TABLE OF CONTENTS - SECTION IX

SECTION IX - OPEN CHANNEL FLOW

SECTION IX - OPEN CHANNEL FLOW

9.1 GENERAL

Open channels for use in the major drainage system have significant advantage in regard to cost, capacity, multiple use for recreational and aesthetic purposes, and potential for detention storage. Disadvantages include right-of-way needs and maintenance costs. Careful planning and design are needed to minimize the disadvantages, and to increase the benefits.

Open channels may be used in lieu of storm sewers to convey storm runoff where:

(1) Sufficient right-of-way is available;

(2) Sufficient cover for storm sewers is not available;

(3) To maintain compatibility with existing or proposed developments; and

(4) Where economy of construction can be shown without long-term public maintenance expenditures.

Intermittent alternating reaches of opened and closed systems should be avoided. Closed systems are preferred due to the inherent hazard of open channels in urban areas and the tendency for trash to collect in open channels.

The ideal channel is a natural one carved by nature over a long period of time. The benefits of such a channel are:

(1) Velocities are usually low, resulting in longer concentration times and lower downstream peak flows.

(2) Channel storage tends to decrease peak flows.

(3) Maintenance needs are usually low because the channel is somewhat stabilized.

(4) The channel provides a desirable green belt and recreational area adding significant social benefits.

Generally speaking, the natural channel or the man-made channel which most nearly conforms to the character of the natural channel is the most efficient and the most desirable.

The City has adopted an ongoing ditch maintenance program that is based upon comprehensive field inventories and analysis, and a system of establishing priorities based upon flooding potentials.

In many areas facing urbanization, the runoff has been so minimal that natural channels do not exist. However, a small trickle path nearly always exists which provides an excellent basis for location and construction of channels. Good land planning should reflect even these minimal trickle channels to reduce development cost and minimize drainage problems. In most cases, the prudent utilization of natural water routes in the development of major drainage system will reduce the requirements for an underground storm sewer system.

Channel stability is a well recognized problem in urban hydrology because of the significant increases in low flows and peak storm runoff flows. A natural channel must be studied to determine the measures needed to avoid future bottom scour and bank cutting. Erosion control measures can be used. This also helps reduce public cost and maintaining the channel in the future.

Sufficient right-of-way or permanent easement should be provided adjacent to open channels to allow entry of City maintenance vehicles.

9.2 DESIGN CRITERIA

Open channels shall be designed to the following criteria:

(1) Channel shall carry the 25 year storm minimum with free board specified herein.

(2) Channel or adjacent public drainage easement, floodway, etc., shall be capable of carrying the 100 year storm.

(3) When open channel flow velocity exceeds 5 fps, the channel shall be paved to a point 1 foot above the design water surface or other forms of stabilization shall be used.

9.2.1 CHANNEL DISCHARGE - MANNING'S EQUATION

Careful attention must be given to the design of drainage channels to assure adequate capacity and minimum maintenance to overcome the results of vegetative growth, erosion, and silting. The hydraulic characteristics of channels shall be determined by Manning's equation.

$$Q = \frac{1.49}{n} AR^{2/3}S^{1/2}$$

Q = Total discharge in CFS

n = Coefficient of roughness

A = Cross-sectional area of channel (square feet)

R = Hydrologic radius of channel (feet)

S = Slope of channel (feet per foot)

For a given channel condition of roughness, discharge and slope, there is only one possible depth for maintaining a uniform flow. This depth is the normal depth. When roughness, depth, and slope are known at a channel section, there can only be one discharge for maintaining a uniform flow through the section. This discharge is the normal discharge.

If the channel is uniform in resistance and gravity forces are in exact balance, the water surface will be parallel to the bottom of the channel. This is the condition of uniform flow.

Uniform flow is more often a theoretical abstraction than an actuality. True uniform flow is difficult to find in the field or to obtain in the laboratory. Channels are sometimes designed on this assumption that they will carry uniform flow at the normal depth, but because of conditions difficult, if not impossible, to evaluate and hence not taken into account, the flow will actually have depths considerably different from uniform depth. The Engineer must be aware of the fact that uniform flow computation provides only an approximation of what will occur; however, such computations are useful and necessary for planning.

The normal depth is computed so frequently in trapezoidal channels that it is convenient to use nomographs for such types of cross sections to eliminate the need for trial and error solutions, which are time-consuming. A nomograph for uniform flow is given in Figure 9.1.

Open channel flow in urban drainage systems is usually nonuniform because of bridge openings, curbs, and structures. This necessitates the use of backwater computations for all final channel design work.

A water surface profile must be computed for all channels and shown on all final drawings. Computation of the water surface profile should utilize standard backwater methods or acceptable computer routines, taking into consideration all losses due to the changes in velocity, drops, bridge openings, and other obstructions.

Channels should have trapezoidal sections of adequate cross-sectional areas to take care of uncertainties in runoff estimates, changes in channel coefficients, channel obstructions, and silt accumulations.

Accurate determinations of the "n" value is critical in the analysis of the hydraulic characteristics of a channel. The "n" value of each channel reach should be based on experience and judgment with regard to the individual channel characteristics. Table 9.1 gives a method of determining the composite roughness coefficient based on actual channel conditions.

Where practical, unlined channels should have sufficient gradient, depending upon the type of soil, to provide velocities that will be self-cleaning but will not be so great as to create erosion. Lined channels, drop structures, check dams, or concrete spillways may be required to control erosion that results from the high velocities of large volumes of water. Unless approved otherwise by the City Engineer, channel velocities in paved man-made channels shall not exceed ten (10) feet per second.

Where velocities in excess of five (5) feet per second are encountered, riprap, pavement, or other approved protective erosion shall be required. As minimum protection to reduce erosion, all open channels slopes shall be seeded or sodded as soon after grading as possible.

9.2.2 CHANNEL CROSS SECTIONS

The channel shape may be almost any type suitable to the location and to the environmental conditions. Often the shape can be chosen to suit open space and recreational needs to create additional benefits.

(1) Side Slope

Except in horizontal curves, the flatter the side slope, the better. Normally, slopes shall be no steeper than 3 horizontal:1 vertical (3:1), which is also the practical limit for mowing equipment, unless approved in writing by City Engineer.

Rock or concrete lined channels or those that for other reasons do not require slope maintenance may have slopes as steep as 1-1/2 horizontal:1 vertical (1.5:1), or rectangular vertical if walls are structurally designed, unless approved in writing by City Engineer.

(2) Depth

Deep channels are difficult to maintain and can be hazardous. Constructed channels should, therefore, be as shallow as practical, and they shall not exceed 4 feet unless approved in writing by City Engineer.

(3) Bottom Width

Channels with narrow bottoms are difficult to maintain and are conducive to high velocities during high flows. It is desirable to design open channels such that the bottom width is at least twice the depth unless approved in writing by City Engineer.

(4) Bend Radius

Twenty-five (25) feet or ten (10) times the bottom width, whichever is larger, is the minimum bend radius required for open channels.

(5) Trickle Channels

The low flows, and sometimes base flows, from urban areas must be given specific attention. If erosion of the bottom of the channel appears to be a problem, low flows shall be carried in a paved trickle channel which has a capacity of 5.0 percent of the design peak flow. Care must be taken to ensure that low flows enter the trickle channel without the attendant problem of the flow paralleling the trickle channel. Concrete trickle channels are required when channel slope is less than 1%.

(6) Freeboard

For channels with flow at high velocities, surface roughness, wave action, air bulking, and splash and spray are quite erosive along the top of the flow. Freeboard height should be chosen to provide a suitable safety margin. The height of freeboard should be a minimum of 1-foot for velocities up to 8 FPS and 2' for velocities over 8 FPS or provide an additional capacity of approximately one-third of the design flow. For deep flows with high velocities, one may use the formula:

Freeboard (in feet) = $1.0 + 0.025\ VD^{1/3}$, where

V = Velocity of flow

D = Depth of flow

For the freeboard of a channel on a sharp curve, extra height must be added to the outside bank or wall in the amount:

$$H = V^2 \frac{(T + B)}{2gR}$$

H = Additional height on outside edge of channel (feet)

V = Velocity of flow in channel (feet per sec.)

T = Width of flow at water surface (feet)

B = Bottom width of channel (feet)

R = Centerline radius of turn (feet)

g = Acceleration of gravity (32.2 feet per $sec.^2$)

If R is equal or greater than 3 x B, additional freeboard is not required.

(7) Connections

Connections at the junction of two or more open channels shall be smooth. Pipe and box culvert or sewers entering an open channel will not be permitted to project into the normal channel section, nor will they be permitted to enter an open channel at an angle which would direct flow from the culvert or sewer upstream in the channel.

9.3 CHANNEL DROP

The use of channel drops permits adjustment of channel gradients which are too steep for the design conditions. In urban drainage work, it is often desirable to use several low head drops in lieu of a few higher drops.

The use of sloped drops will generally result in lower installation cost. Sloped drops can easily be designed to fit the channel topography.

Sloped drops shall have roughened faces and shall be no steeper than 2:1. They shall be adequately protected from scour, and shall not cause an upstream water surface drop which will result in high velocities upstream. Side cutting just downstream from the drop is a common problem which must be protected against.

The length of the drop (L) will depend upon the hydraulic characteristics of the channel and drop. For a Q of 30 cubic feet per second/feet, L would be about 15 feet, that is, about 1/2 of the Q value. The L should not be less than 10 feet, even for low Q values. In addition, follow-up riprapping will often be necessary at most drops to more fully protect the banks and channel bottom. The criteria given is minimal, based on the philosophy that it's less costly to initially under protect with riprap, and to place additional protection after erosional tendencies are determined in the field. Project approvals are to be based on provisions for such follow-up construction.

9.4 BAFFLE CHUTES

Baffle chutes are used to dissipate the energy in the flow at a larger drop. They require no tailwater to be effective. They are useful where the water surface upstream is held at a higher elevation to provide head for filling a side storage pond during peak flows.

Baffle chutes are used in channels where water is to be lowered from one level to another. The baffle piers prevent undue acceleration of the flow as it passes down the chute. Since the flow velocities entering the downstream channel are low, no stilling basin is needed. The chute, on a 2:1 slope or flatter, may be designed to discharge up to 60 CFS per foot of width, and the drop may be as high as structurally feasible. The lower end of the chute is constructed to below stream bed level and backfilled as necessary. Degradation of the streambed does not, therefore, adversely affect the performance of the structure. In urban drainage design, the lower end should be protected from the scouring action.

The baffled apron shall be designed for the full discharge design flow. Baffle chutes shall be designed using acceptable methods such as those presented by A.J. Perterka, Engineering Monograph No. 25, "Hydraulic Design of Stilling Basins and Energy Dissipators", U.S. Department of the Interior, Bureau of Reclamation.

9.5 STRUCTURAL AESTHETICS

The use of hydrologic structures in the urban environment requires an approach not encountered elsewhere in the design of such structures. The appearance of these structures is very important. The treatment of the exterior should not be considered of minor importance. Appearance must be an integral part of the design.

Parks. It must be remembered that structures are often the only above-ground indication of the underground works involved in an expensive project. Furthermore, parks and green belts may later be developed in the area in which the structure will play a dominant environmental role.
Play Areas: An additional consideration is that the drainage structures offer excellent opportunities for neighborhood children to play. It is almost impossible to make drainage works inaccessible to children, and therefore, what is constructed should be made as safe as is reasonably possible. Safety hazards should be minimized and vertical drops protected with decorative fencing or rails.

Concrete Surface Treatment: The use of textured concrete presents a pleasing appearance and removes form marks. Exposed aggregate concrete is also attractive but may require special control of aggregate used in the concrete.

Rails and Fences: The use of rails and fences along concrete walls provides a pleasing topping to an otherwise stark wall, and also gives a degree of protection against someone inadvertently falling over the wall.

9.6 COMPUTATION FORMAT

Figure 9.2 is to be used for open channel design. Computer generated computations and output are accepted and subject to review by City Engineer.

The steps to follow in an open channel design are:

1. List all the design data (i.e., location, area, runoff coefficients, typical section, slope, etc.).

2. Determine the initial time of concentration (T_o).

3. Estimate travel time (T_d) through study reach and add to initial time of concentration to obtain time of concentration (T_c) at lower end of study reach.

4. Determine the discharge for the design storm using T_c.

5. Enter the discharge and slope in the appropriate channel design chart with the discharge in the slope to find the velocity and depth of flow.

6. Check the estimated travel time against the calculated velocity using Manning's equation.

   A. If the estimated travel time is comparable to the calculated travel time (±1.0 min.) proceed to Step 7.

   B. If the estimated travel time does not check with the calculated travel time, repeat Steps 3-6 until an agreement is reached.

7. If excessive velocities or water depths are determined, select another typical section, revise channel grade, or revise lining and repeat Steps 3-7.

8. Similar calculations are to be made to determine operational characteristics - freeboard, velocity, etc.

9.7 CHANNEL LINING DESIGN

9.7.1 UNLINED CHANNELS

The design charts for unlined channels (bare soils) are based on tests on 10 different classes of soils, ranging from cohesive clays to noncohesive sands and gravels. These are Figures 9.3 and 9.4. Generally, sandy, noncohesive soils tend to be very erodible, the large grained gravel clay-silt mixtures are erosion resistant, and the mixtures of sand, clay, and colloids are moderately erodible.

9.7.2 TEMPORARY LININGS

Temporary linings are flexible coverings used to protect a channel until permanent vegetation can be established using seeding. For the most part, the materials used are biodegradable. Listed below are some of the temporary linings that can be used, which are established in the charts for this section. Among the factors which should be known in order to use these are hydraulic radius, soil condition, and channel slope. When one or all of these factors are known, then a flow velocity or maximum flow depth can be determined from these charts.

1. *Fiber Glass Roving
2. *Jute Matting
3. *Wood Fiber

* Refer to the Arkansas Highway and Transportation Department's Standard Specifications for material descriptions and construction methods.

9.7.3 GRASS LININGS

Several different types of vegetative covers are listed and grouped according to degree of retardance in Table 9.2. This Table can be used in conjunction with seeding specification in the Arkansas Highway and Transportation Department's Standard Specifications. Figures 9.14 through 9.21 determine flow velocities or maximum flow depths given such factors as channel slope, hydraulic radius, and/or soil types. Table 9.3 is relatively good source to check permissible velocities for different types of grass linings in channels.

9.7.4 ROCK RIPRAP

The resistance of random riprap to displacement by moving water depends upon:

1. Weight, size, shape, and composition of the individual stones.
2. The gradation of the stone.
3. The depth of water over the stone blanket.
4. The steepness and stability of the protected slope and angle of repose of riprap.
5. The stability and effectiveness of the filter blanket on which the stone is placed.
6. The protection of toe and terminals of the stone blanket.

The size of stone needed to protect a streambank or highway embankment from erosion by a current moving parallel to the embankment is determined by the use of Figures 9.22, 9.23 and 9.24.

When rock riprap is used, the need for an underlying filter material must be evaluated. The filter material may be either a granular blanket or plastic filter cloth. All rip-rap shall include concrete slurry to increase stability and minimize vegetative growth.

9.8 DESIGN OF GRANULAR FILTER BLANKET

For a granular filter blanket, the following criteria should be met:

$$\frac{D_{15}\text{ filter}}{D_{85}\text{ base}} < 5 < \frac{D_{15}\text{ filter}}{D_{15}\text{ base}} < 40$$

and

$$\frac{D_{50}\text{ filter}}{D_{50}\text{ base}} < 40$$

In the above relationships, filter refers to the overlying material. The relationships must hold between the filter blanket and base material and the riprap and filter blanket.

9.9 CONCRETE

Concrete lined channels provide high capacities, but also have high outlet velocities so erosion problems become evident and must be dealt with. Capacity Figures 9.25 through 9.36 related velocity and discharge to the channel geometry, slope and resistance. The Manning equation may be solved through trial and error by using the trapezoidal channel charts. Maximum velocity of concrete lined channel shall be 10 fps unless otherwise approved in writing by City Engineer.

9.10 OTHER LINING OPTIONS

Other lining options shall be reviewed on a case by case basis and approved by the City Engineer.

TABLE 9.1

COMPUTATION OF COMPOSITE ROUGHNESS COEFFICIENT FOR EXCAVATED AND NATURAL CHANNELS

$$n = (n_o + n_1 + n_2 + n_3 + n_4)\, m$$

	CHANNEL CONDITIONS	VALUE
Material Involved n_0	Earth	0.020
	Rockcut	0.025
	Final Gravel	0.024
	Coarse Gravel	0.028
Degree of Irregularity n_1	Smooth	0.000
	Minor	0.005
	Moderate	0.010
	Severe	0.020
Variation of Channel Cross Section n_2	Gradual	0.000
	Alternating Occasionally	0.005
	Alternating Frequently	0.010-0.015
Relative Effect Of Obstructions n_3	Negliible	0.000
	Minor	0.010-0.015
	Appreciable	0.020-0.030
	Severe	0.040-0.060
Vegetation n_4	Low	0.005-0.010
	Medium	0.010-0.025
	High	0.025-0.050
	Very High	0.050-0.100
Degree of Meandering m	Minor	1.000-1.200
	Appreciable	1.200-1.500
	Severe	1.500

Roughness Coefficient For Lined Channels

Concrete Lined - n = 0.017
Rubble RipRap - n = 0.022

<u>Open Channel Hydraulics</u>
Ven Te Chow, Ph.D.

TABLE 9.2

CLASSIFICATION OF VEGETEL COVERS AS TO DEGREE OF RETARDANCE

Note: Covers classified have been tested in experimental channels.
Covers were green and generally uniform.

Retardance	Cover	Condition
A	Weeping lovegrass....................	Excellent stand, tall, (average 30")
	Yellow bluestem, Ischaemum........	Excellent stand, tall, (average 36")
B	Kudzu....................................	Very dense growth, uncut
	Bermudagrass.........................	Good Stand, tall (average 12")
	Native grass mixture, (little bluestem, blue grama, and other long and short mid-west grasses)...	Good Stand, unmowed
	Weeping Lovegrass....................	Good stand, tall, (average 24")
	Lespedeza sericea.....................	Good stand, not woody, tall average 19")
	Alfalfa....................................	Good stand, uncut (average 12")
	Weeping lovegrass.....................	Good stand, mowed, (average 18")
	Kudzu....................................	Dense growth, uncut
	Blue Grama..............................	Good stand, uncut, (average 18")
C	Crabgrass................................	Fair Stand, uncut (10" to 48")
	Bermudagrass.........................	Good Stand, mowed (average 6")
	Common lespedeza....................	Good Stand, uncut (average 6")
	Grass legume mixture—summer (orchard grass, redtop, Italian ryegrass, and common lespedeza)..	Good Stand, uncut (average 6" to 2')
	Centipedegrass........................	Very dense cover (average 6")
	Kentucky Bluegrass....................	Good Stand, headed (6" to 12")
D	Bermudagrass.........................	Good stand, cut to 2.5" height
	Common lespedeza....................	Excellent Stand, uncut (average 4"-6")
	Buffalograss...........................	Good Stand, cut to 3"-6"
	Grass legume mixture—fall, spring (orchard grass, redtop, Italian ryegrass, and common lespedeza)..	Good Stand, uncut (4" to 5")
	Lespedeza Sericea.....................	After cutting to 2" height Very good stand before cutting
E	Bermudagrass.........................	Good Stand, cut to 1.5" height
	Bermudagrass.........................	Burned stubble

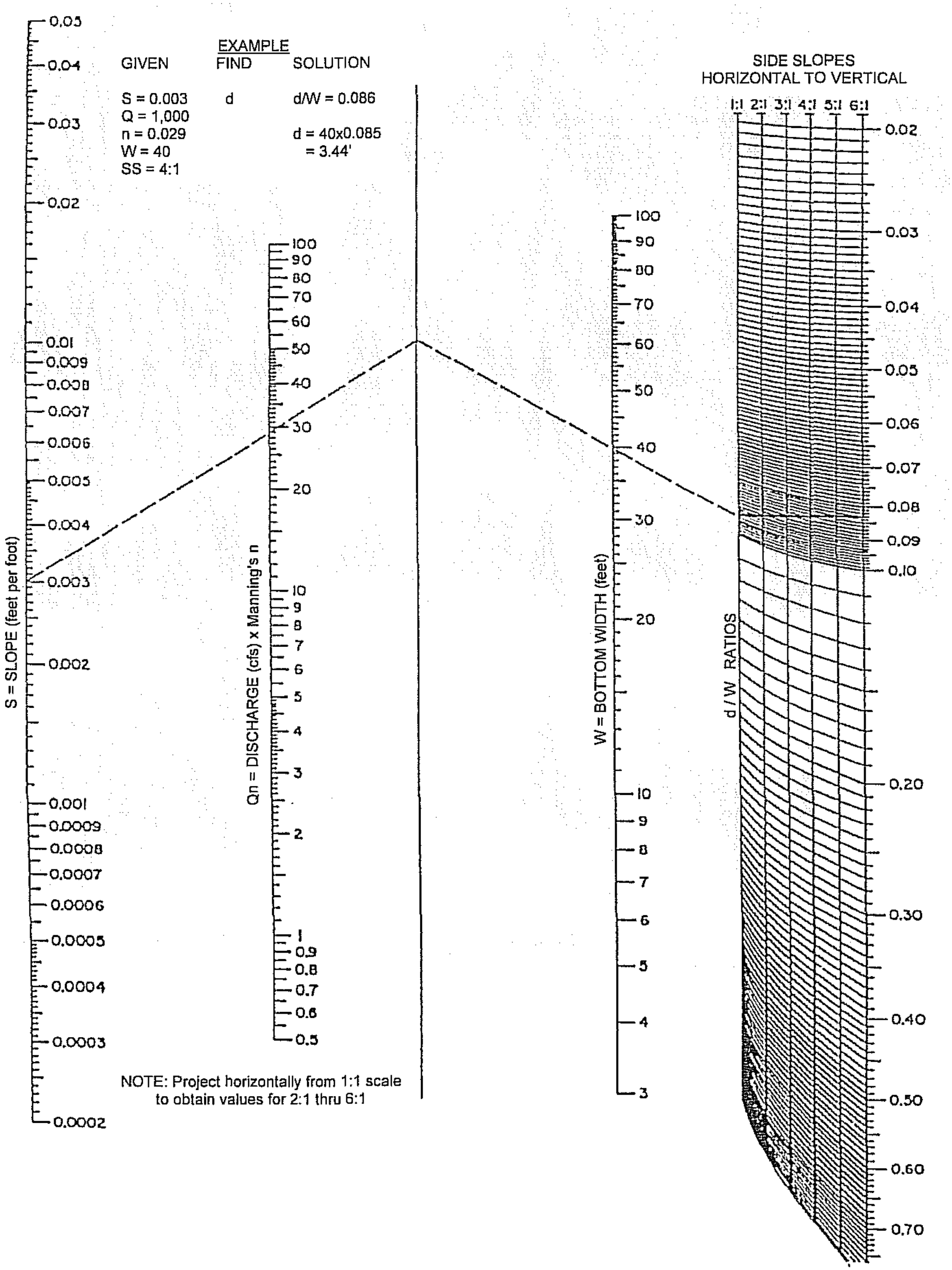
From: SCS "Handbook of Channel Design for Soil and Water Conservation".

TABLE 9.3

PERMISSIBLE VELOCITIES FOR CHANNELS LINED WITH GRASS

Cover	Slope Range %	Permissible Velocity, fps: Erosion-Resistant Soils	Permissible Velocity, fps: Easily Eroded Soils
Bermudagrass	0-5	5	5
	5-10	5	5
	>10	5	4
Buffalo Grass, Kentucky Bluegrass, smooth brome, blue grama	0-5	5	5
	5-10	5	4
	>10	5	3
Grass Mixture	0-5	5	4
	5-10	4	3
	Do not use on slopes steeper than 10%		
Lespedeza Sericea, weeping love grass, ischaemum, yellow bluestem, kudzu, alfalfa, crabgrass	0-5	3.5	2.5
	Do not use on slopes steeper than 5% except for side slopes in combination channel		
Annuals -- used on mild slopes or as temporary protection until permanent covers are established, common lespedeza, Sudan Grass	0-5	3.5	2.5
	Use on Slopes steeper than 5% not recommended		

Remarks: The values apply to average, uniform stands of each type of cover. Use velocities exceeding 5 fps only for paved channels.



UNIFORM FLOW FOR TRAPEZOIDAL CHANNELS

SOURCE: Texas Highway Department

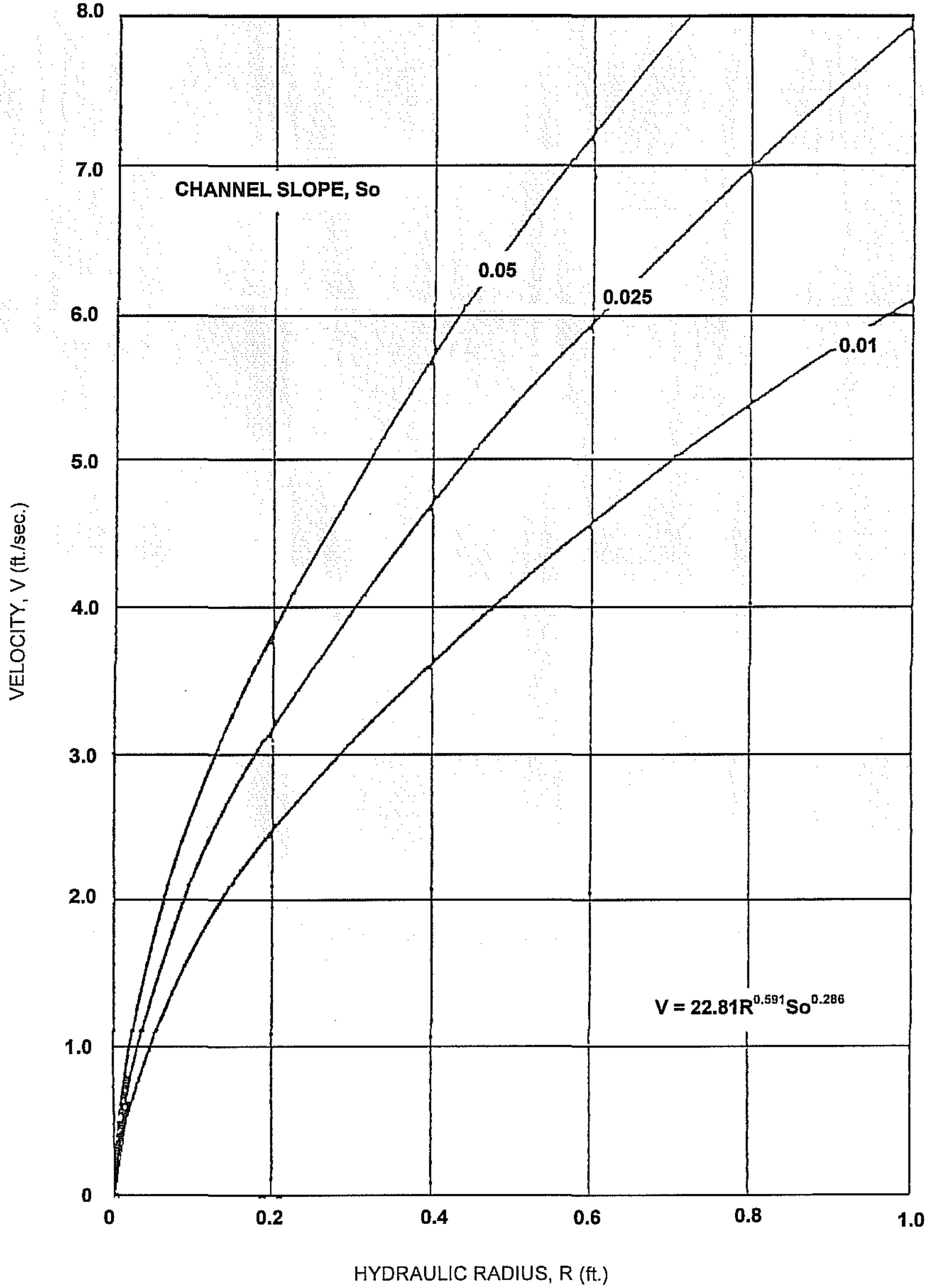
Figure 9.1

DITCH DESIGN FROM

Location	Area Acres	C	EA x C	∑A x C	T_o Min	T_d Min	I IN/HR	Q CFS	Typical Section	So f/f	n	V. Calc Ft/Sec	Water Depth	Lining Depth	Type Lining	Remarks

DITCH DESIGN FORM

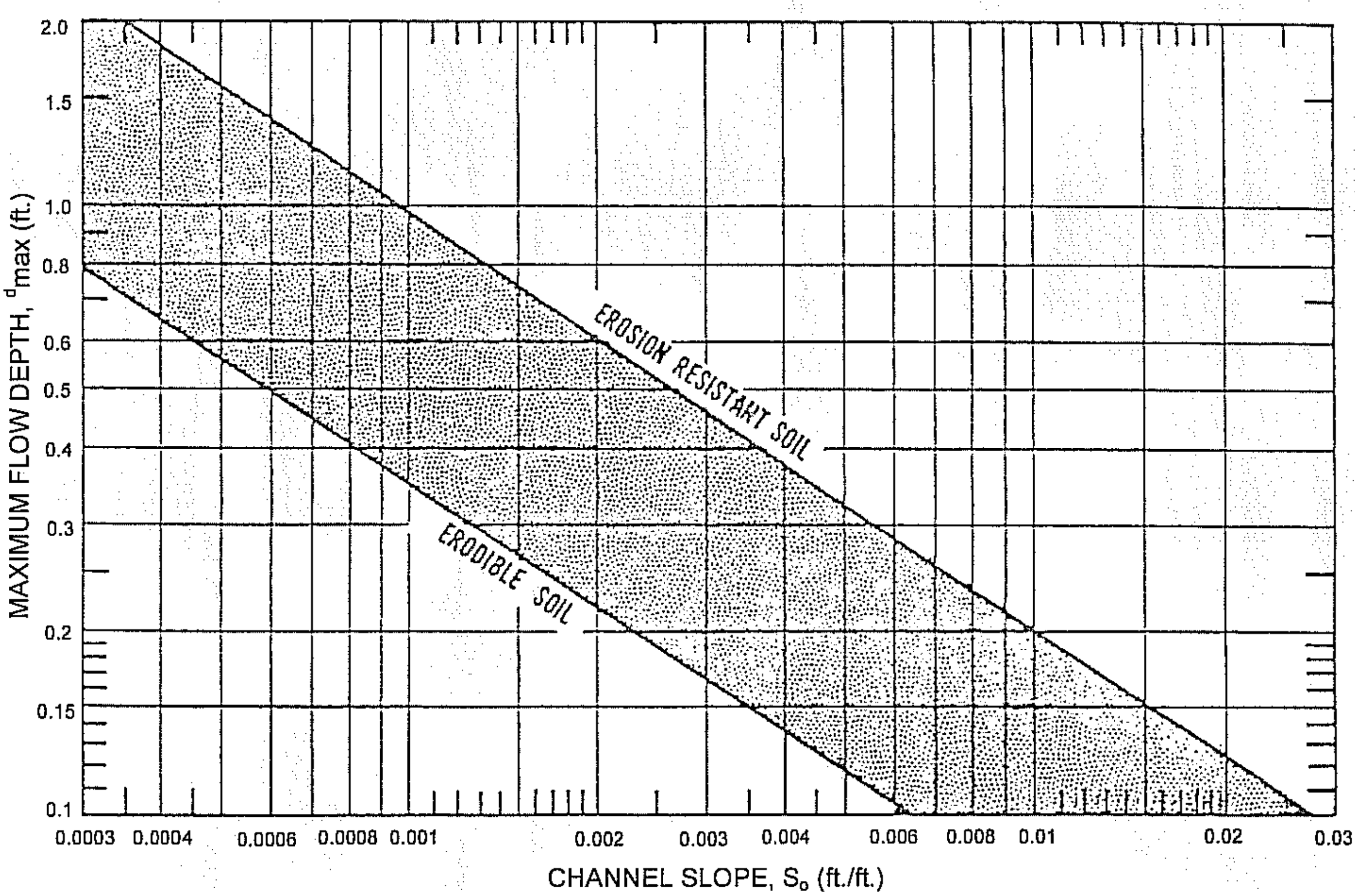
Figure 9.2



FLOW VELOCITY FOR UNLINED CHANNELS
(BARE SOIL)

SOURCE: AHTD

Figure 9.3

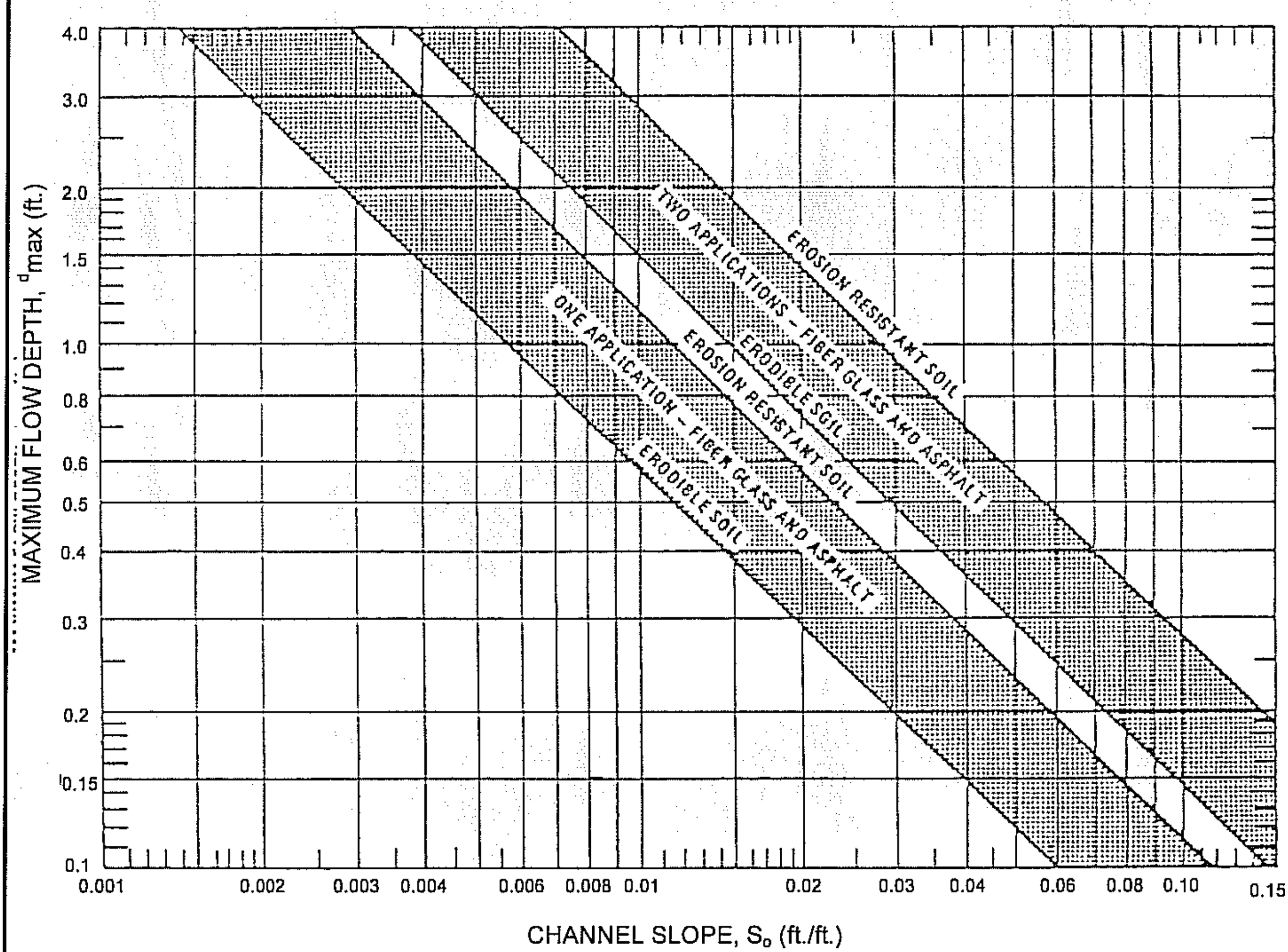


THE CITY OF BENTONVILLE

MAXIMUM PERMISSIBLE DEPTH OF FLOW (^{d}max.) FOR UNLINED CHANNELS (BARE SOIL)

SOURCE: AHTD

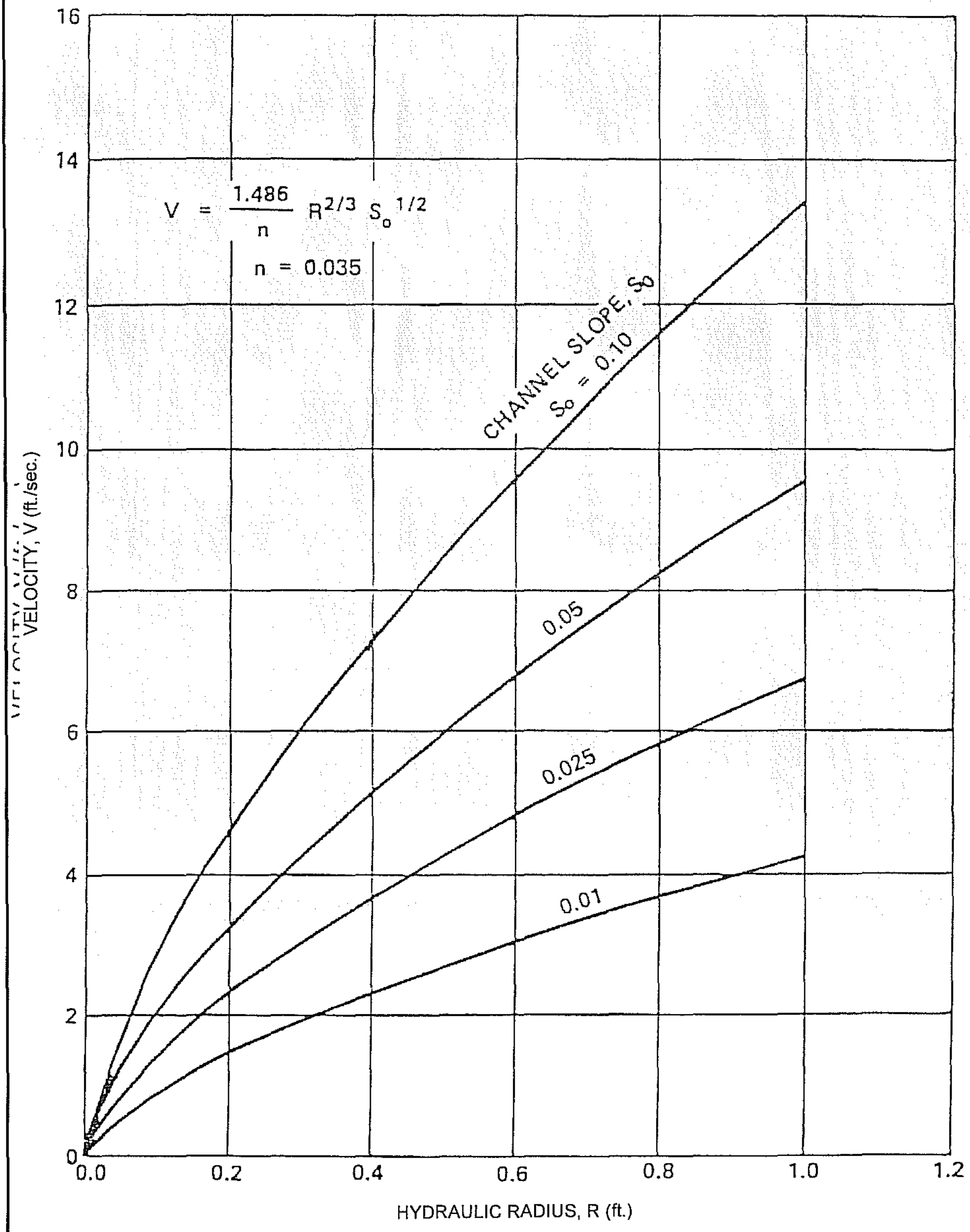
Figure 9.4



MAXIMUM PERMISSIBLE DEPTH OF FLOW (^{d}max.) FOR CHANNELS LINED WITH FIBER GLASS ROVING (SINGLE AND DOUBLE LAYER)

SOURCE: AHTD

Figure 9.5



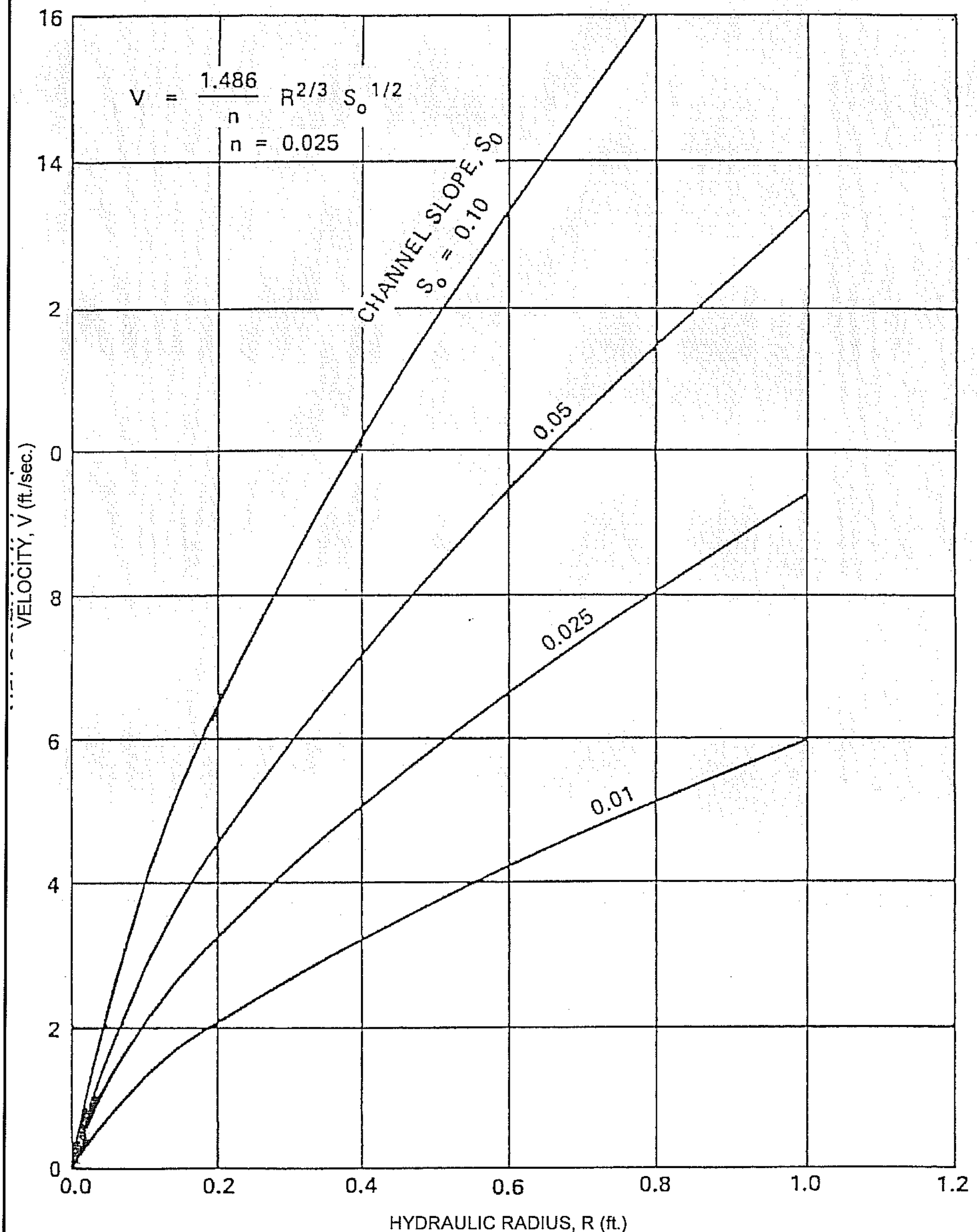
$$V = \frac{1.486}{n} R^{2/3} S_o^{1/2}$$

THE CITY OF BENTONVILLE

FLOW VELOCITY FOR CHANNELS LINED WITH FIBER GLASS ROVING TACKED WITH ASPHALT SINGLE LAYER

SOURCE: AHTD

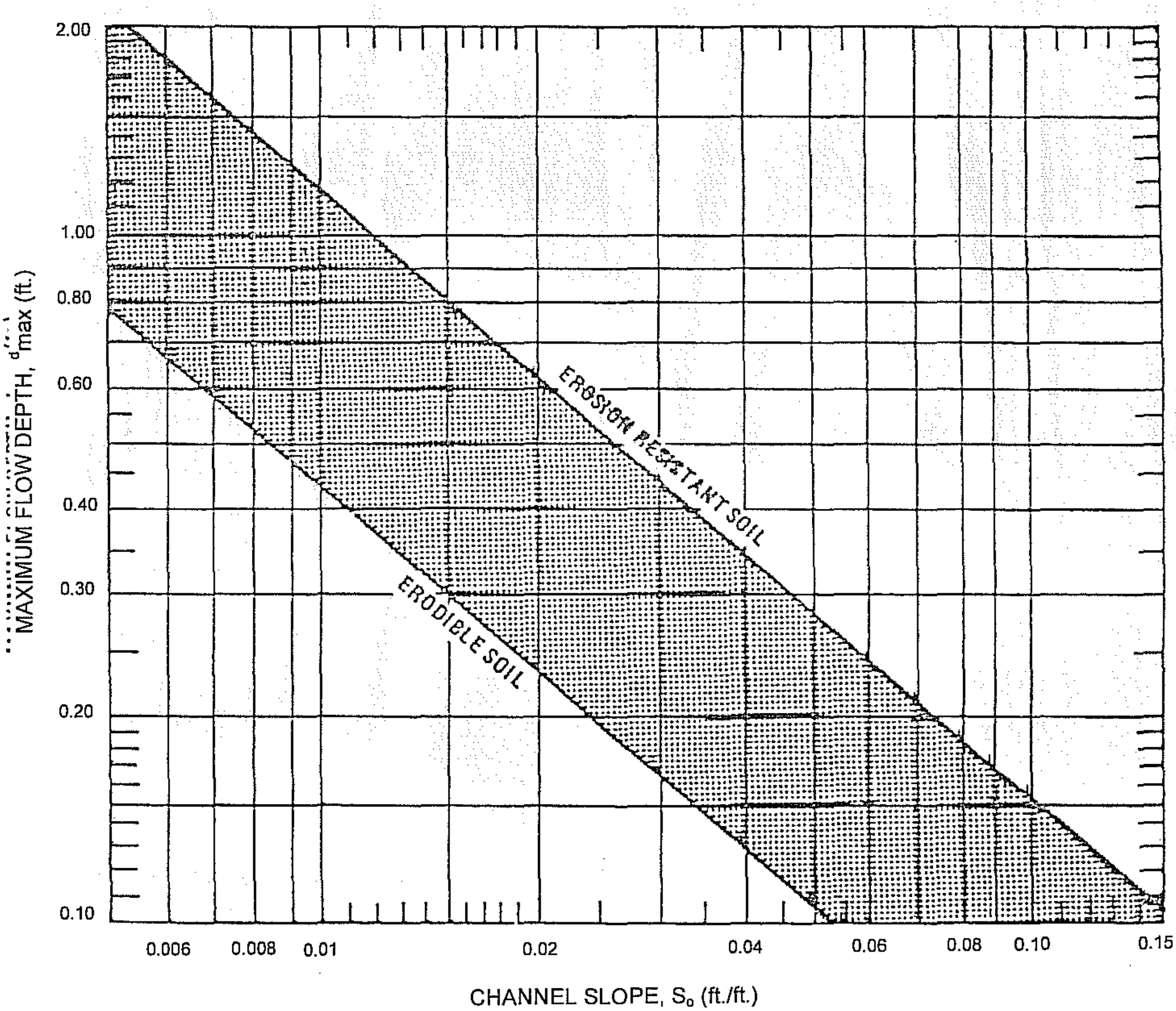
Figure 9.6



FLOW VELOCITY FOR CHANNELS LINED WITH FIBER GLASS ROVING TACKED WITH ASPHALT DOUBLE LAYER

SOURCE: AHTD

Figure 9.7

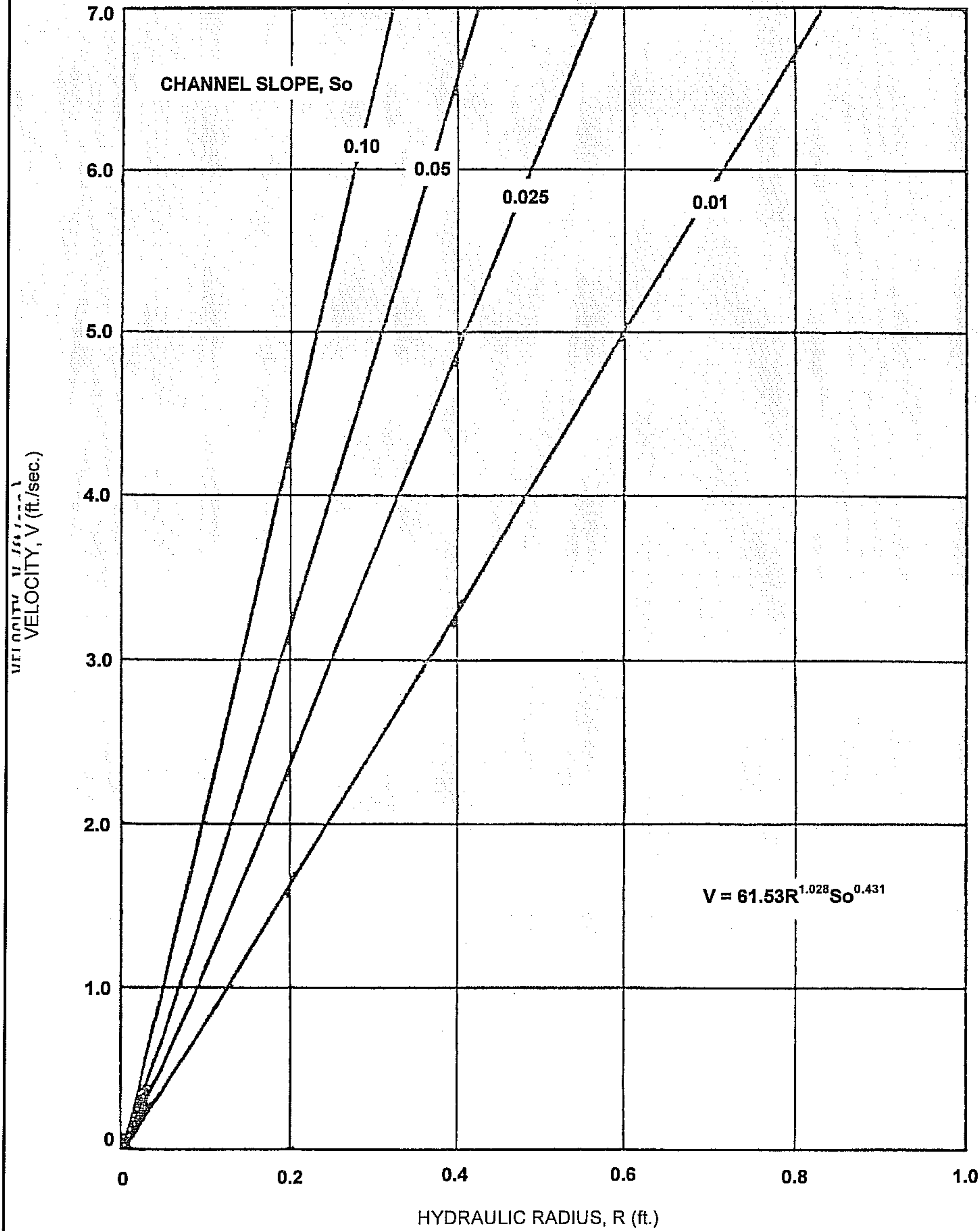


THE CITY OF BENTONVILLE

MAXIMUM PERMISSIBLE DEPTH OF FLOW (^{d}max.) FOR CHANNELS LINED WITH JUTE MESH

SOURCE: AHTD

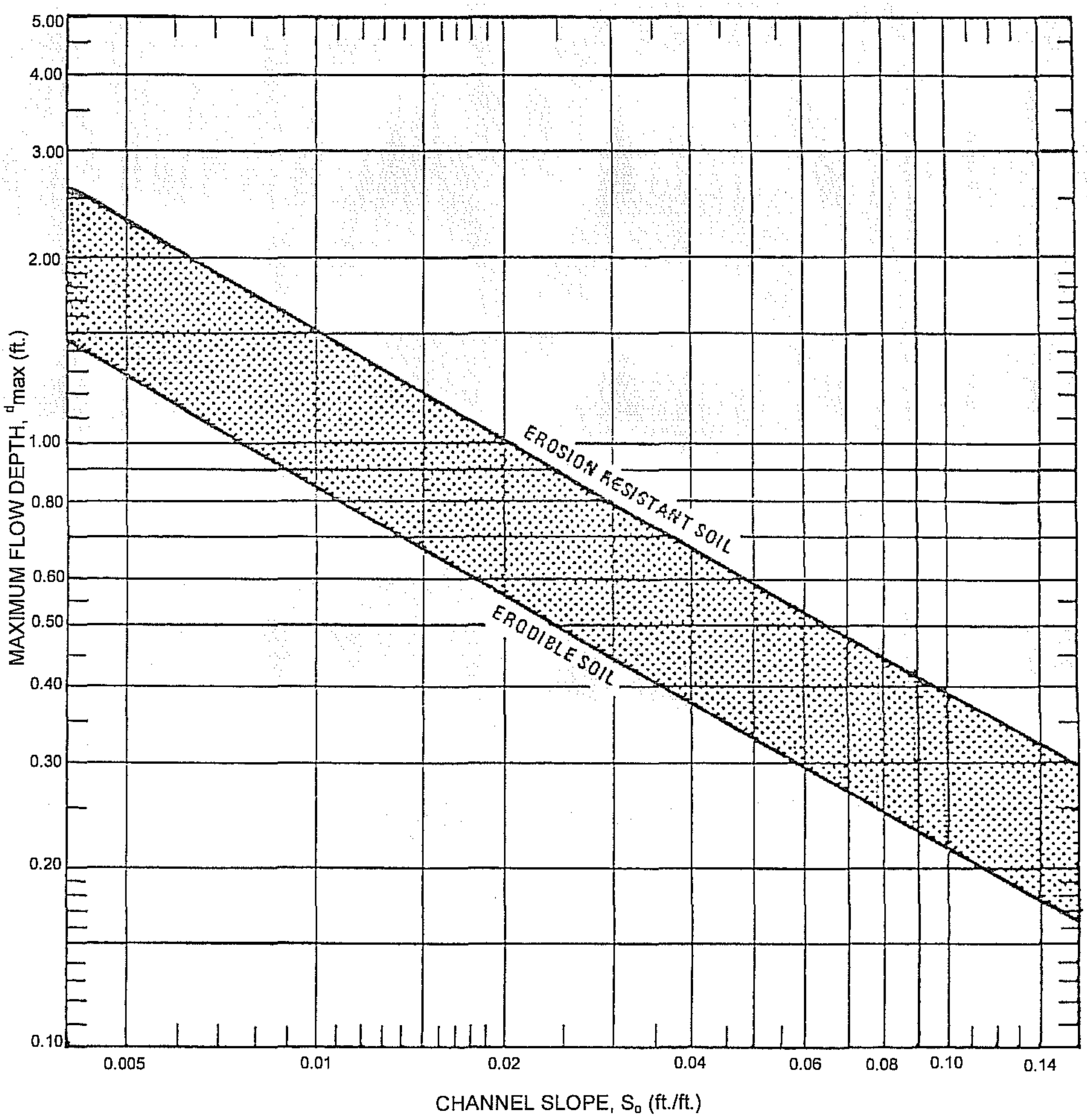
Figure 9.8



FLOW VELOCITY FOR CHANNELS LINED WITH JUTE MESH

SOURCE: AHTD

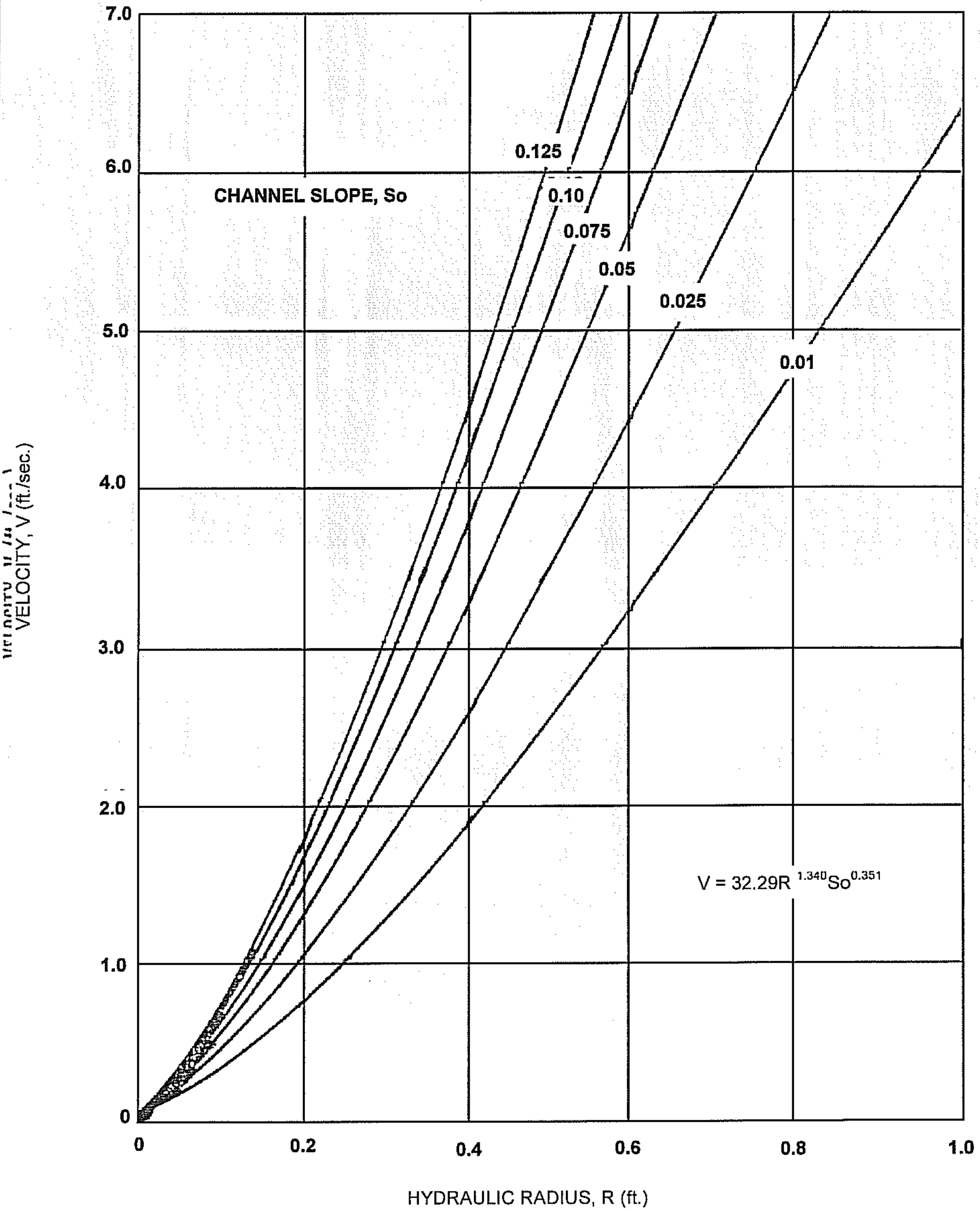
Figure 9.9



MAXIMUM PERMISSIBLE DEPTH OF FLOW (^{d}max.) FOR CHANNELS LINED WITH EXCELSIOR MAT

SOURCE: AHTD

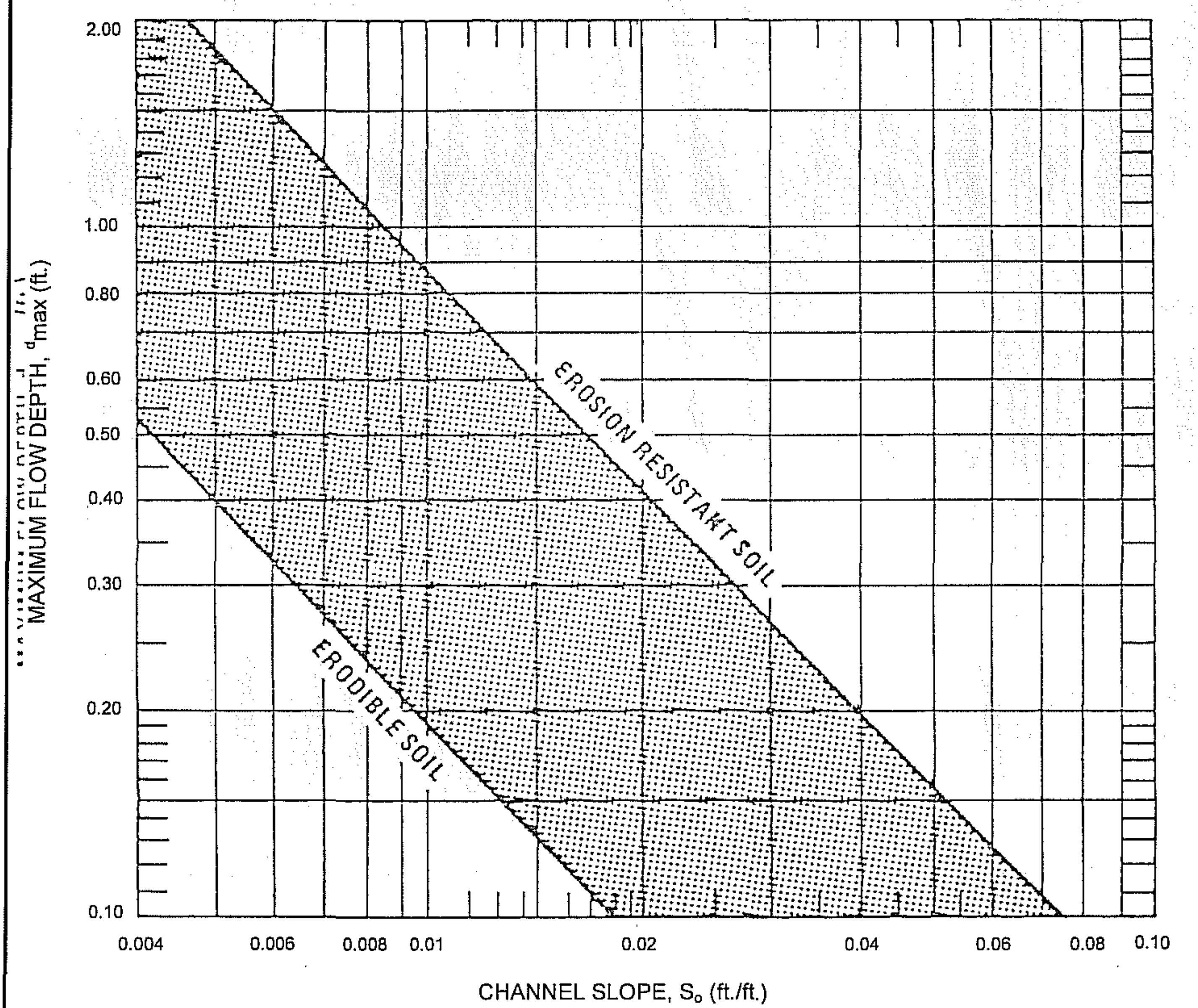
Figure 9.10



FLOW VELOCITY FOR CHANNELS LINED WITH EXCELSIOR MAT

SOURCE: AHTD

Figure 9.11

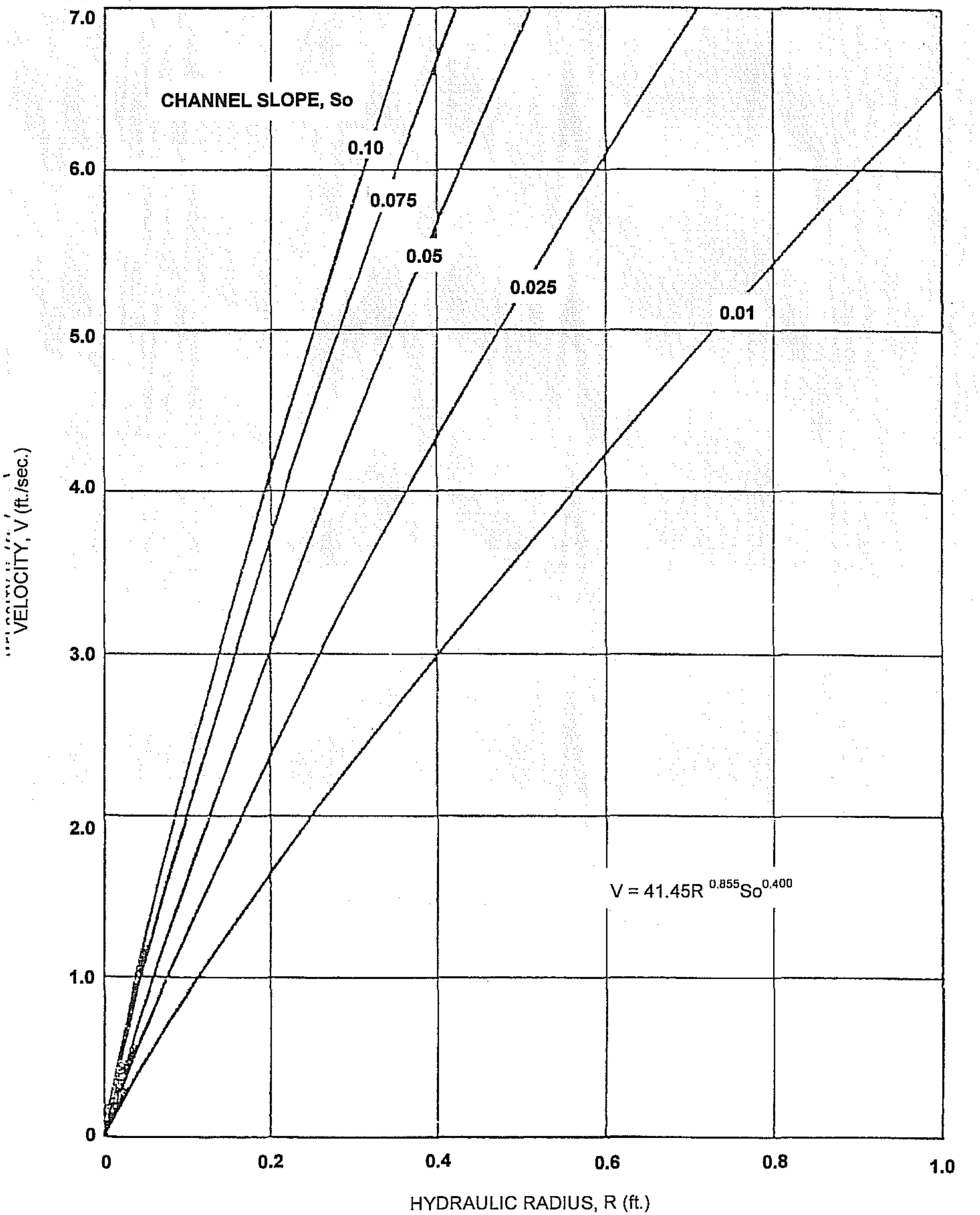


THE CITY OF BENTONVILLE

MAXIMUM PERMISSIBLE DEPTH OF FLOW ($d_{max.}$) FOR CHANNELS LINED WITH EROSIONET

SOURCE: AHTD

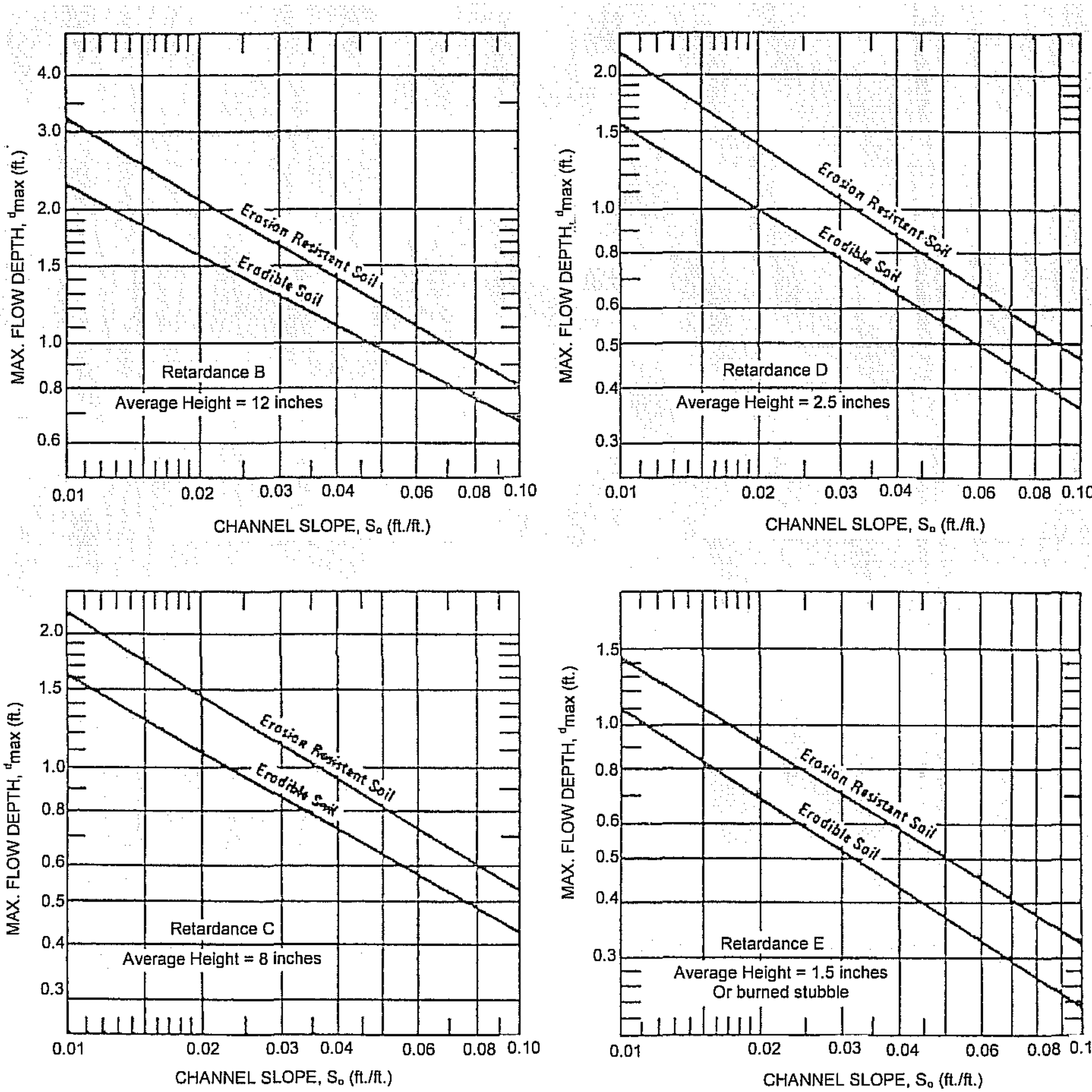
Figure 9.12



FLOW VELOCITY FOR CHANNELS LINED WITH EROSIONET

SOURCE: AHTD

Figure 9.13



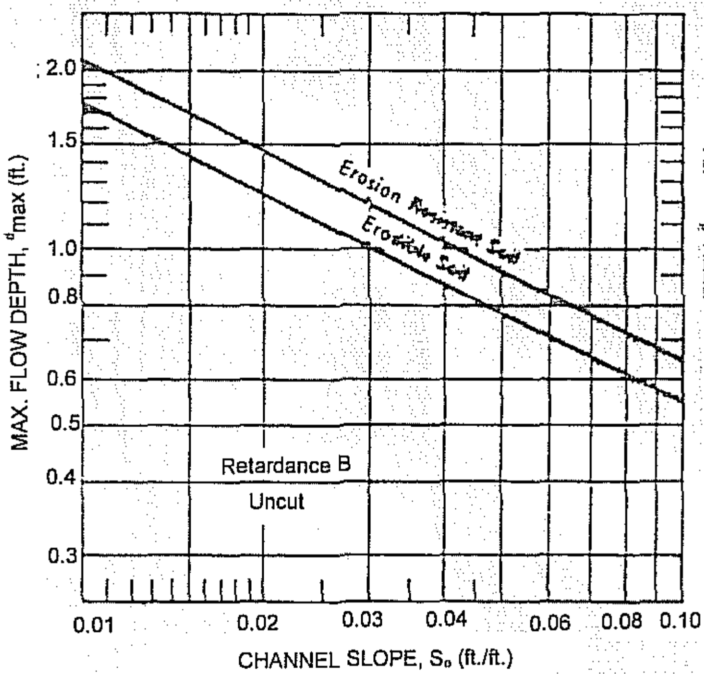
NOTE: Use on slopes greater than 10% is not recommended.

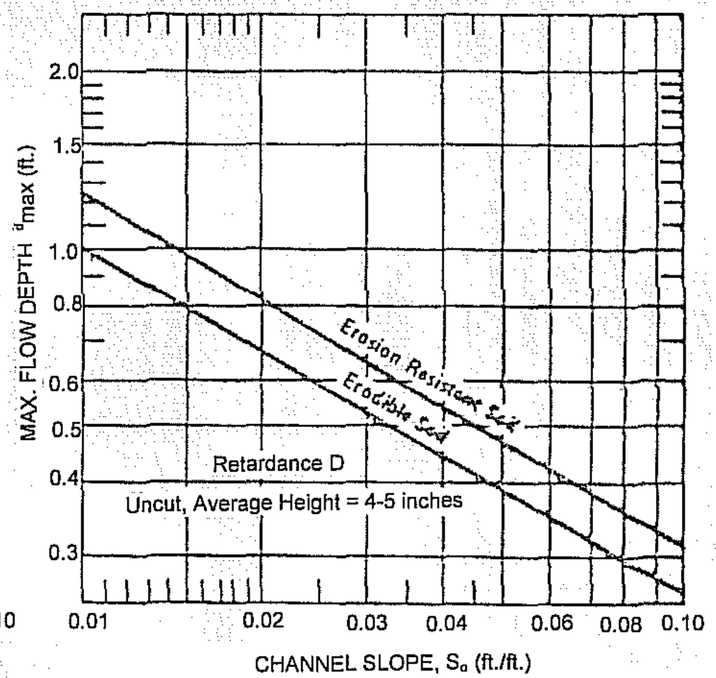
THE CITY OF BENTONVILLE

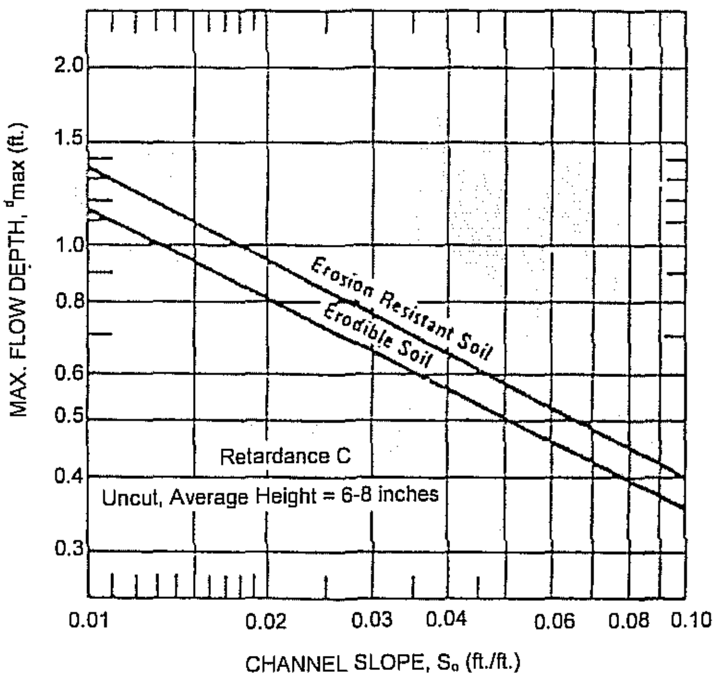
MAXIMUM PERMISSIBLE DEPTH OF FLOW (^{d}max.) FOR CHANNELS LINED WITH BERMUDA GRASS. GOOD STAND, CUT TO VARIOUS LENGTHS

SOURCE: AHTD

Figure 9.14







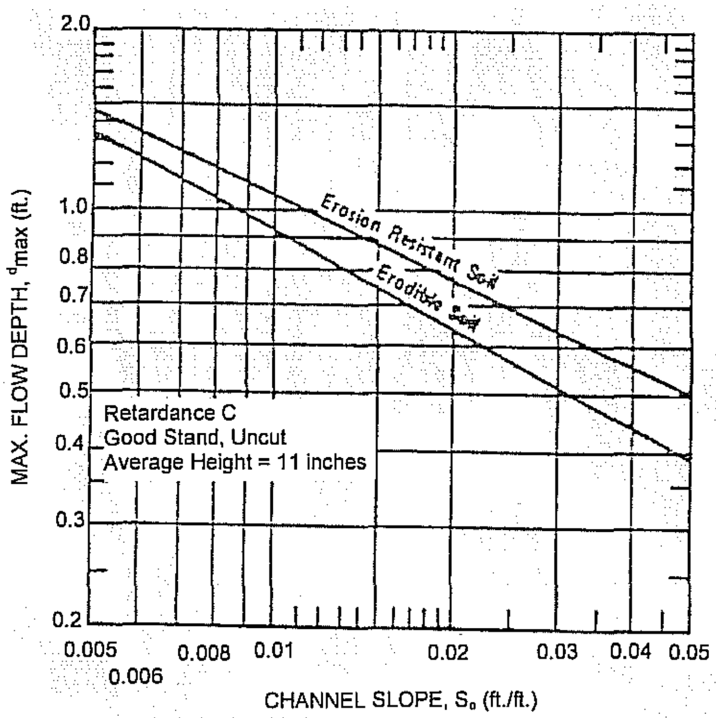
Retardance B: Native-Grass Mixture
Little Bluestem, Blue-Grama, Other
Long and Short Midwest Grasses.
Retardance C: Grass-Legume Mixture
Summer-Orchard Grass, Redtop,
Italian Ryegrass, Common Lespedeza
Retardance D: Grass-Legume Mixture
Fall, Spring – Orchard Grass, Redtop,
Italian Ryegrass, Common Lespedeza

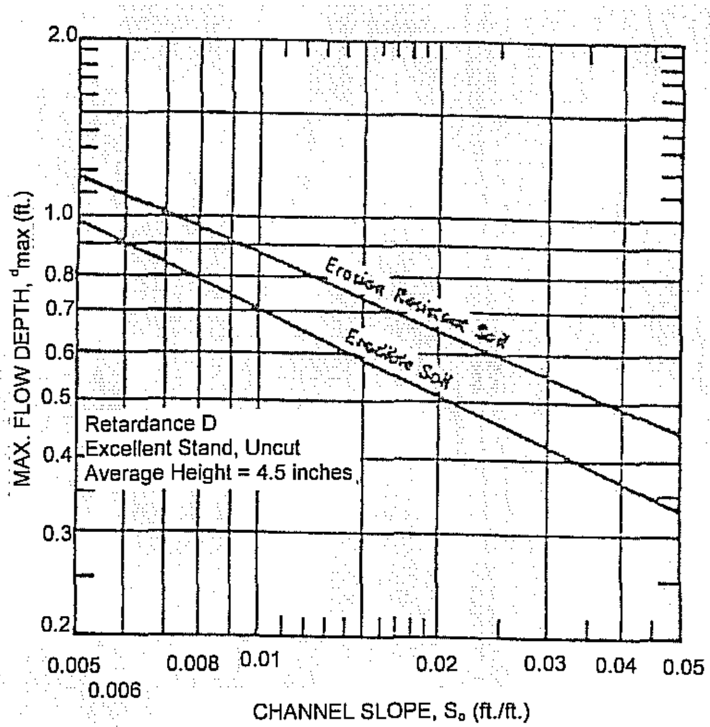
THE CITY OF BENTONVILLE

MAXIMUM PERMISSIBLE DEPTH OF FLOW (^{d}max.) FOR CHANNELS LINED WITH GRASS MIXTURES GOOD STAND, UNCUT

SOURCE: AHTD

Figure 9.15



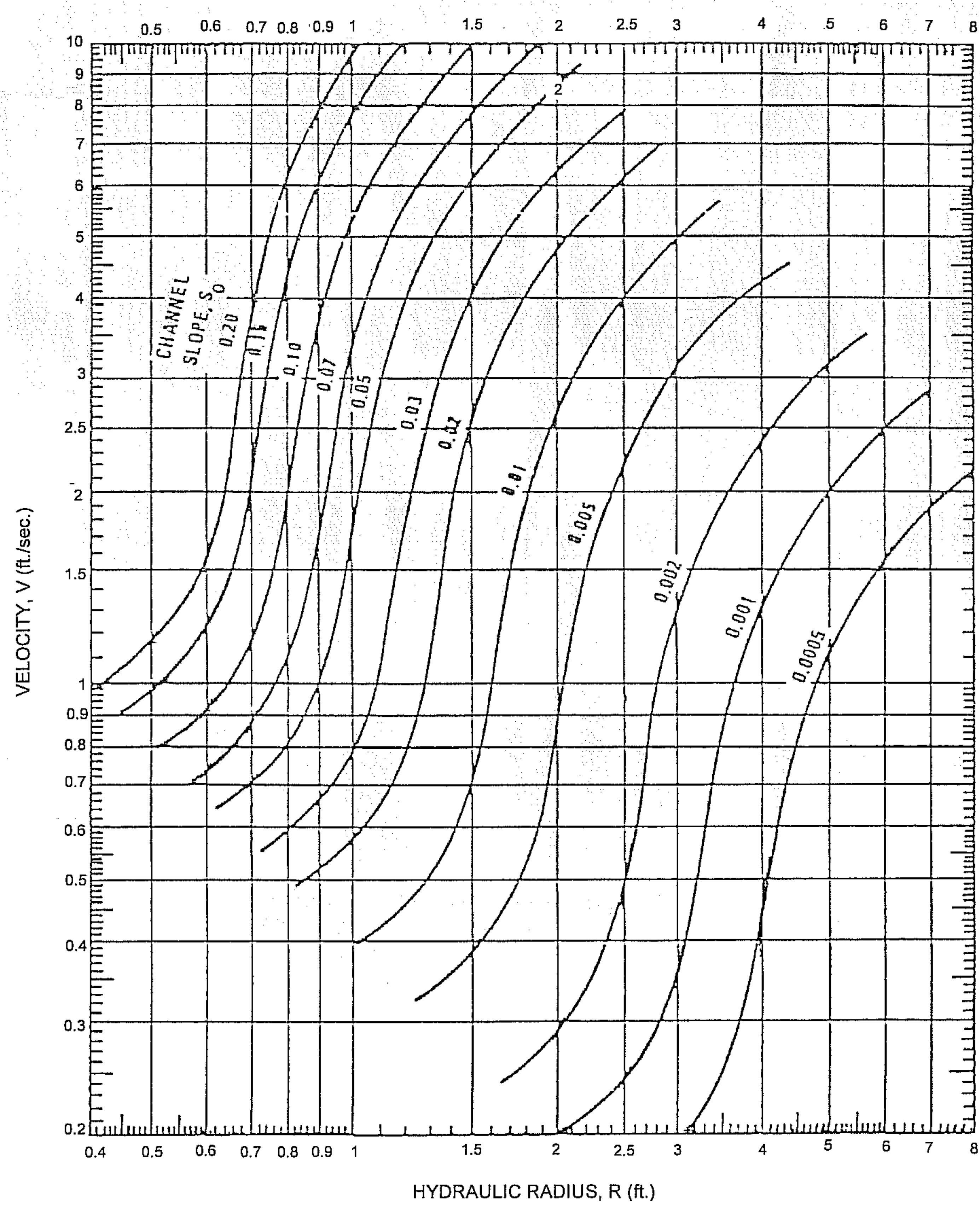


THE CITY OF BENTONVILLE

MAXIMUM PERMISSIBLE DEPTH OF FLOW (^{d}max.) FOR CHANNELS LINED WITH COMMON LESPEDEZA OF VARIOUS LENGTHS

SOURCE: AHTD

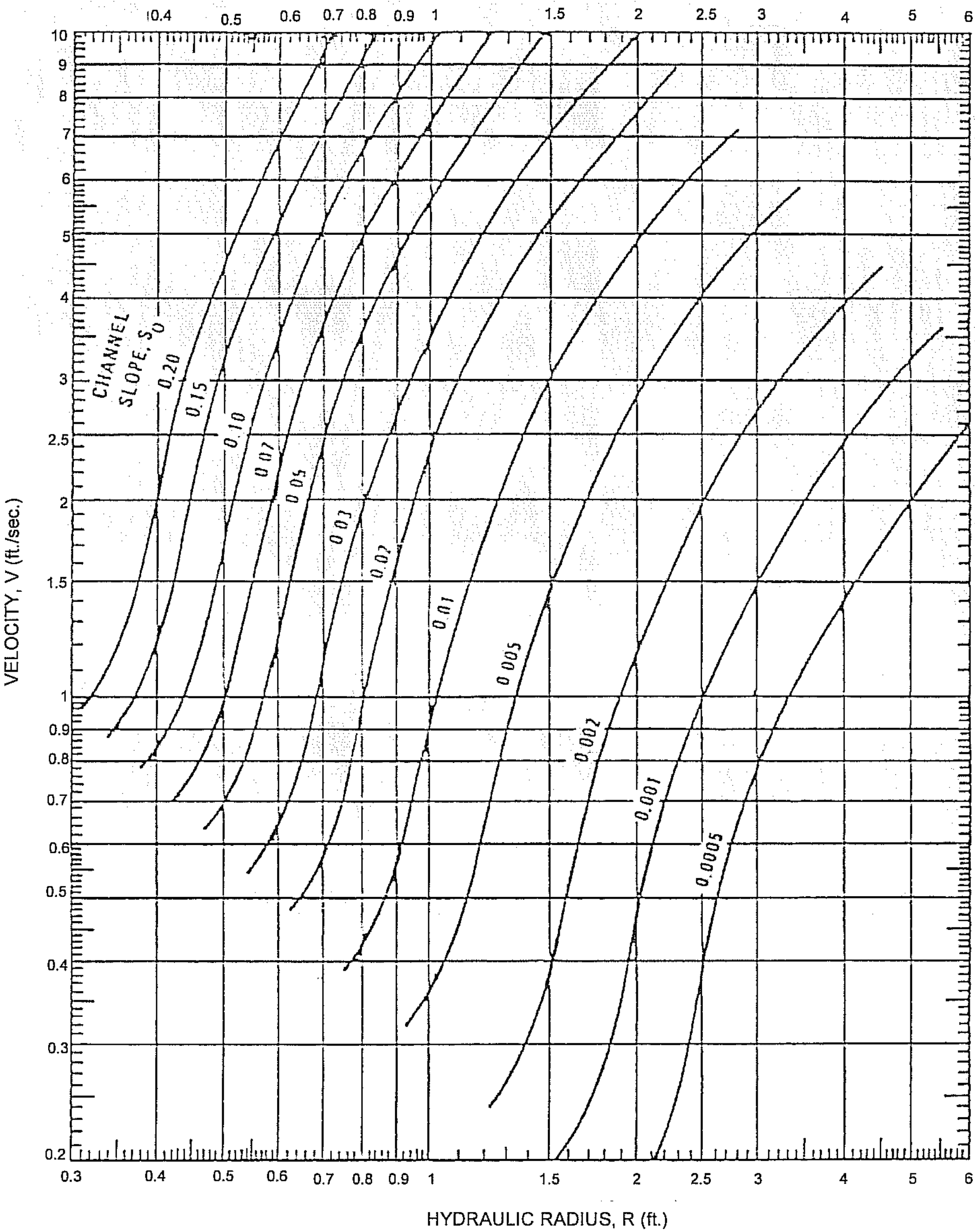
Figure 9.16



FLOW VELOCITY FOR CHANNELS LINED WITH VEGETATION OF RETARDANCE A

SOURCE: AHTD

Figure 9.17

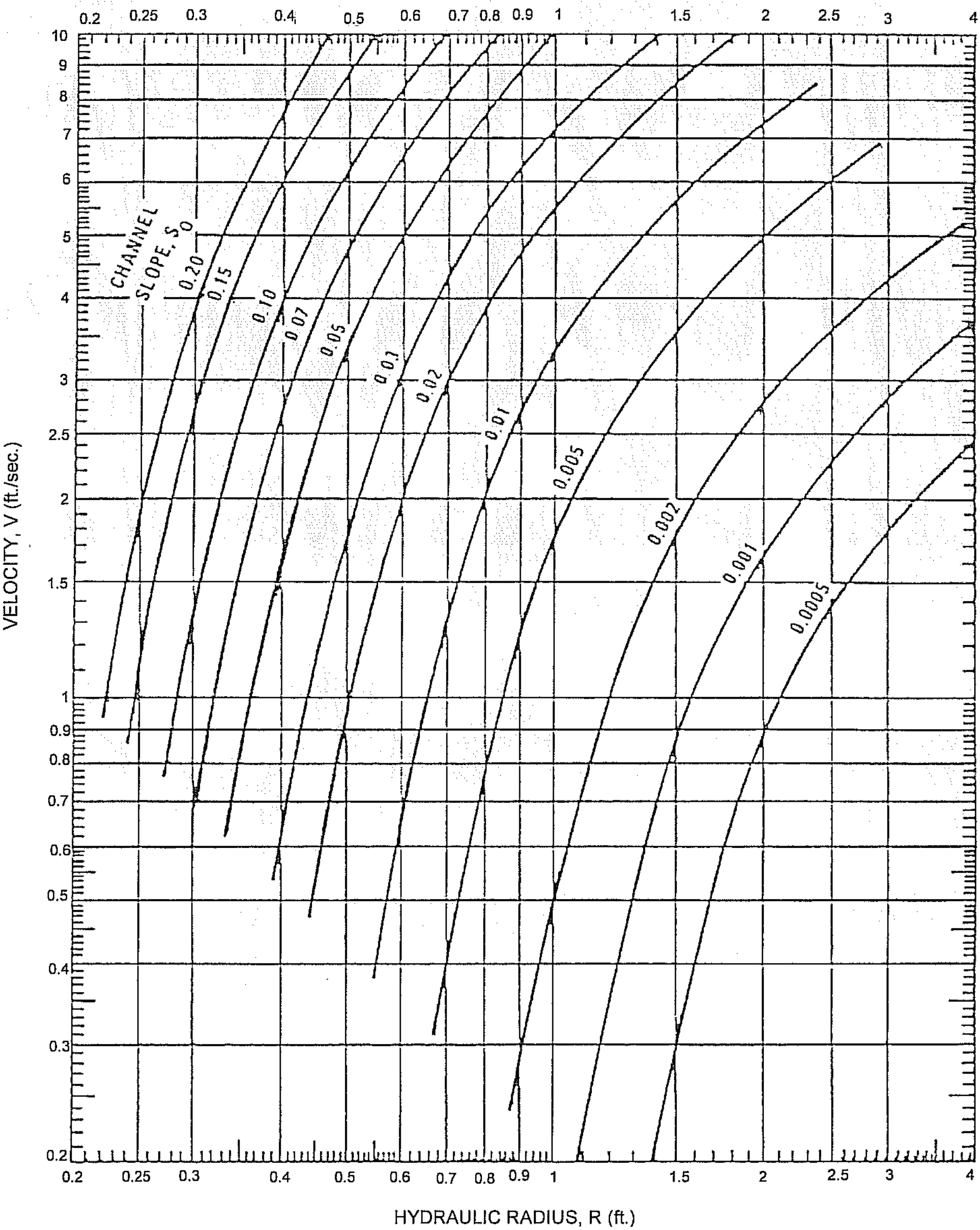


THE CITY OF BENTONVILLE

FLOW VELOCITY FOR CHANNELS LINED WITH VEGETATION OF RETARDANCE B

SOURCE: AHTD

Figure 9.18

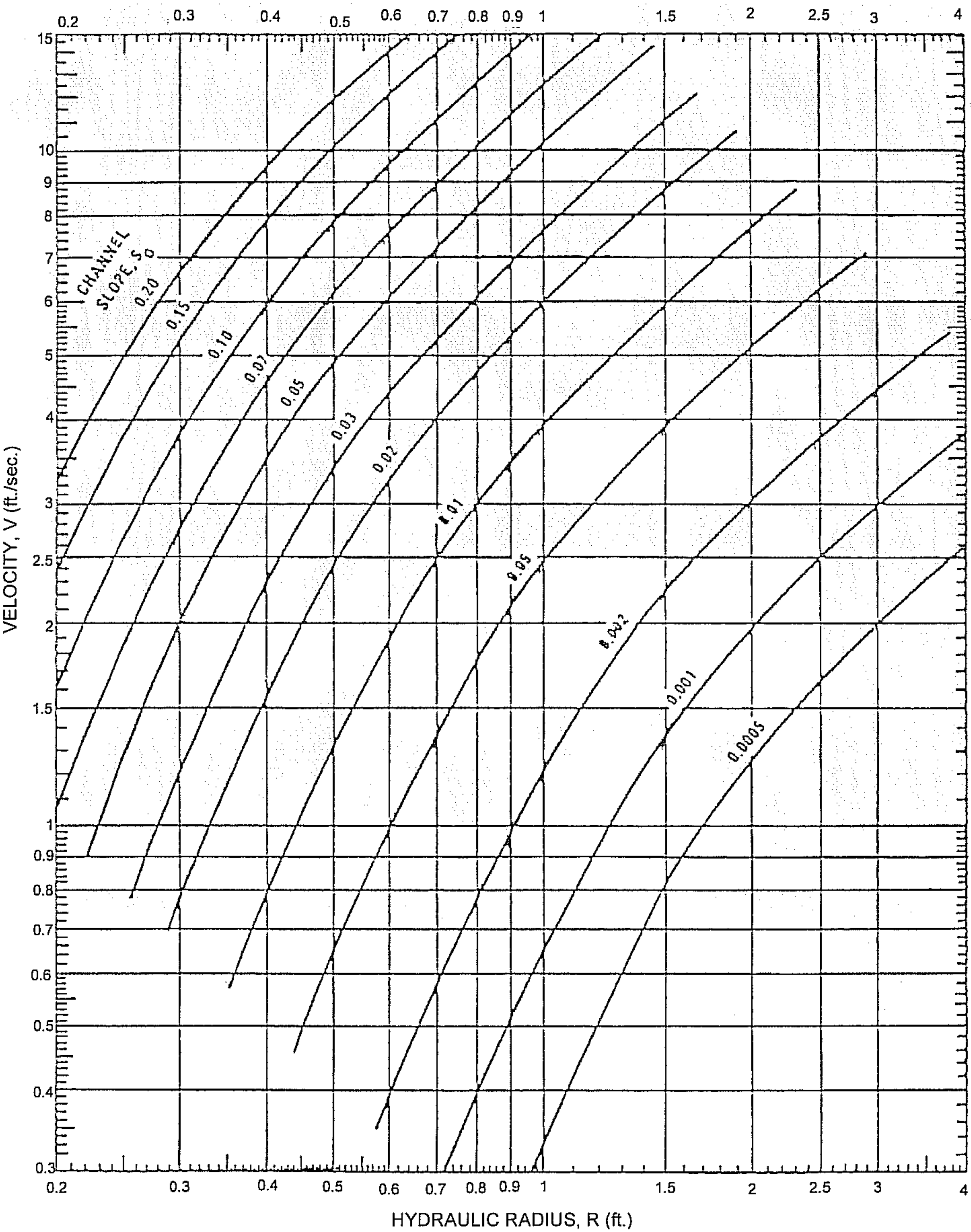


THE CITY OF BENTONVILLE

FLOW VELOCITY FOR CHANNELS LINED WITH VEGETATION OF RETARDANCE C

SOURCE: AHTD

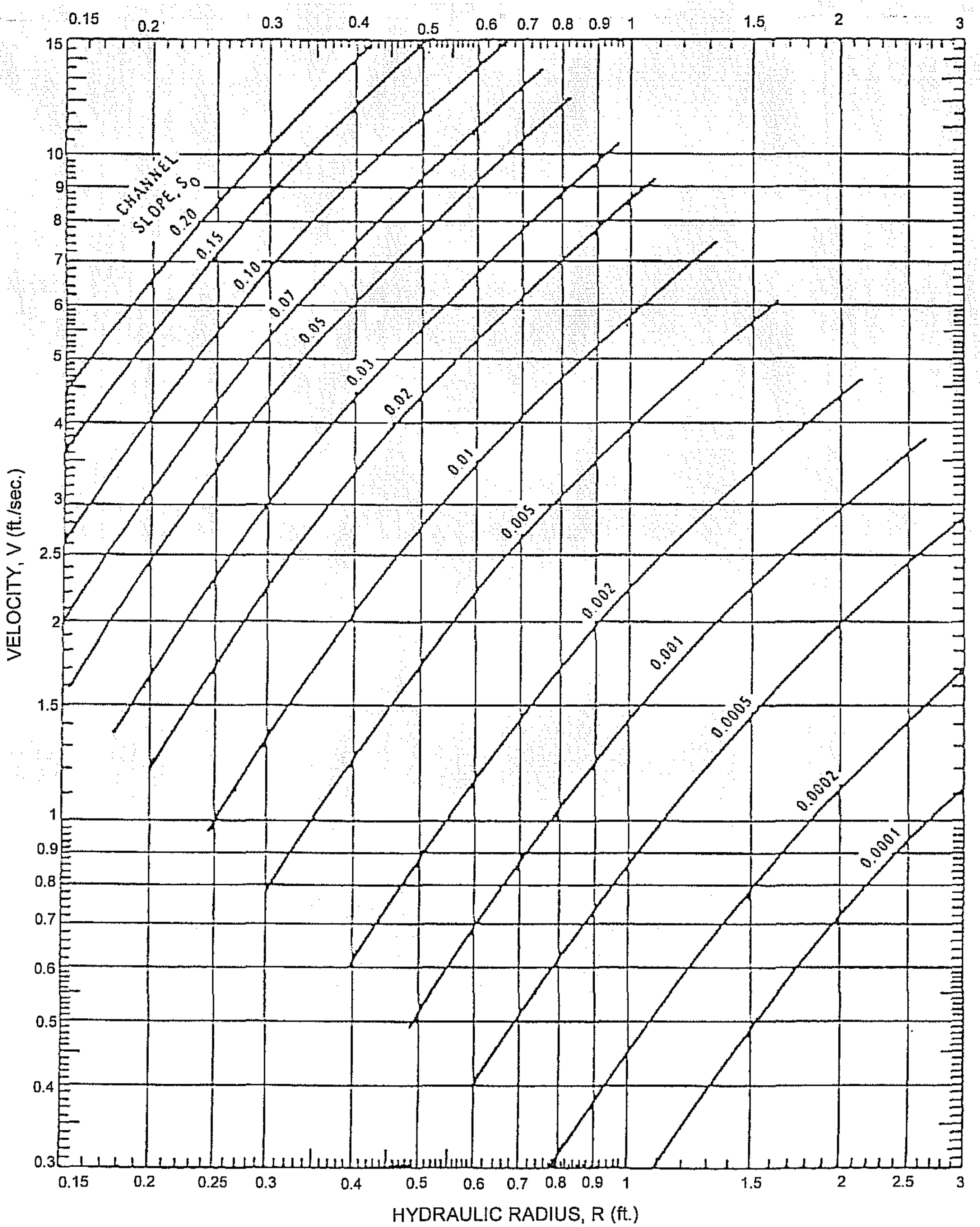
Figure 9.19



FLOW VELOCITY FOR CHANNELS LINED WITH VEGETATION OF RETARDANCE D

SOURCE: AHTD

Figure 9.20

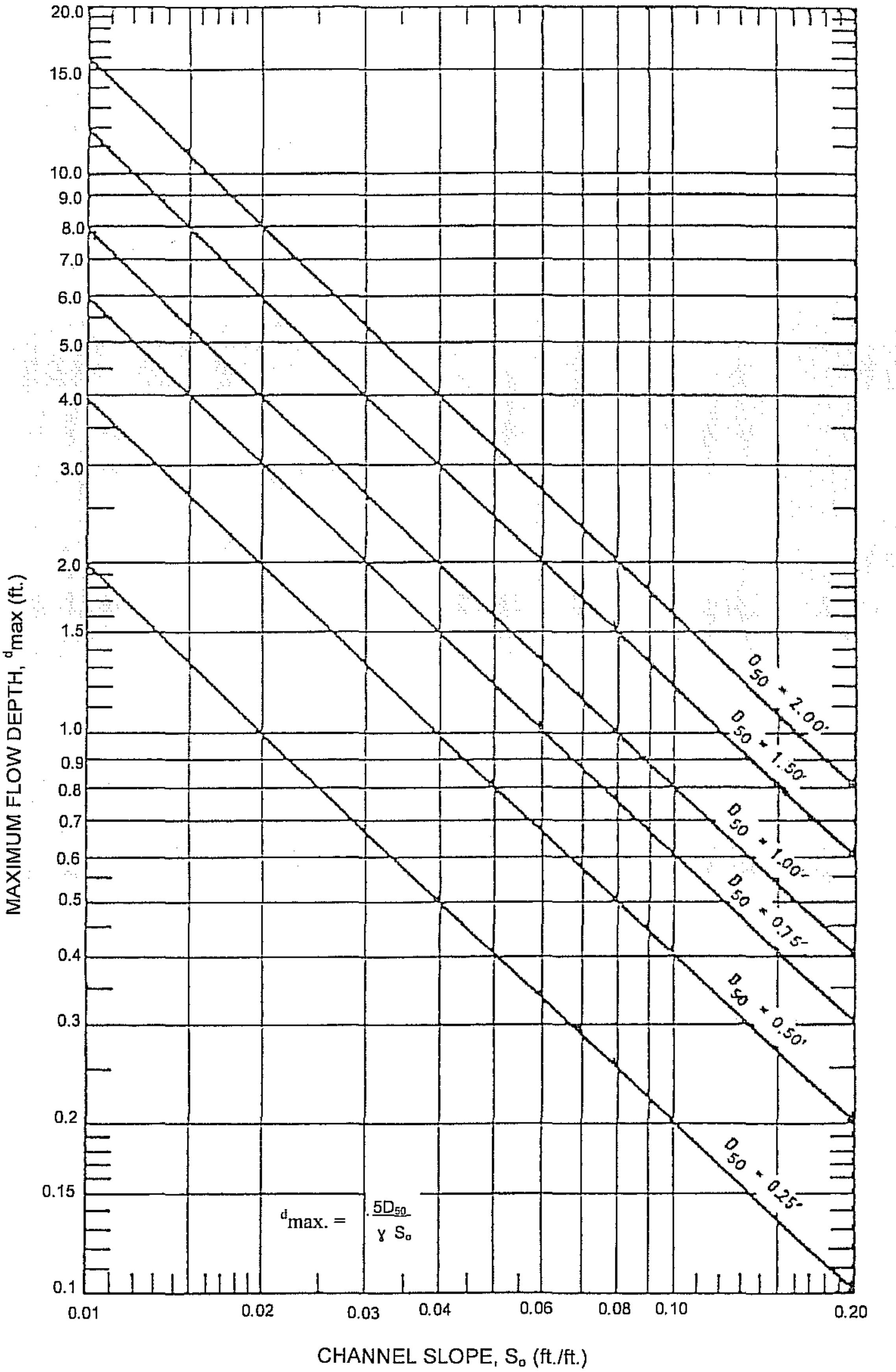


THE CITY OF BENTONVILLE

FLOW VELOCITY FOR CHANNELS LINED WITH VEGETATION OF RETARDANCE E

SOURCE: AHTD

Figure 9.21

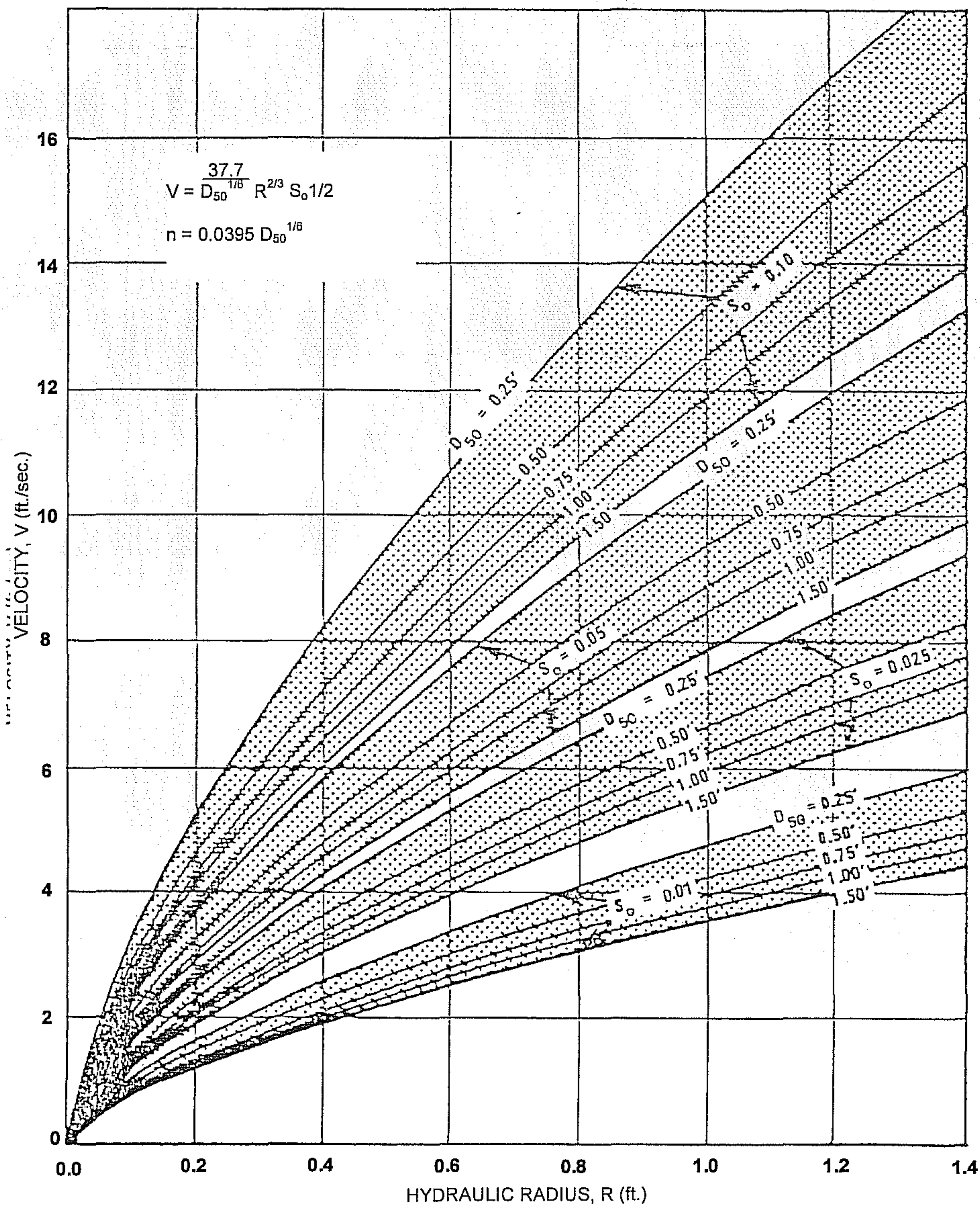


THE CITY OF B BENTONVILLE

MAXIMUM PERMISSIBLE DEPTH OF FLOW (^{d}max.) FOR CHANNELS LINED WITH ROCK RIPRAP

SOURCE: AHTD

Figure 9.22

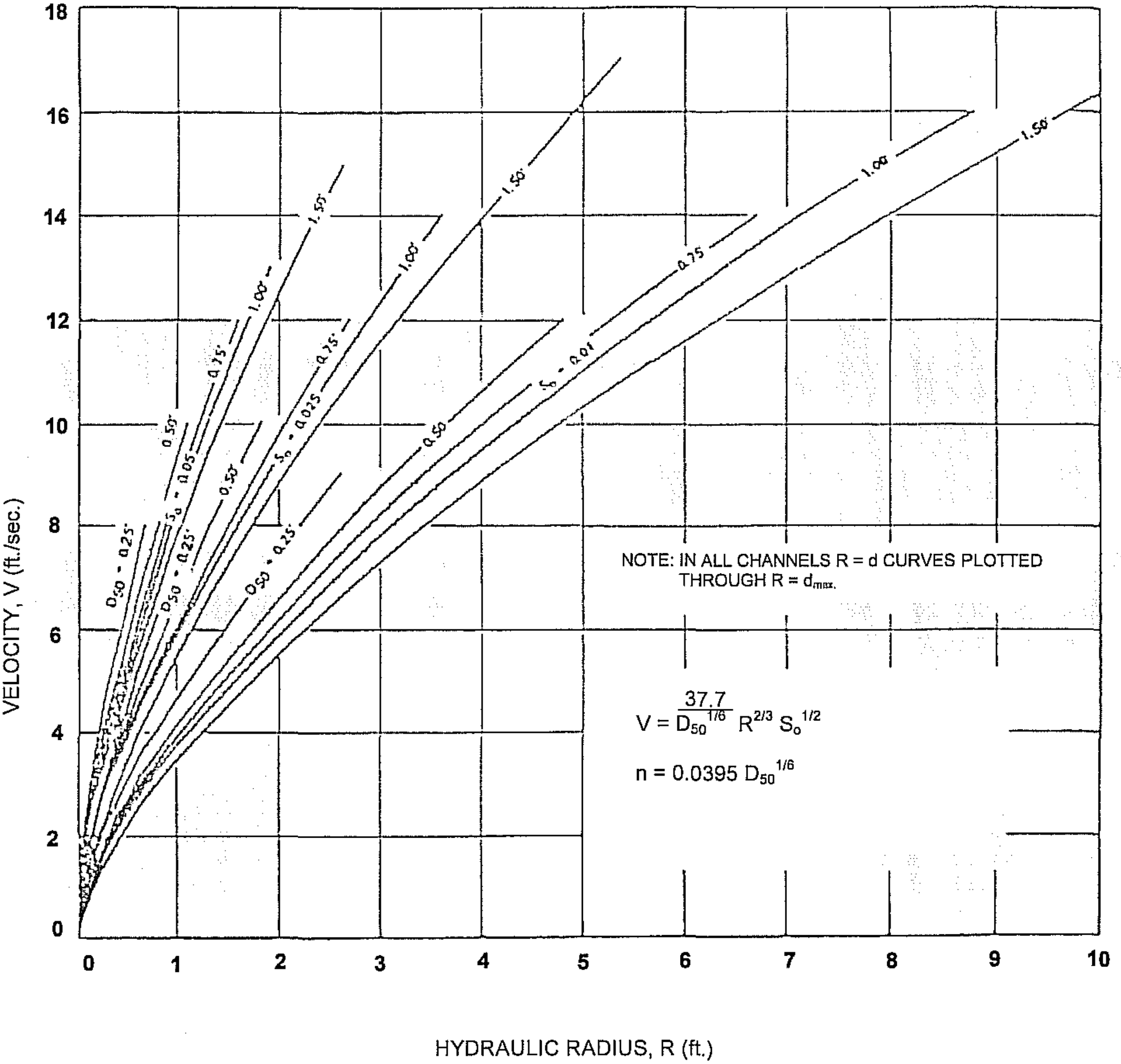


THE CITY OF BENTONVILLE

FLOW VELOCITY FOR CHANNELS LINED WITH ROCK RIPRAP
SLOPES = 0.01 TO 0.10, D_{50} = 0.25' TO 1.50'

SOURCE: AHTD

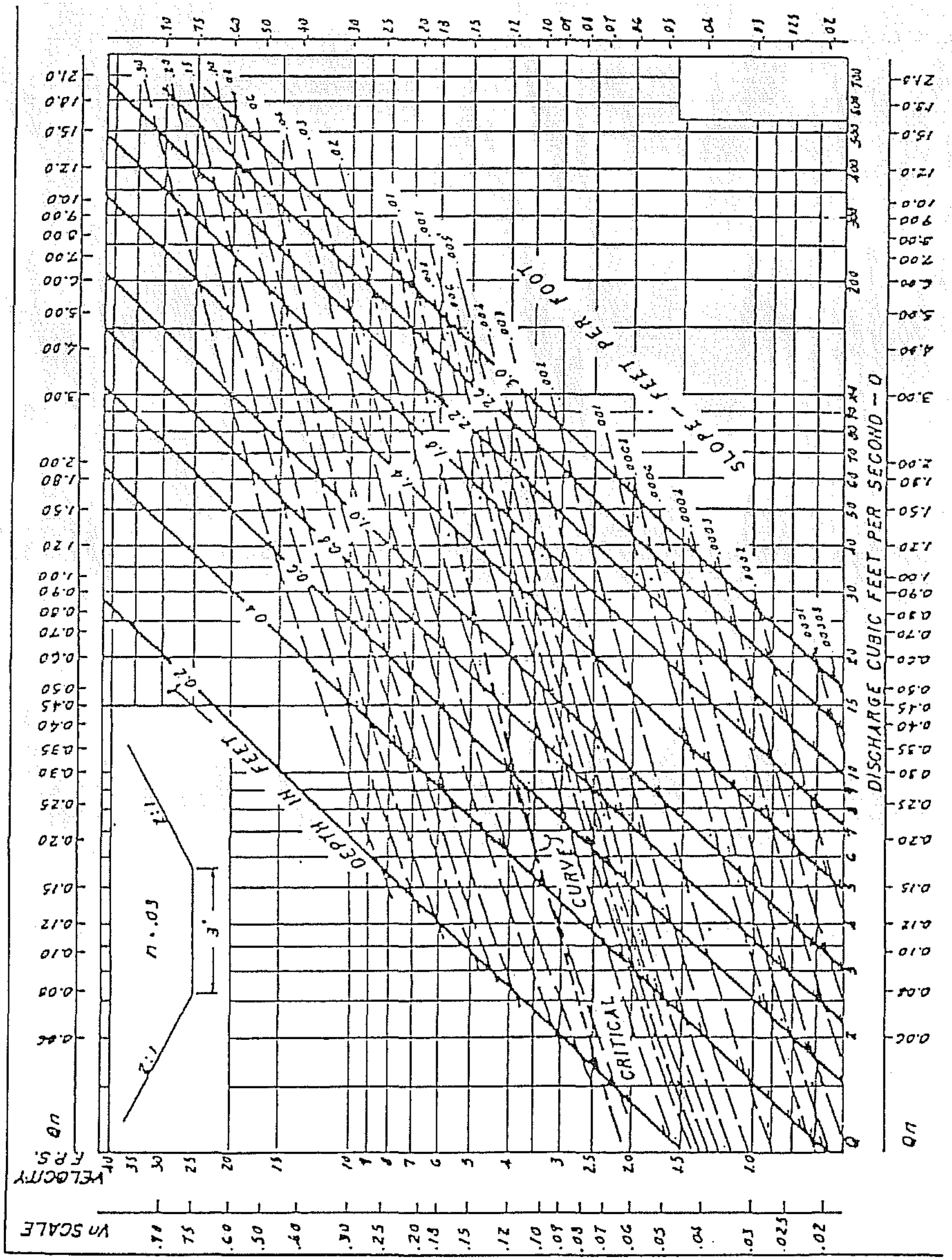
Figure 9.23



FLOW VELOCITY FOR CHANNELS LINED WITH ROCK RIPRAP
SLOPES = 0.01 TO 0.05, D_{50} = 0.25' TO 1.50'

SOURCE: AHTD

Figure 9.24

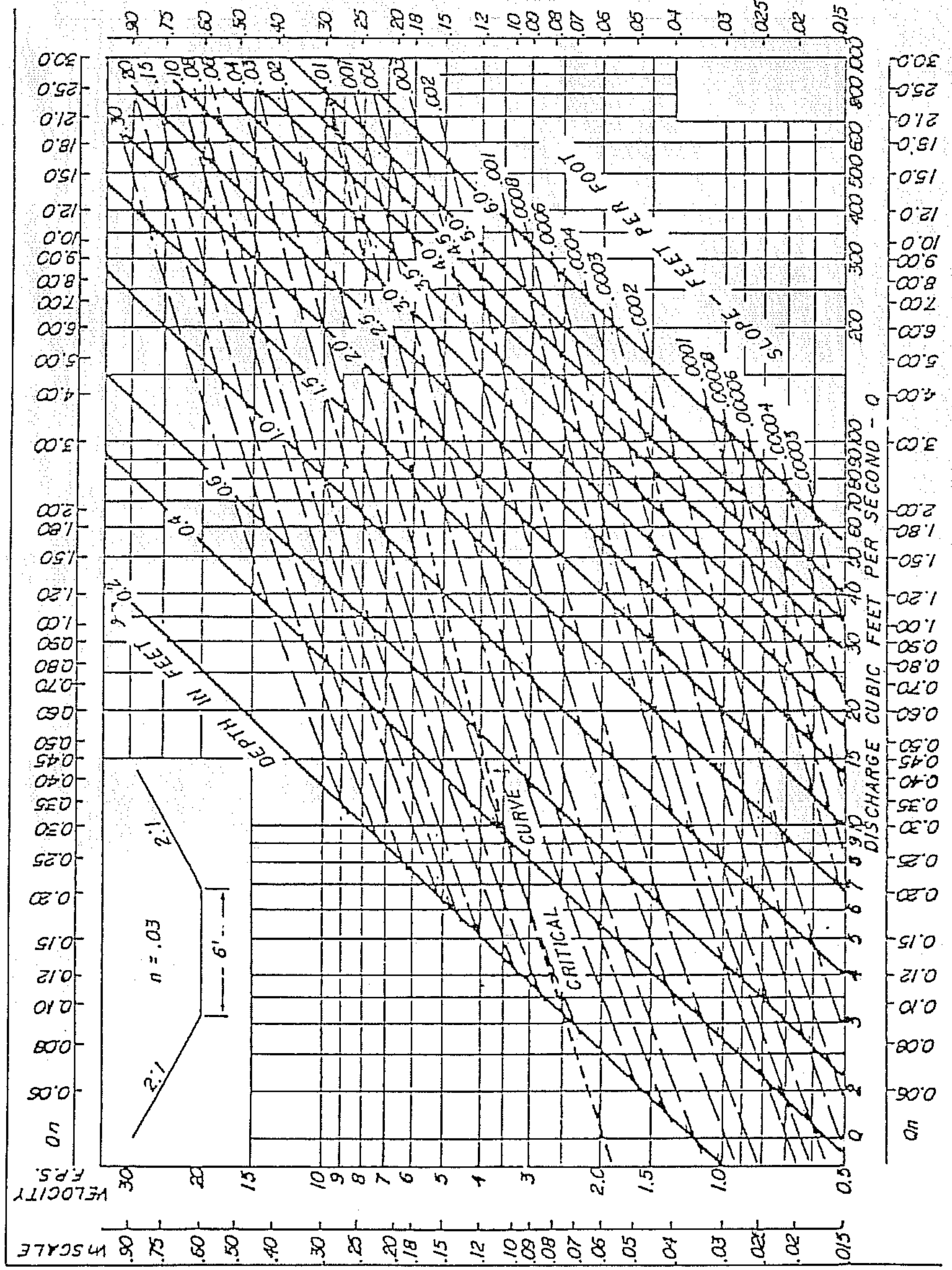


THE CITY OF BENTONVILLE

Source: AHTD

CHANNEL CHART
2:1 b = 3 Ft.

Figure 9.25

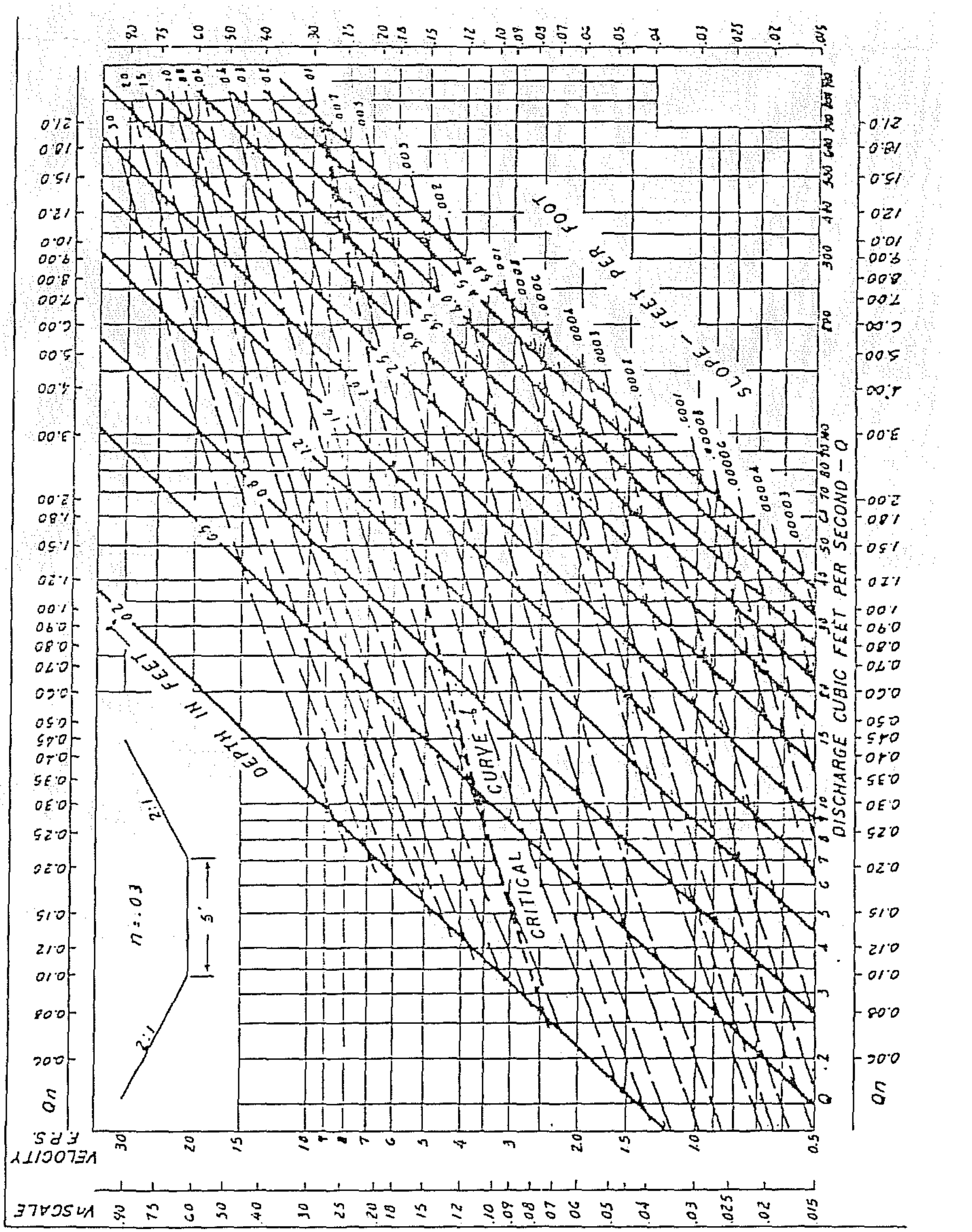


THE CITY OF BENTONVILLE

CHANNEL CHART
2:1 b = 6 Ft.

Source: AHTD

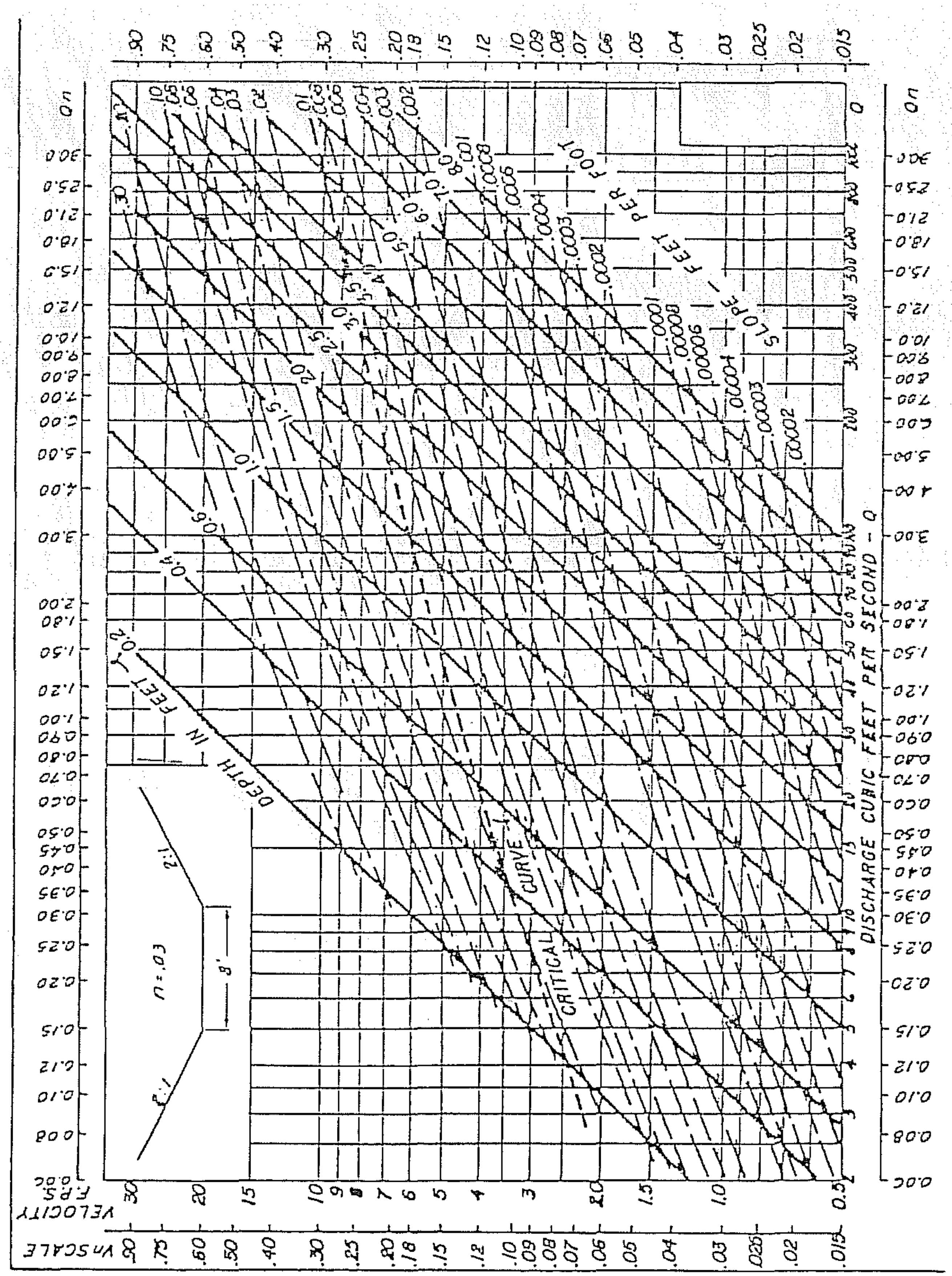
Figure 9.26



CHANNEL CHART
2:1 b = 5 Ft.

Source: AHTD

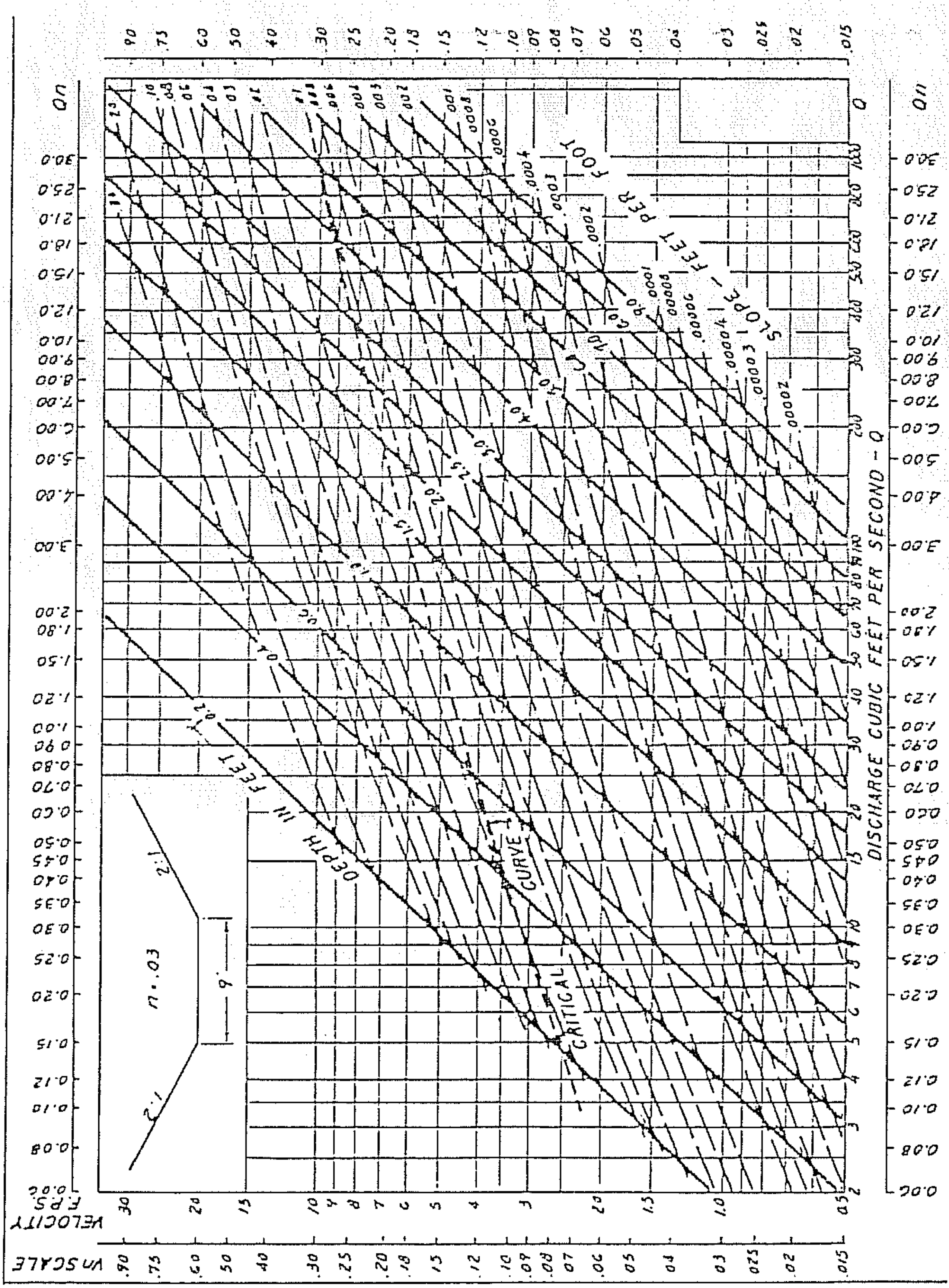
Figure 9.27



CHANNEL CHART
2:1 b = 8 Ft.

Source: AHTD

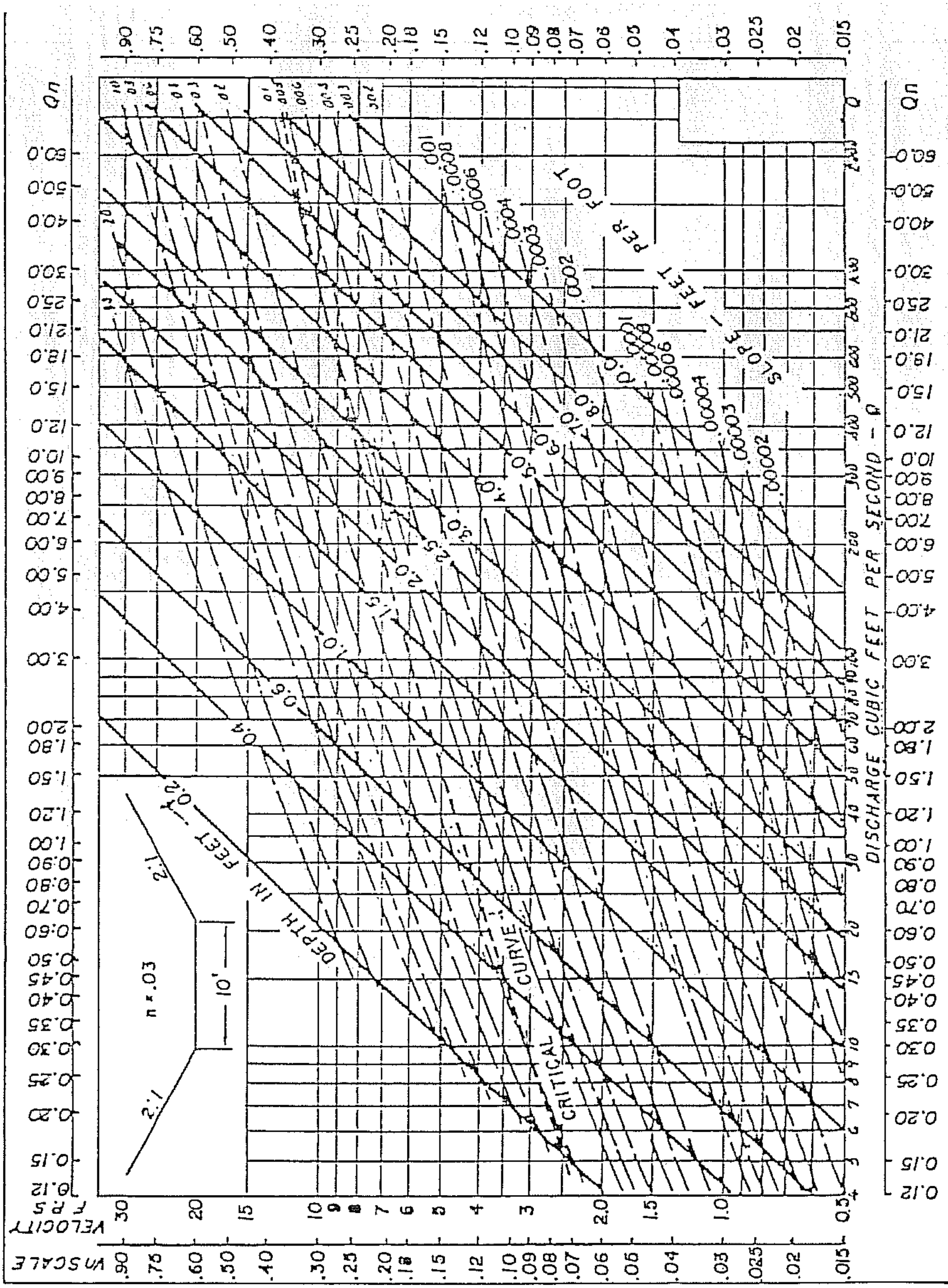
Figure 9.29



CHANNEL CHART
2:1 b = 9 Ft.

Source: AHTD

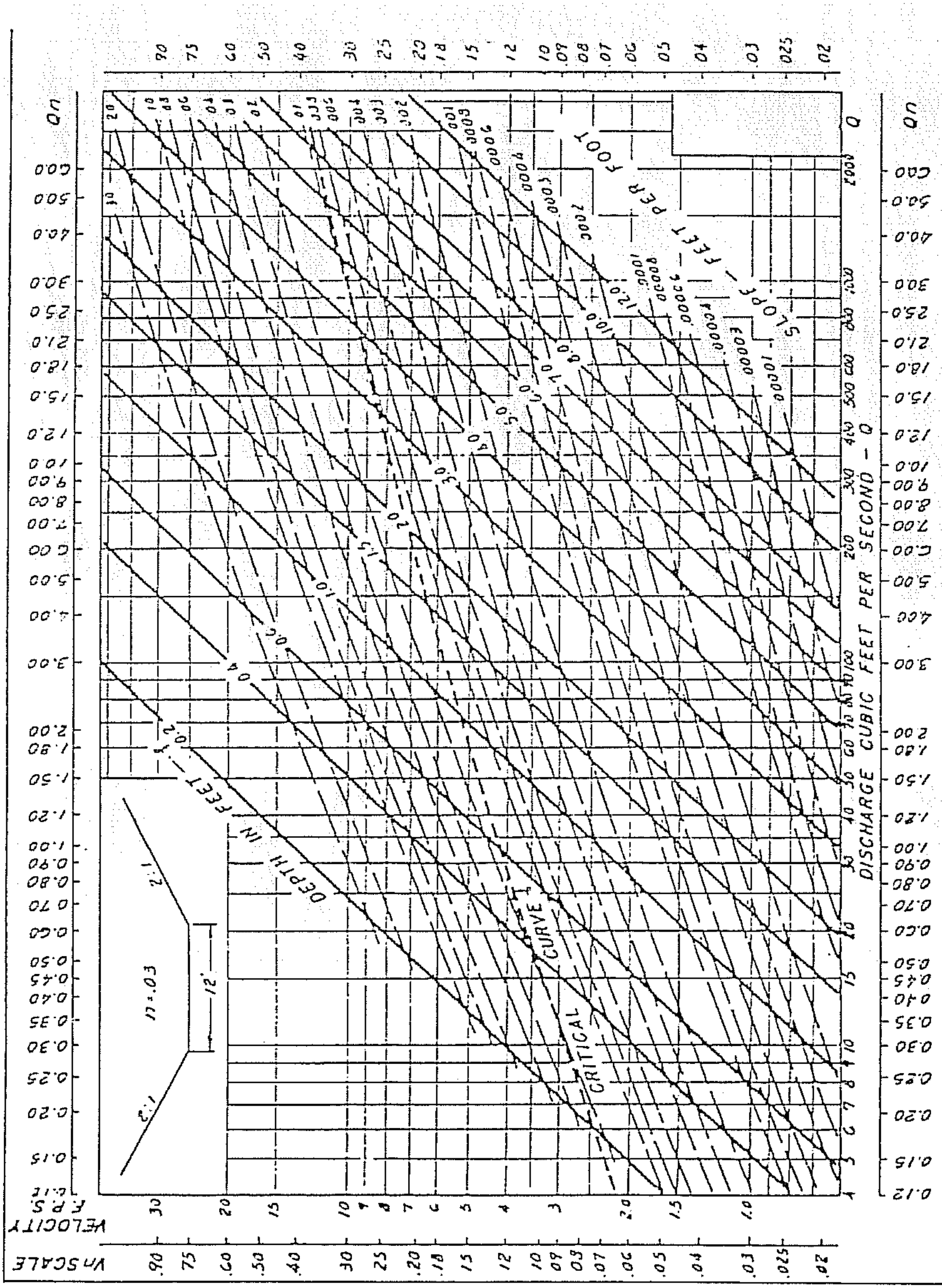
Figure 9.30



CHANNEL CHART
2:1 b = 10 Ft.

Source: AHTD

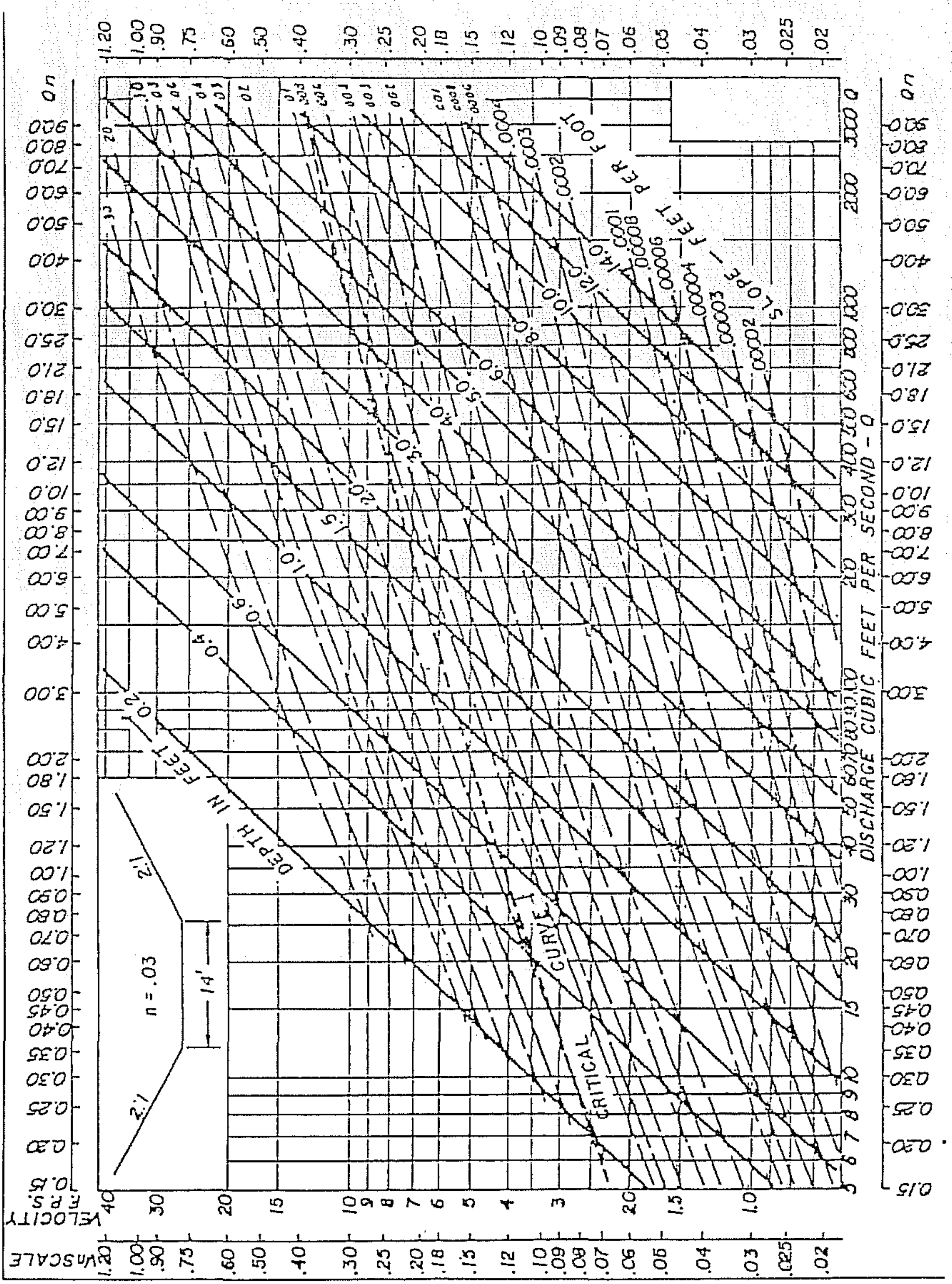
Figure 9.31



CHANNEL CHART
2:1 b = 12 Ft.

Source: AHTD

Figure 9.32

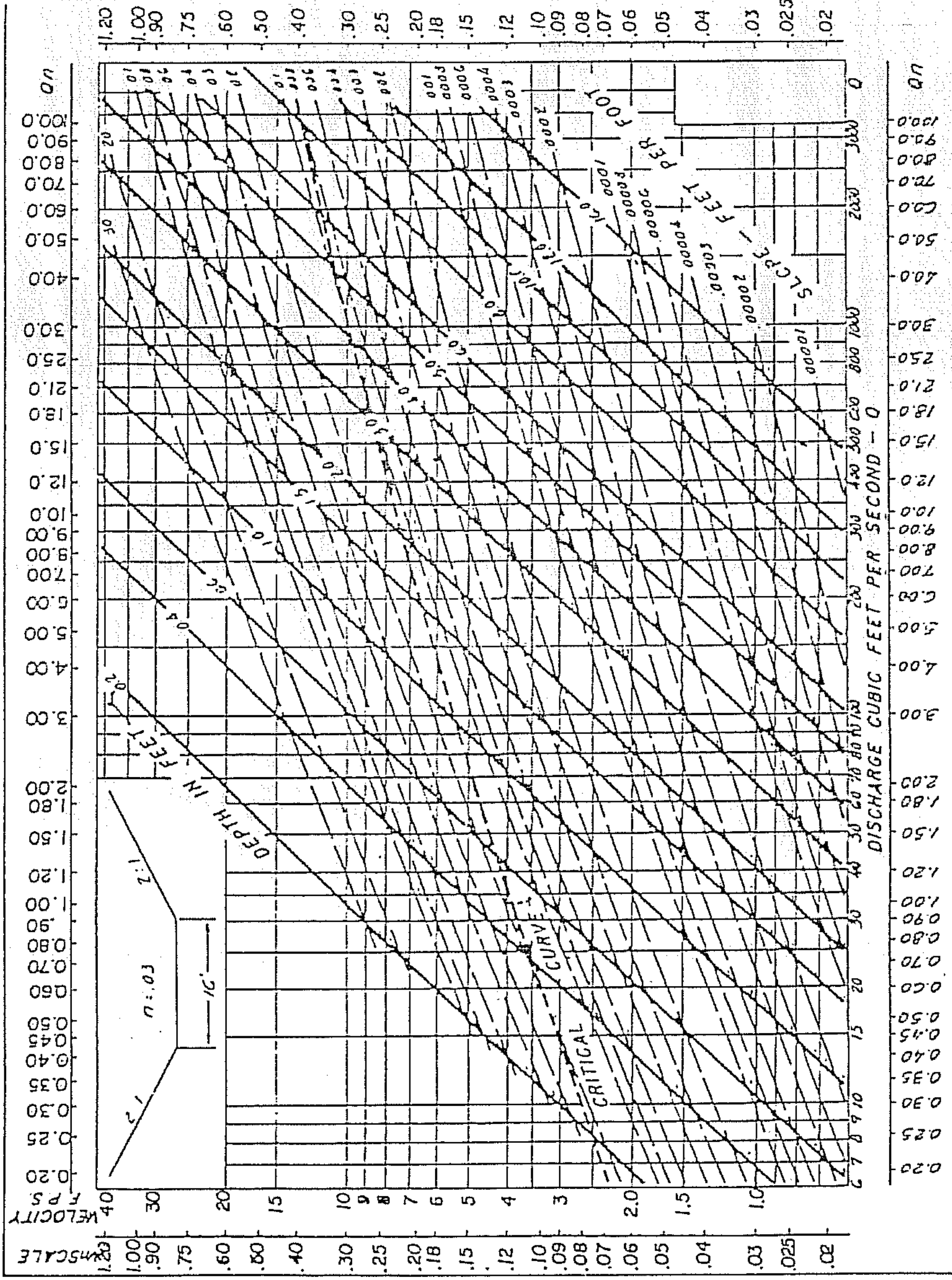


THE CITY OF BENTONVILLE

CHANNEL CHART
2:1 b = 14 Ft.

Source: AHTD

Figure 9.33

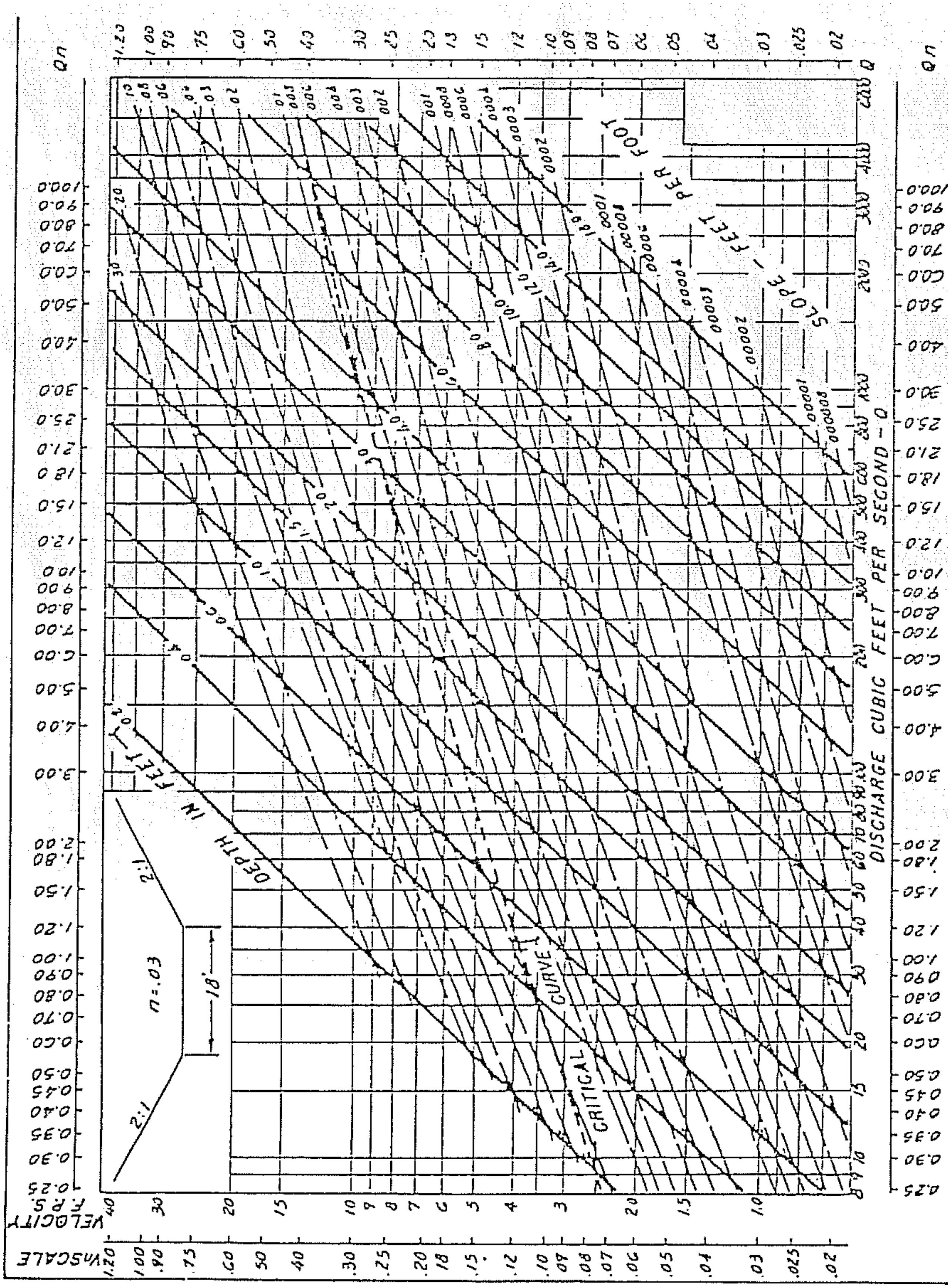


CHANNEL CHART

2:1 b = 16 Ft.

Source: AHTD

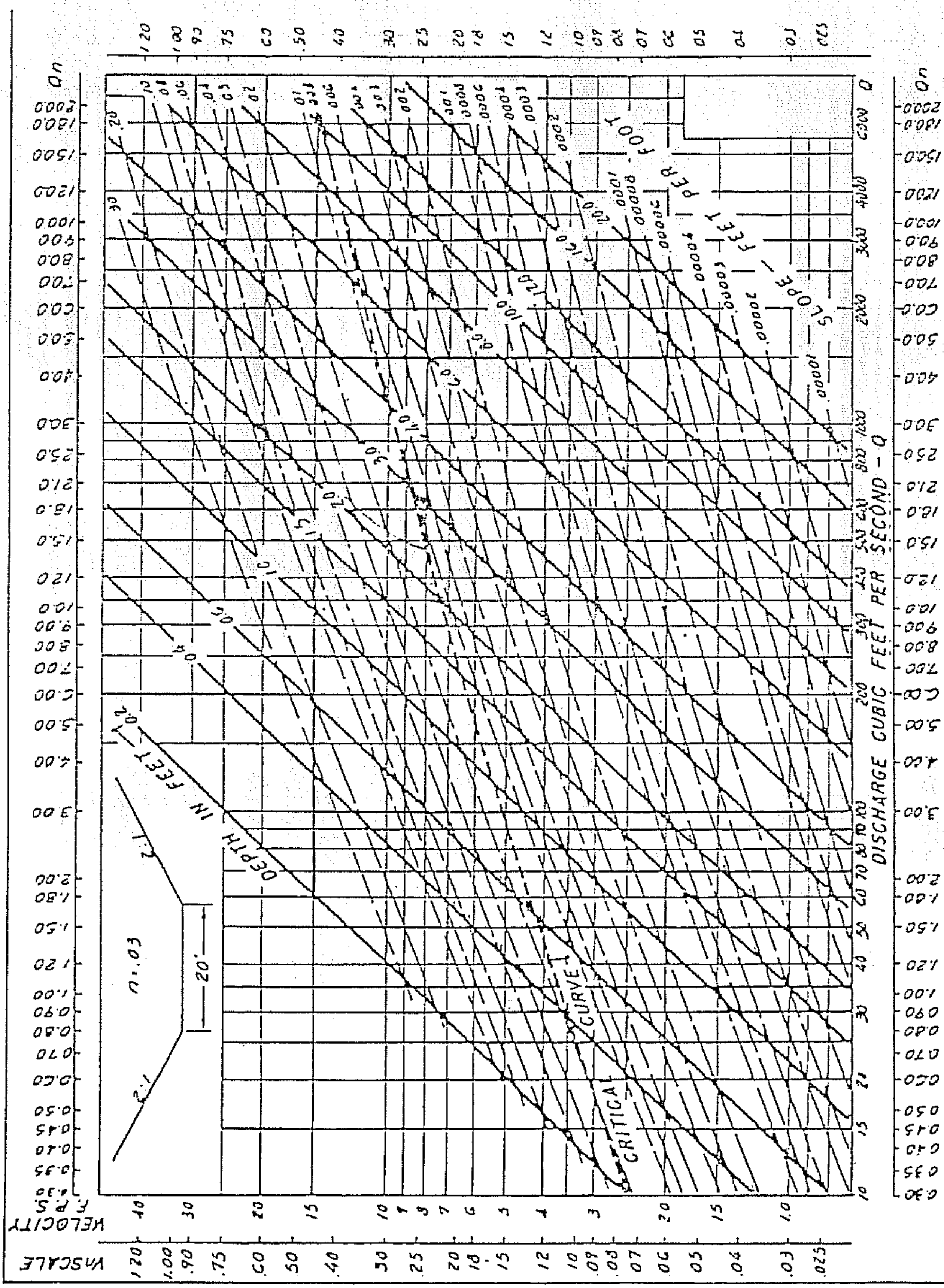
Figure 9.34



CHANNEL CHART
2:1 b = 18 Ft.

Source: AHTD

Figure 9.35

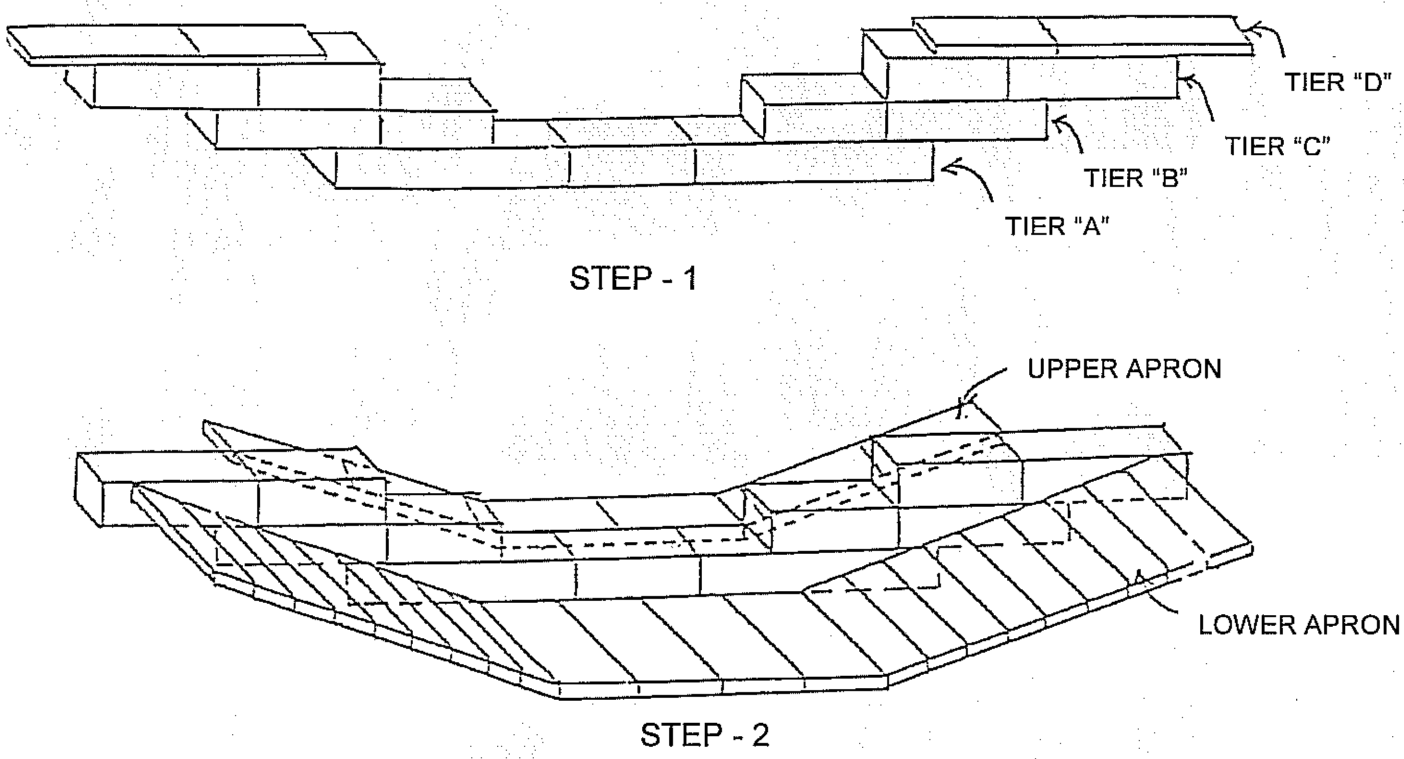


THE CITY OF BENTONVILLE

CHANNEL CHART
2:1 b = 20 Ft.

Source: AHTD

Figure 9.36



THE CITY OF B BENTONVILLE

GABION DROP STRUCTURE
CONSTRUCTION DETAIL

Figure 9.37