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MILITARY HANDBOOK

DRAINAGE SYSTEMS

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ABSTRACT

This military handbook provides design criteria and planning guidelines for use by experienced engineers for design of drainage systems. The topics include drainage system objectives and criteria for both surface water and groundwater; hydraulic computation criteria and methodologies for open-channel flow and closed-conduit flow; open-channel systems; closed-conduit systems; groundwater drainage; storage facilities; pumping facilities; outfalls; and drainage law, regulations, and regulatory agencies.

FOREWORD

This handbook is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies, and the private sector. This handbook uses, to the maximum extent feasible, national and institute standards in accordance with NAVFACENGCOM policy. Do not deviate from MIL-HDBK-1005/3 without prior approval of NAVFACENGCOM Headquarters (Code 04).

Recommendations for improvement are encouraged from within the Navy, other Government agencies, and the private sector and should be furnished on the DOD Form 1426 provided inside the back cover to Commander, Atlantic Division, Naval Facilities Engineering Command, Code 04A4, Norfolk, VA 23511-6287; commercial telephone (804) 444-9970.

THIS HANDBOOK SHALL NOT BE USED AS A REFERENCE DOCUMENT FOR PROCUREMENT OF FACILITIES CONSTRUCTION. IT IS TO BE USED IN THE PURCHASE OF FACILITIES ENGINEERING STUDIES AND DESIGN (FINAL PLANS, SPECIFICATIONS, AND COST ESTIMATE.) DO NOT REFERENCE IT IN MILITARY OR FEDERAL SPECIFICATIONS OR OTHER PROCUREMENT DOCUMENTS.

CIVIL ENGINEERING DESIGN MANUALS

Criteria Number	Title	PA
MIL-HDBK-1005/2	Hydrology	LANTDIV
MIL-HDBK-1005/3	Drainage Systems	LANTDIV
DM-5.04	Pavements	LANTDIV
DM-5.06	Trackage	NORTHDIV
MIL-HDBK-1005/7	Water Supply Systems	LANTDIV
MIL-HDBK-1005/8	Domestic Wastewater Control	NEESA
MIL-HDBK-1005/9	Industrial and Oily Wastewater Control	HDQTRS
DM-5.10	Solid Waste Disposal	PACDIV
MIL-HDBK-1005/12	Fencing, Gates, and Guard Towers	NCEL
MIL-HDBK-1005/13	Hazardous Waste Storage Facilities	HDQTRS
DM-5.14	Groundwater Pollution Control	HDQTRS

DRAINAGE SYSTEMS

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TABLES

Section 1: INTRODUCTION

1.1 Scope. MIL-HDBK-1005/3 addresses the criteria, computational methodologies, and sources of information relating to drainage systems. This handbook is subdivided into the following general categories:

a) Drainage System Objectives and Criteria

b) Hydraulic Computation Criteria

c) Open-Channel Systems

d) Closed-Conduit Systems

e) Groundwater Drainage

f) Storage Facilities

g) Pumping Facilities

h) Outfalls

i) Drainage Law

1.2 Application. MIL-HDBK-1005/3 is to be used by the qualified designer who has general training, education, and experience with the design of drainage systems. The purpose of this handbook is to provide NAVFACENGCOM design guidance, criteria, and computational methodology.

1.3 Cancellation. This handbook, MIL-HDBK-1005/3, dated 20 September 1990, cancels and supersedes NAVFAC DM-5.03, Drainage Systems, dated February 1986.

1.4 Deviation From Criteria. Under the Total Quality Management (TQM) procedures adopted by NAVFACENGCOM, criteria should not be considered as hard and fast, as in the past. Should it appear that relaxation of criteria will result in a more cost effective solution for the user, or result in greater user satisfaction with the completed construction, the criteria should be questioned and brought to the attention of NAVFACENGCOM Code 04A1B, telephone (202) 325-0036. NAVFACENGCOM will then do the research and paperwork required, to either waive the criteria for the project in question, or if applicable, to waive the criteria for all EFDs.

(The above direction received at the DOD Quality Management (DQM) Conference held at NAVFACENGCOM, March 1990.)

1.5 Application of Criteria

1.5.1 Existing Facilities. The criteria presented in this handbook is generally applicable to new construction only and does not apply to existing facilities which do not conform to this criteria. The exception is in cases which affect safety, security, or is critical in some way to the operational requirement of the activity.

1.5.2 Repair of Existing Facilities. If a facility is being repaired by replacement in kind, then the criteria will generally be applicable. The prohibition against construction in a flood plain, for instance, where a viable alternative exists, is to reduce the risk of catastrophic loss of the facilities. However, in some cases, construction and repair of facilities in a flood plain may be required due to engineering or cost reasons, where the risk can be justified. The following are essential considerations:

a) The nature of facility; whether construction and repair of the facility is critical to the mission of the facility, and if so, how critical uninterrupted operation is to this mission. (Are there backup facilities?)

b) Whether local flood control measures can be inexpensively done. If not, the changes to the regional drainage pattern must be made and its cost justified.

c) The effect of not taking any action pertaining to drainage and the potential effect on the facilities. The predicted frequency with which the criteria in the handbook will be exceeded and the effect on the facility.

Section 2: DRAINAGE SYSTEM OBJECTIVES AND CRITERIA

2.1 Surface Water. Design drainage systems to properly drain surface runoff, including runoff from melting snow, which can damage Government facilities, property, and adjoining land. A well-designed system will accomplish this objective in a safe, economical, ecologically sound, and aesthetically pleasing manner without damaging adjacent facilities, developments, and land.

2.1.1 Classification. Surface drainage systems are functionally classified as minor or major drainage systems depending on the consequences of drainage flows exceeding the system capacity. For minor drainage systems, the consequences should be only minor temporary flooding and inconvenience without loss of facility use. For major drainage systems, the consequences may be serious property damage, possible loss of life, or loss of facility use. Except for unusual situations, the division between minor and major drainage systems will be taken as a contributory watershed of 100 acres or a design runoff of 300 cubic feet per second.

2.1.2 Runoff Frequencies. The capacities of drainage systems and the degree of protection against flooding for various facilities are expressed in terms of runoff frequencies (i.e., storm frequencies). The frequency of the runoff event is taken as the frequency of the precipitation event. Thus, a 10-year storm or precipitation event is assumed to produce a 10-year runoff event.

2.1.3 Drainage System Design Frequency. The design frequency of a drainage system is that runoff frequency for which the system has sufficient hydraulic capacity to maintain the flow within given hydraulic criteria. For a closed-conduit system, the hydraulic criteria may be expressed as limitations on the hydraulic or energy grade lines. For open channels, the hydraulic criteria may be freeboard or velocity limitations. Design frequencies for various elements of drainage systems are given in Table 1.

2.1.4 Facility Degree of Protection. The degree of protection for a facility against flooding is also expressed in terms of runoff frequency. In this case, however, the criteria relate to the flood plains associated with the drainage systems. Flooding will occur when the hydraulic capacity of the drainage system is exceeded. Degrees of protection for various facilities are given in Table 2. The values are consistent with MIL-HDBK-1190, Facility Planning and Design Guide.

Table 1
Drainage System Design Frequency (Years)

Type of Facility	Minor System DA <100 ac	Major System 100 ac ≤DA ≤640 ac	DA >640 ac
<u>Element of Drainage System</u>			
Temporary systems			
Gutters, swales	2	N/A	N/A
Analysis of natural channels	2	50	100
Improved open channels	2	25	50
Lining for improved channels	2	N/A	N/A
Closed conduits	2	N/A	N/A
Culverts *	2	5	10
Bridges	N/A	10	25
Permanent systems			
Gutters, swales, and inlets	5-10	N/A	N/A
Natural channels	10	100	100
Improved channels	10	50	100
Lining for improved channels	5	25	50
Closed conduits	5-10	25	50
Culverts *	10	10-100	25-100
Bridges	N/A	50-100	100

DA - Drainage area
ac - Acres
N/A - Not applicable

The design frequency of culverts is determined by the classification of roadway under which the culvert conveys water (see Table 2).

* Local roads and streets, driveways, and entrance roadways may be excepted, where necessary, provided depth of flow does not exceed 4 inches at crown of roadway.

Table 2
Facility Degree of Protection (Years)

Type of Facility	Minor System DA <100 ac	100 ac ≤DA ≤640 ac	Major System DA > 640 ac
Temporary Facilities			
Roads and other surface facilities	2	5	10
Critical buildings	25	50	100
Other buildings and structures	10	25	100
Permanent Facilities			
Roads - AASHTO classification			
Expressways	10	100	100
Arterials	10	50	100
Collectors	10	25	50
Local roads and streets*	5	10	25
Other Surface Facilities*			
Paved	5	10	25
Nonpaved	5	5	10
Critical Facilities	100	500	500
Hazardous chemical/storage			
Hospitals			
Communication facilities			
Defense operational facilities			
Other Facilities	50	100	100
Industrial operational facilities			
Housing			
Administrative facilities			
Recreational Buildings	25	50	100
Other Structures	25	50	100

DA - Drainage area   ac - Acres

* Local roads and streets, driveways, and entrance roadways may be excepted, where necessary, provided depth of flow does not exceed 4 inches at crown of roadway.

2.1.5 Examples of Design Frequency and Degree of Protection. The following examples illustrate the application of design frequency and degree of protection.

a) Example 1: A permanent collector road crosses a stream with a 1,000-acre (ac) drainage area (DA) and a culvert is to be utilized. The roadway is open sectioned. Find the design frequency of both systems.

	Frequency (Years)	
Element	Table 1 Design Frequency	Table 2 Degree of Protection
Roadway - open section	N/A (open section embankment)	50 (DA = 1,000 ac > 640 ac)
Culvert	50 (DA = 1,000 ac > 640 ac)	N/A

Use 50-year frequency for the design of both systems.

b) Example 2: A permanent administrative facility with a paved parking lot having curbs, inlets, and closed-conduit drainage system is to be located adjacent to a stream with a 400-acre drainage area.

	Frequency (Years)	
Element	Table 1 Design Frequency	Table 2 Degree of Protection
Parking lot	N/A	10 (Stream DA = 400 ac <640 ac)
Gutters, inlets	5 (Parking lot DA < 100 ac)	N/A
Closed-conduit drains	5 (Parking lot DA < 100 ac)	N/A
Administrative facility	N/A	100 (Stream DA = 400 < 640 ac)

Use 10-year frequency for parking lot, 5-year frequency for gutters and inlets, 5-year frequency for closed-conduit drains, and 100-year frequency for administrative facility. If the adjacent stream channel is an improved channel with a lining, the lining will be designed for a 25-year frequency, but the total channel, including the portion above the lining, will be designed for a 50-year frequency (see Table 1).

2.1.6 Runoff Computations. Develop layout, points of entry, and contributory areas; and compute runoffs for the design frequencies at appropriate locations in the drainage system. Use the methodologies given in MIL-HDBK-1005/2, Hydrology, to determine runoffs.

2.1.7 Interfaces With Other Drainage Systems. Where Government drainage systems connect with other drainage systems, comply with applicable state or local regulations as required. Use NAVFACENGCOM criteria if it is more stringent than state or local regulations. In all cases, coordinate with local authorities.

2.1.8 Drainage System Components. The objectives, general criteria, and guidelines for the design of various components of the minor and major drainage systems are established below.

a) Minor Drainage System. The minor drainage system is that part of the overall drainage system which initially collects surface runoff before it becomes an inconvenience and conveys it to a suitable point of discharge.

(1) Surface Drainage. Provides positive drainage away from buildings and other facilities. For the first 10 feet, provide a minimum slope of 5 percent and, where possible, 10 percent. Establish finished floor elevations at least 6 inches above finish grade at perimeter. Where vehicular or handicapped access is required, provide a ramp or build a pavement to meet finished floor at the building entrance. In open areas, provide a minimum slope of 0.3 percent for asphalt, concrete, and earth surfaces.

(2) Swales. In locations where drainage is directed toward buildings and other facilities, provide intercepting swales and/or drains as far removed from the structure perimeter as topography will permit. Use swales to collect surface runoff and direct it to inlets, catch basins, and other points of entry into the minor drainage system. Where vehicular or pedestrian traffic must cross swales, limit depth of flow to comply with the traffic flow.

(3) Gutters. Provide gutters and limit lateral spread to parking and slow travel areas with depth of gutter flow compatible with type of curbing and traffic. Intercept gutter flow at intersections upstream from pedestrian crossings. For cold climates, consider the use of a gutter on the higher side of a sloped roadway to intercept upland flow which would drain across traveled lanes and possibly freeze.

(4) Open Channels. Use natural or improved open channels and ditches wherever land use requirements permit the allocation of space. Provide culverts at crossings with vehicular or pedestrian traffic.

(5) Closed Conduits. Where land uses require the minimum possible space to be devoted to a storm drainage system, use a closed-conduit system. Examine the path of storm water which does not enter the closed-conduit system to determine if it will cause intolerable damage. Consider storm water management techniques to reduce the design capacity requirements of closed-conduit systems. Provide adequate horizontal and vertical separation from other utilities and underground facilities; do not locate in the same trench as another utility without specific approval of the particular application.

(6) Storage. Where operational land uses and safety requirements permit, use temporary storage of storm water (detention storage) to reduce peak flow rates, satisfy storm water management requirements, and reduce the capacity of storm water drainage and pumping systems. Consider the permanent storage of storm water (retention storage) for recreational, aesthetic, and ecological purposes.

b) Major Drainage Systems. The major drainage system is that part of the overall drainage system which has a contributory drainage area of 100 acres or more, or has a design runoff of 300 cubic feet per second or greater. If the design runoff is not fully confined in a natural or improved channel or drainage structure, a flood plain will be created. Identify and delineate any such flood plain, both in elevation and lateral extent. Provide flood protection for facilities crossing or adjacent to the flood plain. Protect the facility from runoff having a frequency equal to the degree of protection frequency given in Table 2.

(1) Natural Channels. Wherever possible, use natural channels and flood plains in lieu of improved channels. Although a natural major drainage system may require a greater allocation of land, it often has significant advantages over an improved system. These usually include better storm water management, better ecological characteristics, and lower project costs. If the proposed development significantly increases the runoff in a natural channel, examine the channel for potential erosion hazards. Approach channel improvements in stages, beginning with the removal of local constrictions and the protection of erosion prone segments.

(2) Improved Channels. Where space requirements of a major natural channel conflict with existing or proposed facilities, modifications to the natural channel shall be minimized to the fullest extent. Fully consider and evaluate the environmental, hydraulic, and legal aspects of the proposed modifications.

(3) Culverts and Bridges. Where the major drainage system must be crossed for vehicular, trackage, or pedestrian access, provide culverts or bridges depending on the specifics of the locations. Provide the required degree of protection for the access crossing based on the flood plain of the major drainage system. Consider a low point in the access crossing, away from the culvert or bridge, to provide an overflow in case of runoff in excess of

the design frequency. Fully consider and evaluate the environmental, hydraulic, and legal aspects of the proposed culvert or bridge.

2.2 Groundwater. Objectives of groundwater drainage systems may include dewatering for excavations, stabilization of soil, reduction of pore pressure, reduction of frost susceptivity, drainage of base and subbase pavement courses, interception of flowing groundwater, and drainage for agricultural purposes.

2.2.1 Need for Subsurface Drainage Systems. Refer to the following specific references relating to the type of facility for conditions requiring subsurface drainage and design criteria:

a) Dams, Levees, and Flood Walls: U.S. Army Corps of Engineers (COE), EM 1110-2-1913, Design and Construction of Levees, and EM 1110-2-2501, Wall Design: Flood Walls.

Hydraulic Engineering Center (HEC), Hydrologic Engineering Methods for Water Resources Development, Volume 10, Principles of Groundwater Hydrology, Chapter 5.

b) Pavements: U.S. Army COE, TM 5-820-2, Drainage and Erosion Control: Subsurface Drainage Facilities for Airfield Pavements.

c) Buildings: NAVFAC DM-7.02, Foundations and Earth Structures.

d) Trackage: NAVFAC MIL-HDBK-1029/2, Marine Railways, Sections 3 and 4.

e) Soil Conservation: U.S. Army COE, TM 5-820-3, Drainage and Erosion Control: Structures for Airfields and Heliports, and TM 5-820-4, Drainage and Erosion Control: Drainage for Areas Other Than Airfields.

U.S. Environmental Protection Agency (EPA), EPA-R2-72-015, Guidelines for Erosion and Sediment Control Planning and Implementation.

2.2.2 Economic Considerations. Utilize locally available materials and gravity drainage to reduce costs. Select materials compatible with corrosiveness of soils and groundwater, required life, and structural loading. Consult local highway departments for practices and experiences.

2.2.3 Flow Quantities. The quantity and rate of discharge of groundwater flow is dependent on soil characteristics, head conditions, seasonal variations in supply, geometric configurations, and other factors. These are usually evaluated on the basis of empirical equations involving some measure of the soil permeability and hydraulic gradient based on subsurface investigation. The maximum rate of discharge is estimated for the conditions present and the system is usually designed without regard to design frequency.

2.2.4 <u>Subsurface Drainage System Components</u>. The basic components of a subsurface drainage system are filters, drains, collectors, appurtenances, outlets, and possibly storage, pumping, and wellpoint facilities.

a) Filters. Provide a graded aggregate filter or filter cloth to prevent soil grains from entering the drain.

b) Drains. Use open channels or 4-inch minimum diameter perforated pipe with closed joints as drains. Set invert elevations to lower groundwater level to desired elevation at critical design points. Design open channels to convey surface runoff and subsurface flows.

c) Collectors. Use open channels or nonperforated pipe with closed joints as collectors. Size gravity pipe, 6-inch minimum diameter, to provide minimum 2 fps velocity when flowing full. Size open channels for combined subsurface and surface runoff; provide minimum 2 fps velocity for maximum design subsurface discharge. Where sufficient gradient is available, depress collectors below drains.

d) Appurtenances. Provide manholes, observation basins, and risers for access to gravity drainage system for observation and maintenance.

e) Gravity Outlets. Locate outlets to prevent surface drainage from entering the subsurface drainage system. Provide flap gates where the subsurface drain outlet must be submerged. Where gravity outlets are located at groundwater pumping facilities, provide positive shutoff.

f) Storage. Provide temporary storage where appropriate to reduce the capacity of pumping facilities.

g) Groundwater Pumping Facilities. Where wells may be used economically to draw groundwater below the required level, provide a 4-inch minimum diameter submersible or vertical shaft pump in well. For locations where the gravity outlet will be frequently blocked by surface drainage or will be blocked during periods of critical need for subsurface drainage, provide pumps to remove the groundwater.

h) Wellpoints. For temporary construction installations, use 2-inch minimum diameter wellpoints; for permanent installations, use 4-inch minimum diameter wellpoints.

Section 3: HYDRAULIC COMPUTATION CRITERIA

3.1 Open-Channel Flow. Use the Manning equation for computation of friction losses in open channels. General references for hydraulic computation methodologies for open-channel flow include the following:

a) Open-Channel Hydraulics, V. T. Chow: Part II, Uniform Flow; Part III, Gradually Varied Flow; and Part IV, Rapidly Varied Flow.

b) Handbook of Hydraulics, H.W. King and E.F. Brater: Section 7, Steady Uniform Flow in Open Channels; Section 8, Open Channels with Nonuniform Flow; and Section 9, High-Velocity Transitions.

c) U.S. Army COE, EM 1110-2-1409, Backwater Curves in River Channels and EM 1110-2-1601, Hydraulic Design of Flood Control Channels.

d) U.S. Department of Agriculture, Soil Conservation Service (SCS), Engineering Handbook, Section 5, Hydraulics.

3.1.1 Manning's Roughness Factors. Typical design values of Manning's roughness factor, "n," for open channels are given in Table 3. For minor drainage system channels, consider the degree of maintenance of vegetal lining and design for maximum seasonal growth. For major drainage system flood plains, consider individual "n" values for channel and overbank flows and design for maximum seasonal growth. For additional information, refer to the following:

a) SCS, Guide for Selecting Roughness Coefficient "n" Values for Channels, Technical Release No. 24 (TR-24).

b) U.S. Geological Survey (USGS), Roughness Characteristics of Natural Channels, Geological Survey Water-Supply Paper 1849.

3.1.2 Water Surface Profiles. Determine control sections and normal depth in each reach under consideration. For minor drainage systems, use normal depth for the water surface profile. For major drainage systems, consider nonuniform flow. Proceed upstream for water surface profile computations if the flow depth exceeds critical depth; proceed downstream if the flow depth is less than critical.

3.1.3 Transitions. Consider the effects of transitions in both natural and improved channels. For natural channels, examine potential erosion or deposition due to transitions and consider local protection or improvements to mitigate effects thereof. For improved channels, provide smooth transitions to confine flow and prevent boundary separation and eddy flow. Allow for the superelevation of the water surface due to the centrifugal force acting on the flow around a bend.

Table 3
Manning's Roughness Coefficients for Open Channels

Type	Range	Design
Natural Channels (minor streams with top width at flood stage less than 100 feet)		
Clean, straight, regular shape	0.025 - 0.033	
Same as above but with weeds and stones	0.035 - 0.050	
Same as above but with deep pools, sluggish reaches, and irregular shape	0.050 - 0.080	
Flood Plains		
Woods, dense brush, summer	0.080 - 0.150	
Woods, light brush, summer	0.060 - 0.100	
Dense brush, heavy weeds, summer	0.020 - 0.160	
Light brush, summer	0.040 - 0.080	
Cultivated land, summer	0.030 - 0.050	
Pasture	0.030 - 0.050	
Urban land, grass, pavement, scattered trees	0.030 - 0.050	
Excavated Channels		
Earth, straight and uniform	0.020 - 0.030	0.025
Rock	0.030 - 0.045	0.035
Unmaintained (use values for natural channels)		
Lined Channels		
Asphalt	0.013 - 0.017	0.015
Brick	0.012 - 0.018	0.015
Concrete, float finish		0.013
Concrete, trowel finish		0.015
Concrete, Gunite finish		0.020
Riprap (6" - 9" stone)	0.020 - 0.035	0.030
Riprap (12" - 15" stone)	0.025 - 0.040	0.034
Gabions	0.020 - 0.030	0.028
Vegetal (unmaintained)	0.030 - 0.045	0.040
Grass (maintained)	0.025 - 0.035	0.030

a) Minor Head Losses. Consider minor head losses due to transitions, such as contractions, expansions, and bends. For gradual transitions, account for the head losses by increasing the Manning "n" value or compute as a function of the velocity head or change in velocity heads. For sudden transitions, compute the head losses as a function of the velocity head or change in velocity heads.

b) Hydraulic Jumps. Where supercritical flow impinges upon subcritical flow, a hydraulic jump will form. Determine location, horizontal length, and height of hydraulic jump.

c) Cross Waves. Supercritical flow through transitions causes cross (stationary) waves. In the case of bends, the cross waves are additive above and below the superelevated water surface. Estimate the height and extent of cross waves and consider them in the determination of freeboard and channel linings. See Chow, 1959, Chapter 16, "Flow in Channels of Nonlinear Alignment," and Chapter 17, "Flow Through Nonprismatic Channel Sections."

3.2 Closed-Conduit Flow. For gravity flow in closed conduits, use the Manning formula for computation of friction losses. For pressure flow, use either the Manning, Hazen-Williams, or Darcy-Weisbach equation. General references for hydraulic computational methodologies for closed-conduit flow include the following:

a) Water Pollution Control Federation (WPCF), Design and Construction of Sanitary and Storm Sewers (WPCF Manual of Practice (MOP) No. 9) and Gravity Sanitary Sewer Design and Construction (WPCF MOP FD-5).

b) King and Brater (1976), Section 6, Pipes.

c) SCS, Engineering Handbook, Section 5, Hydraulics.

3.2.1 Manning's Roughness Factors. Recommended design values of Manning's roughness factor, "n", are given in Table 4 for the design of storm drainage systems. Where friction loss is critical to the control of the outlet rate, such as from a storm water management facility, consider "n" values up to 20 percent less.

3.2.2 Hydraulic and Energy Grade Lines. Determine both hydraulic and energy grade lines for closed conduits. Where energy losses cause the hydraulic grade line to rise above the top of the conduit, analyze the pressure flow. Where conduits flow partially full, analyze the open channel flow.

3.2.3 Transitions. Determine the energy losses caused by flow transitions, such as entrances, expansions, contractions, structures, junctions, and bends. Account for the energy loss through the transition as a function of velocity head, or change in velocity heads, and determine the associated hydraulic grades upstream and downstream from the transition.

Table 4
Manning's Roughness Coefficients for Closed Conduits

Material	Manning's Coefficient "n"
Brick	0.016
Cast-Iron Pipe	0.013
Concrete, Cast in Place	
Smooth forms	0.013
Rough forms	0.015
Concrete Pipe	0.013
Vitrified Clay Pipe	0.013
Corrugated Steel/Aluminum Alloy Pipe 2 2/3-inch x 1/2-inch Helical Corrugations	
Unpaved 12" - 18" diameter	0.014
21" - 30" diameter	0.018
36" - 48" diameter	0.020
25% Paved 21" - 30" diameter	0.016
36" - 48" diameter	0.020
Fully Paved (all diameters)	0.013
Corrugated Steel/Aluminum Alloy Pipe 3-inch x 1-inch Helical Corrugations	
Unpaved 36" - 60" diameter	0.024
66" diameter and larger	0.027
25% Paved 36" - 60" diameter	0.020
66" diameter and larger	0.023
Fully Paved (all diameters)	0.013
Corrugated Steel/Aluminum Alloy Pipe 2 2/3-inch x 1/2-inch Annular Corrugations	
Unpaved	0.024
25% Paved	0.021
Fully Paved	0.013
Structural Plate Pipe 6-inch x 2-inch corrugations	
Unpaved	0.033
25% Paved	0.027
Tunnel Liner Plate	0.040-0.045
Plastic Pipe	0.011

Section 4: OPEN-CHANNEL SYSTEMS

4.1 Minor Drainage Systems

4.1.1 Application. Use swales, ditches, and gutters to convey storm water and groundwater. Swales are used for surface drainage of graded areas around buildings and other developments. Ditches are used to collect water in outlying areas and along roadway shoulders. Gutters, trench drains, and slotted pipe are used for street and pavement drainage.

4.1.2 Hydraulics

a) Velocity. Design for safe, nonerosive velocities based on the lining type. Limit velocity in paved channels to 15 fps. See Tables 5 and 6 for maximum permissible velocities in erodible channels. For additional information, see SCS, Engineering Field Manual, Chapter 7, "Grassed Waterways and Outlets," or U.S. Army COE, TM 5-820-3, Chapter 9.

b) Freeboard. Provide a minimum of 0.5 foot freeboard below the top of the swale or ditch and design flow water surface. Where possible, for ditches along roadways and railways, limit the depth of flow to no higher than the lowest subbase or subballast. Nonerodible lining may be limited to the depth of flow if the vegetal lining is provided above it to the top of the swale or ditch. Limit the depth of flow in gutters as required by roadway design criteria.

4.1.3 Materials

a) Vegetation. Use grasses to line minor drainage system channels where velocities permit.

b) Riprap. Select riprap size based on design velocities. Refer to U.S. Army COE, TM 5-820-4, Sections 2 through 16, for size selection and criteria.

c) Concrete. Use concrete for lining swales with highly erosive velocities and for monolithic curb and gutter sections.

d) Erosion Protection Fabric. Several types of erosion protection fabrics are available. Follow manufacturer's recommendation for type selection and installation.

4.1.4 Side Slopes. See Table 7. Consider degree and ease of maintenance in selection of side slopes for unlined and vegetal-lined channels.

4.2 Natural Channels and Flood Plains

4.2.1 Application. Use natural channels and flood plains to convey storm water and groundwater wherever land use requirements permit.

Table 5
Maximum Permissible Velocities in Waterways
Without Vegetal Lining*

Original material excavated	Clear water no detritus (fps)	Water transporting colloidal silts (fps)	Water transporting noncolloidal silts, sands, gravels, or rock fragments (fps)
Fine sand, noncolloidal	1.50	2.50	1.50
Sandy loam, noncolloidal	1.75	2.50	2.00
Silt loam, noncolloidal	2.00	3.00	2.00
Alluvial silts, noncolloidal	2.00	3.50	2.00
Ordinary firm loam	2.50	3.50	2.25
Volcanic ash	2.50	3.50	2.00
Fine gravel	2.50	5.00	3.75
Stiff clay, very colloidal	3.75	5.00	3.00
Graded, loam to cobbles, noncolloidal	3.75	5.00	5.00
Alluvial silts, colloidal	3.75	5.00	3.00
Graded, silt to cobbles, colloidal	4.00	5.50	5.00
Coarse gravel, noncolloidal	4.00	6.00	6.50
Cobbles and shingles	5.00	5.50	6.50

Table 5 (Continued)
Maximum Permissible Velocities in Waterways
Without Vegetal Lining*

Shales and hardpans	6.00	6.00	5.00

* These velocities are applicable to waterways on mild slopes and with long tangents.

Table 6
Maximum Permissible Velocities in Waterways Lined With Different Kinds of Vegetation[1]

Vegetation	Slope range percent	Permissible velocity Erosion-resistant soils (fps)	Easily eroded soils (fps)
Bermuda grass	0-5	8	6
Bermuda grass	5 -10	7	5
Bermuda grass	over 10	6	4
Buffalo grass	0-5	7	5
Kentucky bluegrass	5-10	6	4
Smooth bronze	over 10	5	3
Blue grama	over 10	5	2
Grass mixture(2)	0-5	5	4
Grass mixture(2)	5-10	4	3
Lespedeza sericea(3)	0-5	3.5	2.5
Weeping lovegrass(3)	0-5	3.5	2.5
Yellow bluestem(3)	0-5	3.5	2.5
Kudzu(3)	0-5	3.5	2.5
Alfalfa(3)	0-5	3.5	2.5
Crabgrass(3)	0-5	3.5	2.5
Common lespedeza(4)	0-5	3.5	2.5
Sudan grass(4)	0-5	3.5	2.5

Table 6 (Continued)
Maximum Permissible Velocities in Waterways Lined
With Different Kinds of Vegetation[1]

(1) Velocities exceeding 5 fps should not be used, except where good cover and proper maintenance can be obtained.

(2) Do not use on slopes steeper than 10 percent, except for side slopes in a combination channel.

(3) Do not use on slopes steeper than 5 percent, except for side slopes in a combination channel.

(4) Annuals--use on mild slopes or as temporary protection until permanent covers are established. Not recommended for slopes steeper than 3 percent.

Table 7
Maximum Permissible Side Slopes for Drainage Channels

Material	Slope	Application
Unlined clay	1 on 1	For heavy clay only, otherwise use lining.
Grass	1 on 3	1 on 4 or flatter preferred.
Riprap	1 on 1	For slope less than 5 feet in height, use filter fabric.
Riprap	1 on 1.5	Used for slopes greater than 5 feet in height; 1 on 2 preferred. Use filter fabric.
Gabion blankets 12 inches and less in thickness	1 on 2	Use filter fabric and toe basket(s). Use top anchor basket if design high water is above top of channel lining.
Gabion blankets 18 inches in thickness	1 on 1.5	Use filter fabric and toe basket(s).
Gabion baskets (3 x 3 x 6 feet)	Stepped back or 6 on 1 exposed face	Use filter fabric and sufficient depth or apron to prevent undermining.
Concrete lining	1 on 1	For slopes less than 5 feet in height, use weep holes.
Concrete lining	1 on 1.5	For slopes greater than 5 feet in height, 1 on 2 preferred, use weep holes.
Structural concrete	Vertical	Retaining wall designs with weep holes.
Erosion protection fabric (all types)	1 on 2	Use manufacturer's recommendation for installation.

4.2.2 Hydraulics. If encroachment and filling within flood plains decreases the existing stream conveyance capacity, provide channel improvements to compensate for the loss of capacity, unless alteration of the flood plain will not damage Government facilities or adjacent land.

4.2.3 Erosion and Sediment Control. Review stream velocities for erosion or deposition potential. Compare velocities with permissible velocities in Tables 5 and 6. Consider local bank protection where erosion potential may damage Government facilities or adjacent land. Consider local channel improvements, realignment, clearing, and training where deposition may reduce capacity.

4.3 Improved Channels

4.3.1 Application. Use improved channels to increase the conveyance capacity of streams where there are flood hazards or where functional considerations require limited land use or reduced maintenance.

4.3.2 Hydraulics

a) Freeboard. Provide minimum freeboard below top of channel as follows:

0.5 foot	minor drainage systems (drainage area less than 100 acres)
1.0 foot	major drainage systems (drainage area between 100 and 640 acres)
2.0 feet	major drainage systems (drainage area greater than 640 acres)

b) Velocity. Limit the velocity in paved channels to 15 fps. See Tables 5 and 6 for maximum permissible velocities in unlined and vegetal-lined channels. Select riprap and other channel linings consistent with the design velocity.

c) Gradient. Where possible, choose a gradient which will produce stable, subcritical flow at a nonerosive velocity. Supercritical flow in steep channels produces cross (standing) waves at bends and transitions, thereby increasing the design water surface elevation. Consider the elimination of supercritical flow by the use of drops or cascades in the channel.

4.3.3 Lining Materials. Material selection is dependent on the following factors: stream velocity, flow turbulence, material cost and availability, and channel maintenance.

a) Unlined Earth Channels. Use unlined earth channels where flow velocities are nonerosive.

b) Lined Channels. Use linings of vegetation, erosion protection fabric, soil cement, concrete, asphalt, or riprap where flow velocities are erosive to unlined earth channels.

4.3.4 Side Slopes. See Table 7. Perform a stability analysis for channels having side slopes steeper than 1 horizontal on 1 vertical; consider sudden drawdown condition. Consider the degree and ease of maintenance in the selection of side slopes for unlined and vegetal-lined channels.

4.3.5 Safety and Security. Provide bridges or sidewalks on vehicular bridges where pedestrian traffic must be maintained. Provide fencing as required for safety and security. At locations where channels enter or leave secured areas, provide security barriers or multiple 10-inch diameter pipes.

4.4 Bridges

4.4.1 Application. Use bridges for the crossing of major streams. Consider bridges instead of culverts if the waterway opening exceeds 200 square feet.

4.4.2 Hydraulics

a) Waterway Opening. Select a waterway opening consistent with structure economics, backwater limitations, and scour potential. Use U.S. Department of Transportation, Federal Highway Administration, Hydraulic Design Series No. 1, "Hydraulics of Bridge Waterways," for computation procedures.

b) Backwater Limitation. Limit the upstream increase in water surface elevation due to new bridge construction to an elevation consistent with flood insurance and flood plain management regulations. In the absence of regulations, limit upstream increase to avoid flooding detrimental to existing property or to future use of the upstream property.

c) Freeboard. Provide minimum freeboard between the lowest superstructure member, excluding bearings, and the design high water surface as follows:

Drainage area less than 1,000 acres	1.5 ft
Drainage area equal or greater than 1,000 acres	3.0 ft

In areas where logging operations are present or justifiably anticipated in the upstream reaches of the watershed, consider increasing minimum freeboard.

4.4.3 Structural Design. Refer to American Association of State Highway and Transportation Officials (AASHTO), Standard Specifications for Highway Bridges, or American Railway Engineering Association (AREA), Manual for Railway Engineering, as appropriate.

Section 5: CLOSED-CONDUIT SYSTEMS

5.1 General References. The following are suggested general references for the design of closed-conduit systems: WPCF MOP No. 9 and WPCF MOP FD-5.

5.2 Pipes

5.2.1 Application. Use pipes and other prefabricated shapes or cast-in-place conduits for the transmission of storm water either by gravity flow or pressure flow. Except for interior courtyards and roof drainage, do not extend drainage system under buildings.

5.2.2 Hydraulics

a) Gravity Systems. Use the Manning equation for friction losses. Design conduits to flow full or to be surcharged. Limit the hydraulic grade line to no higher than 12 inches below the top or lowest opening of inlets, catch basins, manholes, and other structures. Regardless of hydraulic considerations, do not decrease the conduit size in the direction of the flow.

b) Pressure Systems. Where precise parameters are required, use the Darcy-Weisbach equation for friction losses; otherwise, use the Hazen-Williams equation. Design piping and valve systems for total dynamic head (TDH) with an allowance for water hammer. For additional information, see American Society of Civil Engineers (ASCE), Pipeline Design for Water and Wastewater.

c) Minimum Velocity. Design the system to achieve a minimum flow velocity of 2.5 fps in all conduits.

d) Maximum Velocity. Limit the maximum flow velocity to 15 fps in gravity systems and 10 fps in pressure systems.

5.2.3 Minimum Sizes

a) Gravity Systems. Use a minimum inside diameter (equivalent diameter for arch or elliptical pipe) of 12 inches. See paragraph 5.3.3 for additional requirement of minimum pipe sizes for secured areas.

b) Pressure Systems. Use a minimum inside diameter of 4 inches.

5.2.4 Materials. Consider the following factors in the selection of pipe materials: flow characteristics, durability, strength, type of joint, availability of pipe, availability of special shapes, ease of installation, cost of material, and cost of installation. Use watertight joints where infiltration may cause a loss of soil surrounding the pipe. Refer to NAVFAC Guide Specification NFGS-02720, Storm Drainage System.

5.2.5 NAVFAC Structural Design. For the structural design of rigid and flexible conduits, see NAVFAC DM-7.01, Soil Mechanics. For the structural design of cast-in-place reinforced concrete conduits, refer to AASHTO or AREA.

a) Safety Factor. Provide a structural safety factor above Ultimate Strength (US) as follows:

Conduit Material	Safety Factor	Basis of US
Plain rigid	2.0	three-edge bearing
Reinforced concrete pipe	1.5	0.01-in. crack three-edge bearing
Flexible metal or plastic pipe	1.25	5% deflection (Deflection lag factor = 1.5 and bedding constant = 0.1)
Pipes under levees and similar critical locations (plain rigid pipe not permitted)	2.0	See above for conduit material
Cast-in-place reinforced concrete	per AASHTO or AREA requirements	

5.2.6 Cover. Limit the minimum cover for pipes to 12 inches. Measure the cover from the top of the pipe to the bottom of the rigid pavement and from the top of the pipe to the top of the flexible pavement or ground surface. Consider improved pipe bedding and concrete encasement to increase the load capacity of pipes.

5.2.7 Alignment

a) Horizontal. Normally, provide straight alignments between structures with deflections at structures no greater than 95 degrees for main line flow. The maximum deflection at junctions from contributory flows is 120 degrees. The minimum size pipe on horizontal curves shall be 48-inch or equivalent diameter. Consider long radius curves only where substantial savings can be realized. Long radius curves are those for which the ratio of the radius of the horizontal curve to the diameter of the pipe is equal to or greater than 30.

b) Vertical. Normally, provide straight alignment between structures. Consider vertical curves, either parabolic or circular, under the same conditions specified for horizontal curves.

c) Pressure. Use standard pipe fittings and joint deflections to achieve required horizontal and vertical alignments. Do not exceed the manufacturer's recommended joint deflections.

5.3 Culverts

5.3.1 Application. Use culverts for the conveyance of storm water under roads, trackage, and other surface features.

5.3.2 Hydraulics. Refer to U.S. Department of Transportation, Federal Highway Administration, Hydraulic Engineering Circular No. 5, "Hydraulic Charts for the Selection of Highway Culverts", and Hydraulic Engineering Circular No. 10, "Capacity Charts for the Hydraulic Design of Highway Culverts."

a) Freeboard Requirements. Freeboard is measured from the headwater elevation to the lowest subbase, subballast or, in the case of an unpaved road, shoulder elevation. Where possible, provide a minimum freeboard of 1.0 foot for paved roads and trackage and 2.0 feet for unpaved roads. Where freeboard requirements cannot be met, provide erosion protection for flow overtopping the road or tracks and limit the depth of flow to 4 inches at the crown of the roadway or the top of the rail. Consider the overflow condition in the design of roadway pavement or railway track and ballast.

5.3.3 Minimum sizes. Use a minimum inside diameter (equivalent diameter for arch or elliptical pipe) as follows:

Driveway, entrance, and parking lots	12 in.
Roadway	15 in.

For secured areas, limit the entry and exit openings to a 10-inch diameter maximum. Where additional capacity is required, use multiple 10-inch diameter openings (see MIL-HDBK-1013/1, Design Guidelines for Physical Security of Fixed Land-Based Facilities).

5.3.4 Materials. Refer to NFGS-02720.

a) Types. Use galvanized corrugated steel, corrugated aluminum, reinforced concrete, or cast-in-place concrete culverts. Use watertight joints where infiltration may cause a loss of soil surrounding the culvert.

b) Coatings. Where additional protection is required from corrosive soil or water, use coated metal culverts.

5.3.5 Structural Design. Refer to paragraphs 4.4.3 and 5.2.5.

5.3.6 Alignment. Align culverts parallel to the stream, with not more than a 45-degree skew angle (angle between centerline of culvert and perpendicular to the centerline of the road or track). Use channel realignment, preferably on the upstream end, where the natural skew is greater than 45 degrees. For major streams, consider a realignment of the roadway.

a) Inlet and Outlet Treatment. Provide embankment stabilization, erosion protection, and hydraulic efficiency at inlets and outlets. Avoid projecting inlets, except for small diameter or temporary culverts. Head-walls, wingwalls, and rounded or beveled entrances will improve hydraulic efficiency. Refer to U.S. Department of Transportation, Federal Highway Administration, Hydraulic Engineering Circular No. 13, Hydraulic Design of Improved Inlets for Culverts.

5.3.7 Erosion and Sedimentation Control. Where outlet velocities exceed permissible velocities for downstream channel material, provide erosion protection and velocity reduction by increasing the area of flow. Allow sufficient length of erosion protection to prevent the persistence of high velocities past the downstream end of protection. Consider possible downstream sediment deposition which may reduce capacity or channelize flow. Where no other alternative is practical, consider special energy dissipation structures. Refer to U.S. Army COE, TM 5-820-4, paragraph 2-13, for hydraulic design of special energy dissipation structures.

5.3.8 Safety and Security. In residential areas where the ends of culverts are not otherwise protected, i.e., by a fence or physical land feature, provide hinged grates at both ends of culverts 24 inches in diameter and larger. In secured areas, refer to 1) MIL-HDBK-1013/1, 2) OPNAVINST 5530.13, Chief of Naval Operations, Physical Security Instruction for Sensitive Conventional Arms, Ammunition, and Explosives, and 3) OPNAVINST 5530.14, Chief of Naval Operations, Physical Security and Loss Prevention Instruction and Handbook.

5.4 Inlets and Catch Basins

5.4.1 Application. Provide inlets to collect storm water from roadways and parking lots. Provide catch basins to collect storm water from swales.

5.4.2 Hydraulics. See NFGS-02720 for types and hydraulic capacities of available inlets and catch basins.

a) Location and Spacing of Inlets. Provide inlets to limit the gutter flow spread for design runoff to 8 feet from the curb for expressways and 10 feet from the curb for collector and local roads. In areas of high pedestrian traffic, provide inlets upstream from crosswalks.

b) Location and Spacing of Catch Basins. Locate catch basins to maximize the overland flow with overland flow runs not to exceed approximately 200 feet. Space catch basins according to desired size, depth, and capacity of swale flow.

c) Clogging. Reduce the capacity of inlets and catch basins in areas of deciduous woods by 50 percent to account for possible clogging from leaves.

d) Sumps. For inlets and catch basins located in sumps, consider any flows which may not have been intercepted by upstream inlets or catch basins.

5.4.3 Materials. Refer to NFGS-02720.

5.4.4 Maintenance and Safety. Inlets and catch basins must be maintained free of trash and debris. Consider access for cleaning, pedestrian and child safety, and security in the design of nonstandard inlet or catch basin structures.

5.5 Appurtenances. For structural design, see the Structural Engineering Series: MIL-HDBK-1002/1, General Requirements; MIL-HDBK-1002/2, Loads; MIL-HDBK-1002/3, Steel Structures, NAVFAC DM-2.04, Concrete Structures; MIL-HDBK-1002/5, Timber Structures; and MIL-HDBK-1002/6, Aluminum Structures, Composite Structures, Structural Plastics, and Fiber-Reinforced Composites. Consider the impact forces caused by changes in the direction of the flow.

5.5.1 Manholes. Unless other access structures (inlets, catch basins, or bend structures) can be utilized, provide manholes at every junction, with a change in vertical or horizontal alignment or at intervals specified below.

Pipe size	Maximum Spacing (ft)
48-inch diameter and smaller	400
Over 48-inch diameter	800

Use NFGS-02720 for manhole construction.

5.5.2 Drain Connections. Wherever possible, locate roof drain connections at manholes or other access structures. Where the preferred location would be unfeasible for aesthetic or economic reasons, connect roof drains with appropriate fittings, saddles, or pipe stubs to the receiving pipe. Limit the size of roof drain connections by saddles or pipe stubs to less than 0.4 of the receiving pipe size.

5.5.3 Pressure Pipe Systems. Brace, anchor, or buttress all bends and fittings. Provide check and shutoff valves, blowoffs at low points, air and vacuum release valves at summits, water hammer control, and vents as required for particular installation. See ASCE Pipeline Design for Water and Wastewater, for design. See NFGS-02730, Exterior Sanitary Sewer Systems, for standard details.

5.5.4 Trackage Drains. Arrange drainage facilities so that water will not stand and freeze in rail flangeways, frogs, and switches.

Section 6: GROUNDWATER DRAINAGE

6.1 Application. Groundwater drainage systems include subsurface drainage and temporary and permanent water table depressions using wellpoints.

6.1.1 Interceptor Ditches. Design interceptor ditches for both groundwater and surface water flow. Determine the depth of interceptor subsurface drains from the invert of incoming subsurface drains and the invert of the ditch outfall. In cohesionless soils, where erosion may be a problem, provide a low-flow channel consisting of protective matting or fabric, pavement, or riprap. Use vegetal cover compatible with the ditch environment. Refer to SCS, Engineering Field Manual, Chapter 14, Part II.

6.1.2 Field Drains and Underdrains. The effectiveness of field drains and underdrains is a function of the permeability of the surrounding soil, the selection of the aggregate for filtering, and the spacing and alignment of the drains. For subsurface drainage of pavements, refer to U.S. Army COE, TM 5-820-2 and SCS, Engineering Field Manual, Chapter 14, Part II. In some locations, flap gates at system outlets are necessary to prevent storm water inflow.

6.1.3 Vertical Drains. Wick drains can be used to dewater areas of high water tables and to consolidate deep fills.

6.1.4 Pumping. Submersible groundwater pumps are used for both water supply and dewatering. Vertical-shafted pumps with surface-mounted power supplies are normally used for larger capacity installations for ease of maintenance and for reducing the bore hole size.

6.1.5 Envelopes, Filters, and Appurtenances. Refer to SCS, Engineering Field Manual, Chapter 14, for criteria on sand and gravel envelopes, filters, surface inlets, flap gates, and junction boxes.

6.2 Economic Considerations. Use life cycle cost analysis for the comparison of alternate drainage schemes. Consider pumping power costs, maintenance, and replacement of materials.

6.3 Hydraulics. Refer to the following:

a) Federal Aviation Administration (FAA) Advisory Circular AC 150/5320, Airport Drainage.

b) U.S. Army COE, EM 1110-2-1905, Design of Finite Relief Well Systems.

c) U.S. Army COE, TM 5-820-2. d) U.S. Army COE, TM 5-820-4, Section III.

6.4 Materials

6.4.1 Permanent Groundwater Relief Wells. For material selection, location, spacing, and other design criteria, refer to U.S. Army COE, EM 1110-2-1905.

6.4.2 Temporary Wellpoints for Construction. Refer to the wellpoint system in manufacturers' and suppliers' catalogs.

Section 7: STORAGE FACILITIES

7.1 Application. Use storage facilities for storm water management and in conjunction with storm water pumping facilities. Where space is available, storage facilities can reduce the required capacities of storm water pumping facilities and the sizes of downstream pipes and ditches.

7.1.1 Temporary Ponding. Provide temporary ponding in the form of parking lot storage, swale storage, or underground storage.

7.1.2 Sediment Control Basins. Provide sediment control basins during construction to reduce site erosion and stream sedimentation. Where appropriate, design sediment control basins for permanent use and convert to detention basins after the construction period.

a) Design Criteria. Refer to EPA, EPA-R2-72-015.

7.1.3 Detention Basins. Detention basins provide temporary storage of storm water to control the peak runoff rate. They are sometimes called "dry" ponds.

a) Approval for Use of Open Basins. Obtain approval from the appropriate Engineering Field Division prior to using a permanent detention basin. Prior to construction, submit plans and obtain approval for construction from appropriate state reviewing agencies.

b) Design the outlet structure to drain the detention basin within 24 hours after the end of rainfall. Several inlets for outlet structures are given in ASCE Book No. 480, Storm Water Detention Outlet Control Structures. These inlets include: 1) simple headwall, 2) multiple stage timber inlet, 3) single stage riser, and 4) multiple stage riser.

c) Provide a minimum bottom slope of 1 percent (2 percent preferable) for dry ponds.

d) Provide subsurface drainage for detention ponds built in soils with very low permeability where the possibility of creating wetlands would be objectionable.

7.1.4 Retention Basins. Retention basins have a permanent pool in addition to temporary storage for the control of the storm water peak runoff rate. They are also used for the control of the quality of storm water runoff. Obtain approval from the appropriate Engineering Field Division prior to using a retention basin. Prior to construction, submit plans and obtain approval for construction from appropriate state reviewing agencies.

7.2 Hydraulics. Refer to SCS, Engineering Field Manual, Chapter 11, for design criteria and methodologies used in all aspects of pond development.

7.2.1 Principal Spillway. Provide 2 feet of freeboard when passing the design storm for all types of ponds.

7.2.2 Emergency Spillway. Provide an emergency spillway which is capable of passing a 100-year storm with 1 foot of freeboard. The emergency spillway may be incorporated with the principal spillway.

7.2.3 Pond. Provide a minimum of 2 percent slope for nonpaved surfaces within detention ponds to facilitate interior drainage, or provide a paved drainage swale at no less than 0.5 percent slope.

7.2.4 Major Structure. If the embankment height is over 15 feet, use methods described in SCS, National Engineering Handbook, NEH-4, Chapter 21, "Emergency Spillways," Section 4, Hydrology, to determine the emergency spillway and embankment freeboard.

7.3 Material. Refer to SCS, Engineering Field Manual, Chapter 11.

7.3.1 Embankment. Construct the pond embankment of compacted soil free of debris, rocks over 6 inches, roots, and topsoil. Permanent retention ponds may require a clay core or cutoff trenches under the embankment to prevent seepage.

7.3.2 Principal Spillway. Provide principal spillways that are cast-in-place concrete, precast concrete, or corrugated metal pipe risers. Vertical risers shall have antivortex devices and debris barriers.

7.3.3 Emergency Spillway. Protect emergency spillways from erosion by grass cover, erosion protection fabric, cast-in-place concrete, or bituminous concrete.

7.4 Structural Design. Refer to SCS, Engineering Field Manual, Chapter 17.

7.4.1 Embankment. Design retention pond embankments with consideration for seepage, sudden drawdown for slope stability, and erosion protection.

7.4.2 Emergency Spillway. Align the emergency spillway so that the flow is directed away from the base of the embankment.

7.5 Safety Considerations

7.5.1 Depth of Ponds. In residential areas, limit unprotected ponds to a maximum depth of 3 feet.

7.5.2 Fencing. Enclose ponds in residential areas with a 6-foot fence.

7.5.3 Embankment Failure. Where embankments are higher than 5 feet, examine the downstream area to determine if the sudden failure of the embankment could result in danger to life or property; if so, use the special design criteria found in SCS, NEH-4, Chapter 21, Section 4, Hydrology.

7.5.4 Local Regulations. Check local jurisdiction for regulations and requirements regarding construction of storage facilities.

7.6 Maintenance. Provide trash racks or bar grates and antivortex baffles for principal spillways.

Section 8: PUMPING FACILITIES

8.1 Application

8.1.1 Storm Water Drainage. Use storm water pumping facilities for levee-protected areas during periods of blocked gravity drainage and in extremely flat or low-lying areas where it is impossible or uneconomical to drain surface runoff by gravity systems. If an existing drainage system is inadequate, consider the possibility of increased capacity by installing pumping facilities and converting the gravity outfall to a force main.

8.1.2 Groundwater Drainage. Use groundwater pumping facilities to relieve high groundwater levels during temporary construction periods, at permanent structures, and to control seepage in dams and levees.

8.2 Design Considerations

8.2.1 Location. Locate pumping facilities to minimize overall costs without sacrificing safety.

a) Leveed Areas. Locate pumping facilities as close as practical to the gravity outfall to minimize the length of force main. Refer to U.S. Army COE, EM 1110-2-3102, General Principles of Pumping Station Design and Layout.

b) Flat Terrain. Where the terrain is flat and a gravity outfall is feasible but pumping facilities are required to limit the depth of drains, locate the pumping facility at a point which will effect the largest savings in drain construction.

c) Groundwater Drainage. Locate the pumping facility to maximize gravity drainage either on the inlet or outlet side of the facility to effect the largest overall savings in construction cost.

8.2.2 Storage. Temporary storage, used in conjunction with a pumping facility, often results in overall cost savings over a pumping station without temporary storage designed to discharge the peak flow rate. Wherever possible and applicable, use temporary upstream storage to reduce the design flow of pumping facilities.

8.2.3 Arrangement

a) General References. For a comprehensive general reference on pumping stations, see WPCF, MOP No. FD-4. For major pumping stations for leveed areas, see the following U.S. Army COE series:

(1) EM 1110-2-3102

(2) EM 1110-2-3103, Architectural Design of Pumping Stations

(3) EM 1110-2-3104, Structural Design of Pumping Stations

(4) EM 1110-2-3105, Mechanical and Electrical Design of Pumping Stations

b) Minimum Number of Pumps. Provide at least two pumps per station. Size pump capacities to discharge the design flow with the largest pump out of service.

c) Standby Power. Provide standby power when the project area is valuable and a power failure would cause damage.

d) Operation. Keep the pumping facility arrangement simple. Reliability and efficiency are equally important factors.

e) Flooding. Unless a submersible pump is used, keep the electric motor and controls above the design flood level.

8.2.4 Pump Types

a) Storm Water Pumps. For installations having a design capacity of 100 gal/min or less, pneumatic ejectors may be used. For larger capacity installations, use vertical impeller, mixed- and axial-flow pumps, or nonclog and submersible pumps.

b) Groundwater Pumps. Use submersible or vertical-shafted centrifugal pumps as appropriate to the installation.

8.2.5 Appurtenances. Use the detailed design guidelines for pumping stations found in WPCF, MOP No. FD-4.

8.3 Hydraulics

8.3.1 Design Discharge. Use Table 2 of this manual to determine the degree of protection for the facility or area being protected by the pumping facility. Use MIL-HDBK-1005/2 procedures to determine runoff and, if storage is to be utilized, also use MIL-HDBK-1005/2 for hydrograph and reservoir routing procedures.

8.3.2 System Curve. Develop a system curve for pumping facilities based on the elevation and piping characteristics. Refer to WPCF MOP No. FD-4. Use the Hazen-Williams equation for calculating friction head losses. Consider use of the Darcy-Weisbach equation, particularly for Net Positive Suction Head (NPSH), where flow rates are high and an available suction head is limited.

8.3.3 Pump Rating Curve. Obtain pump rating curves from pump manufacturers. Select pumps to match system requirements near the point of maximum efficiency. Determine that available NPSH exceeds required NPSH to prevent cavitation.

8.3.4 Emergency Operation. Investigate all of the following possible pump operating conditions:

a) Operation at shutoff head.

b) Runaway flow (pipeline break).

c) Flow reversal and valve failure.

d) Suction head conditions, air entry (vortices), and cavitation.

e) High water level flooding.

8.3.5 Surge Control. If pressure surge (water hammer) exceeds recommended maximum pipe or valve operating pressures, provide electric or pneumatic check valves. Refer to WPCF MOP No. FD-4, Chapter 5, or ASCE, Pipeline Design for Water and Wastewater, for surge calculation methodology and design guidelines.

8.4 Materials. See paragraph 8.2.3 a) of this manual.

8.4.1 Pumps. Base the specifications of pump materials on the following:

a) Degree of protection required.

b) Degree of pump reliability required.

c) Power cost.

d) Storm water characteristics.

e) Availability of required maintenance.

8.4.2 Suction and Discharge Piping. See WPCF MOP No. FD-4 or U.S. Army COE, EM 1110-2-3105.

8.4.3 Force Mains. See WPCF MOP No. FD-4 or ASCE, Pipeline Design for Water and Wastewater.

8.5 Maintenance, Operation, and Safety. For general operating practices, emergency operations, maintenance, and safety considerations for design, refer to WPCF MOP No. FD-4, Chapter 9. Contact the appropriate Engineering Field Division for specific procedures.

Section 9: OUTFALLS

9.1 Application. Give special consideration to the design of storm drain outfalls subject to tail water in leveed and tidal areas and to outfalls with high velocity flows.

9.2 Design

9.2.1 Ungraded. Design ungraded outfalls to function with anticipated tail water elevations due to river or tidal flooding. Methodology references for prediction of joint probability of river tide and tributary river peak floods are given in MIL-HDBK-1005/2, paragraphs 3.2.6 and 4.4. Since the operation of this type of outfall requires pressure flow in the conduit, design the conduit for internal pressure and consider the possibility of structural failure during critical flood stages. Refer to U.S. Army COE, EM 1110-2-1410, Interior Drainage of Leveed Urban Areas: Hydrology, Chapter 4.

9.2.2 Automatic Flap Gates. Where there are frequent or sudden fluctuations in river tide stage, use automatic flap type gates as service gates on outlets. Since flap gates are susceptible to clogging, consider redundant systems in critical protection areas. Refer to U.S. Army COE, EM 1110-2-1410, Chapter 4 or U.S. Army COE, EM 1110-2-1913, paragraph entitled "Closure Devices."

9.2.3 Positive Closure Devices. Slide gates and valves offer positive control but require manual operation, and should only be used as service gates where the river stage fluctuation is slow enough to give ample time for safe operation (12 hours) and trained personnel are available. In critical areas, provide supplemental emergency gates in case of service gate failure. Refer to U.S. Army COE, EM 1110-2-1410, Chapter 4.

9.2.4 Outlet Protection. Provide erosion and sedimentation protection for both the receiving body of water and the outlet. The design principles are the same whether the outlet is a gravity drain, pressure drain, or force main.

a) Erosion Protection. Where outlet velocities exceed permissible velocities for the natural channel, provide erosion protection. Protect the outlet from high velocities in the receiving stream. Consider, in order of degree of protection, vegetal lining, riprap, gabions, and nonerodible lining. Where no other alternative is practical, consider a special energy dissipation structure. See U.S. Army COE, TM 5-820-4, paragraph entitled "Outlet Energy Dissipators," for hydraulic design of special energy dissipator structures. Protect the downstream ends of the outlets by endwalls, headwalls, wingwalls, riprap, and nonerodible linings. Consider pipe capable of supporting itself by cantilever action in severe outlet locations. Where possible, consider endwall or wingwalls or flared-end sections for ease of moving and erosion control.

b) Sediment Protection. Where the receiving body of water is subject to low or adverse velocities as in a deep river, lake, or tidal water, deposition may occur downstream from outlets carrying sediment laden flows. Additionally, outlets with blocked drainage may have sediment depositions within the conduit. Minimize sediment loads in the outlet by providing erosion and sediment control within the tributary watershed or sediment traps within the drainage system. Where appropriate, provide low flow channels downstream from the outlet to convey sediment. If these measures cannot be achieved, there is no alternative to physical removal of accumulated sediment deposits. If the receiving body of water is sediment laden, arrange the outlet so that velocities in the receiving stream carry past the outlet to keep the sediment in suspension. Do not locate the outlet in slack water which might promote deposition.

Section 10: DRAINAGE LAWS, REGULATIONS, AND REGULATORY AGENCIES

10.1 General References. For a general discussion of drainage and water concepts, refer to the following:

a) Journal of the Water Resources Planning and Management Division, A. M. Cox (1982), "Water Law Primer."

b) Contracts, Specifications, and Law for Engineers, C. W. Dunham and R. D. Young (1971), Chapter 21.

10.2 Legal Considerations. Drainage laws and regulations vary greatly with location. The legal section of the appropriate Engineering Field Division should be consulted when questions arise. The following information outlines and defines the legal terms, topics, and concepts that may require consideration in the design of NAVFAC facilities:

10.2.1 Flood Control. The U.S. COE has constructed numerous major flood control works throughout the United States. Within the United States, COE is responsible for the coordination of flood control for navigable rivers. In addition to flood protection, COE regulates the maintenance dredging of harbors.

10.2.2 Flood Plain Management. Many states and local communities have adopted flood plain management regulations controlling development and construction in flood plains. Refer to MIL-HDBK-1190, Chapters 4 through 10, for Department of Defense (DOD) criteria for construction in flood plains.

10.2.3 Water Pollution Control. The Federal Water Pollution Control Act (Public Law 92-500), as amended 1977 (Public Law 95-217), establishes a national standard of water quality. The EPA coordinates and funds this pollution abatement program through state health departments.

10.2.4 Soil and Erosion Control. The SCS has published design criteria and specifications on a state-by-state basis to promote erosion and sedimentation control measures for agriculture and new construction sites. Refer to state soil conservation district offices for detailed regulations. General guidelines are published by the EPA.

10.2.5 Surface Water Drainage. State and local ordinances may require storm water management. Refer to MIL-HDBK-1005/2.

10.2.6 Subsurface Water Drainage. Groundwater rights include those rights to water based on ownership of the overlying land, on priority of appropriation, and on beneficial use of water. Comply with state groundwater codes in the development and use of groundwater.

10.2.7 Riparian Rights. In some states, particularly in the Western United States, riparian rights are established by state and local laws.

10.2.8 Reservoirs. Many states have laws that require permits to construct dams, ponds, or reservoirs for many intended uses, such as water storage. Comply with these requirements in the planning and design of such facilities.

10.2.9 Easements and Rights-of-Way. Easements may be required to legally convey waters over private property. Rights-of-way for roads, drains, and utilities may also need to be obtained from local jurisdictions or property owners.

10.2.10 Eminent Domain. Eminent domain can be exercised if necessary with just compensation to the land owner.

REFERENCES

NOTE: THE FOLLOWING REFERENCED DOCUMENTS FORM A PART OF THIS HANDBOOK TO THE EXTENT SPECIFIED HEREIN. UNLESS OTHERWISE SPECIFIED IN THE TEXT, USERS OF THIS HANDBOOK SHOULD UTILIZE THE LATEST REVISIONS OF THE DOCUMENTS CITED HEREIN.

FEDERAL/MILITARY SPECIFICATIONS, STANDARDS, BULLETINS, HANDBOOKS, AND NAVFAC GUIDE SPECIFICATIONS:

Unless otherwise indicated, copies are available from the Naval Publishing and Printing Service Office (NPPSO), Standardization Document Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

SPECIFICATIONS

NFGS-02720	Storm Drainage System
NFGS-02730	Exterior Sanitary Sewer System

HANDBOOKS

MIL-HDBK-1002/1	Structural Engineering - General Requirements
MIL-HDBK-1002/2	Structural Engineering - Loads
MIL-HDBK-1002/3	Structural Engineering - Steel Structures
MIL-HDBK-1002/5	Structural Engineering - Timber Structures
MIL-HDBK-1002/6	Structural Engineering - Aluminum Structures, Composite Structures, Structural Plastics, and Fiber-Reinforced Composite
MIL-HDBK-1005/2	Hydrology
MIL-HDBK-1005/7	Water Supply Systems
MIL-HDBK-1013/1	Design Guidelines for Physical Security of Fixed Land-Based Facilities
MIL-HDBK-1029/2	Marine Railways
MIL-HDBK-1190	Facility Planning and Design Guide

NAVY MANUALS, P-PUBLICATIONS, AND MAINTENANCE OPERATING MANUALS:

Available from Commanding Officer, Naval Publications and Forms Center (NPFC),

5801 Tabor Avenue, Philadelphia, PA 19120-5099. To order these documents: Government agencies must use the Military Standard Requisitioning and Issue Procedure (MILSTRIP); the private sector must write to NPFC, ATTENTION: Cash Sales, Code 1051, 5801 Tabor Avenue, Philadelphia, PA 19120-5099.

DESIGN MANUALS

DM-2.04	Structural Engineering -Concrete Structures
DM-7.01	Soil Mechanics
DM-7.02	Foundations and Earth Structures
P-73	Real Estate Procedural Manual
OPNAVINST 5530.13	Department of the Navy Physical Security Instruction for Sensitive Conventional Arms, Ammunition, and Explosives
OPNAVINST 5330.14	Department of the Navy Physical Security and Loss Prevention Instruction and Handbook

OTHER GOVERNMENT DOCUMENTS AND PUBLICATIONS:

Public Law 92-500, Section 208	Federal Water Pollution Control Act Amendments of 1972 as Amended

Available from Environmental Protection Agency (EPA), 401 M Street S.W., Legislative Library A-102, Washington, DC 20460.

MOP No. FD-4	Design of Wastewater and Storm Water Pumping Stations
MOP No. FD-5	Gravity Sanitary Sewer Design and Construction
MOP No. 9	Design and Construction of Sanitary and Storm Sewers

Available from Water Pollution Control Federation, 2626 Pennsylvania Avenue, N.W., Washington, DC 20037.

U.S. ARMY COASTAL ENGINEERING RESEARCH CENTER

Shore Protection Manual, 4th ed., Volumes I and II, 1984.

Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

U.S. ARMY CORPS OF ENGINEERS (COE)

Cost Report on Non-Structural Flood Damage Reduction Measures for Residential Buildings Within the Baltimore District, July 1977.

Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

U.S. ARMY COE

Carson, W. D. (1975), Estimating Costs and Benefits for Nonstructural Flood Control Measures.

Owens, H. J. (1977), Annotations of Selected Literature on Nonstructural Flood Plain Management Measures.

HEC-1	Flood Hydrograph Package
HEC-3	Reservoir System Analysis for Conservation
HEC-5	Simulation of Flood Control of Conservation Systems
HEC-5Q	Simulation of Flood Control of Conservation Systems With Water Quality
HEC-6	Scour and Deposition in Rivers and Reservoirs
TM 5-820-2	Drainage and Erosion Control: Subsurface Drainage Facilities for Airfield Pavements
TM 5-820-3	Drainage and Erosion Control: Structures for Airfield and Heliports
TM 5-820-4	Drainage and Erosion Control: Drainage for Areas Other Than Airfields
WQRRS	Water Quality for River-Reservoir Systems

<u>Hydrologic Engineering Methods for Water Resources Development</u>:

Volume 1	Requirements and General Procedures
Volume 3	Hydrologic Frequency Analysis
Volume 4	Hydrograph Analysis
Volume 8	Reservoir Yield

Volume 10	Principles of Groundwater Hydrology

Available from U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC), 609 Second Street, Davis, CA 95616.

U.S. ARMY COE

EM 1110-2-1409	Backwater Curves in River Channels
EM 1110-2-1410	Interior Drainage of Leveed Urban Areas: Hydrology
EM 1110-2-1601	Hydraulic Design of Flood Control Channels
EM 1110-2-1905	Design of Finite Relief Well Systems
EM 1110-2-1913	Design and Construction of Levees
EM 1110-2-2501	Wall Design: Flood Walls
EM 1110-2-3102	General Principles of Pumping Station Design and Layout
EM 1110-2-3103	Architectural Design of Pumping Stations
EM 1110-2-3104	Structural Design of Pumping
EM 1110-2-3105	Mechanical and Electrical Design of Pumping Stations

Available from U.S. Army Corps of Engineers, Publications Depot, 2803 52nd Avenue, Hyattsville, MD 20781-1102.

U.S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE (SCS)

Engineering Field Manual for Conservation Practices

Engineering Handbook

TR-24	Guide for Selecting Roughness Coefficient "n" Values for Channels
NEH-4	National Engineering Handbook, Section 4, Hydrology

Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

U.S. DEPARTMENT OF COMMERCE

Rainfall Intensities for Local Drainage Design in Coastal Regions of North Africa, Longitude 11°W to 14°E for Durations of 5 to 240 Minutes and 2-, 5-, and 10-Year Return Periods, 1954.

Rainfall Intensities for Local Drainage Design in Arctic and Subarctic Regions of Alaska, Canada, Greenland, and Iceland for Durations of 5 to 240 Minutes and 2-, 5-, 10-, 20-, and 50-Year Return Periods, 1955.

Available from U.S. Department of Commerce, Washington, DC 20235.

U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA)

EPA-R2-72-015	Guidelines for Erosion and Sediment Control Planning and Implementation
Hydraulic Design Series No. 1	Hydraulics of Bridge Waterways
Hydraulic Engineering Circular No. 5	Hydraulic Charts for the Selection of Highway Culverts
Hydraulic Engineering Circular No. 10	Capacity Charts for the Hydraulic Design of Highway Culverts
Hydraulic Engineering Circular No. 13	Hydraulic Design of Improved Inlets for Culverts

Available from U.S. Environmental Protection Agency, Office of Research and Monitoring, Washington, DC 20460.

FEDERAL AVIATION ADMINISTRATION (FAA)

AC 150/5320	Airport Drainage

Available from Federal Aviation Administration, Office of Airport Standards (AAS-200), Department of Transportation, 800 Independence Avenue, S.W., Washington, DC 20591.

U.S. GEOLOGICAL SURVEY (USGS)

Geological Survey Water-Supply 1849	Characteristics of Natural Channels

Available from U.S. Geological Survey, Arlington, VA

NON-GOVERNMENT PUBLICATIONS:

Chow, V. T. (1959), Open-Channel Hydraulics, McGraw-Hill, New York, NY 10036.

Dunham, C. W. and Young, K. D. (1971), Contracts, Specifications, and Law for Engineers, 2nd ed., available from McGraw-Hill, New York, NY 10036.

King, H. W. and Brater, E. F. (1976), Handbook of Hydraulics, 6th ed., available from McGraw-Hill, New York, NY 10036.

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

Standard Specifications for Highway Bridges (1983)

Available from American Association of State Highway and Transportation Officials, 444 North Capital Street, N.W., Washington, DC 20001.

AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE)

Cox, A. M. (1982), Journal of the Water Resources Planning and Management Division, "Water Law Primer," ASCE.

Available from the American Society of Civil Engineers (ASCE), 345 East 47th Street, New York, NY 10017.

GLOSSARY

Backwater. Water upstream from a dam, bridge, or other obstruction which is deeper than it would normally be without the obstruction.

Closed Conduit. A pipe or other closed-section conduit.

Critical Flow. The maximum flow for a given specific energy. The flow depth and flow velocity associated with the critical flow condition are the critical depth and critical velocity, respectively.

Cross Waves. The disturbance pattern produced by water reflected back and forth between the walls of a channel producing standing waves.

Eminent Domain. The right of a government to take private property for public use by virtue of the superior dominion of the sovereign power over all lands within its jurisdiction.

Energy Grade Line. The total energy in the flow of a section with reference to a datum line which is the sum of the elevation head, pressure head, and velocity head.

Freeboard. Vertical distance from the design water surface to some designated reference, such as the top of the channel, levee, or dam.

Hydraulics. The science which treats water and other fluids in motion.

Hydraulic Grade Line. Elevation head plus pressure head or free water surface in conduits flowing partially full or in open channels. For closed-conduit flow, the water level reached in piezometer tubes installed on the conduit.

Hydraulic Jump. The condition at which the flow in an open channel increases from a depth less than critical to one that is greater than critical.

Hydrology. The science dealing with the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.

Levee. An embankment to prevent flooding.

Nonprismatic Channel. A channel of varying cross section and bottom slope.

Nonuniform Flow. Flow condition where the depth or velocity or both are changing from one point to another point along a channel.

Open Channel. Flow with a free surface subject to atmospheric pressure. Open-channel flow occurs in a partially full closed conduit.

Outfall. The discharge end of drains, force mains, and sewers.

Prismatic Channel. A channel of unvarying cross section and constant bottom slope.

Pump Rating Curve. A plot of pump head capacity characteristics; and required NPSH.

Riparian Rights. Legal principles which require that any user of waters adjoining or flowing through owned land must so use and protect them so that others utilizing the same waters will not have diminished quantity and quality of water.

Routing. The calculation of rates of flow and time increments at specific locations in streams or structures during the passage of floods.

Runoff. The portion of rainfall and melted snow which runs off a drainage area and appears in surface streams.

Subcritical Flow. The condition of flow for which the depth is greater than critical depth and the velocity is less than critical velocity.

Supercritical Flow. The condition of flow for which the depth is less than critical depth and the velocity is greater than critical velocity.

Superelevation. Rise in water surface at the outer bank of a bend with an accompanying lowering at the inner bank due to centrifugal force.

Swale. A low lying or depressed, and often wet, stretch of land. System Curve. Plot of the head losses in a conduit system versus pump discharge.

System Curve. A plot of total dynamic head versus pumping rate for a particular system.

Trackage. The lines of railway tracks.

Uniform Flow. Flow condition where the depth and velocity of flow are the same at every section of the channel.

Water Hammer. The dynamic pressure caused by sudden changes in flow rate transforming kinetic energy to pressure energy.

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