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CHAPTER TWENTY-EIGHT

GENERAL INFORMATION

In aggregate, Part IV discusses INDOT policies, practices, and procedures for performing hydraulic analyses on each project which is the responsibility of the Department. Specifically, this Chapter discusses general information on INDOT hydraulic practices. This includes defining the responsibilities of Department entities in hydraulic analyses, discussing the coordination between the *Indiana Design Manual* and the AASHTO *Model Drainage Manual*, describing the basic legal authority for drainage, providing the documentation requirements for the hydraulic analyses, and discussing the Department's Pipe Classification System.

28-1.0 GENERAL

28-1.01 Introduction

For highway applications, hydraulics is the science of collecting, transporting, and disposing of surface water originating on or near the highway right of way or flowing in a stream crossing or bordering such right of way. Proper drainage control is one of the essential elements of highway construction. The cost for the adequate removal of surface water justifies a scientific approach for the design of a drainage facility. A large percent of highway construction costs is devoted to culverts, bridges, or other drainage structures.

Drainage design is a unique field of Civil Engineering because there are no definitive methods or rules that provide absolute answers to engineering questions. The hydraulics designer must rely on engineering judgment, experience, and common sense to achieve meaningful results. The many drainage design methodologies available to the designer are only tools to aid him or her in making judgments. The drainage designer must fully understand each method that is employed, especially its limitations. Only with understanding can the designer be assured of producing a reasonable hydraulics design.

For this *Manual*, highway drainage design will be confined to methods of preventing the accumulation and retention of water on and by the roadway through the following:

1. anticipating the amount and frequency of storm runoff;

2. determining natural points of concentration and discharge and other hydraulic controls;

3. providing the most efficient disposal facility consistent with cost, the importance of the road, maintenance, and legal obligations; and

4. removing detrimental amounts of subsurface water.

In hydraulic design, the basic objective is to protect the highway against damage from storm and subsurface waters considering the effect of the proposed improvement on traffic and property. Therefore, unless the State will benefit, no improvement in the drainage of areas outside the right of way is warranted.

28-1.02 Responsibilities

28-1.02(01) Department-Designed Project

For a project designed in-house by INDOT personnel, the following summarizes the responsibilities of Department entities.

1. Designer. For roadway-drainage appurtenances, the designer is responsible for the hydrologic or hydraulic analyses of an open channel or pavement-surface drainage.

   The designer is responsible for gathering all needed information for the hydraulic analysis of a culvert or storm drain.

2. Hydraulics Team. The Hydraulics Team is responsible for the hydrologic or hydraulic analyses of the following:

   a. bridge waterway opening (in coordination with the designer);
   b. culvert;
   c. urban area where the drainage basin exceeds 80 hectares;
   d. closed drainage system; and
   e. as requested by the designer.

   The Hydraulics Team is responsible for developing criteria and policies for each hydraulic analysis performed by the Department. The Team does not check the analysis performed by the designer. However, the Team serves as a technical resource as needed.

28-1.02(02) Consultant-Designed Project

For a project designed by a consultant, the following summarizes the division of responsibilities.

1. Consultant. The consultant is responsible for the following:

   a. all hydrologic and hydraulic computations for a local-transportation project; and

   b. all hydrologic and hydraulic computations for an INDOT project related to each storm drain or culvert except that titled in the system as a small-structure replacement.

   The consultant is responsible for performing its analyses consistent with the policies and criteria adopted by the Department. The consultant must submit its calculations to the INDOT project manager for the design file for the following:

   a. culvert of 900 mm diameter or less, or deformed pipe of equivalent area; and

   b. storm drain.

2. Hydraulics Unit. For roadway drainage appurtenances, the Hydraulics Team will perform the following:

   a. review the consultant's computations for a culverts of greater than 900 mm diameter or deformed pipe of equivalent area;

   b. review the consultant's computations for a project in an urban area where the drainage basin exceeds 80 ha; and

   c. perform computations for an INDOT project listed as a small-structure replacement.

   The Hydraulics Team does not review storm-drain calculations except for a project in an urban area where the drainage basin exceeds 80 ha.

   For a bridge waterway opening, the Hydraulics Team will perform the following:

   a. review all bridge hydraulic computations performed by the consultant for a local-agency project;

   b. review scour computations performed by the consultant for a local-agency project; and

   c. perform all bridge hydraulic computations for an INDOT project.

28-1.02(03) Pipe-Classification System

Section 28-6.0 discusses the designer responsibilities specifically for the INDOT Pipe-Classification System.

28-2.0 AASHTO *MODEL DRAINAGE MANUAL*

The AASHTO Task Force on Hydrology and Hydraulics has produced the *Model Drainage Manual* (*MDM*). The *MDM* provides design theories, concepts, guidelines, criteria, policies, and procedures for use by the hydraulics designer. It has been prepared in a format suitable for direct use, with State-specific modifications, by INDOT.

This Part has been prepared based on the AASHTO *MDM*. Where practical, the text and graphics in the *MDM* have been incorporated into this *Manual* with modifications to reflect INDOT practice. The following summarizes the disposition of each chapter of the *MDM* herein.

1. Chapter One, Introduction. Chapter One is not incorporated herein.

2. Chapter Two, Legal Aspects. Chapter Two has been edited and incorporated into Section 28-3.0.

3. Chapter Three, Policy. Sections 3.1 and 3.2 have been edited and incorporated into Section 28-4.0.

4. Chapter Four, Documentation. Chapter Four has been edited and incorporated into Section 28-5.0.

5. Chapter Five, Planning and Location. This *Manual* references Chapter Five.

6. Chapter Six, Data Collection. Part III discusses data collection for a drainage survey based on this *MDM* Chapter.

7. Chapter Seven, Hydrology. Chapter Seven has been used as a resource for the development of *Manual* Chapter Twenty-nine.

8. Chapter Eight, Channels. Chapter Eight has been edited and incorporated into *Manual* Chapter Thirty.

9. Chapter Nine, Culverts. Chapter Nine has been edited and incorporated into *Manual* Chapter Thirty-one.

10. Chapter Ten, Bridges. Chapter Ten has been used as a resource for the development of *Manual* Chapters Thirty-two and Thirty-three.

11. Chapter Eleven, Energy Dissipaters. Chapter Eleven has been edited and incorporated into *Manual* Chapter Thirty-four.

12. Chapter Twelve, Storage Facilities. Chapter Twelve has been edited and incorporated into *Manual* Chapter Thirty-five.

13. Chapter Thirteen, Storm Drainage Systems. Chapter Thirteen has been edited and incorporated into *Manual* Chapter Thirty-six.

14. Chapter Fourteen, Pump Stations. This *Manual* references Chapter Fourteen.

15. Chapter Fifteen, Surface Water Environment. This *Manual* references Chapter Fifteen.

16. Chapter Sixteen, Erosion and Sediment Control. Chapter Sixteen has been used as a resource for the development of *Manual* Chapter Thirty-seven.

17. Chapter Seventeen, Bank Protection. Chapter Seventeen has been edited and incorporated into *Manual* Chapter Thirty-eight.

18. Chapter Eighteen, Coastal Zone. Chapter Eighteen is not applicable to Indiana.

19. Chapter Nineteen, Construction. This *Manual* references Chapter Nineteen.

20. Chapter Twenty, Maintenance of Drainage Facilities. This *Manual* references Chapter Twenty.

21. Chapter Twenty-one, Restoration. This *Manual* references Chapter Twenty-one.

28-3.0 LEGAL ASPECTS

28-3.01 Overview

The drainage laws and rules that are applicable to a highway facility are discussed in this Section. It should not be treated as a basis for legal advice or legal decisions. It is not a summary of all existing drainage laws and is not intended as a substitute for legal counsel.

The following generalizations can be made for drainage liability.

1. A goal in highway-drainage design should be to perpetuate natural drainage as practical.

2. The courts look with disfavor upon infliction of injury or damage that can reasonably be avoided by a prudent designer, including where some alteration in flow is legally permissible.

3. The laws relating to the liability of government entities are undergoing radical change, with a trend toward increased government liability.

The descending order to law supremacy is Federal, State, then local, and except as provided for in the statutes or constitution of the higher level of government, the superior level is not bound by laws, rules, or regulations of a lower level. The following summarizes the role of drainage law at each level of government.

28-3.02 Federal Laws

28-3.02(01) General

Federal law consists of the Constitution of the United States, Acts of Congress, regulations which government agencies issue to implement these acts, Executive Orders issued by the President, and case law. Compilations of Federal Statutory Law, revised annually, are available in the United States Code (USC) and the United States Code Service (USCS). Compilations of Federal regulatory material, revised annually, are available in the Code of Federal Regulations (CFR).

Federal law does not address drainage per se, but many laws have implications which affect drainage design. These include laws concerning the following:

1. flood insurance and construction in a flood-hazard area;
2. navigation and construction in a navigable waterway;
3. water-pollution control;
4. environmental protection; and
5. protection of fish and wildlife.

Federal agencies formulate and promulgate rules and regulations to implement these laws. A highway-hydraulics designer should attempt to remain informed on proposed and final regulations.

28-3.02(02) Navigable-Waters Regulations

The Congress of the United States is granted constitutional power to regulate Interstate commerce, including navigable waters. The Federal agencies which implement existing Federal regulations are as follows.

1. United States Coast Guard (USCG). The USCG has regulatory authority under the Rivers and Harbors Act of 1899, Section 9 (33 U.S.C. 401), to approve plans and issue permits for bridges and causeways across navigable rivers. FHWA has the responsibility to determine that a USCG permit is not required. The USCG has the responsibility for the following:

    a. to determine whether or not a USCG permit is required for the improvement or construction of a bridge over a navigable waterway except for the exemption exercised by FHWA; and

    b. to approve the bridge location, alignment, and appropriate navigational clearances for each bridge permit application.

2. Corps of Engineers. The U.S. Army Corps of Engineers has regulatory authority over the construction of dams, dikes, or other obstructions which are not bridges and causeways under Section 9 (33 U.S.C. 401). The Corps also has authority to regulate of the Rivers and Harbors Act of 1899, Section 10 (33 U.S.C. 403), which prohibits the alteration or obstruction of a navigable waterway with the excavation or deposition of fill material in such waterway. The Clean Water Act, Section 404 (33 U.S.C. 1344) prohibits the unauthorized discharge of dredged or fill material into waters of the United States, including navigable waters. Such discharges require a Permit. The term discharges of fill material means the addition of rock, sand, dirt, concrete, or other material into the waters of the United States incidental to the construction of a structure. The Corps of Engineers will grant a Regional General Permit for certain categories of minor activities involving discharge of fill material. Otherwise, an Individual 404 Permit is required.

3. Federal Highway Administration. The Federal Highway Administration has the authority to implement the Section 404 Permit Program (Clean Water Act of 1977) for each Federal-aid highway project processed under a 23 CFR 771.115 (b) categorical exclusion. This permit is granted for a project where the activity, work, or discharge is categorically excluded from environmental documentation because such activity does not have an individual or cumulative significant effect on the human environment.

4. Environmental Protection Agency (EPA). The EPA is authorized to prohibit the use of an area as a disposal site if it is determined that the discharge of materials at the site will have an unacceptable adverse effect on municipal water supplies, shellfish beds, fishery areas, or wildlife or recreational areas per the Clean Water Act, Section 404(c) (33 U.S.C. 1344). Also EPA is authorized under the Clean Water Act, Section 402 (33 U.S.C. 1344)

to administer and issue a National Pollutant Elimination Discharge System (NPDES) Permit for a point-source discharge, provided prescribed conditions are satisfied.

See Chapter Nine for more information on permits.

28-3.02(03) Fish and Wildlife Service

The Fish and Wildlife Act of 1956 (16 U.S.C. 742 et seq.), the Migratory Game-Fish Act (16 U.S.C. 760c-760g), and the Fish and Wildlife Coordination Act (16 U.S.C. 611-666c), express the concern of Congress with the quality of the aquatic environment as it affects the conservation, improvement, and enjoyment of fish and wildlife resources. The Fish and Wildlife Coordination Act requires the following:

> *whenever the waters of any stream or body of water are proposed or authorized to be impounded, diverted, the channel deepened, or the stream or other body of water otherwise controlled or modified for any purpose whatever, including navigation and drainage, by any department or agency of the United States, or by any public or private agency under Federal permit or license, such department or agency shall first consult with the United States Fish and Wildlife Service, Department of the Interior, and with the head of the agency exercising administration over the wildlife resources of the particular state with a view to the conservation of wildlife resources by preventing loss of and damage to such resources as well as providing for the development and improvement thereof.*

The Fish and Wildlife Service's role in the permit-review process is to review and comment on the effects of a proposal on fish or wildlife resources. It is the function of the regulatory agency (e.g., Corps of Engineers, U. S. Coast Guard) to consider and balance all factors, including anticipated benefits and costs in accordance with NEPA, in deciding whether to issue the permit.

28-3.02(04) National Flood Insurance Program (NFIP)

The Flood Disaster Protection Act of 1973 denies Federal financial assistance to flood-prone communities that fail to qualify for flood insurance. The Act requires communities to adopt certain land use controls to qualify for flood insurance. These requirements could impose restrictions on the construction of highways in floodplains or floodways in communities which have qualified for flood insurance. A floodway is that portion of the floodplain required to pass a flood that has a 1-percent chance (i.e., a 100-year flood) of occurring in a 1-year period without cumulatively increasing the water surface elevation more than the allowable backwater. See Chapter Thirty-two for specific INDOT / IDNR criteria.

1. Flood Insurance. The National Flood Insurance Act of 1968 requires that communities adopt adequate land use and control measures to qualify for insurance. Federal criteria promulgated to implement this requirement include the following which can affect certain highways.

   In a riverine situation, the community must require that, until a floodway has been designated, no use, including landfill, may be permitted within the floodplain area having flood hazards for which base flood elevations have been provided. Unless it is demonstrated that the cumulative effect of the proposed use, when combined with all other existing and reasonably-anticipated uses of a similar nature, this will not increase the water-surface elevation of the 100-year flood more than the allowable backwater at a given location within the community.

   After the floodplain area having flood hazards has been identified, and the water surface elevation for the 100-year flood and floodway data have been provided, the community must designate a floodway. The floodway will convey the 100-year flood without increasing the water surface elevation of the flood more than the allowable backwater at a given point. It will prohibit, within the designated floodway, fill, encroachments, or new construction and substantial improvements of existing structures which can result in an increase in flood height within the community during the occurrence of the 100-year flood discharge.

   See Chapter Thirty-two for specific INDOT / IDNR criteria.

   The local community with land-use jurisdiction has the responsibility for enforcing National Flood Insurance Program (NFIP) regulations in that community if the community is participating in the NFIP. Consistency with NFIP standards is a requirement for Federal-aid highway action involving a regulatory floodway. The community, by necessity, must submit proposals to the Federal Emergency Management Agency (FEMA) for amendments to NFIP ordinances and maps in that community if necessary. Determination of the status of a community's participation in the NFIP and review of applicable NFIP maps and ordinances are, therefore, essential first steps in conducting location hydraulic studies and preparing environmental documents.

2. NFIP Maps. Where NFIP maps are available, their use is mandatory in determining whether a highway-location alternative will include an encroachment on the base floodplain. The types of NFIP maps that are published are as follows:

   a. Flood Hazard Boundary Map (FHBM);
   b. Flood Boundary and Floodway Map (FBFM); and
   c. Flood Insurance Rate Map (FIRM).

A FHBM is not based on a detailed hydraulic study and, therefore, the floodplain boundaries shown are approximate. A FBFM is derived from a detailed hydraulic study and should provide reasonably accurate information. The hydraulic data from which the FBFM was derived are available through the regional office of FEMA. This is in the form of computer input data records for calculating the water-surface profile. The FIRM is produced at the same time using the same hydraulic model and has appropriate rate zones and base flood elevations added.

A community may or may not have published one or more of the above maps depending on its level of participation in the NFIP. Information on community participation in the NFIP is provided in the *National Flood Insurance Program Community Status* which is published semiannually for the State.

28-3.03 State Drainage Law

28-3.03(01) Types

State drainage law is derived from two sources as follows.

1. Common Law. Common law is that body of principles which developed from immemorial usage and custom and which receives judicial recognition and sanction through repeated application. These principles were developed without legislative action and are embodied in the decisions of the courts.

2. Statutory Law. Statutory laws of drainage are enacted by legislatures to enlarge, modify, clarify, or change the common law applicable to a particular drainage condition. This type of law is derived from constitutions, statutes, ordinances, and codes.

The common-law rules of drainage predominate unless they have been enlarged or superseded by statutory law.

28-3.03(02) Classification of Waters

The first step in the evaluation of a drainage problem is to classify the water as surface water, stream water, floodwater, or groundwater. Once the classification has been established, the rule that applies to the particular class of water determines responsibilities with respect to disposition of the water. The following definitions apply.

1. Surface Water. Surface water is that which has been precipitated on the land from the sky or forced to the surface from a spring and which has then spread over the surface of the ground without being collected into a definite body or channel.

2. Stream Water. Stream water is former surface or groundwater which has entered and now flows in a well-defined natural watercourse, together with other waters reaching the stream by direct precipitation or rising from springs in the bed or banks of the watercourse. Legally, a watercourse refers to a definite channel with bed and banks within which water flows either continuously or intermittently.

3. Floodwater. Floodwater is former stream water which has escaped from a watercourse (and its overflow channels) and flows or stands over adjoining land. It remains a floodwater until it disappears from the surface as a result of infiltration or evaporation, or return to a natural watercourse.

4. Groundwater. In legal considerations, groundwater is either percolating water or an underground stream. The term percolating water includes all waters which pass through the ground beneath the surface of the earth without a definite channel. All underground waters are presumed to be percolating and, to remove them from the percolating class, the existence and course of a permanent channel must be clearly shown. An underground stream is water passing through the ground beneath the surface in a permanent, distinct, well-defined channel.

28-3.04 State Water Rules

28-3.04(01) Basic Concepts

Two rules have been developed by the courts regarding the disposition of surface waters. One is the civil-law rule of natural drainage. The other is the common-enemy doctrine. Much of the law regarding stream water is founded on a common-law maxim that states that water runs and ought to run as it is by natural law accustomed to run. Thus, an interference with the flow of a natural watercourse to the injury or damage of another will result in liability. However, there are qualifications as follows.

1. In common law, a floodwater is treated as a common enemy of all people, lands, and property attacked or threatened by it.

2. In ground water law, the English Rule, which is analogous to the common-enemy rule in surface-water law, is based on the doctrine of absolute ownership of water beneath the property by the landowner.

28-3.04(02) Surface Water

The civil-law rule is based upon the perpetuation of natural drainage. The rule places a natural easement or servitude upon the lower land for the drainage of surface water in its natural course, and the natural flow of the water cannot be obstructed by the servient owner to the detriment of the dominant owner. The State has modified this rule so that the owner of upper lands has an easement over lower lands for drainage of surface water, and natural drainage conditions can be altered by an upper proprietor provided the water is not sent down in a manner or quantity to do more harm than formerly. The following also applies.

1. Under the common-enemy doctrine, surface water is regarded as a common enemy which each property owner may fight off or control as he or she will or is able, either by retention, diversion, repulsion, or altered transmission. Thus, there is not necessarily cause of action if an injury occurs causing damage. This doctrine has been subject to a limitation that one must use his or her land so as not to unreasonably or unnecessarily damage the property of others.

2. Under the reasonable-use rule, each property owner can legally make reasonable use of his or her land, though the flow of surface waters is altered thereby and causes some harm to others. However, liability occurs if his or her harmful interference with the flow of surface water is unreasonable. Whether a landowner's use is unreasonable is determined by means of a nuisance-type balancing test. The analysis involves the questions as follows.

    a. Was there reasonable necessity for the actor to alter the drainage to make use of his or her land?

    b. Was the alteration done in a reasonable manner?

    c. Does the utility of the actor's conduct reasonably outweigh the gravity of harm to others?

28-3.04(03) Stream water

Where a natural watercourse is unquestioned in fact, permanence, and stability, there is little difficulty in application of the rule. A highway crosses channel on a bridge or culvert, with some constriction of the width of the channel and obstruction by the substructure within the channel, both causing backwater upstream and acceleration of flow downstream. The changes in regime must be so small as to be tolerable by adjoining owners, or there may be liability of injuries or damages suffered.

Surface water from a highway is often discharged into the most convenient watercourse. The right is unquestioned if the water was naturally tributary to the watercourse and unchallenged if

the watercourse has adequate capacity. However, if all or part of the surface water has been diverted from another watershed to a small watercourse, a downstream owner may complain and recover for ensuing damage.

28-3.04(04) Floodwater

Considering floodwater as a common enemy permits all affected landowners, including owners of highways, to act in a reasonable way to protect themselves and their property from the common enemy. They may obstruct its flow from entering their land, backing or diverting water onto the land of another without penalty, by gravity or pumping, by diverting dikes or ditches, or by other reasonable means.

The test of reasonableness has frequently been applied, and liability can result where unnecessary damage is caused. The highway designer should make provision for overflow in an area where it is foreseeable that it will occur. There is a definite risk of liability if such water is impounded on an upstream owner or, worse yet, is diverted into an area where it would not otherwise have gone. To label water as floodwater does not mean that it can be disregarded.

The English Rule has been modified by the Reasonable-Use Rule which states in essence that each landowner is restricted to a reasonable exercise of his or her own right and a reasonable use of his property in view of the similar right of his or her neighbors.

Although *reasonable* may be interpreted somewhat differently for each situation, it means that a landowner can utilize subsurface water on his or her property for the benefit of agriculture, manufacturing, irrigation, etc., pursuant to the reasonable development of the property, although such action may interfere with the underground waters of neighboring proprietors. However, it does preclude the withdrawal of underground waters for distribution or sale for uses not connected with beneficial ownership or enjoyment of the land from whence they were taken.

A further interpretation of *reasonable* in relation to highway construction views the excavation of a deep cut section that intercepts or diverts underground water to the detriment of adjacent property owners as unreasonable. Highway construction has permitted the introduction of surface contamination into subsurface waters and thus incurred liability for resulting damages.

28-3.05 Statutory Law

The inadequacies of the common law or court-made law of drainage has led to a gradual enlargement and modification of the common-law rules by legislative mandate. If the common-law rules have been enlarged or superseded by statutory law, the statute prevails. Statutes have been enacted that affect drainage as described below.

28-3.05(01) Eminent Domain

In the absence of an existing right, a public agency may acquire the right to discharge highway drainage across adjoining lands through the use of the right of eminent domain. Eminent domain is the power of a public agency to take private property for public use.

The State constitution grants the right of eminent domain which allows the taking of property for public purposes, including the development of a watercourse or watershed area. However, if a property is taken under eminent domain, the private landowner must be compensated for his or her loss.

28-3.05(02) Water Right

The water right which attaches to a watercourse is a right to the use of the flow, and not ownership of the water itself. This is true under both the riparian doctrine and the appropriation doctrine. This right of use is a property right, entitled to protection to the same extent as other forms of property, and is regarded as real property. After the water has been diverted from the stream flow and reduced to possession, the water itself becomes the personal property of the riparian owner or the appropriator. The following applies.

1. Riparian Doctrine. Under the riparian doctrine, lands contiguous to a watercourse has prior claim to waters of the stream solely by reason of location and regardless of the relative productive capacities of riparian and non-riparian lands.

2. Doctrine of Prior Appropriation. The essence of this doctrine is the exclusive right to divert water from a source if the water supply naturally available is not sufficient for the needs of all those holding rights to its use. Such exclusive right depends upon the effective date of the appropriation, the first in time being the first in right.

A highway designer must consider that proposed work in the vicinity of a stream should not impair either the quality or quantity of flow of a water right to the stream.

28-3.06 Local Laws and Applications

Each local government (city, town, county, improvement district) has ordinances and codes which require consideration during design. For example, zoning ordinances can have a substantial effect on the design of a highway and future drainage from an area. The State is not legally required to comply with local ordinances except where compliance is required by specific

State statute. However, INDOT will, as practical, satisfy local ordinances as a courtesy, especially if it can be done without imposing a burden on the State.

A municipality is treated as a private party in State drainage matters. A municipality undertaking a public improvement is liable like an individual for damage resulting from negligence or an omission of duty. A municipality is under no legal duty to construct drainage improvements unless public improvements necessitate drainage (e.g., where street construction accelerates or alters storm runoff). A municipality is not liable for adoption or selection of a defective plan of drainage.

A municipality can be held liable for negligent construction of drainage improvements, for negligent maintenance and repair of drainage improvements, or if it fails to provide a proper outlet for drainage improvements. In the absence of negligence, a municipality will not be held liable for increased runoff occasioned by the necessary and desirable construction of storm drains, nor will a municipality be held liable for damages caused by overflow of its storm drains occasioned by extraordinary, unforeseeable rains or floods. Municipal liability will occur where a municipality does the following:

1. collects surface water and casts it in a body onto private property where it did not formerly flow;

2. diverts, by means of artificial drains, surface water from the course it would otherwise have taken, and casts it into a body large enough to do substantial injury on private land where, but for the artificial storm drain, it would not go; and

3. fills up, dams back, or otherwise diverts a stream of running water so that it overflows its banks and flows on the land of another.

28-3.07 Legal Drains

Most counties have established a system of legal drains which are maintained by the county surveyor. State law grants the counties certain privileges where a project impacts an established legal drain. More detailed information on legal-drain regulations can be found in IC 36-2-12-15 and IC 36-9-27.

At the initiation of a bridge or road project, the designer should contact the appropriate county surveyor’s office to determine if an affected waterway is a legal drain. If so, the designer should invite the county surveyor to all field checks. This will provide an opportunity for the surveyor to express concerns and provide comments on the project. The designer should also request available information regarding legal flow lines or other requirements. This information must be

included with the grade review plans. If not, include a note on the plans stating that the waterway is not a legal drain.

28-4.0 POLICY

28-4.01 Introduction

28-4.01(01) Purpose

Drainage concerns are one of the most important aspects of highway design and construction. The purpose of this Section is to outline specific policies that guide and determine the variables which influence drainage design.

28-4.01(02) Policy vs. Criteria

Policy and criteria statements are closely related. Criteria are INDOT's numerical or specific guidance which is founded in broad policy statements. For this *Manual*, the following definitions apply.

1. Policy. A definite course of action or method of action selected to guide and determine present and future decisions.

2. Design Criteria. The standards by which a policy is implemented or placed in action.

Thus, design criteria are needed for design; policy statements are not. The following is an example of a policy statement.

> *The designer will size the drainage structure to accommodate a flood compatible with the projected traffic volume.*

The following is an example of a design criterion.

> *For projected traffic volume less than or equal to 750 vehicles per day, each drainage structures should be designed for a 10-year flood (exceedance probability of 10%). For projected traffic volume greater than 750 vehicles per day, each drainage structure should be designed for a 25-year flood (exceedance probability of 4%).*

The following provides information on the hydraulic design of a drainage structure and related Federal, State, and local policies. Some of the following outline the relevant policies (with

references indicating where details can be obtained). Some of the following state the policies and provide detailed information.

28-4.02 General Hydraulic Design Policies

28-4.02(01) Introduction

An adequate drainage structure is defined as one which satisfies the following:

1. the design of the structure satisfies or exceeds INDOT standard engineering practice; and

2. the design is consistent with what a reasonably competent and prudent designer will do under similar circumstances.

Hydrologic and hydraulic analyses, and engineering evaluation of selected alternatives, are conducted as a part of the design of a highway-drainage structure and serve as a means of achieving an adequate drainage design.

These studies are discussed further below.

28-4.02(02) Hydrologic Analysis

Present state-of-practice formulas and models for estimating flood flow are based on statistical analyses of rainfall and runoff records. The designer should select appropriate hydrologic estimating procedures and obtain runoff data where available for purposes of evaluation, calibration, and determination of the predicted value of the desired flood frequencies. The predicted value of the flood flow represents the designer's best estimate, with varying degrees of error. The expected magnitude of this variation can be determined for some formulas or models as a part of the hydrologic design procedure.

28-4.02(03) Hydraulic Analysis

The next step in the design process involves preliminary selections of alternative designs that are judged to meet the site conditions and to accommodate the flood flow selected for analysis. The hydraulic analysis is made utilizing appropriate formulas, physical models, or computer programs for purposes of defining, calibrating, and checking the performance of the preliminary designs over a range of flows.

28-4.02(04) Engineering Evaluation

The final step in the design process is the engineering evaluation of the preliminary designs and approval of the selected final design. This process involves consideration and balancing of a number of factors. Some of these factors are as follows:

1. legal considerations;
2. flood hazards to highway users or neighboring property owners;
3. hydraulic efficiencies;
4. costs;
5. environmental and social concerns; and
6. other site-specific concerns.

28-4.02(05) General Policies

Hydrologic and hydraulic analyses set forth the design-process representative of INDOT's standard engineering practice. Engineering evaluation outlines the approach to be followed by a reasonably competent and prudent designer in evaluating, selecting, and approving a final design. The following policies are made regarding this design process.

1. It is the designer's responsibility to provide an adequate drainage structure. The designer is not required to provide a structure that will accommodate all conceivable flood flows under all possible site conditions.

2. The detail of design studies should be commensurate with the risk associated with the encroachment and with other economic, engineering, social, or environmental concerns.

3. The overtopping or design flood may serve as criteria for evaluating the adequacy of a proposed design. The overtopping flood is the smallest recurrence-interval flood which will result in flow over the highway or other watershed boundary. The overtopping flood flow is the flow that overtops the highway or other watershed boundary limit. The design flood is the recurrence interval of the flood for which the drainage structure is sized to ensure that no traffic interruption or significant damage will result. The overtopping flood and the design flood may vary widely depending on the grade, alignment, and classification of the road and the characteristics of the watercourse and floodplain.

4. The predicted value of the 100-year or base flood serves as the present engineering standard for evaluating a flood hazard and as the basis for regulating a floodplain under the National Flood Insurance Program. The designer must make a professional judgment on the degree of risk that is tolerable for the base flood as required for each project.

5. The developed hydraulic performance curve of a drainage structure depicts the relationship between floodwater stage (or elevation) and flood-flow magnitude and frequency. The performance curve should include the 100-year flood. With the performance curve, the designer can evaluate the adequacy of the design for a range of flows and consider errors of estimate in the hydrologic estimating procedure. It is standard engineering practice to use the predicted value of the 100-year flood as the basis for evaluating a flood hazards. However, a flow larger than this value may be considered for a complex, high-risk, or unusual situation that requires special studies or risk analyses.

28-4.03 Water Main or Sanitary Sewer Construction

The INDOT *Standard Specifications* do not include most elements related to the construction of water main or sanitary sewer construction. However, many contracts, mostly those for local public agencies, include construction of these facilities. Therefore, special provisions should be developed and included each individual contract. The special provisions should adequately describe the work, determine material and construction requirements, and establish methods to measure and pay for the work.

There are many reference materials available from which information can be obtained to assist in the preparation of a required special provision. One such reference is the *Model Specifications For Water and Sewer Main Construction In Indiana*, prepared as a result of a joint effort between the Consulting Engineers of Indiana, Inc., Purdue University, and the Indiana Constructors Association. Other such reference documents have been prepared by individual public- and privately-owned entities.

The designer is free to develop a project-specific special provision or to incorporate a document into a contract by reference. The work must be completely addressed in the special provision. If a document is incorporated into a contract by reference, the special provision must indicate that the INDOT *Standard Specifications* govern if there is conflict with the referenced document. The designer should also be certain that the referenced document is readily available for use by the contractor or field personnel. The designer may indicate in a special provision how or where the document may be obtained.

28-5.0 DOCUMENTATION

28-5.01 Overview

28-5.01(01) Introduction

An important part of the design or analysis of a hydraulic facility is its documentation. Appropriate documentation of the design of a hydraulic facility is essential because of the following:

1. the importance of public safety;

2. justification of expenditure of public funds;

3. future reference by engineers (where improvements, changes, or rehabilitations are made to the highway facility);

4. information leading to the development of defense in litigation; and

5. public information.

It may be necessary to refer to plans, specifications, or analyses long after the actual construction has been completed. Documentation permits evaluation of the performance of a structure after a flood event to determine if the structure performed as anticipated or to establish the cause of unexpected behavior. If the structure fails, it is essential that contributing factors be identified so that recurring damage can be avoided.

28-5.01(02) Definition

The definition of hydrologic and hydraulic documentation as used in this Section is the compilation and preservation of the design and related details and all pertinent information on which the design and decisions were based. This should include the drainage area and other maps, field survey information, source references, photographs, engineering calculations and analyses, measured and other data, and flood history including narratives from newspapers and individuals such as highway maintenance personnel or local residents who witnessed or had knowledge of an unusual event.

28-5.01(03) Purpose

This Section provides the documentation which should be included in the design file and on the construction plans. Although the Department's documentation requirements for an existing or proposed drainage facility are similar, the data retained for an existing facility is often slightly different than that for a proposed facility, and these differences are discussed. This Section focuses on the documentation of the findings obtained in using the other chapters of this *Manual*. Thus, the designer should be familiar with all of the hydrologic and hydraulic design procedures associated with this Section. This Section identifies the Department's system for organizing the

documentation of a hydraulic design or review to provide as complete a history of the design process as is practical.

The purpose of providing documentation is to define the design procedure that was used and to show how the final design and decisions were selected. Often, there is expressed the myth that avoiding documentation will prevent or limit litigation losses as it supposedly precludes providing the plaintiff with incriminating evidence. This seldom occurs, and documentation should be viewed as the record of reasonable and prudent design analysis based on the best available technology. Thus, good documentation can provide the following:

1. protecting the Department by proving that reasonable and prudent actions were, in fact, taken (such proof should certainly not increase the potential court award, and may decrease it by disproving any claims of negligence by the plaintiff);

2. identifying the situation at the time of design which might be very important if legal action occurs in the future;

3. documenting that rationally-accepted procedures and analyses were used at the time of the design which were commensurate with the perceived site importance and flood hazard (this should further disprove negligence claims);

4. providing a continuous site history to facilitate future reconstruction;

5. providing the file data necessary to quickly evaluate a future site problem that can occur during the facility's service life; and

6. expediting plan development by providing the reasons and rationale for specific design decisions.

28-5.01(04) Types

The types of documentation which should be considered are preconstruction, design, and construction or operation.

1. Preconstruction documentation should include the following, if available, or within the budgetary restraints of the project.

    a. aerial photographs;

    b. contour mapping;

c. watershed map or plan including flow directions, watershed boundaries, and watershed areas;

d. surveyed data reduced to include existing hydraulic facilities, existing controls, profiles (roadway, channel, drives), and cross sections (roadway, channel, faces of structure);

e. flood insurance studies and maps by FEMA;

f. Natural Resource Conservation Service soil maps;

g. field trip report(s) which may include videocassette recordings, audio tape recordings, still-camera photographs, movie-camera films, or written analysis of findings with sketches; and

h. reports from other agencies (local, State, or Federal), INDOT personnel, newspapers, and abutting property owners.

2. Design documentation should include all of the information used to justify the design, including the following:

a. reports from other agencies;
b. hydrological report;
c. hydraulic report; and
d. approvals.

3. Construction or operation documentation should include the following:

a. plans;
b. revisions;
c. as-built plans and subsurface borings;
d. photographs; and
e. record of operation during flooding events, complaints, and resolutions.

The as-built plans should be prepared and maintained in a permanent file for each drainage structure to document subsurface foundation elements such as footing types and elevations, pile types, (driven) tip elevations, etc. There may be other information which should be included or may become evident as the design or investigation develops. This additional information shall be incorporated at the discretion of the designer.

28-5.01(05) Scheduling

Documentation should not be considered as occurring at specific times during the design, or as the final step in the process; this could be long after the final design is completed. Documentation should rather be an ongoing process and part of each step in the hydrologic and hydraulic analysis and design process. This will increase the accuracy of the documentation, provide data for future steps in the plan development process, and provide consistency in the design if different designers are involved at different times of the plan development process.

28-5.01(06) Responsibility

The designer should be responsible for determining which hydrologic analyses, hydraulic design, and related information should be documented during the plan-development process. The designer should make a determination that complete documentation has been achieved during the plan-development process which will include the final design. To assist in this determination, see Section 28-5.04.

28-5.02 Procedures

28-5.02(01) Introduction

A complete hydrologic and hydraulic design and analysis documentation file for each waterway encroachment or crossing should be maintained by the Hydraulics Team. If practical, this file should include the following:

1. identification and location of the facility;
2. photographs (ground and aerial);
3. hydrologic investigations;
4. drainage area maps, vicinity maps, and topographic maps;
5. contour maps;
6. interviews (local residents, adjacent property owners, or maintenance forces);
7. newspaper clippings;
8. design notes and correspondence relating to design decisions;
9. history of performance of the existing structure; and
10. assumptions.

The documentation file should include design and analysis data and information which influenced the facility design.

28-5.02(02) Practices

The following are the Department's practices related to documentation of hydrologic and hydraulic design and analysis.

1. Hydrologic and hydraulic data, preliminary calculations and analyses, and all related information used in developing conclusions and recommendations related to drainage requirements, including estimates of structure size and location, should be compiled in a documentation file.

2. The designer should document all design assumptions and selected criteria including the decisions related thereto.

3. The amount of detail of documentation for each design or analysis should be commensurate with the risk and the importance of the facility.

4. Documentation should be organized to be as concise and complete as practicable so that future designers can understand what was done by predecessors.

5. Circumvent incriminating statements if possible by stating uncertainties in less than specific terms (e.g., *the culvert may back water* rather than *the culvert will back water*).

6. Provide all related references in the documentation file to include such things as published data and reports, memos and letters, or interviews. Include dates and signatures where appropriate.

7. Documentation should include data and information from the conceptual stage of project development through construction to provide successors with all information.

8. Documentation should be organized to logically lead the reader from past history through the problem background, into the findings, and through the performance.

9. A summary at the beginning of the documentation will provide an outline of the documentation file to assist the user in finding detailed information.

<u>28-5.03 Documentation Procedures</u>

28-5.03(01) Introduction

The following should be included in the documentation file. The intent is not to limit the data to only those items listed but, rather, to establish a minimum requirement consistent with the

hydraulic design procedures as outlined in this *Manual*. If circumstances are such that the drainage facility is sized by other than normal procedures or if the size of the facility is governed by factors other than hydrologic or hydraulic factors, a narrative summary detailing the design basis should appear in the documentation file. The designer should include the items listed below which are useful in understanding the analysis, design, findings, and final recommendations.

28-5.03(02) Hydrology

The items used in the design or analyses to be included in the documentation file are as follows:

1. contributing watershed-area size and identification of source (map name, etc.);

2. hydrologic discharge and hydrograph estimating method and findings;

3. IDNR Recommendation Letter (if an IDNR permit is required); and

4. method for estimating 500-year discharge (when applicable).

28-5.03(03) Bridge

The items to be included in the documentation file are as follows:

1. 100-year high-water elevation for natural, existing, and proposed conditions;

2. cross sections used in the design high-water elevation determination;

3. roughness coefficient (*n* value) assignments;

4. information on the method used for design high-water elevation determination;

5. observed high-water elevation, date, and discharge;

6. velocity measurements or estimates and locations (including both the through-bridge and channel velocity) for the 100-year flood;

7. calculated backwater, velocity, and scour for the 100-year and 500-year floods for scour evaluation;

8. magnitude and frequency of overtopping flood;

9. copies of computer analyses (existing and proposed) and disk containing all data files;

10. complete hydraulic study report;

11. economic analysis of design and alternatives;

12. bridge scour results;

13. roadway geometry (plan and profile); and

14. potential flood hazards to adjacent properties.

28-5.03(04) Culvert

The items to be included in the documentation file are as follows:

1. culvert performance curves;

2. allowable headwater elevation and basis for its selection;

3. cross sections used in the design high-water elevation determination;

4. roughness coefficient assignments (*n* values);

5. observed high-water elevation, date, and discharge;

6. stage-discharge curve for natural, existing, and proposed conditions to include the depth and velocity measurements or estimates and location for the 100-year flood;

7. performance curves showing the calculated backwater elevations, outlet velocity, and scour (if applicable), and the 100-year flood;

8. type of culvert-entrance condition;

9. culvert-outlet appurtenances and energy dissipation calculations and designs (if applicable);

10. copies of all computer analyses and a disk containing all data files;

11. roadway geometry (plan and profile); and

12. potential flood hazard to adjacent properties.

28-5.03(05) Open Channel

The items to be included in the documentation file are as follows:

1. stage-discharge curves for the 100-year and historical water-surface elevations;
2. cross sections used in the design water-surface determinations and their locations;
3. roughness coefficient assignments (*n* values);
4. information on the method used for design water-surface determinations;
5. observed high water elevation, date, and discharge;
6. channel velocity measurements or estimates and locations;
7. water-surface profiles through the reach for the 100-year or historical flood;
8. design or analysis of materials proposed for the channel bed and banks;
9. energy dissipation calculations and designs; and
10. copies of all computer analyses, including data disks.

28-5.03(06) Storm Drain

The items to be included in the documentation file are as follows:

1. computations for inlets and pipes, including hydraulic grade lines;

2. copies of the standard computation sheets shown in Chapter Thirty-six or the computer printout;

3. complete drainage area map;

4. design frequency (10-year gravity and 50-year pressure flow);

5. information concerning outfalls, existing storm drains, or other design considerations; and

6. a schematic indicating storm-drain system layout.

28-5.03(07) Pumping Station

The items to be included in the documentation file are as follows:

1. inflow design hydrograph from drainage area to pump,
2. flood-frequency curve for the attenuated peak discharge,
3. maximum allowable headwater elevation and related probable damage,
4. starting sequence and elevations,
5. sump dimensions,
6. available storage amounts,
7. pump size and operation,
8. pump calculations and design report, and
9. line storage and pit storage capacity.

28-5.03(08) Computer Files

The input data listing (hard copy and data disk) and output results of selected alternatives should be included in the documentation file and should be labeled.

28-5.04 Documentation Project Checklist

The Documentation Project Checklist is shown as Figure 28-5A. An editable version of this form may also be found on the Department's website at www.in.gov/dot/div/contracts/design/dmforms/ .

28-6.0 PIPE CLASSIFICATION SYSTEM

28-6.01 Introduction

INDOT has developed and implemented a Pipe Classification System which is intended to enhance the performance and longevity of pipe material used for a culvert, storm drain, underdrain, or other drainage facility. This is a comprehensive system which impacts all INDOT procedures and documents related to pipes, including the following:

1. the *Indiana Design Manual*,
2. the INDOT *Standard Specifications*, and
3. the INDOT *Standard Drawings*.

The information is segregated as follows:

1. Section 28-6.0 discusses information which applies to each pipe regardless of type of drainage appurtenance.

2. Chapter Twenty-nine has incorporated those elements of the System which apply to hydrology (e.g., choice of hydrologic method).

3. Chapter Thirty-one has incorporated those elements of the System which apply to a culvert (e.g., culvert design process, cover height).

4. Chapter Thirty-six has incorporated those elements of the System which apply to a storm drain or underdrain (e.g., minimum velocity, inlet spacing).

28-6.02 Description

The Pipe Classification System consists of the following.

1. Type 1 Pipe. Culvert under mainline and or public-road-approach pavement.
2. Type 2 Pipe. Storm-drain pipe.
3. Type 3 Pipe. Culvert under drive or field entrance.
4. Type 4 Pipe. Underdrain or drain tile.
5. Type 5 Pipe. Broken-back or other pipe installation which requires coupled pipe.

The INDOT *Standard Specifications* lists the materials that have been approved for each pipe type.

Although the Pipe Classification System serves as the foundation of drainage-structure design, other structure types are available for use as appropriate. One such category is referred to as Specialty Structure. A Specialty Structure should be used if the design process indicates that the materials included in the Pipe Classification System do not provide an adequate hydraulic structure. Specialty Structures include the following:

1. precast reinforced concrete box section;
2. precast reinforced concrete three-sided structure; or
3. structural-plate arch.

Specific-Application Structures are also not included in the Pipe Classification System but are available for use as appropriate. These structures include the following:

1. concrete-culvert extension;
2. pipe extension;
3. slotted-drain pipe or slotted-vane-drain pipe; and
4. end-bent-drain pipe.

28-6.03 Design Process

The drainage-structure design process, excluding a Specific-Application Structure, begins based on the assumption that the Pipe Classification System includes material that can provide a structure that satisfies all design requirements. A Specialty Structure must not be considered until it has been demonstrated that the appropriate System pipe type cannot provide a hydraulically-adequate structure.

Specific design requirements relative to culvert (Chapter Thirty-one) or storm-drain (Chapter Thirty-six) sizing are detailed elsewhere herein. The general concepts that apply to the implementation of the Pipe Classification System are discussed below.

1. Interior Designation. Sizing of a pipe-type structure is based interior designation. An interior designation of smooth or corrugated has been assigned to each type 1, 2, 3, or 5 pipe material. A type 4 pipe size is not determined by means of hydraulic calculations. Individual materials must not be considered during the sizing process for a pipe-type structure. More information on interior designation is included in Chapter Thirty-one.

2. Material. Each pipe type in the Pipe Classification System includes a list of approved materials. However, except for a type 4 pipe, the approval is general in nature. For example, an individual mainline culvert site may possess features that render the site unsuitable for some approved type 1 Pipe materials. Therefore, it is necessary to perform a Structure Site Analysis for each type 1, 2, 3, or 5 pipe structure. Features to be considered during the analysis include cover-height and service-life criteria (i.e., service life duration, abrasive or non-abrasive site designation, and structure pH). See Section 28-6.04 for additional information on Structure Site Analysis.

28-6.04 Structure Site Analysis

A Structure Site Analysis is required for each type 1, 2, 3, or 5 pipe structure. Unless otherwise specified, the analysis is not required for a type 4 pipe, Specialty, or Specific-Application Structure. The scope of the analysis is discussed below.

28-6.04(01) Cover

Cover is measured from the pipe crown to the bottom of the proposed pavement. The depth of aggregate base under HMA pavement or subbase under concrete pavement is included in the cover dimension. The allowable cover depth can vary based on pipe material. For a circular pipe, the minimum cover should be at least 300 mm, and the maximum cover should be at least

30 m. For a deformed pipe with a corrugated interior designation, the minimum cover should be at least 450 mm. If these requirements cannot be satisfied, it is necessary to consider other structure types before continuing with the Structure Site Analysis.

The cover depth must be determined for a structure with a precast reinforced-concrete box section.

28-6.04(02) Pipe-Service-Life Duration

This indicates the desired length of service for the drainage structure. The duration is based on the functional classification of the mainline roadway. If the mainline roadway is a freeway or expressway, or is functionally classified as an arterial, the required service-life duration for each type 1, 2, 3, or 5 pipe structure is 75 years. If the mainline roadway is functionally classified as a collector or local road, the required service-life duration for each such structure is 50 years.

28-6.04(03) Abrasive or Non-Abrasive Site Designation

A site is considered abrasive if it is probable that runoff will transmit material which can damage the pipe. Each mainline culvert site or each site where a public-road-approach or drive culvert is installed in a natural channel is considered abrasive.

A storm-drain site or public-road-approach or drive culvert site on a constructed side-ditch line is considered non-abrasive. However, the designer must use judgment to confirm that abrasive elements are not likely to impact such a site. If the designer concludes that a storm-drain- or side-ditch-culvert site can have abrasive materials transported by runoff, an abrasive site designation must be assigned to each affected structure.

28-6.04(04) Structure pH

Acidic runoff may have contributed to service-life problems with a pipe structure. To mitigate these problems, the designer must determine a pH value for each type 1, 2, 3, or 5 pipe structure. The pH data may be provided in the Engineer's or Geotechnical Reports. The data should include the stream pH-test result for each type of existing structure as follows:

1. mainline culvert;
2. public-road-approach or drive culvert in a natural channel;
3. storm-drain-system outlet pipe; or
4. the most-downstream culvert on each constructed ditch line.

The designer will use the following guidelines to establish each proposed structure's pH value.

1. Culvert. Assign the data provided for each existing mainline culvert to the corresponding proposed pipe structure. Likewise, assign the data associated with each existing public-road-approach or drive culvert located in a natural channel to the corresponding proposed structure. Each proposed public-road-approach or drive culvert installed on a constructed ditch line should be assigned the report's pH value for the most-downstream culvert on the corresponding existing ditch line.

2. Storm Drain. If a proposed storm-drain system will replace an existing system, assign the pH value obtained at the existing system's outlet pipe to each pipe structure in the proposed system. If the proposed system is replacing an existing open-drainage system, apply the pH value collected at the most-downstream existing side-ditch culvert to each structure in the proposed system.

The final structure pH is the lowest of the following values.

1. Preliminary Field Check Plans pH Value. This value is obtained from one of the following sources.

   a. Engineer's Report.

   b. pH Testing. If pH data is not available from the Engineer's Report, the designer is required to perform pH testing of water samples taken at the structure. The scope of the testing required is below and is illustrated by the flowcharts included in the following figures.

28-6B	Structure pH Determination Procedure for Proposed Mainline Culvert or Other Culvert in Natural Channel (Area Where Map pH = 7.0)
28-6C	Structure pH Determination Procedure for Proposed Storm-Drain Structure (Area Where Map pH = 7.0)
28-6D	Structure pH Determination Procedure for Proposed Side-Ditch Culvert (Area Where Map pH = 7.0)
28-6E	Structure pH Determination Procedure for Proposed Mainline Culvert or Other Culvert in Natural Channel (Area Where Map pH < 7.0)
28-6F	Structure pH Determination Procedure for Proposed Storm-Drain Structure (Area Where Map pH < 7.0)
28-6G	Structure pH Determination Procedure for Proposed Side-Ditch Culvert (Area Where Map pH < 7.0)

c. pH Map. If the Engineer's Report does not provide structure pH data, and pH testing is not appropriate, Figure 28-6A, pH Map, is used to determine the Preliminary Field Check pH value.

2. Final Check Prints pH Value. This value is obtained from one of the following sources.

a. Geotechnical Report.

b. pH Testing. If a structure pH value is not available from the Geotechnical Report and testing is appropriate (see Item 1b. above), pH testing of a water sample taken from the corresponding existing structure site is required.

c. pH Map. Use of the pH map is appropriate only if a structure pH value is not available from the two sources listed above.

3. Final Tracings pH Value. If the pH values from Items 1 and 2 for a structure are not within 0.5 of each other, a third value must be obtained for comparison. The third value is obtained from one of these two sources.

a. pH Testing. If pH testing is appropriate, testing of water samples at the corresponding existing structure is required.

b. pH Map. If pH testing is not appropriate, the pH map is the appropriate source for the third pH value.

Before pH testing is performed, the project location must be determined from Figure 28-6A, pH Map. If the project is located in a county with a posted 7.0 pH value, the testing scope is as follows:

1. Identify Structure Requiring Testing. The structure type to be considered for testing is as follows:

a. mainline culvert;
b. public-road-approach or drive culvert located in a natural channel;
c. outlet pipe of storm-drain system; or
d. the most downstream culvert on a constructed ditch line.

2. Structure Inspection. The testing process begins by inspecting the structure. If an existing structure does not show signs of corrosion, pH testing is not required. If the structure shows signs of corrosion, a water sample at the structure must be obtained and the pH of the sample must be determined.

If the project is located in a county with a pH map value < 7.0, the structure-inspection step described in Item 2 does not apply. Each structure identified in Item 1 requires obtaining a water sample for pH determination.

The following apply to the determination of a structure pH value, regardless of the source of the data.

1. Maximum Structure pH Value. The pH value for a structure cannot exceed the map pH value for the project location. If the pH value obtained from a report on pH testing is greater than the map pH value, the obtained value is ignored and the map value is used for the structure.

2. Precision of pH Value. The pH value is expressed to the nearest 0.5. If a report or pH testing yields a value that is more precise, the structure pH is rounded to the next lower 0.5.

3. Lack of Sample Availability. If pH testing is required, but a sample is not available at a structure site, the structure pH value will equal the value for the nearest adjacent structure. If a water sample is not available at an appropriate structure within the project limits, the pH map value is used for all structures.

4. Storm-Drain-Structure pH Determination. The structure pH assigned to the outlet pipe of a storm-drain system is assigned to each structure in the proposed system.

5. Side-Ditch-Culvert Structure pH Determination. The structure pH assigned to the most downstream pipe in a segment of side ditch is assigned to each culvert installed in that ditch line segment.

28-6.05 Pipe-Material-Selection Process

The data collected during the Structure Site Analysis is used to determine which pipe materials are acceptable for installation at an individual structure site. A computer program has been developed to perform the required material selection for a type 1, 2, 3, or 5 pipe structure.

The input required for the Pipe-Material-Selection Software includes the following:

1. required pipe type;
2. required pipe-interior designation, if applicable (see Chapter Thirty-one);
3. pipe size;
4. cover;
5. required service-life duration;

6. abrasive or non-abrasive site designation; and
7. structure pH.

The software analyzes the input and lists all pipe materials that are acceptable for installation at each individual structure site.

For material selection, each corrugated-metal pipe's protective coating or invert treatment is considered to define a unique material. For example, an acceptable-materials list showing zinc-coated corrugated steel pipe and zinc-coated corrugated steel pipe with bituminous-paved invert is considered to include two materials.

The following apply to the performance of the Pipe-Material-Selection Process.

1. Software Indicates No Acceptable Materials for Structure. If this occurs, the cause is likely to be incorrect-input-data entry. If a review of the input reveals that there are no errors, the designer must contact the INDOT Hydraulics Team for additional instructions.

2. Software Indicates Only One Acceptable Material for Structure. By definition, a pipe-type designation indicates that a contractor may select from a list of materials that have been determined to be acceptable for an individual structure. If the list includes only one acceptable material, the pipe-type designation is meaningless. If this occurs, the structure cannot refer to a pipe type. See Section 28-6.08 for more information on contract document requirements for such a structure.

3. Software Indicates Two or More Materials are Acceptable for Structure. By definition, a pipe-type designation remains appropriate for this structure.

4. Pipe-Extension Structure. A pipe extension requires the selection of a specific material. If possible, the selected material should match the existing pipe material. However, the material thickness and coating combination or material-strength classification must satisfy the cover and service-life-criteria requirements. By definition, a pipe-extension structure is a structure that involves attaching a new pipe to an existing pipe.

5. Selection of Corrugated-Metal Pipe Optimum Corrugation Profile. The Pipe-Material-Selection Software may indicate that more than one corrugation-profile and material-thickness combination is acceptable for a structure. It is then necessary to determine the optimum corrugation profile. The procedure for determining the optimum corrugation profile is as follows.

    a. Select the Profile with the Minimum Thickness. If the acceptable corrugation profiles require different material thicknesses, select the profile with the minimum thickness.

b. Select the Smallest Profile. If all acceptable corrugation profiles require the same material thickness, select the smallest profile. By definition, a 68 mm x 13 mm corrugation profile is considered smaller than a 75 mm x 25 mm profile.

28-6.06 Draintile Structure

If it is known that the proposed construction will require the removal of existing field tile, the drainage will be perpetuated in the following manner.

1. Tile Replacement Within Temporary Right of Way. Type 4 pipe is used to perpetuate the drainage. The pipe size will match the existing tile and must be perforated in accordance with the INDOT *Standard Specifications*.

2. Tile Outlet in Ditch Prior to Crossing Mainline Pavement. Type 4 non-perforated pipe and a 3.0-m length segment of drain tile terminal section are required between the right-of-way line and the proposed outlet. If necessary, a concrete collar is used to connect to the existing pipe at the right-of-way line, and a rodent screen is required at the terminal-section outlet. Revetment riprap or other gradation [as required to satisfy the clear-zone criteria (see Chapter Forty-nine)] is required between the tile outlet and the ditch flow line to prevent erosion.

3. Tile Outlet in Ditch After Crossing Mainline Pavement. Type 1 pipe is required between the right-of-way line and the proposed outlet. The concrete collar, rodent screen, and riprap requirements described in Item 2 above will apply to the type 1 pipe installation. The acceptable type 1 pipe materials must satisfy the cover and service-life criteria. The site is assumed to be non-abrasive and the map pH can be assigned to the structure.

4. Tile Outlet in Storm Drain System. Type 2 pipe is required between the right-of-way line and the outlet location. A concrete collar is required. The acceptable type 2 pipe materials must satisfy the cover and service-life criteria. The site is assumed to be non-abrasive, and the structure pH must match the value for the storm-drain structure that serves as the tile outlet.

5. Tile is Perpetuated Across Right of Way. Type 1 pipe is required from right-of-way line to right-of-way line. A concrete collar is required. The acceptable type 1 pipe materials must satisfy the cover and service-life criteria. The site is assumed to be non-abrasive, and the pH map value for the project location is assigned to the structure.

28-6.07 [blank section]

28-6.08 Contract Documents

Part II discusses the INDOT requirements on the preparation of contract documents (e.g., plans preparation, quantity estimate, cost estimate). This section provides additional information on contract-document preparation for drainage-structures requirements.

28-6.08(01) Plans Content

The following is necessary to incorporate drainage-structures information into a set of plans.

1. Typical Cross Sections Sheet. This is the appropriate location for details related to the installation of longitudinal underdrains.

2. Plan and Profile Sheet. This is the appropriate location for drainage-structure identification. Samples are as follows.

    a. 20.0 m of 900 mm Pipe and 2 Pipe End Sections Required

    b. 20.0 m of 900 mm Smooth Pipe and 2 Pipe End Sections, or 1050 mm Corrugated Pipe Type 2 and 2 Concrete Anchors Required

    c. 20.0 m of 900 mm Smooth Pipe and 2 Pipe End Sections Required

    d. Manhole Type C-4 and 100.0 m of 450 mm Pipe Required.

    e. 20.0 m of 300 mm Slotted Drain Pipe Required.

    f. 75.0 m of 2400 mm x 1200 mm Precast Reinforced Concrete Box Section Required. Skew 30° Rt.

    Each culvert structure or storm-drain outlet-structure length will be expressed to the nearest 0.5 m. Other storm-drain structure lengths are expressed to the nearest 0.1 m, with the measurement taken from outside face to outside face of adjacent manholes, inlets, catch basins, or similar structures.

    A structure that includes a pipe type or requires a specific pipe material is identified only as Pipe. A Specialty Structure or Specific-Application Structure must be identified as such.

3. Detail Sheet. All drainage-structure-related features that are not included on the *Standard Drawings* must be detailed here. The features that require such detailing include the concrete collar required to join existing and proposed pipes or Specialty-Structure backfill requirements.

4 Structure Data Sheet. The following apply to the preparation of this sheet.

a. For a structure that refers to a pipe type, identify it in the Pipe Type column. The word *Pipe* is entered in the Description column.

b. For a structure that requires a specific pipe material, an entry is not placed in the Pipe Type column. The word *Pipe* is entered in the Description column.

c. A pipe-type structure that requires different sizes based on the interior designation requires separate rows of input data for each interior designation.

d. A Specialty Structure or Specific-Application Structure is identified in the Description column. The identification for a pipe-extension structure is *Pipe Extension*. A concrete-culvert extension using precast reinforced-concrete box sections is identified with *Precast Reinforced-Concrete Box-Section Culvert Extension* in the Description column. No entry is made in the "Pipe Type" column.

5. Pipe Material Sheet. This is used to list the acceptable pipe materials for each pipe-type structure excluding type 4 pipe, specific-pipe-material structure, or pipe-extension structure.

6. Underdrain Table. This is used to summarize the complete underdrain design for the project. For more details regarding underdrain design procedures, see Chapter Fifty-two.

28-6.08(02) Backfill Material

See Section 17-2.09 for backfill-material requirements.

28-6.08(03) Pay Items

Sample drainage-system-related pay items are listed below.

1. Pipe, Type 1, Circular, 900 mm. This is the pay-item-name format for a pipe-type structure. Its use indicates that at least two materials are acceptable for the structure.

Also, for type 1, 3, or 5 pipe, the lack of an interior designation in the pay item name indicates that the materials acceptable for installation include those with a smooth-interior designation and others with a corrugated-interior designation.

2. Pipe, Type 2, Circular, 300 mm. This is the pay-item-name format for a storm-drain pipe structure. Since all type 2 pipe materials have a smooth-interior designation, the interior designation is not included in the pay item name.

3. Pipe, Type 1, Circular, 900 mm Smooth or 1050 mm, Corrugated. This pay-item name indicates that there are at least two materials acceptable for the structure. At least one has a smooth-interior designation and at least one has a corrugated-interior designation. The hydraulic design indicates that different-sized smooth- and corrugated-interior pipe sizes are required.

4. Pipe Type 3, Deformed, Min. Area = 0.15 m^2, Corrugated. This pay-item name indicates that there are at least two materials acceptable for installation and all have a corrugated interior designation.

5. Pipe, RCP, Class II, $D_{0.3}$ = 50, 900 mm. This pay-item name indicates that reinforced-concrete pipe of the specified strength classification is the only acceptable material for a new pipe structure. A reinforced-concrete-pipe pay-item name must include the required-strength classification and the D-load rating.

6. Pipe Extension, ZC CSP w/BPI, 2.77 mm, 450 mm. This pay-item name indicates that a zinc-coated corrugated steel pipe with a bituminous-paved invert and a material thickness of 2.77 mm is the only acceptable material for a structure that involves placing a new pipe on an end of an existing pipe. A corrugated-metal-pipe pay-item name must include the protective coating, required invert treatment, and the required material thickness.

7. Structure, Precast Reinforced-Concrete Three-Sided, 6000 mm x 3000 mm. This is the pay-item-name format for a Specialty Structure or Specific-Application Structure. The Specialty Structure or Specific-Application Structure must be identified in the pay item name.

8. Pipe End Section, 900 mm. This is the pay-item-name format for an object placed on each end of a structure that has only one specified pipe size.

9. Concrete Anchor 1050 mm or 1200 mm. This is the pay-item-name format for a structure with different-sized smooth-interior and corrugated-interior alternatives. A concrete anchor is required regardless of the pipe size that is actually installed.

10. Pipe End Section, 900 mm or Concrete Anchor, 1050 mm. This is the pay-item-name format for a structure with different-sized smooth-interior and corrugated-interior alternatives which each require a different object to be placed on each pipe end. Pipe end sections are required if the 900-mm structure alternative is installed, and concrete anchors are required if the 1050-mm structure alternative is installed.

28-6.09 English-to-Metric Conversion Information

Figures 28-6H through 28-6S provide conversion information related to drainage structures. These figures are provided to give the designer the ability to convert results from English-units design software, nomographs, etc., to the appropriate corresponding metric-units dimensions. The figure designations with their titles are listed below.

28-6H	Circular Smooth Pipe (Conversion from English-Units Designed Pipe Size to Metric-Units Pay-Item Pipe Size)
28-6 I	Circular Corrugated Pipe (Conversion from English-Units Designed Pipe Size to Metric-Units Pay-Item Pipe Size)
28-6J	Circular Corrugated Structural-Plate Pipe (Conversion from English-Units Designed Pipe Size to Metric-Units Pay-Item Pipe Size)
28-6K	Deformed Corrugated Pipe (Conversion from English-Units Designed Pipe Size to Metric-Units Pay-Item Pipe Size)
28-6L	Deformed Corrugated Structural-Plate Pipe (Conversion from English-Units Designed Pipe Size to Metric-Units Pay-Item Pipe Size)
28-6M	Deformed Smooth Pipe (Conversion from English-Units Designed Pipe Size to Metric-Units Pay-Item Pipe Size)
28-6N	Precast Reinforced-Concrete Box Sections (Conversion from English-Units Designed Pipe Size to Metric-Units Pay-Item Pipe Size)
28-6 O	Precast Reinforced-Concrete Three-Sided Structure (Conversion from English-Units Designed Pipe Size to Metric-Units Pay-Item Pipe Size)
28-6P	Non-Reinforced-Concrete Pipe Class 3 Wall Thickness
28-6Q	Reinforced-Concrete Pipe Wall Thickness
28-6R	Precast Reinforced-Concrete Box Section Wall Thickness
28-6S	Reinforced-Concrete Horizontal Elliptical Pipe Wall Thickness

Project Documentation Checklist

Route Project No. City/Town: County:

Description: Engineer:

Check Appropriate Items

REFERENCE DATA

Maps:
- ☐ USGS – Quad., Scale, Date
- ☐ USGS – Other
- ☐ Local Zoning Maps
- ☐ Flood Hazard Delineation (Quad.) for 100 Yr. Flood Plain Delineation (HUD)
- ☐ Local Land Use
- ☐ Soils Maps
- ☐ Geologic Maps
- ☐ Aerial Photos – Scale, Date

Studies By External Agencies:
- ☐ FEMA Flood Insurance Studies
- ☐ SCS Watershed Studies
- ☐ USGS Gages & Studies
- ☐ Interim Flood Plain Studies
- ☐ Water Resource Data
- ☐ Regional Planning Data
- ☐ Forestry Service
- ☐ Utility Company Plans

Studies By Internal Sources:
- ☐ Hydraulics Section Records
- ☐ Flood Records (High Water, Newspaper)

HYDROLOGY

Technical Resources:
- ☐ Part IV, *Indiana Design Manual*
- ☐ INDOT Directives
- ☐ Technical Library

Discharge Calculations:
- ☐ Drainage Areas
- ☐ Gaging Data – Regional Analysis
- ☐ Regression Equations (if no other method available)
- ☐ Area-Discharge Coordinated Curves
- ☐ Log-Pearson Type III Gage Rating (B 17B)
- ☐ Computer Programs: HYDRO, SCS (TR-20), HEC-1

HYDROLOGY (Cont'd.)

High Water Elevations:
- ☐ INDOT Survey
- ☐ External Sources
- ☐ Personal Reconnaissance

Flood History:
- ☐ External Sources
- ☐ Personal Reconnaissance
- ☐ Maintenance Records
- ☐ Photographs
- ☐ IDNR Historic Flood Profiles

HYDRAULIC DESIGN

Calibration of High Water Data:
- ☐ Discharge and Frequency of H.W. el.
- ☐ Influences Responsible for H.W. el.
- ☐ Analyze Hydraulic Performance of Existing Facility for 100 Yr.
- ☐ Analyze Hydraulic Performance of Proposed Facility

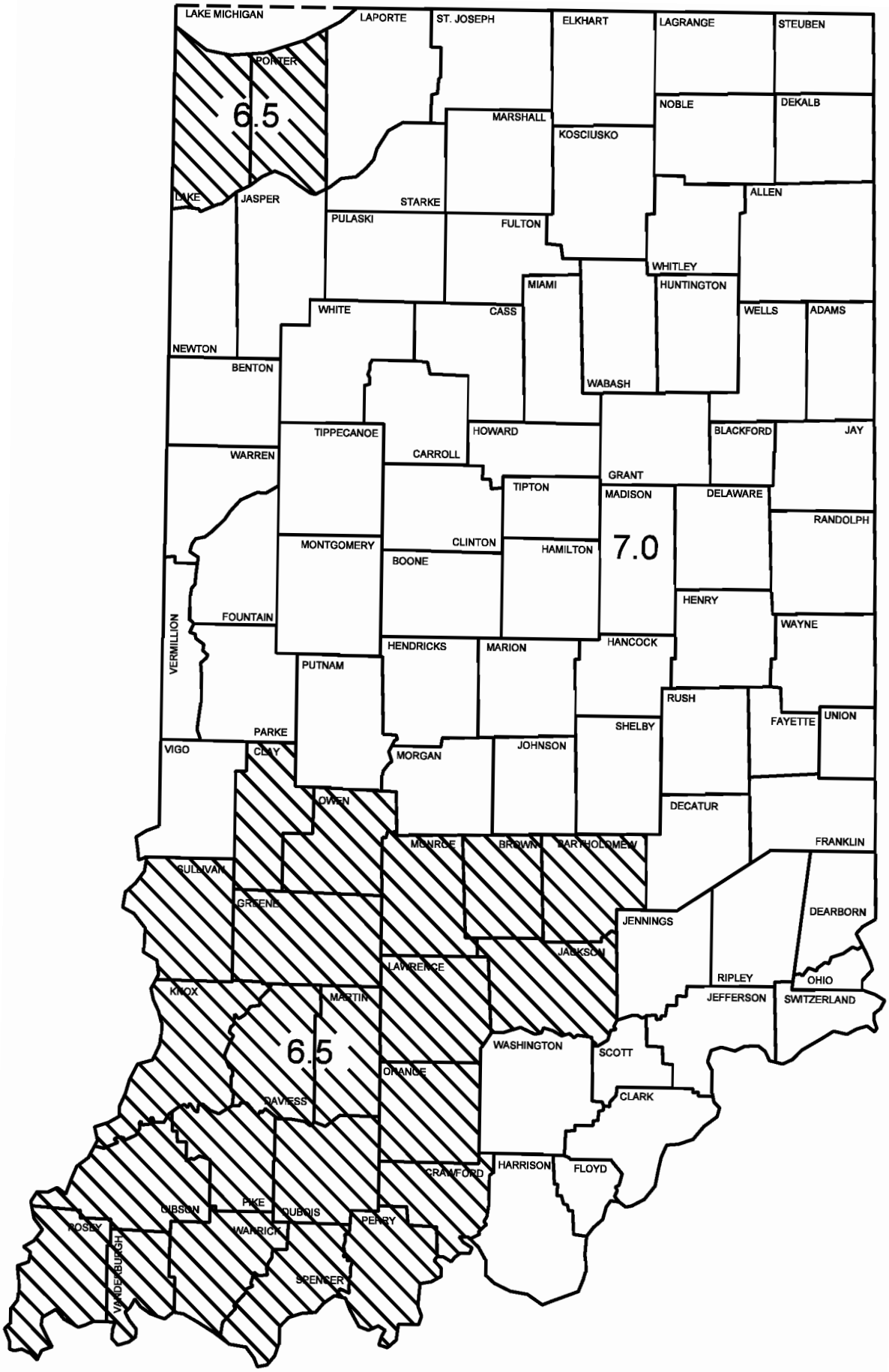
Design Appurtenances:
- ☐ Dissipators
- ☐ Riprap
- ☐ Erosion and Sediment Control

Technical Aids:
- ☐ *Indiana Design Manual*, Part IV
- ☐ INDOT and FHWA Directives
- ☐ Technical Library

Computer Programs:
- ☐ FESWMS-2DH
- ☐ HEC-RAS
- ☐ HEC-2
- ☐ HYDRAIN
- ☐ HY8
- ☐ WSPRO

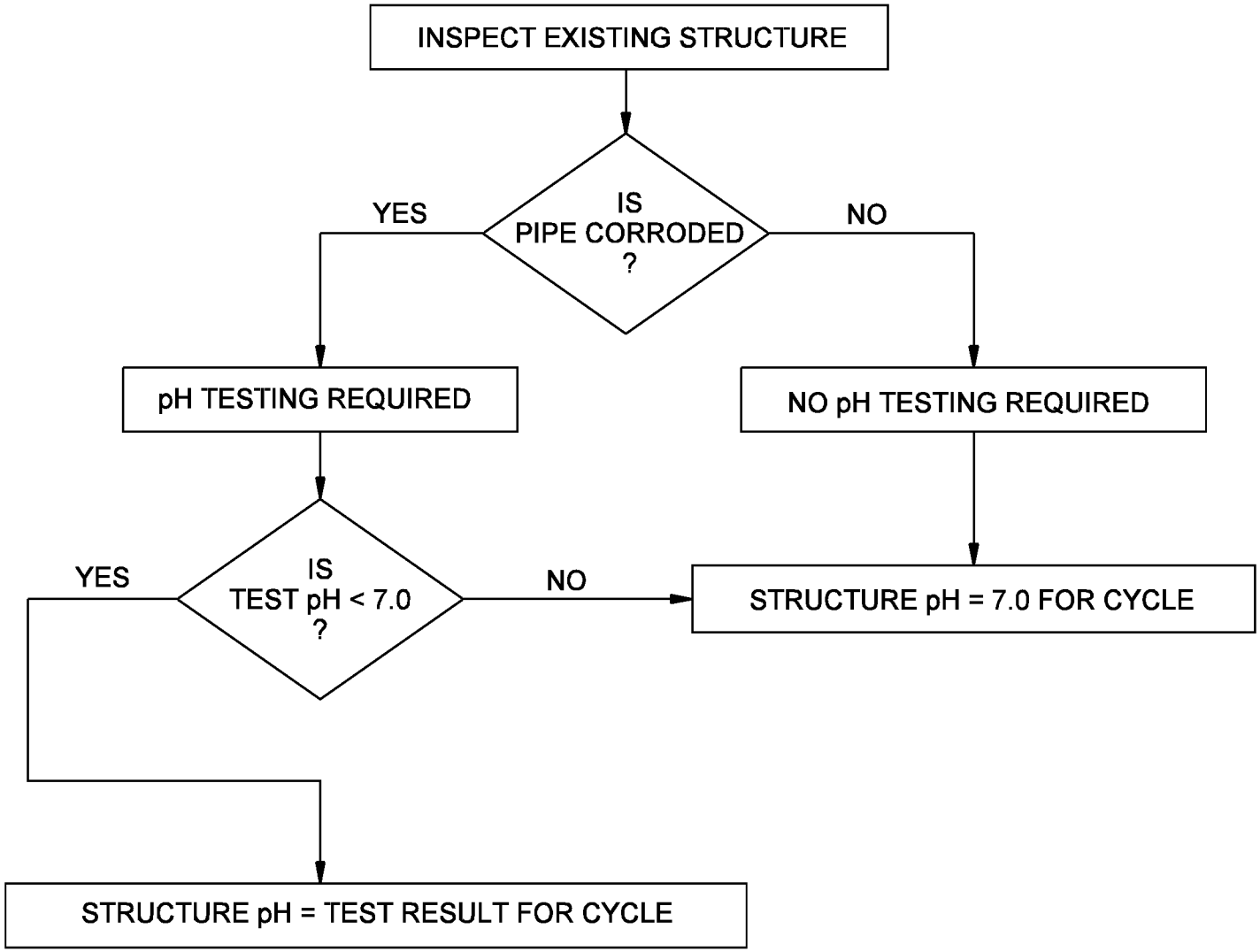
HYDROLOGIC-HYDRAULIC REPORTS

Data Reports:
- ☐ Environmental Reports
- ☐ Reconnaissance Report
- ☐ Hydraulic Recommendations from Engineer's Report
- ☐ INDOT Data



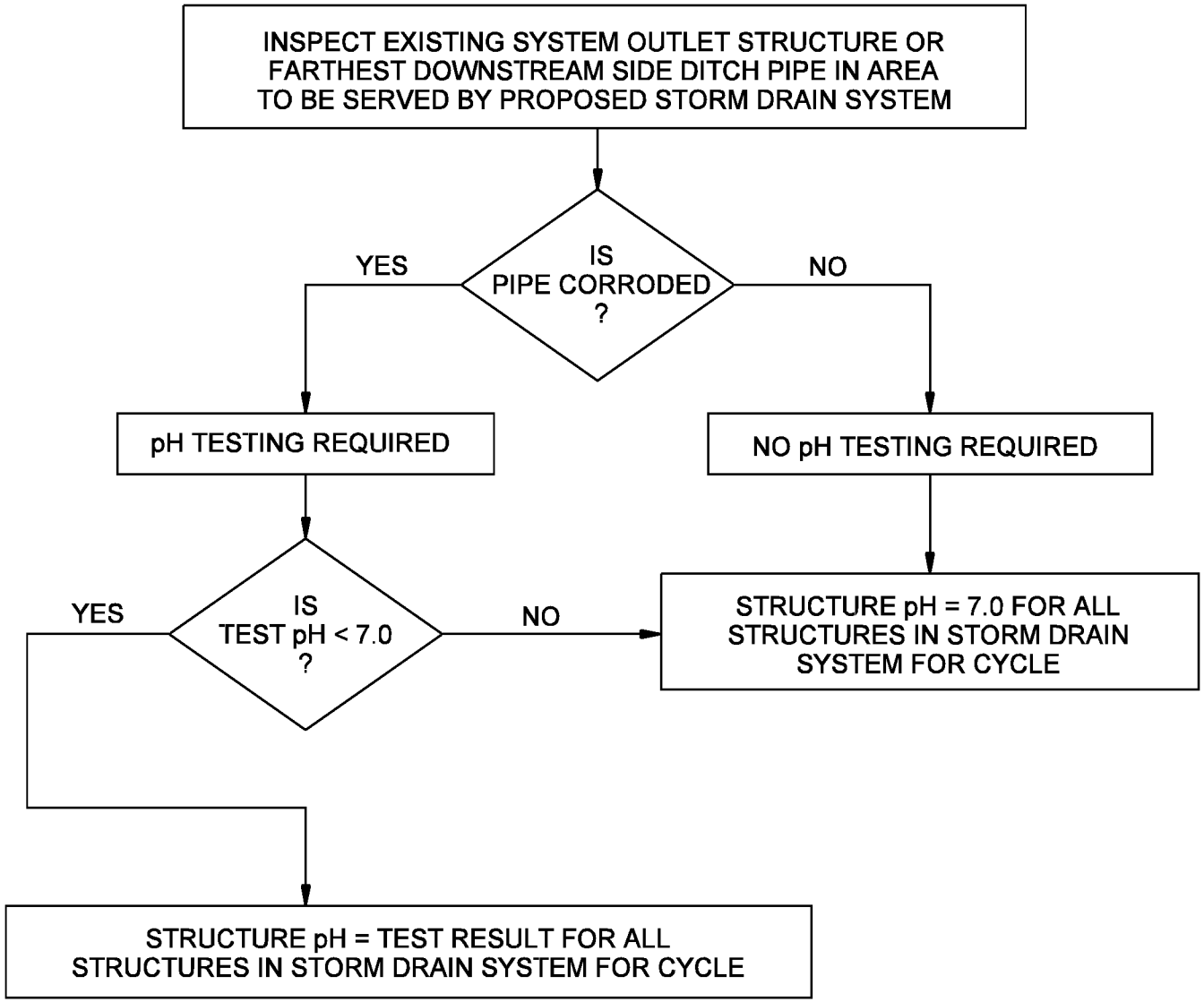
pH MAP

Figure 28-6A



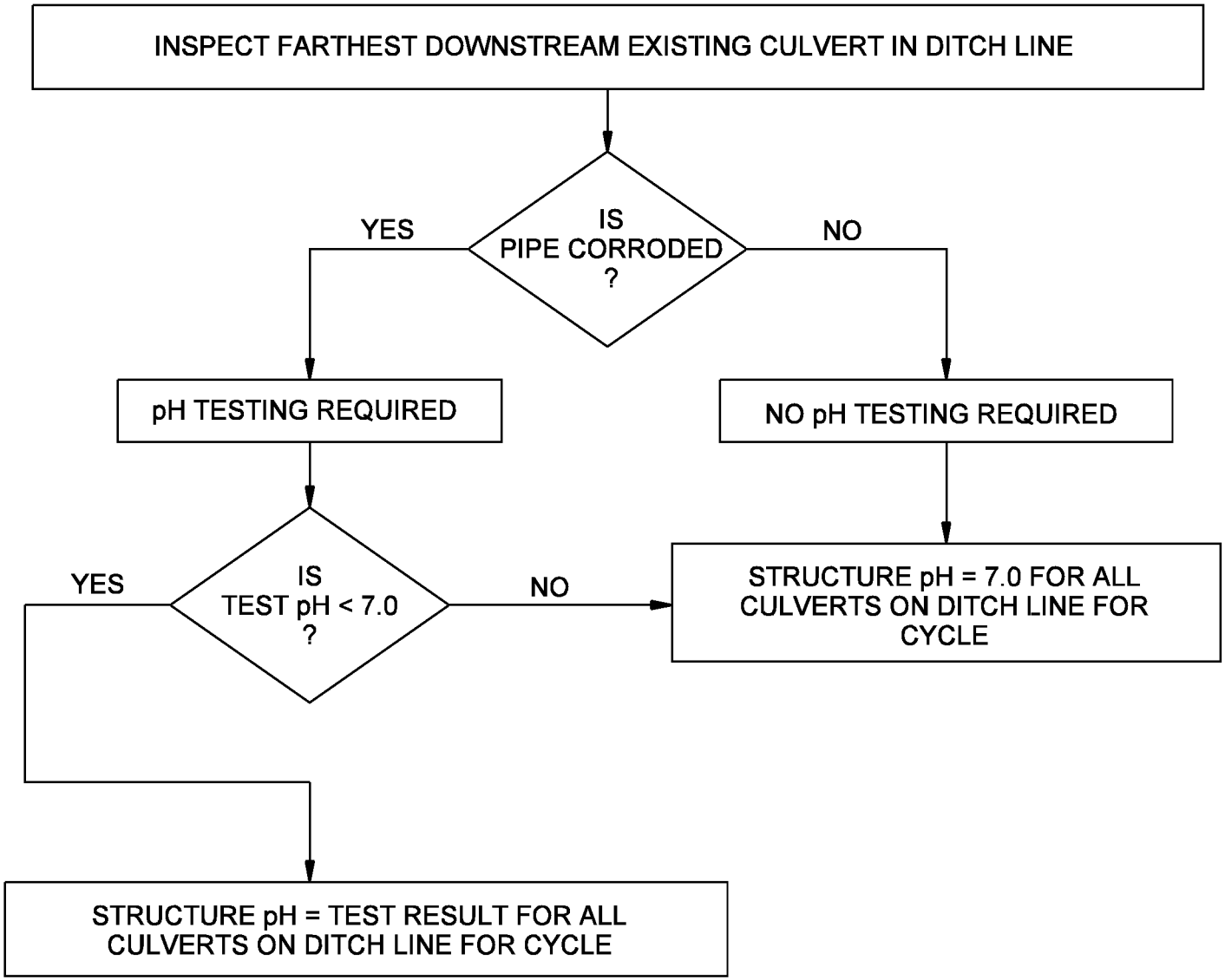
STRUCTURE pH DETERMINATION PROCEDURE
(Proposed Mainline Culverts & Other Culverts in Natural Channels)
(Project in Area Where Map pH = 7.0)

Figure 28-6B



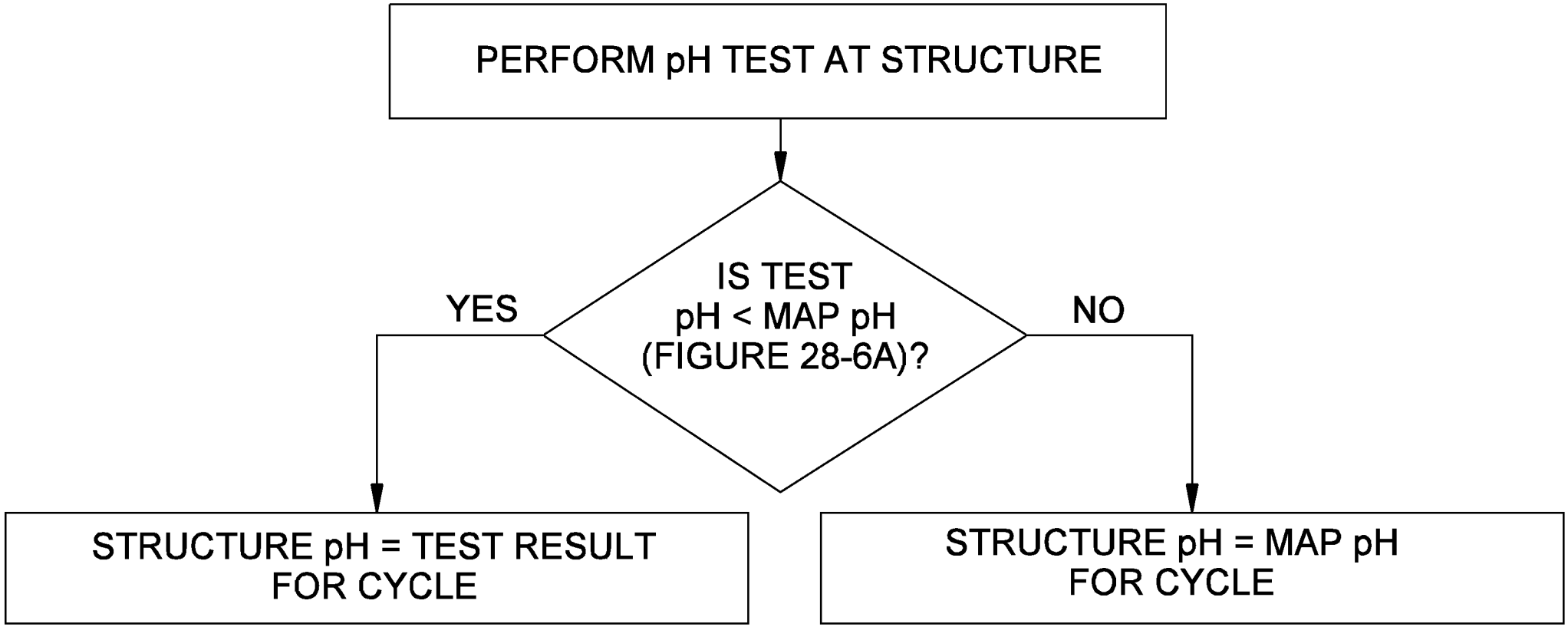
STRUCTURE pH DETERMINATION PROCEDURE
(Proposed Storm Drain Structures)
(Project in Area Where Map pH = 7.0)

Figure 28-6C



STRUCTURE pH DETERMINATION PROCEDURE
(Proposed Side Ditch Culverts)
(Project in Area Where Map pH = 7.0)

Figure 28-6D

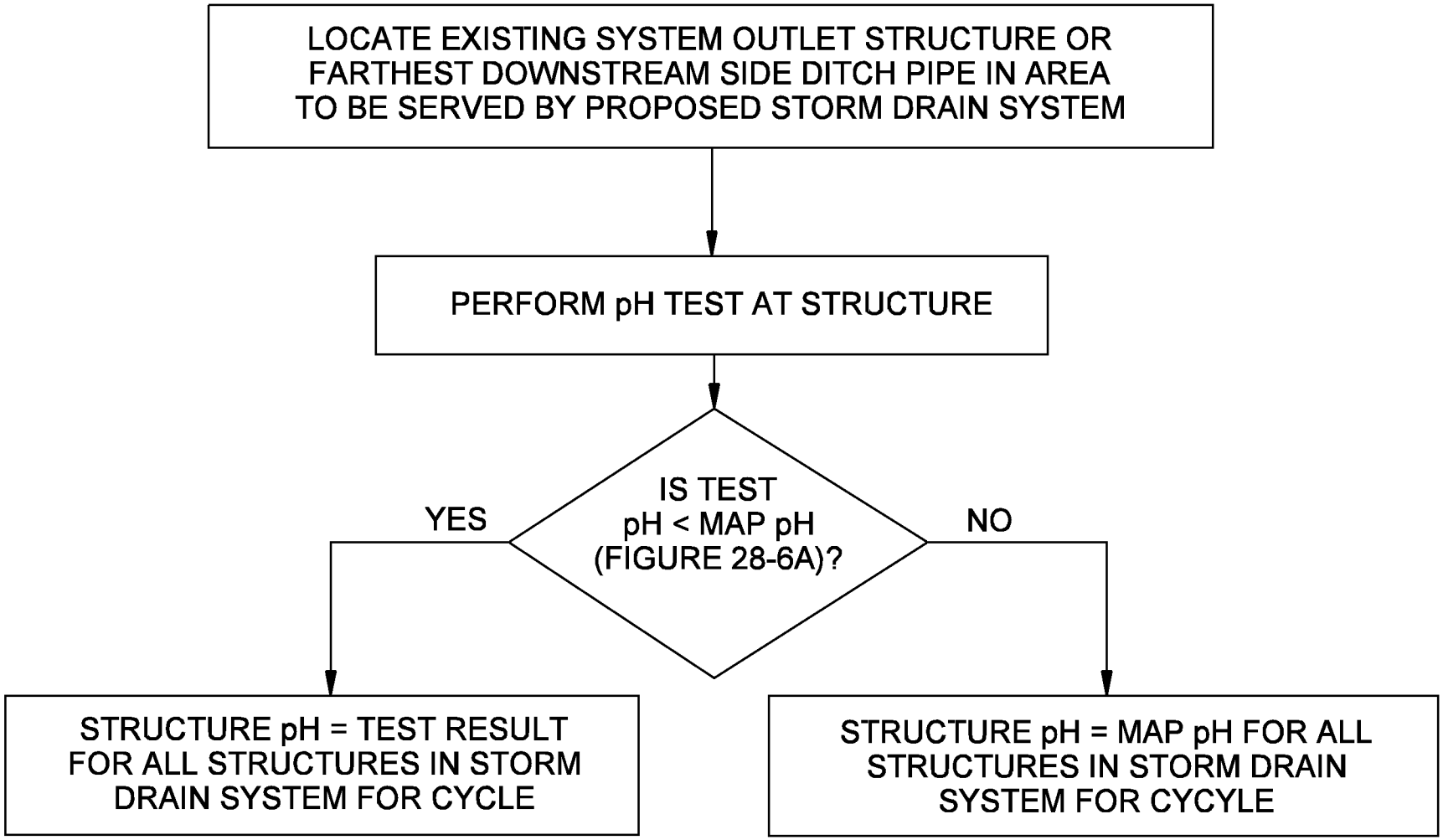


STRUCTURE pH DETERMINATION PROCEDURE

(Proposed Mainline Culverts & Other Culverts in Natural Channels)

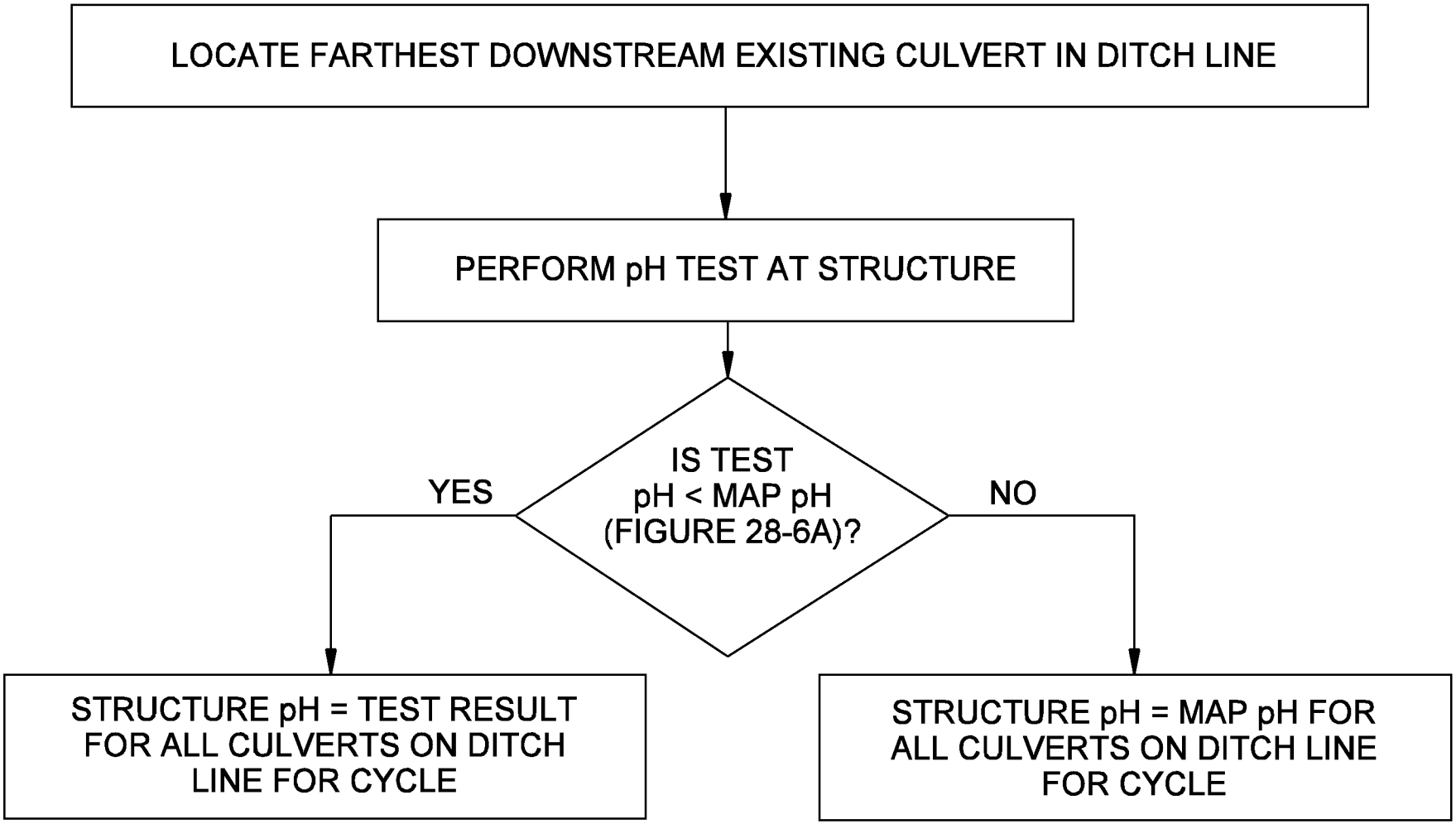
(Project in Area Where Map pH < 7.0)

Figure 28-6E



STRUCTURE pH DETERMINATION PROCEDURE
(Proposed Storm Drain Structures)
(Project in Area Where Map pH < 7.0)

Figure 28-6F



STRUCTURE pH DETERMINATION PROCEDURE
(Proposed Side Ditch Culverts)
(Project in Area Where Map pH < 7.0)

Figure 28-6G

DESIGN DIAMETER (in.)	PAY-ITEM DIAMETER (mm)
12	300
15	375
18	450
21	525
24	600
27	675
30	750
33	825
36	900
42	1050
48	1200
54	1350
60	1500
66	1650
72	1800
78	1950
84	2100
90	2250
96	2400
102	2550
108	2700
114	2850
120	3000
126	3150
132	3300
138	3450
144	3600

CIRCULAR SMOOTH PIPE
(Conversion from English-Units-Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6H

DESIGN DIAMETER (in.)	PAY-ITEM DIAMETER (mm)
12	300
15	375
18	450
21	525
24	600
27	675
30	750
33	825
36	900
42	1050
48	1200
54	1350
60	1500
66	1650
72	1800
78	1950
84	2100
90	2250
96	2400
102	2550
108	2700
114	2850
120	3000
126	3150
132	3300
138	3450
144	3600

CIRCULAR CORRUGATED PIPE
(Conversion from English-Units-Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6I

DESIGN DIAMETER (ft-in.)	PAY-ITEM DIAMETER (mm)
5′-0″	1500
5′-6″	1655
6′-0″	1810
6′-6″	1965
7′-0″	2120
7′-6″	2275
8′-0″	2430
8′-6″	2585
9′-0″	2740
9′-6″	2895
10′-0″	3050
10′-6″	3205
11′-0″	3360
11′-6″	3515
12′-0″	3670
12′-6″	3825
13′-0″	3980
13′-6″	4135
14′-0″	4290
14′-6″	4445
15′-0″	4600
15′-6″	4755
16′-0″	4910
16′-6″	5065
17′-0″	5220
17′-6″	5375
18′-0″	5530
18′-6″	5685
19′-0″	5840
19′-6″	5995
20′-0″	6150
20′-6″	6305
21′-0″	6460

CIRCULAR CORRUGATED STRUCTURAL-PLATE PIPE
(Conversion from English-Units-Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6J

DESIGN PIPE SIZE (in. x in.)	DESIGN AREA (ft^2)	PAY-ITEM AREA (m^2)
17″ x 13″	1.1	0.10
21″ x 15″	1.6	0.15
24″ x 18″	2.2	0.20
28″ x 20″	2.9	0.27
35″ x 24″	4.5	0.42
42″ x 29″	6.5	0.60
49″ x 33″	8.9	0.83
57″ x 38″	11.6	1.08
60″ x 46″	15.6	1.45
64″ x 43″	14.7	1.37
66″ x 51″	19.3	1.79
71″ x 47″	18.1	1.68
73″ x 55″	23.2	2.16
77″ x 52″	21.9	2.03
81″ x 59″	27.4	2.55
83″ x 57″	26.0	2.42
87″ x 63″	32.1	2.98
95″ x 67″	37.0	3.44
103″ x 71″	42.4	3.94
112″ x 75″	48.0	4.46
117″ x 79″	54.2	5.04
128″ x 83″	60.5	5.62
137″ x 87″	67.4	6.26
142″ x 91″	74.5	6.92

DEFORMED CORRUGATED PIPE
(Conversion from English-Units-Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6K

MATERIAL	DESIGN PIPE SIZE (ft-in x ft-in)	DESIGN AREA (ft^2)	PAY-ITEM AREA (m^2)
STEEL	6′-1″ x 4′-7″	22	2.0
	6′-4″ x 4′-9″	24	2.2
	6′-9″ x 4′-11″	26	2.4
	7′-0″ x 5′-1″	28	2.6
	7′-3″ x 5′-3″	31	2.9
	7′-8″ x 5′-3″	33	3.1
	7′-11″ x 5′-7″	35	3.3
	8′-2″ x 5′-9″	38	3.5
	8′-7″ x 5′-11″	40	3.7
	8′-10″ x 6′-1″	43	4.0
	9′-4″ x 6′-3″	46	4.3
	9′-6″ x 6′-5″	49	4.6
	9′-9″ x 6′-7″	52	4.8
	10′-3″ x 6′-9″	55	5.1
	10′-8″ x 6′-11″	58	5.4
	10′-11″ x 7′-1″	61	5.7
	11′-5″ x 7′-3″	64	5.9
	11′-7″ x 7′-5″	67	6.2
	11′-10″ x 7′-7″	71	6.6
	12′-4″ x 7′-9″	74	6.9
	12′-6″ x 7′-11″	78	7.2
	12′-8″ x 8′-1″	81	7.5
	12′-10″ x 8′-4″	85	7.9
	13′-3″ x 9′-4″	97	9.0
	13′-6″ x 9′-6″	102	9.5
	14′-0″ x 9′-8″	105	9.8
	14′-2″ x 9′-10″	109	10.1
	14′-5″ x 10′-0″	114	10.6
	14′-11″ x 10′-2″	118	11.0
	15′-4″ x 10′-4″	123	11.4
	15′-7″ x 10′-6″	127	11.8
	15′-10″ x 10′-8″	132	12.3
	16′-3″ x 10′-10″	137	12.7
	16′-6″ x 11′-0″	142	13.2
	17′-0″ x 11′-2″	146	13.6
	17′-2″ x 11′-4″	151	14.0

DEFORMED CORRUGATED STRUCTURAL-PLATE PIPE
(Conversion From English-Units Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6L

MATERIAL	DESIGN PIPE SIZE (ft-in x ft-in)	DESIGN AREA (ft^2)	PAY-ITEM AREA (m^2)
STEEL	17′-5″ x 11′-6″	157	14.6
	17′-6″ x 11′-8″	161	15.0
	18′-1″ x 11′-10″	167	15.5
	18′-7″ x 12′-0″	172	16.0
	18′-9″ x 12′-2″	177	16.4
	19′-3″ x 12′-4″	182	16.9
	19′-6″ x 12′-6″	188	17.5
	19′-8″ x 12′-8″	194	18.0
	19′-11″ x 12′-10″	200	18.6
	20′-5″ x 13′-0″	205	19.0
	20′-7″ x 13′-2″	211	19.6
ALUMINUM ALLOY	6′-7″ x 5′-8″	29	2.7
	6′-11″ x 5′-9″	31	2.9
	7′-3″ x 5′-11″	34	3.2
	7′-9″ x 6′-0″	36	3.3
	8′-1″ x 6′-1″	39	3.6
	8′-5″ x 6′-3″	41	3.8
	8′-10″ x 6′-4″	44	4.1
	9′-3″ x 6′-5″	47	4.4
	9′-7″ x 6′-6″	49	4.6
	9′-11″ x 6′-8″	52	4.8
	10′-3″ x 6′-9″	55	5.1
	10′-9″ x 6′-10″	58	5.4
	11′-1″ x 7′-0″	61	5.7
	11′-5″ x 7′-1″	64	5.9
	11′-9″ x 7′-2″	67	6.2
	12′-3″ x 7′-3″	70	6.5
	12′-7″ x 7′-5″	73	6.8
	12′-11″ x 7′-6″	77	7.2
	13′-1″ x 8′-2″	83	7.7
	13′-1″ x 8′-4″	86	8.0
	13′-11″ x 8′-5″	90	8.4
	14′-0″ x 8′-7″	94	8.7
	13′-11″ x 9′-5″	101	9.4
	14′-3″ x 9′-7″	105	9.8
	14′-8″ x 9′-8″	109	10.1

DEFORMED CORRUGATED STRUCTURAL-PLATE PIPE
(Conversion From English-Units Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6L (Contd.)

MATERIAL	DESIGN PIPE SIZE (ft-in x ft-in)	DESIGN AREA (ft^2)	PAY-ITEM AREA (m^2)
ALUMINUM ALLOY	14′-11″ x 9′-10″	114	10.6
	15′-4″ x 10′-0″	118	11.0
	15′-7″ x 10′-2″	123	11.4
	16′-1″ x 10′-4″	127	11.8
	16′-4″ x 10′-6″	132	12.3
	16′-9″ x 10′-8″	136	12.6
	17′-0″ x 10′-10″	141	13.1
	17′-3″ x 11′-0″	146	13.6
	17′-9″ x 11′-2″	151	14.0
	18′-0″ x 11′-4″	156	14.5
	18′-5″ x 11′-6″	161	15.0
	18′-8″ x 11′-8″	167	15.5
	19′-2″ x 11′-9″	172	16.0
	19′-5″ x 11′-11″	177	16.4
	19′-10″ x 12′-1″	182	16.9
	20′-1″ x 12′-3″	188	17.5
	20′-1″ x 12′-6″	194	18.0
	20′-10″ x 12′-7″	199	18.5
	21′-1″ x 12′-9″	205	19.0
	21′-6″ x 12′-11″	211	19.6
	20′-1″ x 13′-11″	216	20.1
	20′-7″ x 14′-3″	224	20.8
	21′-5″ x 14′-3″	241	22.4
	21′-11″ x 14′-11″	254	23.6
	22′-8″ x 15′-3″	267	24.8

DEFORMED CORRUGATED STRUCTURAL-PLATE PIPE
(Conversion From English-Units Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6L (Contd.)

DESIGN DIAMETER (in. x in.)	DESIGN AREA (ft^2)	PAY-ITEM AREA (m^2)
23″ x 14″	1.8	0.17
30″ x 19″	3.3	0.31
34″ x 22″	4.1	0.38
38″ x 24″	5.1	0.47
42″ x 27″	6.3	0.59
45″ x 29″	7.4	0.68
49″ x 32″	8.8	0.82
53″ x 34″	10.2	0.95
60″ x 38″	12.9	1.20
68″ x 43″	16.6	1.55
76″ x 48″	20.5	1.90
83″ x 53″	24.8	2.30
91″ x 58″	29.5	2.73
98″ x 63″	34.6	3.21
106″ x 68″	40.1	3.73
113″ x 72″	46.1	4.28
121″ x 77″	52.4	4.87
128″ x 82″	59.2	5.49
136″ x 87″	66.4	6.17
143″ x 92″	74.0	6.87
151″ x 97″	82.0	7.63
166″ x 106″	99.2	9.22
180″ x 116″	118.6	11.02

DEFORMED SMOOTH PIPE
(Conversion from English-Units-Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6M

DESIGN BOX SIZE (ft x ft)	PAY-ITEM SIZE (mm x mm)
3′ x 2′	900 x 600
3′ x 3′	900 x 900
4′ x 2′	1200 x 600
4′ x 3′	1200 x 900
4′ x 4′	1200 x 1200
5′ x 3′	1500 x 900
5′ x 4′	1500 x 1200
5′ x 5′	1500 x 1500
6′ x 3′	1800 x 900
6′ x 4′	1800 x 1200
6′ x 5′	1800 x 1500
6′ x 6′	1800 x 1800
7′ x 4′	2100 x 1200
7′ x 5′	2100 x 1500
7′ x 6′	2100 x 1800
7′ x 7′	2100 x 2100
8′ x 4′	2400 x 1200
8′ x 5′	2400 x 1500
8′ x 6′	2400 x 1800
8′ x 7′	2400 x 2100
8′ x 8′	2400 x 2400
9′ x 5′	2700 x 1500
9′ x 6′	2700 x 1800
9′ x 7′	2700 x 2100
9′ x 8′	2700 x 2400
9′ x 9′	2700 x 2700
10′ x 5′	3000 x 1500
10′ x 6′	3000 x 1800
10′ x 7′	3000 x 2100
10′ x 8′	3000 x 2400
10′ x 9′	3000 x 2700
10′ x 10′	3000 x 3000
11′ x 4′	3300 x 1200
11′ x 6′	3300 x 1800
11′ x 8′	3300 x 2400
11′ x 10′	3300 x 3000
11′ x 11′	3300 x 3300
12′ x 4′	3600 x 1200
12′ x 6′	3600 x 1800
12′ x 8′	3600 x 2400
12′ x 10′	3600 x 3000
12′ x 12′	3600 x 3600

PRECAST REINFORCED-CONCRETE BOX SECTIONS
(Conversion from English-Units-Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6N

DESIGN STRUCTURE SIZE (ft x ft)	PAY-ITEM SIZE (mm x mm)
12′ x 3′	3600 x 900
12′ x 4′	3600 x 1200
12′ x 5′	3600 x 1500
12′ x 6′	3600 x 1800
12′ x 7′	3600 x 2100
12′ x 8′	3600 x 2400
12′ x 9′	3600 x 2700
12′ x 10′	3600 x 3000
13′ x 3′	3900 x 900
13′ x 4′	3900 x 1200
13′ x 5′	3900 x 1500
13′ x 6′	3900 x 1800
13′ x 7′	3900 x 2100
13′ x 8′	3900 x 2400
13′ x 9′	3900 x 2700
13′ x 10′	3900 x 3000
14′ x 3′	4200 x 900
14′ x 4′	4200 x 1200
14′ x 5′	4200 x 1500
14′ x 6′	4200 x 1800
14′ x 7′	4200 x 2100
14′ x 8′	4200 x 2400
14′ x 9′	4200 x 2700
14′ x 10′	4200 x 3000
15′ x 3′	4500 x 900
15′ x 4′	4500 x 1200
15′ x 5′	4500 x 1500
15′ x 6′	4500 x 1800
15′ x 7′	4500 x 2100
15′ x 8′	4500 x 2400
15′ x 9′	4500 x 2700
15′ x 10′	4500 x 3000

PRECAST REINFORCED-CONCRETE THREE-SIDED STRUCTURE
(Conversion from English-Units Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6 O

DESIGN STRUCTURE SIZE (ft x ft)	PAY-ITEM SIZE (mm x mm)
16′ x 3′	4800 x 900
16′ x 4′	4800 x 1200
16′ x 5′	4800 x 1500
16′ x 6′	4800 x 1800
16′ x 7′	4800 x 2100
16′ x 8′	4800 x 2400
16′ x 9′	4800 x 2700
16′ x 10′	4800 x 3000
17′ x 3′	5100 x 900
17′ x 4′	5100 x 1200
17′ x 5′	5100 x 1500
17′ x 6′	5100 x 1800
17′ x 7′	5100 x 2100
17′ x 8′	5100 x 2400
17′ x 9′	5100 x 2700
17′ x 10′	5100 x 3000
18′ x 3′	5400 x 900
18′ x 4′	5400 x 1200
18′ x 5′	5400 x 1500
18′ x 6′	5400 x 1800
18′ x 7′	5400 x 2100
18′ x 8′	5400 x 2400
18′ x 9′	5400 x 2700
18′ x 10′	5400 x 3000
19′ x 3′	5700 x 900
19′ x 4′	5700 x 1200
19′ x 5′	5700 x 1500
19′ x 6′	5700 x 1800
19′ x 7′	5700 x 2100
19′ x 8′	5700 x 2400
19′ x 9′	5700 x 2700

PRECAST REINFORCED-CONCRETE THREE-SIDED STRUCTURE
(Conversion from English-Units Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6 O (Contd.)

DESIGN STRUCTURE SIZE (ft x ft)	PAY-ITEM SIZE (mm x mm)
19′ x 10′	5700 x 3000
20′ x 3′	6000 x 900
20′ x 4′	6000 x 1200
20′ x 5′	6000 x 1500
20′ x 6′	6000 x 1800
20′ x 7′	6000 x 2100
20′ x 8′	6000 x 2400
20′ x 9′	6000 x 2700
20′ x 10′	6000 x 3000
21′ x 3′	6300 x 900
21′ x 4′	6300 x 1200
21′ x 5′	6300 x 1500
21′ x 6′	6300 x 1800
21′ x 7′	6300 x 2100
21′ x 8′	6300 x 2400
21′ x 9′	6300 x 2700
21′ x 10′	6300 x 3000
22′ x 3′	6600 x 900
22′ x 4′	6600 x 1200
22′ x 5′	6600 x 1500
22′ x 6′	6600 x 1800
22′ x 7′	6600 x 2100
22′ x 8′	6600 x 2400
22′ x 9′	6600 x 2700
22′ x 10′	6600 x 3000
23′ x 3′	6900 x 900
23′ x 4′	6900 x 1200
23′ x 5′	6900 x 1500
23′ x 6′	6900 x 1800
23′ x 7′	6900 x 2100
23′ x 8′	6900 x 2400

PRECAST REINFORCED-CONCRETE THREE-SIDED STRUCTURE
(Conversion from English-Units Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6 O (Contd.)

DESIGN STRUCTURE SIZE (ft x ft)	PAY-ITEM SIZE (mm x mm)
23′ x 9′	6900 x 2700
23′ x 10′	6900 x 3000
24′ x 3′	7200 x 900
24′ x 4′	7200 x 1200
24′ x 5′	7200 x 1500
24′ x 6′	7200 x 1800
24′ x 7′	7200 x 2100
24′ x 8′	7200 x 2400
24′ x 9′	7200 x 2700
24′ x 10′	7200 x 3000
25′ x 3′	7500 x 900
25′ x 4′	7500 x 1200
25′ x 5′	7500 x 1500
25′ x 6′	7500 x 1800
25′ x 7′	7500 x 2100
25′ x 8′	7500 x 2400
25′ x 9′	7500 x 2700
25′ x 10′	7500 x 3000
26′ x 3′	7800 x 900
26′ x 4′	7800 x 1200
26′ x 5′	7800 x 1500
26′ x 6′	7800 x 1800
26′ x 7′	7800 x 2100
26′ x 8′	7800 x 2400
26′ x 9′	7800 x 2700
26′ x 10′	7800 x 3000
27′ x 3′	8100 x 900
27′ x 4′	8100 x 1200
27′ x 5′	8100 x 1500
27′ x 6′	8100 x 1800
27′ x 7′	8100 x 2100

PRECAST REINFORCED-CONCRETE THREE-SIDED STRUCTURE
(Conversion from English-Units Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6 O (Contd.)

DESIGN STRUCTURE SIZE (ft x ft)	PAY-ITEM SIZE (mm x mm)
27′ x 8′	8100 x 2400
27′ x 9′	8100 x 2700
27′ x 10′	8100 x 3000
28′ x 3′	8400 x 900
28′ x 4′	8400 x 1200
28′ x 5′	8400 x 1500
28′ x 6′	8400 x 1800
28′ x 7′	8400 x 2100
28′ x 8′	8400 x 2400
28′ x 9′	8400 x 2700
28′ x 10′	8400 x 3000
29′ x 3′	8700 x 900
29′ x 4′	8700 x 1200
29′ x 5′	8700 x 1500
29′ x 6′	8700 x 1800
29′ x 7′	8700 x 2100
29′ x 8′	8700 x 2400
29′ x 9′	8700 x 2700
29′ x 10′	8700 x 3000
30′ x 3′	9000 x 900
30′ x 4′	9000 x 1200
30′ x 5′	9000 x 1500
30′ x 6′	9000 x 1800
30′ x 7′	9000 x 2100
30′ x 8′	9000 x 2400
30′ x 9′	9000 x 2700
30′ x 10′	9000 x 3000

PRECAST REINFORCED-CONCRETE THREE-SIDED STRUCTURE
(Conversion from English-Units Design Pipe Size to Metric-Units Pay-Item Pipe Size)

Figure 28-6 O (Contd.)

PIPE SIZE (mm)	WALL THICKNESS (mm)
300	44
375	47
450	57
525	69
600	85
675	94
750	107
825	113
900	119

NON-REINFORCED-CONCRETE PIPE CLASS 3, WALL THICKNESS

Figure 28-6P

PIPE SIZE (mm)	WALL THICKNESS (mm)
300	69
375	75
450	82
525	88
600	94
675	100
750	106
825	113
900	119
1050	132
1200	144
1350	157
1500	169
1650	182
1800	194
1950	207
2100	219
2250	232
2400	244
2550	257
2700	269
2850	282
3000	294
3150	307
3300	319
3450	332
3600	344

REINFORCED-CONCRETE-PIPE WALL THICKNESS

Figure 28-6Q

Span x Rise (mm x mm)	Wall Thickness (mm)	
	COVER < 0.6 m	COVER ≥ 0.6 m
900 x 600	175	100
900 x 900	175	100
1200 x 600	190	125
1200 x 900	190	125
1200 x 1200	190	125
1500 x 900	200	150
1500 x 1200	200	150
1500 x 1500	200	150
1800 x 900	200	175
1800 x 1200	200	175
1800 x 1500	200	175
1800 x 1800	200	175
2100 x 1200	200	200
2100 x 1500	200	200
2100 x 1800	200	200
2100 x 2100	200	200
2400 x 1200	200	200
2400 x 1500	200	200
2400 x 1800	200	200
2400 x 2100	200	200
2400 x 2400	200	200
2700 x 1500	225	225
2700 x 1800	225	225
2700 x 2100	225	225
2700 x 2400	225	225
2700 x 2700	225	225
3000 x 1500	250	250
3000 x 1800	250	250
3000 x 2100	250	250
3000 x 2400	250	250
3000 x 2700	250	250
3000 x 3000	250	250
3300 x 1200	275	275
3300 x 1800	275	275
3300 x 2400	275	275
3300 x 3000	275	275
3300 x 3300	275	275
3600 x 1200	300	300
3600 x 1800	300	300
3600 x 2400	300	300
3600 x 3000	300	300
3600 x 3600	300	300

PRECAST REINFORCED-CONCRETE BOX SECTION, WALL THICKNESS

Figure 28-6R

SPAN X RISE (mm x mm)	WALL THICKNESS (mm)
575 x 365	69
770 x 490	82
865 x 550	88
960 x 610	94
1055 x 670	94
1150 x 730	113
1250 x 795	119
1345 x 855	125
1535 x 975	138
1730 x 1095	150
1920 x 1220	163
2110 x 1340	175
2305 x 1465	188
2495 x 1585	200
2690 x 1705	213
2880 x 1830	225
3070 x 1950	238
3265 x 2075	244
3455 x 2195	250
3648 x 2315	263
3840 x 2440	275
4225 x 2680	300
4610 x 2995	325

REINFORCED-CONCRETE HORIZONTAL-ELLIPTICAL PIPE, WALL THICKNESS

Figure 28-6S