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ABSTRACT

This document is an instructional module package prepared in objective form for use by an instructor familiar with the application of hydraulic principles for operation and maintenance of water supply systems, water distribution systems, wastewater treatment systems and wastewater collection systems. Included are objectives, instructor guides, student handouts and transparency masters. This is the first level of a two module series. The module is concerned with the study of fluid properties and their units, the continuity equation and its use in calculations, flow measuring devices, frictional head loss in open channels and in pipes by the Chezy-Manning method and by the Hazen-Williams method, and hydraulics of sewers flowing full and partially full. (Author/RH)

HYDRAULICS FOR OPERATORS

Training Module 1.330.2.77

Prepared for the

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September, 1977

Module No:	Module Title:
I2JG	Hydraulics for Operators
	Submodule Title:
Approx. Time 24 Hours	Topic: Basic principles of hydraulics and their application to water and wastewater systems operation.

Instructional Objective:

To gain familiarity with common fluid properties and their units and gain the ability to use them in hydraulics calculations; to gain familiarity with common flow measuring devices for open channel flow and for pressure flow in pipes; to gain familiarity with the continuity equation and frictional head loss relationships as well as the ability to apply them to flow through pipes and open channels in general and to flow through sewers and pressure water distribution systems in particular.

Instructional Aids:

See Next Sheet

Instructional Approach:

Lecture, Discussion, Problem Session

References:

See Next Sheet

Class Assignments:

Completion of practice problems which aren't finished in class.

Instructional Aids:

Handouts No. A.1.1, A.2.1, A.2.2, A.3.1, A.3.2, A.4.1
B.1.1, B.2.1, B.2.2, B.3.1
C.1.1, C.2.1, C.4.1, C.5.1 - C.5.5, C.6.1
D.1.1, D.1.2, D.2.1, D.2.2, D.3.1 - D.3.4, D.4.1 - D.4.3,
D.5.1 - D.5.3, D.6.1, D.6.2, D.7.1, D.7.2
E.1.1, E.2.1 - E.2.3, E.3.1 - E.3.3

Transparencies No. A.1.1, A.2.1, A.4.1, B.2.1, C.1.1, C.3.1

References:

1) Chow, V.T., Open-Channel Hydraulics, McGraw-Hill Book Co., New York, N.Y., 1959.

2) Clark, J.W., Viessman, W., Jr., & Hammer, M.J., Water Supply and Pollution Control, 3rd Edition, IEP, New York, N.Y., 1977.

3) Fair, G.M., Geyer, J.C., & Okun, D.A., Water and Wastewater Engineering, Vol, I. Water Supply and Wastewater Removal, Wiley, New York, N.Y., 1966.

4) John, J.E.A. and Haberman, W., Introduction to Fluid Mechanics, Prentice Hall, Englewood Cliffs, N.J., 1971.

5) Murdock, J.W., Fluid Mechanics and Its Applications, Houghton, Mifflin, Boston, MA., 1976.

6) National Clay Pipe Institute, Clay Pipe Engineering Manual, National Clay Pipe Institute, Atlanta, GA., 1968.

7) Simon, A.L., Practical Hydraulics, Wiley, New York, N.Y., 1976.

8) Spink, L.K., Principles and Practice of Flow Meter Engineering, 8th Edition, Foxboro Co., Foxboro, MA., 1958.

9) Texas Water Utilities Association, Manual of Wastewater Operations, 4th Edition, Lancaster Press, Lancaster, PA., 1971.

Module No:	Module Title:
I2UG	Hydraulics for Operators
	Submodule Title: Fluid Properties
Approx. Time: 45 minutes	Topic: Definitions and Units

Instructional Objective:

To be able to define pressure, density, specific weight, specific gravity and viscosity, and give common units used for each; and to be able to state Pascal's Principle.

Instructional Aids:

Transparency No. A.1.1
Handout No. A.1.1

Instructional Approach:

Lecture-discussion

References:

1) Murdock, J.W., pages 5-7, 20-26, 34-46
2) First or second chapter of almost any fluid mechanics textbook

Class Assignments:

None

Module No: I2JG	Topic: Definitions and Units

Instructor Notes:	Instructor Outline:
Handout No. A.1.1 Fluid Properties	I. Pass out Handout No. A.1.1 and mention that it will now be discussed
Transparency No. A.1.1 Fluid Properties	II. Briefly discuss each fluid property, its meaning and its units, using the transparency to focus attention during the discussion.

Additional Notes:

1) It may be pointed out that density and specific weight can be used interchangeably with the English units, lb/ft^3, even though there is a difference in meaning for mass and weight. The difference between mass and weight may or may not be discussed qualitively at this point as suits the individual instructor.

2) It may be pointed out that other reference fluids besides water are sometimes used for specific gravity.

3) As a common example to clarify the meaning of viscosity, briefly discuss Sae numbers for motor oil. Higher Sae numbers indicate higher viscosity and also indicate oils which do not pour or flow as readily.

4) Meanings, interpretations and significance can be expanded upon in the discussion to suit the particular instructor and class.

Module No: I2JG	Module Title: Hydraulics for Operators
Approx. Time: 1 hour	Submodule Title: Fluid Properties
	Topic: Pressure Unit Conversions

Instructional Objective:

To be able to convert a pressure given in any of the following units to any of the other following units if given an appropriate set of conversion factors: psi, in. of mercury, psf, atmospheres, Pascals.

Instructional Aids:

Handouts No. A.2.1, A.2.2
Transparency No. A.2.1

Instructional Approach:

Discussion and Problem Session

References:

Class Assignments:

Any practice problems on Handout No. A.2.2, which were not completed in class

Module No: I2JG	Topic: Pressure Unit Conversions

Instructor Notes:	Instructor Outline:
Handout No. A.2.1 Conversion factors	I. Pass out Handout No. A.2.1
Transparency No. A.2.1 Example Problem	II. Go through sample calculations on transparency No. A.2.1, pointing out how the conversion factors on Handout No. A.2.1 are used. Draw attention to the fact that units in the right hand column can be converted to units in the left hand column by dividing by the conversion factor instead of multiplying.
Handout No. A.2.2 Practice Problems - 1	III. Allow students to work on practice problems on Handout No. A.2.2.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Fluid Properties
Approx. Time 1 hour	Topic: Gauge and Absolute Pressure

Instructional Objective:

To be able to convert gauge pressure to absolute pressure and absolute pressure to gauge pressure, at the earths surface, for any of the following units, if given pressure conversion factors: psi, in. of mercury, psf, atmospheres, Pascals.

Instructional Aids:

Handouts No. A.3.1., A.3.2

Instructional Approach:

Discussion and Problem Session

References:

Murdock, J.W., pages 6-7

Class Assignments:

Any practice problems on Handout No. A.3.2 which are not completed in class.

Module No: I2JG	Topic: Gauge and Absolute Pressure
Instructor Notes:	**Instructor Outline:**
Handout No. A.3.1 Gauge and Absolute Pressure	I. Discuss gauge pressure and absolute pressure guided by the handout. Make sure that the class understands the relationship among gauge pressure, absolute pressure and atmospheric pressure.
Handout No. A.3.2 Practice Problems-2	II. Allow students to work on practice problems on Handout No. A.3.2

Module No: L2JG	Module Title: Hydraulics for Operators
	Submodule Title: Fluid Properties
Approx. Time 45 minutes	Topic: Specific Gravity

Instructional Objective:

To be able to calculate the density of a fluid and its specific weight if given its specific gravity.

Instructional Aids:

Transparency No. A.4.1
Handout No. A.4.1

Instructional Approach:

Discussion and Problem Session

References:

Murdock, J.W. pp 24-26

Class Assignments:

Any problems on Handout A.4.1 which weren't completed in class

Module No: 12JG	Topic: Specific Gravity
Instructor Notes:	**Instructor Outline:**
Transparency No. A.4.1 Specific Gravity	I. Review the meaning of specific gravity and discuss calculations of density or specific weight for a fluid of given specific gravity.
Handout No. A.4.1 Practice Problems - 3	II. Allow students to work practice problems on Handout No. A.4.1

Module No:	Module Title:
I2JG	Hydraulics for Operators
Approx. Time 30 minutes	Submodule Title: The Continuity Equation
	Topic: Conservation of Mass

Instructional Objective:

To be able to state in words the steady flow form and unsteady state form of the continuity equation for a flow system.

Instructional Aids:

Handout No. B.1.1

Instructional Approach:

Lecture - discussion

References:

Murdock, J.W pp. 112-115

Class Assignments:

None

Module No: I2JG	Topic: Conservation of Mass
Instructor Notes:	**Instructor Outline:**
Handout No. B.1.1 Conservation of Mass	Discuss the general continuity equation and steady state continuity equation and their relationship to the principle of conservation of mass as outlined on the handout.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: The Continuity Equation
Approx. Time 1 hour	Topic: Velocity and Volumetric Flow Rate

Instructional Objective:

For a known cross sectional area of flow, A, to be able to calculate either average velocity V, or volumetric flow rate, Q, if given a value for the other one. In these calculations the student is to be responsible for converting V,Q, and/or A to appropriate units if necessary.

Instructional Aids:

Transparency No. B.2.1
Handouts No. B.2.1 , B.2.2 , A.2.1

Instructional Approach:

Discussion and Problem Session

References:

Texas Water Utilities Ass'n, pp. 135-136

Class Assignments:

Complete practice problems on Handout No. B.2.2 if not finished in class.

Module No: I2JG	Topic: Veloctity and Volumetric Flow Rate

Instructor Notes:	Instructor Outline:
Handout No. B.2.1 Velocity and Flow Rate Transparency No. B.2.1 Velocity and Flow Rate	I. Discuss volumetric flow rate and average veloctity as measures of flow rate and their relationship to each other, using the handout and transparency.
Handout No. B.2.2 Practice Problems - 4 Handout No. A.2.1 Conversion Factors	II. Allow students to work on practice problems on Handout No. B.2.2 Conversion factors from Handout A.2.1 will be necessary.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: The Continuity Equation
Approx. Time 1 hour	Topic: Mass Flow Rate and Volumetric Flow Rate

Instructional Objective:

For a flow of water or wastewater, to be able to calculate mass flow rate, $\dot{m}$, or volumetric flow rate, Q, if given a value for the other one, where $\dot{m}$ could be in ℓb/min, ℓb/sec, or ℓb/hr and Q could be in cfs, gpm, or MGD.

Instructional Aids:

Transparency No. B.2.1
Handout No. B.3.1

Instructional Approach:

Discussion and Problem Session

References:

Murdock, J.W. p.112

Class Assignments:

Complete practice problems on Handout No. B.3.1 if not finished in class.

Module No: I2JG	Topic: Mass Flow Rate and Volumetric Flow Rate
Instructor Notes:	**Instructor Outline:**
Transparency No. B.2.1 Velocity and Flow Rate Handout No. B.3.1 Mass Flow Rate	I. Discuss mass flow rate and its relationship to volumetric flow rate and average velocity using the second part of the transparency and the first part of the handout. II. Allow the students to work out the practice problems on the handout.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Flow Measurement
Approx. Time 45 minutes	Topic: Velocity by Timing Float Travel

Instructional Objective:

To be able to calculate the volumetric flow rate of water or wastewater in an open channel or sewer if given the time required for a float or dye to travel a specified distance and sufficient information to allow calculation of the cross-sectional area of flow.

Instructional Aids:

Transparency No. C.1.1
Handout No. C.1.1

Instructional Approach:

Discussion and Problem Session

References:

Texas Water Utilities Ass'n, pp 135-136

Class Assignments:

Complete any practice problems not finished in class.

Module No: 12JG	Topic: Velocity by Timing Float Travel

Instructor Notes:	Instructor Outline:
Transparency No. C.1.1 Velocity Measurement	I. Discuss the method of measuring velocity and thus flow rate by timing a float's travel, as outlined on the transparency.
Handout No. C.1.1 Practice Problems 5	II. Allow students to work on problems on Handout No. C.1.1

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Flow Measurement
Approx. Time 45 minutes	Topic: Sharp-Crested Weir Geometry

Instructional Objective:

To be able to describe rectangular and V-notch weirs and their uses and to be able to list precautions which should be observed in their setup and use.

Instructional Aids:

Handout No. C.2.1

Instructional Approach:

Discussion

References:

1) Texas Water Utilities Ass'n, pp 136-141
2) Spink, L.K. pp. 263-272

Class Assignments:

None

Module No: 12JG	Topic: Sharp-Crested Weir Geometry
Instructor Notes:	**Instructor Outline:**
Handout No. C.2.1 Sharp-Crested Weirs	Discuss rectangular and V-notch weirs, their uses and precautions in their use as outlined on the handout.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Flow Measurement
Approx. Time: 1 hour	Topic: Parshall Flume Geometry

Instructional Objective:

To be able to sketch a plan and elevation view of a Parshall flume, identifying the throat width and the locations for measuring the upstream head and downstream head.

Instructional Aids:

Transparency No. C.3.1

Instructional Approach:

Discussion and "Sketching" session

References:

1) Texas Water Utilities Ass'n, pp 144-150
2) Chow, V.T., pp 74-80
3) Spink, L.K., pp 272-283

Class Assignments:

None

Module No: I2JG	Topic: Parshall Flume Geometry
Instructor Notes:	**Instructor Outline:**
Transparency C.3.1 Parshall Flume	Show the geometry of the Parshall flume, its various parts, and the location of the gaging stations using the transparency. Then have the class sketch both views of the Parshall flame, labeling the various parts.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Flow Measurement
Approx. Time: 1 hour	Topic: Parshall Flume Operation

Instructional Objective:

To be able to list advantages and disadvantages of a Parshall flume as compared with a sharp-crested weir, to be able to define submergence for a Parshall flume, and to be able to specify the maximum value of submergence for which a Parshall flume can be used without a correction factor.

Instructional Aids:

Transparency No. C.3.1
Handout No. C.4.1

Instructional Approach:

Discussion

References:

1) Texas Water Utilities Ass'n. pp 144-150
2) Chow, V.T., pp 74-80
3) Spink, L.K., pp 272-283

Class Assignments:

None

Module No: 12JG	Topic: Parshall Flume Operation
Instructor Notes:	**Instructor Outline:**
Transparency C.3.1 Parshall Flume Handout No. C.4.1 Parshall Flume	Discuss Parshall flume operation, including advantages and disadvantages as compared with a sharp-crested weir as well as meaning and interpretation of submergence.

Module No:	Module Title:
I2JG	Hydraulics for Operators
	Submodule Title: Flow Measurement
Approx. Time: 1 1/2 hours	Topic: Weirs and Parshall Flume-calculations

Instructional Objective:

To be able to determine the discharge of water or wastewater over a sharp-crested weir or through a Parshall flume if given the upstream head, the necessary information about size and geometry of the weir or flume and either a monograph or table giving discharge as a function of upstream head and size.

Instructional Aids:

Handouts No. C.5.1 - C.5.5

Instructional Approach:

Discussion and Problem Session

References:

1) Texas Water Utilities Ass'n., pp 136-150
2) Simon, A.L., pp 268-277

Class Assignments:

Complete any practice problems not finished in class.

Module No: I2JG	Topic: Weirs and Parshall Flume

Instructor Notes:	Instructor Outline:
Handout No. C.5.1 Weir and Parshall Flume Discharge	I) Discuss methods of determining the discharge from an upstream head reading of a sharp-crested weir or Parshall flume and work examples.
Handout No. C.5.2 Discharge of sharp-crested weirs	
Handout No. C.5.3 Flow in V-notch weirs	
Handout No. C.5.4 Flow in Parshall Flume	
Handout No. C.5.5 Practice Problems-6	II) Allow students to work out the practice problems.

Module No:	Module Title:
I2JG	Hydraulics for Operators
	Submodule Title: Flow Measurement
Approx. Time: 1 hour	Topic: Pressure Flow Measurement

Instructional Objective:

To be able to briefly describe the venturi meter, orifice meter, Dall tube, and magnetic flow meter as devices for pressure flow measurement and to be able to compare them by giving advantages and dis advantages of each.

Instructional Aids:

Handout No. C.6.1

Instructional Approach:
Discussion

References:
1) Texas Water Utilities Ass'n., pp 150-155.
2) Spink, L.k., pp 7-40

Class Assignments:

None

Module No: I2JG	Topic: Pressure Flow Measurement

Instructor Notes:	Instructor Outline:
Handout No. C.6.1 Pressure Flow Measurement	Discuss the venturi meter, orifice meter, Dall tube, and magnetic flow meter as devices for pressure flow measurement as outlined on the handout.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Frictional Head Loss
Approx. Time 1 hour	Topic: Uniform and Nonuniform Flow

Instructional Objective:

To be able to classify open channel flow as either uniform or nonuniform if given a description of the flow situation.

Instructional Aids:

Handout No. D.1.1 D.1.2

Instructional Approach:

Discussion and Problem Session

References:

1) John, J.E.A., and Haberman, W. pp 209-211
2) Simon, A.L., p 159

Class Assignments:

Complete any practice problems not finished in class

Module No: I2JG	Topic: Uniform and Nonuniform Flow
Instructor Notes:	**Instructor Outline:**
Handout No. D.1.1 Uniform and Nonuniform Flow	I) Discuss uniform and nonuniform flow as outlined on the handout.
Handout No. D.1.2 Practice Problems-7	II) Allow students to work out practice problems.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Frictional Head Loss
Approx. Time 1 hour	Topic: Hydraulic Radius

Instructional Objective:

To be able to calculate the hydraulic radius for open channel flow through

a) a rectangular channel of specified width and liquid depth
b) any shape channel with specified wetted perimeter and liquid cross-sectional area.

Instructional Aids:

Handouts No. D.2.1, D.2.2

Instructional Approach:

Discussion and Problem Session

References:

1) Murdock, J.W., pp 123-125
2) John, J.E.A. and Haberman, W., pp 226-227
3) Simon, A.L., pp 159-160

Class Assignments:

Complete any practice problems not finished in class.

Module No: I2JG	Topic: Hydraulic Radius
Instructor Notes:	**Instructor Outline:**
Handout No. D.2.1 Hydraulic Radius	I) Discuss hydraulic radius and its calculations as outlined on the handout.
Handout No. D.2.2 Practice Problems-7	II) Allow students to work out the practice problems on the handout.

Module No: 12JG	Module Title: Hydraulics for Operators
	Submodule Title: Frictional Head Loss
Approx. Time 2 hours	Topic: Manning Equation - Open-channel Flow

Instructional Objective:

For uniform open channel flow, to be able to use a nomographic solution of the Chezy-Manning equation to calculate a value for any one of the following four variables if values are known for the other three: average velocity of flow, V, hydraulic radius, R_H, slope of channel, S, and Manning roughness coefficient, n.

Instructional Aids:

Handouts No. D.3.1, D.3.2, D.3.3, D.3.4

Instructional Approach:

Discussion - Problem Session

References:

1) Simon, A.L., pp 159-169
2) John, J.E.A and Haberman, W. pp 224-227

Class Assignments:

Complete practice problems on Handout No. D.3.4 if not completed in class

Module No: I2JG	Topic: Manning Equation - Open-channel Flow

Instructor Notes:	Instructor Outline:
Handout D.3.1 Manning Equation-Open-channel Flow Handout D.3.2 Chezy-Manning Nomograph Handout D.3.3 Values of n and C	I. Discuss the relationship among V, S, R_H, and n for open channel flow and the use of a nomograph for uniform flow calculations.
Handout D.3.4 Practice Problems - 9	II. Allow the students to work out the practice problems, giving individual help on reading the scales on the nomograph if necessary.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Frictional Head Loss
Approx. Time 1 1/2 hours	Topic: Pressure Flow in Pipes

Instructional Objective:

For pressure flow in a pipe to be able to use a nomograph of the Hazen-Williams equation to find a value for any one of the following four variables if values are known for the other three: discharge through the pipe, Q, diameter of pipe, D, head loss per foot of pipe length, S, and Hazen-Williams coefficient, C.

Instructional Aids:

Handouts D.4.1, D.4.2, D.4.3, D.3.3

Instructional Approach:

Discussion and Problem Session

References:

1) Simon, A.L., pp. 44-45

Class Assignments:

Complete any practice problems not finished in class.

Module No: I2JG	Topic: Pressure Flow in Pipes
Instructor Notes:	**Instructor Outline:**
Handout No. D.4.1 Pressure Flow in Pipes	I. Discuss pressure flow in pipes and the use of the Hazen-Williams equation.
Handout No. D.4.2 Hazen-Williams Nomograph	
Handout No. D.3.3 Values of n and C	
Handout No. D.4.3 Practice Problems-10	II. Allow the students to work on practice problems.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Frictional Head Loss
Approx. Time 1 hour	Topic: Minor Losses in Pipes

Instructional Objective:

To be able to estimate frictional head losses for flow through valves and fittings in a piping system if given a value for the average velocity of flow in the pipe and a table of loss coefficients (K values) for values and fittings.

Instructional Aids:

Handouts D.5.1, D.5.2, D.5.3

Instructional Approach:

Discussion and problem session

References:

Simon, A.L. pp. 59-64

Class Assignments:

Complete any practice problems not finished in class.

Module No: I2JG	Topic: Minor Losses in Pipes
Instructor Notes:	**Instructor Outline:**
Handout D.5.1 Minor Losses in Pipes	I. Discuss minor losses in piping system and their estimation as outlined on Handout D.5.1
Handout D.5.2 Loss Coefficients for Fittings	
Handout D.5.3 Practice Problems-11	II. Allow class to work out the practice problems.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Frictional Head Loss
Approx. Time 1 hour	Topic: Frictional Pressure Loss

Instructional Objective:

For flow through a horizontal pipe to be able to calculate either frictional pressure loss or frictional head loss if given a value for the other.

Instructional Aids:

Handout D.6.1, D.6.2

Instructional Approach:

Discussion and problem session

References:

Class Assignments:

Complete any practice problems not finished in class.

Module No: I2JG	Topic: Frictional Pressure Loss
Instructor Notes:	**Instructor Outline:**
Handout D.6.1 Frictional Pressure Loss	I. Discuss frictional pressure loss and its relation to frictional head loss for pressure flow through a horizontal pipe, as outlined in the handout.
Handout D.6.2 Practice Problems-12	II. Allow the class to work out the practice problems.
Note: Nonhorizontal pipes will be considered in the section on Bernoulli's equation in the "Advanced Hydraulics for Operators" module.	

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Frictional Head Loss
Approx. Time 1 hour	Topic: Water Distribution Systems

Instructional Objective:

To be able to apply calculations of the type in the previous three objectives to flow through a water distribution system.

Instructional Aids:

Handouts D.7.1, D.7.2

Instructional Approach:

Discussion and Problem Session

References:

1) Clark, J.W., Viessman, W, Jr., & Hammer, M.J. pp. 142-148
2) Murdock, J.W., pp. 292-297

Class Assignments:

Complete any practice problems not finished in class.

Module No: I2JG	Topic: Water Distribution Systems

Instructor Notes:	Instructor Outline:
Handout D.7.1. Water Distribution Systems	I. Discuss the examples worked out in the handout.
Handout D.7.2 Practice Problems-13	II. Allow students to work out the practice problems.

Module No: I2JG	Module Title: Hydraulics for Operators
Approx. Time: 30 minutes	Submodule Title: Hydraulics of Sewers
	Topic: Velocity Requirements

Instructional Objective:

To be able to explain the reasons for requiring a minimum velocity and a maximum velocity for flow through sewers.

Instructional Aids:

Handout No. E.1.1

Instructional Approach:

Lecture-discussion

References:

1) Fair, Geyer, & Okun, pp. 14-1 - 14-2, 14-5 - 14-7

Class Assignments:

None

Module No: I2JG	Topic: Velocity Requirements
Instructor Notes:	**Instructor Outline:**
Handout E.1.1 Velocities in Sewers	Discuss general requirements related to velocity and size of sewer for flow in sewers as discussed in the handout.

Module No: I2JG	Module Title: Hydraulics for Operators
	Submodule Title: Hydraulics of Sewers
Approx. Time 1½ hours	Topic: Sewers Flowing Full

Instructional Objective:

To be able to determine from a graph or nomograph the discharge, the slope, or the diameter of a sewer flowing full if given values for the other two and a value for the Manning roughness coefficient for the sewer.

Instructional Aids:

Handouts No. E.2.1, E.2.2, E.2.3, D.3.2, D.3.3, D.4.2

Instructional Approach:

Discussion and Problem Session

References:

1) Fair, Geyer, and Okun, pp. 14-2, 14-4
2) National Clay Pipe Institute, pp. 15-22

Class Assignments:

Complete any practice problems not finished in class.

Module No: I2JG	Topic: Sewers Flowing Full
Instructor Notes:	**Instructor Outline:**
Handout No. E.2.1 Flow in Filled Sewers Handout No. E.2.2 Pipe Discharge Flowing Full Handout No. D.3.2 Chezy-Manning Nomograph Handout No. D.3.3 Values of n and c Handout No. D.4.2 Hazen-Williams Nomograph	I. Discuss flow in filled sewers, the relationship among discharge, velocity, slope, diameter, and roughness of the sewer and calculations with those variables.
Handout No. E.2.3 Practice Problems - 14	II. Allow students to work out the practice problems.

Module No:	Module Title:
I2JG	Hydraulics for Operators
Approx. Time	Submodule Title: Hydraulics of Sewers
1½ hours	Topic: Partially Filled Sewers

Instructional Objective:

To be able to calculate the velocity of flow, V, and discharge, Q, through a partially filled sewer if given values for the Manning roughness coefficient, n, the sewer diameter, D, the depth of water in the sewer, d, the slope of the sewer, S, and a tabulated or graphical presentation of the relationship of $\frac{V}{V_{full}}$ and $\frac{Q}{Q_{full}}$ to $\frac{d}{D}$.

Instructional Aids:

Handouts E.3.1, E.3.2, E.3.3

Instructional Approach:

Discussion and Problem Session

References:

1) Fair, Geyer, and Okun, pp. 14-7 - 14-12
2) National Clay Pipe Institute, pp. 17-22

Class Assignments:

Complete any practice problems not finished in class.

Module No: I2JG	Topic: Partially Filled Sewers
Instructor Notes:	**Instructor Outline:**
Handout No. E.3.1 Flow in Partially Filled Sewers	I. Discuss flow through partially filled sewers and estimation of velocity and discharge for such cases.
Handout No. E.3.2 Discharge and Velocity in Partially Filled Sewers	
Handout No. E.3.3 Practice Problems - 15	II. Allow students to work out the practice problems.

EXAM QUESTIONS

Definitions and Units

1) What are three different units for measuring pressure?

2) Define specific gravity.

3) What are two different units for measuring specific weight?

Pressure Unit Conversions

1) Convert a pressure of 1.5 atmospheres to psi.

2) What is a pressure of 2800 psf equal to in psi?

3) Convert 12.6 inches of mercury to psi.

Gauge and Absolute Pressure

1) If the gauge on a tank reads 15 psi, what is the absolute pressure in the tank?

2) If the pressure at a certain point is supposed to be 31 psia, what should be the reading on a pressure gauge at that point?

Specific Gravity

1) What is the specific weight of a liquid which has a specific gravity of 1.16?

Conservation of Mass

1) What basic law of physics is the continuity equation based on?

Velocity and Volumetric Flow Rate

1) What are three common sets of units used for measuring discharge or volumetric flow rate.

2) Wastewater is flowing 1 1/2 feet deep through a 2 foot wide rectangular open channel at a rate of 2.1 MGD. What is the velocity of the wastewater?

Mass Flow Rate and Volumetric Flow Rate

1) If wastewater is flowing through a section of channel at a rate of 30 ft^3/min, what is its mass flow rate in lb/min?

2) Water at 60°F is flowing through a pipe at a rate of 639 lb/min. What is its discharge in MGD?

Velocity by Timing Float Travel

1) The time required for a cork to travel between two manholes, 535 ft apart was 108 seconds.
   a) What was the velocity in the sewer?
   b) What was the discharge through the sewer if it was a 12 inch sewer flowing half full? (area of a circle = $\pi d^2/4$)

Sharp-Crested Weir Geometry

1) Where should the upstream head above the weir crest be measured for a sharp-crested weir?

2) What is meant by the "crest" of a rectangular sharp-crested weir?

3) What are three precautions that should be observed in the set-up and use of sharp-crested weirs in order to insure accurate flow measurements?

Parshall Flume Geometry

1) What is meant by the throat of a Parshall flume?

2) Is there any special location where the upstream head should be measured in a Parshall flume?

3) What is the crest, which the upstream head is measured above in a Parshall flume?

Parshall Flume Operation

1) What is meant by submergence in connection with a Parshall flume?

2) What is the maximum allowable submergence of the flow through a Parshall flume if the discharge is to be predicted from the upstream head only?

3) What are two advantages of a Parshall flume over a sharp-crested weir.

Weir and Parshall Flume Calculations

1) What are three commonly used methods of determining the discharge for a measured value of upstream head for a sharp-crested weir or a Parshall flume?

2) Use the attached nomograph to find the discharge through a 90° V-notch weir with a head of 6 inches. (attach Handout No. C.5.3)

3) Use the attached table to determine the discharge over a 6 foot long rectangular sharp-crested weir with a 7 1/2 inch head. (attach Handout No. C.5.2)

Pressure Flow Measurement

1) What are advantages and disadvantages of a magnetic flow meter in comparison with a venturi meter?

2) What is actually measured with a venturi meter in order to determine the flow rate through the meter?

3) What are some advantages and disadvantages of a Dall tube in comparison with a venturi meter?

Uniform and Nonumiform Flow

1) What is necessary for flow in an open channel in order to give uniform flow?

Hydraulic Radius

1) What is the hydraulic radius for flow through a 24 inch wide rectangular channel if it is flowing 15 inches deep?

2) What is the hydraulic radius for flow through a partially filled sewer if the cross-sectional area of flow is 10 inches and the wetted perimeter is 9.3 inches?

Manning Equation - Open Channel Flow

1) What are the three most important variables which affect the velocity of water flowing through an open channel?

2) Would the velocity of flow in an open channel increase or decrease if the hydraulic radius is increased?

3) Would the velocity of flow in an open channel increase or decrease if the channel surface becomes rougher.

4) Use the attached Chezy-Manning Nomograph to determine the slope required to give a velocity of 2.0 ft/sec with a hydraulic radius of 1.5 ft and a Manning roughness of 0.015. (attach Handout No. D.3.2)

Pressure Flow in Pipes

1) How is the hydraulic radius calculated from the diameter of a circular pipe?

2) Use the attached Hazen-Williams nomograph to find the discharge through 500 feet of 24 inch pipe with a head loss of 12 feet if the Hazen-Williams coefficient is 100. (attach Handout No. D.4.2)

Minor Losses in Pipes

1) In what type of situations would frictional losses due to valves and fittings be important in comparison with frictional loss due to straight pipe?

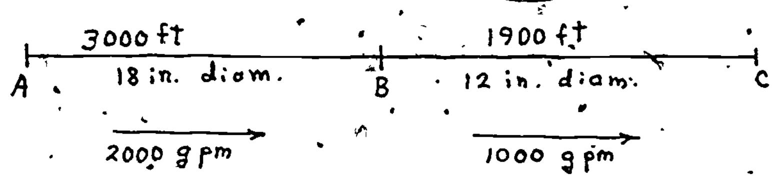
Frictional Pressure Loss

1) If the head loss across a piping system is 15 ft what would be the pressure loss through the system is psi?

2) Express a pressure loss of 15 psi as head loss in feet.

Water Distribution Systems

1) What pressure would be required at point A in order to give a pressure of 40 psig at point C?



Velocities in Sewers

1) What is the normally recommended range of velocities for flow through sewers?

2) What problem will be caused by the velocity being too low for flow through a sewer?

3) What problem will be caused by the velocity being too high for flow through a sewer?

Flow in Filled Sewers

1) Use the attached Hazen-Williams nomograph to find the velocity and discharge through a 24 inch sewer with a slope of 0.0015 if it is flowing full? (attach Handout No. D.4.2)

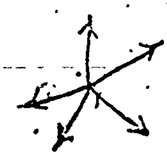
Flow in Partially Filled Sewers

1) Use the attached graph and nomograph to find the velocity and discharge through a 24 inch sewer with a slope of 0.0015 if it is flowing 0.6 full? (attach Handouts No. D.4.2 and E.3.2)

FLUID PROPERTIES

1) Pressure $= \dfrac{\text{Force}}{\text{Area}}$

Pascals Principle:



Pressure acts in all directions

2) Density $= \dfrac{\text{Mass}}{\text{Volume}}$; $\rho = \dfrac{M}{V}$

3) Specific Weight $= \dfrac{\text{Weight}}{\text{Volume}}$; $\gamma = \dfrac{W}{V}$

4) Specific Gravity $= \dfrac{\rho}{\rho_{water}} = \dfrac{\gamma}{\gamma_{water}}$

5) Viscosity, μ, resistance to flow

No. A.1.1

EXAMPLE PROBLEM

Problem: Convert 14.7 psi to a) in. of Hg, b) psf, c) atmospheres, and c) Pa.

Solution: (Obtain conversion factors from handout)

a) psi → in. of Hg : mult. by 2.03

14.7 psi = 14.7 × 2.03 in. of Hg = 29.9 in. of Hg.

b) psi → psf : mult. by 144

14.7 psi = 14.7 × 144 psf = 2117 psf

c) psi → atm : divide by 14.7

$14.7 \text{ psi} = \frac{14.7}{14.7} \text{ atm} = 1.0 \text{ atm}$

d) psi → Pa : Convert psi to psf (mult. by 144), Then convert psf to Pa (mult. by 47.88)

14.7 psi = 14.7 × 144 psf = 2117 psf

= 2117 × 47.88 Pa = 101, 400 Pa

No. A.2.1

SPECIFIC GRAVITY

$$S_A = \frac{\gamma_A}{\gamma_{water}} = \frac{\rho_A}{\rho_{water}}$$

or $\gamma_A = S_A \gamma_{water}$ $\quad \rho_A = S_A \rho_{water}$

Note: $\gamma_{water} = \rho_{water} = 62.4 \frac{lb}{ft^3} = 8.34 \frac{lb}{gal}$

for Temp. between 35°F and 65°F

Example: The specific gravity of Kerosene is 0.79 at 60°F. What is its specific weight at that Temp.?

Solution:

$$\gamma_{kerosene} = S_{kerosene} \gamma_{water}$$

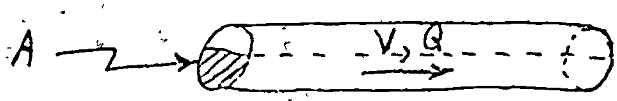
$$\gamma_{kerosene} = (0.79) \times (62.4) \frac{lb}{ft^3} = 49.3 \frac{lb}{ft^3}$$

No. A.4.1

VELOCITY AND FLOW RATE

Volumetric Flow Rate – Q – cfs, gpm, MGD

Average Velocity – V – ft/sec, ft/min, etc.



$$Q = VA \quad \text{or} \quad V = \frac{Q}{A}$$

units: V – ft/sec, A – ft^2, Q – ft^3/sec

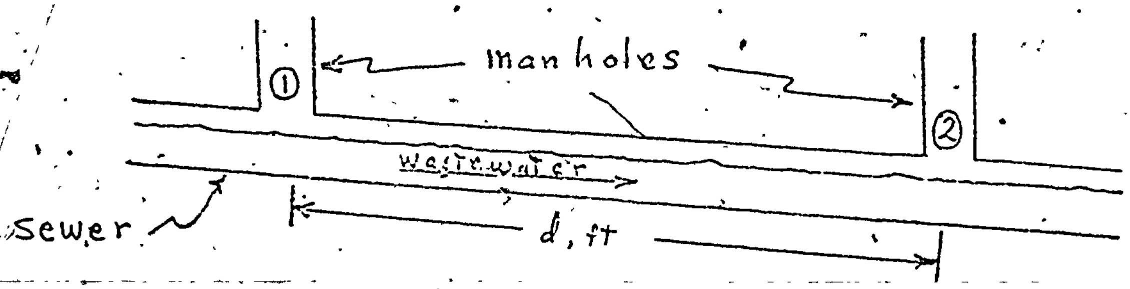
Mass Flow Rate – $\dot{m}$ – lb/min, lb/hr, lb/sec

$$\dot{m} = \rho Q \quad \text{or} \quad Q = \frac{\dot{m}}{\rho}$$

units: Q – ft^3/sec, ρ – lb/ft^3, $\dot{m}$ – lb/sec

No. B.2.1

VELOCITY MEASUREMENT



T = Time for float to go from ① to ②

Then, velocity, $V = \frac{d}{T}$

flow rate, $Q = VA$

where A = cross-sect. area of flow.

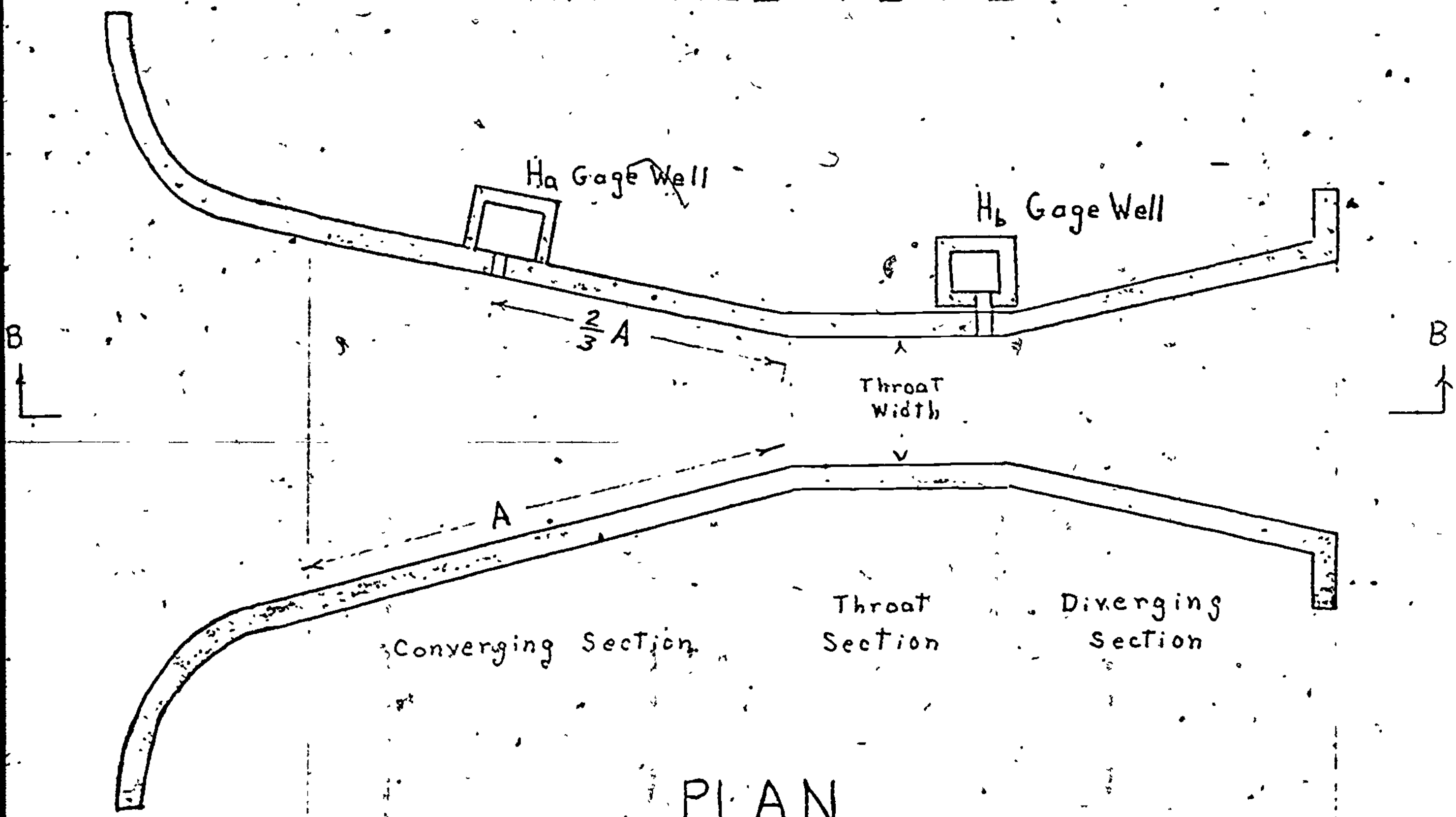
Example: $d = 200$ ft, $T = 30$ sec, $A = 0.9$ ft^2

Then $V = \frac{200}{30} = 6.7$ ft/sec

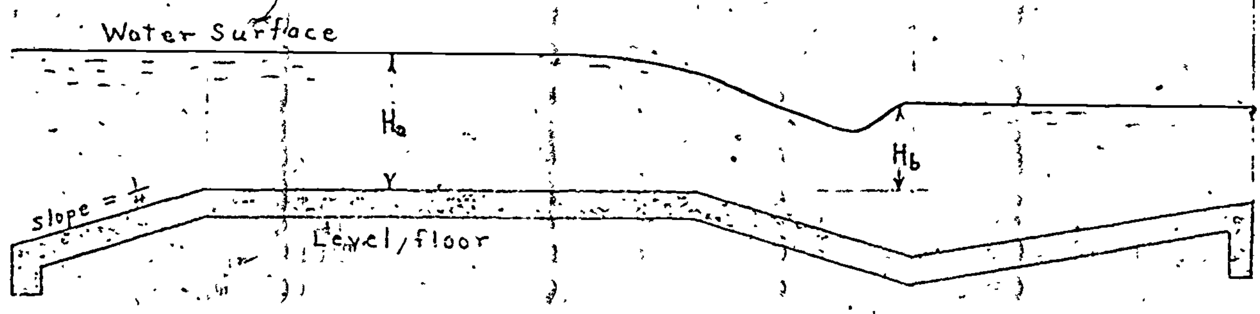
$Q = (6.7)(0.9) = 6.0$ ft^3/sec

No. C.1.1

PARSHALL FLUME



PLAN



SECTION B-B

No. C.3.1

FLUID PROPERTIES

Pressure: symbol- P

Meaning: Force per unit area which a fluid exerts on any surface it is in contact with.

Units: lb/in^2 (psi), lb/ft^2 (psf), inches of mercury (in. Hg), atmospheres (atm), Pascals (Pa)

Pascals Principle: Pressure is the same in all directions at any point in a fluid.

Density: symbol- ρ

Meaning: mass of a substance per unit volume

Units: lb/ft^3, lb/gal, kg/m^3

Specific Weight: symbol- γ

Meaning: weight of a substance per unit volume

Units: lb/ft^3, lb/gal, $Newtons/m^3$

Specific Gravity: symbol- S

Meaning: $\dfrac{\text{density of another substance}}{\text{density of water}}$

e.g. Specific Gravity of gasoline $= \dfrac{\text{density of gasoline}}{\text{density of water}}$

This may be written as $S_{gasoline} = \dfrac{\rho_{gasoline}}{\rho_{water}}$

Units: None, however the same units must be used for the density of water and the other substance.

Notes: 1) specific weight can be used in place of density for both water and the other substance.

2) $\rho_{water} = \gamma_{water} = 62.4\ lb/ft^3 = 8.34$ lb/gal for temperature between $32^oF - 60^oF$

Viscosity: symbol- μ

Meaning: a measure of a fluids resistance to flow

Units: $\dfrac{lb\text{-}sec}{ft^2}$, centipoise

Handout No. A.1.1.

CONVERSION FACTORS

	Given Unit	x	Conversion Factor	=	New Unit
Pressure	lb/sq. in.		144		lb/sq.ft.
	atmospheres		14.7		lb/sq.in.
	atmospheres		29.92		inches of mercury
	lb/sq.ft.		47.88		pascals
	lb/sq.in.		2.034		inches of mercury
	atmospheres		760		mm of mercury
Volume	cubic feet		7.48		gallons
	cubic feet		1728		cubic inches
	cubic feet		0.0283		cubic meters
	acre-feet		43,560		cubic feet
	gallons		3.785		liters
Area	square feet		144		square inches
	acres		43,560		square feet
	square meters		10.764		square feet
Mass	pounds		453.6		grams
	kilograms		2.205		pounds
Discharge	cu.ft./sec		0.646		million gals./day
	cu.ft./sec		449		gal/min
	million gals/day		694		gal/min

Note: To convert from a unit in the "New Unit" column to a unit in the "Given Unit" column, divide by the conversion factor.

Handout No. A-2.1

PRACTICE PROBLEMS - 1

1) Convert a pressure of 2.3 atm to a) psi, and b) in. of Hg.

2) If a pressure gauge reads 8.5 in. of Hg what is the pressure in psi?

3) Convert a pressure of 3500 psf to a) psi and b) in. of Hg.

4) Convert a pressure of 45,000 Pa to psi.

GAUGE AND ABSOLUTE PRESSURE

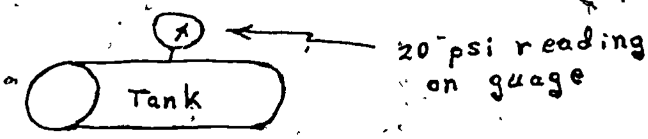
I. Atmosphere Pressure:

P_{atm} = 14.7 psi at sea level

Meaning: Normal atmosphere pressure exerts a force of 14.7 lb on each square inch of surface exposed to it.

Other Units: P_{atm} = 29.9 in. of Hg = 1 atm = 2120 psf = 101,000 Pa

II. Gauge Pressure:



interpretation: The pressure in the tank is 20 psi greater than the pressure outside the tank.
(Pressure outside tank = atmospheric pressure)

Other ways of stating this:
1) gauge pressure in tank = 20 psi
2) pressure in tank = 20 psi gauge
3) pressure in tank = 20 psig

III. Absolute Pressure:

The pressure in the tank above may also be expressed as absolute pressure where:

Absolute Pressure = Gauge Pressure + Atmospheric Pressure
or $P_{abs} = P_g + P_{atm}$

If atmospheric pressure is 14.7 psi around the tank, then the pressure in the tank could also be expressed as:

P_{tank} = 34.7 psi absolute
or P_{tank} = 34.7 psia
or The absolute pressure in the tank is 34.7 psi

Note: Assume P_{atm} = 14.7 psi unless other information is available

Handout No. A.3.1.

PRACTICE PROBLEMS - 2

1) If the pressure above a pressure filter is given as 10 inches of mercury gauge, what is the absolute pressure in inches of mercury and in psi?

2) If the pressure at a certain point in a pressure line is to be 28 psia what should be the reading in psi on a pressure gauge at that point?

3). If the pressure on a gauge reads 18.5 psi and the local barometric pressure (atmospheric pressure) is 29.8 inches of mercury, what is the absolute pressure being read by the gauge?

Handout No. A.3.2

PRACTICE PROBLEMS - 3

1) What are the specific weight and density of an oil which has a specific gravity of 0.94?

2) Sea water has a specific gravity of 1.03. What is its density in lb/ft^3 and in lb/gal?

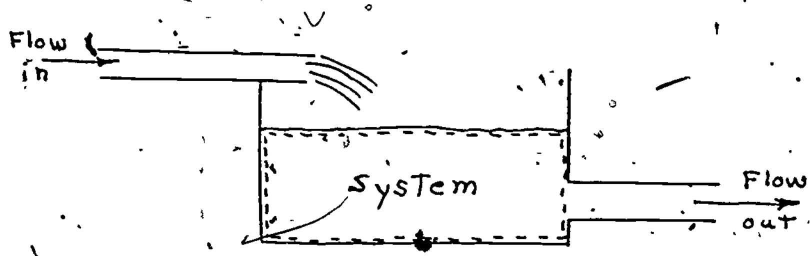
Handout No. A.4.1

THE CONTINUITY EQUATION

Basic Law of Physics: Mass can be neither created nor destroyed

General Continuity Equation: From the basic law above, the following relationship must be true for a system with streams flowing in and/or out as illustrated below.

rate of mass flow into system − rate of mass flow out of system = rate of accumulation of mass in system



e.g. If the mass flow rate in is 20 lb/min and the mass flow rate out is 15 lb/min, then there is a "buildup" or "accumulation" of 5 lb/min in the tank.

The "system" may be a clarifier, a sand filter, an aeration tank, a section of open channel, or any such item which has water or wastewater flowing in and/or out.

From the above relationship, flow rate in, flow rate out, or rate of accumulation can be found if the other two are known. If the outflow is greater than the inflow, then the rate of accumulation is negative, or in other words, there is a net loss of mass from the system.

Steady State Continuity Equation: For many cases, the total amount of mass in a system remains constant. This condition is referred to as steady state. There is no accumulation during steady state conditions and the continuity equation becomes

rate of mass flow into system = rate of mass flow out of system

Handout No. B.1.1

VELOCITY AND FLOW RATE

There are several possible ways of specifying the flow rate through a pipe, channel, or tank. Two which will be considered now are:

1) Volumetric flow rate, Q, measured in units such as cfs (cu.ft./sec), gpm (gal/min), MGD (millions of gallons per day), etc.

2) Average velocity, V, measured in units such as ft/sec, ft/min, etc.

For flow through a pipe, channel, or tank as shown in the diagram below, Q, V, and A are related as follows: (A = cross-sectional area of flow)

$$Q = VA$$

The velocity times the cross-sectional area gives the volume swept out per unit time, or volumetric flow rate, as shown in the equation above.

For calculations with this equation Q, V, and A must be in proper units. One possible set of consistent units is:

V in ft/sec, A in ft^2, Q in ft^3/sec

If any of the variables are given in different units, such as gpm for Q or in^2 for A, they should be converted to the units above before making calculations with the above equation.

<u>Example</u>: Water is flowing through a 3 ft wide channel at a depth of 2 ft, and has an average velocity of 5 ft/sec. What is the flow rate through the channel in cfs and in MGD?

<u>Solution</u>: $A = (2 \times 3)\ ft^2 = 6\ ft^2$
$V = 5$ ft/sec

$Q = VA = (5) \times (6)$ cfs = <u>30 cfs</u>

Convert to MGD - multiply by 0.646

$Q = (30) \times (0.646)$ MGD = <u>19.4 MGD</u>

Handout No. B.2.1

PRACTICE PROBLEMS - 4

1) A 6 inch diameter sewer is flowing full with wastewater. What flow rate through the sewer will give a velocity of 10 ft/sec? Express your answer in cfs and in MGD. (Note: the area of a circle = $\pi D^2/4$)

2) Wastewater is flowing through a grit chamber at a rate of 1.4 MGD. If the grit chamber is 1 ft wide and it is flowing 2 ft deep, what is the velocity of the wastewater in the grit chamber?

MASS FLOW RATE

A third possible measure of flow rate is mass flow rate, $\dot{m}$, in units such as lb/min, lb/hr, etc. Mass flow rate is related to volumetric flow rate and average velocity as follows:

$$\dot{m} = \rho Q \qquad \text{or} \qquad \dot{m} = \rho VA$$

where ρ = density of water
(ρ = 62.4 lb/ft^3 = 8.34 lb/gal for temperature between 35^{o}F and 65^{o}F)

Consistent Units:

1) volume units in ρ and Q must be the same for the first equation
   e.g. ρ in lb/ft^3 and Q in ft^3/sec
   or ρ in lb/gal and Q in gal/min

2) for the second equation if ρ is in lb/ft^3, V in ft/sec, and A in ft^2, then $\dot{m}$ will be in lb/sec.

Practice Problems:

1) If water at 50^{o}F is flowing through a channel at a rate of 30 ft^3/min, what is its mass flow rate in lb/min and in lb/sec?

2) Wastewater at 60^{o}F is flowing through an 18 inch diameter pipe at a rate of 43 lb/sec and the depth of flow is 9 inches. a) What is its volumetric flow rate in cfs and in MGD? b) What is its average velocity in ft/sec?

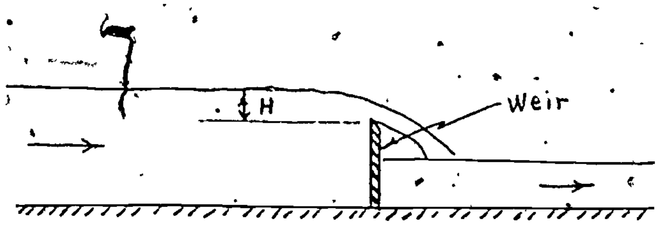
PRACTICE PROBLEMS - 5

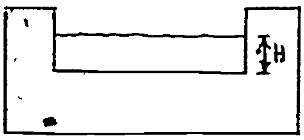
1) The time required for a cork to travel between two manholes, 500 ft apart, was 90 seconds. a) What was the velocity in the sewer? b) What was the volumetric flow rate (discharge) through the sewer if it is a 12 inch sewer flowing half full? (area of a circle = $\pi d^2/4$)

2) The flow in an open channel is to be estimated by timing a corks travel. If the channel is 18 inches wide, with 15 inch flow depth, and a cork takes 2 1/2 minutes to travel 400 ft., then what are the velocity and volumetric flow rate in the channel?

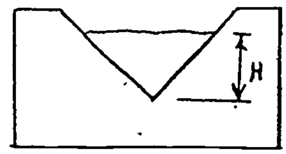
Handout No. C.1.1

SHARP-CRESTED WEIRS





Rectangular Wier



V-Notch Wier

Uses for sharp-crested weirs:

1) To measure flow rate in open channels and through outlets from tanks and ponds.

2) To maintain the proper depth of liquid in tanks, channels, and ponds.

Precautions in set-up and use:

1) The crest of the weir must be level

2) There should be a pool in the approach channel to keep the approach velocity below 1.5 ft/sec.

3) The depth in the approach channel must be at 2.5 times as great as H.

4) The weir crest must be at least 3 inches above the receiving water level.

5) The head above the weir crest, H, must be measured at a location which is a distance at least 2.5 H upstream from the crest.

Handout No. C.2.1.

PARSHALL FLUME

Comparison with sharp-crested weirs

Advantages of Parshall flume:

1) Lower head loss required
2) Sand and silt deposits are minimized because a stilling pool isn't required
3) Gauging points are well defined which improves uniformity from one instrument to another.

Disadvantages of Parshall flume:

1) More complicated and expensive to construct than a weir.

Submergence

Definition: $\text{Submergence} = \frac{H_B}{H_A} 100\%$

Where H_B and H_A are the liquid heads above the flume crest at the specified locations.

"Free flow" occurs when submergence is less than 60% for flumes with up to 1 foot throat width or less than 70% for flumes with 1 to 8 foot throat width.

"Submerged flow" occurs when submergence is greater than the figures given above.

For free flow the flow rate Q can be determined from only a value for H_A and the throat size of the flume.

For submerged flow correction factors can be applied as discussed in more detailed references.

Other Notes:

1) Parshall flumes are specified by their throat width, e.g., a 6" Parshall flume means one with a 6" throat.

2) The heads H_A and H_B are usually measured in stilling wells connected to the flume with pipes. The level of water in the stilling well is measured using a float.

Handout No. C.4.1

WEIR AND PARSHALL FLUME DISCHARGE

With both the sharp crested weir and the Parshall flume, the discharge, Q, is determined by measuring an upstream head, H. For the weirs H is the height above the weir crest and for the Parshall flume H is the height above the level floor portion of the flume.

For both the sharp crested weir and the Parshall flume, three major ways of finding discharge, Q, for a measured value of upstream head, H, are as follows:

1) Use of an equation relating Q and H, such as $Q = 3.33\ LH^{1.5}$ for a rectangular sharp crested weir.

2) Use of a table relating Q and H, such as Handout No. C.4.2.

3) Use of a nomograph relating Q and H, such as Handouts No. C.4.3 and C.4.4.

Examples:

1) What is the discharge over a 6 ft. long rectangular sharp crested weir if the upstream head above the weir crest is 4 1/2 inches?

Solution: From Handout No. C.5.2, the discharge is 343 gal/min per foot of weir lengths for 4 1/2 inches head. The total discharge must then be

$Q = 343 \times 6$ gal/min = 2058 gal/min

2) What is the discharge through a 90° V-notch weir with a head of 6 inches?

Solution: From Handout C.5.2: Q = 204 gal/min

From Handout C.5.3: Line up a straight edge with the two points representing 6 inches head and 90°, then read off flow equal to 0.285 MGD

converting to gal/min: Q = (0.285)(694) gal/min = 198 gal/min

3) What is the flow rate through a Parshall flume with 1 foot throat width and 8 inch head?

Solution: From Handout C.5.4, using a straight edge

Q = 1.4 MGD

Handout No. C.5.1

DISCHARGE OF SHARP-CRESTED WEIRS

Rectangular Weir		V-Notch Weir			
	(1)		(2)		
			Discharge, gal/min		
Head, inches	Discharge per foot of length, gal/min	Head, inches	90°	60°	30°
1/8	1.6	1	2.5	1.4	0.7
1/4	4.5	1 1/2	6.6	3.5	1.7
3/8	8.2	2	12	7.7	3.5
1/2	12.7	2 1/2	24	13	5.8
5/8	17.7	3	37	20	9.5
3/4	23.3	3 1/2	53	31	14
7/8	29.4	4	76	42	20
1	35.9	4 1/2	100	57	26
1 1/8	42.9	5	129	72	36
1 1/4	50.2	5 1/2	166	86	46
1 1/2	66.0	6	204	114	56
1 3/4	83.2	6 1/2	247	142	69
2	102	7	300	163	82
2 1/4	121	7 1/2	354	201	97
2 1/2	142	8	413	228	114
2 3/4	164	8 1/2	486	271	132
3	187	9	555	313	152
3 1/4	211	9 1/2	632	367	173
3 1/2	235	10	713	407	197
3 3/4	261	10 1/2	815	457	222
4	288	11	905	517	248
4 1/4	315	11 1/2	1,010	573	277
4 1/2	343	12	1,120	642	307
4 3/4	372	12 1/2	1,240	710	340
5	402	13	1,360	784	374
5 1/4	432	13 1/2	1,500	861	410
5 1/2	464	14	1,640	943	448
5 3/4	496	14 1/2	1,790	1,030	489
6	528	15	1,940	1,121	531
6 1/2	596				
7	666				
7 1/2	738				
8	813				
8 1/2	891				
9	971				
9 1/2	1,053				
10	1,137				
10 1/2	1,223				
11	1,312				
11 1/2	1,402				
12	1,494				

(1) From equation

$$\frac{Q}{L} = 3.33H^{1.5}$$

(2) From following equations:

$$90^\circ - Q = 2.52H^{2.47}$$
$$60^\circ - Q = 1.43H^{2.50}$$
$$30^\circ - Q = 0.685H^{2.45}$$

Handout No. C.5.2

PAGE 167 "Flow in V-Notch Weirs" and PAGE 169 "Flow in Parshall Flumes" REMOVED PRIOR TO BEING SHIPPED TO EDRS DUE TO COPYRIGHT RESTRICTIONS.

PRACTICE PROBLEMS - 6

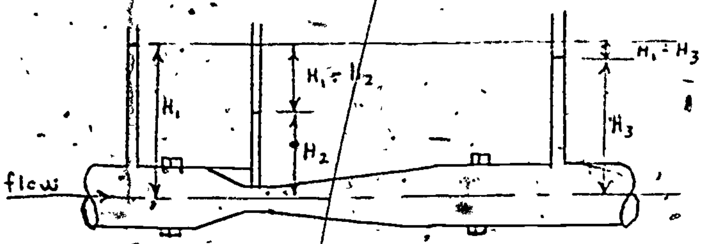
1) What is the flow rate through a 60° V-notch weir with 7 1/2 inches head?

2) What is the flow rate over a 4 foot long rectangular sharp-crested weir with 5 3/4 inches head?

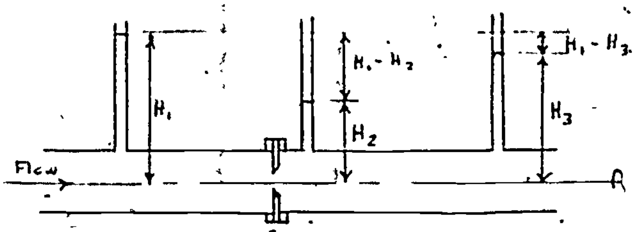
3) What is the flow through a 3 foot Parshall flume with 9 1/2 inches head?

Handout No. C.5.5

PRESSURE FLOW MEASUREMENT



Venturi Meter



Orifice Meter

For both the venturi meter and orifice meter the flow rate is related to the drop in head, $H_1 - H_2$, as follows: $Q=K\ H_1 - H_2$. A calibration curve is usually used to find the flow rate indicated by a measured value of head loss.

Both orifice meter and venturi meter will have some permanent head loss due to the meter shown as $H_1 - H_3$ on the diagrams above.

Dall Tube: This is similar to a venturi meter, but has a differently shaped entrance section and throat which gives a higher pressure recovery.

Magnetic Flow Meter: An electromagnet is used to create a magnetic field in the pipe. The flow of a conductive fluid (such as wastewater) through the magnetic field generates a voltage proportional to the velocity of the flow. The voltage is measured and used to indicate flow rate.

COMPARISON OF METER TYPES

Venturi Meter:

1) less permanent pressure loss than orifice meter; but more than Dall tube or magnetic flow meters.
2) can be used with higher solids content than Dall tube
3) greater space requirement than orifice meter

Orifice Meter:

1) greatest permanent pressure loss of the four types
2) least space requirement of the four
3) easy to change to different sizes to change the measurable flow range

Dall Tube:

1) less permanent pressure loss than venturi or orifice meter
2) cannot be used with liquids having a high solids concentration as well as the venturi meter.

Magnetic Flow Meter:

1) least permanent pressure loss of the four types.
2) the liquid must have a high enough solids content to be conductive
3) unaffected by sludge buildup on the wall as long as the built up sludge has the same conductivity as the flowing liquid

Handout No. C.6.1

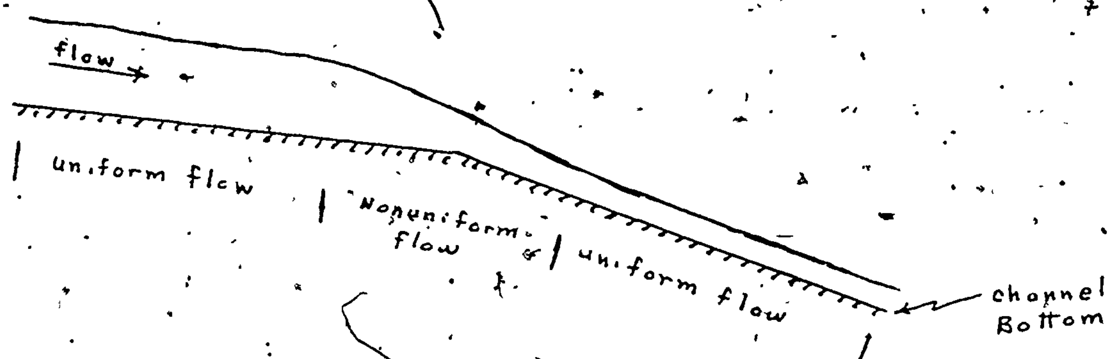
UNIFORM AND NONUNIFORM FLOW

Flow in open channels can be classified as either uniform or nonuniform flow as follows.

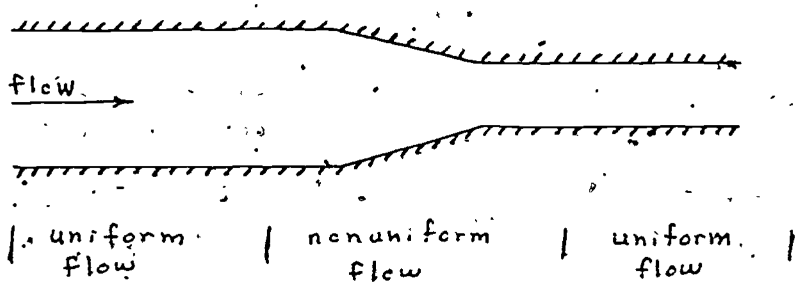
Uniform flow- Flow in an open channel of uniform cross-section with the slope of the water surface the same as the slope of the channel bottom.

Nonuniform flow- (also called varied flow)- Open channel flow with the liquid depth and/or the channel cross section changing.

Flow in a straight stretch of channel of constant bottom slope and constant cross section will develop into uniform flow. A change in the bottom slope and/or cross-section will cause a region of nonuniform flow as indicated below for a change in bottom slope.



Another example of uniform and nonuniform flow:

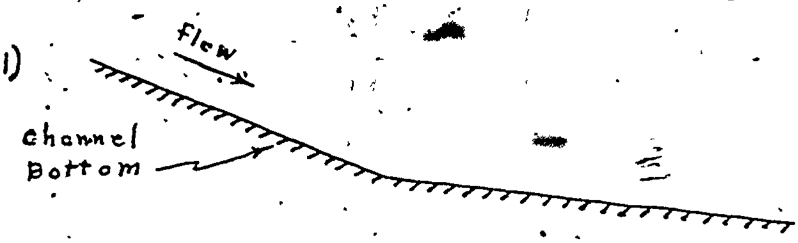


Top View of Channel, Constant Slope

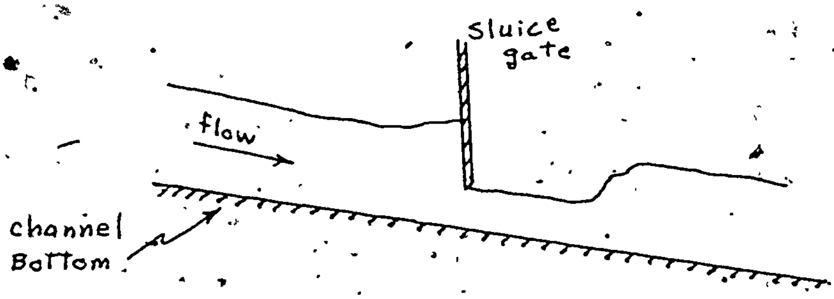
Handout No. D.1.1

Indicate where you would expect to find uniform flow and where nonuniform flow for each of the following cases.

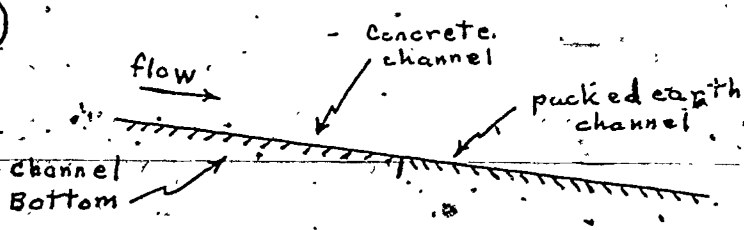
1)



2)



3)



Handout No. D.1.2

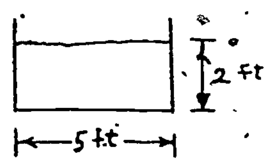
HYDRAULIC RADIUS

Hydraulic radius is often used in calculations for open channel flow and for pressure flow in a non-circular conduit.

Definition: Hydraulic Radius $= \dfrac{\text{Cross-sectional Area of Flow}}{\text{Wetted Perimeter}}$

or $R_h = \dfrac{A}{P}$

Example: Calculate the hydraulic radius for flow through a 5 ft. wide rectangular open channel at a depth of 2 ft.



$A = (2 \times 5)\ ft^2 = 10\ ft^2$

$P = (5 + 2 + 2)\ ft = 9\ ft$

$R_h = \dfrac{A}{P} = \dfrac{10\ ft^2}{9\ ft} = \underline{1.1\ ft}$

For a rectangular channel in general with bottom width, b, and depth of flow, h, the hydraulic radius is given by

$$R_h = \frac{bh}{2h+b}$$

For any other shape channel the hydraulic radius can be calculated if the cross-sectional area of flow and the wetted perimeter can be determined.

Example: Calculate the hydraulic radius for flow through an 18 inch sewer flowing half full.

$A = \dfrac{1}{2}\ \dfrac{\pi d^2}{4} = \dfrac{1}{2}\ \dfrac{\pi (1.5)^2}{4}\ ft^2 =$

$P = 1/2\ (\pi d) = 1/2\ (\pi)\ (1.5)\ ft =$

$R_h = \dfrac{A}{P} =$

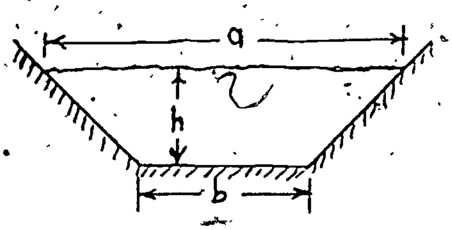
Handout No. D.2.1

PRACTICE PROBLEMS - 8

1) What is the hydraulic radius for flow through a 30 inch wide channel if the water is flowing 22 inches deep?

2) What is the hydraulic radius for flow through an irregularly shaped channel for which the liquid cross-sectional area has been estimated as 8.5 ft^2 and the wetted perimeter has been estimated as 7.8 ft?

3) What is the hydraulic radius for flow through a trapezoidal channel with bottom width of 2 ft and surface width of 44 inches if the depth of liquid is 20 inches and the length of the wetted wall is 23 inches on each side? Note: The area of the trapezoid shown below is $h/2(a+b)$.



MANNING EQUATION - OPEN CHANNEL

The velocity of water flowing through an open channel is affected mainly by three factors as follows:

1) Slope of channel, S: greater slope causes higher velocity.

2) Roughness of the channel surface as indicated by the Manning roughness coefficient, n: higher value of n (measuring rougher surface) causes lower velocity.

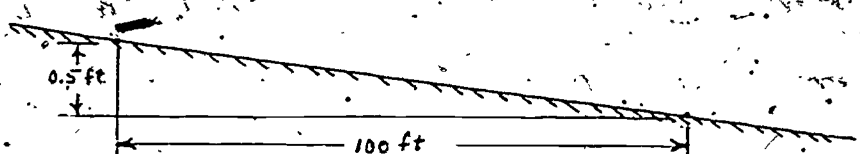
3) Size and shape of the channel as indicated by the hydraulic radius, R_H: Higher values of hydraulic radius result in higher velocity.

An equation frequently used to give the relationship among these variables for uniform open channel flow is the Chezy-Manning equation.

$$V = \frac{1.49}{n} R_H^{2/3} S^{1/2}$$

Instead of using this equation for each calculation, a nomograph such as that on Handout No. D.3.2 can be used to find a value for V, n, S, or R_H if values are known for the other three. Handout No. D.3.3 gives values of the Manning coefficient, n, for various materials.

The slope of a channel is normally expressed as feet of rise or fall per foot of horizontal distance. The slope of the channel shown below, for example, would be 0.5ft/100ft or 0.005.



Examples:

1) An open channel has S = 0.001, n = 0.014 and R_H = 0.8 ft. What is the velocity of flow under uniform flow conditions?

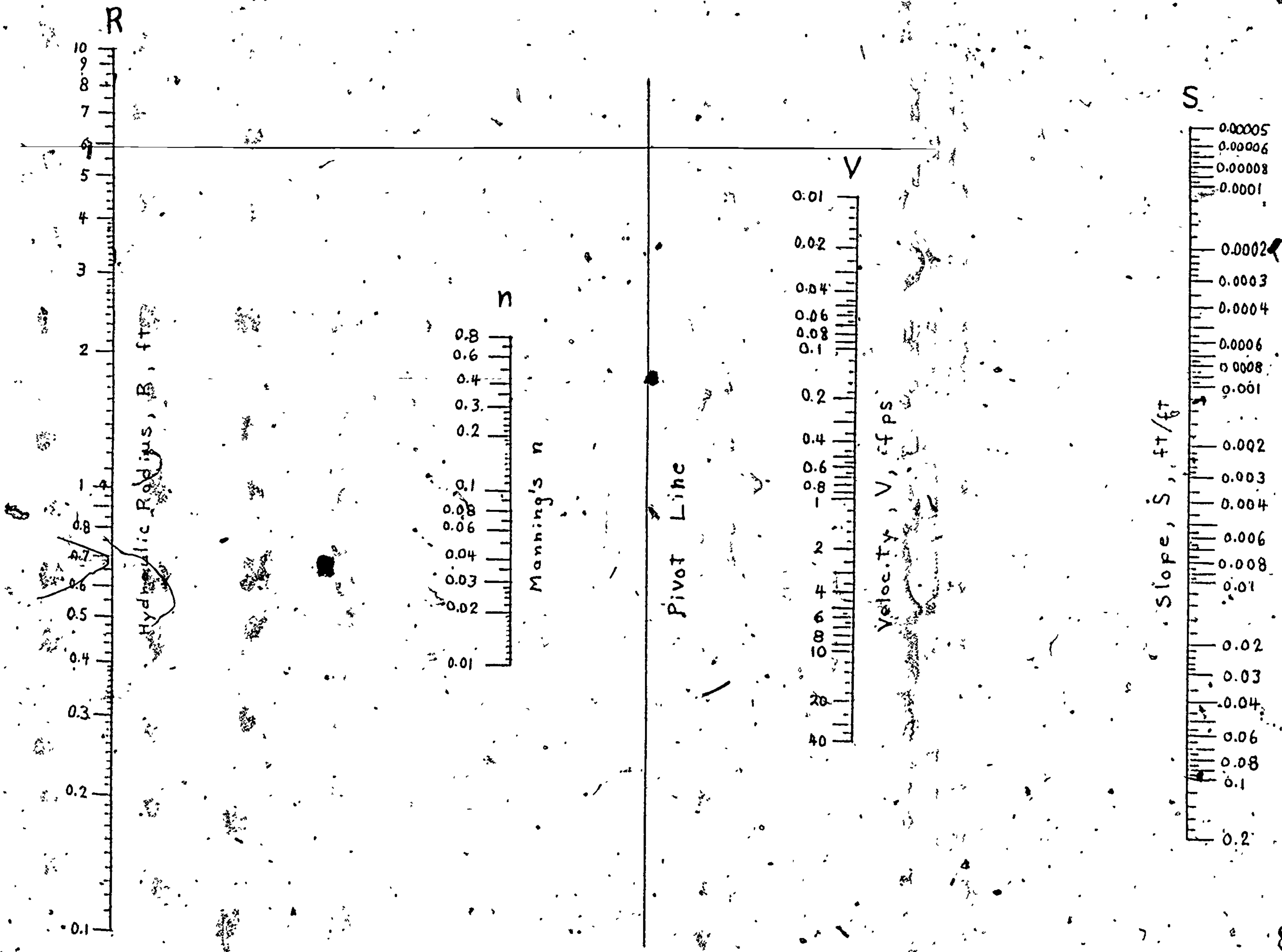
Solution: On Handout No. D.3.2 align a straight edge with R_H = 0.8 and n = 0.014 to locate a point on the pivot line. Then align the straight edge with that point on the pivot line and S = 0.001. Read off V at the intersection of that straight line and the V scale to find V = 2.4 ft/sec.

2) What should be the slope, S, to give V = 3ft/sec., with R_H = 2 ft. and n = 0.1?

Solution: Using Handout No. D.3.2 yields S = 0.015.

Handout No. D.3.1

CHEZY-MANNING NOMOGRAPH



MANNING ROUGHNESS COEFFICIENTS

Surface	n
Closed conduits flowing partly full:	
Smooth Brass	0.010
Glass	0.010
Clay drain tile	0.013
Concrete culvert with bends and connections	0.013
Unfinished Concrete	0.014
Cast Iron	0.015
Corrugated-metal storm drains	0.024
Lined or built-up channels:	
Smooth tar or paint coating	0.010
Unpainted steel	0.012
Planed wood	0.012
Unplaned wood	0.013
Trowel finished concrete	0.013
Glazed brick	0.013
Rough brick	0.016
Unfinished concrete	0.017
Excavated Channels:	
Clean earth (straight channel)	0.022
Earth with weeds (winding channel)	0.030

Values were taken from V.T. Chow, Open Channel Hydraulics, McGraw-Hill, 1959 and A.L. Simon, Practical Hydraulics, Wiley, 1976.

HAZEN WILLIAMS COEFFICIENTS

Type of Pipe	C
Brass	130-140
Brick sewer	100
Cast Iron	
New, unlined	130
Old, unlined	55-120
Tar coated	115-135
Concrete or concrete lined	
Steel forms	140
Wooden forms	120
Centrifugally spun	135
Copper	130-140
Galvanized iron	120
Glass	140
Lead	130-140
Plastic	140-150
Steel	
New, unlined	140-150
Riveted	110
Vitrified clay	100-140

Values were taken from A.L. Simon, Practical Hydraulics, Wiley, 1976 and H.M. Morris and J.M. Wiggert, Applied Hydraulics in Engineering, 2nd. Ed., Ronald Press, 1972.

PRACTICE PROBLEMS - 9

1) For uniform open channel flow, if V=1.0 ft/sec., S=0.002, and R_H=2.3 ft. what is the value of n?

2) Water is flowing through a concrete rectangular open channel 2 ft. wide at a depth of 1.8 ft. a) If the slope of the channel is 0.0016, estimate the velocity of flow. b) What is the discharge in cfs?

3) A rock lined channel, rectangular in shape and 6 ft. wide is to carry 40 cfs at a depth of 3 ft. what slope would be required to do this?

4) For a concrete rectangular channel, 2ft. wide, with a slope of 0.002, what would be the depth of flow for a velocity of 3 ft/sec?

Handout No. D.3.4

PRESSURE FLOW IN PIPES

For pressure flow in pipes, the Chezy-Manning equation and nomograph (discussed previously for open channel flow) can be used with the following modifications. The hydraulic radius becomes equal to one-fourth of the diameter and S equals the head loss per foot of pipe length rather than the pipe slope.

An alternate equation frequently used for pressure flow in pipes is the Hazen-Williams formula,

$$Q = 0.285\ C\ D^{2.63}\ S^{0.54}$$

where Q= discharge in gpm
D= diameter of pipe in inches
S= head loss per foot of pipe
C= Hazen -Williams coefficient

Values of C for various pipe materials are given on Handout No. D.3.3 and a nomograph solution of the Hazen -Williams equation is given on Handout No. D.4.2

Examples:

1) What would be the head loss due to a flow of 3500 gpm through 200 ft. of 18 inch new cast iron pipe?

Solution: From Handout No. D.3.3, C = 130

Using the Hazen -Williams nomograph with :
Q= 3500 gpm, D=18 inches, and C= 130 gives S=0.011 ft/ft

$$S = \frac{H_f}{L} = 0.011\ \text{ft/ft or } \frac{H_f}{200\ \text{ft}} = 0.011\ \text{ft/ft}$$

$$H_f = (200)\ (0.011)\ \text{ft} = 2.2\ \text{ft}$$

2) What flow rate would be caused through 500 ft of steel form concrete pipe 18 inches in diameter by a head of 10 ft?

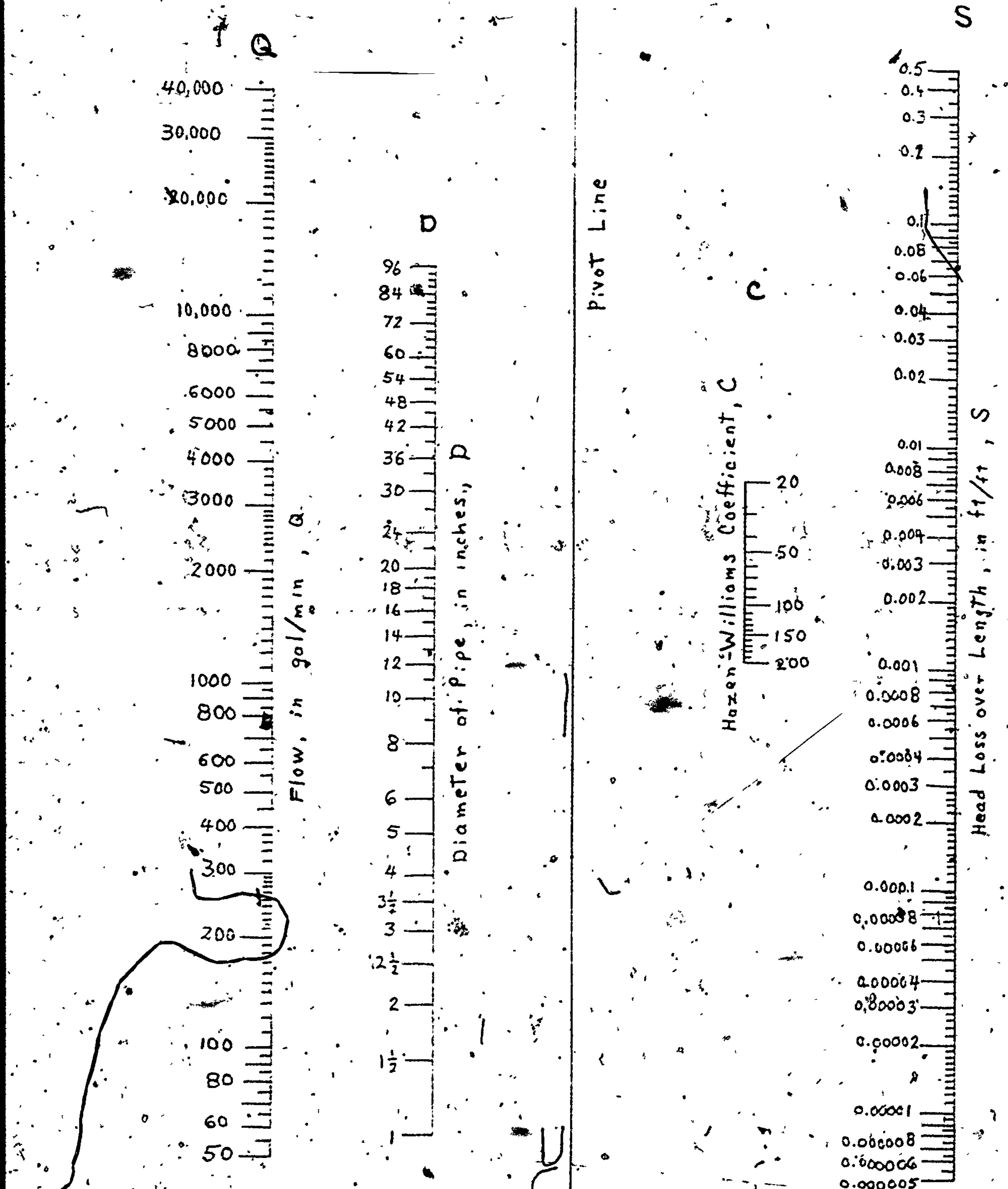
Solution: From Handout No. D.3.3, C=140

$$S = \frac{H_f}{L} = \frac{10}{500} = 0.02$$

Using the nomograph with S = 0.02, C = 140, and D = [illegible] gives
<u>Q = 11,000 gpm</u>

Handout No. D.4.1

HAZEN-WILLIAMS NOMOGRAPH



Handout No. D.4.2

PRACTICE PROBLEMS - 10

1) What would be the head loss due to a flow of 5000 gpn through 100 ft. of 24 inch centrifugally spun pipe?

2) What will be the discharge through 200 feet of 12 inch riveted steel pipe is a head of 5 feet is available to drive the flow?

3) What diameter brass pipe would be required to carry 200 gpm with a head loss per foot of 0.01?

Handout No. D.4.3

MINOR LOSSES IN PIPES

In addition to the frictional head loss due to flow through straight lengths of pipe, there are also head losses due to elbows, valves, pipe entrances, etc. These losses are called "minor losses" or "local losses". For systems with 100 ft. of pipe length or more, with few fittings, the minor losses are often negligible, but for shorter lengths of pipe the minor losses may be a significant portion of the total head loss. The minor losses can be estimated by the following equation:

$$h_f = K \frac{V^2}{2g}$$

Where h_f is the head loss across the fitting in ft, V is the average velocity in the pipe entering the fitting in ft/sec, K is the loss coefficient for the particular fitting (values are given on Handout D.5.2), and g = 32.2 ft/sec.

Example: What would be the total of the minor losses in a piping system containing 5 standard 90° elbows, 2 half open gate valves, one swing type check valve, a perpendicular square entrance, and an exit from the pipe to a large tank. The pipe in the system is 4 inches in diameter and the discharge is 300 gal/min.

Solution:

Find average velocity,

$$V = \frac{Q}{A} = \frac{(300/449)\ \text{cfs}}{\frac{\pi(4/12)^2}{4}\ \text{sq.ft}} = \frac{0.668\ \text{cfs}}{0.0873\ \text{sq.ft.}} = 7.65\ \text{ft/sec}$$

From Handout D.5.2, the K values are as follows:

std. 90 elbows:	$K_1 = 0.8$
half open gate valve:	$K_2 = 5.6$
check valve:	$K_3 = 2.5$
entrance:	$K_4 = 0.5$
exit:	$K_5 = 1.0$

$$(h_f)_{\text{Total}} = 5(0.8)\frac{V^2}{2g} + 2(5.6)\frac{V^2}{2g} + (2.5)\frac{V^2}{2g} + (0.5)\frac{V^2}{2g} + (1.0)\frac{V^2}{2g}$$

$$(h_f)_{\text{Total}} = [5(0.8) + 2(5.6) + 2.5 + 0.5 + 1.0]\frac{V^2}{2g}$$

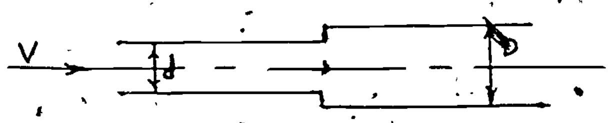
$$(h_f)_{\text{Total}} = (19.2)\frac{(7.65)^2}{(2)(32.2)}\ \text{ft} = \underline{17.4}\ \text{ft.}$$

Handout No. D.5.1

LOSS COEFFICIENTS FOR FITTINGS

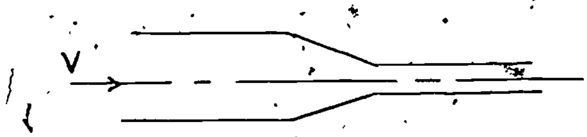
Type of Fitting	K
Globe valve, fully open	10.0
Angle valve, fully open	5.0
Swing check valve, fully open	2.5
Gate valve, fully open	0.2
Gate valve, 3/4 open	1.0
Gate valve, 1/2 open	5.6
Gate valve, 1/4 open	24.0
Short-radius 90 elbow	0.9
Standard-radius 90 elbow	0.8
Long-radius 90 elbow	0.6
45 Elbow	0.4
Closed return bend	2.2
Tee, through side outlet	1.8
Tee, straight run	0.3
Coupling	0.3
Sharp-edged inlet	0.5
Rounded inlet	0.05
Inlet with pipe projecting in	1.0
Exit loss	1.0

Sudden Enlargement



$$(1 - (d/D)^2)^2$$

Gradual Reduction



0.05

These K values are for use in the following equation:

$$\text{Head loss through fitting} = K\left(\frac{V^2}{2g}\right)$$

Where V = velocity in the pipe approaching the fitting.

Handout No. D.5.2

PRACTICE PROBLEMS - 11

1) What would be the total minor losses due to fittings in a piping system containing a fully open globe valve, a fully open swing check valve, 3 long-radius 90° elbows, a projecting entrance, and an exit into a reservoir? The pipe in the system is 6 inches in diameter and the discharge is 0.8 MGD.

2) What would be the total frictional head loss, due to straight pipe and fittings, for a system made up of 100 ft. of 4 inch diameter pipe, a sudden enlargement to 6 inch pipe, 200 ft. of 6 inch pipe, and a swing check valve? The entrance is a sharp-edged inlet and the flow rate is 300 gal/min.

Handout No. D.5.3

FRICTIONAL PRESSURE LOSS

The discussion up to now has centered on frictional head loss. For pressure flow through a horizontal pipe the frictional head loss will actually be a pressure loss.

Another way of stating this is that the pressure always decreases in the direction of flow for a horizontal pipe, or the flow is always from a higher to a lower pressure. (In uniform open channel flow, for comparison, flow is always from a higher to a lower height).

The frictional pressure loss and frictional head loss are related as follows:

$$\Delta P_f = \gamma h_f \quad \text{or} \quad h_f = \frac{\Delta P_f}{\gamma}$$

Where γ is the specific weight of water, 62.4 lb/ft^3, ΔP_f is the frictional pressure loss in psf, and h_f is the frictional head loss in ft.

Examples:

1) For a certain section of pipe the frictional head loss is 30 ft.. If water is discharging into the atmosphere at one end, what is the pressure in psi at the other end of the section?

Solution:

$\Delta P_f = \gamma h_f = (62.4 \text{ lb/ft}^3)(30 \text{ ft}) = 1872$ psf

convert to psi: $\Delta P_f = \frac{1872}{144}$ psi = 13 psi

This is the pressure loss along the section of pipe. If it is discharging against atmospheric pressure, then the pressure at the upstream point must be 13 psig or 27.7 psia.

2) What head loss in feet corresponds to a pressure loss of 20 psi?

Solution:

$$\Delta P_f = 20 \text{ psi} = 20 \times 144 \text{ psf} = 2880 \text{ psf}$$

$$h_f = \frac{\Delta P_f}{\gamma} = \frac{2880}{62.4} \text{ ft} = 46 \text{ ft}$$

Handout No. D.6.1

PRACTICE PROBLEMS - 12

1) In the example on handout D.5.1, a head loss of 17.4 ft. was found due to minor losses in fittings. What would be the pressure loss due to the fittings?

2) If the pressure loss through a piping system is measured to be 17.5 psi what is the head loss through the system in feet?

Handout No. D.6.2

WATER DISTRIBUTION SYSTEMS

The methods of calculations considered in the last three sections can be used to analyze flow through piping systems as follows.

<u>Example</u>: Water is to flow at a rate of 300 gpm through a section of a piping system consisting of 220 ft of 4 inch diameter pipe, 5 standard 90° elbows, and 2 half open gate valves. If the water exits the section to atmospheric pressure, what must the gage pressure be at the entrance to the section?

<u>Solution</u>: If the section exits to atmospheric pressure, then the gage pressure at the entrance to the section must be equal to the frictional pressure loss through the section of piping.

$$\Delta P_f = \gamma h_f = \gamma(h_f - \text{st. pipe} + h_f - \text{minor losses})$$

i) Find h_f - st. pipe:

Using the Hazen-Williams nomograph with Q = 300 gpm, D = 4 inches, & C = 120 gives

$$S = 0.047 = \frac{h_f}{L}$$

h_f - st. pipe = 0.047L = 0.047 x 200 ft = <u>10.3 ft</u>

ii) Find h_f - minor losses:

$$V = \frac{Q}{A} = \frac{(300/449)\ \text{cfs}}{\frac{\pi}{4}\left(\frac{4}{12}\right)^2 \text{ft}^2} = 7.65\ \text{ft/sec}$$

K values are as follows:

Standard 90° elbows	- K_1 = 0.8
half open gate valve	- K_2 = 5.6
exit	- K_3 = 1.0

$$h_f - \text{minor losses} = [5(0.8) + 2(5.6) + 1.0]\ \frac{(7.65)^2}{2(32.2)}\ \text{ft}$$

h_f - minor losses = <u>14.7 ft</u>

iii) Calculate ΔP_f

$$\Delta P_f = 62.4(10.3 + 14.7)\ \text{psf} = 1560\ \text{psf}$$

Required gage pressure = <u>1560 psfg</u>

$$= \frac{1560}{144}\ \text{psig} = \underline{10.8\ \text{psig}}$$

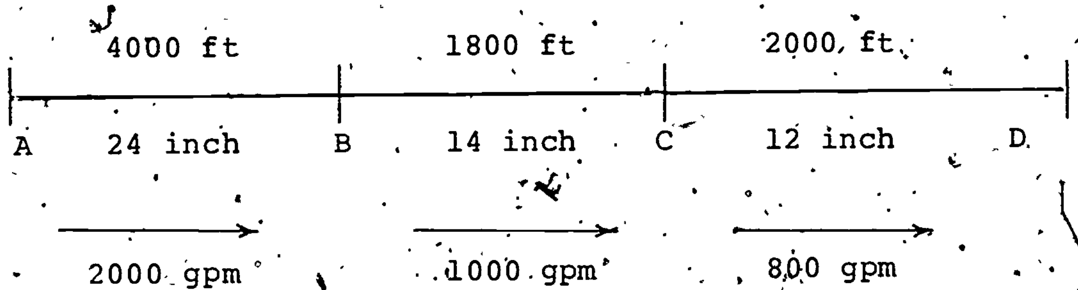
Handout No. D.7.1

PRACTICE PROBLEMS - 13

1) Water flows through a steel piping system at 400 gpm. The system consists of 110 ft. of horizontal straight 4 inch pipe, a sudden enlargement from 4 to 5 inches, 220 ft. of horizontal 5 inch pipe, and a 90° long radius elbow. A pressure gage at the system inlet shows a pressure of 100 psig. What would be the pressure reading at a gage located in the 5 inch pipe at the system outlet?

2) a) What pressure would be required at point A in order to give a pressure of 30 psig at point D?

b) What would be the pressure at point B?



Handout No. D.7.2

VELOCITIES IN SEWERS

There are several general requirements for flow in sewers which relate to velocity in the sewers and size of the sewers as follows.

1) The sewer must convey the required flow rate while flowing partially full or barely full.

2) The velocity must be great enough to prevent deposition of entrained solids along the bottom of the sewer.

3) The velocity must not be so great as to cause erosion of the channel surface.

Typically this is accomplished by designing sewers for velocity between 2 ft/sec as a minimum to 10 ft/sec as a maximum at either half or full flow.

Sewers are typically designed for different depths of flow as follows.

1) Sanitary wastewater

a) diameter less than 24 inches - to flow less than half full.

b) diameter greater than 24 inches - designed to flow less than 0.7 full.

2) Storm water - designed to run full with velocity between 2 ft/sec and 10 ft/sec.

The sewer diameter, sewer surface roughness, velocity of flow, and slope of sewer are all related to each other as previously discussed in connection with the Chezy-Manning equation and the Hazen-Williams equation. Thus in order to meet the requirements listed above, the slope and roughness of the sewer must be considered together with the velocity and diameter of the sewer.

Handout No. E.1

FLOW IN FILLED SEWERS

For flow in filled sewers, the velocity or discharge can be related to the slope, diameter, and roughness of the sewer by the Chezy-Manning equation or the Hazen-Williams equation as discussed earlier.

The Chezy-Manning equation or nomograph can be used for calculation of V, S, or D if given values of the other two and a value for the roughness coefficient.

There are several possibilities for the calculation of Q, S, or D if given values for the other two and a value for the roughness coefficient.

1) Use the Chezy-Manning nomograph on Handout No. D.3.2 together with the relation Q = VA.
2) Use the Hazen-Williams nomograph on Handout No. D.4.2
3) Use the graph on Handout No. E.2.2 which relates Q, S, & D for n =0.013 (The value n = 0.013 is commonly used for sanitary sewers - see Handout No. D.3.3).

Example: What would be the velocity and discharge through an 18 inch diameter sewer with a slope of 0.002 if it is flowing full and is made of vitrified clay?

Solution: From Handout No. D.3.3 n = 0.013, C = 100
Calculate area of flow: $A = \frac{\pi (1.5)^2}{4} \text{ ft}^2 = 1.77 \text{ ft}^2$

i) Using the Hazen-Williams nomograph with S = 0.002, C = 100, and D = 18" gives Q = 1950 gpm

$$V = \frac{Q}{A} = \frac{(1950/449) \text{ cfs}}{1.77 \text{ ft}^2} = 2.5 \text{ ft/sec}$$

ii) Using the Chezy-Manning nomograph with $R = \frac{1.5}{4}$ ft = 0.375 ft, n = 0.013, and S = 0.002 gives V = 2.6 ft/sec

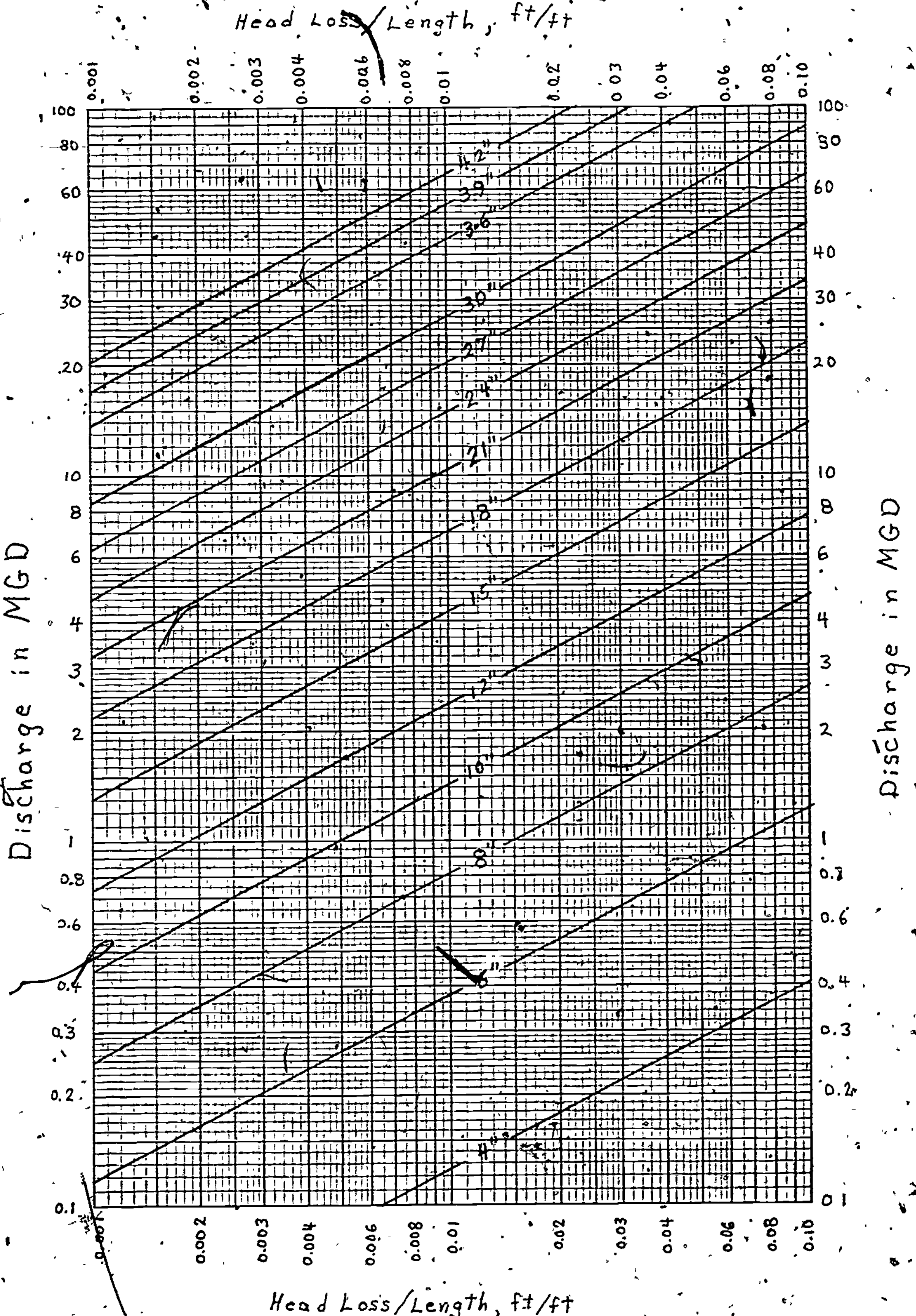
$$Q = VA = (2.6)(1.77) \text{ cfs} = (2.6)(1.77)(449) \text{ gpm} = 2066 \text{ gpm}$$

iii) Using the graph on Handout E.2:2 with S = 0.002 and D = 18" gives Q = 3.0 MGD = 3.0 x 694 gpm = 2082 gpm

Handout No. E.2.1

PIPE DISCHARGE, FLOWING FULL

(from Manning Equation, with n = 0.013)



Handout No. E.2.2

PRACTICE PROBLEMS - 14

1) What would be the velocity and discharge through a 24 inch diameter sewer of vitrified clay with a slope of 0.001 if it is flowing full?

2) What diameter vitrified clay pipe would be required to carry 4000 gpm along a slope of 0.006 with the pipe flowing full?

3) What slope would be required to carry 8000 gpm through a 36 inch diameter sewer flowing full, if n = 0.013 and C = 100?

Handout No. E.2.3

FLOW IN PARTIALLY FILLED SEWERS

The velocity and discharge in a partially filled sewer can be estimated by first calculating V_f and Q_f, the velocity and discharge if it were flowing full, and then using a table or graph relating $\frac{V}{V_f}$ and $\frac{Q}{Q_f}$ to $\frac{d}{D}$.

where d = depth of flow in sewer
D = diameter of sewer
V = velocity in partially full sewer
Q = discharge through partially full sewer

Example: On Handout No. E.2.1 the velocity and discharge were calculated for an 18 inch vitrified clay sewer with a slope of 0.002 if it were flowing full. What would be the velocity and discharge if the sewer were only flowing 12 and 1/2 inches deep?

Solution:

From the previous calculations Q_f = 2000gpm and V_f = 2.5 ft/sec

From the graph on Handout No. E.3.2 with $d/D = \frac{12.5}{18} = 0.7$,

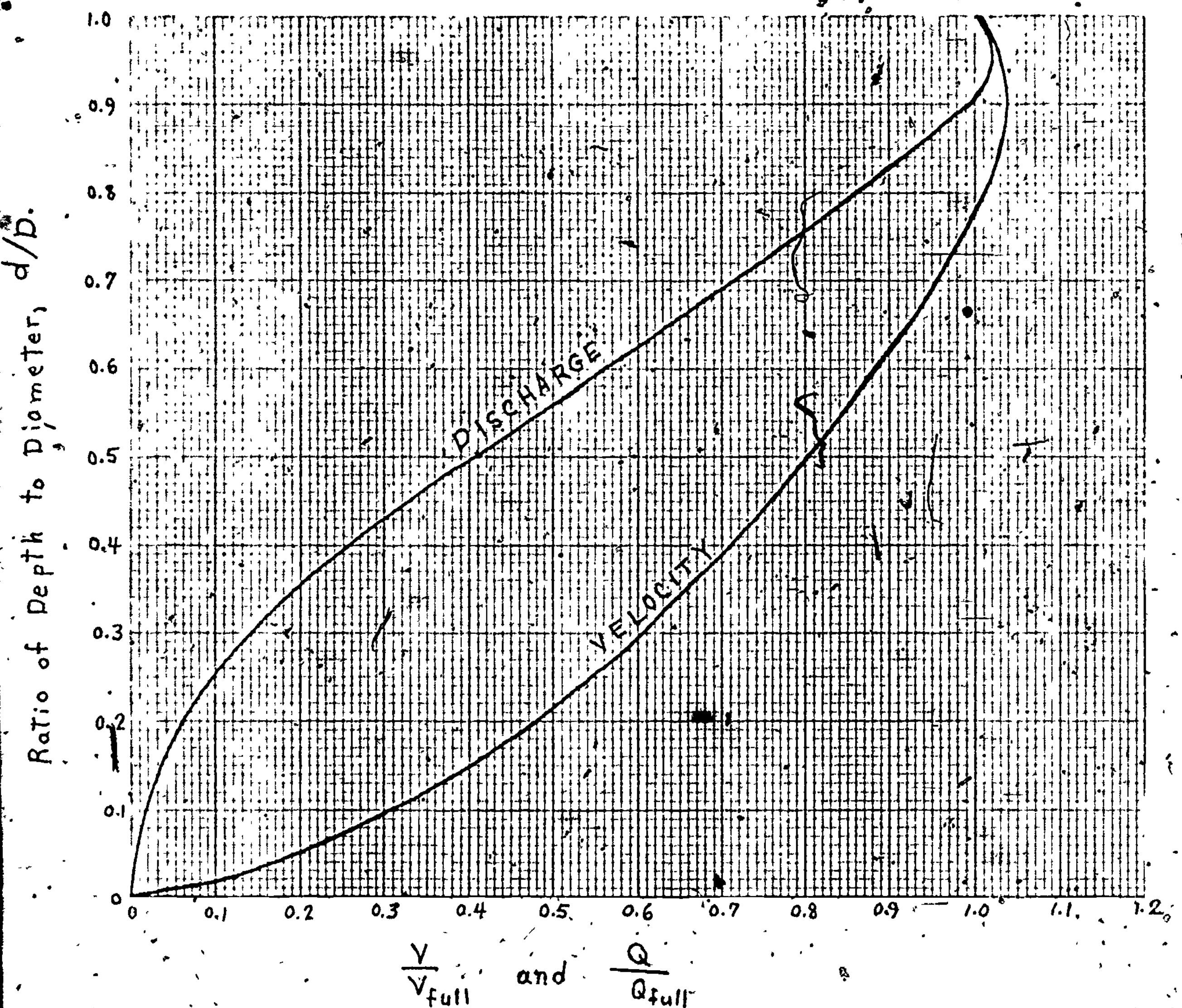
$$\frac{V}{V_f} = 0.95 \quad \frac{Q}{Q_f} = 0.71 \quad \text{thus, } V = 0.95 \times 2.5 \text{ ft/sec} = 2.4 \text{ ft/sec}$$
$$Q = 0.71 \times 2000\text{gpm} = 1420 \text{ gpm}$$

The curves given on Handout No. E.3.2 do take into account the fact that the roughness factor, n, changes if the sewer is not flowing full.

Note that the velocity remains within 10% of the full sewer velocity as long as d/D is greater than 0.63. In fact, if the velocity will be great enough for self-cleansing if the full sewer velocity is adequate, because the required self-cleansing velocity is less if the sewer is flowing less than full.

Handout No. E.3.1

DISCHARGE & VELOCITY IN PARTIALLY FILLED SEWERS



Handout No. E.

1) What would be the velocity and discharge through a 24 inch diameter sewer of vitrified clay with a slope of 0.001, if it is flowing 0.6 full? (see problem 1 on Handout E.2.3)

2) What slope would be required to carry 8000 gpm through a 36 inch diameter sewer flowing 0.7 full, if n = 0.013 and C = 100? (Hint: Use d/D = 0.7 to find Q/Q_f and then find Q_f using Q = 8000 gpm. Then use Q_f to find the required diameter the full sewer method discussed previously).

Handout No. E.3.3