROADS INCLUDING INTERSTATE)
ROADWAY ℄
DITCH SLOPE
CUT SLOPE
15' MINIMUM
2:1
2:1
2' MINIMUM
INTERCEPTOR DITCH
(b)
INTERCEPTOR DITCHES
ROADWAY ℄
FILL SLOPE
MINIMUM
10' WITH 3:1 DITCH SLOPE
15' WITH 2:1 DITCH SLOPE
2' MINIMUM
3:1 DESIRABLE SLOPE
2:1 MINIMUM SLOPE
SURFACE DITCH
(c)
SURFACE DITCHES

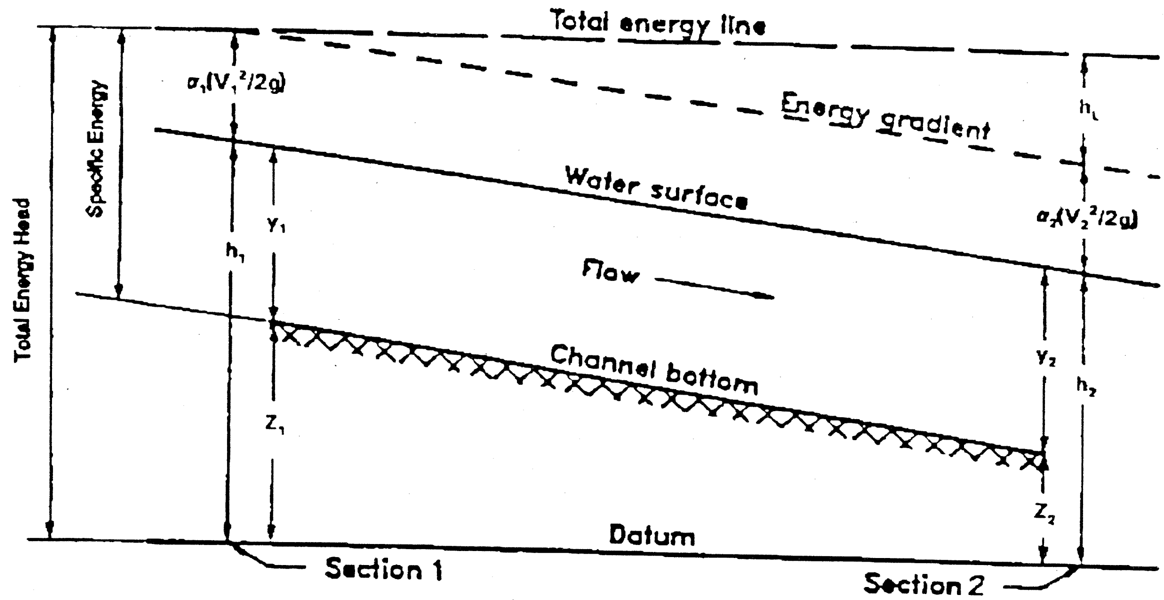
EMBANKMENTS ADJACENT TO CHANNEL CHANGES



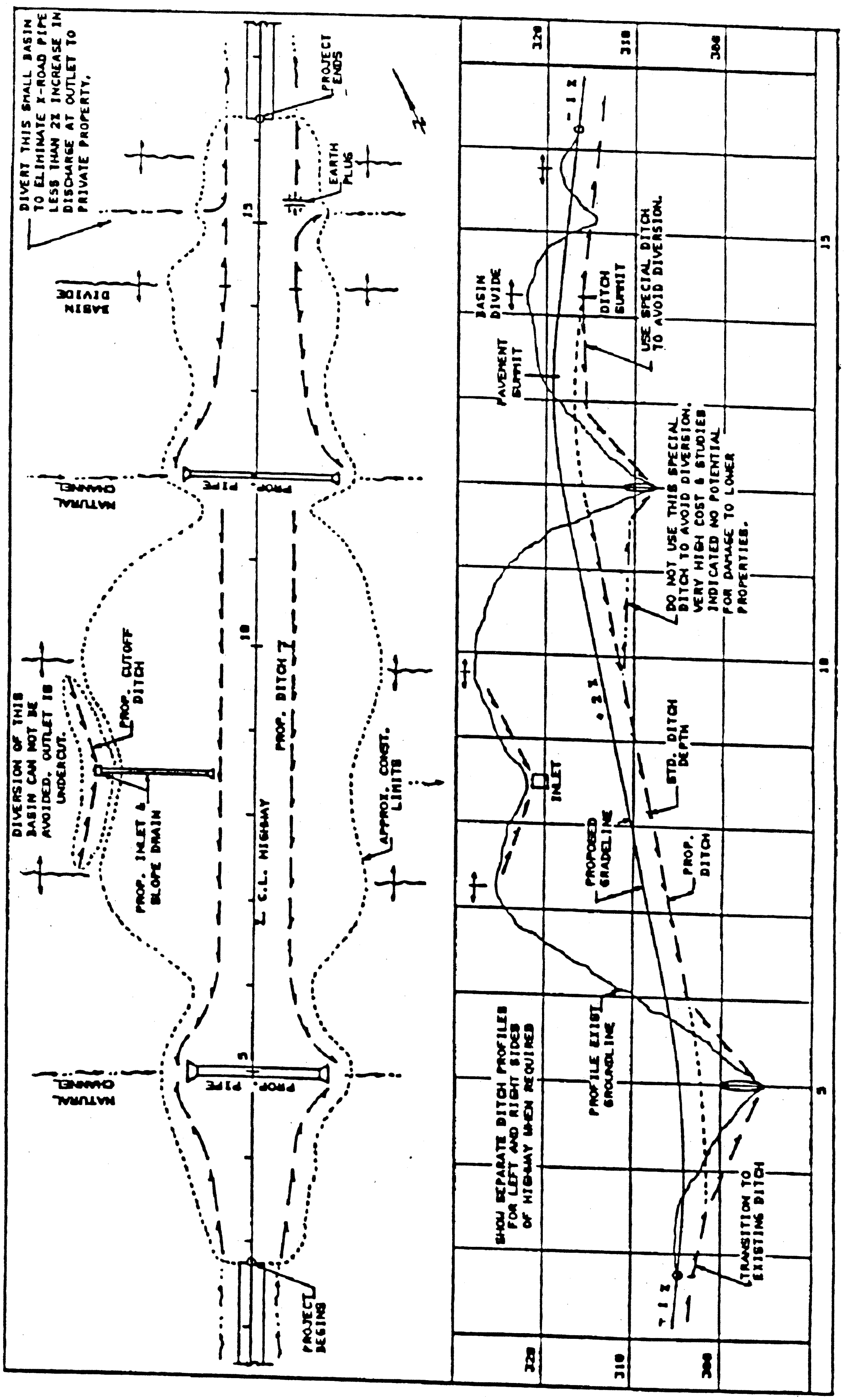
01-01-93	PERMISSIBLE SHEAR STRESS - NON- COHESIVE SOILS	EXHIBIT DR-05.910



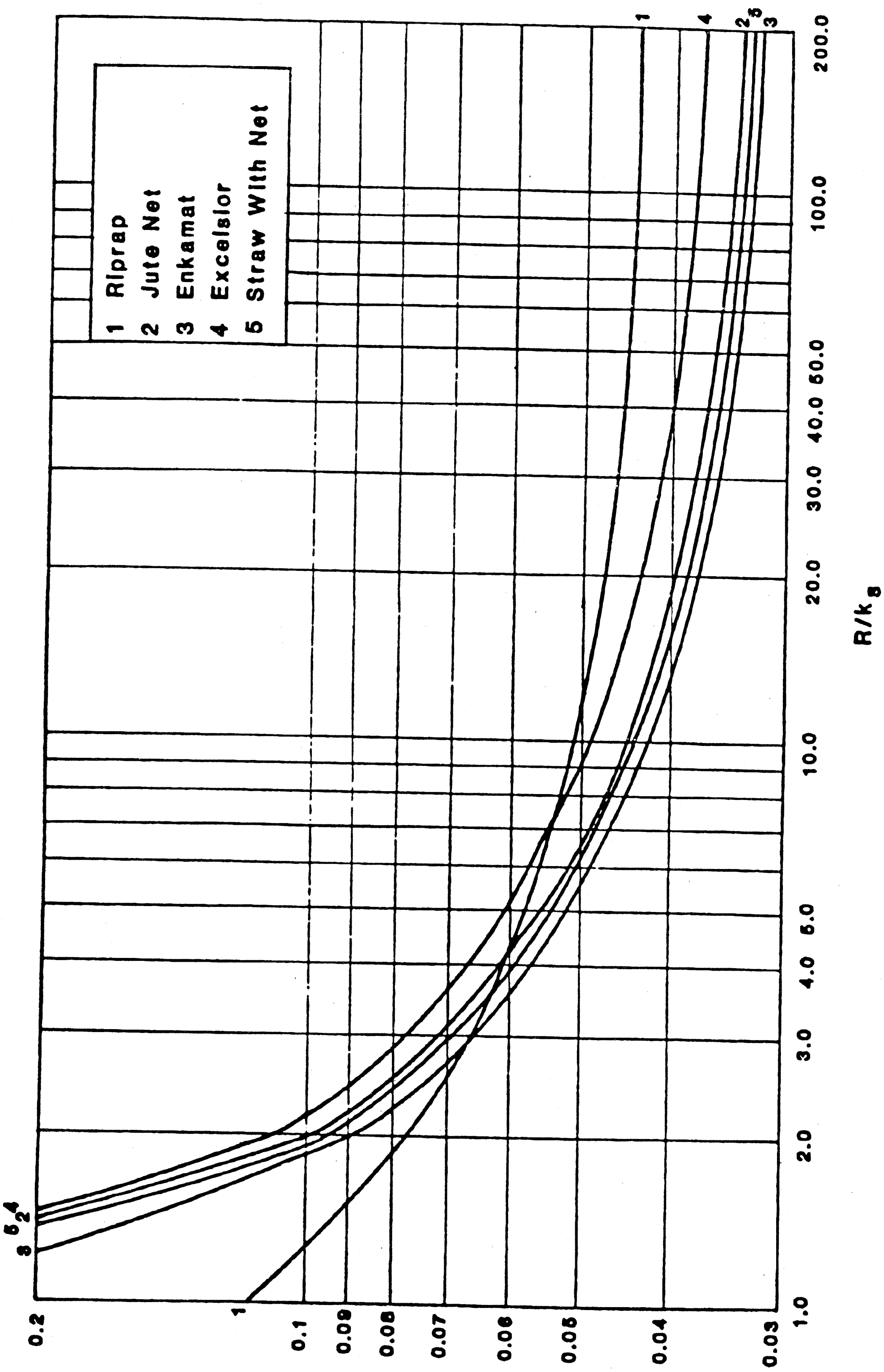

EXPLANATION
"N" Value
Loose 4 - 10
Medium Compact 10 - 30
Compact 30 - 50
N = Number of blows required to effect 12" penetration of the 2" split-spoon sampler seated to a depth of 6" driven with a 140 lb. weight falling 30".
1.0
0.5
0.1
0.05
0.01
τp
lb/ft2
COMPACT
MEDIUM COMPACT
LOOSE
5.0
10.0
50.0
PLASTICITY INDEX - P.I.



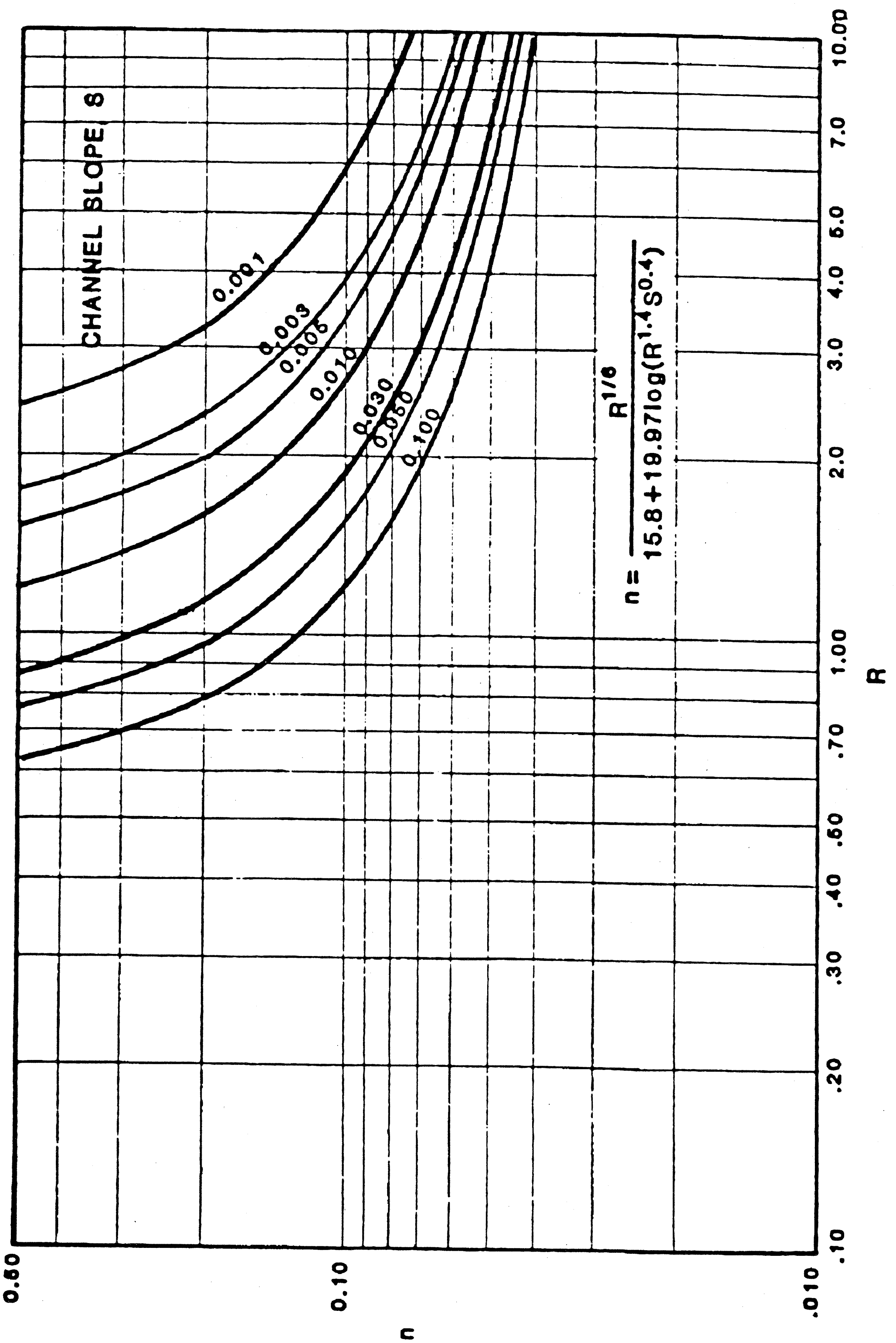
Total energy line
Energy gradient
Water surface
Flow
Channel bottom
Datum
Section 1
Section 2
Total Energy Head
Specific Energy
$\alpha_1(V_1^2/2g)$
$\alpha_2(V_2^2/2g)$
h_L
h_1
h_2
y_1
y_2
Z_1
Z_2



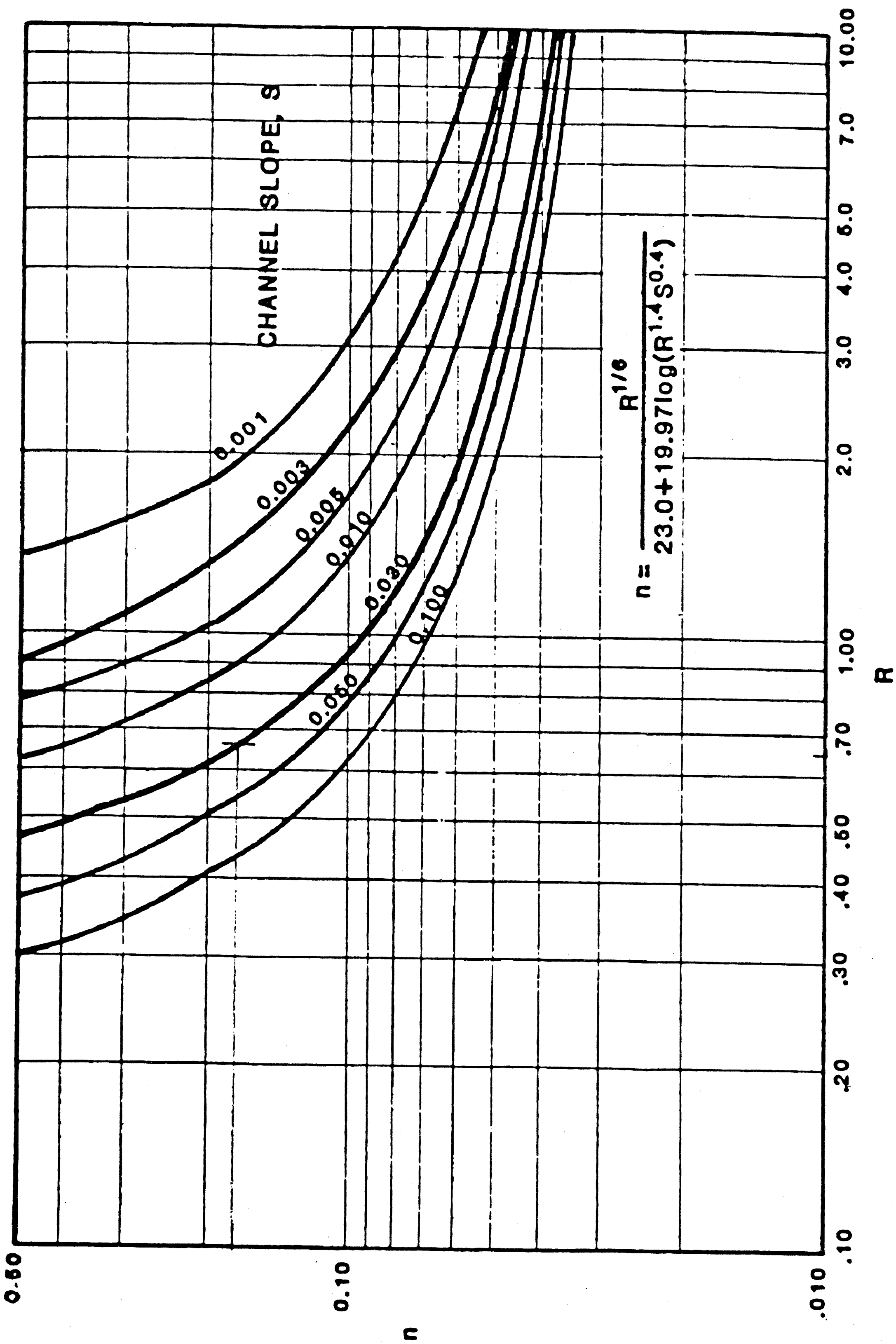
DIVERT THIS SMALL BASIN TO ELIMINATE X-ROAD PIPE LESS THAN 2% INCREASE IN DISCHARGE AT OUTLET TO PRIVATE PROPERTY.
PROJECT ENDS
EARTH PLUG
BASIN DIVIDE
NATURAL CHANNEL
PROP. PIPE
DIVERSION OF THIS BASIN CAN NOT BE AVOIDED, OUTLET IS UNDERCUT.
PROP. CUTOFF DITCH
PROP. INLET & SLOPE DRAIN
PROP. DITCH
C.L. HIGHWAY
APPROX. CONST. LIMITS
PROJECT BEGINS
PAVEMENT SUMMIT
DITCH SUMMIT
USE SPECIAL DITCH TO AVOID DIVERSION.
DO NOT USE THIS SPECIAL DITCH TO AVOID DIVERSION. VERY HIGH COST & STUDIES INDICATED NO POTENTIAL FOR DAMAGE TO LOWER PROPERTIES.
INLET
PROPOSED GRADELINE
STD. DITCH DEPTH
PROFILE EXIST. GROUNDLINE
SHOW SEPARATE DITCH PROFILES FOR LEFT AND RIGHT SIDES OF HIGHWAY WHEN REQUIRED
TRANSITION TO EXISTING DITCH



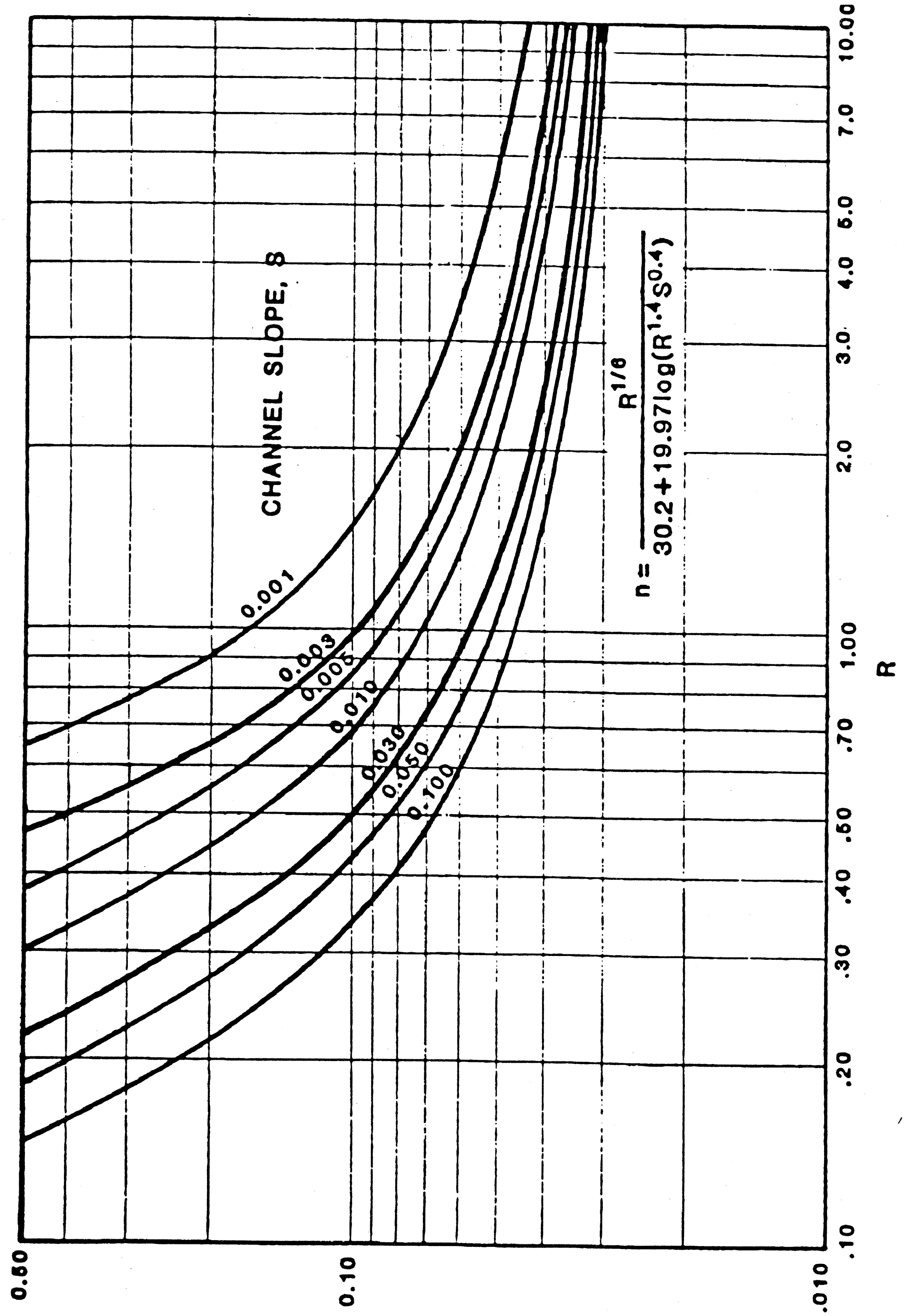
Manning's n Verses Relative Roughness
For Selected Lining Types (HEC - 15)



Manning's n Verses Hydraulic Radius ,R,
For Class A Vegetation (HEC - 15)

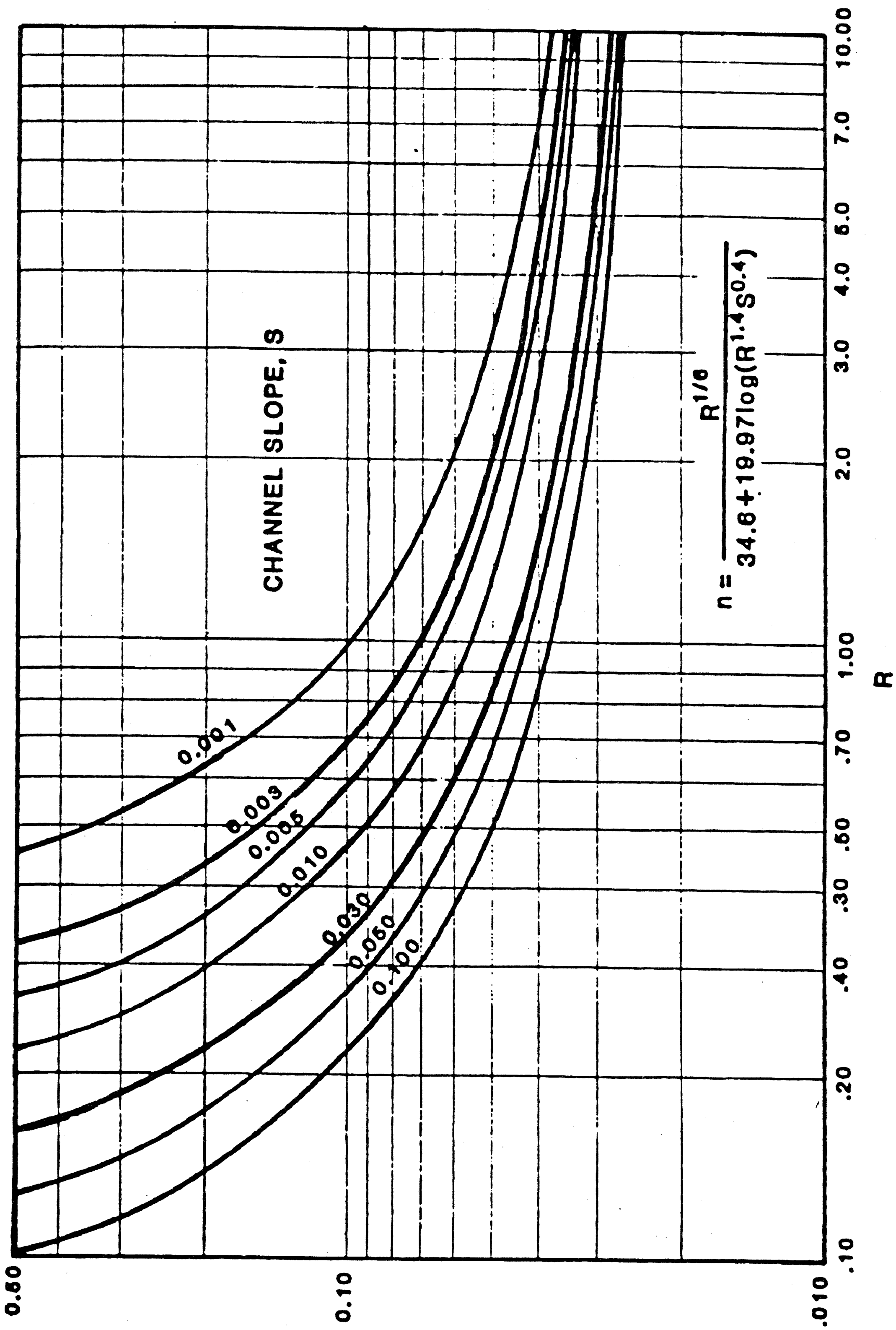


Manning's n Verses Hydraulic Radius ,R,
For Class B Vegetation (HEC - 15)

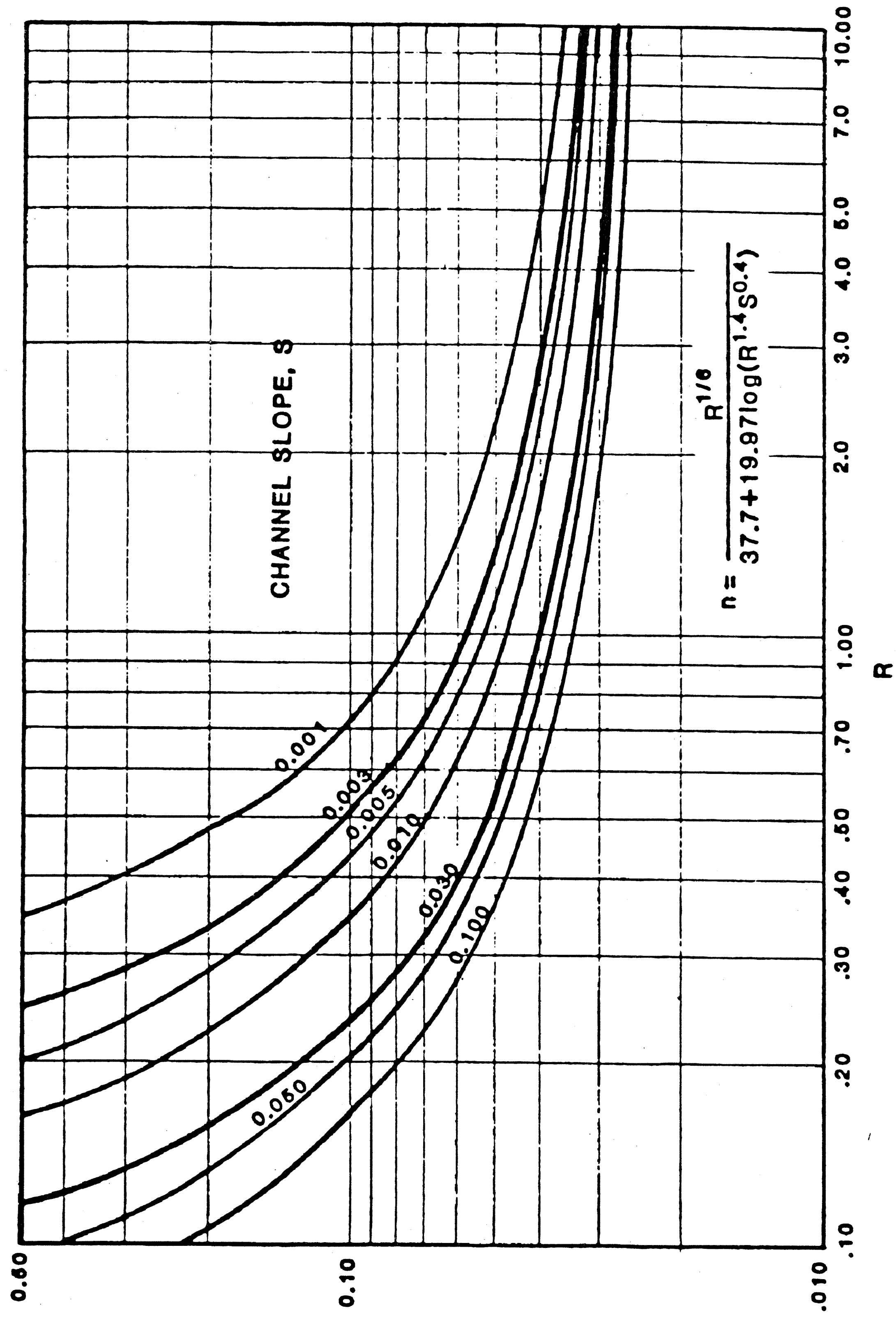


Manning's n Verses Hydraulic Radius ,R,
For Class C Vegetation (HEC - 15)

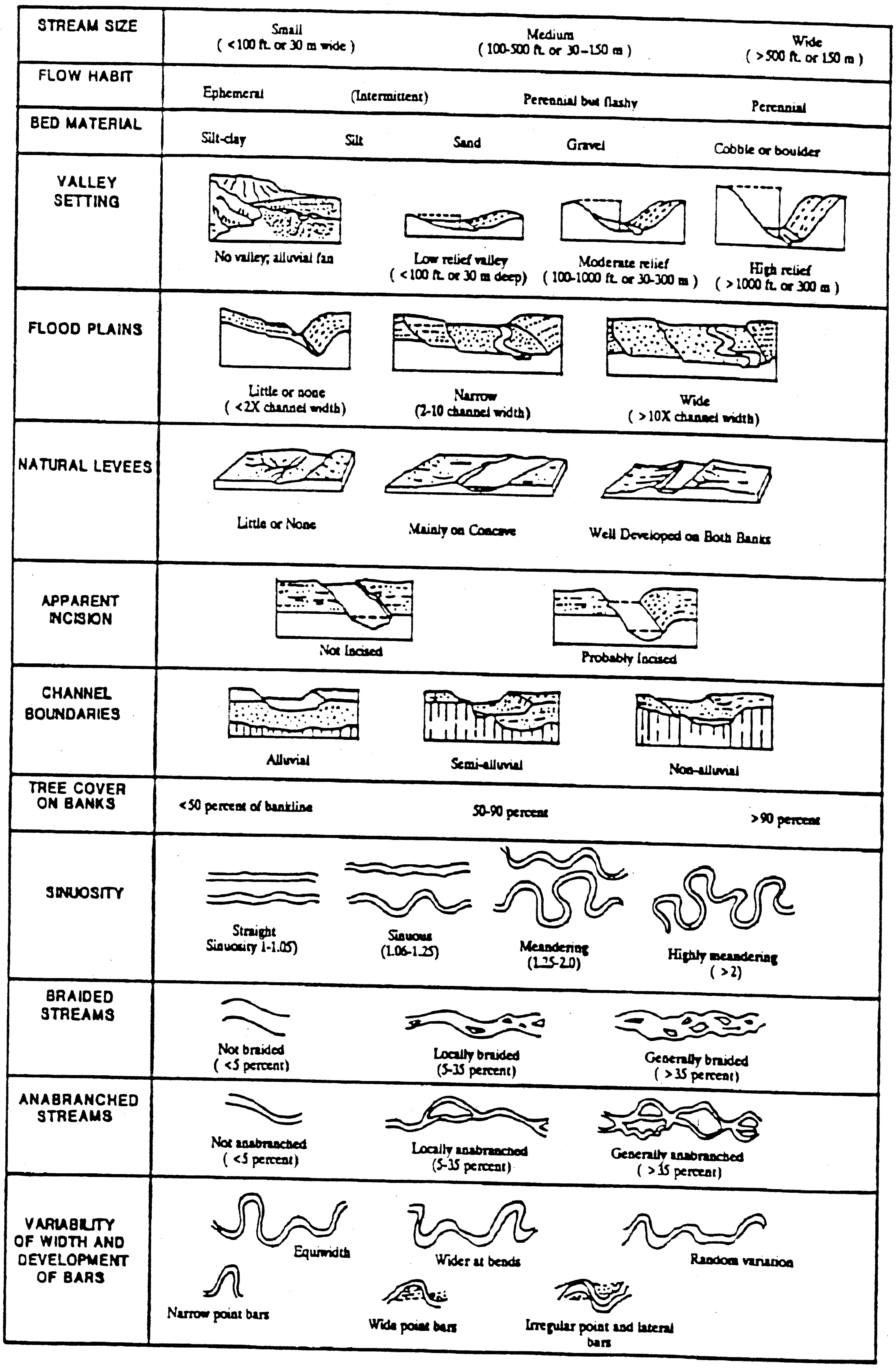
01-01-93	"N" VS. HYDRAULIC RADIUS FOR CLASS "D" VEG.	EXHIBIT DR-05.954



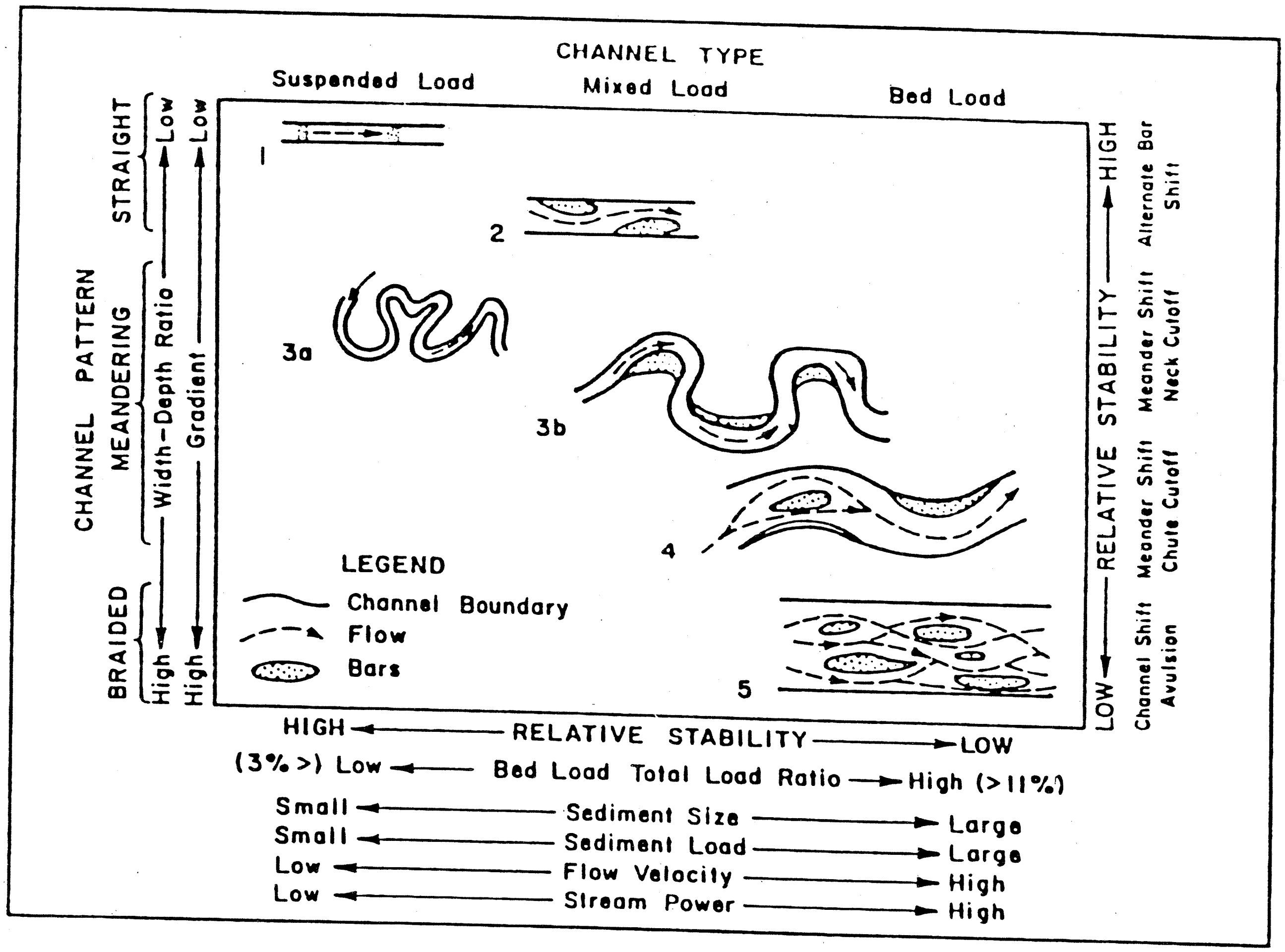
Manning's n Verses Hydraulic Radius ,R,
For Class D Vegetation (HEC - 15)



Manning's n Verses Hydraulic Radius ,R,
For Class E Vegetation (HEC - 15)

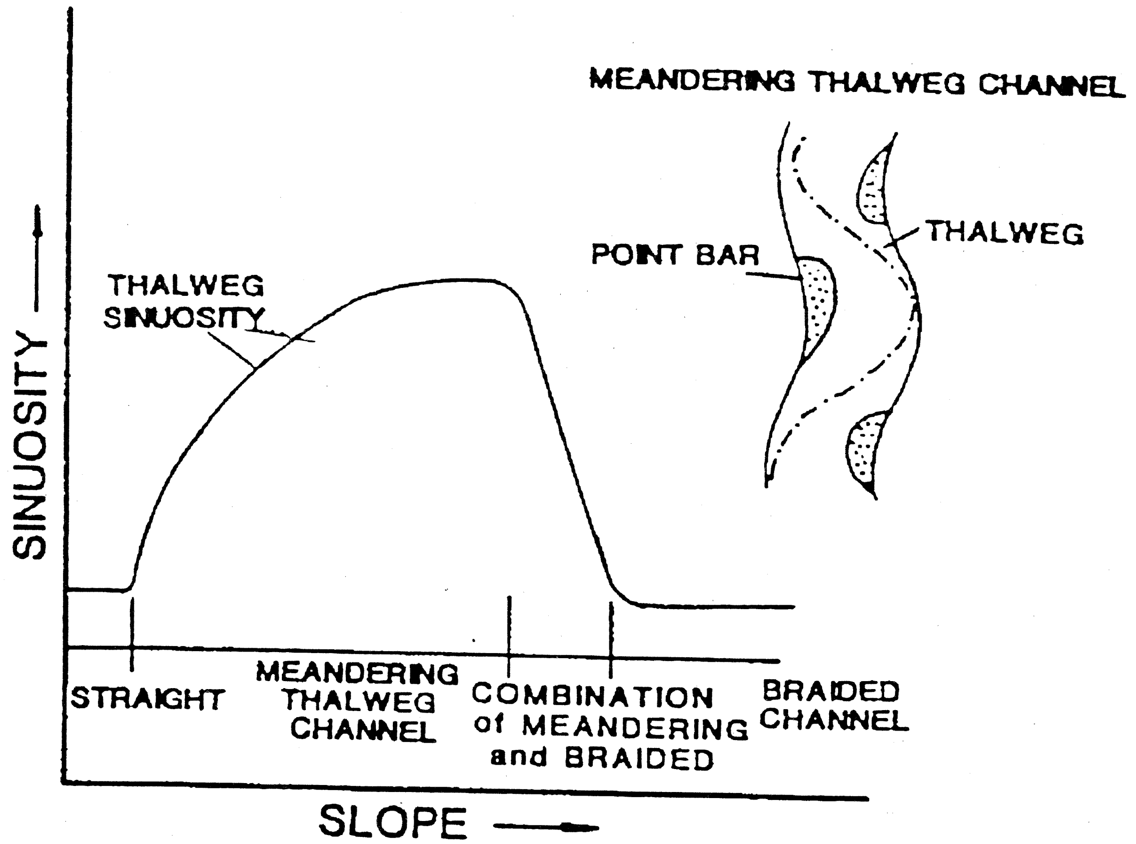


Geomorphic Factors That Affect Stream Stability
Source: Adapted From Brice and Blodgett, 1978

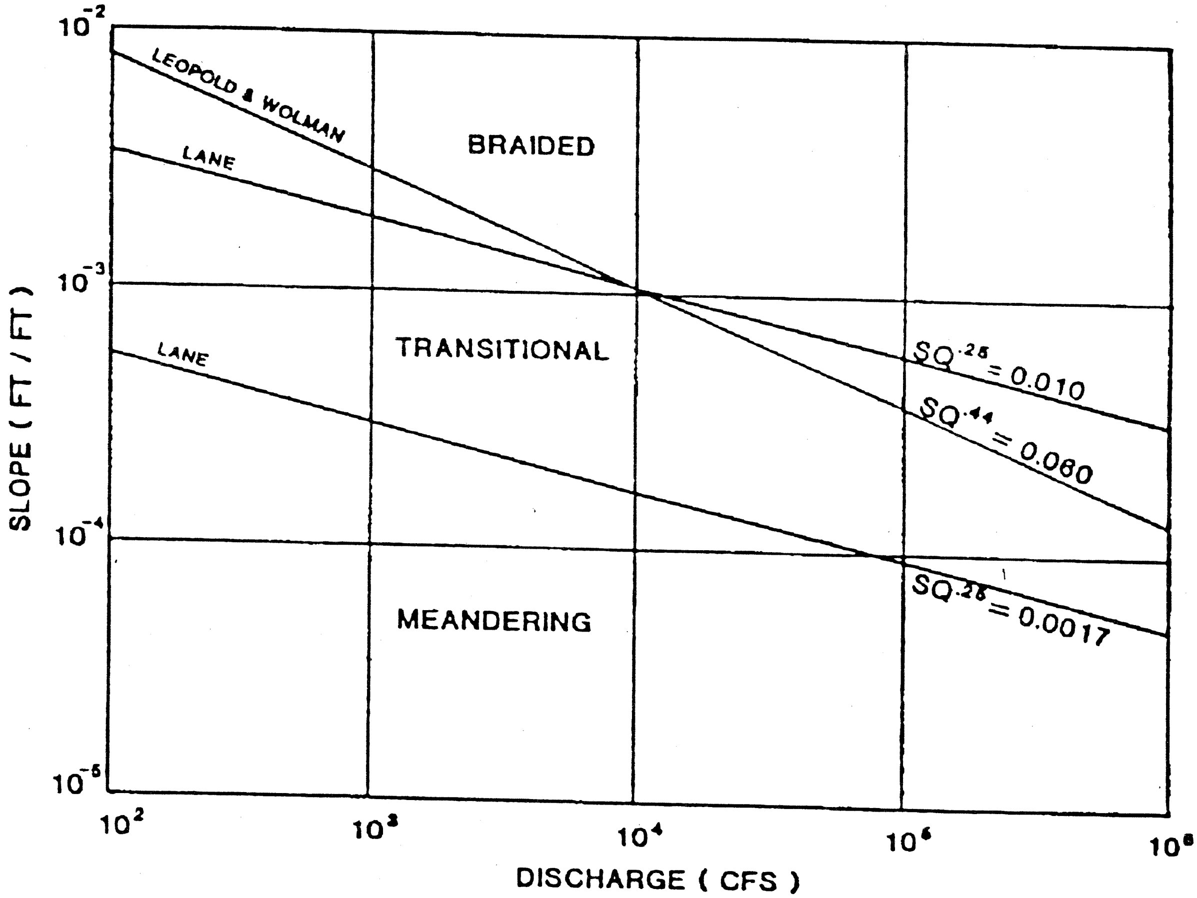


Channel Classification And Relative Stability As Hydraulic Factors Are Varied (Source: Atter,Shen et al., 1981)

01-01-93	SINUOSITY VS. SLOPE WITH CONSTANT DISCHARGE	EXHIBIT DR-05.980



Sinuosity vs Slope with Constant Discharge
Source: After Richardson et al., 1988



Slope-Discharge For Braiding Or Meandering Bed Streams
Source: After Lane, 1957