SALMONID PASSAGE AT STREAM-ROAD CROSSINGS

A Report with Department Standards

for

Passage of Salmonids

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INTRODUCTION

This chapter of the Environmental Management Manual provides guidance in the review of bridge and culvert projects. Maintenance of credibility with road construction agencies and contractors and to achieve compliance with statewide fish management programs requires that fish passage recommendations be consistent throughout the state.

Department standards are not hard, fast rules that must always apply. Deviation from the standards may be made upon recommendation of the fishery biologist and approval by the Fishery Division.

Department of Fish and Wildlife Standards

Authority is granted to the state by ORS 498.268 and ORS 509.605 to require any person placing an artificial obstruction across a stream to provide fish passage (Appendix 1). Fish passage will be required on any stream, regardless of size or whether perennial or intermittent, that is utilized by anadromous or resident fish during any period of the year. In addition, fish passage should be recommended for the following streams:

1. Any stream that has a history of fish production, but that production has been eliminated because of a barrier that can be removed in foreseeable future.

2. Any stream that has significant potential for fish production that has been precluded by some condition that can be resolved in foreseeable future.

Where fish passage is to be provided the following criteria apply:

1. Criteria for upstream movement of adult fish.

Adult anadromous fish expend approximately 80 percent of their stored energy reserve during the upstream migration. The remainder is used for spawning and any delay or exertion required to pass barriers. Undue exertion at stream-road crossings will be minimized if the following criteria are met.

a. <u>Maximum</u> water velocities

(1) 8 fps for salmon and steelhead

(2) 4 fps for trout

(3) 3 fps for kokanee

b. <u>Minimum</u> water depth

(1) 0.8 foot (9.6 inches) for chinook salmon

(2) 0.6 foot (7.2 inches) for other salmon, steelhead, sea-run cutthroat and other trout over 20 inches.

(3) 0.4 foot (4.8 inches) for trout under 20 inches and kokanee

c. <u>Maximum</u> entrance jump (vertical height)

(1) 1 foot for salmon and steelhead

(2) 0.5 foot (6 inches) for trout and kokanee

Where more than one species is present, criteria should be selected that will accommodate all species. For example, if a stream contained sea-run cutthroat, coho and fall chinook, the following criteria would apply:

Maximum water velocity = 4fps

Minimum water depth = 0.8'

Maximum entrance jump = 0.5'

The previously listed maximum velocity criteria are for culverts less than 100 feet long. Table 1 lists maximum water velocities for longer culverts.

Table 1. Recommended maximum water velocity in culverts for adult fish passage.

Culvert length (ft.)	Recommended maximum water velocity (fps)		
	Salmon & Steelhead	Trout	Kokanee
Under 100 and all baffled culverts	8	4	3
100 to 200	4	2	1.5
200 to 300	3	1.5	1.1
300 to 400	2	1	0.75
400 to 500	1.8	0.9	0.66

Criteria for upstream movement of adults should not be exceeded more than 10 percent of the time when fish are migratting. Passage is not required during flood flows.

2. Criteria for instream movement of juvenile salmonids.

Minimum depths required for instream movement of juveniles will vary with species and size of fish present. Generally, 0.2 foot (2.4 inches) is sufficient for passage. Maximum water velocities will also vary depending upon fish size and species. Refer to Figure 1 for maximum water velocity recommendations. The necessity for and required period of criteria satisfaction shall be determined by appropriate district biologist.

Fish Passage Problems and Solutions

Excessive water velocity, inadequate water depth and excessive entrance jump are the most frequent causes of fish passage problems at bridges and culverts. When existing culverts or other road-related structures appear to block fish passage, it must be determined that a problem actually exists before requesting corrective measures. Procedures for resolving existing fish passage problems will be presented in a future chapter of the Environmental Management Section Manual.

Excessive water velocity

1. Problem. Water velocities can block fish movement simply by exceeding the swimming ability of fish. Ability varies with species, size and age of fish, and water quality. Studies of fish movement, primarily at fishways, have provided the following information:

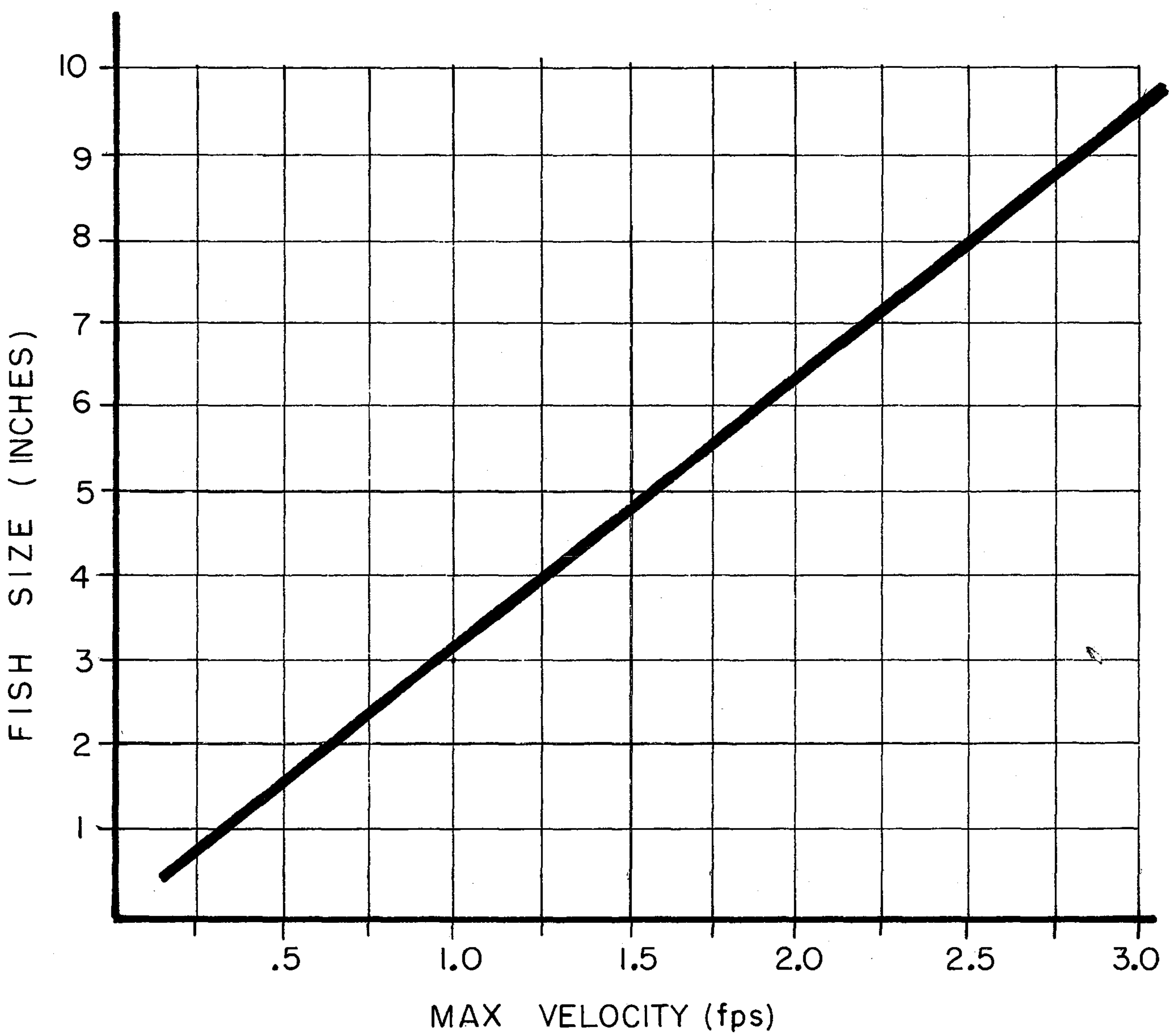


Figure 1. Recommended maximum velocities for upstream passage of juvenile salmonids - fish over 10 inches require velocity criteria presented in Table 1 (Source: Metsker, Howard E., Fish Versus Culverts)

a. In general, fish of equal size have similar swimming abilities. However, kokanee seem to have less ability than other species.

b. Optimum swimming speed efficiency for salmon, based on energy output, occurs at water velocities near 2 fps (Appendix 2). Table 2 shows the best water velocities for adult fish passage as determined by tests conducted on passage through an incline pipe.

Table 2. Best water velocities for passage of adult fish.

Species	Water Velocities (fps)
Chinook	2.5
Sockeye	2.5-4.0
Coho	4.0
Steelhead	4.0

c. Swimming ability of fish is directly related to size, the larger the fish the greater its ability. They are capable of short bursts equalling approximately ten times their body length per second. Maximum speeds recorded for steelhead and chinook are 26 fps and 22 fps, respectively.

d. Swimming stamina is reduced as water temperature decreases; being highest at 65-75°F. and lowest at 32-40°F. Optimum temperature for swimming ability of juveniles is 68°F. Atlantic salmon and rainbow trout experience reduced movement and jumping activity when water temperatures are less than 42°F.

e. The amount of dissolved oxygen in the water contributes to the swimming ability of fish. Changes in dissolved oxygen concentrations from 7 mg/l to 3 mg/l can reduce sustained swimming speeds by 500 percent.

f. Upstream migrants show a lack of movement during the peak of freshets. Upstream movement is generally highest on receding flows after freshets.

2. Causes of excessive velocities.

a. Roughness factors for culverts and natural stream bottoms are listed in Table 3. The impact of this factor is generally unimportant except when smooth concrete or steel pipe and concrete aprons are utilized.

Table 3. Roughness factors for various type channels.

Bottom type	Roughness factor
Concrete pipe (smooth)	0.012
Concrete apron (smooth)	0.012
Steel pipe (smooth)	0.012
Corrugated stack	0.024
Natural bottom (gravel bar)	0.025
Natural bottom (boulders)	0.035 to 0.06

b. Size of structure in relation to flow.

This factor has minimal importance in velocities except when the structure is considerably undersized and a head is developed (pooling at upstream end). In that case, the head causes higher velocities. Head should not be designed into projects where fish passage is desired.

c. Slope.

Slope is the most important factor determining velocity in culverts. Slopes steeper than .5 percent (1/2 foot drop in 100 feet) generally create excessive velocities for fish passage.

3. Solution to excessive water velocity problems.

a. Properly designed baffles can reduce velocities in culverts on slopes up to 5 percent (Figure 2). The velocity is reduced because the path of flow is lengthened (reduction of slope) and the roughness factor is increased. Baffles are most effective when they are just overtopped; effectiveness drops quickly as water depth increases beyond one foot over baffle tops. Due to this variability in efficiency, reduction of culvert flow capacity and increased debris problems, baffles should only be

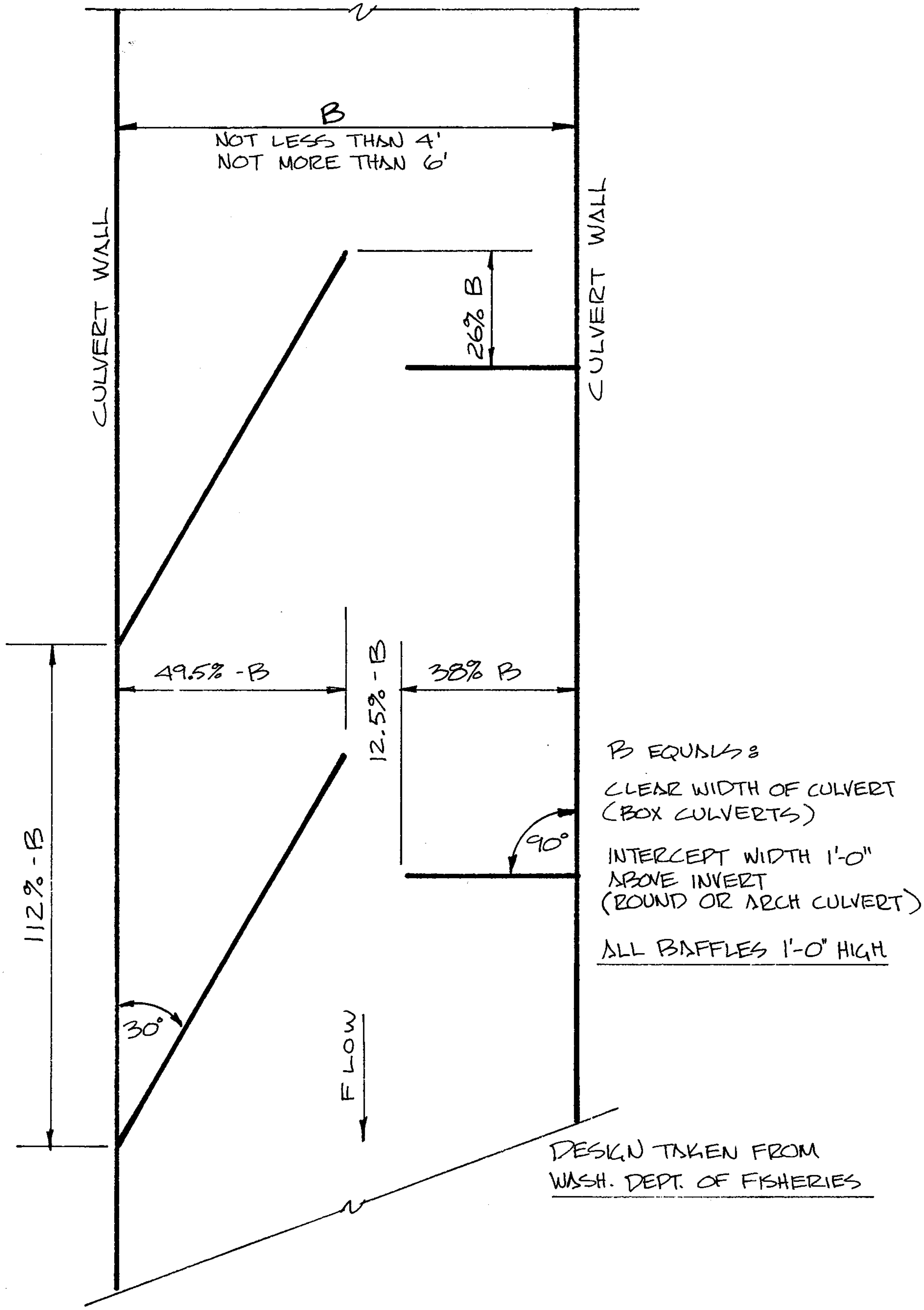


Figure 2. Approved baffled culvert design. (Source: Gebhards, Stacy and Jack Fisher, Fish Passage and Culvert Installations)

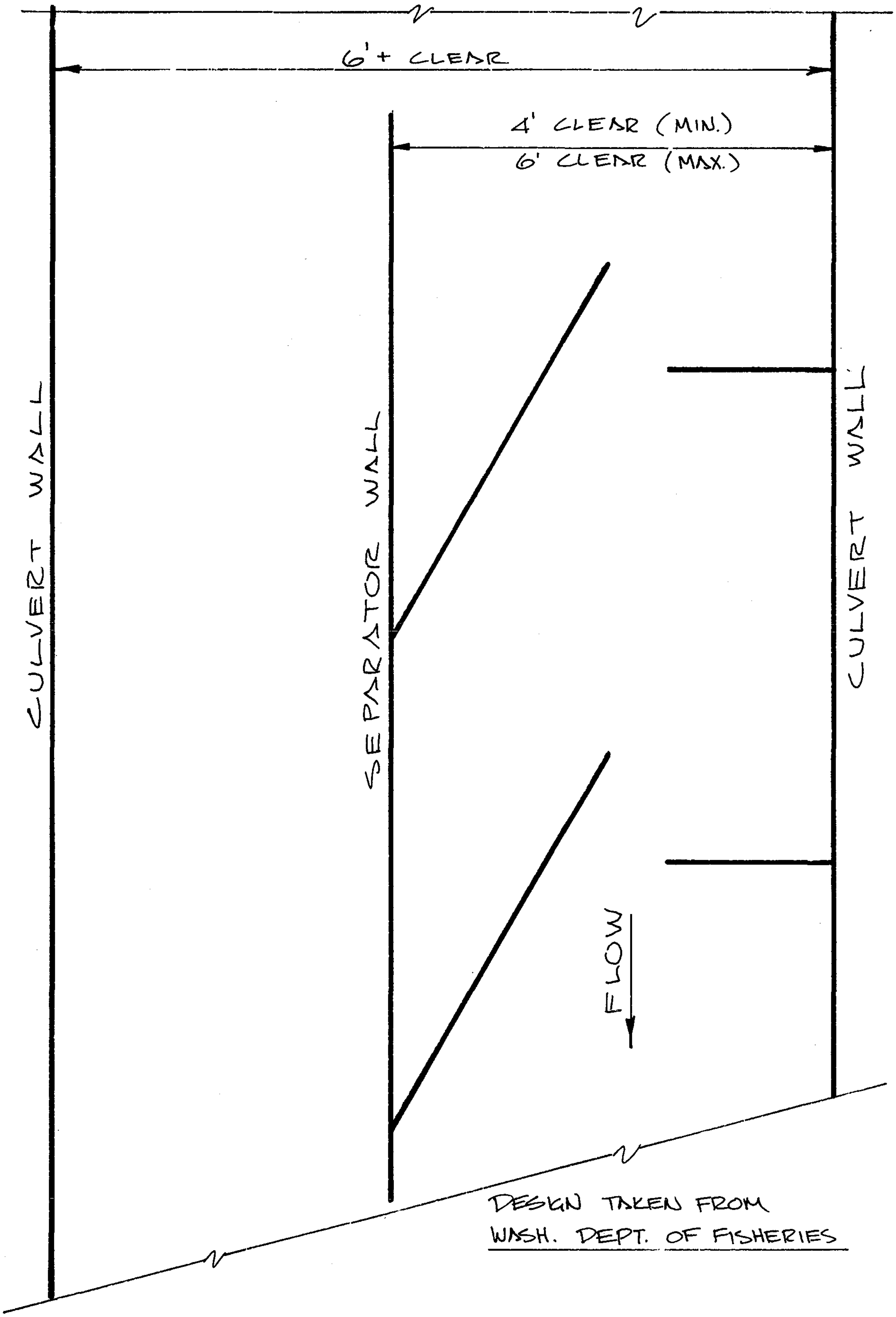


Figure 2. (continued)

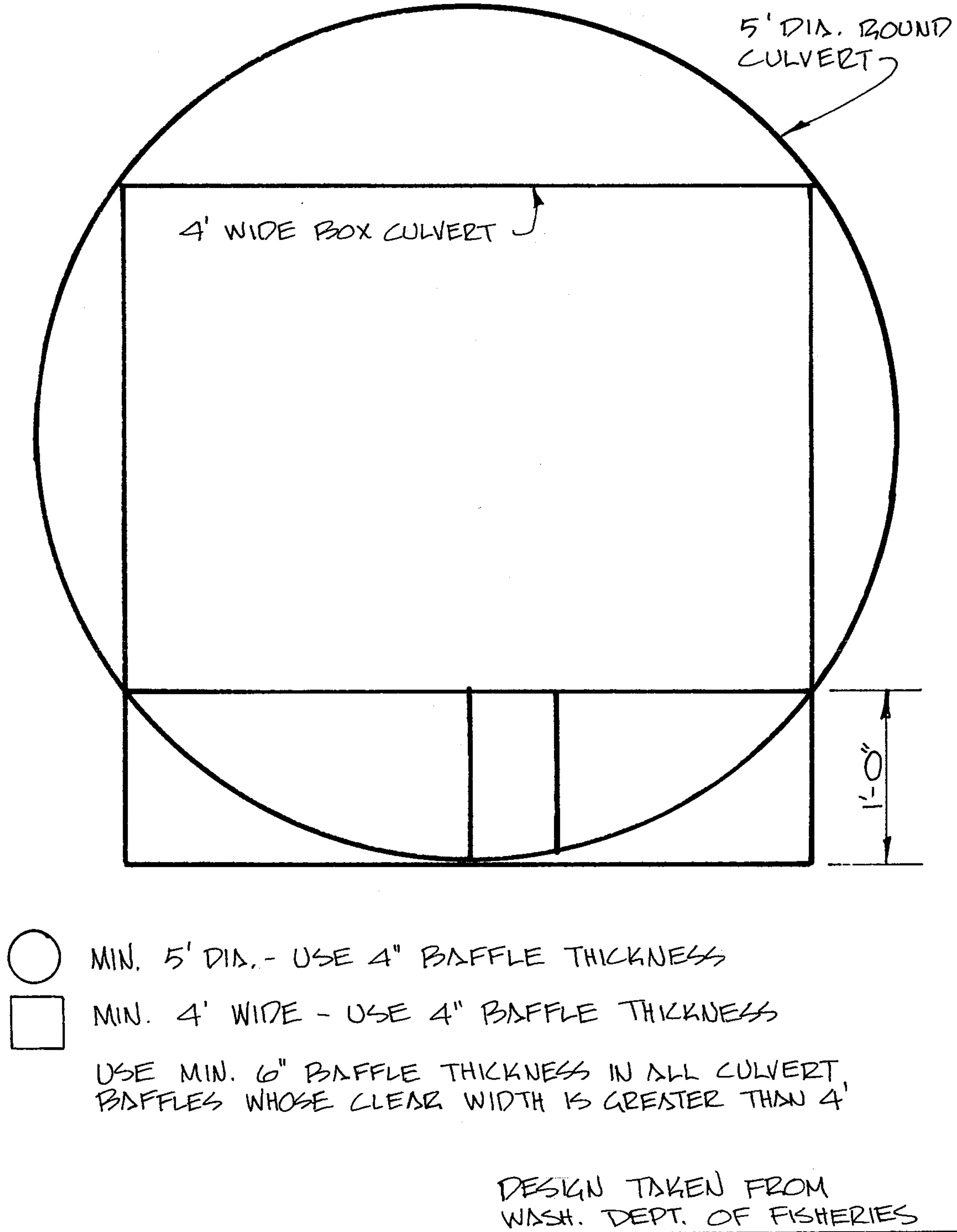


Figure 2. (continued)

used when an open-bottomed structure or an over-sized countersunk culvert is not practical.

b. Construct weir(s) downstream to back water into structure. This technique reduces velocity by reducing slope. Figures 3 and 4 present approved design for weir utilization.

c. Auxiliary culverts will decrease excessive velocities caused by development of a head upstream of the structure. Auxiliary culverts should be designed to function only when the primary facility is just under excessive velocity limit.

d. Replace existing structure or change proposed structure design to eliminate velocity problem.

Maximum velocities within a structure are normally encountered at the downstream end. However, if the slope changes within the structure, velocities can be highest within the structure. This situation is most frequently encountered where the structure's slope changes or where the structure is partially backflooded (Figure 5).

The most frequent solution to the problems depicted in Figure 5 is replacement of the structure with one that satisfies passage criteria. Other solutions should be coordinated with Department engineers.

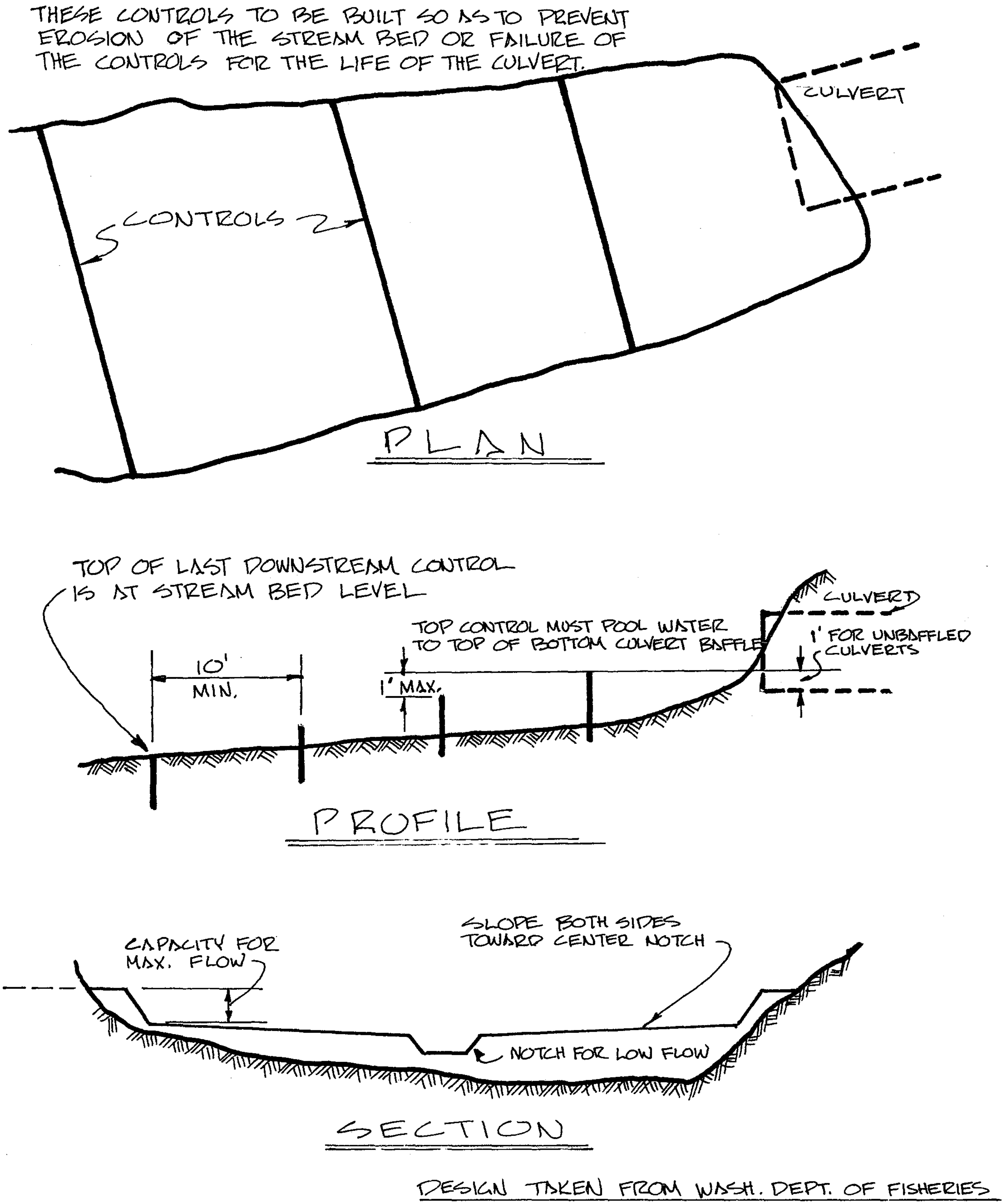


Figure 3. Recommended design of weirs for backflooding culverts. (Source: Gebhards, Stacy and Jack Fisher , Fish Passage and Culvert Installations)

Figure 4. Weir construction used to improve fish passage at mouth of Gold Creek, W. FK. Smith River.

(Source: Evans, Willis A., Fish Migration and Fish Passage A Practical Guide To Solving Fish Passage Problems)

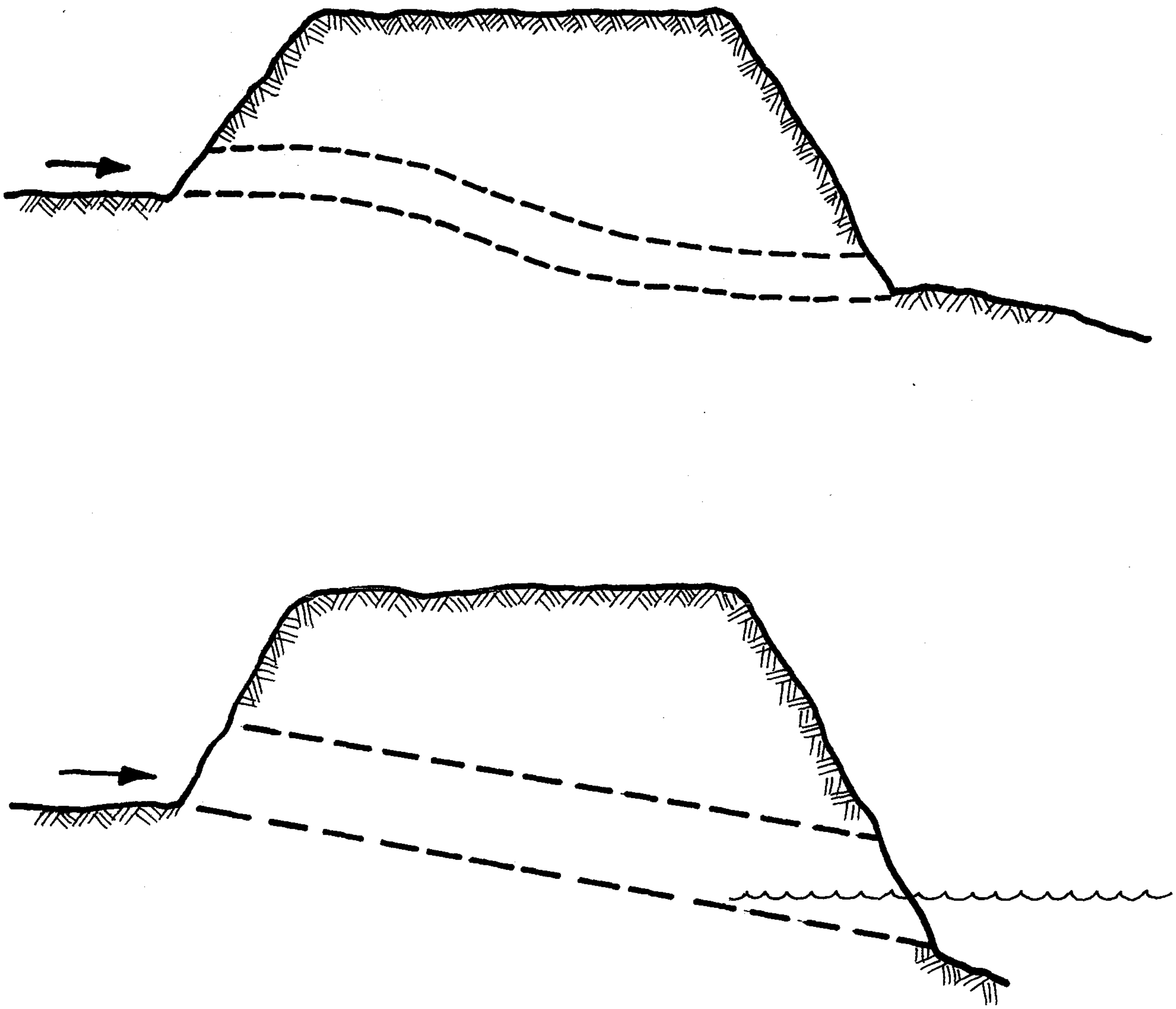


Figure 5. Change of culvert slope or partial backflooding can place the location of maximum velocity at a point other than the outlet.

Inadequate water depth

1. Problem. Fish require sufficient water depth to attain maximum swimming abilities. The depth required is directly related to fish size with larger fish requiring deeper water. When insufficient depths are encountered, fish are unable to produce full propulsion.

2. Causes of inadequate depth. The two most frequently encountered reasons for insufficient water depth are steep slope and a wide, flat channel bottom (no low flow channel).

    a. All other factors being constant, the steeper the slope of a structure the shallower the water depth.

    b. All other factors being constant, the wider the structure bottom the shallower the water depth.

3. Solutions to inadequate water depth problems.

    a. Install properly designed baffles (Figure 2) to concentrate lower flows into low water channel thereby increasing water depth.

b. Construct weir(s) downstream of the structure to back water into it (Figure 3). Weir height can be adjusted to meet minimum depth standards.

c. Replace existing structure or modify proposed design to eliminate depth problem.

Excessive entrance jump

1. Problem. Fish jumping ability can be exceeded, thus blocking fish movement.

a. In general, adult trout can negotiate a vertical jump of one foot. However, if a series of jumps is required, a jump of one-half foot at each is preferred.

b. Salmon and steelhead can normally negotiate single jumps of two to three feet without excessive difficulty. However, any series of individual jumps should not exceed one foot.

c. Any structure that will require a jump should be designed with a vertical drop, not sloped (Appendix 3). Sloped drops significantly increase fish passage problems.

d. Jumps near maximum ability of fish may necessitate numerous jump attempts resulting in undue exertion and possibly physical damage to fish.

2. Causes of jump. The two basic causes for a jump at the downstream end of a structure are bed scour and slope of structure placement (Figure 6).

   a. Degradation of the streambed below the structure can result in lowering the water surface below the downstream end of the structure. This occurs most frequently in steep gradient streams with erodible bottom materials. Degradation of a receiving stream can create a jump at a structure near the mouth of a tributary.

   b. Placement of a flat sloped structure on a steep sloped stream builds in a jump.

3. Solutions to excessive entrance jump.

   a. Fish have difficulty in jumping when an adequate pool is not available for them to gain required swimming speed and vertical thrust. The following approximate dimensions should be used to design a jump pool.

      (1) Pool length should equal three times the maximum width of the culvert or a minimum of ten feet.

      (2) Pool width should equal two times the maximum width of the culvert or a minimum of eight feet.

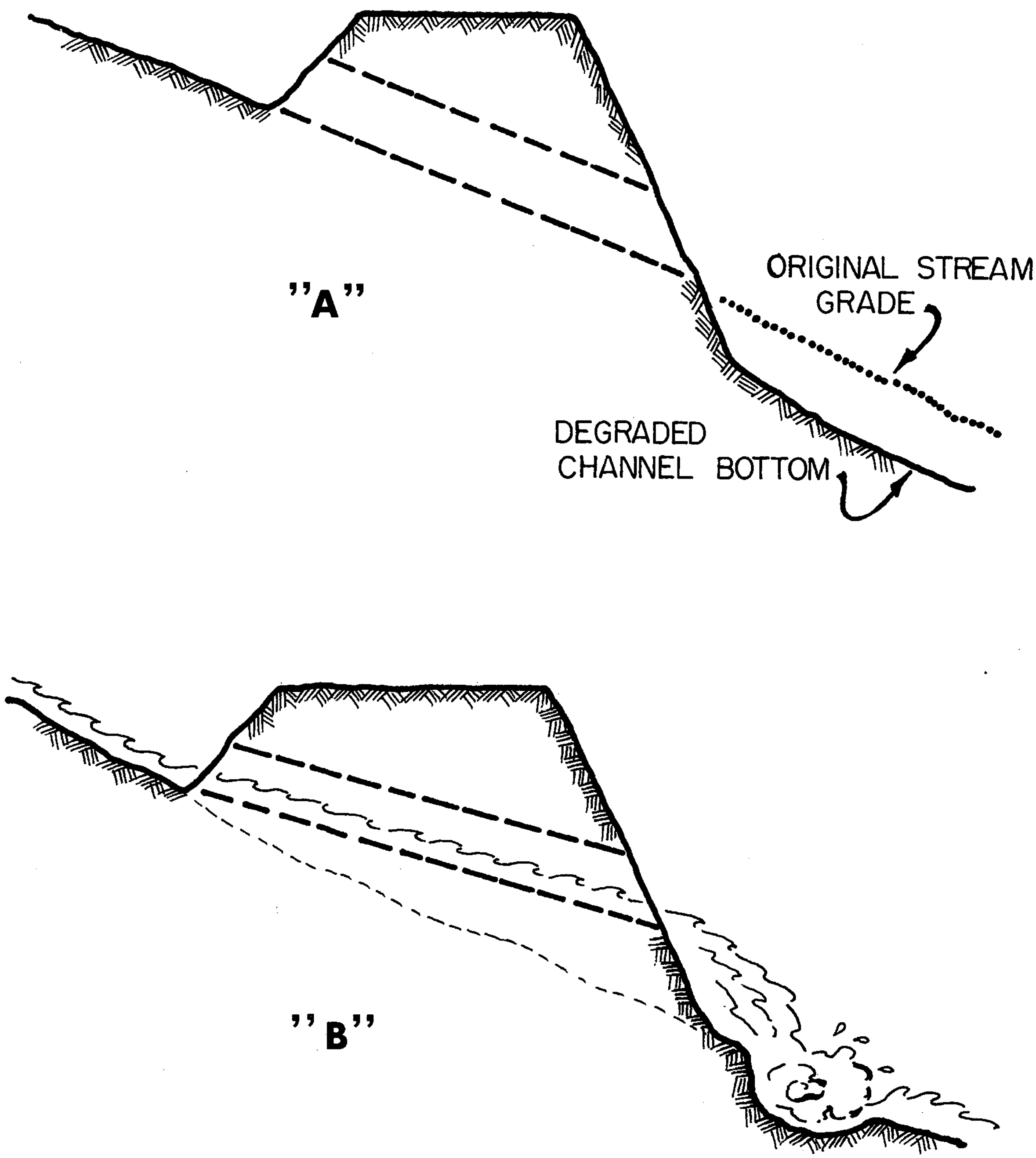


Figure 6. Jumps at structure outlet caused by "A" degraded channel and "B" by placing structure on a grade considerably flatter than streambed.

(3) Depth should equal one and one-half to two times the height of the jump required with a minimum depth of two feet.

b. Utilization of weir(s) to backflood structure which eliminates or reduces jump to acceptable height (Figure 3).

c. Replace existing structure or redesign proposed structure to eliminate entrance jump problem.

d. Utilize a fish passage facility such as an Alaskan steep pass, to provide entrance into structure.

Guidelines for Structures

Location

Structures should be located according to the following:

1. There should not be a sudden increase in velocity immediately above, below, or at the crossing.

2. Structures should not be located on a sharp bend in the stream channel.

3. Structures should be designed to fit the stream channel alignment. They should not necessitate a channel change to fit a particular crossing design.

Type

When a new structure is to be installed, the Department of Fish and Wildlife would recommend the following in order of priority:

1. Bridge
2. Arch plate
3. Open bottom box culvert
4. Countersunk corrugated pipe
5. Countersunk box culvert or smooth pipe
6. Corrugated pipe with grade less than 0.5 percent
7. Concrete bottom or smooth pipe with grade less than 0.5 percent
8. Corrugated pipe with baffles on grade between 0.5 and 5 percent
9. Concrete bottom or smooth culverts with baffles on grade between 0.5 and 5 percent
10. Structure with fishway

Bridges: Bridges are the preferred structural type as they seldom cause fish passage problems and permit retention of the natural streambed. Bridges with concrete aprons cause problems by necessitating a jump and/or by causing the water to spread out in a thin flow across a wide apron (Figure 7).

Arch plate: This structure is desirable for fish passage as it maintains a natural stream bottom. Most frequently encountered problem is an inadequate foundation.

Concrete box culvert: Open bottomed or countersunk concrete box culverts maintain a natural stream bottom and generally are a desirable fish passage structure. Box culverts designed with a bottom should always be countersunk. It may be necessary to construct low crosswalls (baffles) to hold natural bottom materials in a countersunk box.

Corrugated pipe: Corrugated pipe normally provides desirable fish passage when placed on a grade less the 0.5 precent and countersunk below the stream grade. This technique maintains a natural stream bottom through the structure. It may be necessary to construct low crosswalls (baffles) to hold natural bottom materials. Appendix 4 suggests depths for countersinking various sized culverts.

Corrugated pipe with standard placement generally provides adequate fish passage when placed on a grade less than 0.5 percent. When using this type of installation, the bottom of the culvert should be placed at least six inches below the stream bottom.

Corrugated pipe placed on grades between 0.5 and 5 percent can provide adequate fish passage if properly designed baffles are utilized. Baffles function best when they are just being overtopped with flow. Their effectiveness drops off quickly as water depth increases beyond one foot over baffle tops. Due to this variability in baffle efficiency

APRON UNDER BRIDGE MAY CAUSE UNSUITABLE FISH PASSAGE CONDITION.

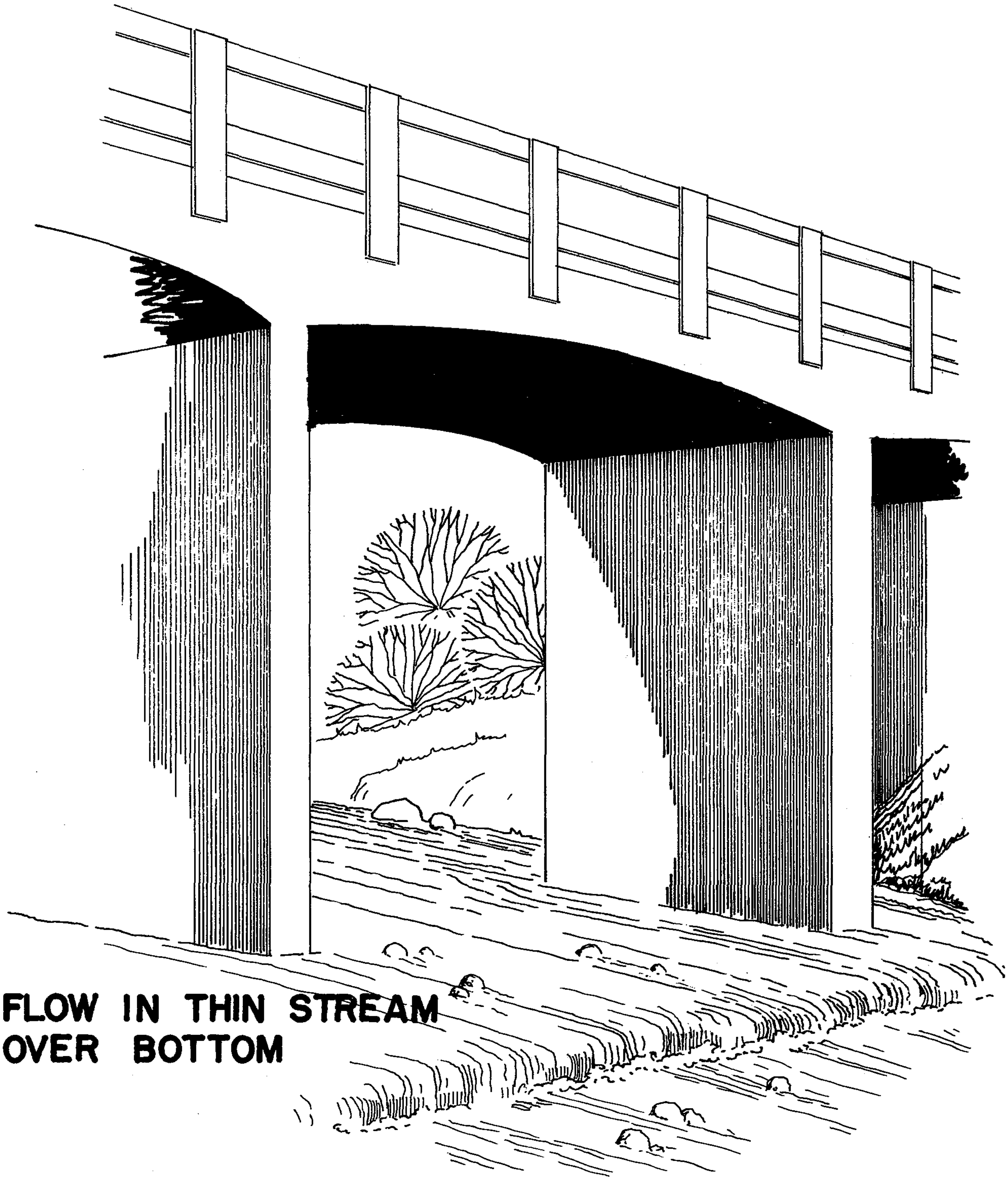


Figure 7. Apron under bridge may cause unsuitable fish passage condition. (Source: Evans, Willis A., Fish Migration and Fish Passage A Practical Guide To Solving Fish Passage Problems)

and inherent debris problems, baffled structures are only recommended at new crossings when a bridge or other more desirable structure is not practical.

Smooth pipe: Due to their lower roughness factor, smooth pipes have more problems meeting fish passage criteria than do corrugated pipe. Otherwise, comments for corrugated pipe apply.

Fishways: Structures incorporating fishways should be recommended only if all other options are unsatisfactory. Designs for such structures must be approved by Department of Fish and Wildlife engineers.

Structure size

Data contained in Appendix 5 (performance curves for culverts) are of extreme value in determining slope and size of culverts required to satisfy departmental fish passage criteria.

In addition to fish passage, structure size should consider the following points:

1. New structures should be designed to accommodate at least the flood of 25 year occurrence. Crossings with reduced capacity frequently wash out resulting in substantial sedimentation and need for additional construction.

2. Structures should be of adequate size to accommodate anticipated floatable drift (wood, ice, etc.) and allow for boat traffic where required.

3. Structures and associated approaches should not unduly restrict floodway capacity. Restriction of the floodway can result in structural failure, excessive flooding and abnormally high velocities leading to bed scour downstream of structure.

4. Structure size should be sufficient to prevent formation of a head upstream of structure.

Miscellaneous

1. Research has not indicated that lighting of long culverts is necessary to achieve adequate fish passage.

2. Multiple barreled culvert installations are not generally desirable. A larger single pipe will normally have lower velocities and will be less apt to plug with debris.

3. When two or more culverts are available, fish will generally try to enter the one with higher velocities.

4. When two or more culverts are available with equal velocities, fish will generally attempt to pass the wider one.

REFERENCES

Alaska Department of Fish and Game and U. S. Forest Service, Logging and Fish Habitat. 22 pp.

Alaska Department of Fish and Game. Swimming Capability of Migrating Salmon in Freshwater.

AASHTO. 1975. Task Force on Hydrology and Hydraulics, Memo.

Bainbridge, R. 1960. Speed and Stamina in Three Fish. Journal of Experimental Bio. 37:129-153.

Bell, Milo C. 1973. Fisheries Handbook of Engineering Requirements and Biological Criteria. U. S. Army Engineer Division, North Pacific Corps of Engineers, Portland, Oregon.

Blaxter, J. H. S. and W. Dickson. 1959. Observation on the Swimming Speeds of Fish. Scottish Home Department.

Bureau of Commercial Fisheries. May 1964. Progress Report No. 106.

______________. June 1964. Progress Report No. 107.

______________. November 1964. Progress Report No. 112.

______________. June 1967. Progress Report No. 142.

______________. January-March 1969. Progress Report No. 154.

______________. Research on Fishway Problems.

Clay, C. H. 1961. Design of Fishways and Other Fish Facilities. Queen's Printer, Ottawa, Canada 1-301.

Dellisle, G. E. 1962. Water Velocities Tolerated by Spawning Kokanee Salmon. California Fish and Game Department. Vol. 48, No. 1, pg. 77-78.

Evans, Willis A. 1974. Fish Migration and Fish Passage a Practical Guide to Solving Fish Passage Problems. U. S. Department of Agriculture, U. S. Forest Service, Region 5 43 pg.

Fish Commission of Oregon. September 4, 1969. Some Effect of Delay on Migrating Adult Salmonids. Water Resources Division.

Gauley, J. R. 1967. Effect of Water Velocity on Passage of Salmonids in a Transportation Channel. Fish and Wildlife Service, Fish. Bull. 66:59-63.

Gauley, J. R. - C. S. Thompson. 1963. Further Studies on Fishway Slope and Its Effect on Rate of Passage of Salmonids. U. S. Department of Interior, Fish and Wildlife Service, Fish. Bull. Vol. 63, No. 1, pg. 45-62.

Gebhards and Fisher. Fish Passage and Culvert Installations. Idaho Fish and Game Department.

Huston, J. 1966. Fish Passage Through Culverts. Montana Fish and Game Department. Memo. 1 pg.

Idaho, State of. Statement of Policy Concerning Facilities at Culvert Installations.

Kay, A. R. and R. B. Lewis. June 1970. Passage of Anadromous Fish Through Highway Drainage Structures. California Division of Highways, Research Report 629110.

King, Horace Williams. 1954. Handbook of Hydraulics, Fourth Edition, McGraw-Hill Book Company, Inc., New York.

Koski and Saltzman. Fish Passage Through Culverts. Oregon Game Commission.

McClellan, Thomas. Fish Passage Through Highway Culverts. Federal Highway Administration.

Metsker. Fish versus Culverts. U. S. Forest Service - Region 4.

Miller, J. M. 1972. Guidelines for Protection of the Fish Resource Resulting from Highway Construction and Operation. Fisheries Research Board, Winnipeg.

Oregon State Highway Division. 1974. Hydraulics Manual, Salem, Oregon.

Oregon, State of. Oregon Revised Statutes. Legislative Counsel Committee, Salem, Oregon.

Oregon Wildlife Commission. 1973. Oregon Wildlife Code. Portland, Oregon. 126 pp.

Otis, M. B. 1964. Suggested Measures for Minimizing Damage to Fishing Streams from Highway Projects. New York State, Department of Environmental Conservation. 4 pp.

Prett, J. R. August 1965. Swimming Energetics of Salmon. Scientific American, Vol. 213, No. 2. 6 pg.

Reimers, N. Trout Stamina. Progressive Fish Culturist, 18:112.

Shoemaker, R. H., Jr. Hydraulics of Box Culverts with Fish Ladder Baffles, OSC.

Slatick, E. Passage of Adult Salmon and Trout Through an Incline Pipe. Trans. American Fisheries Society 100(3): 448-455.

__________. Passage of Adult Salmon and Trout Through Pipes. U. S. Fish and Wildlife Service. Special Scientific Report 592, 18 pp.

U. S. Government. 1975. Logging Road and Protection of Water Quality. U. S. Environmental Protection Agency, Region X, Seattle, Washington. 313 pp.

Washington Department of Fisheries. Regulations and Recommendations for Fish Passage, Facilities at Culvert Installations.

Weaver, C. R. 1963. Influence of Water Velocity Upon Orientation and Performance of Adult Migrating Salmonids. USDI and F&WS Fishery Bulletin Vol. 63, No. 1. 97-122 pp.

Webster, D. A. 1965. Leaping Rainbow of the Finger Lakes. New York State Conservation Department. Information Leaflet.

Appendix 1. Oregon Revised Statutes 498.268 and 509.605

ORS 498.268

498.268 Fishway required for artificial obstruction across body of water. (1) Except as otherwise provided by law, no person shall construct, operate or maintain any dam or artificial obstruction across any body of water in this state in which game fish exist unless he provides a fishway in such location and of such design as the commission determines will provide adequate upstream and downstream passage for fish at the dam or obstruction.

(2) If the commission determines that a fishway required by subsection (1) of this section does not provide adequate passage for fish, the commission shall so notify the person who constructed or who operates or maintains the dam or obstruction. The notice shall also specify the manner in which the fishway is inadequate, and shall require the person who constructed or who operates or maintains the dam or obstruction to make appropriate alterations, specifying a reasonable time for the completion thereof.

(3) A person required to alter a fishway pursuant to subsection (2) of this section may file with the State Water Resources Board a protest against the alteration requirements on the grounds that such alterations are not in the public interest. A person who protests pursuant to this subsection must file the protest with the board not later than the 10th day after the date of the notice of alteration requirements from the commission.

(4) Within a reasonable time after receiving a protest, the State Water Resources Board shall give notice to the protestant and the commission and hold a hearing to determine whether the fishway alterations are in the public interest. In making the determination, the board shall approve, disapprove or approve with modifications the fishway alterations required by the commission. In making the determination, the board shall consider the state water resources policy and the considerations set forth in ORS 536.310.

(5) If the person required by this section to make alterations to a fishway fails to make the alterations in the manner and within the time required by the commission or the State Water Resources Board, as the case may be, the commission may remove the dam or obstruction, or any parts thereof.

Appendix 1. (continued)

(6) No person who has constructed or who operates or maintains a dam or artificial obstruction for which a fishway is required by this section shall fail to keep the fishway free from obstruction to the passage of fish. However, no prosecution for violation of this subsection shall be commenced unless the violation continues after the commission has given writen notice of the violation to the person who is to be prosecuted. Every day of violation of this subsection after the date written notice was given to the person to be prosecuted constitutes a separate offense.

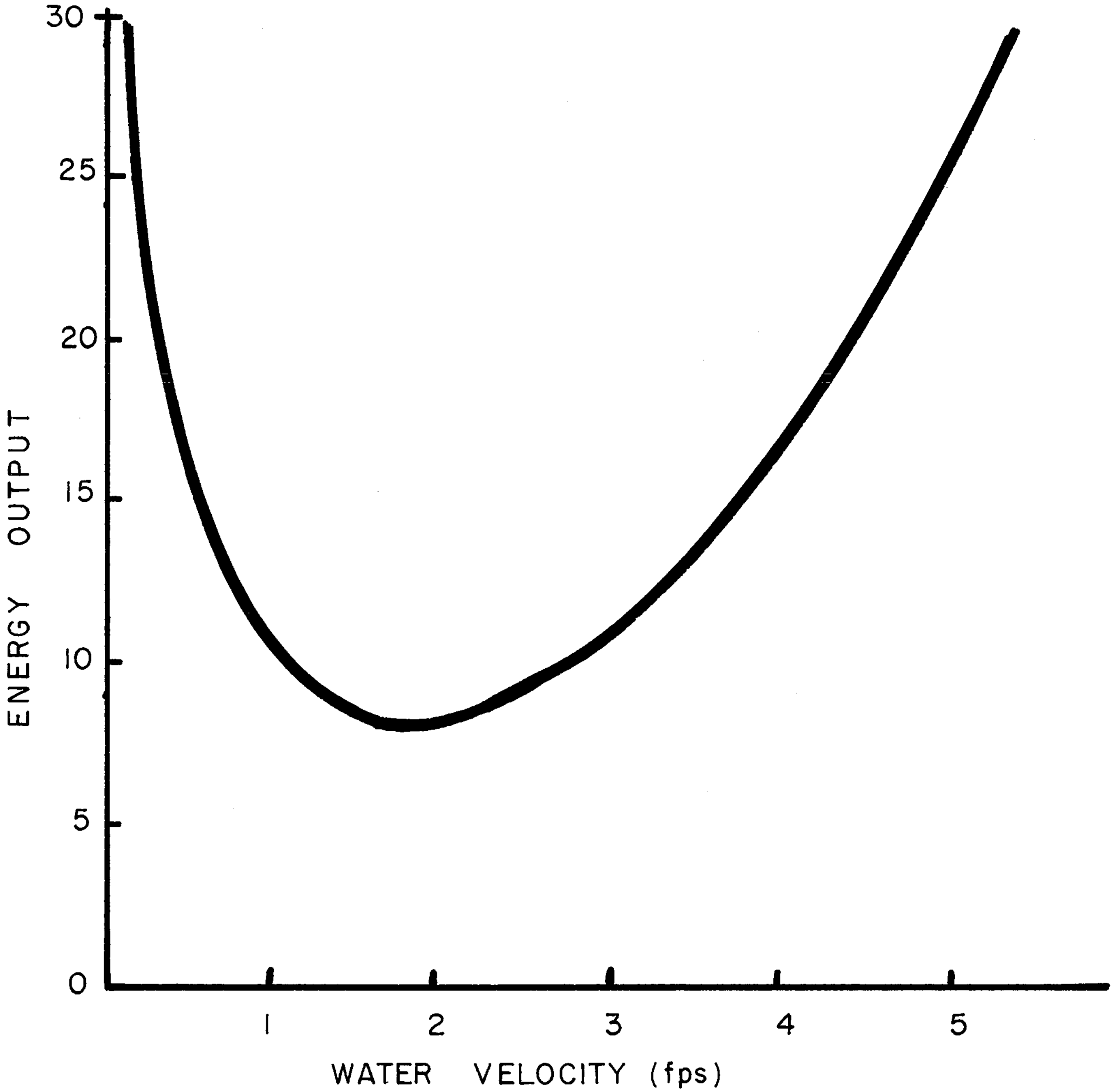
ORS 509.605

509.605 Fishways required over artificial obstructions; approval by director; failure to complete fishway. (1) Except as otherwise provided in ORS 498.268 or 509.640 or 509.645 or the state water resources policy formulated under ORS 536.300 to 536.350, it is unlawful for any person, municipal corporation, political subdivision or governmental agency to construct or maintain any dam or artificial obstruction across any stream in this state frequented by anadromous or food fish without providing a passageway for such fish over the dam or artificial obstruction as near the main channel as practicable.

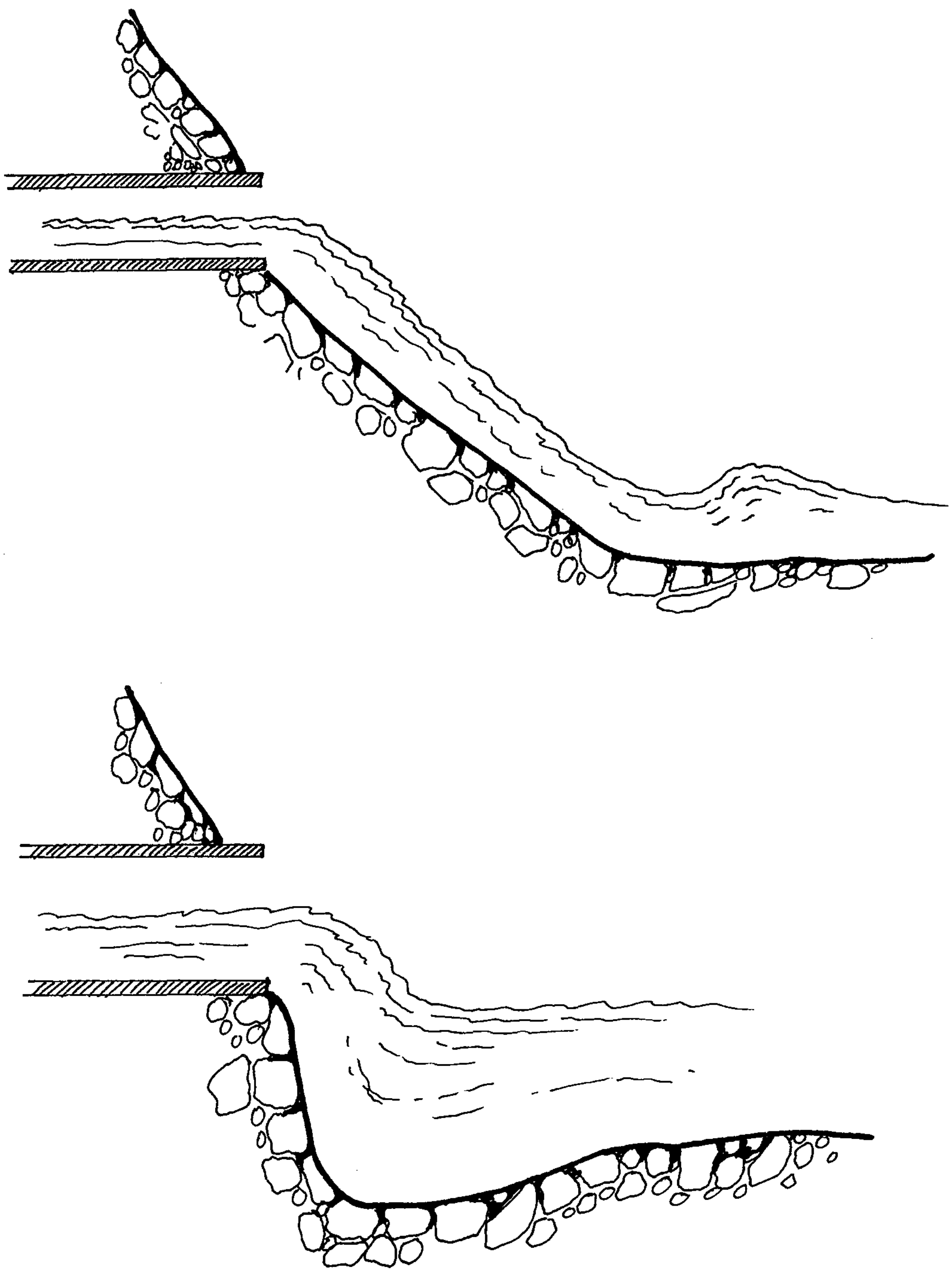
(2) The director shall examine, from time to time, all dams and artificial obstructions in all waters of this state frequented by anadromous or food fish. If in his opinion there is not a free passage for such fish over any dam or artificial obstruction, and except as otherwise provided in ORS 509.640, the director may notify the owner or occupant thereof to provide free passage within a reasonable time with a durable and efficient fishway, of such form and capacity and in such location as shall be determined by the director. Except as otherwise provided in ORS 509.645, no owner or occupant of such dam or artificial obstruction shall fail to complete such fishway to the satisfaction of the director within the time specified.

(3) Any person, municipal corporation, political subdivision or governmental agency shall, prior to construction of any dam or artificial obstruction in any waters of this state, obtain a determination from the director as to the need or lack of need for passage of anadromous or food fish. If the director determines that a fish passage facility is needed, approval of the proposed plans and specifications for such facility must be obtained from the director prior to construction of the dam or artificial obstruction.

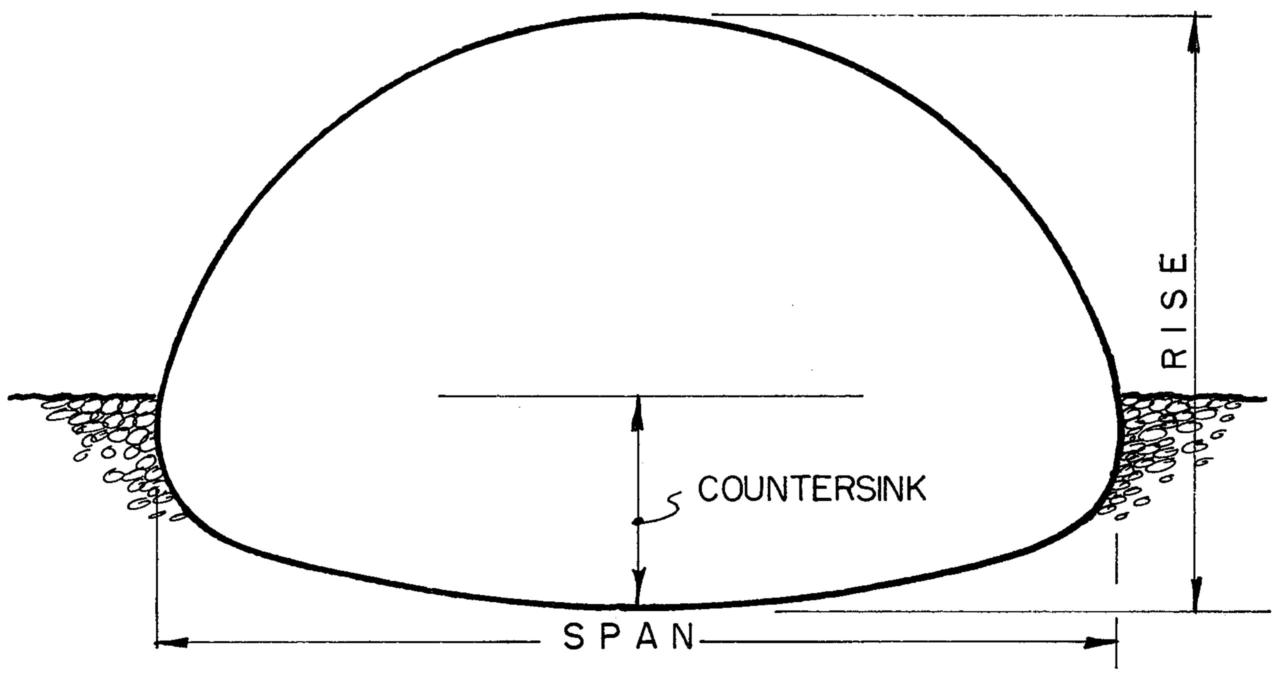
Appendix 2. Salmon energy efficiency curve. (Source: Prett, J. R., The Swimming Energetics of Salmon)



Appendix 3. Vertical drops are preferred over sloped drops.



Appendix 4. Recommended depth to countersink arch pipe culverts. (Source: AASHTO. Culvert Guidelines)



Span (ft.-in.)	Rise (ft.-in.)	Countersink (in.)
6'- 1"	4'- 7"	21.0"
6'- 4"	4'- 9"	20.5"
6'- 9"	4'-11"	22.0"
7'- 0"	5'- 1"	21.4"
7'- 3"	5'- 3"	20.8"
7'- 8"	5'- 5"	27.4"
7'-11"	5'- 7"	21.7"
8'- 2"	5'- 9"	20.9"
8'- 7"	5'-11"	22.7"
8'-10"	6'- 1"	21.9"
9'- 4"	6'- 3"	23.8"
9'- 6"	6'- 5"	22.9"
9'- 9"	6'- 7"	21.9"
10'- 3"	6'- 9"	24.0"
10'- 8"	6'-11"	26.1"
10'-11"	7'- 1"	25.1"
11'- 5"	7'- 3"	27.4"
11'- 7"	7'- 5"	26.3"
11'-10"	7'- 7"	25.2"
12'- 4"	7'- 9"	27.5"
12'- 6"	7'-11"	26.4"
12'- 8"	8'- 1"	25.2"
12'-10"	8'- 4"	24.0"
13'- 5"	8'- 5"	26.4"
13'-11"	8'- 7"	28.9"
14'- 1"	8'- 9"	27.6"
14'- 3"	8'-11"	26.3"
14'-10"	9'- 1"	28.9"
15'- 4"	9'- 3"	31.6"
15'- 6"	9'- 5"	30.2"
15'- 8"	9'- 7"	28.8"
15'-10"	9'-10"	27.5"
16'- 5"	9'-11"	30.1"
16'- 7"	10'- 1"	28.7"

Appendix 5

CALCULATION OF VELOCITY AND WATER DEPTH THROUGH CULVERTS OF VARIOUS TYPES (Source: Evans, Willis A., Fish Migration and Fish Passage A Practical Guide to Solving Fish Passage Problems)

These data were prepared and made available for this purpose through the cooperation of the Automatic Data Processing Unit of Region 5 Engineering and Ron Schmidt, Hydraulic Engineer, Shasta-Trinity National Forest.

This Appendix will present information to aid the Engineer and Biologist in determining velocity and water depth for those culvert types most commonly utilized. They include:

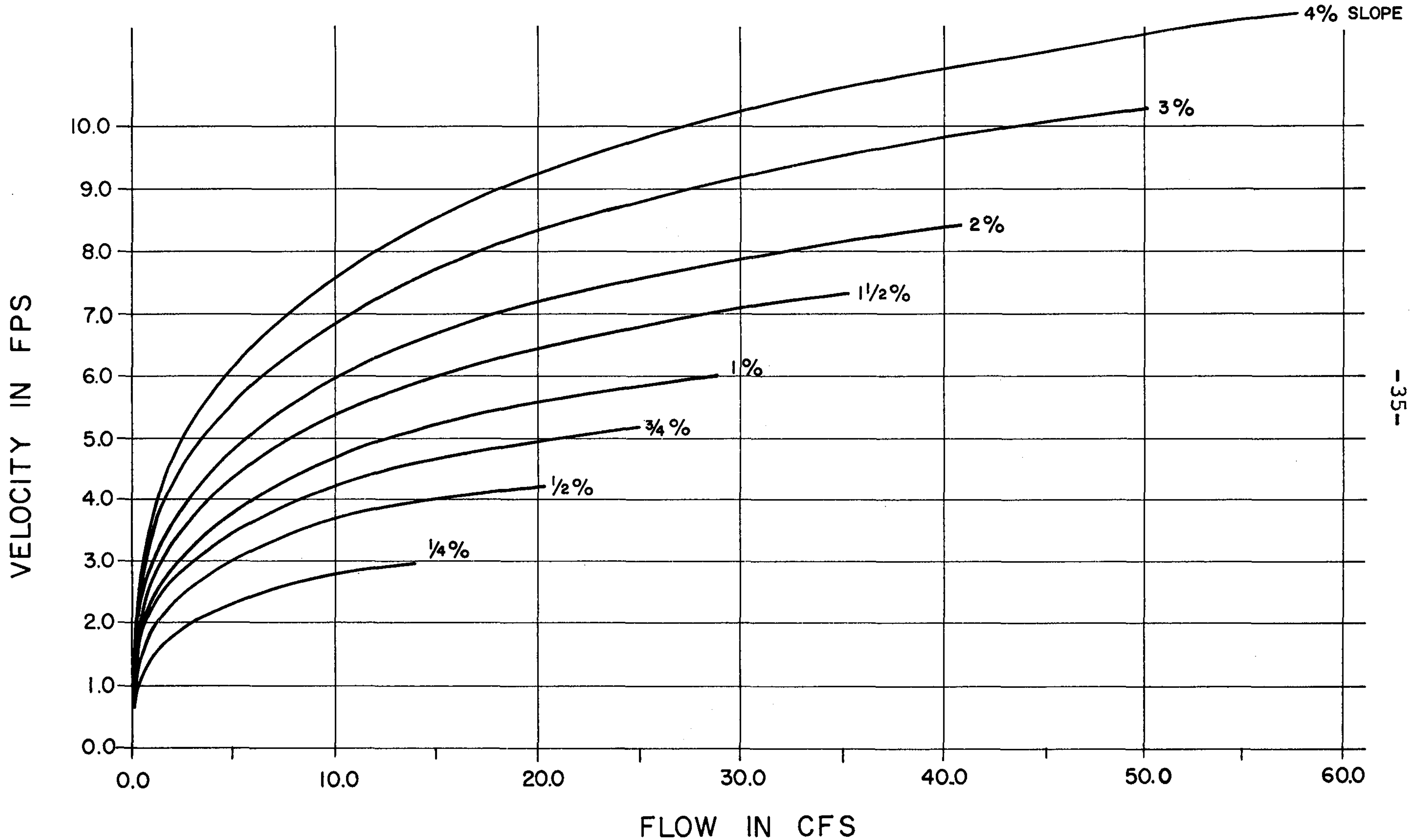
1. 3 x 1 corrugated metal circular culverts 36, 48, 60, 72, 84, 96, 108, 120 inch diameter.

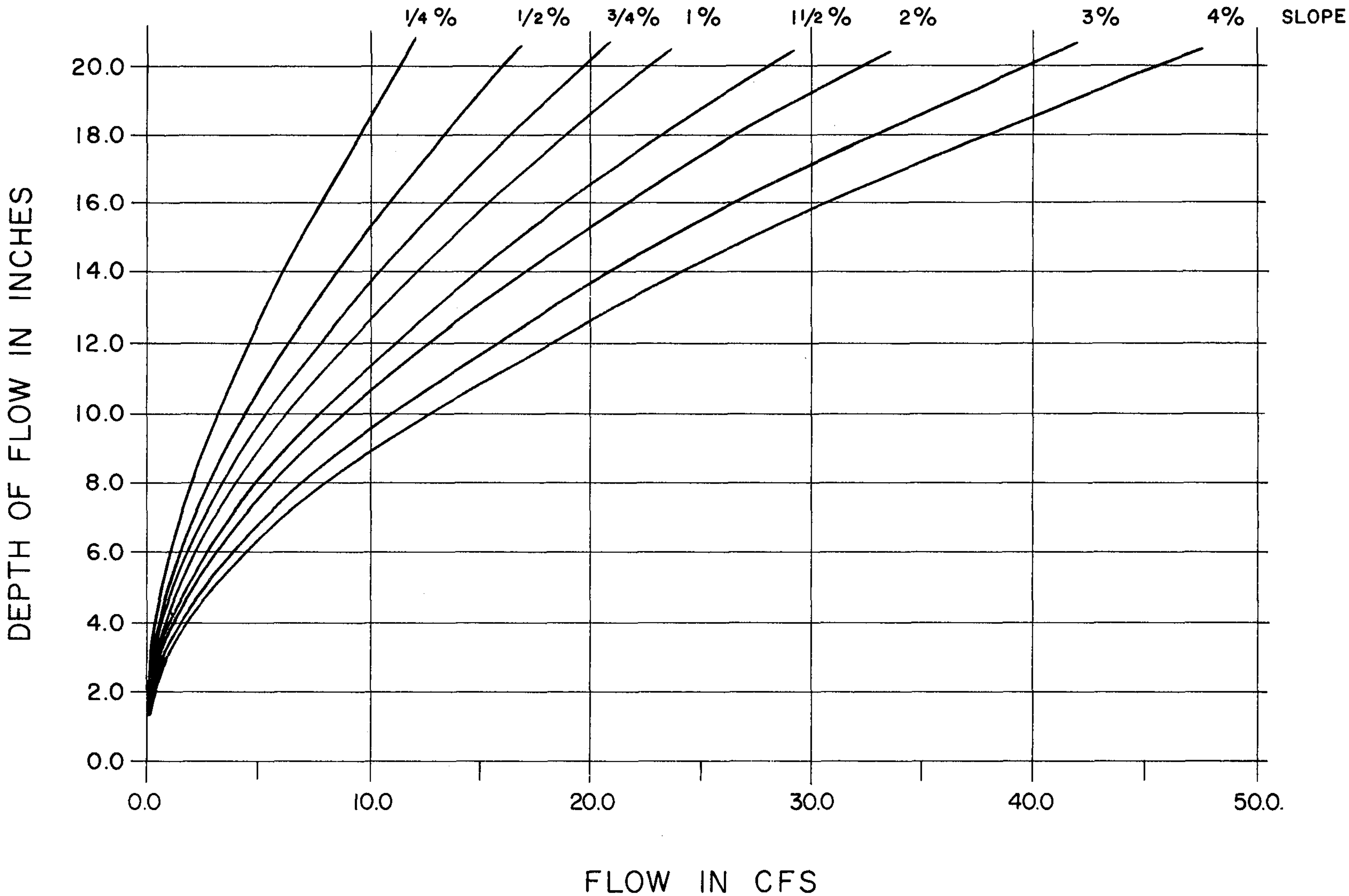
2. Concrete box culverts 36, 48, 60, 72, 84, 96, 108, 120 inch diameter.

3. 3 x 1 corrugated metal pipe arch
   - 7'0" x 5'11"
   - 8'10" x 6'1"
   - 10'11" x 7'1"
   - 12'8" x 8'1"
   - 14'10" x 9'1"
   - 16'7" x 10'1"

For all culverts data are shown for slopes ranging from 12 - 14%. It is emphasized that by use of the charts presented only approximate answers are obtained. These should suffice, however, for the degree of accuracy required for fish passage determination but may not be suitable for other purposes in which more accurate measurements of the variables are required. For example, the charts presented are not intended for and should not be used to select a culvert size and culvert slope for maximum flow. (For further information as to how these charts were developed, refer to Appendix 2).

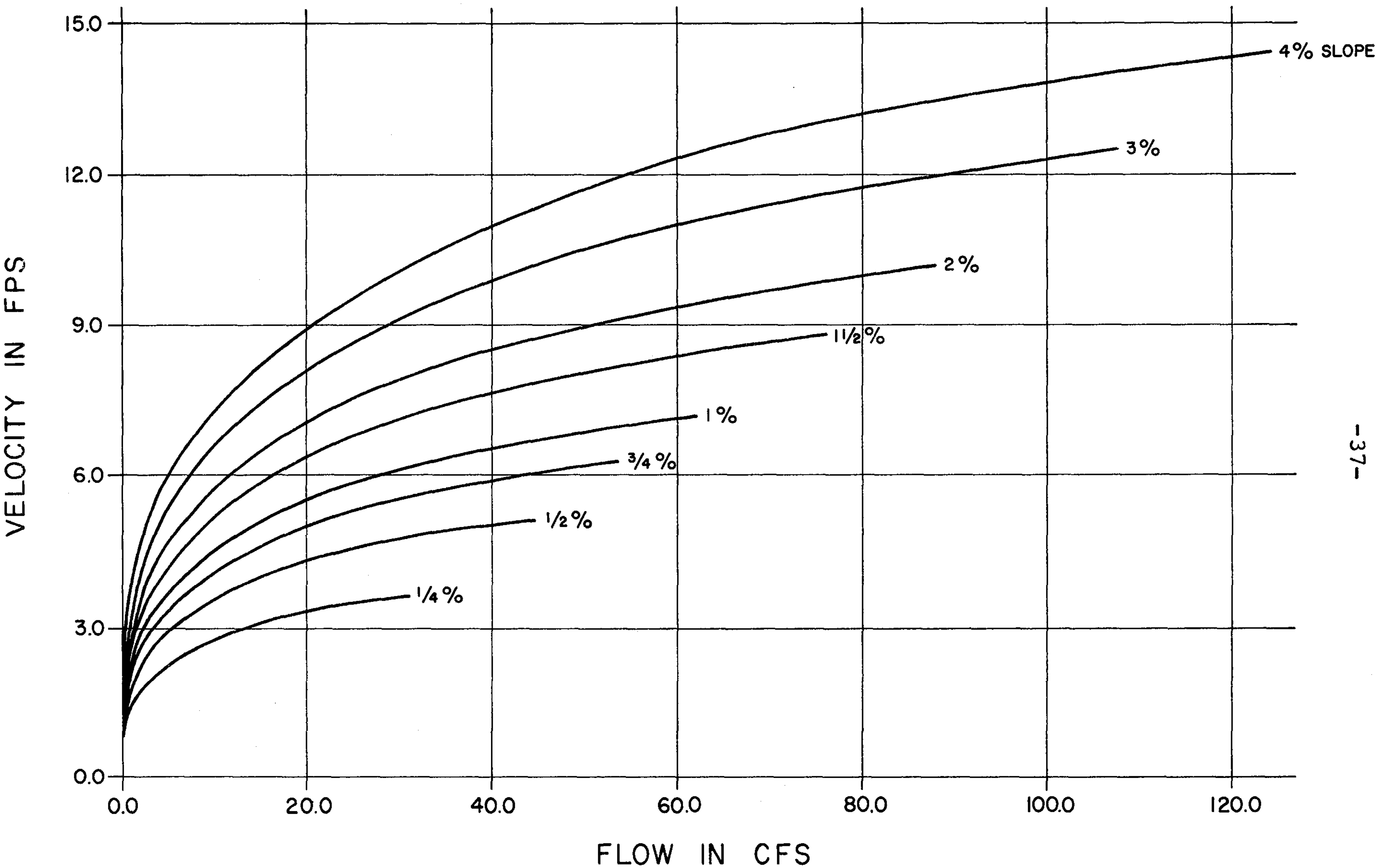
36" CIRCULAR CULVERT

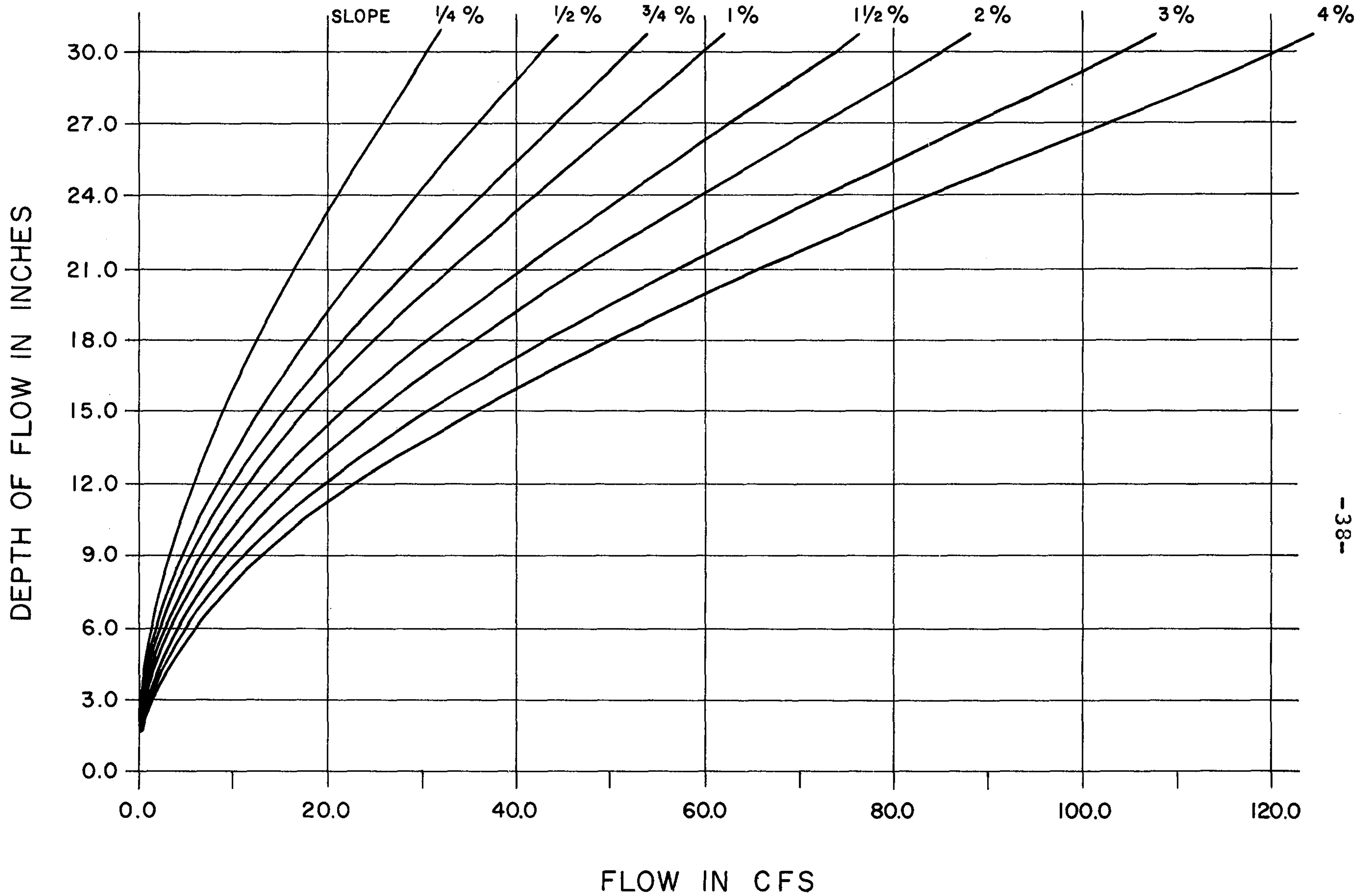




36" CIRCULAR CULVERT

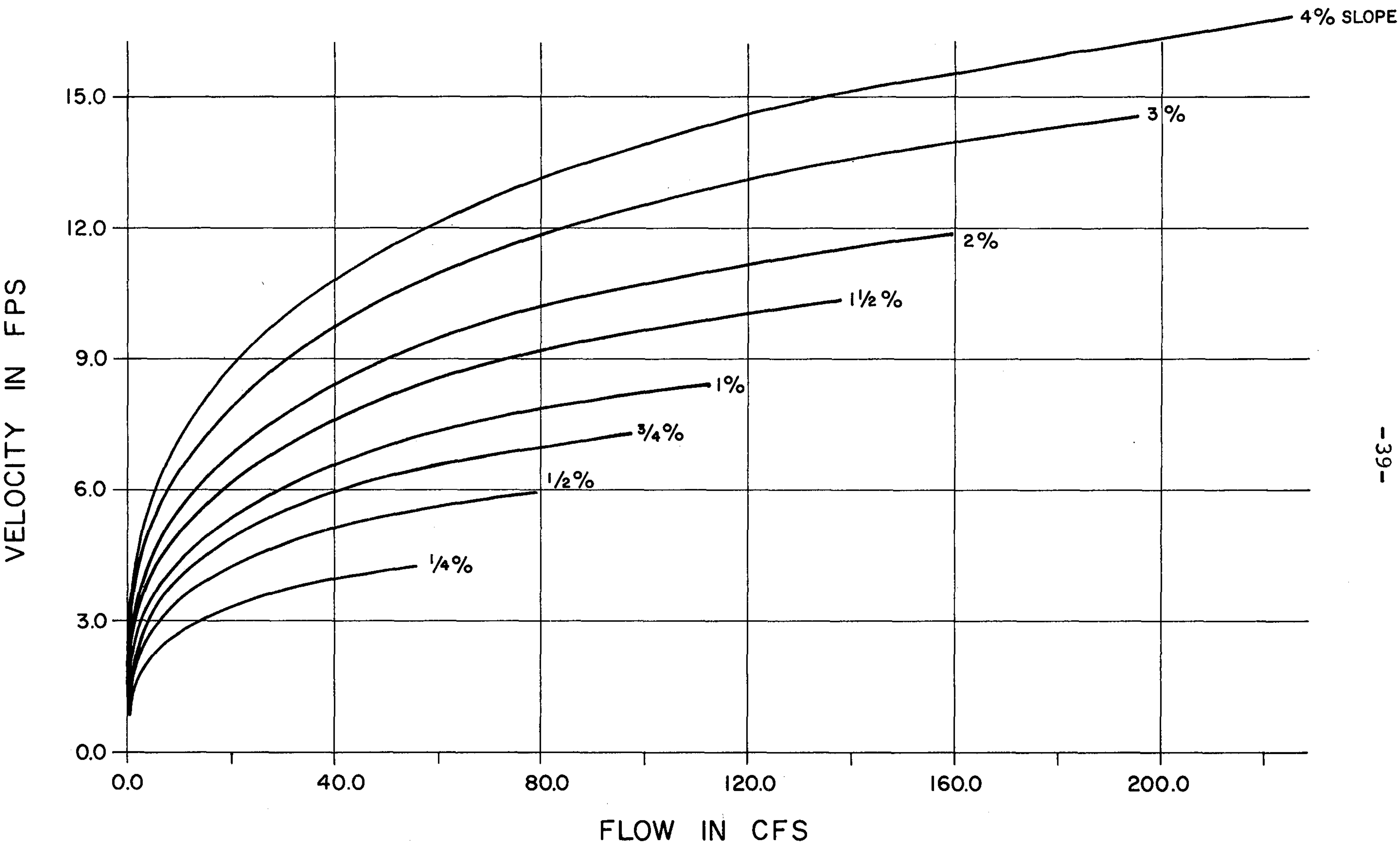
48" CIRCULAR CULVERT

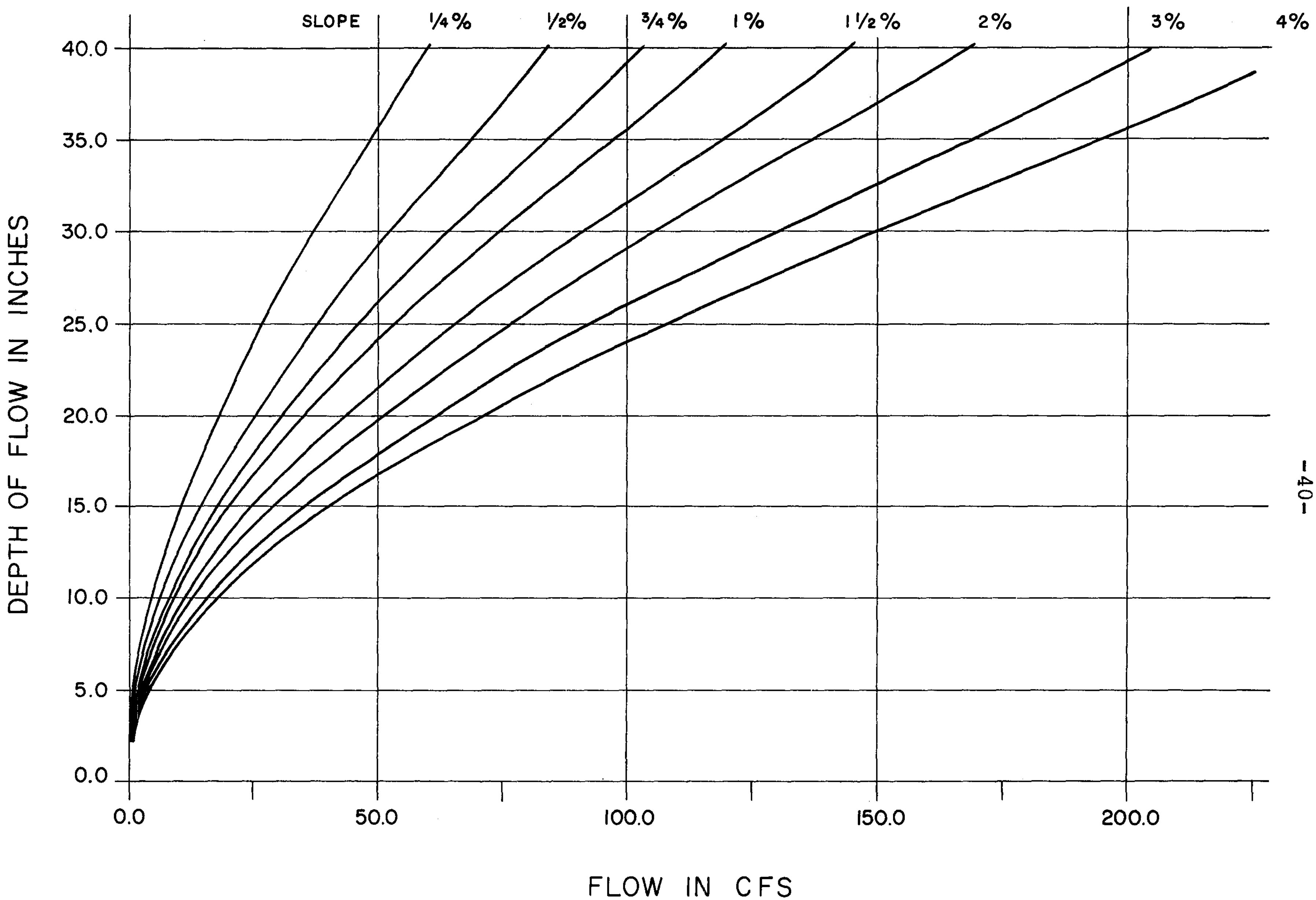




48" CIRCULAR CULVERT

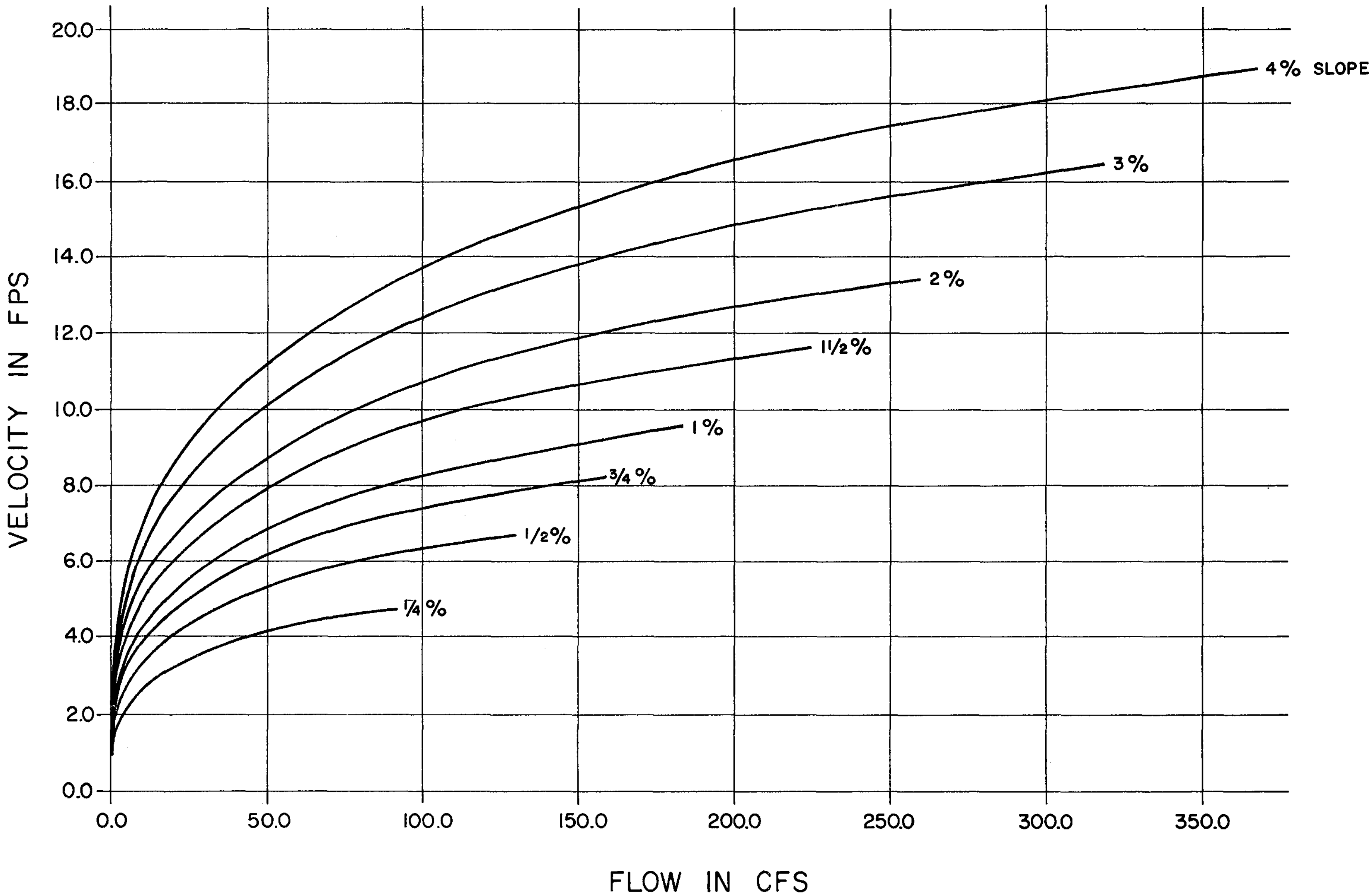
60" CIRCULAR CULVERT

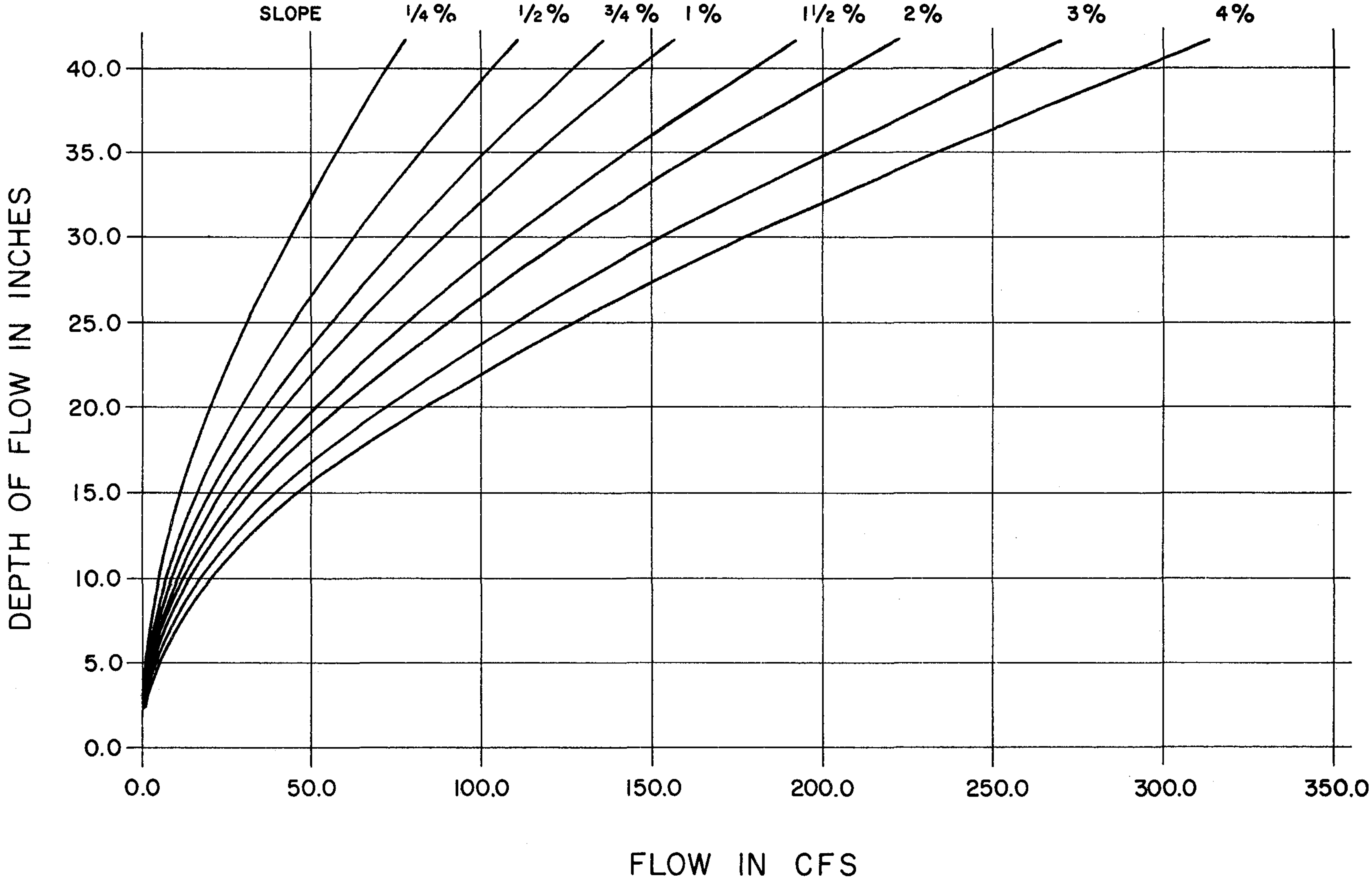




60" CIRCULAR CULVERT

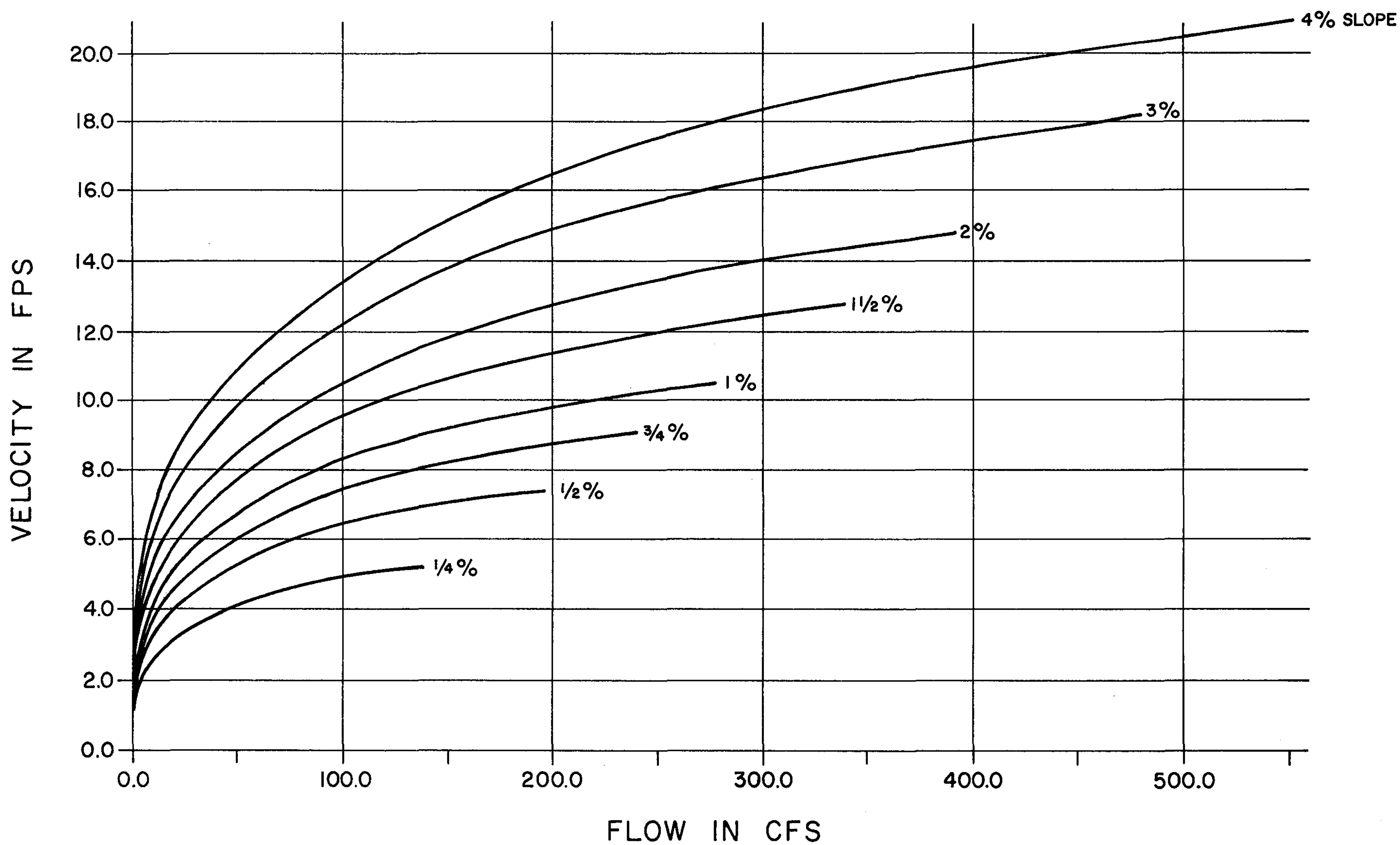
72" CIRCULAR CULVERT

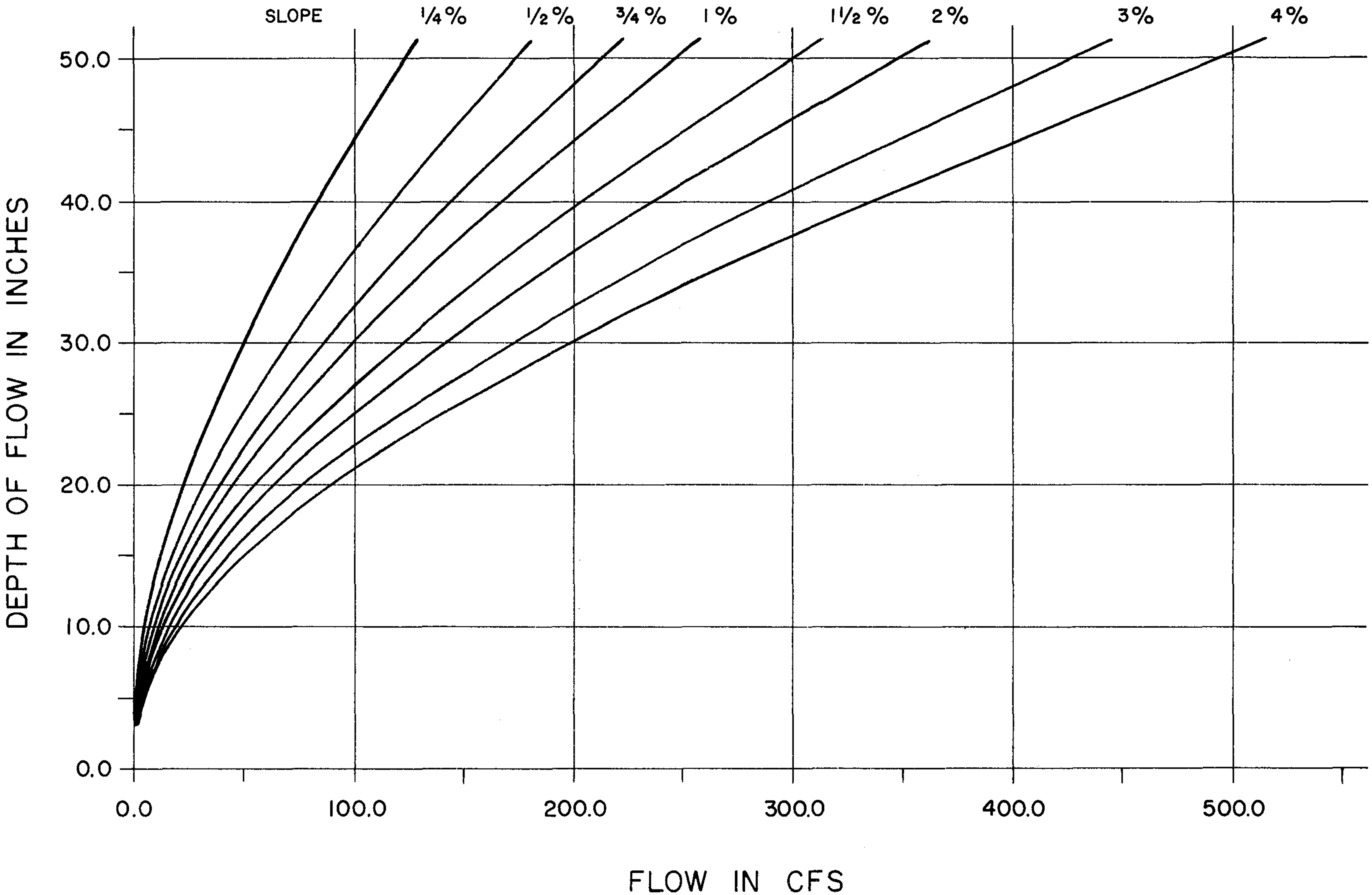




72" CIRCULAR CULVERT

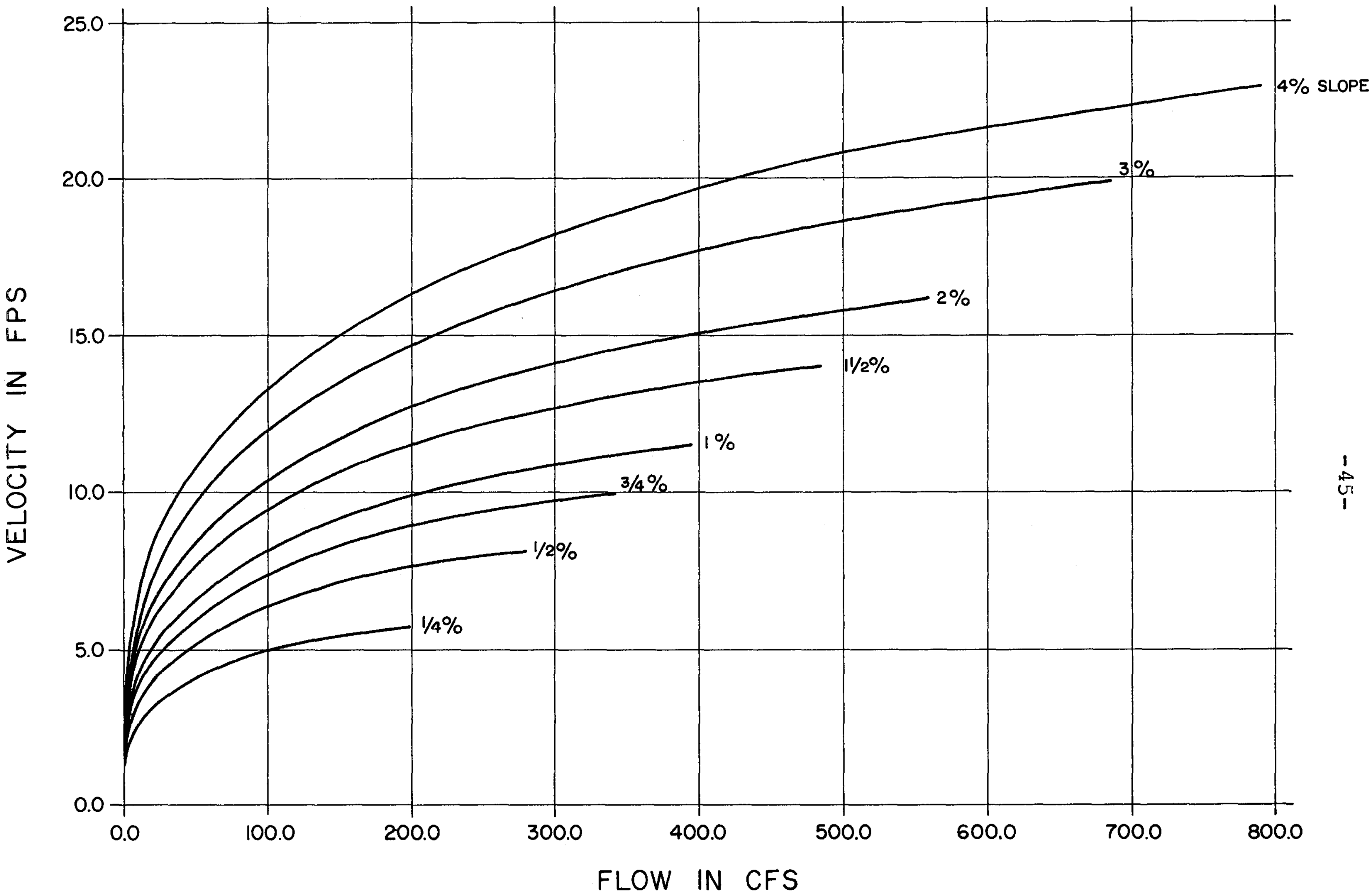
84" CIRCULAR CULVERT

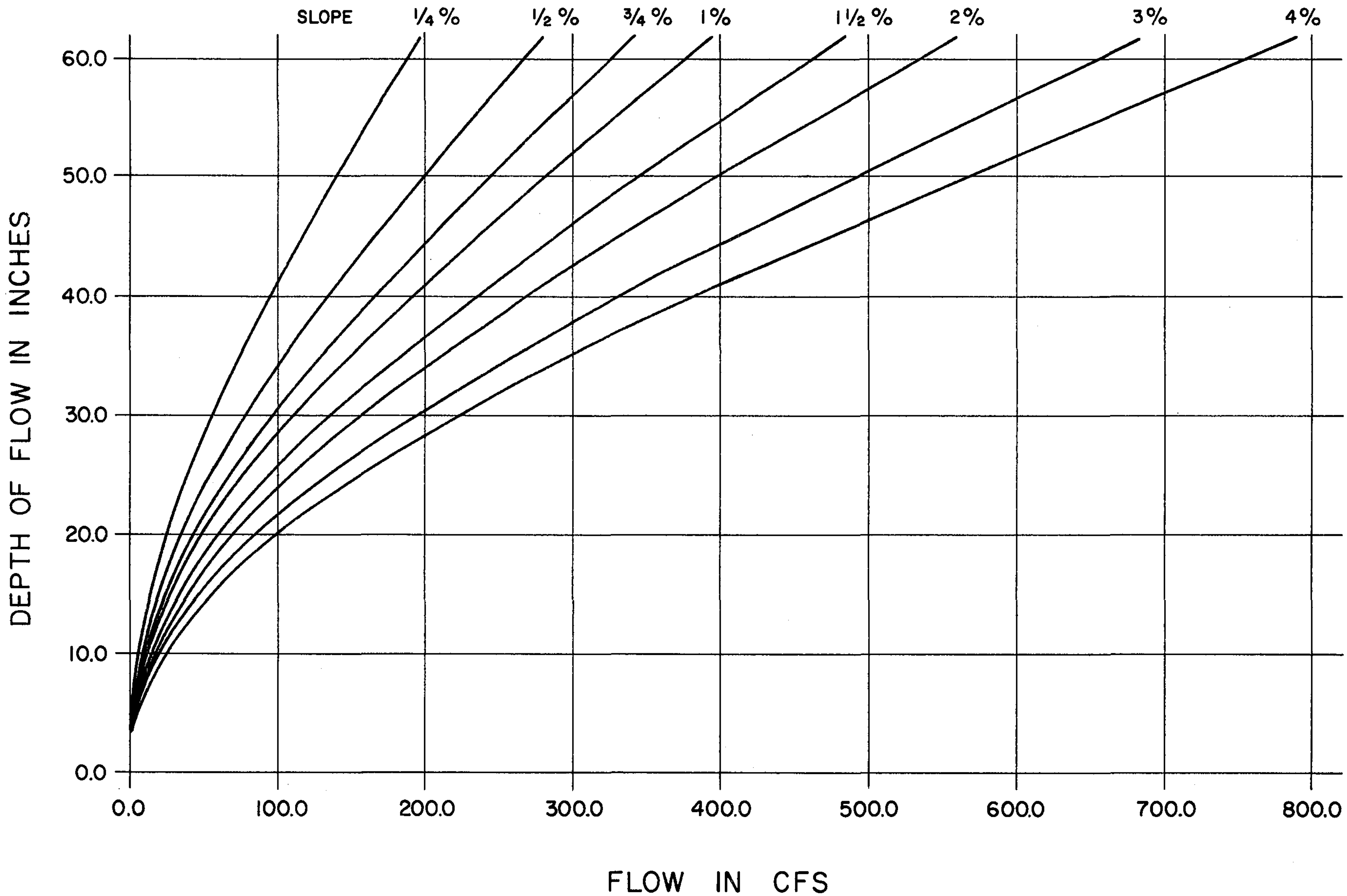




84" CIRCULAR CULVERT

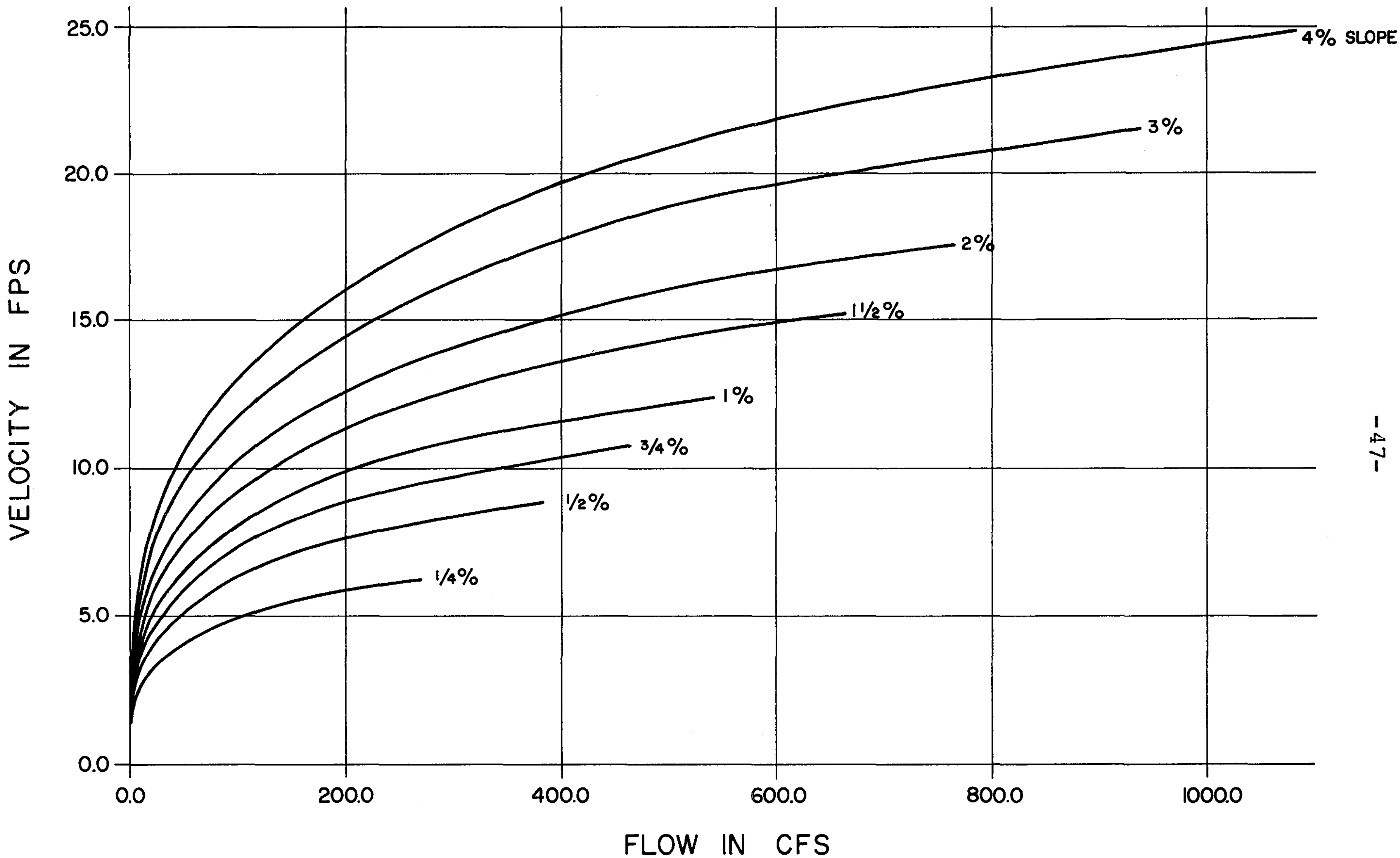
96" CIRCULAR CULVERT

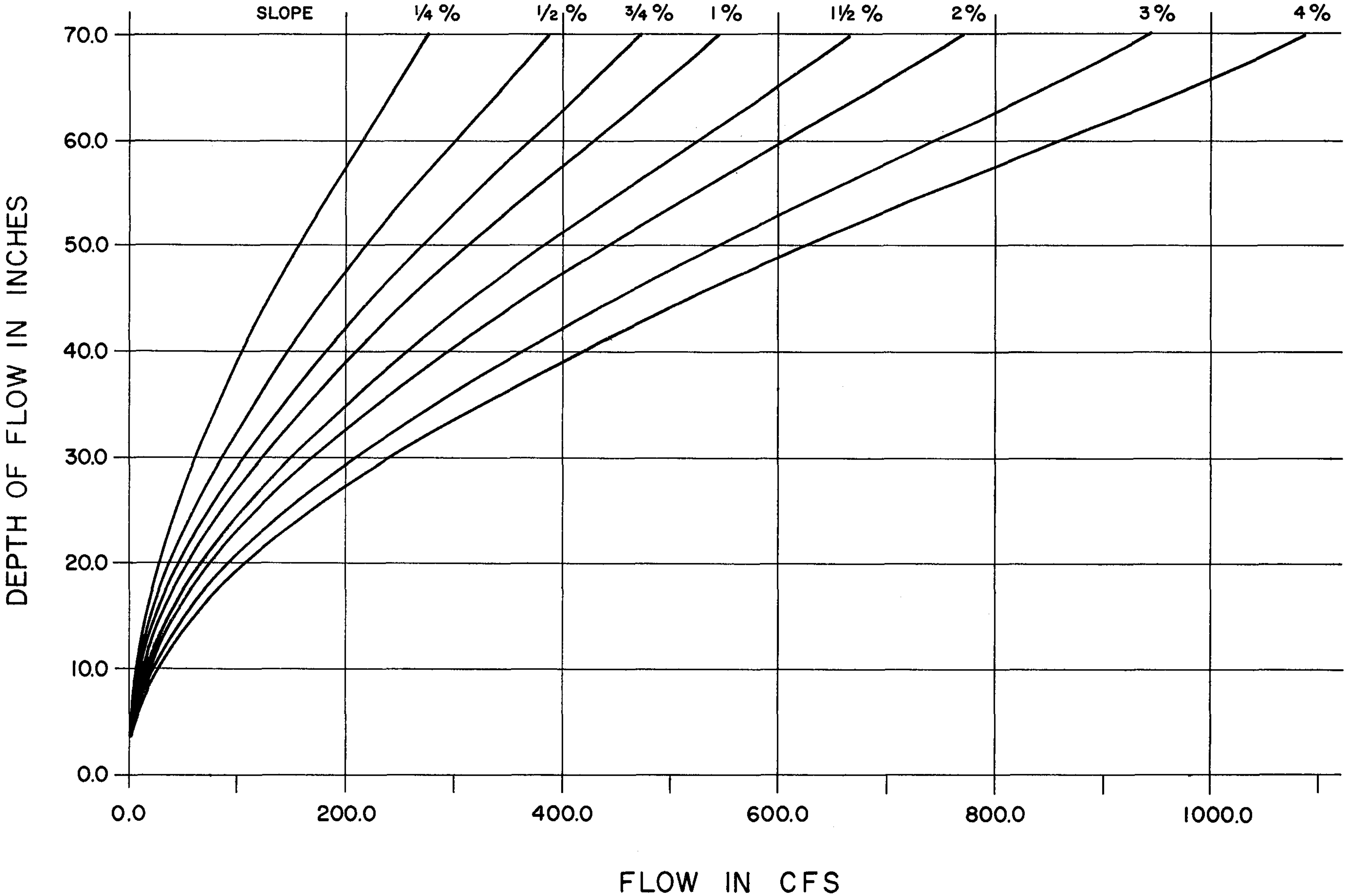




96" CIRCULAR CULVERT

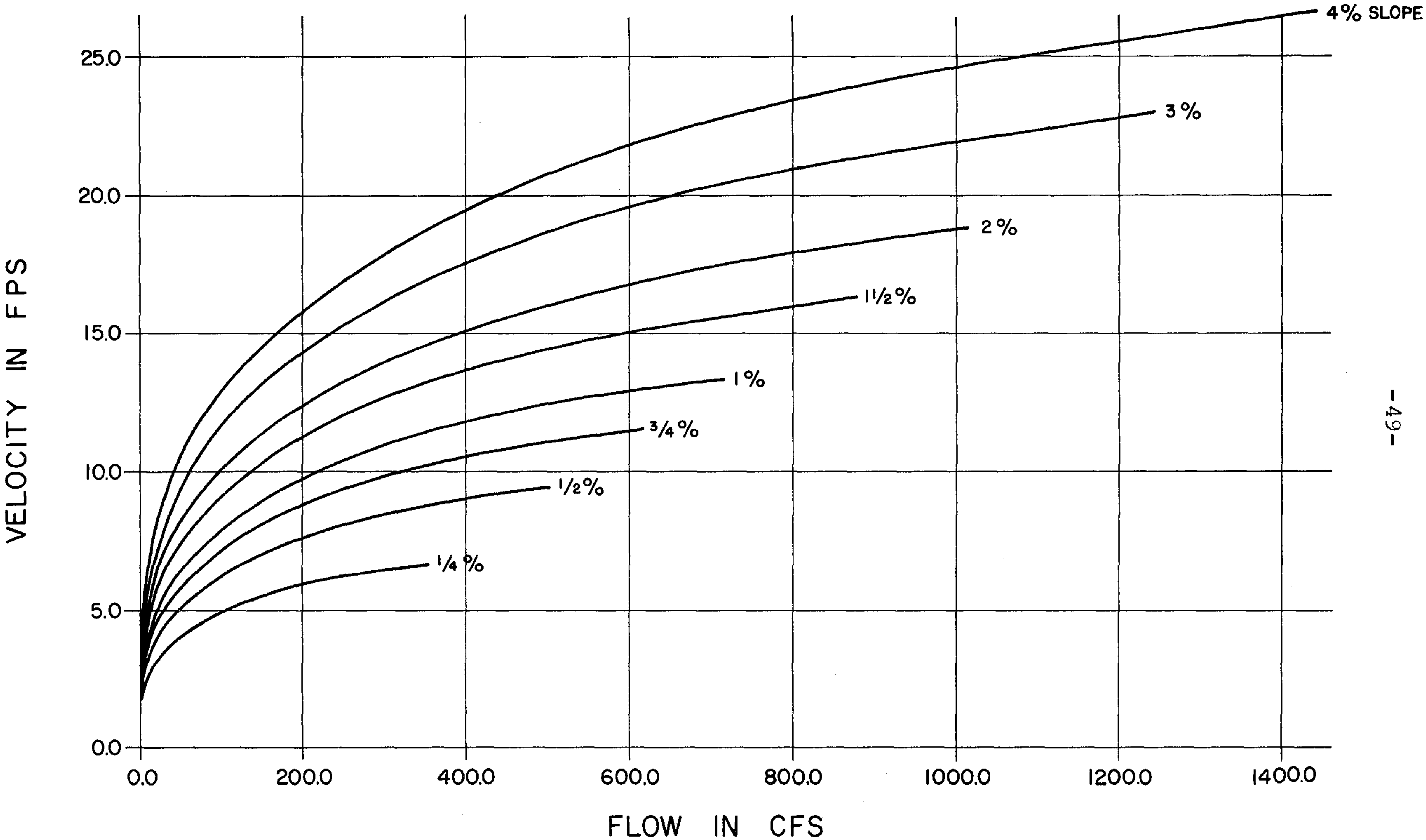
108" CIRCULAR CULVERT

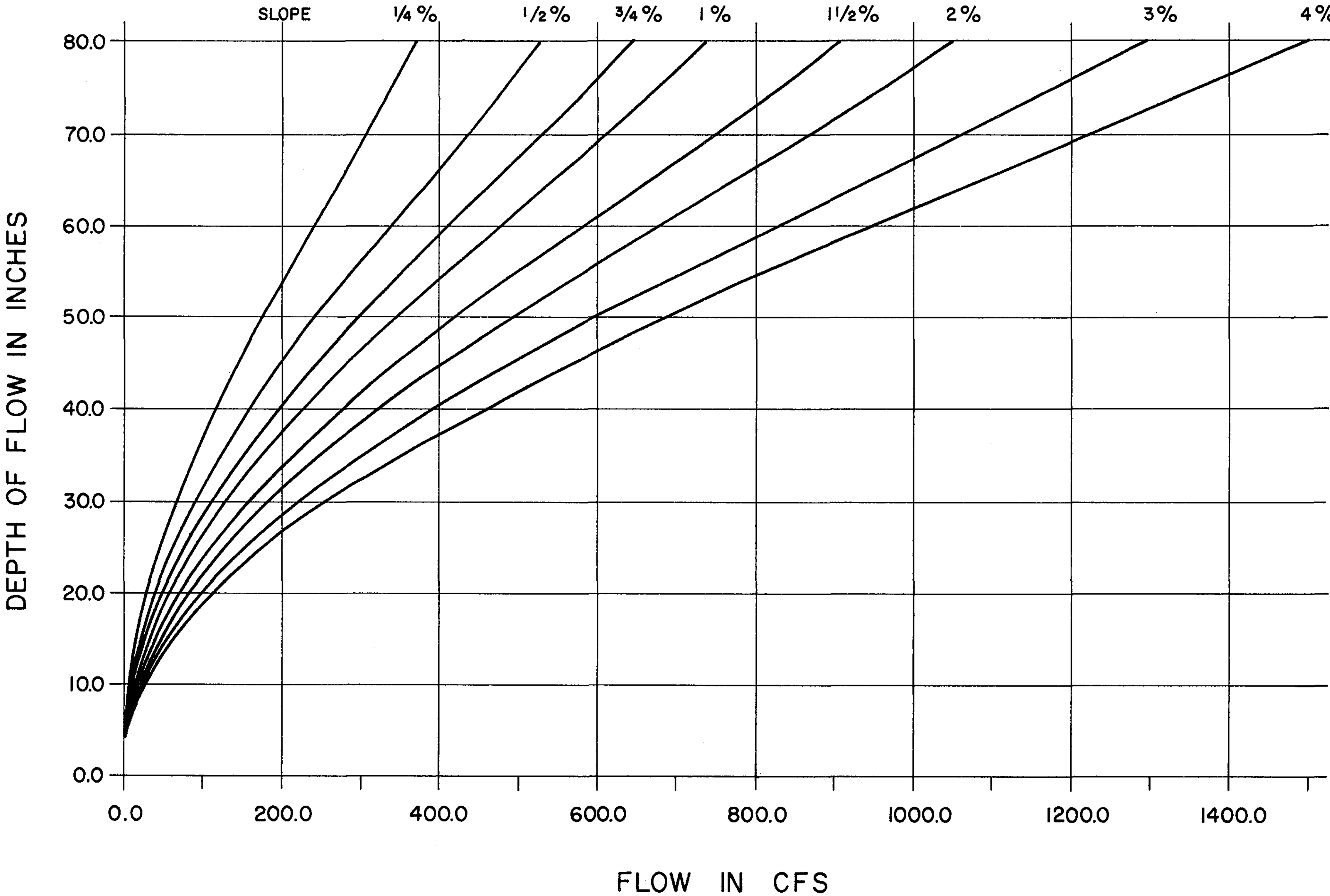




108" CIRCULAR CULVERT

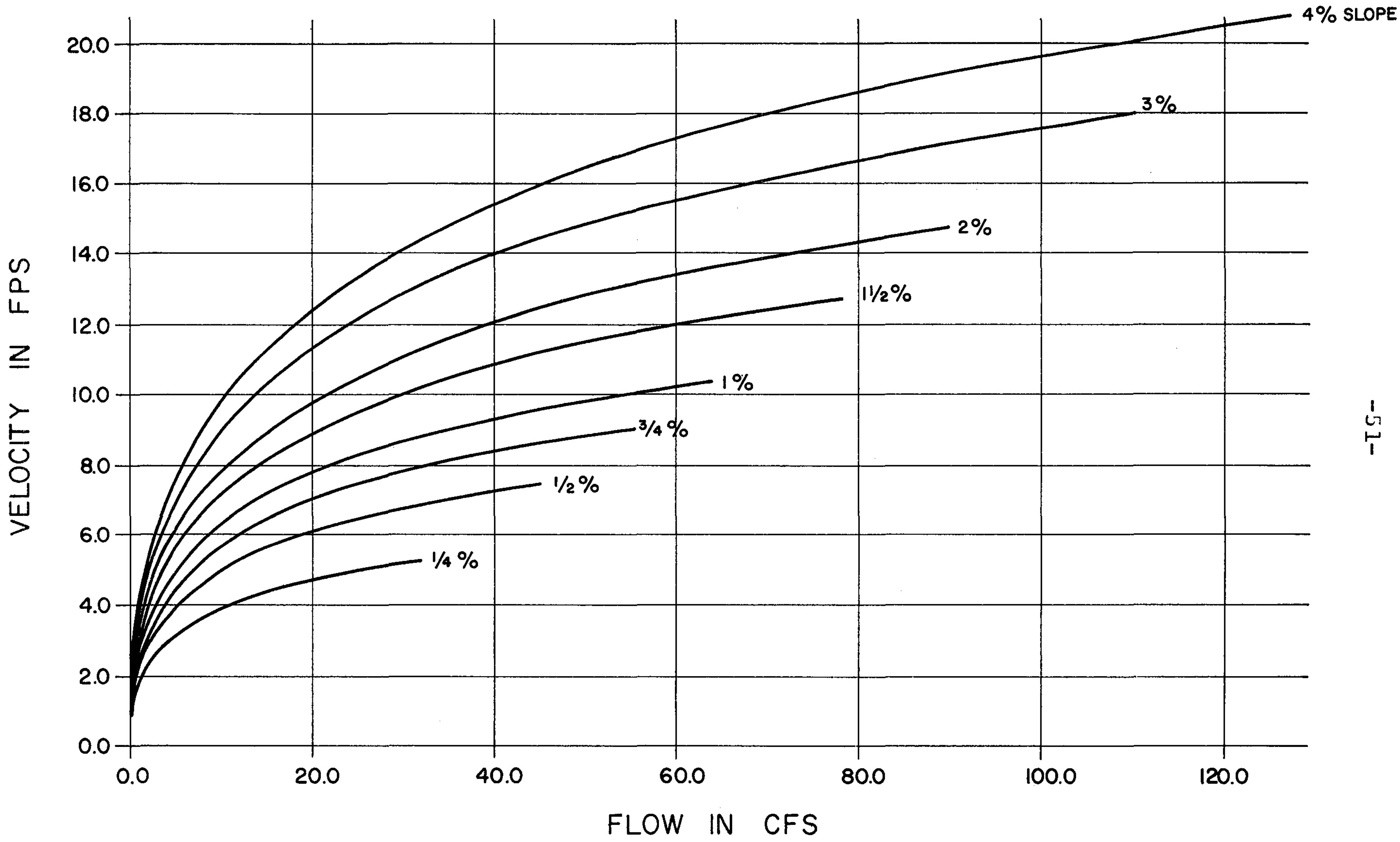
120" CIRCULAR CULVERT

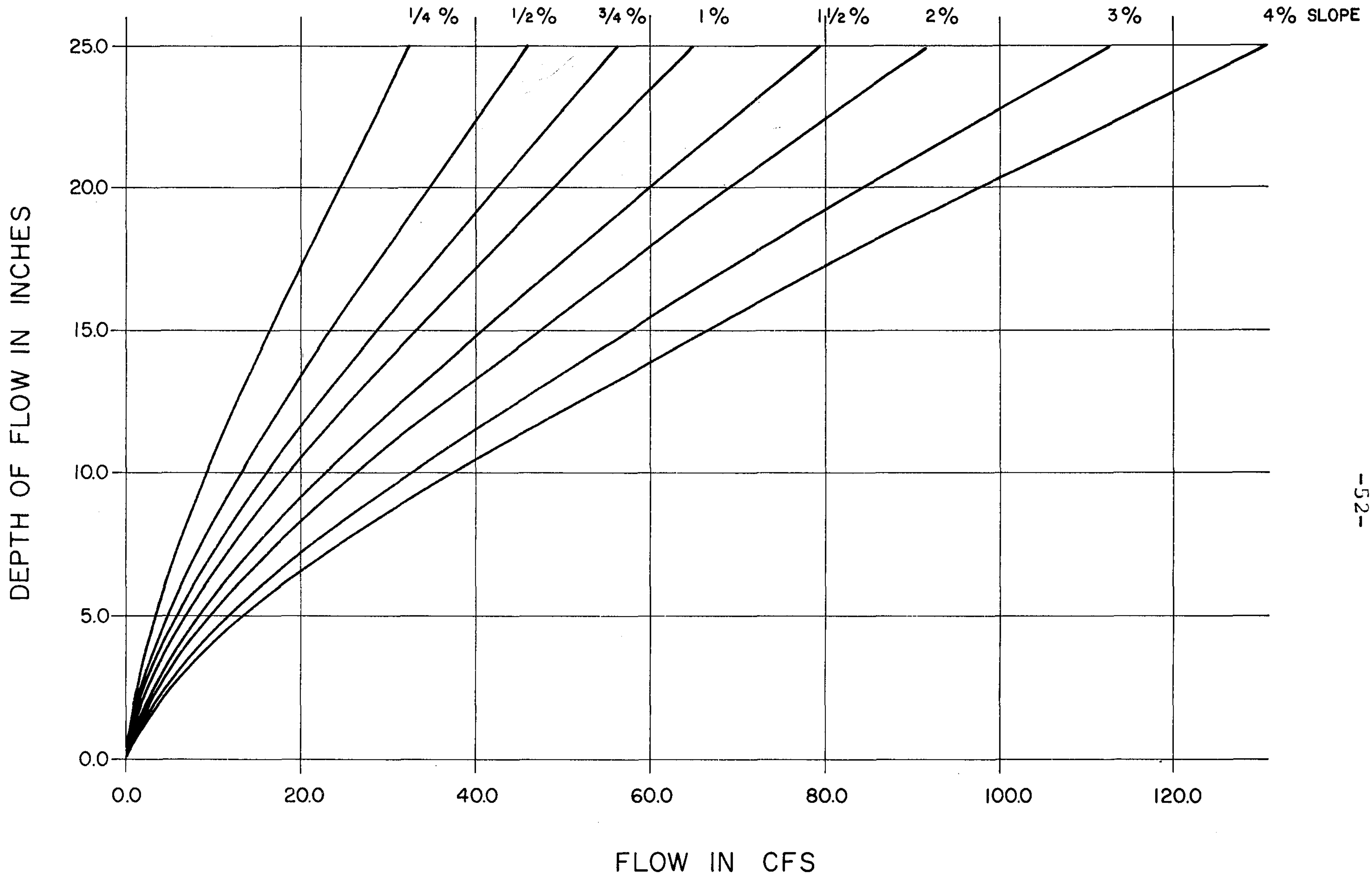




120" CIRCULAR CULVERT

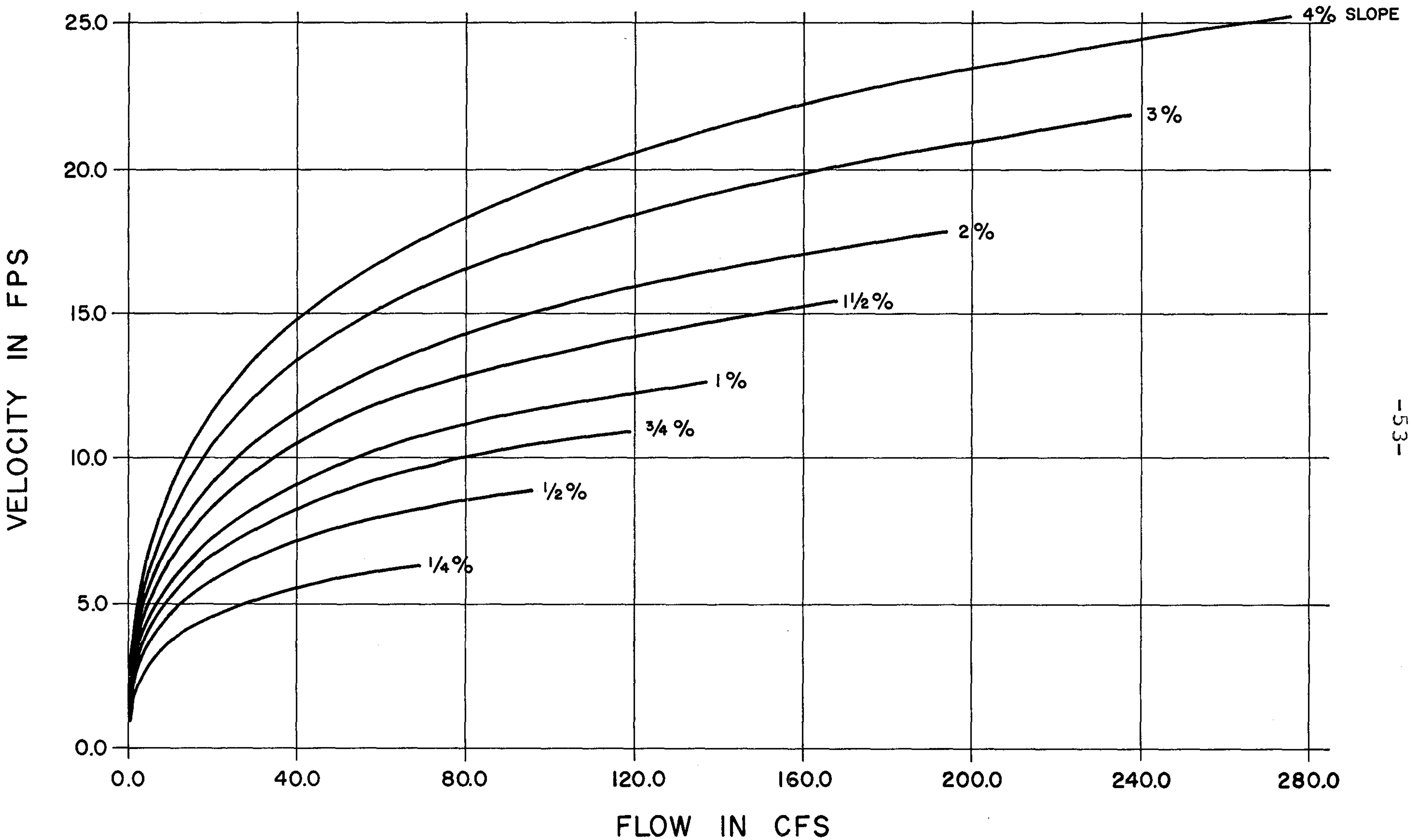
36" BOX CULVERT





36" BOX CULVERT

48" BOX CULVERT



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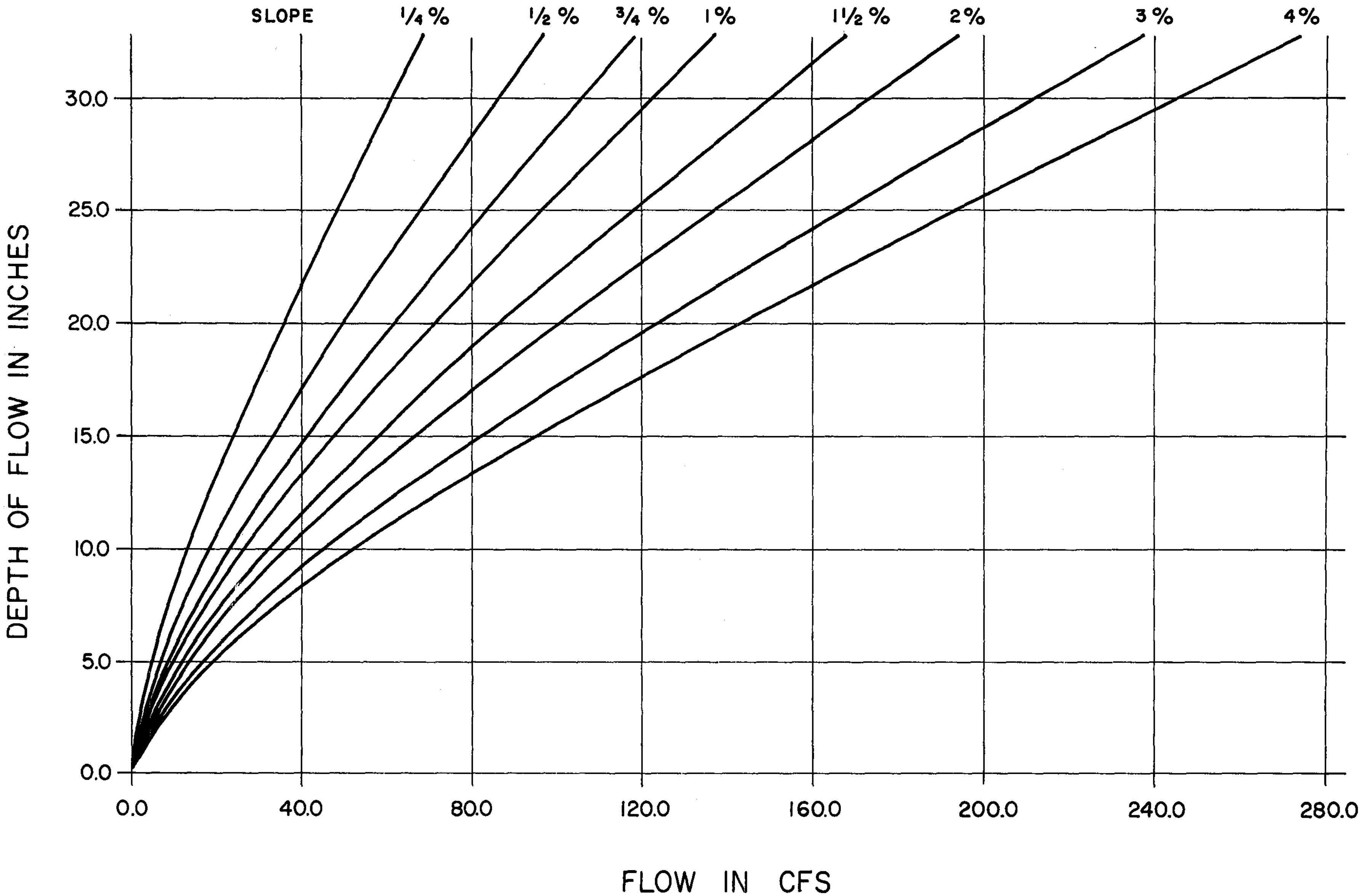
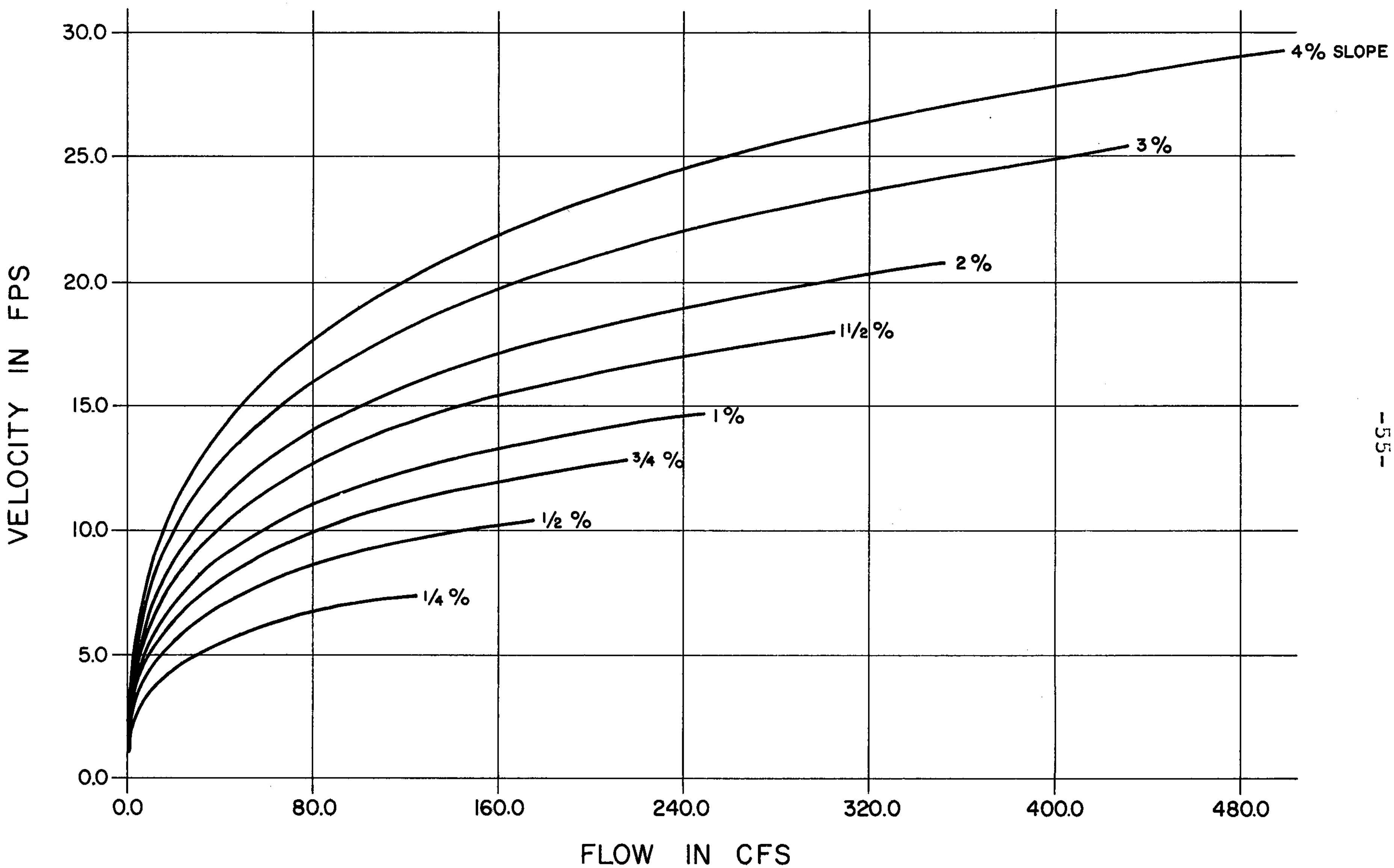
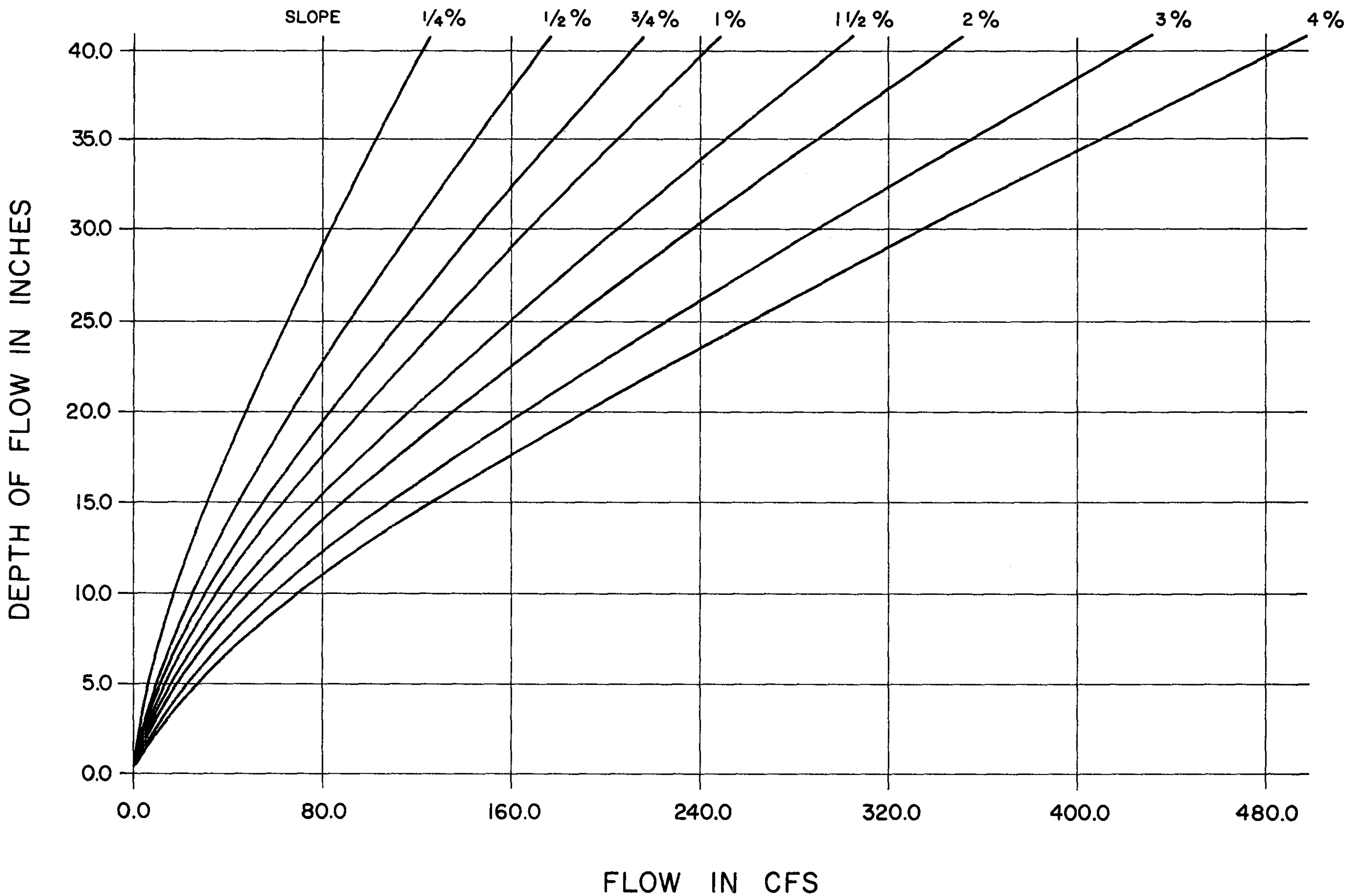


48" BOX CULVERT

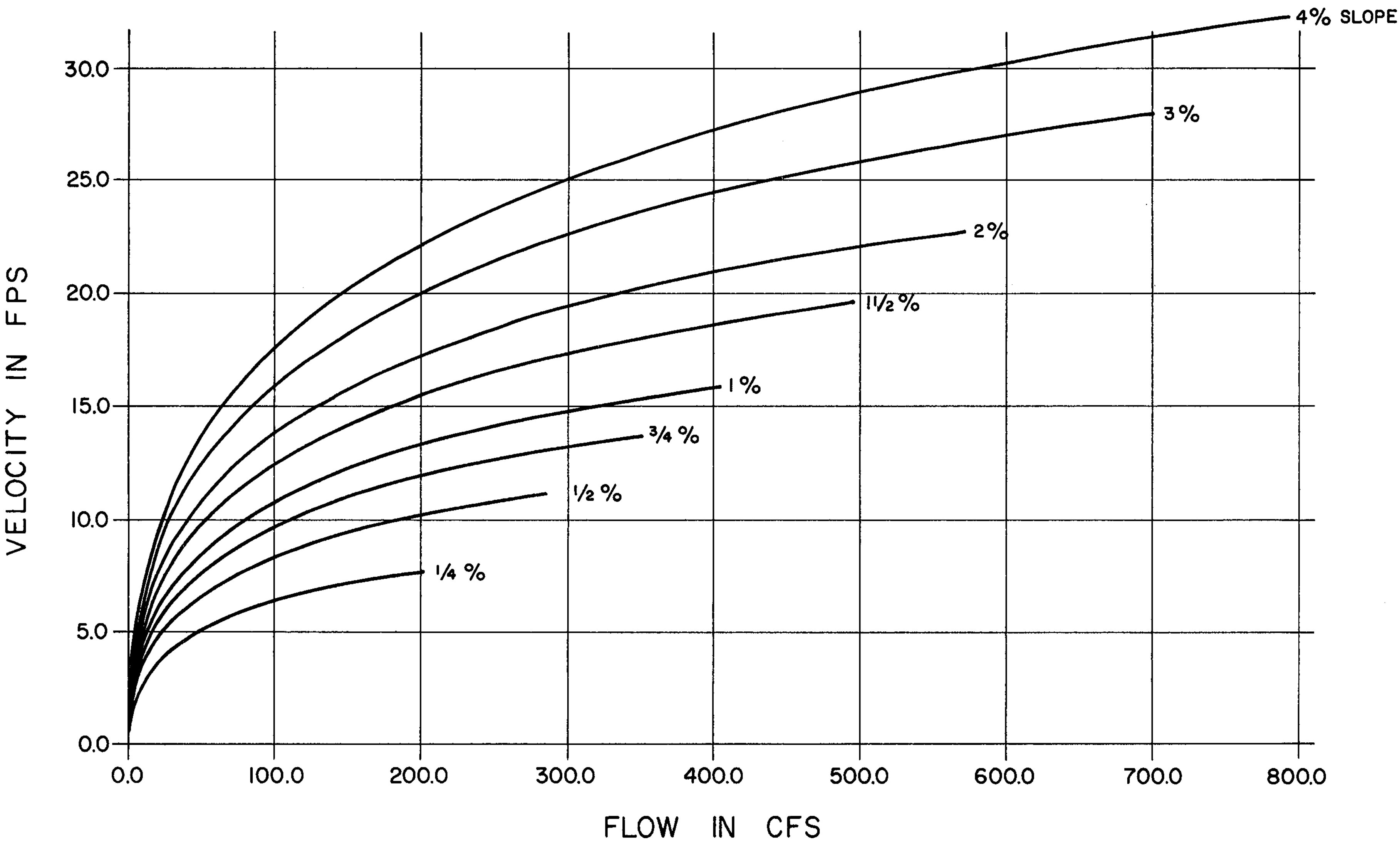
60" BOX CULVERT

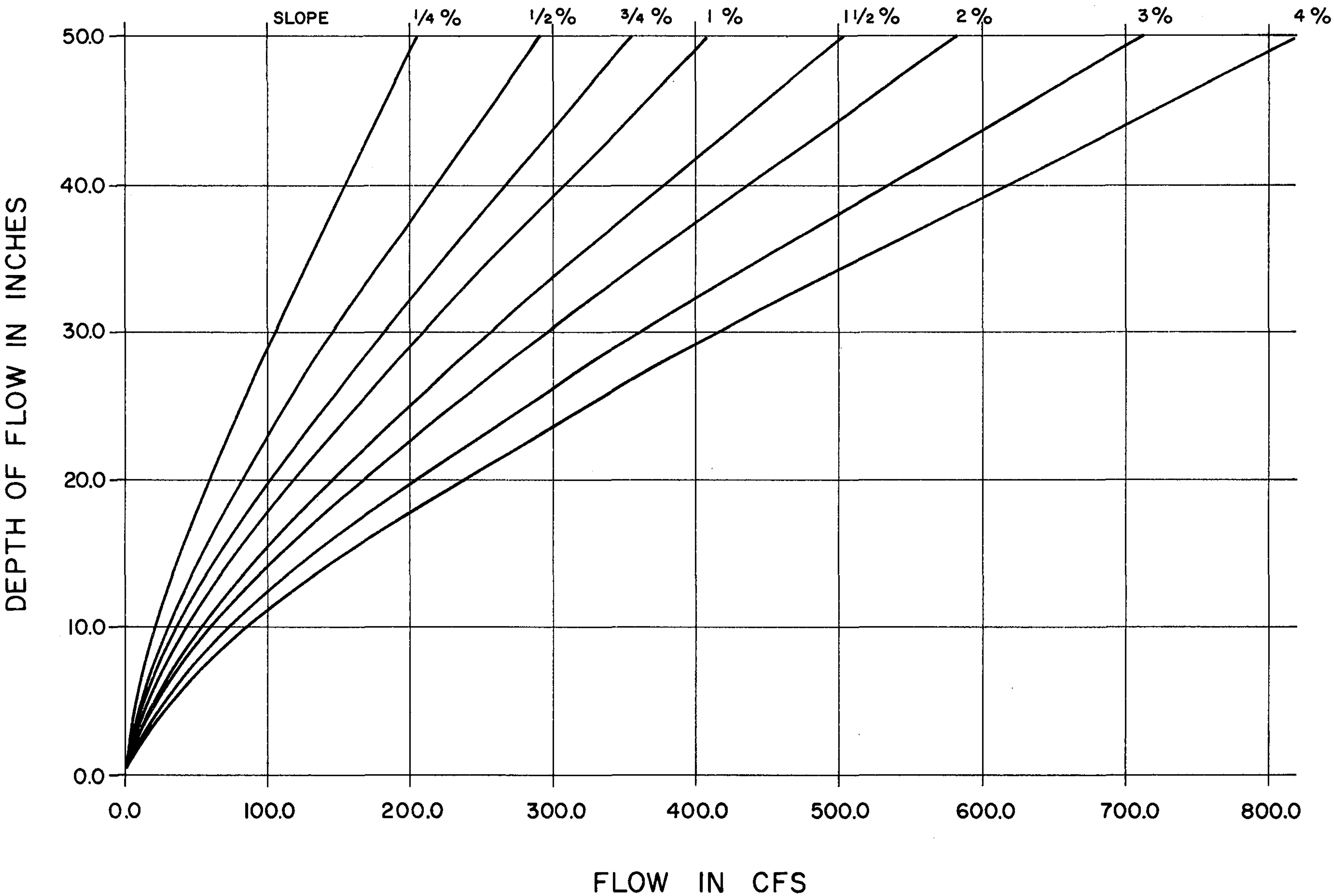




60" BOX CULVERT

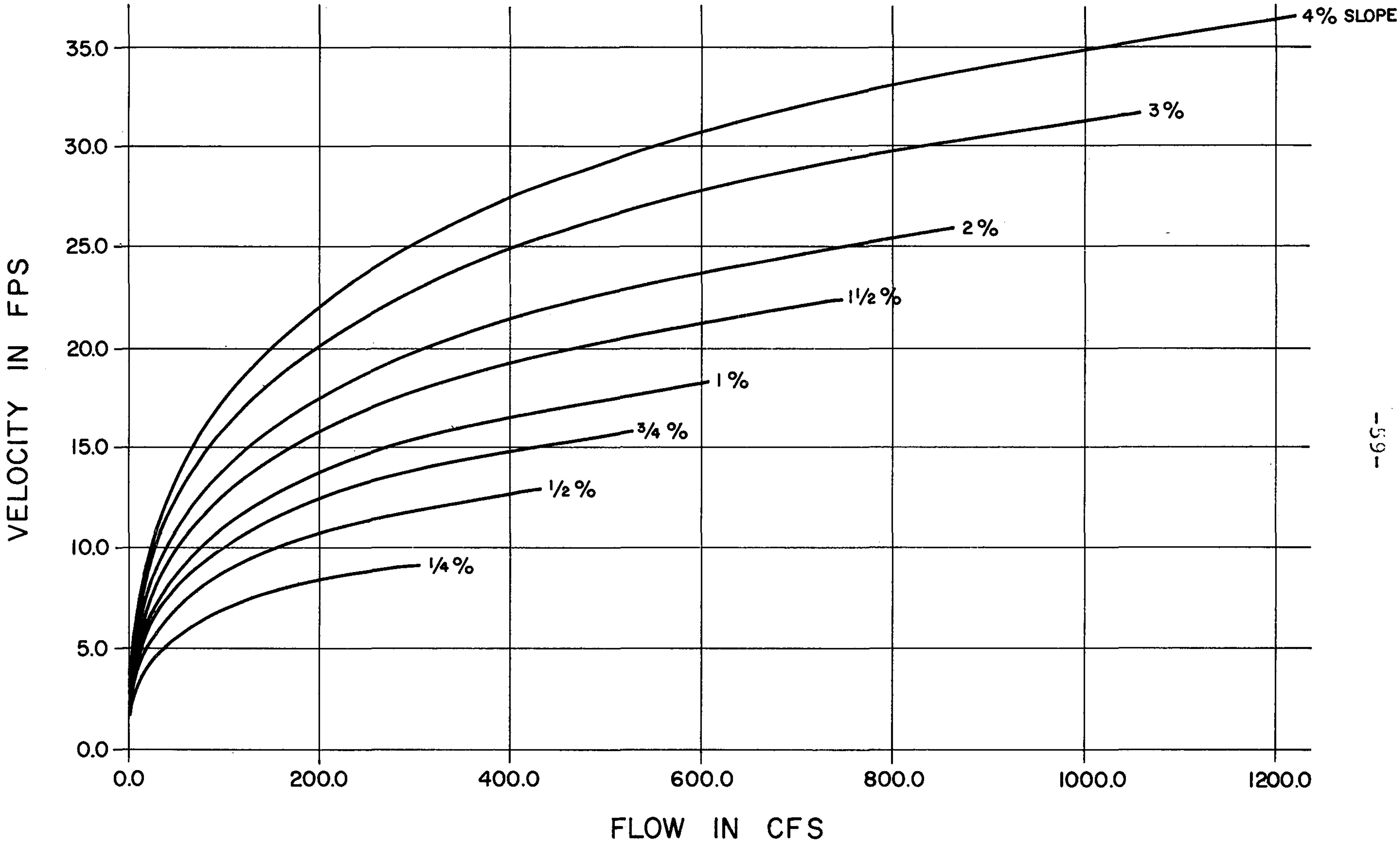
72" BOX CULVERT

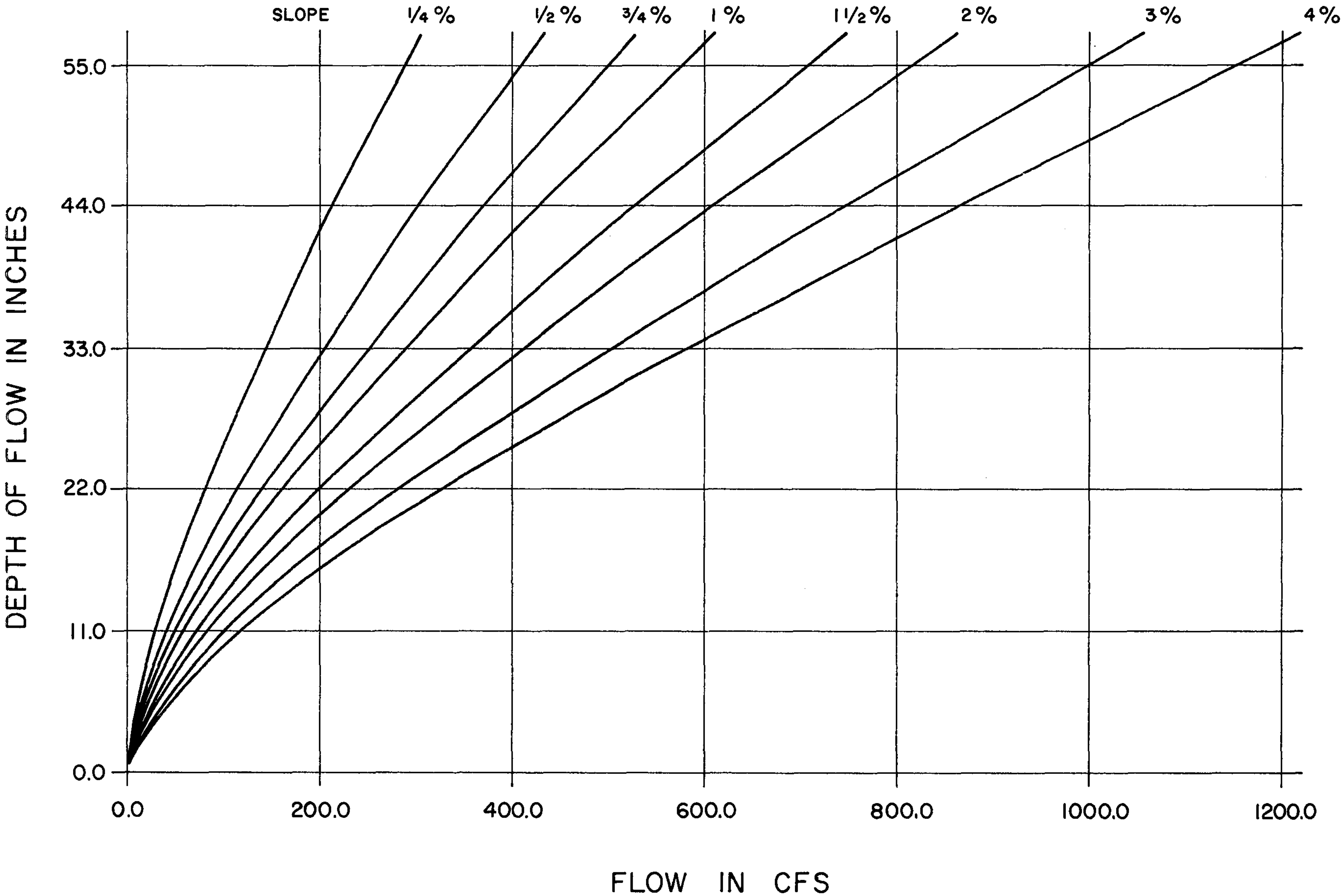




72" BOX CULVERT

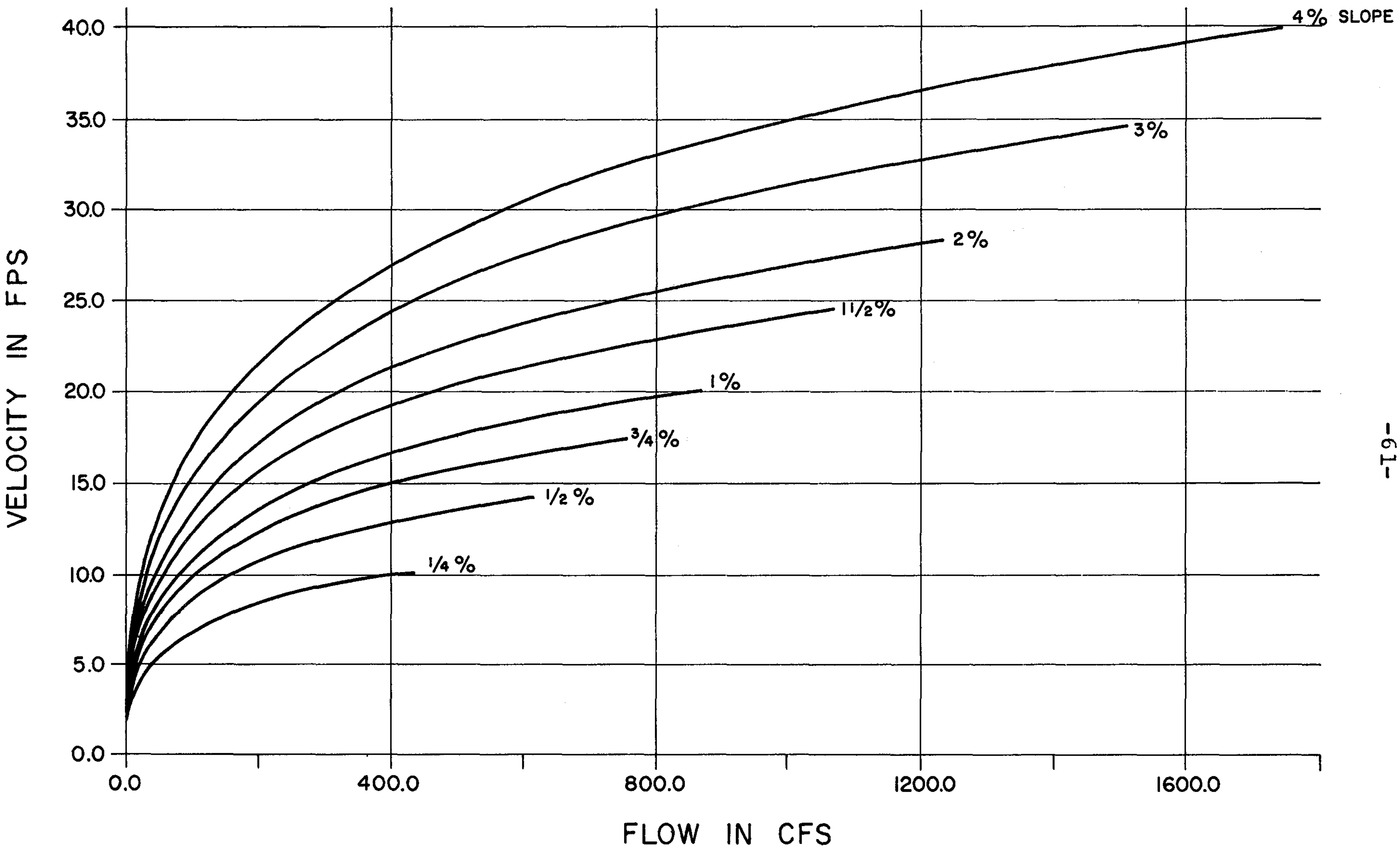
84" BOX CULVERT

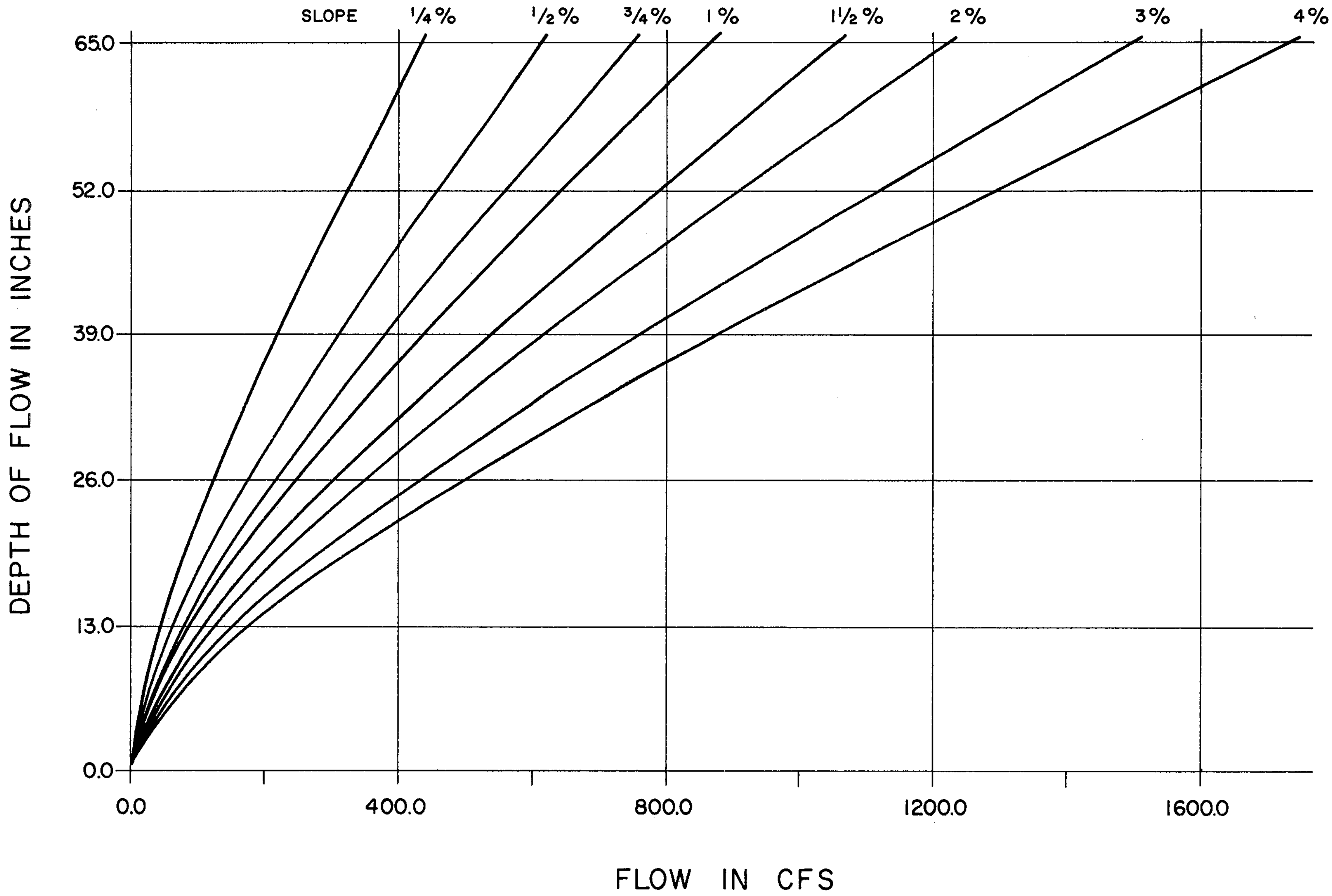




84" BOX CULVERT

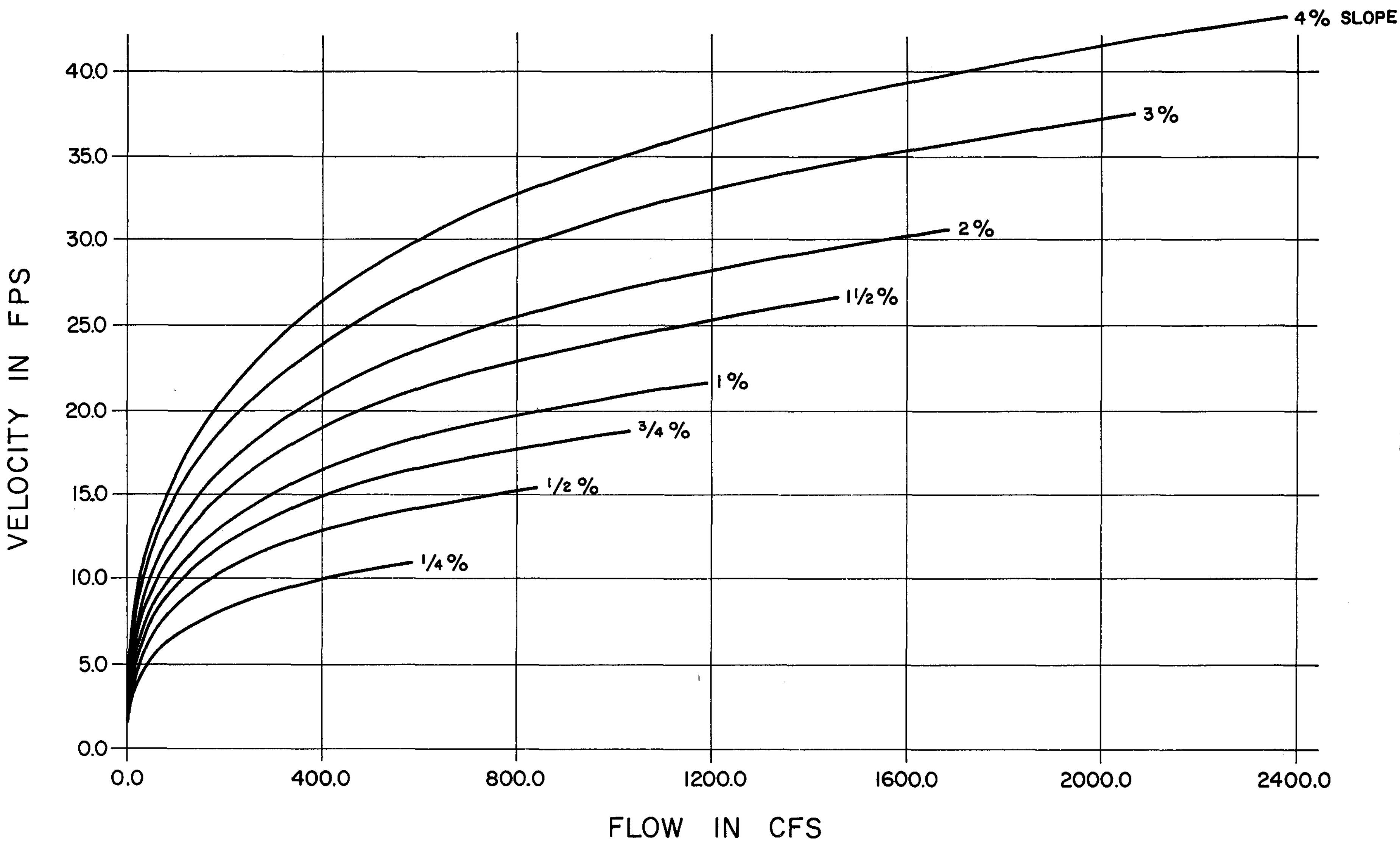
96" BOX CULVERT

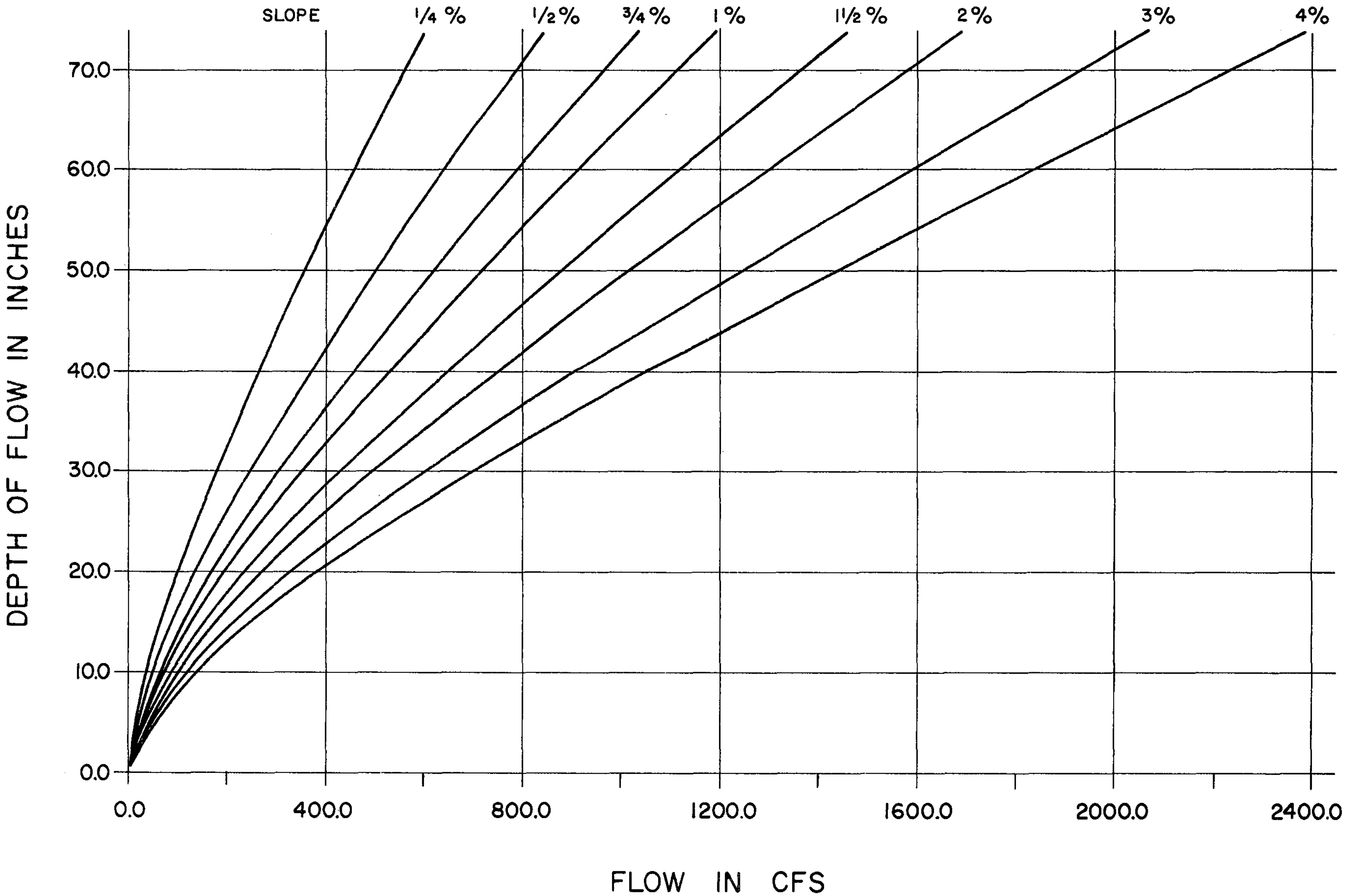




96" BOX CULVERT

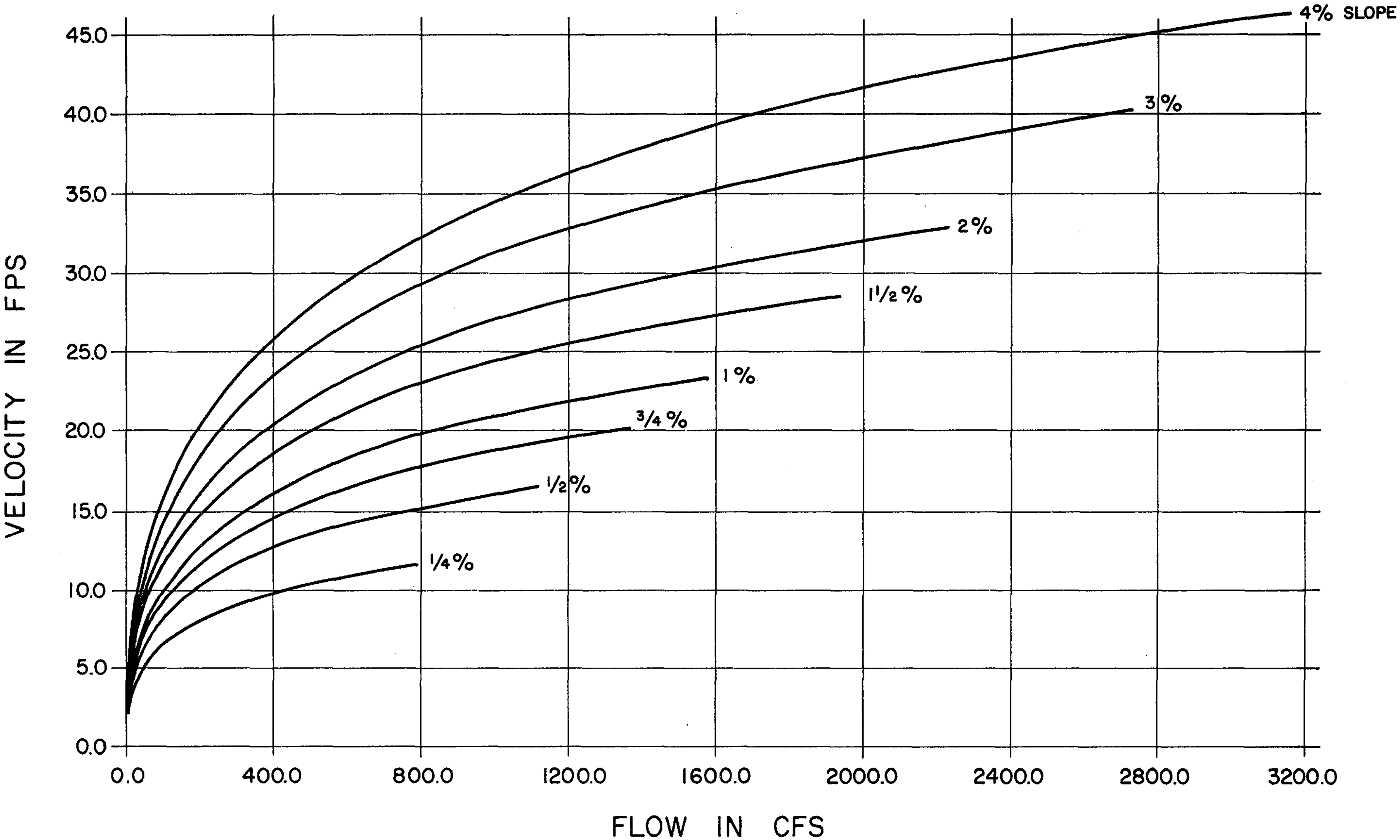
108" BOX CULVERT

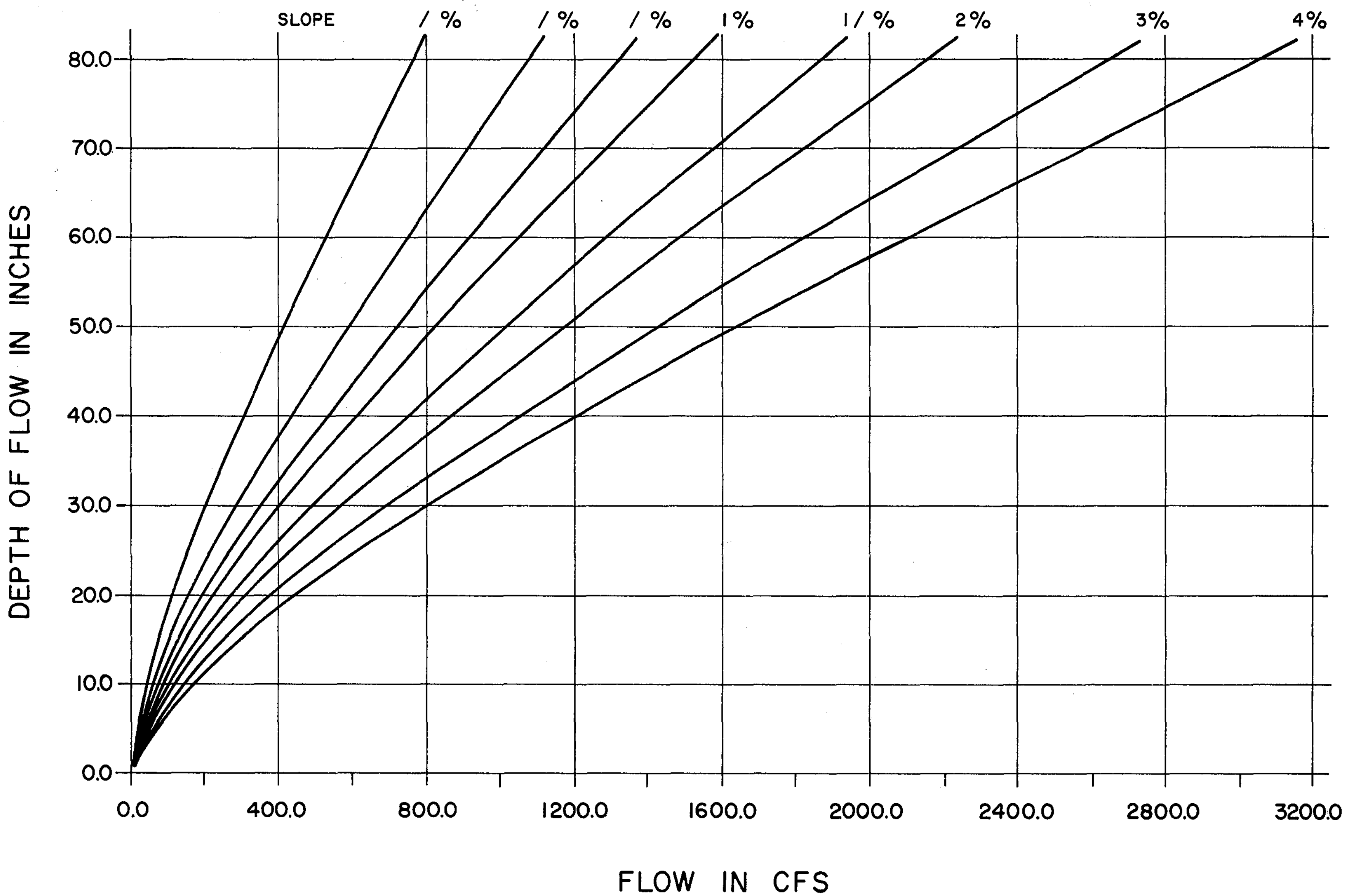




108" BOX CULVERT

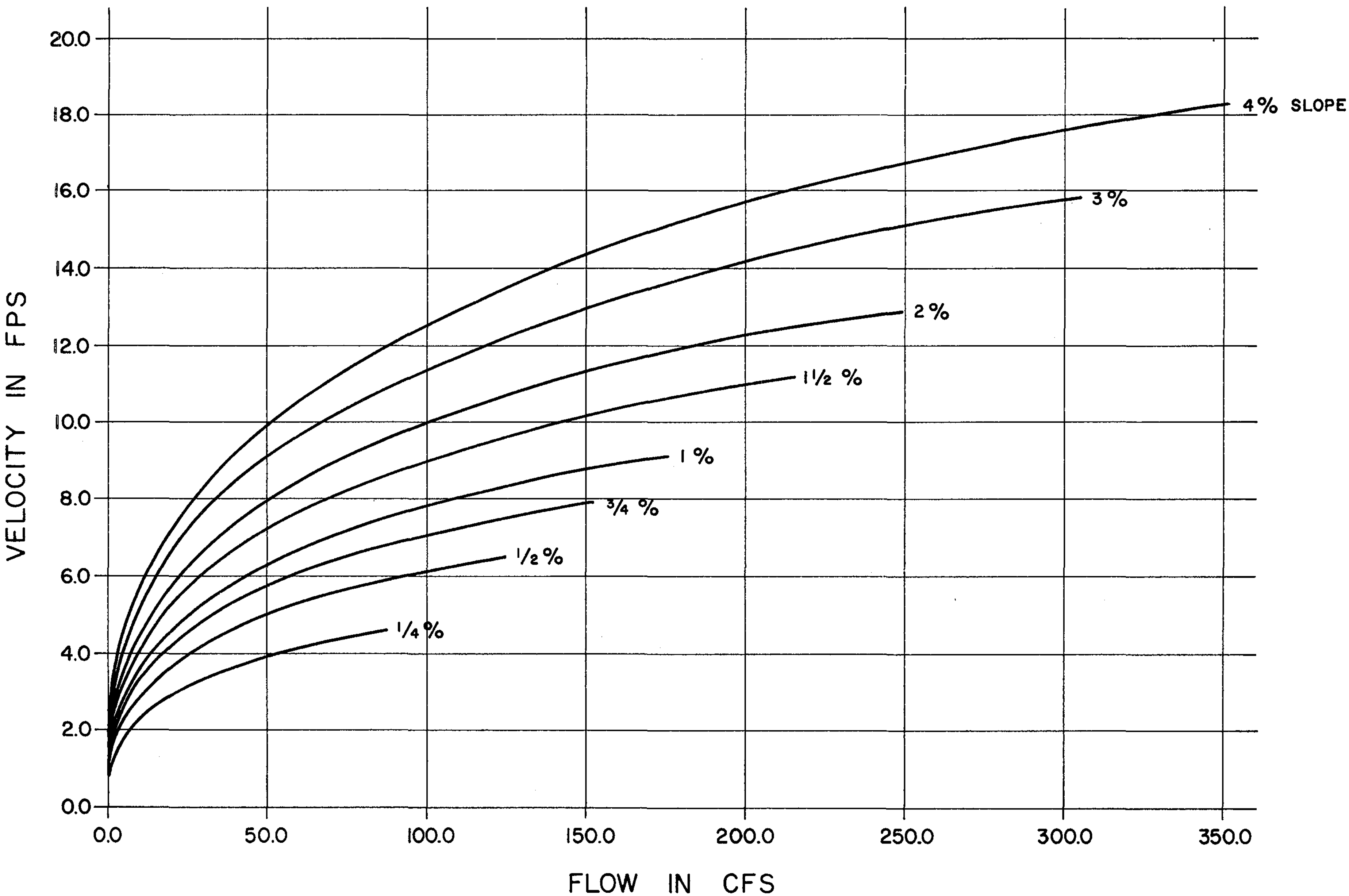
120" BOX CULVERT

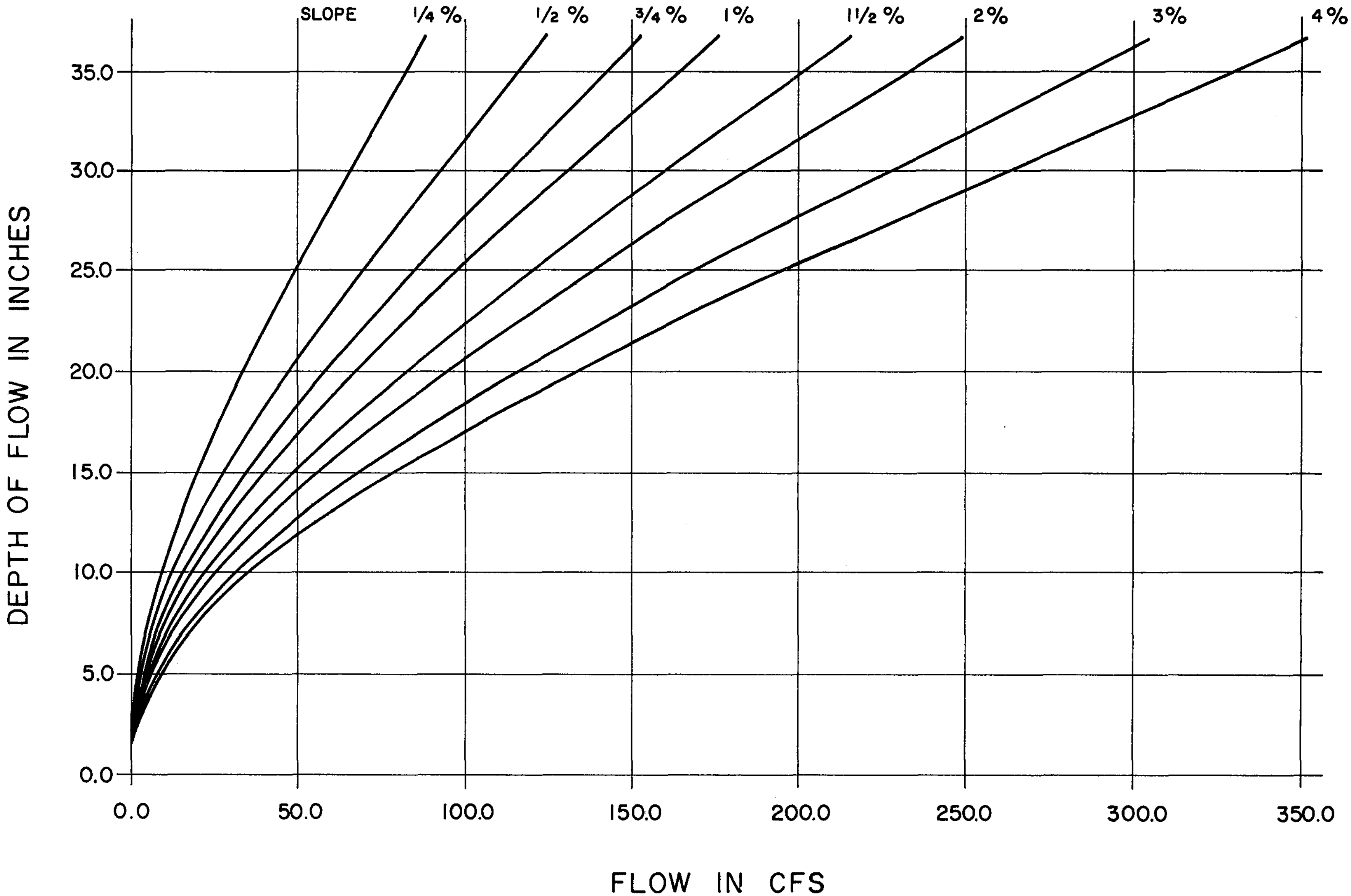




120" BOX CULVERT

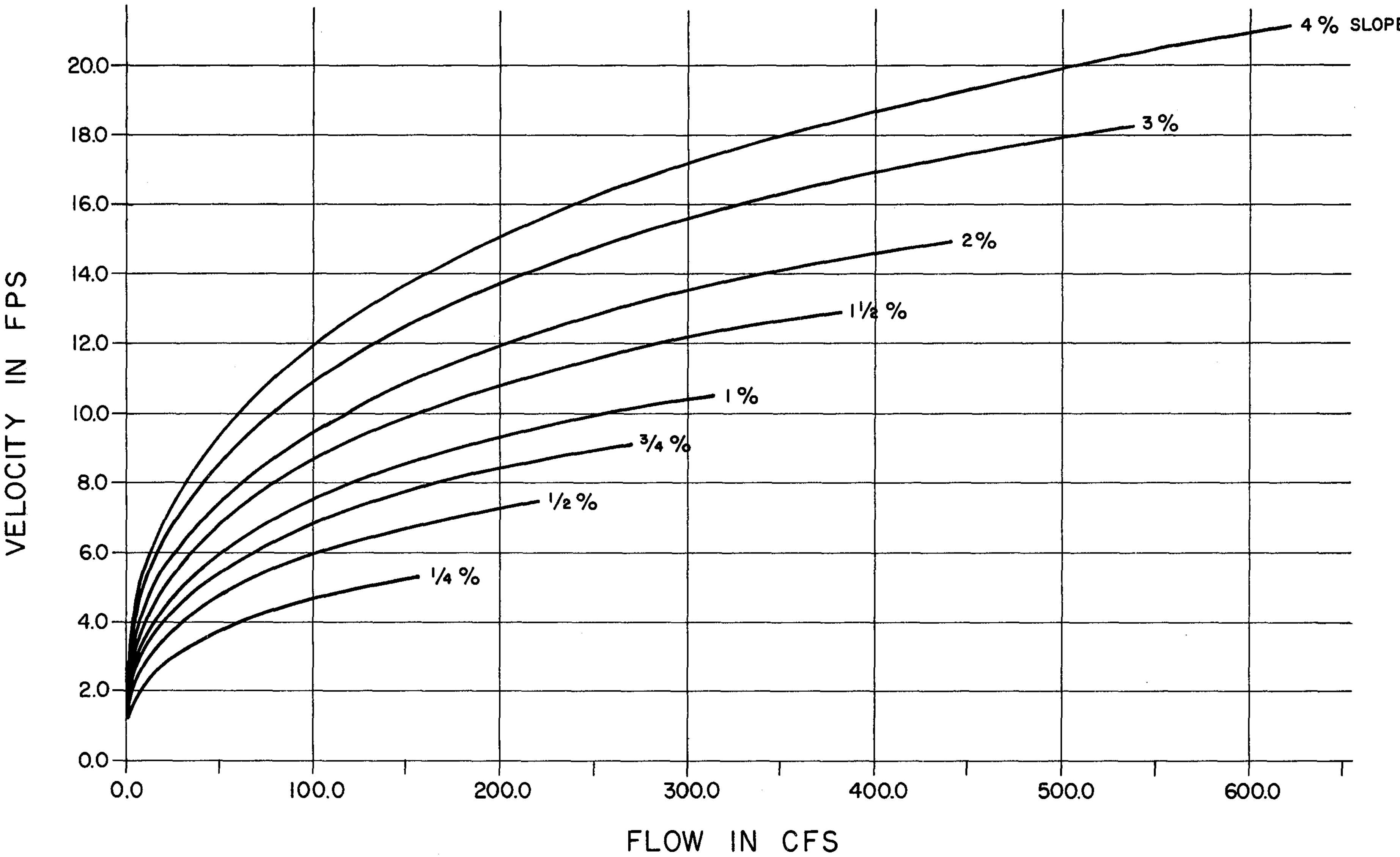
7'0" x 5'1" PIPE ARCH

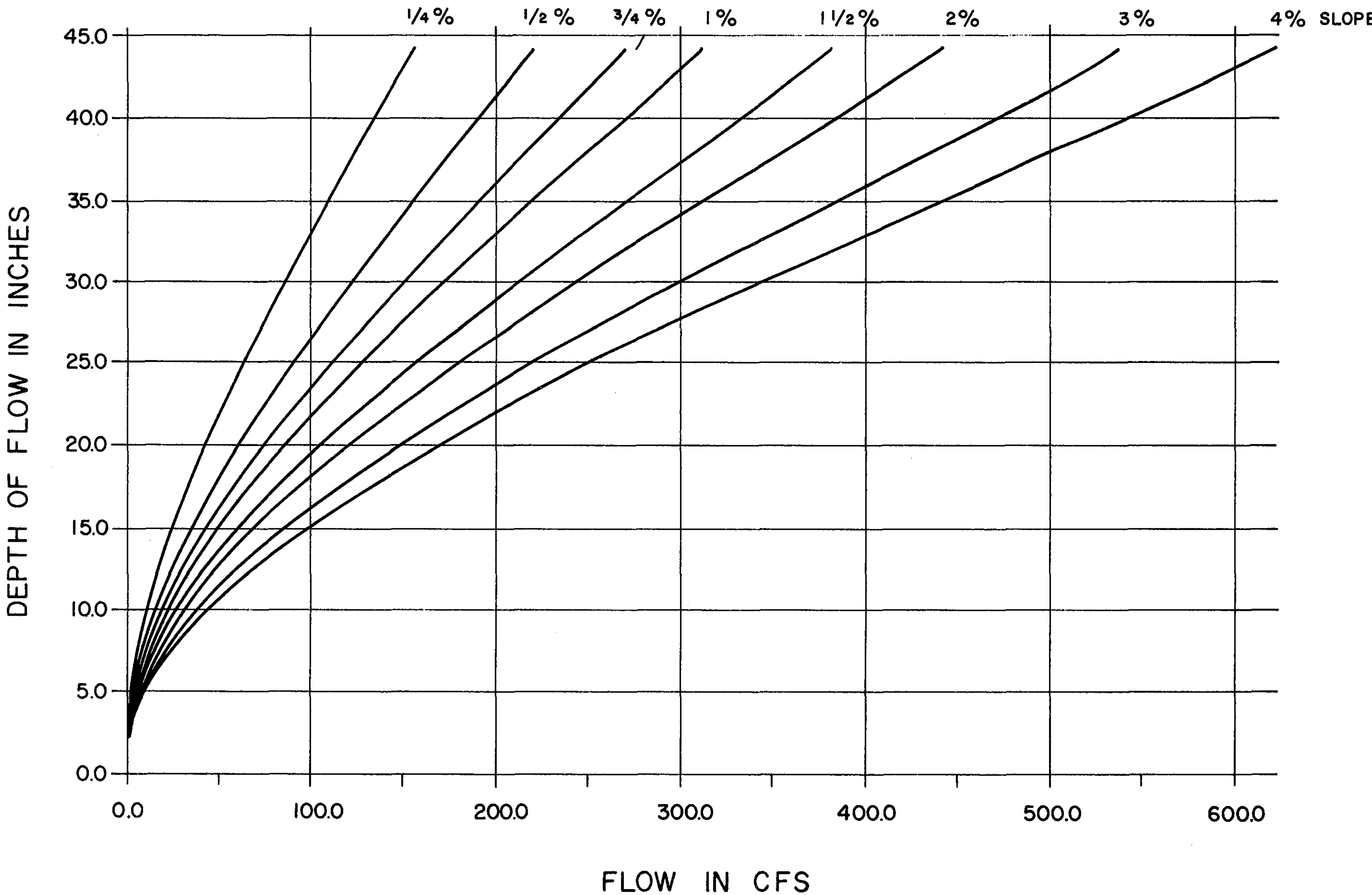




7'0" x 5'1" PIPE ARCH

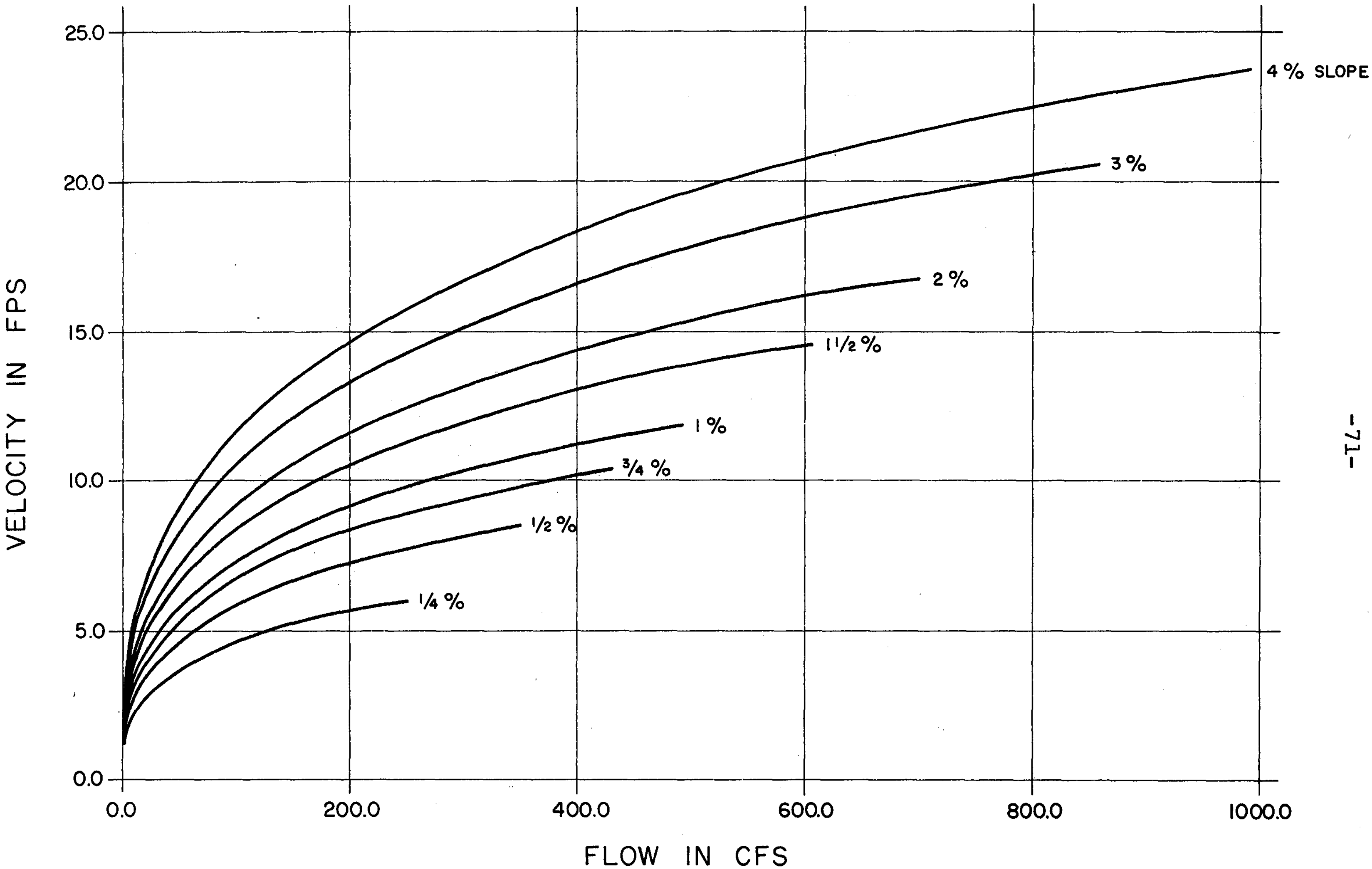
8'10" x 6'1" PIPE ARCH

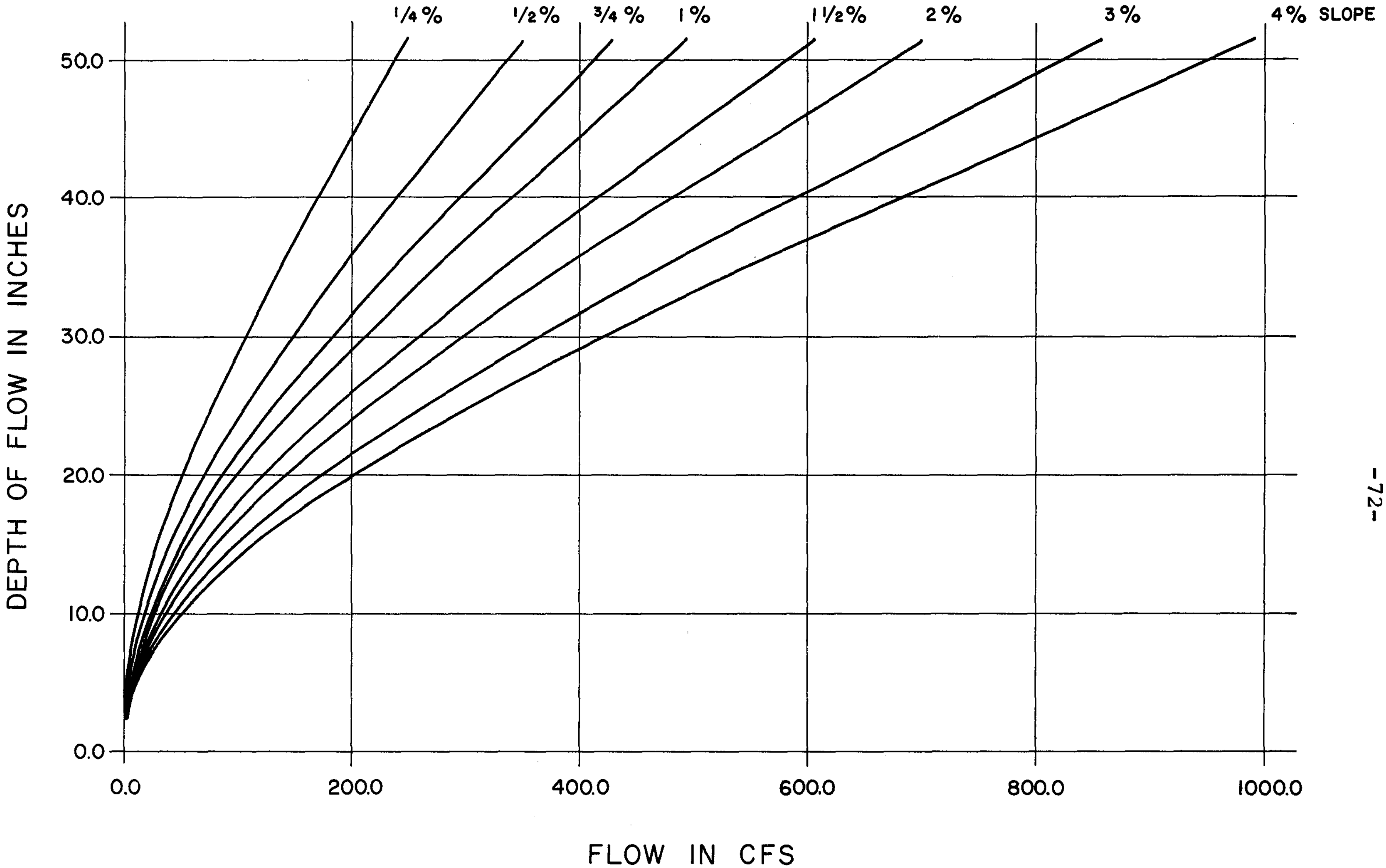




8' 10" x 6' 1" PIPE ARCH

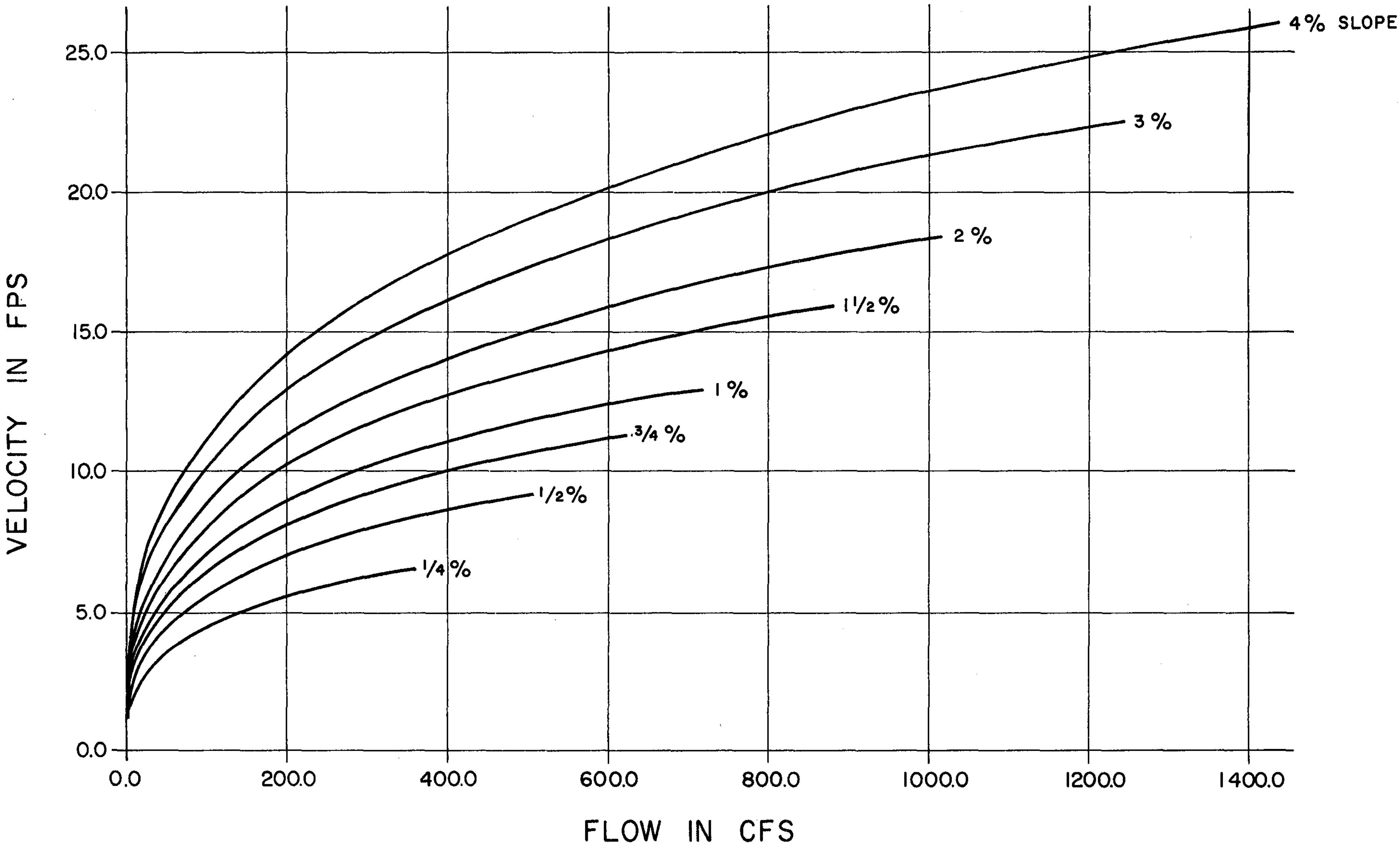
10' 11" x 7' 1" PIPE ARCH

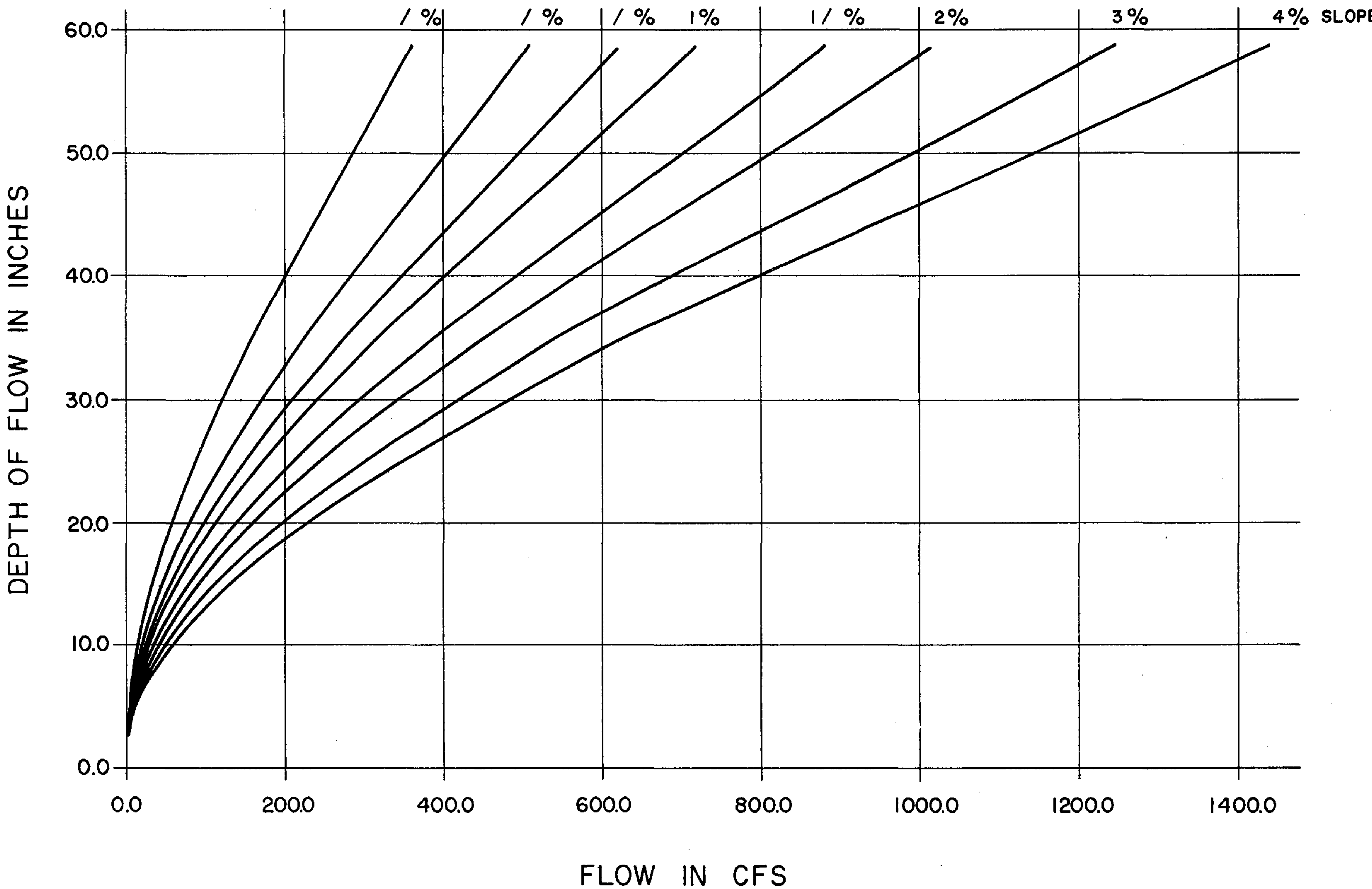




10' 11" x 7' 1" PIPE ARCH

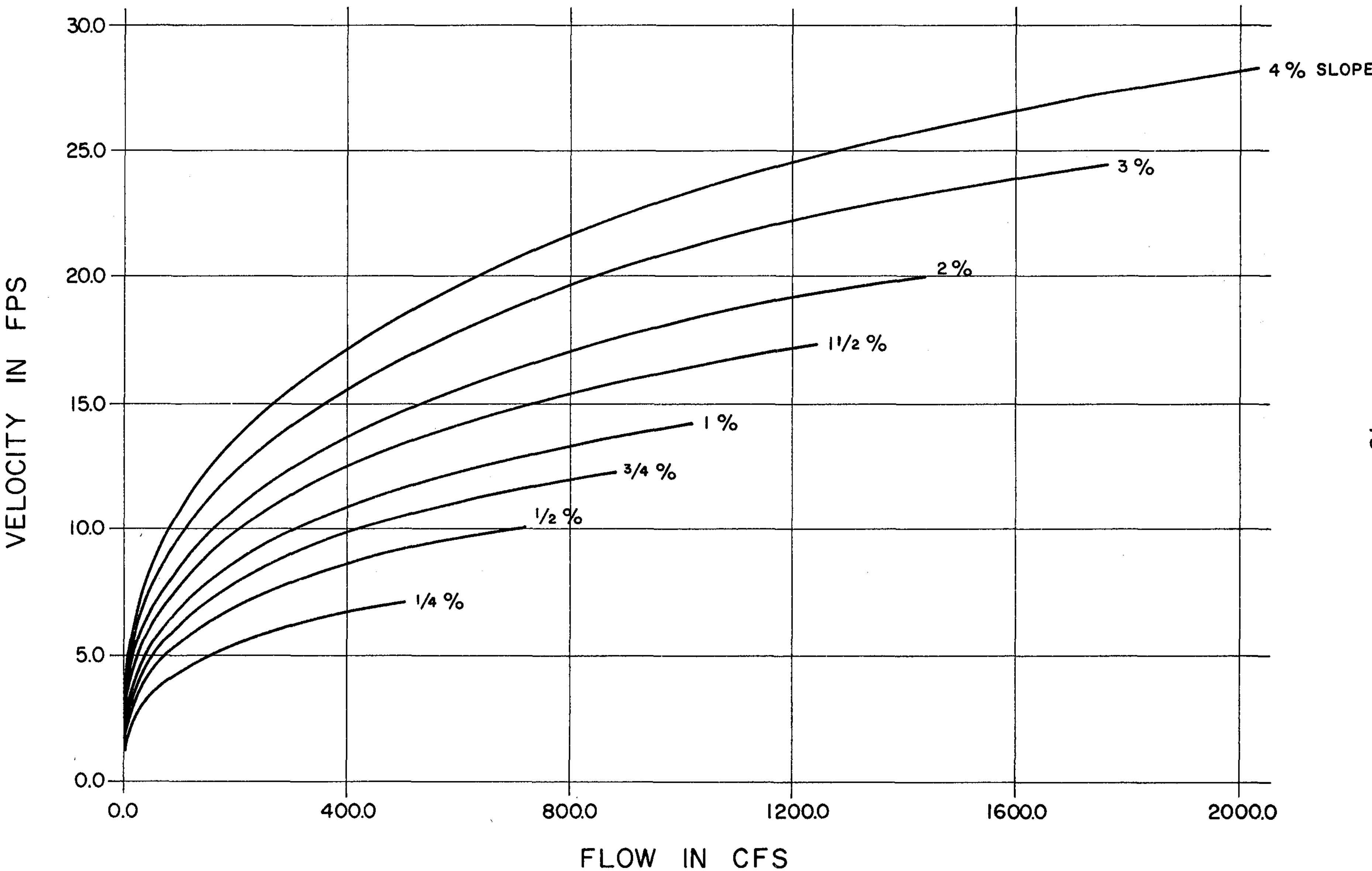
12' 8" x 8' 1" PIPE ARCH

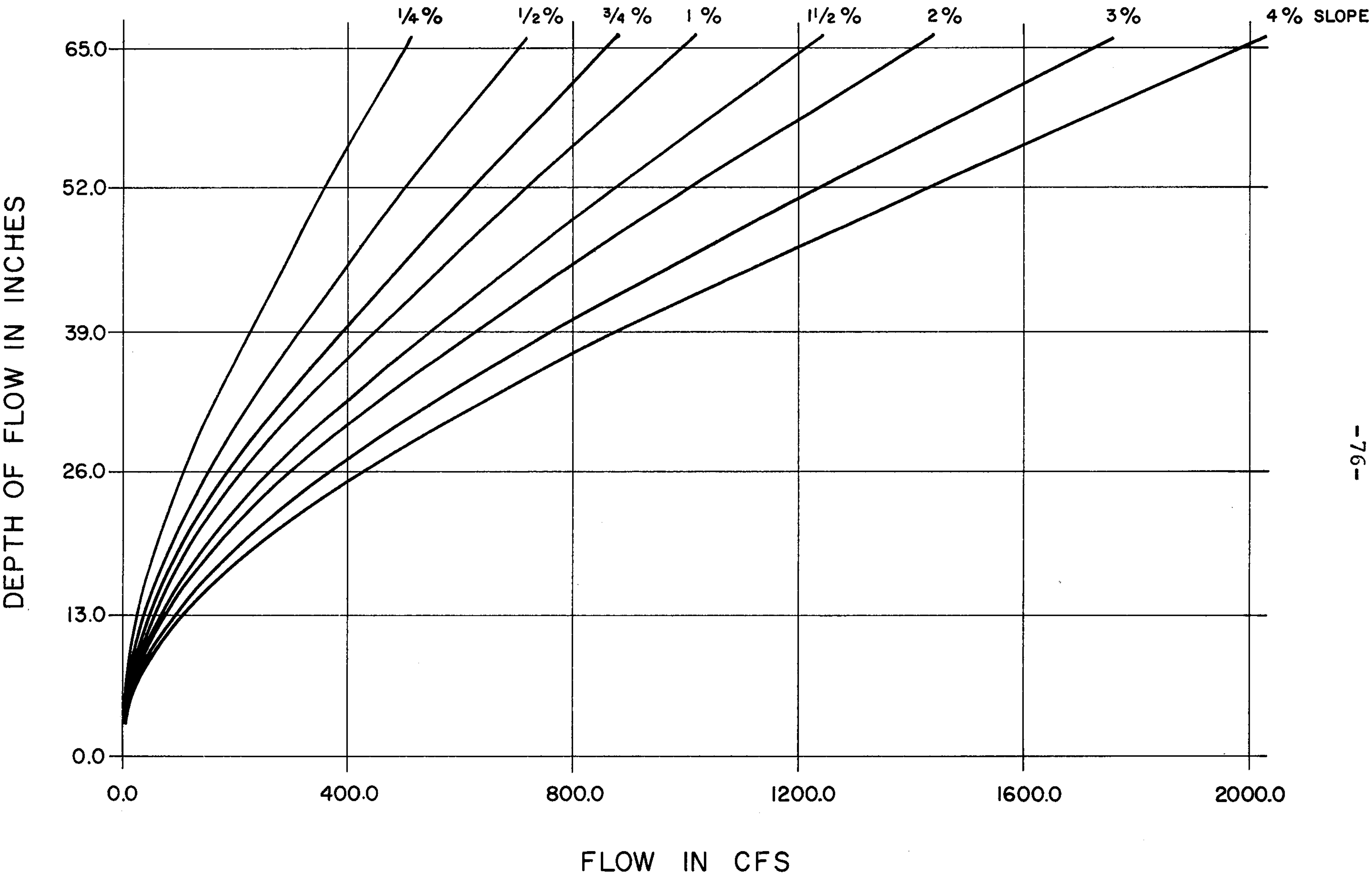




12' 8" x 8' 1" PIPE ARCH

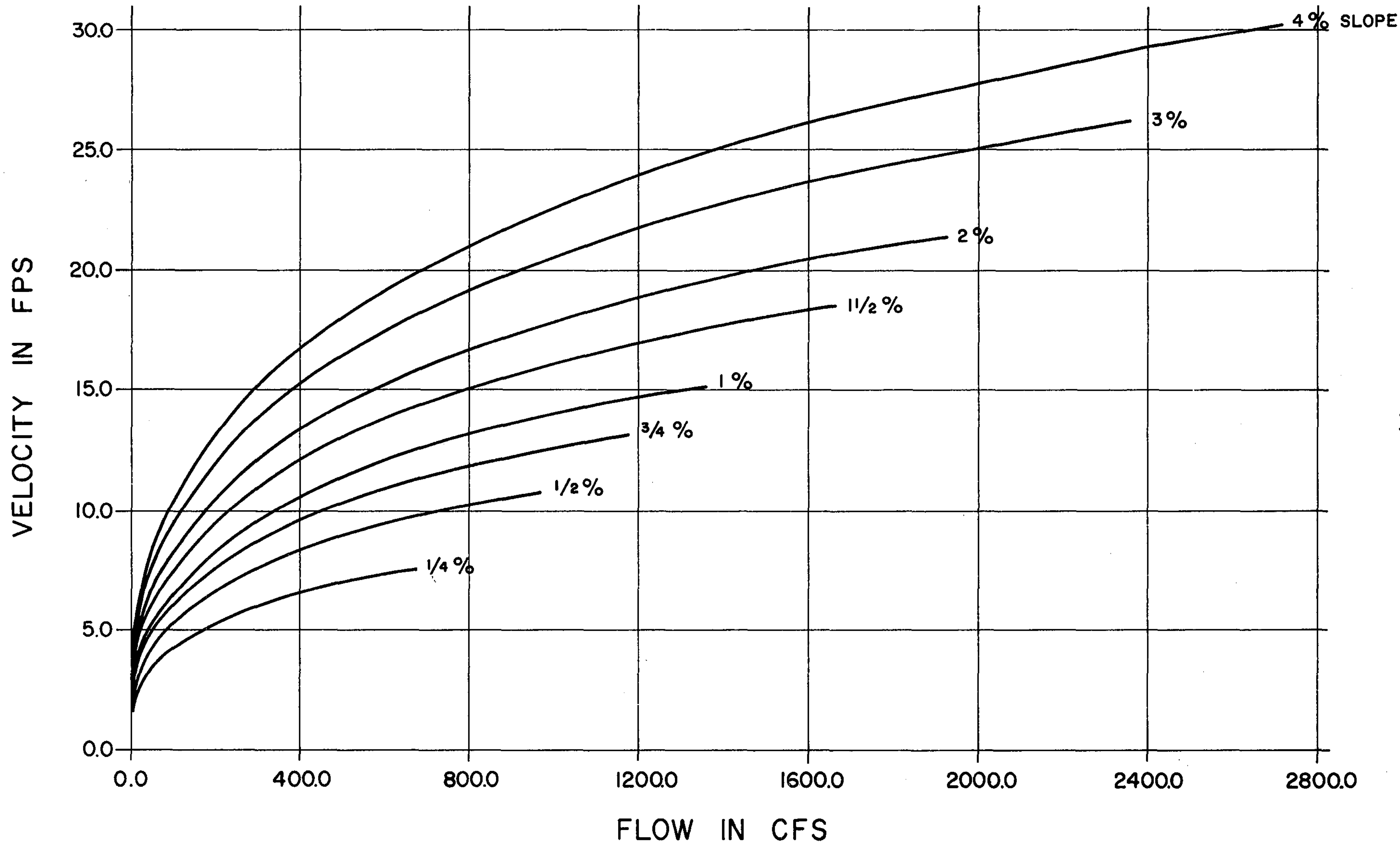
14' 10" x 9' 1" PIPE ARCH

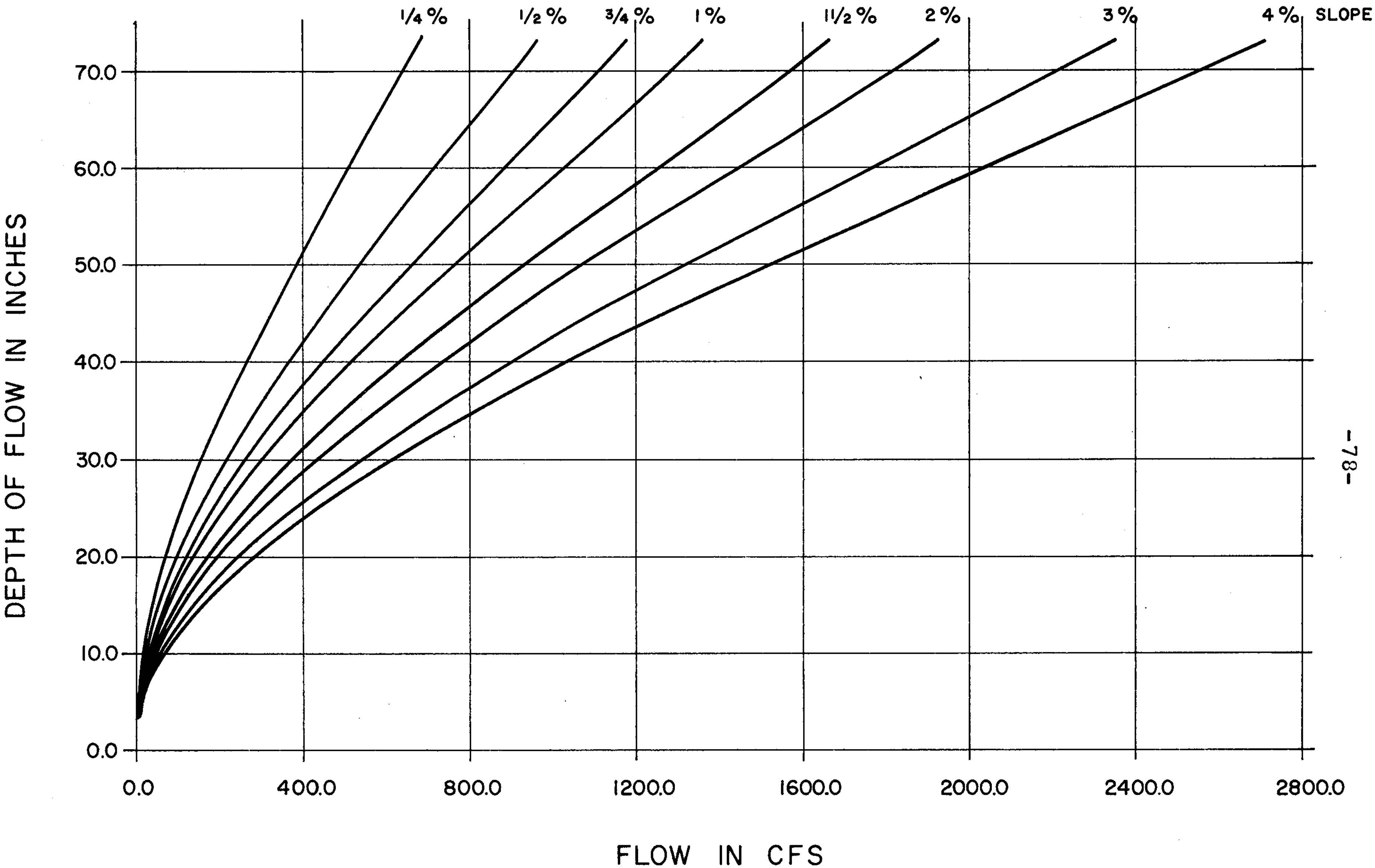




14'10" x 9'1" PIPE ARCH

16' 7" x 10' 1" PIPE ARCH





16' 7" x 10' 1" PIPE ARCH