DRAINAGE CRITERIA MANUAL AND REGULATIONS

ORANGE COUNTY DRAINAGE DISTRICT

8081 Old Hwy 90
Orange, TX 77630

Ph. (409) 745-3225

Approved and adopted by the Board of Directors on October 6, 2020

Effective date: October 6, 2020

Executive Summary

The Orange County Drainage District (the "District") has developed this Drainage Criteria Manual and Regulations (the "Drainage Regulations Manual" or "Manual") in order to better regulate the impact of development on the District's drainage system and to assist in mitigating the risk of flooding throughout the County. This Manual establishes standard principles and practices for the analysis, design, review, approval and construction of drainage systems for developments occurring within the District, with the goal of allowing and promoting development, and simultaneously protecting the residents of Orange County from any increased risk of flooding due to such developments.

The District was created pursuant to Section 59 of Article XVI, Constitution of Texas, and Article 8280-292 (Tex. Rev. Civ. Statutes – Title 128. Water Auxiliary Laws) (hereinafter, the "enabling statute"), as a governmental agency for the purpose of reclamation and drainage of its overflowed lands and other lands needing drainage in Orange County. The District's mission and jurisdictional authority is focused almost exclusively on activities related to drainage and flood mitigation within the jurisdictional boundaries of the District, which includes all of the property and territory situated in Orange County. This Manual was developed in alignment with the District's purpose and mission statement:

> *"The Orange County Drainage District is committed to maintaining and improving drainage throughout the District, thereby enhancing the quality of life and safety of the residents of Orange County. The District is further committed to developing and managing a drainage system which will meet the present and long term residential, municipal, commercial, agricultural and industrial drainage needs within the District's boundaries, thereby enhancing economic development throughout the District. Importantly, the District is committed to maintaining fiscal responsibility, demonstrating accountability, and to allocating resources in a fair and equitable manner throughout the District."*

Orange County is in the Texas Coastal Plain and is relatively flat. Ground surface elevations across Orange County have relatively little variance, ranging from sea level to approximately 30 feet. In general, most of the District's drainage facilities, which include the natural bayous, creeks and gullies, are at maximum capacity for the conveyance of stormwater runoff during extreme rain events. Additionally, riverine and tidal conditions can have a dramatic limiting effect upon drainage within the County. For these reasons, the District must ensure that new development does not negatively affect or worsen drainage in the immediate and adjacent areas of the new development, as well as areas upstream and downstream of the new development. By developing and adopting this Manual pursuant to its enabling statute and Section 49.211 of the Texas Water Code, the District is authorized to more rigorously manage and regulate development, as it pertains to drainage and flood mitigation within Orange County.

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SECTION 1 – PURPOSE OF REGULATIONS

For the protection of the health, safety, and welfare of the residents of Orange County, it is the expressed intent of the District to control, or to the greatest extent reasonably achievable, mitigate flooding and detain increased stormwater runoff that would otherwise occur as a result of new development within the District. To that end, the drainage criteria/requirements (also, hereinafter the "regulations") set forth herein provide and require no adverse impact upon the drainage system upstream and downstream of the new development, as well as no adverse impact on the drainage of the properties adjacent to the new development.

The regulations set forth in this Manual shall be the official policies of the District and applicable to all regulated activity as that term is defined in Section 1.5 and Section 2.2 of this Manual.

1.1 OVERVIEW OF THE REGULATIONS SET FORTH IN THIS MANUAL

The primary purpose of this Manual is to establish standard principles and accepted practices for the analysis, design, and construction of primary drainage systems for the regulated activity within the District's jurisdictional boundaries. This Manual is intended to support and implement the Master Drainage Plan (October 8, 2019) (hereinafter, the "Master Drainage Plan") that has been adopted by the District pursuant to the authority set forth in the Texas Water Code §49.211. The Master Drainage Plan is accessible from the District's website. Paper copies may be obtained at the District offices.

The Manual is for users with knowledge and experience in the applications of standard engineering principles and accepted practices of drainage design and management. It is the purpose of this Manual to outline criteria/requirements and guidance to be used by developers, engineers, and land surveyors in the design of drainage measures to manage rainfall/stormwater-runoff. These criteria/requirements shall be applicable to the regulated activity unless otherwise amended and/or modified as approved by the District's General Manager or Board of Directors. The District considers that these regulations are clear and understandable. However in the event that an ambiguity is alleged to exist, the District reserves the sole authority to interpret same.

Stormwater management is an essential component of public infrastructure and serves to provide increased convenience and protection of life and property. A properly designed and installed drainage system is intended to function so as to control and/or convey runoff from more frequent rainfall events, and also allow for the movement of vehicles to homes and businesses. Such a system is also intended to detain and/or drain stormwaters from infrequent "extreme rainfall events", thereby preventing or limiting damage to habitable structures and major streets so that they are passable to public safety vehicles, or the risk thereof is reduced.

Providing Orange County and the incorporated municipalities within the boundaries of the District with an effective stormwater management system that allows sustainable community growth is a continuing challenge as discussed in the District's Hazard Mitigation Plan (the "2017 HMP") and Master Drainage Plan . It involves establishing minimum standards and requirements, planning for future detention basins and drainage channels, working with private development interests, coordination with other governmental agencies, maintaining the efficiency of the existing drainage system and as well, upgrading and expanding the drainage system with new elements as necessary to adapt to future challenges.

Recognizing that the development, maintenance and upgrading of an effective stormwater management system should be accomplished by written policies which clearly set forth the applicable criteria/requirements, the District undertook a planning process aimed at setting consistent standards designed to protect public safety and welfare from the adverse effects of flooding and that is also responsive to the reasonable needs of property developers, designers/engineers and compliant with federal and state regulations and guidelines. To the extent that the criteria/requirements set forth in this Manual (except with regard to criteria for secondary drainage facilities as set forth in Section 7 of this Manual) may conflict with, or be inconsistent with any applicable requirement of a local code or ordinance which is less stringent, the criteria/requirements of this Manual shall prevail. All submittals which are required in accordance with the criteria/requirements set forth in this Manual and applicable to a regulated activity shall be timely submitted to the District for approval. Approval will be determined by the District according to whether or not the project is in compliance with this Manual.

The District does not, by adoption of this Manual, intend to infringe upon the rights or obligations of other governmental entities which share concurrent jurisdiction with the District and to the extent practical and reasonable the criteria/requirements of this Manual and those applicable requirements of any other governmental entity shall be interpreted to be complimentary of each other. However, where any criteria/requirement of this Manual imposes standards that are different from those imposed by the County or an incorporated municipality within the boundaries of the District (except with regard to criteria for secondary drainage facilities as set forth in Section 7 of this Manual), the provisions which are more restrictive or impose higher standards shall control.

These regulations do not address pipelines, utilities, or other co-occupancy or crossings of District facilities. The District has administrative procedures for applications for construction, maintenance, and repair of pipelines and utilities that are proposed within and across the District's facilities and easements.

1.2 OVERVIEW OF THE DISTRICT'S COUNTYWIDE DRAINAGE RESPONSIBILITIES

The District is tasked with providing and managing drainage throughout the County, taking into consideration the responsibilities of those other entities which have certain concurrent jurisdiction. In general, most of the District's drainage system, which include the natural bayous, creeks and gullies, are at maximum capacity for the conveyance of stormwater runoff during extreme rain events. Additionally, riverine and tidal conditions can have a dramatic limiting effect upon drainage within the County. For these reasons, the District must ensure that new development does not negatively affect or worsen drainage in the area of the new development, as well as areas upstream and downstream of the new development.

The District has adopted its Master Drainage Plan pursuant to Section 49.211 of the Texas Water Code, a copy of which can be found on the District's website. By developing and adopting this Manual pursuant to Section 49.211 of the Texas Water Code, the District is authorized to more rigorously manage and regulate development, as it pertains to drainage and mitigating flooding within Orange County which is the objective of this Manual. In this connection the District reserves the right and the authority to update, amend and modify this Manual based upon changed conditions and circumstances as may be necessary.

The District's drainage system primarily consists of the major drainage arteries existing within Orange County, including the major natural bayous, creeks and gullies, and the tributaries thereto. The District's drainage system further includes the larger natural and man-made drainage ditches and outfalls which convey stormwater away from subdivisions, roads, streets and highways.

In practice, the responsibility for provision and maintenance of drainage facilities is uniquely divided between the District, Orange County Road and Bridge Department (the "County"), the incorporated Cities within the County (the "Cities"), the Texas Department of Transportation (TX-DOT) and private property owners and homeowner's associations and similar entities, in the following general manner:

1. The District is generally responsible for the major drainage arteries within the County, all major tributaries and tributary drainage outfall ditches that lead to the bayous, creeks gullies and marsh, some of the ditches that convey stormwater away from subdivisions, and any regional, sub-regional, and/or other detention reservoirs constructed and accepted by the District, all within the boundaries of the District.

2. Cities are generally responsible for underground storm sewers, open ditches and piped/covered ditches that extend alongside City roads and streets, neighborhood stormwater collection ditches located within the City, and any detention facilities constructed and/or accepted by the City.

3. Orange County is generally responsible for underground storm sewers, open ditches and piped/covered ditches that extend alongside County roads and streets.

4. Homeowners association(s) and/or private property owner(s) are responsible for site grading, on-site drainage swales, and neighborhood detention facilities and ditches along private streets.

5. TX-DOT generally has responsibility for the drainage ditches that extend alongside the state highways and roads, and for culverts crossing state owned and maintained roadways. In addition to this Manual, TX-DOT requires compliance with its separate drainage criteria for any development that will impact or utilize the drainage ditches or roads that are owned and maintained by TX-DOT.

Notwithstanding the above, the District, Cities, and County may enter into interlocal government agreements whereby, for purposes deemed to be in the best interest of the community and the entities, the entities may accept and/or apportion responsibility for construction and/or maintenance of a drainage facility that is otherwise outside of the normal division of responsibilities described above.

This Manual constitutes a component of the Master Drainage Plan referenced herein, as authorized and allowed by Section 49.211(d) of the Texas Water Code, and applies to all regulated activity within the District that impact, directly or indirectly, the District's drainage system and facilities as outlined herein. The purpose of this Manual is to provide for the efficient, consistent, and adequate design and development of drainage facilities within the District's jurisdiction by applying generally accepted engineering criteria, and establish factual and scientific data required for planning and designing future drainage facilities in order to achieve adequate and acceptable control, detention, retention and conveyance of storm and flood waters through the District's jurisdiction. This Manual also provides Developers and their Engineers with the information and instructions necessary for creating drainage plans that will promote the development while protecting the health and safety of citizens and property within the District's jurisdiction.

Notwithstanding any provision set forth in this Manual, the District does not assume any liability for property damage or personal injury occasioned by reason of the exercise of its governmental rights, obligations and powers as set forth in this Manual which are not otherwise imposed by existing law. The District expressly does not waive the doctrine of sovereign immunity in whole or in part to the extent such doctrine is afforded to the District under existing law. The criteria and regulations of this Manual are applicable to the regulated activities and as such the Developer and/or Owner thereof is solely responsible for the adequate implementation and execution thereof.

1.3 DRAINAGE CRITERIA/REQUIREMENTS -- GENERAL

1.3.1 Zero Impact (No Adverse Impacts)

An impact is defined as a change in the response of a watershed to a storm event. The most common impacts are changes in the volume of runoff, changes in the rate of runoff, and changes in flooding depths. Impacts may be adverse or beneficial. Adverse impacts are those which increase the potential for flooding damages. Beneficial impacts, on the other hand, reduce the potential for flood damage. The policy of "Zero Impact" is normally defined as the absence of adverse impact. The District maintains a strict "Zero Impact" policy in all watersheds located wholly or partially within the boundaries of the District. This means that neither increases in upstream flood levels nor in downstream flow rates are allowed in areas where there is the potential for flooding damages from storms with a statistical recurrence interval of 100 years or less (or having a 1%, or less, chance of being exceeded in any given year).

Adverse impacts associated with new development must be identified and mitigated. Acceptable mitigation measures may include stormwater detention, creation of new flood plain storage, channel improvements, and improvements to channel structures. The "Zero Impact" policy will be enforced by the District. No adverse impacts on downstream peak flow rates or upstream flood levels will be allowed and no net loss in existing flood plain storage will be allowed within the District's boundaries. Further, a new development shall not cause an adverse impact upon neighboring or adjacent properties.

1.3.2 Level of Protection

The level of protection is generally regarded as the storm recurrence interval which future primary drainage facilities, such as open channels, roadway culverts, and detention facilities, are designed to accommodate without significant flooding damages. For the analysis and design of future primary drainage facilities, the District has adopted a 100-year level of protection. Providing a 100-year level of protection would indicate that the future primary drainage facilities are designed to carry stormwater runoff from a 100-year storm event without significant flooding of homes and other buildings, and without resulting in flooding of roadways in excess of 6 inches (6") depth above the crown of the travel surface.

1.3.3 Stormwater Detention

Stormwater detention refers to the temporary storage of stormwater runoff in ponds or other storage facilities. The provision of this temporary storage allows stormwater runoff to be discharged to a receiving stream at a lower rate, thereby protecting downstream areas from increased flooding damages associated with increased flow rates and higher flood levels. The District recognizes the value of stormwater detention in reducing the potential for flood damages and allows the use of detention facilities in addition to adding conveyance capacity for mitigating impacts associated with new development and drainage improvements.

1.3.4 Flood Plain Storage

Flood plain storage is defined for the purposes of this Manual as the space below 100-year flood levels. This space is available for the temporary storage of flood waters during extreme storm events. Preservation of this air space is extremely important because flood plain storage serves to reduce downstream peak flow rates. The District prohibits reductions in existing flood plain storage within the jurisdictional boundaries of the District.

1.3.5 Primary and Secondary Drainage Facilities

For the purposes of this Manual, primary drainage facilities include open channels, bridges, culverts, and enclosed drainage systems (i.e., open channel that has been enclosed). Secondary drainage facilities include storm sewer systems, roadside ditches and associated structures, and other facilities such as sheet flow swales, small culverts, local detention facilities, and other structures which typically serve relatively small drainage areas, as well as lot grading and drainage requirements.

1.4 THE NATIONAL FLOOD INSURANCE PROGRAM

Orange County and the municipalities within the County are participants in the National Flood Insurance Program (NFIP). This program provides federally subsidized flood insurance to those cities and counties which elect to participate. The program is administered by the Federal Emergency Management Agency (FEMA), which is headquartered in Washington, D.C. Flood insurance data for participating cities and counties is published by FEMA in two formats: bound flood insurance studies, which describe the results of flooding studies completed for significant streams, and Flood Insurance Rate Maps (FIRMs), which provide data on 100-year flood levels, illustrate the boundaries of the floodway, 100-year flood plain, and 500-year flood plain, and designate flood hazard zones for insurance purposes.

1.5 DEFINITIONS

- **100-Year Peak Flow Discharge** shall mean that flow caused by a rainfall event with a 1% annual chance (100-year) recurrence interval of a duration which is defined by the size and characteristics of the contributing drainage area and as further defined in this Manual.
- **Aerial overhang** shall mean any obstruction which extends into the easement or right-of-way by crossing the vertical plane extended skyward from the edge of the easement or right of way. Limbs of trees which grow across this plane are aerial overhang and shall be trimmed or removed as needed by the District.

- **Applicant/Owner (sometimes referred to as "Developer")** shall mean any person, group of persons, firm or firms, subdivider, corporation or corporations, or any other legal entity having legal title to or sufficient proprietary interest in the land sought to be subdivided or developed and who is seeking approval pursuant to these regulations; the Applicant/Owner may designate an authorized representative in writing.
- **Approval** (see Concept Approval and Final Approval).
- **Base flood elevation** shall mean the water surface elevation of the flood that has a 1-percent chance of being equaled or exceeded in any given year (commonly called the 100-year flood).
- **Concept Approval** shall mean the written notice issued by the District following the District's review of a Developer's drainage report, drainage plans, and plats for a proposed subdivision or development, which states that the drainage report, drainage plans, plats, and supporting documentation have been determined to conform to the requirements and criteria set forth in this Manual.
- **Detention/Drainage Easement** shall mean an area for restricted use on private property upon which a public entity with jurisdiction for drainage/flood mitigation in Orange County, Texas shall have the right of entry/use as may be determined by such public entity in its sole discretion in the event of sustained default or failure by the Owners and/or HOA to properly and regularly maintain the detention facilities and to allow for such public entity to perform such maintenance of the detention facility and associated intake and discharge culverts, related maintenance berms and pilot channels and drainage ditches and/or underground pipes that lead from the detention facility to drainage ditches or other drainage outfalls within or outside of the subdivision, and/or as may be necessary. The detention/drainage easement shall be dedicated to public entity use in perpetuity for such maintenance use, by depiction on the plat and/or by describing the easement in writing affixed as notes to the final plat.
- **Development** shall mean the new construction or enlargement of any exterior dimension of any residential subdivision, commercial, industrial, public and/or municipal building, structure, or other improvements, including but not limited to site development such as grading and construction of impervious surfaces.
- **Disapproval** shall mean the written notice issued by the District following the District engineering staff's review of a Developer's drainage report, drainage plans, and plats for a proposed subdivision or development, which states that the drainage report, drainage plans, plat, and supporting documentation have been determined not to conform to the requirements and criteria of this Manual.
- **District** shall mean the Orange County Drainage District created pursuant to Section 59, Article XVI, Constitution of Texas, and its enabling statute. The District is a separate and distinct entity from Orange County.
- **Drainage** shall mean runoff of rainfall and stormwater from the surface of the land.

- **Drainage Criteria Manual** shall mean this Manual developed and adopted by the District which sets forth the criteria/requirements for preparation of drainage reports and drainage plans applicable to the regulated activity within Orange County. The contents of this Manual shall include, but are not limited to, accepted computation methods and design specifications for drainage facilities and other components of the drainage system that may be constructed.
- **Drainage Plan** shall mean the Developer's design of, and proposed construction of a drainage system and drainage infrastructure for a proposed regulated development, that is depicted and adequately represented by a combination of documents and drawings. The Drainage Plan shall include a Drainage Report, applicable drainage studies, drawing(s), and a Preliminary Plat for residential, commercial, industrial, and/or municipal subdivision developments as set forth pursuant to Section 2.2 herein, all of which are prepared in accordance with this Manual. The contents of Drainage Plan drawings shall include, but are not limited to: identifying information; location maps; property boundaries and easements; benchmarks and ground elevations; flood hazard areas; location of existing and proposed buildings, impervious areas, drainage features, bridges and culverts; design specifications for drainage structures and ditches; cross-section locations; flow paths; location of wetlands; methods of elevating buildings and specifications for placement of fill; and notes required to be shown on the drainage plans. See Appendix B for required notes.
- **Drainage Report** shall mean the report, including drainage plans, that is prepared to document conformance with the regulations, accepted engineering criteria, and other drainage criteria set forth in this Manual. The contents of the drainage report shall include but are not limited to: identifying information; computations, data, and computer models; identified deviations; identification and description of easements and rights-of-way; the drainage plans; and the engineer's statement. The Drainage Report must be signed and sealed by a professional engineer registered in the State of Texas. See Appendix B for required notes and signature block for preliminary and final plats.
- **Drainage System** shall mean any natural, modified, or man-made channel, ditch, stream, watercourse, conduit, culvert, drain, gully, swale, basin, or other feature of the landscape that is natural or designed to collect, convey, manage, discharge, or dispose of drainage stormwater.
- **Drainage Facility** shall mean the property, either real, personal, or a combination thereof, that is used to provide drainage and that is included in the District's drainage system.
- **Final Approval** shall mean, subject to the District's satisfaction, that all proposed drainage improvements and components of the Drainage Plan have been constructed and completed consistent with the previously accepted Drainage Plan for which the District has issued Concept Approval. For subdivisions, Final Approval shall be indicated with the District's execution of the appropriate signature block on the final plat. For non-subdivision projects requiring District approval, a Notice of Final Approval shall be issued to the project owner indicating Final Approval by the District of the Drainage Plan and drainage improvements and infrastructure as constructed by the owner. Prior to

issuance of Final Approval of the Development, the developer shall provide the District with a written certification by developer's engineer that the development has been constructed in accordance with the previously approved Drainage Plan.

- **Flood Hazard Area** shall mean any normally dry land area that is susceptible to being inundated by water from any source. Flood hazard areas include areas shown on Flood Insurance Rate Maps and other areas that are known and documented by the District to be subject to periodic flooding, or that have experienced a flood of record.
- **Flood Insurance Rate Map** shall mean an official map of a community on which the National Flood Insurance Program has delineated both the special flood hazard areas and the risk premium zones applicable in those areas.
- **Flood of Record** shall mean the greatest flood recorded (documented) for a location.
- **Floodway** shall mean the channel of a waterway and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a height designated in the Flood Insurance Studies of the respective jurisdiction.
- **Impervious Area** shall mean any surface which inhibits infiltration of rainfall into the soil. Surfaces that are impervious include pavement (asphalt, concrete, brick pavers, etc.), rooftops, non-wooden decks and patios (wooden decks with slotted surfaces are deemed pervious unless the underlying surface is impervious), and graveled surfaces.
- **Lowest Floor** shall mean, for buildings in flood hazard areas, the lowest floor of the lowest enclosed area (including basement). An unfinished or flood-resistant enclosure that is used only for parking of vehicles, building access, storage, or as a crawlspace is not the lowest floor provided the enclosure complies with the requirements of the applicable municipality or Orange County.
- **Master Drainage Plan** shall mean the plan adopted by the Board of Directors pursuant to the powers granted to the District in the Texas Water Code § 49.211, and any revisions thereto.
- **Outfall** shall mean the receiving District ditch, the point at which a contributory open drainage ditch discharges into the District's ditch, and/or the end of a drainage pipe that discharges into a District ditch. As appropriate to the circumstance, the term includes slope paving or other means to control erosion at the outfall.
- **Person** shall mean an individual, receiver, trustee, guardian, executor, administrator, fiduciary, or representative of any kind, or any partnership, firm, association, public or private corporation, or any other entity.
- **Pre-Submission Conference** shall mean the meeting with the District which shall take place prior to submission of the Drainage Plan. See Section 3.1.
- **Property Owner's Association**, also referred to as the "homeowners association" ("HOA"), shall be organized as a non-profit corporation pursuant to the Texas Non-Profit Corporation Act (Chapter 22, Tex. Bus. Corp. Code). In addition to the requirements of

the covenants described in Section 8.1.6.B., the bylaws of the HOA must provide for the following requirements: (1) that membership in the HOA is mandatory and will bind all subsequent purchasers; (2) that assessments sufficient for the performance of the maintenance activities will be required and periodically contributed by the members for the duration of the existence of the detention facility; (3) that such assessments cannot be terminated or reduced and are subject to modification only if the cost of maintenance increases in which case, the assessment shall be increased pro rata from the Owners; (4) that the membership and/or the HOA shall not have the authority to abolish or terminate the detention facilities which shall remain fully operable for the duration of the subdivision; (5) that the HOA shall have authority to enforce the requirements of the bylaws concerning the detention facilities and in the event of the failure of any Owner to pay the regular and/or special assessments for the proper performance of the maintenance activities concerning the detention facilities, the HOA is authorized to seek and obtain any relief at law or in equity including injunctive relief and including attorney's fees and costs; and (6) in the event that a public entity determines that it is necessary to use the public detention easement granted in order to perform maintenance concerning the detention facilities which the HOA has refused or failed to perform, the HOA and the Owner shall be liable for all such costs associated with the maintenance performed by such public entity. The HOA shall also be responsible for liability insurance, local property taxes and as stated, the required maintenance of the detention facilities.

- **Registered Professional Land Surveyor** shall mean a person who is duly registered or otherwise authorized by the State of Texas to practice in the field of land surveying.
- **Registered Professional Engineer** shall mean a person who is duly registered or otherwise authorized by the State of Texas to practice in the field of engineering.
- **Regulated activity** shall mean residential subdivision, commercial, industrial, public and/or municipal development as further set forth pursuant to Section 2.2 of this Manual, for which the drainage criteria/requirements of the District as set forth in this Manual shall be applicable.
- **Residential Subdivision** shall mean any land, vacant or improved, which is divided or proposed to be divided into four or more lots, parcels, sites, units, plots, or interests for the purpose of offer, sale, lease, or development, either on the installment plan or upon any and all other plans, terms, and conditions, for single family home construction purposes, including re-subdivision.
- **Stormwater** (see Drainage).
- **Subdivider** shall mean any person who, having an interest in land, causes it, directly or indirectly, to be divided into a subdivision and who is required to obtain approval of the subdivision plat of the proposed subdivision from a municipality or county that is located within the boundaries of the District, as those boundaries may be amended from time to time.

SECTION 2 – APPLICABILITY OF DRAINAGE CRITERIA/ REQUIREMENTS

2.1 JURISDICTION

The District is located in Southeast Texas and has coterminous boundaries with Orange County. The District was created pursuant to the provisions of Section 59 of Article XVI, Constitution of Texas, as a governmental agency for the purpose of reclamation and drainage of its overflowed lands and other lands needing drainage in Orange County. The jurisdiction of the District encompasses all of Orange County, and this Manual applies to all development occurring within the District.

Figure 1 on the following page shows the jurisdictional limits of the District, which encompasses all of Orange County.

It is the purpose of these regulations and criteria to protect, maintain and enhance public health, safety and general welfare, and to minimize the impacts of increases in stormwater runoff and flooding, by providing for the review and approval of the drainage plans and proposals for management of stormwater and flooding associated with certain development proposals, and to establish minimum requirements and efficient procedures by which these regulations are to be administered and enforced.

This Drainage Criteria Manual and Regulations shall apply to all regulated activity as that term is defined in Section 1.5 of this Manual and as further set forth pursuant to Section 2.2 of this Manual.

It is the intent of these regulations that the 100-year peak flow runoff within the boundaries of subdivisions and developments, and the 100-year peak flow runoff that flows from subdivisions and developments, be conveyed safely, that these flows have flow paths to the most appropriate District outfalls, that along the flow paths, property is not adversely impacted by these flows, and that it be demonstrated that the receiving District outfalls and ditches have the capacity to convey the additional flows without increasing downstream flooding.

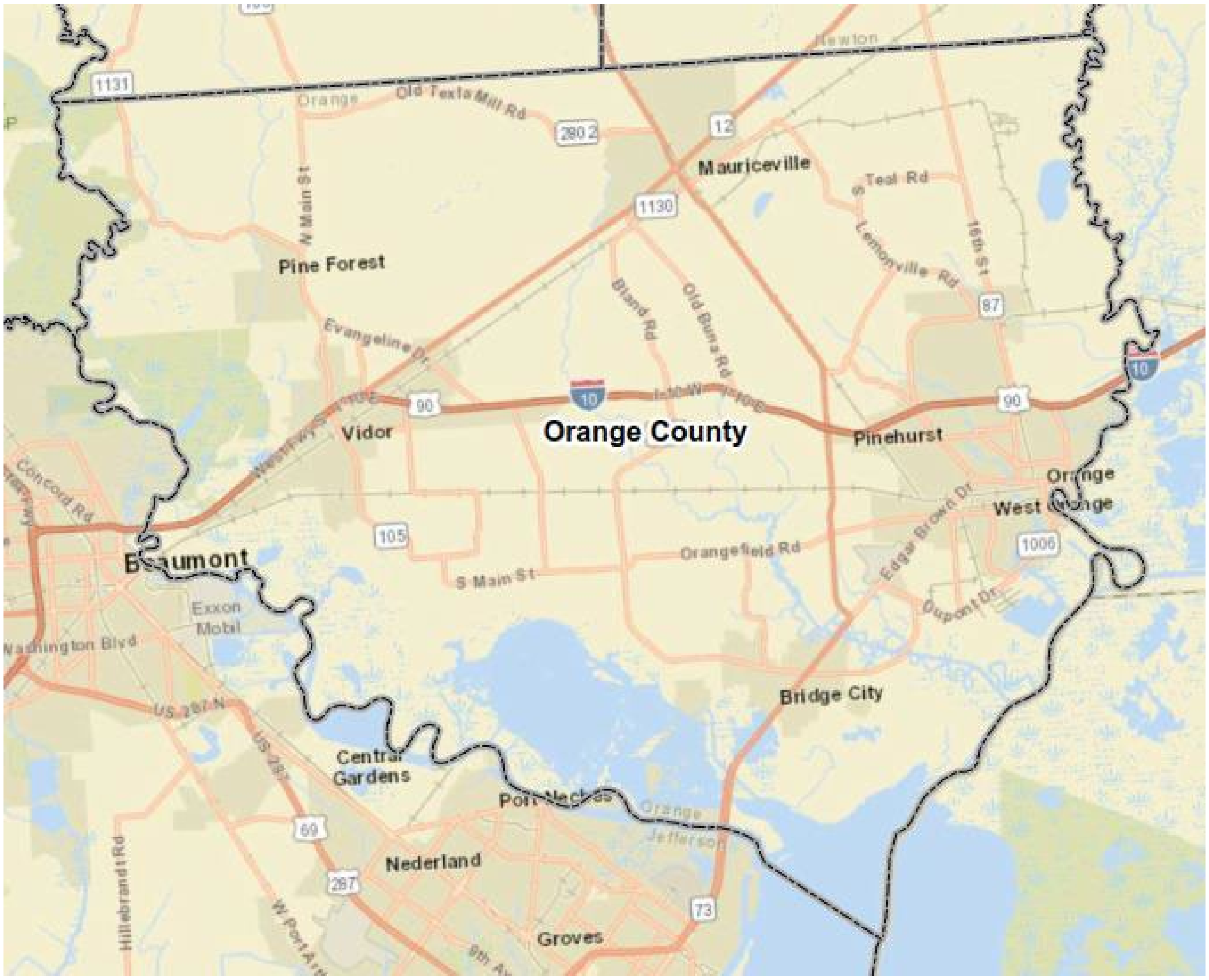

Figure 1 – District Jurisdictional Limits

2.2 REGULATED ACTIVITY FOR WHICH SUBMITTALS TO THE DISTRICT IN ACCORDANCE WITH THIS MANUAL ARE REQUIRED

Regulated activity is defined in Section 1.5 herein to include residential subdivisions, commercial, industrial, public and/or municipal development and as further set forth pursuant to this Section 2.2.

The District requires that the requisite engineering submittals be prepared for all regulated developments which may affect the rate, direction, or volume of stormwater runoff, or the depth and velocity of flow in primary drainage facilities and other infrastructure within the District's jurisdiction as applicable. Drainage criteria for secondary drainage facilities is shown in Section 7 of this Manual but is subordinate to any local municipal and county requirements in the case of conflict. Unless otherwise exempted in this Manual, or unless a waiver is obtained from the District, the District will review the following three types of projects for compliance with this Manual and applicable regulations:

1. Construction of new projects, modification and/or improvement of existing facilities, and other works with a potential to impact drainage, or stormwater flows which are managed by existing facilities which are maintained by the District.

2. Construction of drainage facilities within Orange County which are physically located in, on, over, under, or adjacent to a drainage facility or which may affect the operation or performance of a drainage facility maintained by the District or which are designed to discharge, directly or indirectly, to a drainage facility maintained by the District. These projects may include, but are not limited to:
    a. Land development projects
    b. Roads and highways
    c. Bridges and culverts
    d. Storm sewer outfall pipes
    e. Recreation amenities (hike and bike trails, parks, etc.)
    f. Encroachments

3. Development or public projects that may affect the facilities maintained by the District such as natural channels, lakes, drainage-ways, etc. or future drainage facilities described in a drainage master plan, including, but not limited to:
    a. Residential subdivision development
    b. Multi-family residential, commercial, industrial, and public facilities site development
    c. Roads and highways

Previously Approved Developments: The construction of developments that have been approved, or previously approved, by the District, for which construction has been commenced within the time period set forth in Section 3.1.3, is not subject to revised regulations that have been changed subsequent to the approval of such developments, and shall remain subject to being reviewed by the District for compliance with regulations in effect at the time of approval or as required by said prior approval.

Exempt Activities: The construction of residential homes within a subdivision that has been previously approved by the District, shall not be subject to revised regulations that have been changed subsequent to the approval of such developments. However, all construction shall remain subject to review, inspection and enforcement of building restrictions, site grading, compliance with easements and any other requirements that may be set forth in an approved Plat, Drainage Plan, homeowners agreement or bylaws, or other document approved or filed related to the use or development of the property at issue.

2.3 SAVINGS, REPEALER, SEVERABILITY AND EFFECTIVE DATE

The savings, repealer, severability and effective date provisions of this Manual are as follows:

1. **Savings:** All rights and remedies that have accrued in favor of the District under this Manual and amendments thereto shall be and are preserved for the benefit of the District.

2. **Repealer:** All resolutions, actions, policies, and procedures of the District that are inconsistent herewith or in conflict with state laws and regulations are hereby repealed, but only to the extent of such inconsistency or conflict.

3. **Severability:** If any section, subsection, paragraph, sentence, clause, phrase, word, or portion of this Manual or amendments thereto, is, for any reason, held invalid, unconstitutional, or otherwise unenforceable by any court of competent jurisdiction, such portion shall be deemed a separate, distinct, and independent provision, and such holding shall not affect the validity of the remaining portions thereof, which remaining portions shall continue in full force and effect and be binding upon all parties.

4. **Effective Date:** These Rules, Regulations and Guidelines shall become effective on October 6, 2020 and shall continue in force and effect until amended or repealed.

SECTION 3 – DRAINAGE PLAN SUBMISSIONS AND APPROVALS

3.1 SUBMISSION AND APPROVAL PROCESS

Review and approval of Drainage Plans, Plats, Studies, Reviews, and Drainage Reports by the District shall be accomplished as follows:

1. Pre-submittal Meeting - A pre-submittal conference is mandatory. The District strongly encourages pre-submission conferences and early coordination with the District in development of drainage plans. The form to be used to submit information required for the pre-submission conference is available at http://www.ocddtx.com. Submission of the completed form indicates that the Applicant/Owner is requesting that the pre-submission conference be scheduled. The District shall contact the Applicant/Owner, or designated representative, to schedule the pre-submission conference.

   The District encourages Applicants/Owners to contact the District and submit the information required for the pre-submission conference in order to schedule the pre-submission conference well in advance of submission of the drainage report and drainage plans. Orange County, or a municipality located in the District, may require submission of the District's Concept Approval as part of submissions for approval of subdivision plats, site plans, and building permits. It is the responsibility of the Applicant/Owner to determine the requirements of the applicable jurisdiction.

The pre-submission conference shall take place at the District's office, or at the option of the District, by virtual meeting.

2. Initial Submittal Requirements for Drainage Plan Reviews — Drainage Plan Concept Approval is required prior to commencement of any construction or development activity on any site within the District. **The following items must be submitted before the review process will commence.** The Submission Form and Checklist for District Review of Development, which may be found on the District's website, shall be submitted along with all reports, plans, and plats, and shall be submitted in triplicate (3 paper copies) and 1 electronic copy on a thumb drive and/or via email to development@ocddtx.com.

   a) Application for Submission Form and Checklist for District Review of Development – Any request for review of drainage plans, reports, plats, or master plans shall be accompanied by a completed "Submission Form and Checklist for District Review of Development". Forms are available on the District's website or from the District office during normal business hours.

   b) Review Fee — See Appendix A for Review Fees. NOTE — No submission will be reviewed until the required review fee has been received by the District.

   c) Drainage Studies and Reports – Applicable drainage studies and/or reports shall be submitted to the District for review. Requirements for drainage studies and reports are detailed in Section 3.2.

   d) Drainage Plans – A Drainage Plan consists of drainage studies, reports, plans and plats if applicable, which shall be submitted to the District for review and "concept approval". Each page included in this submission shall be clearly marked "For Review Only – Not for Construction". The Drainage Plan shall contain any and all plans, plats, reports, studies, and master plans, including the detailed design of all drainage improvements as specified in the following sections, the rainfall runoff impact information pertaining to the affected major drainage artery, and any special notes to be included on the Plat, including deed restrictions. A professional Engineer registered in the State of Texas must seal the Drainage Plan for subdivisions, commercial, industrial and public developments of any size.

   e) Preliminary Plats – Complete sets in triplicate (3 paper copies), on size of 24" x 36" (D-sized) paper, shall be delivered to the District office. Each page included in this submission shall be clearly marked "For Review Only – Not for Construction". Additionally, one (1) PDF set of the same plans shall be delivered to the District office on a thumb drive or via email. The PDF file shall contain a "sheet set" i.e. all pages of the plan are contained within a single PDF file.

3. District Review of Plans and Concept Approval — The District will review submitted Drainage Plans, drainage reports, plans, and preliminary plats for compliance with the District's policy of "No Adverse Impact" and other criteria as detailed in this document and in the District's Master Drainage Plan. Reviews shall include, but may not be limited to:

   a) Technical/Engineering Review for compliance with technical aspects of the District's requirements and verification that the proposed development, as planned, will not result in adverse impacts to drainage within the District.

   b) Legal/Real Estate Review for verification of easements, accesses, and similar matters.

   c) Operational Review for assessment of matters which may adversely affect the District's ability to operate and maintain its facilities.

   Additional information may be requested, if necessary, to perform the District's review.

   The Applicant/Owner is responsible for submission to and satisfaction of the requirements of other applicable local jurisdiction(s). Review and concept approval of all Drainage Plans by the District will be performed coincident with other proper approval authorities, as nearly as possible. The review process will be performed by District personnel and the District's designated consultants.

   Suspension of the District's Review. The District may suspend its review if:

   - A written request for suspension is submitted by a municipality or Orange County; the suspension shall remain in effect until such time as a request to resume the review is received from the requesting municipality or Orange County.
   - A proposed subdivision or development falls within a designated Floodway and a floodway analysis prepared in accordance with the specifications of the National Flood Insurance Program has not been prepared or such analysis indicates that there will be a change to the Floodway and/or Base Flood Elevations; the suspension shall remain in effect until such time as the Applicant/Owner modifies the proposal to avoid the Floodway or provides evidence that a Conditional Letter of Map Revision is issued by the National Flood Insurance Program.

   Upon completion of the initial review to the satisfaction of District requirements, the District shall issue a Letter of Concept Approval. The Applicant/Owner shall sign the Letter of Concept Approval, thereby acknowledging the Applicant/ Owner's agreement to construct all drainage-related components of the proposed development in accordance with the Drainage Plan and all other approved submissions. The contractor or developer will be expected to execute all construction in compliance with the approved drainage plans. Final approval by the District shall be subject to the District's inspection(s) of construction and approval of final submittal requirements listed below.

Limits of Approval – All approvals of the District shall be valid for a period not to exceed twelve (12) months, beginning with the issuance of the Concept Approval letter. Failure to commence substantial construction activities of the approved project, or to otherwise make full use of the approvals granted within the 12-month time period shall result in said approvals becoming null and void. All fees shall be forfeited and applicant shall not be entitled to any refund of associated payments. A request for a one-time extension, for a period not to exceed 12 additional months, may be granted by the District, at its sole discretion, provided good cause can be shown for the delay and the request for the extension is made prior to the expiration of the original approval.

4. <u>Construction Inspection</u> – The District has the authority to inspect drainage construction and other work as set forth in this section:

a) The Applicant/Owner, by signing the Concept Approval Letter, grants free and unobstructed access during normal work hours to the District, the District's personnel, or the District's authorized representatives, for the purpose of inspection of the drainage construction and other work covered by the District's Approval.

b) The Applicant/Owner or the designated engineer or contractor shall notify the District engineering staff at least seventy-two (72) hours prior to forming and pouring concrete for any portion of the approved work that will be conveyed to the District; the District engineering staff or other District personnel may meet on site to inspect the proposed concrete work. Failure to request this inspection or failure to coordinate the inspection sufficiently in advance of pouring concrete may require additional work or evidence of compliance. This meeting does not relieve the Applicant/Owner or the designated engineer or contractor of the responsibility to comply with the Approval and the approved drainage plans.

c) At any time, the designated District representative, District engineering staff, or District personnel shall have free access to the development site for the purpose of making on-site observations to determine, in general, whether the construction of the drainage system has been constructed in accordance with the approved drainage design. Notwithstanding this right of access and observation, the Applicant/Owner is solely responsible for construction of the drainage system in full compliance with the approved drainage design, and the District assumes no responsibility or liability for such construction.

d) At any time, the Applicant/Owner or the designated engineer or contractor may request that the District inspect, meet, or consult on the work covered by the Approval or other work determined to be necessary during the course of construction.

e) The Applicant/Owner or the designated engineer or contractor shall notify the District when the work is completed; at the District's discretion, the District shall conduct a final inspection within one (1) month after receipt of such notification.

5. Enforcement by the District – The District has the authority to enforce these regulations as set forth in this section.

a) If the District determines that the work is not proceeding in conformance with the Approval, the District shall notify, in writing, the appropriate authority in the county or the municipality in which the subdivision or development is located.

b) The District shall identify, in writing, any work that is not in substantial conformance with the Approval and the approved Drainage Plans; the work so identified shall be completed as approved or, if applicable, the Applicant/Owner or the designated engineer or contractor may propose alternate work; the District may require submission of written documentation of such alternate work prior to approval. The District's discussion of alternate work that may resolve the nonconformance does not constitute approval of such alternate work; alternate work shall be approved in writing by the District.

c) The District may rescind Approvals if it determines that work is not in substantial conformance with the Approval and the approved drainage plans and the Applicant/Owner or designated engineer or contractor has failed to propose or to obtain the District's approval for alternate work; the District will not accept work for which an Approval has been rescinded.

d) The District will notify the appropriate municipality or Orange County if the District rescinds an Approval. Applicant/Owners are advised that the District's approval is required prior to acceptance, approval, or issuance of an occupancy certificate by the appropriate municipality or Orange County.

6. Notice of Final Acceptance – The District shall issue a Notice of Final Acceptance for drainage work after 1) the developer pays the Fee for review of final submittals; and 2) the developer provides the District with a written certification, by the developer's engineer, that construction has been performed and completed in compliance and accordance with the previously approved Drainage Plan, and the District determines that the work is in substantial conformance with the Concept Approval.

7. Final Submittal Requirements –

a) As-Built Drawings, one (1) D-size, electronic only, PDF set of the plans shall be delivered to the District office on a thumb drive or via email. The plan set will be noted as "as-built" in the drawing revision block.

b) Affidavit of Construction Completion – The Applicant/Owner shall submit an Affidavit executed by the Project Engineer to the District attesting that all construction of drainage facilities and other improvements affecting drainage on the project site has been constructed in strict compliance with the Drainage Plan and all other District requirements.

c) The Applicant/Owner shall submit for review and approval, and thereafter file, all required legal documents, such as the documents necessary to create the Homeowners' Association, including association bylaws, and any other legal documents required by the District.

d) Final Plat (with all required notes) – Refer to Appendix B for required notes and signature block.

8. Final Approval and Acceptance –

a) Plat For Signature - It is the responsibility of the Applicant/Owner to deliver the MYLAR sheet(s) to the District and to obtain signatures by the District. Verify the date of the next meeting and deliver the MYLAR sheet(s) no later than the seven (7) calendar days prior to the Board meeting for consideration of the approval of the plat being placed on the agenda. MYLAR sheets are only required for the sheets which require signature by the District.

b) Final Approval – Final acceptance and approval of a plat requires approval by the District's Board of Directors. Board approval takes place only at regular meetings, unless a Special Meeting is called in the sole discretion o of the Board. The applicant is advised to take this into consideration when setting his / her schedule for the project.

c) Recorded Plat – After the final plat(s) has been entered into the County Clerk's Official Public Record, the Developer shall notify District by providing a copy of the receipt from the County Clerk. It is not necessary for the Developer to provide a copy of the recorded plat to the District.

Responsibility to Obtain Approvals by Others. It shall be the responsibility of the Applicant/Owner to obtain any and all approvals required by other entities. As part of its preliminary comments or review of the drainage report and drainage plans, the District may request submission of evidence that the Applicant/Owner has applied for, or obtained, approvals required by other entities.

3.2 SUBMITTAL REQUIREMENTS

3.2.1 Drainage Studies and Drainage Reports

Drainage Studies and Drainage Reports (collectively referred to as "Drainage Reports") are a component of the Drainage Plan for proposed development. Drainage Reports shall contain the information specified in this section. Drainage Reports shall be prepared in accordance with the standards set forth in this Manual and include all information detailed in this section. The District encourages inclusion of computations and specifications developed to satisfy the requirements of the applicable municipality, or Orange County. Deviations from the District's standards and criteria shall be identified in the Drainage Report, and technical justification for such deviations, including computations as appropriate, shall be provided.

Unless waived by the District in its sole discretion as a result of the pre-submission conference, Drainage Reports are required to contain, at a minimum, the following items:

a) Applicant/Owner name, address, telephone number, and e-mail address.

b) Applicant/Owner's authorized representative's name, address, telephone number, and e-mail address.

c) Name, address, telephone number, e-mail address, and registration of the Registered Professional Engineer who prepared the Drainage Report and Drainage Plan.

d) The title or name under which the proposed subdivision or development is to be recorded.

e) Date of all submittals, with date(s) of revisions, including month, day and year.

f) Geotechnical investigations to establish the static water table at the project site.

g) Computations, data, and diagrams pertaining to the effects of the proposed subdivision or development on 100-year peak flow runoff rates, times of concentration, and flowline elevations and depths, especially relative to the outfall to the District's drainage facility. For properties with multiple drainage areas, the computations shall be provided for each drainage area. Computations shall be performed in accordance with accepted engineering practices and with the methodologies specified in this Manual.

h) If the District has provided a computer model, the model shall be modified as appropriate to include the 100-year peak flow runoff hydrograph from the proposed subdivision or development; a description and documentation of the modifications to the computer model and the consequent changes in peak flows shall be included.

i) Submissions containing HEC models used to develop discharges and water surface elevations shall include a map of the drainage network with subareas and nodes, a printout of the basin and route characteristics (or HEC model input files), and a printout of the master summary of the final design.

j) An electronic copy of computer models used to develop the Drainage Report shall be provided on a portable digital storage device and shall become the property of the District.

k) Computations to support proposed ditches, storm drains, inlets, detention or retention facilities, pipes, culverts, and similar drainage system components.

l) Computations, drawings, and data prepared in a manner consistent with the requirements of the National Flood Insurance Program, if any portion of the proposed subdivision or development falls within the Floodway as designated on the effective Flood Insurance Rate Map.

m) Identified deviations from this Manual and the regulations and criteria set forth herein, and an explanation and technical justification, including computations as appropriate, of all such deviations.

n) Identification and description of drainage easements and/or other rights-of-way obtained by the Applicant/Owner from third parties for the purpose of conveying drainage to a District drainage facility. The Applicant/Owner is responsible for obtaining, recording, and preserving any and all such easements and/or rights-of-way.

o) The drainage plans (drawings) for the proposed subdivision or development.

p) A statement signed, dated, and sealed by the Registered Professional Engineer who prepared or supervised preparation of the Drainage Report and drainage plans, that the drainage report and drainage plans are consistent with and substantially in conformance with the District's drainage standards and this Manual. The statement shall be as follows:

> "I hereby state that I have developed or reviewed this Drainage Report and the accompanying drainage plans, and that the proposed drainage design and methods of construction are consistent with and substantially in conformance with the drainage regulations and standards set forth in the Drainage Criteria Manual and Regulations of the Orange County Drainage District."

3.2.2 Drainage Plan and Plats

For all proposed developments subject to these regulations, the drainage plans (drawings) or preliminary plats shall be prepared in accordance with the standards set forth in this Manual. Unless otherwise approved by the District as part of the pre-submission conference, at a minimum drainage plans (drawings) or preliminary plats shall be submitted on Arch D (24"x36") sized sheets, and are required to show the following:

a) Applicant/Owner name, address, telephone number, and e-mail address.

b) Applicant/Owner's authorized representative's name, address, telephone number, and e-mail address.

c) Name, address, telephone number, e-mail address, registration number, seal and signature of the Registered Professional Engineer who prepared the Drainage Report and Drainage Plan.

d) Name, address, telephone number, e-mail address, registration number, seal and signature of the Registered Professional Land Surveyor who prepared the survey on which the Drainage Plan and Plat are based.

e) The title or name under which the proposed subdivision or development is to be recorded.

f) Date of all submittals, with date(s) of revisions, including month, day and year.

g) Location of the subdivision or development and vicinity map.

h) Scale of the drawings, with a minimum scale of 1" = 100'.

i) Benchmark(s) and reference mark(s) with datum and year of adjustment. All Benchmarks shall be converted and shown adjusted to the North American Vertical Datum 1988. Developers shall set benchmarks within the bounds of their projects in accordance with the requirements of Orange County in force at the time of construction.

j) Boundaries of the property and adjacent property owners.

k) Applicable "Notes for Drainage Plans and Plats," in accordance with Appendix B.

l) Ground elevations and contour lines.

m) The map number and date of the effective Flood Insurance Rate Map, the boundaries and base flood elevations of flood hazard area shown on Flood Insurance Rate Map, the limits of the Floodway, if applicable, and other flood hazard area delineations provided by the District.

n) Delineation of existing and proposed buildings, roads, parking and other impervious areas, with a determination of the total impervious area compared to the total area.

o) Locations of existing and proposed drainage features, including drainage channels, watercourses, ravines, creeks, bayous, streams, gullies, ditches and drainageways, and flood control improvements and other facilities.

p) Locations of existing and proposed bridges, culverts, outfalls, and drainage structures.

q) Drainage area divides for the vicinity of the proposed subdivision or development, including off-site areas draining to the site.

r) Peak runoff rates calculated pursuant to accepted engineering/hydrology standards for each inlet, structure, or drainage area; peak runoff rates shall be as required by the applicable municipality and/or Orange County.

s) 100-year peak flow runoff rates shall be shown where drainage leaves the property boundaries of the proposed subdivision or development and at the District's outfalls.

t) For drainageways, including ditches, storm drain culverts, and pipes, the flow path for runoff discharges that exceed the capacity of the drainageway, up to and including the discharge associated with the 100-year peak flow runoff rates.

u) Details of all ditches, swales and drainageways, for a minimum distance of two hundred (200) feet upstream and two hundred (200) feet downstream, which are to convey rainfall-runoff from the proposed subdivision or development and/or through the proposed subdivision or development to the appropriate downstream drainageway and the location of that drainageway.

v) Locations and dimensions of existing and proposed drainage easements, including widths, on both sides of all natural, existing, and proposed drainage system components.

w) Delineations of wetlands, if applicable.

x) The proposed method of elevating buildings to meet the requirements of the municipality and/or Orange County, if any portion of the proposed subdivision or development falls within the Special Flood Hazard Area as delineated on the effective Flood Insurance Rate Map, or other flood hazard areas identified by the District as subject to flooding.

y) If fill is proposed to elevate buildings in flood hazard areas, final height of the compacted fill, the total volume of fill for each such placement, and the flow path of drainage in the area to accommodate the proposed placement of fill.

3.2.3 District's Approval of Drainage Plan Does Not Constitute Acceptance of Dedicated Easements, Right of Ways

The District's approval of a Drainage Plan and/or Drainage Report, or approval of any preliminary or final subdivision plat accepted and/or approved by a city or other municipality or a county or the District, shall not constitute acceptance by the District of any public easement(s) and/or right of way(s) dedicated and depicted, shown or referenced on such plat; and, in no event shall impose on the District any duty of maintenance or improvement of any such dedicated easement or right of way or related property or parts unless the District's Board of Directors shall take formal action by written resolution or Order passed in a duly noticed public meeting to accept and/or use any such easement, right of way and/or related property.

3.2.4 Development Drainage Master Plans

Overall Master Plan—Larger projects (over 100 acres in size) will be subject to additional requirements as follows:

a) The Developer or his / her designee shall request a pre-development meeting to review the overall project with the District's designated representative and the District Engineer. During this high-level discussion, the conceptual plan, required drainage easement dedications, and proposed modeling methodology will be discussed.

b) The Developer of his/her designee will submit an overall development drainage master plan ('master plan") to the District (details above) for review and approval.

This overall master plan shall show the overall development scheme, approximate roadway locations, sections of development, all stormwater management features, and all District facilities including existing and proposed easements widths.

c) Future submissions of detailed Drainage Reports, Drainage Plans and construction plans shall be in general conformance with the approved overall master plan.

d) The Developer is encouraged to obtain an approved overall master plan for all of the contiguous acreage; however, smaller portions of the overall acreages at least 100 acres in size may be developed in phases. The Developer should keep in mind that future overall master plans must meet the minimum requirements of the current version of this Manual. Due to possible changes in the criteria and regulations set forth in this Manual, developing large projects in phases potentially exposes the Developer to more stringent requirements when seeking approval of Drainage Plans for future phases.

SECTION 4 – HYDROLOGIC AND HYDRAULIC CONCEPTS

The purpose of this chapter is to present a brief summary of hydrologic and hydraulic concepts that are required to understand and apply the criteria presented in this Manual. This chapter also includes a description of the effects of urbanization on the watershed as well as a description of the National Flood Insurance Program (NFIP).

4.1 DEFINITIONS OF BASIC TECHNICAL TERMS

- **conveyance:** the ability of a channel or conduit to carry water in the downstream direction.
- **cross-sectional area:** the total area available to carry flow, measured at a vertical plane (cross- section), which cuts across a channel or conduit perpendicular to the direction of flow.
- **flood plain:** an area inundated by flood waters during or after a storm event of a specific magnitude.
- **friction loss:** a loss in energy associated with friction between flowing water and the sides of a channel or conduit.
- **hydraulic radius:** a parameter computed as the cross-sectional area divided by the wetted perimeter.
- **hydrology:** the study of the processes through which atmospheric moisture passes between the time that it falls to the surface of the earth as rainfall and the time that it returns to the atmosphere.
- **hydrograph:** a graph which relates rate of flow and time.
- **infiltration:** the process by which rainfall soaks into the ground.

- **Manning's Equation:** a mathematical formula which relates the velocity or rate of flow in a channel or conduit to the physical characteristics of the channel or conduit.
- **minor loss:** a loss in energy associated with changes in flow direction or velocity.
- **probability:** the chance, usually expressed in percent, that a storm event of a particular intensity and duration will occur in any given year; equal to the reciprocal of the recurrence interval.
- **rainfall intensity:** the rate at which rainfall occurs, typically expressed in inches per hour.
- **recurrence interval:** the average period of time which will elapse between storms of a particular intensity and duration (equal to the reciprocal of the probability).
- **roughness coefficient:** a number which represents the relative resistance to flow in a channel or conduit.
- **runoff:** precipitation which does not infiltrate into the ground, but instead makes its way to a stormwater drainage facility.
- **storm event:** a single period of heavy rainfall, normally lasting from a few minutes to a few days.
- **time of concentration:** the time required for water to travel from the most remote point in a watershed to the point at which a peak flow rate or runoff hydrograph is to be computed.
- **unit hydrograph:** a runoff hydrograph which represents the response of a watershed to 1 inch of runoff.
- **watercourse:** a path which water follows from the boundary of a watershed to the watershed outlet.
- **wetted perimeter:** the total distance along a channel or conduit cross-section that is in contact with water that is flowing in the channel or conduit.

4.2 BASIC HYDROLOGIC CONCEPTS

4.2.1 Design Rainfall Events

Rainfall normally occurs in irregular patterns with respect both to space and time; however, synthetic rainfall events (referred to as "design storm events") are typically used for hydrologic analyses. These design storm events are developed through statistical analyses of long periods of recorded rainfall data and are defined by the recurrence interval and storm duration. For example, a 100-year, 24-hour storm is a 24-hour duration design storm which has a 100-year statistical recurrence interval (or 1-percent probability of occurring, or being exceeded, in any given year). Table 5-5 provides a summary of the relationship between rainfall depth, duration, and recurrence interval for Orange County, Texas. This chart is also referred to as a "Point Precipitation Frequency

Estimate" and is updated from time to time as available data and scientific methods evolve and improve.

4.2.2 Infiltration and Runoff

A portion of the rainfall that reaches the earth soaks into the ground via infiltration, while the balance of the rainfall is called runoff. Since infiltration increases with the porosity of the soil, infiltration for clay soils is less than for sandy soils. Infiltration is reduced as the moisture content of the soil is increased and ceases when the soil becomes saturated. As infiltration decreases, runoff increases and vice versa.

4.2.3 Runoff Hydrographs

Runoff hydrographs are relationships between the rate of runoff and time. Hydrographs are important because they provide information on the peak rate of runoff and variations in runoff rates throughout the duration of a particular storm event. These variations can be significant in defining the response of a watershed to a rainfall event, especially when the watershed is large, and runoff continues over many hours or days.

A unit hydrograph is a hydrograph which reflects the response of a watershed to a rainfall event that produces exactly 1-inch of runoff. Runoff hydrographs for storm events producing more or less than 1-inch of runoff are computed from a unit hydrograph by multiplying each individual flow rate in the unit hydrograph by the actual runoff volume in inches. This computation is based on various hydrologic parameters and is performed automatically by software programs such as HEC-HMS, which was developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (USACE).

4.3 BASIC HYDRAULIC CONCEPTS

4.3.1 Manning's Equation

Manning's equation is a commonly used formula that relates the hydraulic capacity and the physical condition of an open channel, a storm sewer pipe, or a box culvert. The equation is written as follows:

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

Equation 4-1

where: Q = the flow rate (cubic feet per second);
n = a roughness coefficient related to the relative condition of the channel or structure;
A = the cross-sectional area of flow (square feet);
R = the hydraulic radius, which is computed as the flow area divided by the wetted perimeter (feet);
S = the slope of the channel or structure;

The roughness coefficient (n value) is a measure of the roughness of the surfaces with which water comes into contact. For example, higher n values represent rougher surfaces and lower n values represent smoother surfaces. Information on selecting n values for open channels and storm sewers is included in Chapter 6.

4.3.2 Conveyance

Conveyance is a measure of the capacity of a channel, flood plain, or hydraulic structure to carry stormwater. As indicated in Equation 4-2, conveyance increases with the cross-sectional area of flow, the depth of flow in the structure, and the smoothness of the surfaces with which water comes into contact. For example, enlarging a drainage channel will increase the conveyance and the rate of stormwater flow within the channel. Clearing away trees and brush from a channel will have the same effect. Replacing a corrugated metal pipe (CMP) with a reinforced concrete pipe (RCP) of the same diameter also results in an increased conveyance because of the smoother interior of the RCP.

$$K = \left(\frac{1.49}{n}\right) AR^{2/3}$$ **Equation 4-2**

where: K = conveyance (cubic feet per second).

4.4 EFFECTS OF URBANIZATION

Urbanization includes activities such as land clearing, new development, roadway construction, improvements to drainage systems, changes in natural land topography, placement of fill in flood plains, and construction of pavements and other impervious surfaces. These types of activities have significant effects on the response of a watershed to rainfall, which are summarized below.

- **Increased Volume of Runoff:** Urbanization is typically accompanied by an increase in the percentage of the ground surface that is covered by impervious materials, which decreases infiltration and increases the volume of runoff.
- **Increased Rate of Runoff:** In most urbanized areas, drainage systems are designed to collect and convey stormwater as efficiently as possible away from areas occupied by homes, businesses, and roadways. This efficiency tends to concentrate stormwater runoff more quickly than the natural drainage system in most areas. In addition, re-grading of natural slopes and the removal of flow-retarding vegetation eliminates

natural storage that attenuates runoff rates in non-urbanized areas. These factors cause runoff rates from urbanized areas to exceed rates from undeveloped areas, which tends to increase the water surface elevations (WSELs) in channels.

- **Modified Watershed Response:** The increased efficiency of urban drainage systems tends to decrease the time of concentration from developed drainage areas so that the peak runoff rate occurs more quickly than from the same area prior to development. As a result, development of a drainage area may adversely impact WSELs within the receiving channel due to changes in the timing of peak runoff rates. These adverse impacts may occur even if detention is provided and the developed peak runoff rate is less than the undeveloped peak runoff rate.
- **Reduced Flood Plain Conveyance:** Lots and/or building pads located in flood-prone areas are typically elevated with fill material. The placement of this material in flood plains creates obstructions to flow and reduces the available conveyance in the flood plain. The construction of elevated roads across the flood plain has a similar effect. Such reductions in the conveyance capacity of the flood plain tend to increase WSELs in channels.

4.5 FLOOD INSURANCE CONCEPTS

The purpose of the NFIP, which is administered by the Federal Emergency Management Agency (FEMA)**,** is to offer affordable flood insurance for homes and businesses located in flood-prone areas. Delineations of flood-prone areas are completed in Flood Insurance Studies (FIS) commissioned by individual participants (typically cities and counties) in the program. FEMA publishes the results of these studies as bound FIS and as Flood Insurance Rate Maps (FIRMs). The purpose of FIS is to define areas with a particular chance of flooding. The 100-year rainfall event, which has a 1-percent probability of occurring in any given year, is used as a standard measure. While the FIS and FIRMs provide information about likelihood for flooding, they are not intended to indicate with certainty that a particular area will or will not flood over a given period of time.

FIS include hydrologic studies to define peak flow rates along studied streams for 10-year, 50-year, 100-year and 500-year rainfall events. Hydraulic analyses are also performed to establish base flood elevations (BFEs) along studied streams for each of these rainfall events and to define the boundaries of the 100- and 500-year flood plains as well as the floodway. The floodway is a corridor of effective flow that includes the channel and any adjacent land areas required to pass the 100-year peak discharge rates without increasing the WSEL at any point along the channel more than 1-foot above the 100-year BFEs. FIRMs provide data on 100-year BFEs, illustrate the boundaries of the floodway and 100- and 500-year flood plains, and designate flood hazard zones for insurance purposes. The irregular lines drawn across the 100-year flood plain at 1-foot intervals indicate the BFEs along the stream.

SECTION 5 – HYDROLOGIC ANALYSIS, CRITERIA AND METHODOLOGY

5.1 HYDROLOGIC ANALYSIS OVERVIEW

The purpose of this Section 5 is to provide detailed information on the hydrologic analyses required by the District.

Section 5.2 describes requirements for the hydrologic analysis of "small" drainage areas and may be applied to projects with watersheds up to 200 acres, while Section 5.3 describes requirements for the hydrologic analysis of "large" drainage areas greater than 200 acres. **It is critical to distinguish between project size and watershed or drainage area size. Appropriate hydrologic analysis methods must be selected with consideration for impacted watershed size (the "Drainage Area"), not the project size. For this reason, the Developer (or his designated engineer) must meet with District representatives in a Pre-Submission Conference, and provide to the District, in advance of the submission of a Drainage Plan, the Developer's determination and designation of the Drainage Area, and the number of acres comprising the Drainage Area. The Developer's determination of the Drainage Area must be based on the topography of all of the potentially affected area surrounding the property to be developed, and on the drainage ditches, channels and other drainage structures that may impact, or be impacted by, the proposed development. The District reserves the right to reject the Developer's determination and designation of the Drainage Area, and request that the Developer either provide more information in support of the designated Drainage Area, or to alter such designated Drainage Area to the satisfaction of the District.**

5.2 DRAINAGE AREAS UP TO 200 ACRES

This section describes the methods to be used in hydrologic analyses of drainage areas up to 200 acres. The analyses for small watersheds may be completed using the Rational Method as described in this section. At the discretion of the project Owner or Engineer, a HEC-HMS hydrologic analysis may be utilized as required for drainage areas larger than 200 acres using the methodology described in Section 5.3.

5.2.1 The Rational Method

The Rational Method relates the runoff rate from a watershed to drainage area, land use, and rainfall intensity. The basic equation used in the Rational Method to compute the runoff rate is:

$$Q = C \times C_a \times I \times A$$ **Equation 5-1**

where: Q = the peak runoff rate (cubic feet per second);
C = a runoff coefficient dependent on land use;
C_a = a runoff coefficient adjustment factor dependent on the storm recurrence interval;
I = the rainfall intensity (inches per hour);
A = the drainage area (acres).

See Section 5.2.3 to determine appropriate C and C_a values for Equation 5-1.

5.2.2 Establishing the Drainage Area

Drainage areas for Rational Method analyses should be established using topographic data for **all of the potentially affected area surrounding the property to be developed, and on the drainage ditches, channels and other drainage structures that may impact, or be impacted by, the proposed development**. At each computation point, the drainage area is defined as the total area contributing runoff at that location.

5.2.3 Determining Runoff Coefficients (C and C_a)

Table 5-2 provides a summary of runoff coefficients for various land uses, overland slopes, and soil types. The appropriate runoff coefficient may be selected by establishing the land use and consulting this table. For example, an area developed as an apartment complex on land which slopes at less than 1-percent would have a runoff coefficient of 0.75. Land use data may be obtained from zoning maps, aerial photographs, and site visits.

For drainage areas with multiple land uses, runoff coefficients and drainage areas associated with each land use shall be determined. The composite runoff coefficient shall be determined by calculating the weighted average using Equation 5-2:

$$C_w = \sum \frac{(C_i * A_i)}{A_T}$$

Equation 5-2

where: C_w = weighted runoff coefficient;
C_i = runoff coefficients for various land uses;
A_i = drainage areas corresponding to values of C_i (acres);
A_T = total drainage area (acres).

As indicated previously, a runoff coefficient adjustment factor (C_a) shall be used to adjust peak runoff rates for various recurrence intervals. Table 5-1 lists the runoff coefficient adjustment factors for storm recurrence intervals ranging from 2 to 100 years.

TABLE 5-1: RATIONAL METHOD RUNOFF COEFFICIENT ADJUSTMENT FACTORS	
Storm Recurrence Interval (years)	**Adjustment Factor (C_a)**
2 – 10	1.00
25	1.10
50	1.20
100	1.25

TABLE 5-2: RATIONAL METHOD COEFFICIENTS (C_i) FOR 2- TO 10-YEAR STORMS			
Description of Area	**Basin Slope**		
	< 1%	**1% - 3.5%**	**> 3.5%**
Single-Family Residential Districts/Subdivisions			
Lots greater than 1/2 acre	0.30	0.35	0.40
Lots 1/4 to 1/2 acre	0.40	0.45	0.50
Lots less than 1/4 acre	0.50	0.55	0.60
Multi-Family Residential Districts/Subdivisions	0.60	0.65	0.70
Apartment Dwelling Areas	0.75	0.80	0.85
Business Districts			
Downtown	0.85	0.87	0.90
Neighborhood	0.75	0.80	0.85
Industrial Districts			
Light	0.50	0.65	0.80
Heavy	0.60	0.75	0.90
Railroad Yard Areas	0.20	0.30	0.40
Cemeteries	0.10	0.18	0.25
Playgrounds	0.20	0.28	0.35
Streets			
Asphalt	0.80	0.80	0.80
Concrete	0.85	0.85	0.85
Concrete Drives and Walks	0.85	0.85	0.85
Roofs	0.85	0.85	0.85
Lawn Areas			
Sandy Soil	0.05	0.08	0.12
Clay Soil	0.15	0.18	0.22
Woodlands			
Sandy Soil	0.15	0.18	0.25
Clay Soil	0.18	0.20	0.30
Pasture			
Sandy Soil	0.25	0.35	0.40
Clay Soil	0.30	0.40	0.50
Cultivated			
Sandy Soil	0.30	0.55	0.70
Clay Soil	0.35	0.60	0.80

5.2.4 Establishing the Time of Concentration (T_c)

The time of concentration (T_C) is defined as the time (in minutes) required for all portions of the watershed to contribute runoff at the computation point. The T_C is normally calculated by identifying the longest flow path within the watershed and estimating the time required for runoff to travel the entire length of this path. Stormwater runoff may pass through a range of flow conditions as it moves along the longest flow path. Overland sheet flow is characterized by very shallow depths of less than 2 inches. Within a short distance of about 100 to 300 feet, stormwater runoff begins to flow at greater depths to collect in streets, swales, and small ditches or gullies, and is commonly known as concentrated overland flow. Finally, the runoff collects in storm sewers, creeks, and drainage channels in which flow depths may reach several feet.

In order to estimate T_C, the longest flow path is divided into reaches that represent the various types of flow conditions and the flow velocity for each individual reach is estimated. For example, the longest flow path may include overland sheet flow, concentrated flow in a roadside ditch, and flow in a drainage channel. Flow velocities for overland sheet flow may be estimated using the Equation 5.3 and Table 5.3, which relates flow velocity to overland slope and land use. This method was developed by the Natural Resource Conservation Service (NRCS) and may be found in TxDOT's online hydraulics manual at (http://onlinemanuals.txdot.gov/txdotmanuals/hyd/time_of_concentration.htm#i1108603) for further explanation.

$$t_{sh} = \frac{0.007(n_{ol} * L_{sh})^{0.8}}{{P_2}^{0.5} * {S_{sh}}^{0.4}}$$

Equation 5-3

where:
- t_{sh} = sheet flow travel time (hr)
- n_{ol} = overland flow roughness coefficient (see Table 5-3)
- L_{sh} = sheet flow length (ft) (100ft max.)
- P_2 = 2-year, 24-hr rainfall depth (in) (see Table 5-5)
- S_{sh} = sheet flow slope (ft/ft)

TABLE 5-3: OVERLAND FLOW ROUGHNESS COEFFICIENTS FOR USE IN NRCS METHOD FOR CALCULATING SHEET FLOW TRAVEL TIME (NRCS 1986)		
Surface Description		n_{ol}
Smooth surfaces (Concrete, asphalt, gravel, bare soil)		0.011
Fallow (no residue)		0.05
Cultivated Soils	Residue Cover $\leq$ 20%	0.06
	Residue Cover > 20%	0.17
Grasses	Short Grass Prairie	0.15
	Dense Grasses	0.24
	Bermuda	0.41
Range (natural)		.013
Wooded	Light underbrush	0.40
	Dense underbrush	0.80

Shallow concentrated flow times may be computed using Equation 5.4, which is also available in the TxDOT's online hydraulics manual for further explanation.

$$t_{SC} = \frac{L_{SC}}{3600 K {S_{SC}}^{0.5}}$$

Equation 5-4

where:
- t_{sc} = shallow concentrated flow time (hr)
- L_{SC} = shallow concentrated flow length (ft)
- K = 16.13 for unpaved surfaces, 20.32 for paved surfaces
- S_{SC} = shallow concentrated flow slope (ft/ft)

For storm sewers, creeks, and channels, flow velocities may be estimated using Manning's equation or a HEC-RAS model (see Chapter 6). The length of each individual reach is divided by the flow velocity to obtain the time of travel required for water to pass through the reach, and TC is calculated as the sum of the individual travel times.

5.2.5 Computation of Rainfall Intensity (I)

The rainfall intensity (*I*) for a particular frequency used in the Rational Method may be determined from Equation 5-5, which was developed by the Texas Department of Transportation (TxDOT) from the U.S. Weather Bureau publications *Technical Paper No. 40* and *Hydrometeorological Report No. 35*. The values are currently being updated by TxDOT based on NOAA Atlas 14, volume 11.

$$I = \frac{b}{(T_c + d)^e}$$

Equation 5-5

where: I = rainfall intensity (inches per hour);
T_C = time of concentration (minutes);
b, d, e = rainfall intensity parameters from Table 5-4.

If the calculated T_C is less than 10 minutes, use a T_C of 10 minutes in Equation 5- 5.

TABLE 5-4: RAINFALL INTENSITY PARAMETERS FOR ORANGE COUNTY, TEXAS			
CONSTANTS FOR ORANGE COUNTY			
Storm Frequency	***e***	***b***	***d***
2-Year	0.7514	51.15	10.46
5-Year	0.7469	61.15	11.60
10-Year	0.7371	74.07	11.93
25-Year	0.7357	88.24	13.32
50-Year	0.7285	99.55	14.15
100-Year	0.7301	116.91	15.80

Note: The rainfall data presented above is the latest available as of the date of the Manual issuance. The District may adopt revised data not reflected in this table. It is the engineer's responsibility to ensure that current accepted rainfall intensity information is being utilized for the analysis.

5.2.6 Analyzing a Watershed with Multiple Sub-Areas or Computation Points

When analyzing a watershed with multiple sub-areas or computation points, the peak flow rate at the computation point located furthest upstream is computed first. Peak flow rates are computed at subsequent points, while moving in the downstream direction. At each point, the total drainage area is determined, and T_C is computed for the longest flow path from the most remote point in the entire watershed to the current computation point. The rainfall intensity for the peak flow rate computation is calculated using this T_C. As discussed in Section 5.2.3, a weighted runoff coefficient shall be computed using the coefficients for individual sub-areas upstream of the computation point.

5.3 DRAINAGE AREAS LARGER THAN 200 ACRES

This section describes the methods to be used in hydrologic analyses of drainage areas greater than 200 acres. These analyses shall be completed using the HEC-HMS computer program developed at the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (USACE). This software program can be downloaded from the USACE's website (https://www.hec.usace.army.mil/software/hec-hms/documentation.aspx) at no charge. The *Hydrologic Modeling System HEC-HMS User's Manual,* the *Hydrologic Modeling System HEC- HMS Applications Guide,* and the *Hydrologic Modeling System HEC-HMS Technical Reference Manual* developed by the USACE can be used for further reference. These manuals can also be downloaded from the USACE's website at no charge. The hydrologic parameters discussed in this Section are the basis for developing HEC-HMS models.

5.3.1 Watershed Boundaries

Topographic information, storm sewer layouts, and other available information shall be used to provide the level of detail necessary to delineate additional sub-area boundaries as needed. These boundaries may be delineated by hand or with HEC-GeoHMS, which is a *Geographic Information Systems (GIS)* program that works in conjunction with ArcView to compute hydrologic parameters. However, HEC-GeoHMS sub-area boundaries should be closely reviewed by an engineer familiar with the topography of the drainage area. The number of sub-areas required for the HEC-HMS analysis is a function of the number of computation points, which are typically established at confluences with tributaries, roadway crossings, or other points of interest (lakes and reservoirs, etc). Normally, there is 1 sub-area above the first analysis point and 1 or more between each pair of successive analysis points. In addition, there is at least 1 sub-area foreach tributary.

5.3.2 Rainfall Data

The rainfall depth-duration-frequency data for central Orange County, as listed in Table 5-5 was acquired from NOAA Atlas 14, volume 11, Version 2, Orange, TX, and shall be used in HEC-HMS hydrologic analyses. At this time, USGS Water-Resources Investigations Report 98-4044 (https://pubs.usgs.gov/wri/wri98-4044/pdf/98-4044.pdf) may be consulted to determine Intensity-Duration-Frequency (IDF) curves developed from previous NOAA datasets by TxDOT. The rainfall depth data and exceedance probability associated with the design storm event shall be entered in the meteorological model of HEC-HMS. A 1% exceedance probability would be entered for a 100-year storm event, 4% would be entered for a 25-year event, and 20% would be entered for a 5-year event.

For HEC-HMS Rainfall Data entry as shown in Figure 5-1, a maximum intensity-duration of 5 minutes shall be used for the analysis regardless of the design storm event. A value of

67% is used as the peak center and the HEC-HMS program automatically distributes the rainfall over a 24-hour period in such a manner that the maximum rainfall intensity occurs at approximately two-thirds of storm event. Rainfall leading up to and following the period of maximum intensity is distributed in a manner which produces a balanced rainfall distribution. Since the use of the total area option in HEC-HMS is problematic for many types of hydrologic analysis, point rainfall data is used for Orange County and a total storm area of 0.01 square miles, or other approved area, is used to compute runoff hydrographs. A base flow of zero shall be used unless project-specific considerations warrant the use of this parameter.

TABLE 5-5: RAINFALL DATA FOR ORANGE COUNTY

NOAA Atlas 14, volume 11, Version 2, Orange, TX

Recurrence Interval (years)	Rainfall Depth (inches) for Given Duration								
	5 MIN	15 MIN	30 MIN	1 HR	2 HR	3 HR	6 HR	12 HR	24 HR
2	0.61	1.23	1.76	2.35	2.97	3.35	4.04	4.80	5.62
5	0.75	1.51	2.16	2.90	3.77	4.33	5.32	6.36	7.48
10	0.87	1.74	2.47	3.35	4.45	5.19	6.50	7.85	9.29
25	1.02	2.05	2.90	3.95	5.41	6.43	8.26	10.1	12.1
50	1.15	2.26	3.19	4.37	6.15	7.43	9.73	12.0	14.5
100	1.25	2.49	3.50	4.82	6.95	8.54	11.4	14.3	17.3
500	1.56	3.11	4.41	6.19	9.30	11.7	16.1	20.8	25.8

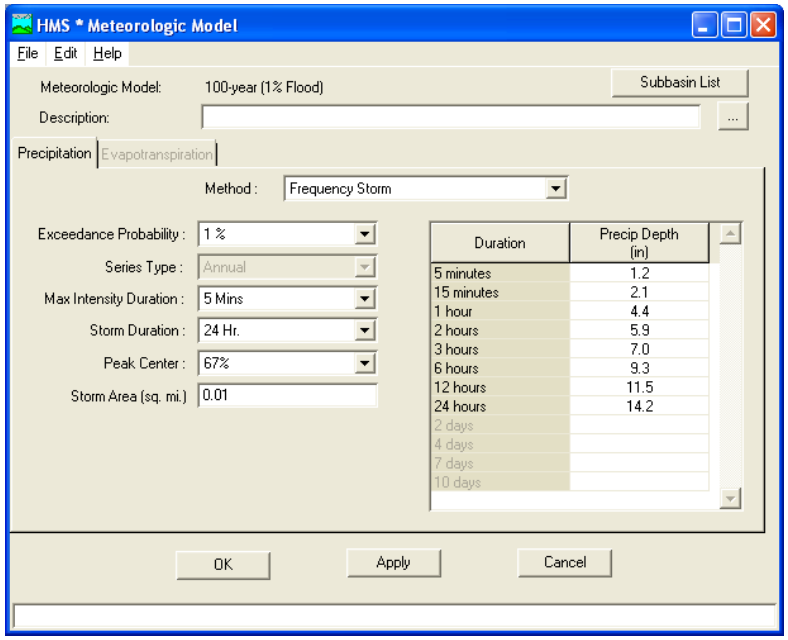

Figure 5-1: HEC-HMS Rainfall Data Window

5.3.3 Infiltration Losses

Infiltration losses shall be accounted for using the Green & Ampt method, which is a conceptual representation of the infiltration process, and was developed in 1911 by Green & Ampt. This method estimates infiltration losses based on a function of soil texture and the capacity of the given soil type to convey water. The advantage of this method is that the parameters can be estimated based on soil type. The parameters should be applied on a watershed-wide basis, similar to the exponential and initial/uniform loss methods from the original Flood Hazard Study.

Table 5-6 shows the volume moisture deficit, wetting front suction, and hydraulic conductivity parameters for various soil textures and types. The hydrologic soil group to which a particular soil belongs may be determined by consulting the Soil Survey or the Soil Survey Geographic Database (SSURGO) for Jefferson and Orange Counties, Texas.

TABLE 5-6: GREEN & AMPT LOSS PARAMETERS			
Soil Classification	**Volume Moisture Deficit**	**Wetting Front Suction (inches)**	**Hydraulic Conductivity (inches/hour)**
Soil Texture			
Sand	0.417	1.95	9.276
Loamy Sand	0.402	2.41	2.354
Sandy Loam	0.412	4.33	0.858
Loam	0.436	3.50	0.520
Silt Loan	0.486	6.57	0.268
Sandy Clay Loam	0.330	8.60	0.118
Clay Loam	0.389	8.22	0.079
Silty Clay Loam	0.431	10.75	0.079
Sandy Clay	0.321	9.41	0.047
Silty Clay	0.423	11.50	0.039
Clay	0.385	12.45	0.024
Soil Group			
A (freely draining)	0.417	1.95	9.276
B (intermediate)	0.436	3.50	0.520
C (intermediate)	0.389	8.22	0.079
D (poorly draining)	0.385	12.45	0.024

5.3.4 Initial Abstraction

Initial abstraction losses shall be accounted for using the Soil Conservation Service (SCS) Curve Number method, which is an empirical method developed by the U.S. Department of Agriculture. Equation 5-6 can be used to compute the initial abstraction for specific soil types.

$$I_a = 0.2S$$ **Equation 5-6**

where: I_a = the initial abstraction depth (inches);
S = initial retention = $(1000/CN) - 10$
CN = SCS Curve Number, from Table 5-7.

The Curve Number is a function of soil structure, antecedent watershed moisture, and land use. Soil structure is defined by assigning individual soils to 1 of 4 hydrologic soil groups (A through D) that represent a wide range of soil porosities. Soils belonging to hydrologic soil group A are the most porous, while soils in group D are the least porous. The hydrologic soil group may be determined from the Soil Survey for Jefferson and Orange County, Texas or the Soil Survey Geographic Database (SSURGO) for Jefferson and Orange Counties, Texas. Table 5-7 provides a summary of SCS Curve Numbers for various land uses, taken from the *SCS National Engineering Handbook, Section 4*.

For watersheds with varying land uses and soil types, composite Curve Numbers may be computed by determining the Curve Number and drainage area associated with each land use and/or soil category. The composite Curve Number may then be computed using the following equation:

$$CN_W = \sum \frac{(CN_i \times A_i)}{A_T}$$

Equation 5-7

where:
CN_w = weighted Curve Number;
CN_i = Curve Number for various land uses and soil types;
A_i = drainage areas corresponding to values of CN_i (acres);
A_T = total drainage area (acres).

In HEC-HMS applications, cumulative totals for rainfall and infiltration are maintained. The total runoff is re-computed for every time step.

TABLE 5-7: SCS CURVE NUMBERS				
Land Use Description	**Hydrologic Soil Group**			
	A	**B**	**C**	**D**
Cultivated Land				
Without Conservation Treatment	72	81	88	91
With Conservation Treatment	62	71	78	81
Pasture or Range Land				
Poor Condition	68	79	86	89
Good Condition	39	61	74	80
Meadow: Good Condition	30	58	71	78
Wood or Forest Land				
Thin Stand, Poor Cover, No Mulch	45	66	77	83
Good Cover	25	55	70	77
Open Spaces, Lawns, Parks, Cemeteries				
Good Condition, 75% Grass Cover	39	61	74	80
Poor Condition, 50-75% Grass Cover	49	69	79	84
Commercial & Industrial Areas				
Commercial and Business Areas (85% Impervious)	89	92	94	95
Industrial Districts (72% Impervious)	81	88	91	93
Residential				
Average Lot Size *Average % Impervious*				
1/8 acre or less *65*	77	85	90	92
1/4 acre *38*	61	75	83	87
1/3 acre *30*	57	72	81	86
1/2 acre *25*	54	70	80	85
1 acre *20*	51	68	79	84
Paved Parking Lots, Roofs, Driveways, Etc.	98	98	98	98
Streets and Roads				
Paved with Curbs and Storm Sewers	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89

Source: *SCS National Engineering Handbook, Section 4*

5.3.5 Percent Impervious Cover

Percent impervious cover is a function of land urbanization and can be estimated from field observations, aerial photographs, and other supporting information on the drainage area. Table 5- 8 provides a summary of percent impervious cover values for different land use categories:

TABLE 5-8: PERCENT IMPERVIOUS COVER VALUES FOR ORANGE COUNTY, TEXAS

Land Use Categories	Land Use Descriptions	% Impervious
Undeveloped	Unimproved, natural, or agricultural	0
Residential – Rural Lot	≥ 5-acre ranch or farm	5
Residential	Average Lot Size	
	1 acre	20
	½ acre	25
	⅓ acre	30
	¼ acre	38
	⅛ acre or less	65
Developed Green Areas	Parks or golf courses	15
Light Industrial/ Commercial	Office parks, nurseries, airports, warehouses, or manufacturing with non-paved areas	60
High Density	Commercial, business, industrial, or apartments	85
Transportation	Highway or major thoroughfare corridors	90
Water	Detention basins, lakes, channels, roadside ditches	100

5.3.6 Loss Rate Computations in HEC-HMS

The Green & Ampt loss rate parameters and percent impervious cover values discussed in Sections
5.3.3 to Section 5.3.5 are entered into the loss rate option of the HEC-HMS Subbasin Model Editor window as shown in Figure 5-2.

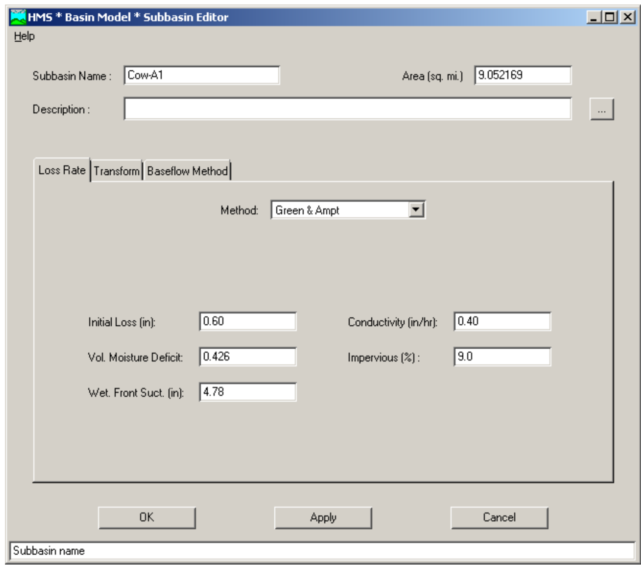

Figure 5-2: HEC-HMS Subbasin Model Editor Loss Rate Window

5.3.7 Unit Hydrograph Methodology

Unit hydrographs shall be computed based on the Clark Unit Hydrograph method, which is one of the unit hydrograph methods available in HEC-HMS. The Clark Unit Hydrograph method uses three parameters to define a unit hydrograph for a watershed: the T_C, a storage coefficient, and a time-area curve. The T_C is defined as the time required for all portions of the watershed to contribute runoff at the computation point. Refer to Section 5.2.4 for more information on estimation of T_C. The storage coefficient (R) is an indicator of the available stormwater storage volume within a watershed within depressions, ponds, channels and flood plains. The value of R varies directly with the relative amount of storage volume within a watershed (i.e., the greater the storage volume, the higher the storage coefficient). For Orange County, R should be estimated from Equation 5-6 or any other methodology approved by the District.

$$R = 3\times \mathrm{T_C} \qquad \textbf{Equation 5-6}$$

The time-area curve relates the percentage of the watershed contributing runoff at the analysis point to the fraction of the TC, which has elapsed since the beginning of runoff. The entire watershed is considered to be contributing runoff at the outlet when the elapsed time is equal to or greater than the TC. This standard curve is applicable as long as extremes in watershed shapes (i.e., very large or very small ratios of watershed length to width) are avoided. Calculation of the time- area curve is handled internally by HEC-HMS with a standard time-area curve based on assumed watershed shape.

Runoff hydrographs can be computed in HEC-HMS by selecting the Clark Unit Hydrograph method from the Transform option of HEC-HMS Subbasin Editor Window. In addition, the TC and R parameters should be entered for each subbasin. The meteorological model data works in conjunction with the subbasin editor data to calculate a hydrograph for each subbasin. Figure 5-3 illustrates the HEC-HMS transform window.

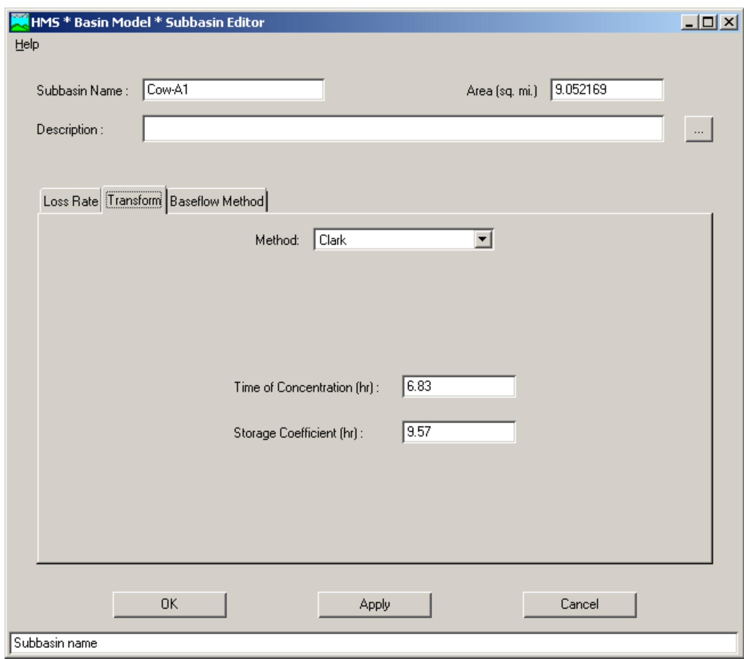

Figure 5-3: HEC-HMS Subbasin Model Editor Transformation Window

5.3.8 Streamflow Routing

Streamflow routing is the process by which the lagging and attenuating effects of travel time and storage on runoff hydrographs are taken into account as flood flows move from one analysis point to another. Although the HEC-HMS program offers a number of streamflow routing methods, the District requires the use of the Modified Puls method where channel cross-sections and a HEC-RAS hydraulic model of the channel are available. For streamflow routing along channels without a HEC-RAS model, the Muskingum-Cunge Standard, Muskingum-Cunge 8-Point, or Muskingum methods should be used depending on which method is best suited to the specific application. However, if backwater conditions and/or overland flooding are anticipated, it is recommended that a HEC-RAS model of the channel be developed and the Modified Puls method be used.

The Modified Puls Method explicitly accounts for the effects of storage volume within the flood plain and is based on a simple continuity equation:

$$\Delta S = I - O \qquad \textbf{Equation 5-7}$$

where: ΔS = change in storage volume within the routing reach;
I = inflow to the routing reach;
O = outflow from the routing reach.

For the Modified Puls method, input to the HEC-HMS program consists of a set of flow rates and corresponding storage volumes, which are input in the basin model routing reach window (see Figure 5-4). Additionally, the number of sub-reaches and initial flow condition are selected in the same window. The Muskingum method is an approximation of the continuity equation (Equation 5-7) where storage is modeled as the sum of prism and wedge storage. Required input parameters for this method include: the Muskingum K, Muskingum X (ranges from 0.0 to 0.5), and the number of sub-reaches. Refer to the HEC-HMS documentation mentioned in Section 5.3 for additional information on these routing methods.

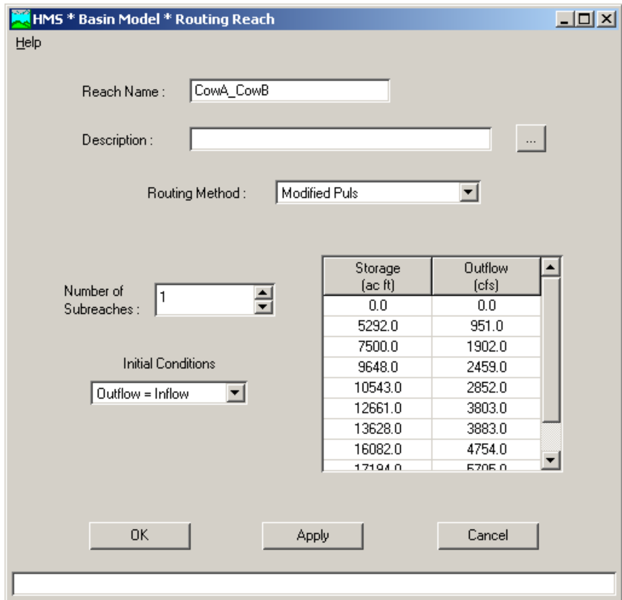

Figure 5-4*:* HEC-HMS Modified Puls Routing Reach Window

HEC-HMS modeling input for the Muskingum-Cunge Standard method consists of the following physical parameters: the length and slope of the routing reach, the Manning's roughness coefficient (n value), the shape of the channel (circular or prismatic), the bottom width or diameter, and the side slope ratio. This mathematical routing method provides an implicit accounting of storage within the channel. However, storage within the flood plain outside the defined channel is not considered. Although the same equations and solution techniques are used for the Muskingum- Cunge 8-Point method, the channel is described with eight station-elevation coordinates instead of a standard cross-section shape. Other required input items for this method are the reach length, energy slope, and n values for the channel and overbanks. For additional information on these routing methods, refer to the HEC-HMS documentation listed in Section 5.3.

5.3.9 Combining Hydrographs

When analyzing basins or subbasins that have been divided into two or more sub-areas, it is necessary to combine runoff hydrographs from the individual sub-areas. Combining the hydrographs yields a single hydrograph, which accounts for all the runoff from the individual sub- areas. This is accomplished by inserting a junction in the HEC-HMS Basin Model. Connect the two sub-areas to the junction to obtain a combined hydrograph as shown in Figure 5-5. In this figure, HEC-HMS will compute individual hydrographs for Subbasin-1 and Subbasin-2 and combine them at Junction-1.

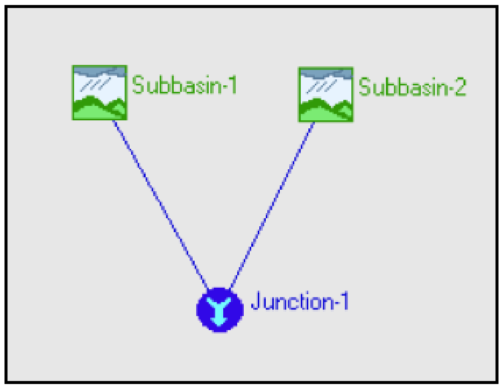

Figure 5-5*:* HEC-HMS Hydrograph Combining Schematic

SECTION 6 – HYDRAULIC ANALYSIS, CRITERIA, AND METHODOLOGY FOR PRIMARY DRAINAGE FACILITIES

6.1 GENERAL DESIGN CRITERIA FOR PRIMARY DRAINAGE FACILITIES

The following design requirements are discussed in this section: design storm frequencies; design requirements for earthen channels; design requirements for concrete-lined channels; design requirements for rectangular concrete low-flow sections; transitions, bends, and confluences; design requirements for culverts; structural requirements for culverts; design requirements for bridges; design requirements for enclosed systems; and maximum allowable velocities

6.1.1 Design Storm Frequencies

The following design storm frequencies shall be used for analysis and design of open channels, bridges, culverts, and enclosed systems:

- Channels draining up to 200 acres shall be designed to convey 100-year peak discharges with a minimum freeboard of 1 foot.

- Channels draining greater than 200 acres shall be designed to convey 100-year peak flow rates with a minimum freeboard of 1 foot. These channels shall also be analyzed using a 10-year design storm event to ensure the channel has adequate capacity to accept and convey a more frequent and more intense storm of shorter duration which could cause “flash flooding”.
- For open channel studies involving *Federal Emergency Management Agency* (*FEMA*) submittals, the 10-year, 50-year, 100-year, and 500-year storm frequencies must be analyzed

6.1.2 Design Requirements for Earthen Channels

Un-lined, earthen channels which are dedicated to the District shall be designed to meet the following minimum requirements:

- Responsibility of new channels within new subdivision developments shall remain with the homeowners association or other entity (City or County). The District will not accept new channels within subdivisions or private developments.
- Channel side slopes shall be no steeper than 3 horizontal to 1 vertical (3:1). Flatter slopes may be required when soil conditions are conducive to slope instability.
- The minimum channel bottom width shall be 6 feet.
- A maintenance berm is required along all drainage channels. For channels with top widths of 30 feet or less, a 25-foot wide maintenance berm is required along one side of the channel and a 5-foot wide maintenance easement shall be provided on the other side of the channel. For channels with top widths between 30 feet and 60 feet, a minimum 25-foot maintenance berm is required along each side of the channel. For channels with top widths greater than 60 feet, a minimum 30-foot maintenance berm is required along each side of the channel. Additional width shall be provided to accommodate backslope swales and minimal easement dedications if necessary.
- Backslope drain swales and interceptor structures are required to prevent flow down the ditch side slopes. The maximum spacing for interceptor structures is 300 feet.
- Channels, channel rights-of-way (ROWs) and side slopes must be vegetated immediately after construction to minimize erosion in accordance with the erosion control requirements discussed in Chapter 9.
- Flow from roadside ditches must be conveyed into open channels through standard roadside ditch interceptor structures as described in Chapter 9.
- A geotechnical investigation and report on local soil conditions is required for all channel construction and improvement projects. The geotechnical investigation must extend to a depth of not less than 5-feet below the proposed channel bottom. Exploratory borings shall be spaced not more than 500’ apart along the proposed channel route.

6.1.3 Minimum Design Requirements for Trapezoidal Concrete-Lined Channels

Concrete-lined channels shall be designed to meet the following minimum requirements:

- All concrete slope paving shall consist of Class A concrete.
- The minimum bottom width shall be eight feet.
- The side slopes of the channel shall be no steeper than 1.5 horizontal to 1 vertical (1.5:1).
- Equipment access ramps shall be provided between each road crossing and at intervals of not more than 1000'. Slope of travel way on access ramps shall be no steeper than 6 horizontal to 1 vertical.
- A maintenance berm is required along all drainage channels. For channels with top widths of 30 feet or less, a 25-foot wide maintenance berm is required along one side of the channel and a 5-foot wide maintenance easement shall be provided on the other side of the channel. For channels with top widths between 30 feet and 60 feet, a minimum 25-foot maintenance berm is required along each side of the channel. For channels with top widths greater than 60 feet, a minimum 30-foot maintenance berm is required along each side of the channel. Additional width shall be provided to accommodate backslope swales if necessary.
- All slope paving shall include a toe wall at the top and sides with a minimum depth of 18 inches. Toe walls shall also be included along the bottom of the channel with a minimum depth of 24 inches for clay soils and 36 inches for sandy soils.
- Backslope drain swales and interceptor structures are required in the channel maintenance berm to prevent overland flow down the bank of partially-lined channels. These items shall be designed in accordance with the minimum requirements specified in Chapter 9. Backslope drain swales and interceptor structures are not required on fully lined channels, with the concrete lining extending to the top of the ditch bank.
- Channel maintenance berms must be vegetated immediately after construction in accordance with erosion control requirements discussed in Chapter 9.
- Weep holes shall be used to relieve hydrostatic pressure behind lined channel sections. The specific type, size, and placement of the weep holes shall be based on the recommendations of the geotechnical report.
- Where construction is to take place under muddy conditions or where standing water is present, a seal slab of Class C concrete shall be placed in the channel bottom prior to placement of the concrete slope paving.
- Control joints shall be provided at a maximum spacing of approximately 25 feet. A sealing agent shall be utilized to prevent moisture infiltration at control joints.
- Concrete slope protection shall have the minimum thickness and reinforcement indicated in Table 6-1.

- A geotechnical investigation and report on local soil conditions is required for all channel construction and improvement projects.

TABLE 6-1: MINIMUM THICKNESS AND REINFORCEMENT FOR CONCRETE SLOPE PAVING			
Channel Side Slope (H:V)	**Minimum Thickness (inches)**	**Minimum Reinforcement**	
		Material	**Dimensions**
3:1	4 inches	welded wire fabric	6 x 6 x W2.9 x W2.9
2:1	5 inches	welded wire fabric	6 x 6 x W4.0 x W4.0
1.5:1	6 inches	reinforcement	4 x 4 x W4.0 x W4.0

6.1.4 Design Requirements for Culverts

Unless otherwise approved, all pipe and box culverts shall satisfy the following minimum design requirements

- Culverts shall be designed to convey the fully developed peak discharge rates associated with the design storm frequency requirements provided in Section 6.1.1 while maintaining a minimum freeboard of 1-foot in the channel upstream of the culvert. In addition, the maximum allowable velocities discussed in Section 6.1.6 must not be exceeded.
- Culverts shall be aligned parallel to the longitudinal axis of the channel to maximize hydraulic efficiency and minimize turbulence and erosion. At locations where a difference between the alignment of the channel and the culvert is necessary, the change in alignment shall be accomplished upstream of the culvert so that the culvert is aligned with the downstream channel.
- The minimum allowable diameter for circular culverts in primary drainage facilities is 24 inches internal diameter.
- The minimum allowable size of box culverts in primary drainage facilities is 2 feet clear height x 2 feet clear width.
- Concrete slope paving or riprap shall be used upstream and downstream of the culvert to protect earthen channels from erosion.
- Culverts shall extend completely across road and railroad ROWs at crossing locations.
- Where hydraulic jumps are anticipated around culverts, the channel geometry shall be modified to force the hydraulic jump to occur in a portion of the channel protected with concrete slope paving. Hydraulic jumps are characterized by a rapid change in

the depth of flow from a low stage to a high stage, which results in an abrupt rise in the WSEL.

- All pre-cast reinforced concrete pipe shall be ASTM C-76.
- All high-density polyethylene (HDPE) pipe culverts shall conform to the AASHTO M294 specifications. Bedding for HDPE culverts shall be designed and constructed in accordance with the manufacturer's recommendations.
- All pre-cast reinforced concrete box culverts with more than 2 feet of earthen cover shall be ASTM C789-79. All pre-cast reinforced box culverts with less than 2 feet of earthen cover shall be ASTM 850-79.
- All corrugated steel pipes shall be aluminized in accordance with AASHTO M-36.
- AASHTO HS20-44 loading shall be used for all culverts.
- Joint sealing materials for pre-cast concrete culverts shall comply with the "AASHTO Designation M-198 74 I, Type B, Flexible Plastic Gasket (Bitumen)" specification.
- Two-sack-per-ton cement-stabilized sand shall be used for backfill and bedding around culverts.
- A 6-inch bedding of two-sack-per-ton cement-stabilized sand is required for all pre-cast concrete box culverts.

6.1.5 Minimum Design Requirements for Enclosed Drainage Systems

Enclosed drainage systems are strongly discouraged for private/non-District-maintained drainage facilities and are generally prohibited for District-maintained primary drainageways. These systems include pipe and box culverts used to replace segments of open channel longer than the typical width of a road or railroad ROW. If permitted, the following are minimum requirements for Enclosed Drainage Systems:

- A pre-submittal meeting between all parties involved will be required for any development containing enclosed drainage systems for primary drainage.
- Enclosed drainage systems shall be designed to accommodate fully developed design peak runoff rates discussed in Section 6.1.1 while maintaining the hydraulic grade line elevations below adjacent natural ground elevations or street gutter elevations, whichever are lower for fully developed watershed conditions.
- The minimum inside pipe dimension shall be 2 feet.
- The minimum and maximum allowable velocities for design peak runoff rates shall be 2 feet per second and eight feet per second, respectively, assuming full pipe flow.
- Structural requirements for enclosed systems are identical to those specified for pipe and box culverts in Section 6.1.4.

- Manholes or junction boxes shall be located no more than 600 feet apart along the entire length of the system and at all locations where changes in culvert size and shape occur.
- Surface inlets and clean-outs on an enclosed drainage system shall be not less than 60 feet apart.
- Outfall structures shall conform to the requirements set forth for storm sewer outfalls in Chapter 8 of this Manual.
- The ROW width required for enclosed systems will be set equal to the larger of the maximum pipe or box width plus 2 times the depth to the culvert invert or 30 feet.

6.1.6 Maximum Flow Velocities

The maximum allowable velocity in open channels and at bridges or culverts shall be analyzed for the design storm event. As shown in Table 6-2, the maximum allowable velocity is related to the type of channel, the slope treatment, and the soil structure throughout the open channel section. If the maximum velocities listed in this table are exceeded during the design storm event, then the channel design shall be modified until acceptable velocities are attained. Alternatively, erosion protection (i.e., riprap, concrete slope paving, or interlocking blocks) could be provided to increase the maximum allowable velocity in that portion of the channel (see Chapter 9). The erosion protection must extend upstream and downstream a sufficient distance to a location where the design storm velocity in the channel is below the maximum allowable levels for earthen channels without slope protection.

TABLE 6-2: MAXIMUM ALLOWABLE VELOCITIES IN OPEN CHANNELS

Soil Description	Slope Treatment	Maximum Velocity (feet per second)
Fine Sand	None	1.50
Sandy Loam	None	1.75
Silt Loam	None	2.00
Clay Loam	None	2.50
Stiff Clay	None	3.75
Sandy Soils (Easily Eroded)	Grass	4.00
Clay Soils (Erosion-Resistant)	Grass	5.00
Sandy Soils (Easily Eroded)	Rip-Rap	6.00
Clay Soils (Erosion Resistant)	Rip-Rap	8.00
Sandy Soils (Easily Eroded)	Concrete	8.00
Clay Soils (Erosion Resistant)	Concrete	10.00
Bridges & Culverts		8.00

6.1.7 Maintenance Provisions

Provisions for adequate maintenance must be made in the design of all drainage facilities. Sufficient ROW must be set aside, slopes must be kept at or below maximum values, and slope treatments must be properly completed. Access to drainage facilities must not be impeded.

6.2 HYDRAULIC ANALYSIS OF PRIMARY DRAINAGE FACILITIES

This section describes the methods to be used in the hydraulic analysis of open channels as well as associated bridge and culvert structures.

6.2.1 Acceptable Open Channel Design Methodologies

The final open channel dimensions shall be determined by using the *HEC-RAS* computer program developed at the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (USACE). The latest version of this software program can be downloaded from the USACE's website (http://www.hec.usace.army.mil/software/hec-ras/hecras-download.html) at no charge. The HEC- RAS program has the capability to analyze unsteady flow conditions, transitions from subcritical to supercritical flow, and other complex hydraulic conditions.

The hydraulic data discussed in Sections 6.2.1 to 6.2.8 should be compiled to facilitate development of HEC-RAS models. Additional information on HEC-RAS can be obtained from the *HEC-RAS River Analysis System User's Manual*, the *HEC-RAS River Analysis System Application's Guide*, and the *HEC-RAS River Analysis System Hydraulic Reference Manual* developed by the USACE. All of these manuals can be downloaded free of cost from the USACE's website at http://www.hec.usace.army.mil/software/hec-ras/hecras-document.html.

6.2.2 Acceptable Bridge and Culvert Design Methodologies

Hydraulic analysis of bridges and culverts may be performed using the HEC-RAS computer program. However, the nomographs developed by the Federal Highway Administration (FHWA) published in *Hydraulic Design of Highway Culverts* may be used for initial estimates of culvert size or to verify that the results obtained from HEC-RAS are reasonable. These nomographs can also be used to size culverts associated with roadside ditches. In addition, any other software programs which meet industry standards can be used, if prior approval is obtained from the District.

6.2.3 Acceptable Enclosed Drainage System Design Methodologies

Hydraulic analysis of enclosed drainage systems that are part of an open channel system may be analyzed using HEC-RAS. In addition, any other software programs which meet industry standards can be used, if prior approval is obtained from the District. For stand-alone enclosed systems, the methodology described in Chapter 6 for storm sewer systems shall be used. For these calculations, full pipe flow may be assumed. Both friction losses and minor losses (i.e., losses due to transitions, bends, junctions, manholes, etc.) should be accounted for.

6.2.4 Flow Data

The Rational Method may be used to compute the peak flow rates for drainage areas up to 200 acres. However, a HEC-HMS hydrologic analysis can also be performed for drainage areas up to 200 acres. For drainage areas greater than 200 acres, the HEC-HMS methodology discussed in Chapter 4 shall be used to compute peak discharge rates for the design storm frequencies specified in Section 5.1.1. These peak flow rates shall be used to develop the flow data in HEC-RAS.

For an unsteady flow analysis, the inflow hydrographs computed in HEC-HMS are used instead of peak discharge rates. These hydrographs should be entered into the Unsteady Flow Data editor of HEC-RAS for unsteady flow detention analyses (see Chapter 7) or the applicable portion of other approved software programs.

6.2.5 Boundary Conditions

In order for HEC-RAS to perform computations, boundary conditions or starting WSELs must be defined. Boundary conditions are required at the downstream and upstream ends of the river system for subcritical and supercritical flow regimes, respectively. For mixed flow regimes, boundary conditions are required at both the upstream and downstream ends of the system. Subcritical flow typically occurs within Orange County. This flow regime has a low velocity and appears tranquil, whereas the supercritical flow regime is characterized by shooting and rapid flows.

For unsteady flow detention analyses (see Chapter 8), a variety of boundary conditions are available within the Unsteady Flow Data editor. Refer to the *HEC-RAS River Analysis System User's Manual* for additional information on the available unsteady flow boundary conditions. For open channel analyses, the downstream boundary conditions should be entered into the Steady Flow Data editor. If a HEC-RAS model of the receiving channel is not available, then normal depth should be used as the downstream boundary condition and the energy slope should be entered. The energy slope can be approximated as the slope of the bottom of the channel. If a HEC- RAS model of the receiving channel is available and the tailwater in this channel can be determined, then the known WSEL downstream boundary condition should be selected.

In order to determine the tailwater elevation in the receiving channel, the Frequencies of Coincidental Occurrence methodology described in the Texas Department of Transportation's (TxDOT's) *Hydraulic Design Manual* shall be used. This methodology is based on the assumption that the rainfall events within the drainage system being analyzed and the receiving channel are neither completely dependent nor completely independent. As shown in Table 6-3, this method provides a basis for selecting an appropriate frequency for the tailwater elevation of the receiving channel versus the frequency for the tributary channel, storm sewer system, or *detention basin*. For example, a 100-year analysis of a tributary channel with a drainage area of 200 acres that discharges to an open channel with an associated drainage area of 2,000 acres would have a ratio of receiving channel to tributary of 10:1. Therefore, the required tailwater elevation for the 100- year analysis of the tributary channel would be the 50-year WSEL in the receiving channel.

Area Ratio	**TABLE 6-3: Design Storm Event for the Hydraulic Analysis of Tributary Channels, Storm Sewer Systems, or Detention Basins**					
	2-year	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
10,000:1	2	2	2	2	2	2
1,000:1	2	2	2	5	5	10
100:1	2	2	5	10	10	25
10:1	2	5	10	10	25	50
1:1	2	5	10	25	50	100

6.2.6 Cross-Section Data

The cross-section data required by HEC-RAS includes: elevation-station data; Manning's roughness coefficients (*n* values), which are described in Section 6.2.7; channel and overbank reach lengths; top of bank (TOB) locations; and expansion and contraction coefficients. If ineffective flow areas (IFAs), levees, or blocked obstructions exist, then geometric information regarding these items would also be entered in the Cross-Section Data Editor.

The elevation-station data shall be obtained from recent field survey data and the cross-sections shall be extended far enough into the left and right overbanks so that all of the flow is contained within the defined cross-section, if possible. Although LIDAR data may be used to supplement field survey data and define the overbank areas of the cross-sections, field survey data is required to accurately define the channel because LIDAR does not penetrate water. Cross-sections shall be taken approximately every 500 feet along the channel, unless project-specific considerations warrant otherwise. In the vicinity of bridges and culverts, cross-section spacing shall adhere to recommendations in the HEC-RAS program documentation referenced in Section 6.2.1. If necessary, additional cross-sections can be interpolated by HEC-RAS or field surveyed cross- sections can be copied to achieve the required cross-section spacing around bridges and culverts.

Channel reach lengths between cross-sections shall be measured along the centerline of the channel. As indicated in the *HEC-RAS River Analysis System Hydraulic Reference Manual*, left and right overbank lengths should be determined as the length along the anticipated path of the center of mass of overbank flow. In many instances, all three reach length values will be similar. However, they may differ significantly at channel bends and locations where the channel meanders while the overbanks remain straight.

For Orange County, the typical expansion and contraction coefficients for open channels are 0.1 and 0.3, respectively. However, higher coefficients of 0.3 and 0.5 should be used at cross-sections two, three, and four around bridges and culverts to simulate expansion and contraction conditions around these structures. Refer to the *HEC-RAS River Analysis System User's Manual* for information on the location of cross-sections two through four around bridges and culverts. IFAs should also be included around bridges and culverts using the recommendations outlined in the *HEC-RAS River Analysis System Hydraulic Reference Manual*.

HEC-GeoRAS can be used to automate the development of HEC-RAS models by importing channel geometric data directly into HEC-RAS. The channel centerline location, cross-section data, reach lengths, assumed TOB locations, *n* values, and expansion/contraction coefficients can be defined within HEC-GeoRAS and imported directly into HEC-RAS. However, this program requires input from an engineer or hydrologist experienced with hydraulic modeling. In addition, TOB locations and overbank reach lengths may need to be modified within HEC-RAS. IFAs, levees, and blocked obstructions would also need to be entered directly into HEC-RAS.

6.2.7 Manning's Roughness Coefficient

The HEC-RAS software program utilizes Manning's Equation, which is discussed in Chapter 4, to compute conveyance and flows in open channels. The *n* value used in this equation varies inversely with conveyance and is a measure of the roughness of the surfaces with which stormwater comes into contact. For example, a forested area would have a higher *n* value and a lower conveyance than a pasture or open field. Recent aerial photographs as well as field reconnaissance can be used in conjunction with Table 6-4 to determine *n* values for channels and flood plains, or overbank areas.

Although Table 6-4 is generally adequate for selecting *n* values corresponding to existing field conditions, project-specific considerations may warrant the use of Equation 6-1 for a more detailed determination of *n* values associated with the channel and flood plains (overbanks). For most applications, it is acceptable to round *n* values to the nearest 0.005 (i.e., an *n* value of 0.033 would be entered into HEC-RAS as 0.035).

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m$$ **Equation 6-1**

where: n = composite Manning's roughness coefficient;
n_0 = base value for the bare soil surface material of the channel or flood plain;
n_1 = value to correct for the irregularity of the channel or flood plain;
n_2 = value to account for variations in the shape and size of the channel or flood plain cross-section;
n_3 = value to account for obstructions in the channel or flood plain;
n_4 = value to account for the effects of vegetation;
m = correction factor for the sinuosity of the channel or flood plain.

Table 6-5 provides a summary of parameters used in Equation 6-1 to compute more specific *n* values for channels.

TABLE 6-4: MANNING'S ROUGHNESS COEFFICIENTS FOR CHANNELS & OVERLAND FLOWS			
Type of Channel and Description	**Minimum**	**Normal**	**Maximum**
Excavated or Dredged Channels			
Concrete Lined Channels	0.011	0.013	0.015
Earthen Channels, Straight and Uniform			
Clean, After Weathering	0.016	0.018	0.020
With Short Grass, Few Weeds	0.022	0.027	0.033
Earthen Channels, Winding and Sluggish			
No Vegetation	0.023	0.025	0.030
Grass, Some Weeds	0.025	0.030	0.033
Dense Weeds or Plants in Deep Channels	0.030	0.035	0.040
Earth Bottom and Rubble Sides	0.028	0.030	0.035
Stony Bottom and Weedy Banks	0.025	0.035	0.040
Cobble Bottom and Clean Sides	0.030	0.040	0.050
Channel Not Maintained, Weeds & Brush Uncut			
Dense Weeds, High as Flow Depth	0.050	0.080	0.120
Clean Bottom, Brush on Sides	0.040	0.050	0.080
Same, Highest Stage of Flow	0.045	0.070	0.110
Dense Brush, High Stage	0.080	0.100	0.140
Natural Streams			
Clean, Straight, Full Stage, No Rifts or Deep Pools	0.025	0.030	0.033
Same as Above, But Some Stones and Weeds	0.030	0.035	0.040
Clean, Winding, Some Pools and Shoals	0.033	0.040	0.045
Same as Above, But Some Weeds and Stones	0.035	0.045	0.050
Same as Above, Lower Stages, More Ineffective Areas	0.040	0.048	0.055
Sluggish Reaches, Weedy, Deep Pools	0.050	0.070	0.080
Flood Plains			
Pasture, No Brush			
Short Grass	0.025	0.030	0.035
High Grass	0.030	0.035	0.050
Cultivated Areas			
No Crop	0.020	0.030	0.040
Mature Row Crops	0.025	0.035	0.045
Mature Field Crops	0.030	0.040	0.050
Brush			
Scattered Brush, Heavy Weeds	0.035	0.050	0.070
Light Brush and Trees, in Winter	0.035	0.050	0.060
Light Brush and Trees, in Summer	0.040	0.060	0.080
Medium to Dense Brush, in Winter	0.045	0.070	0.110
Medium to Dense Brush, in Summer	0.070	0.100	0.160
Trees			
Dense Willows, Summer, Straight	0.110	0.150	0.200
Cleared Land with Stumps, No Sprouts	0.030	0.040	0.050
Same as Above with Heavy Growth of Sprouts	0.050	0.060	0.080
Heavy Stand of Timber, a Few Down Trees, Little Undergrowth, Flood Stage Below Branches	0.080	0.100	0.120
Same as Above, but with Flood Stage Reaching Branches	0.100	0.120	0.160

TABLE 6-5: PARAMETERS USED IN COMPUTING CHANNEL ROUGHNESS COEFFICIENTS		
Parameter	**Accounts For**	**Representative Roughness Values**
n_0	Channel Material	0.011 for Concrete 0.020 for Earth 0.025 for Rock Cut 0.024 for Fine Gravel 0.028 for Coarse Gravel
n_1	Degree of Irregularity	0.000 for Smooth 0.005 for Minor Irregularities 0.010 for Moderate Irregularities 0.020 for Severe Irregularities
n_2	Variation of Channel Cross-Section	0.000 for Gradual Variations 0.005 for Alternating Occasionally 0.010 to 0.015 for Alternating Frequently
n_3	Relative Effect of Obstructions	0.000 for Negligible Obstructions 0.010 to 0.015 for Minor Obstructions 0.020 to 0.030 for Appreciable Obstructions 0.040 to 0.060 for Severe Obstructions
n_4	Vegetation	0.005 to 0.010 for Low Vegetation 0.010 to 0.025 for Medium Vegetation 0.025 to 0.050 for High Vegetation 0.050 to 0.100 for Very High Vegetation 0.100 to 0.150 for Extreme Vegetation
m	Degree of Meandering	1.000 for Minor Meandering 1.150 for Appreciable Meandering 1.300 for Severe Meandering

6.2.8 Bridge and Culvert Data

HEC-RAS requires the following data for bridge and culvert computations: deck/roadway data, geometric data for culverts, sloping abutments and pier data for bridges, and the bridge or culvert modeling approach. Detailed information on all of the HEC-RAS data entry requirements is included in the HEC-RAS program documentation listed in Section 6.2.1. The following data is required to define the deck/roadway within the Deck/Roadway Data Editor: the distance between the upstream side of the bridge/culvert and the cross-section immediately upstream of the structure; the width of the bridge deck/culvert; upstream and downstream bridge deck/culvert station- elevation data; a weir coefficient, which ranges from 2.6 for flow over a bridge deck to 3.0 for flow over elevated roadway approach embankments; upstream and downstream embankment side slopes; the maximum allowable submergence before the program switches to energy based calculations rather than pressure and weir flow; the minimum weir flow elevation; and the weir crest shape.

The following culvert geometric data is entered into the Culvert Data Editor of HEC-RAS: solution criteria, culvert shape and size, culvert chart and scale numbers, distance to upstream cross-section, culvert length, entrance and exit loss coefficients, Manning's *n* values, upstream and downstream invert elevations, number of identical barrels, and centerline stations for each barrel. The highest upstream energy grade option should be selected for the culvert solution criteria. The Manning's *n* value and entrance loss coefficients (K_e) for the culvert(s) should be determined from Tables 6-6 and 6-7, respectively, and entered into the Culvert Data Editor. Typical exit loss coefficients for culverts range from 0.3 to 1.0 but are normally set at 1.0. Additional information on exit loss coefficients can be found in the *HEC-RAS River Analysis System Hydraulic Reference Manual*. A summary of the chart and scale numbers used by HEC-RAS for the FHWA culvert performance nomographs described in Section 6.2.2 is provided in Table 6-8. These FHWA nomographs are used as the basis for inlet control headwater computations in HEC-RAS. Field survey data and construction drawings should be used to determine the remaining culvert geometric data required by HEC-RAS.

TABLE 6-6: MANNING'S ROUGHNESS COEFFICIENTS FOR CULVERTS

Description of Pipe	**Roughness Coefficient (*n*)**
Reinforced Concrete Pipe and Box Culverts	0.013
HDPE Plastic Pipe	0.012
Corrugated Steel Pipe With 2-2/3" x 1/2" Corrugations	0.024
Corrugated Steel Pipe With 3" x 1" Corrugations	0.027
Corrugated Steel Pipe With 6" x 2" Corrugations	0.030

TABLE 6-7: ENTRANCE LOSS COEFFICIENTS FOR CULVERTS	
Type of Structure and Configuration of Entrance	**Coefficient (K_e)**
Concrete Pipe Culverts	
Projecting from Fill	
Socket End (Groove End) of Pipe	0.2
Square-Cut End of Pipe	0.5
Headwall or Headwall & Wingwalls	
Socket End of Pipe (Groove End)	0.2
Square Edge	0.5
Mitered to Conform to Fill Slope	0.7
End Section Conforming to Fill Slope	0.5
Corrugated Steel Culverts	
Projecting From Fill	0.9
Headwall or Headwall & Wingwalls	0.5
Mitered to Conform to Fill Slope	0.2
End Section Conforming to Fill Slope	0.5
Concrete Box Culverts	
Headwall Parallel to Embankment (No Wingwalls)	0.5
Wingwalls at 30 Degrees to 75 Degrees to Barrel	0.4
Wingwalls at 10 Degrees to 25 Degrees to Barrel	0.5
Wingwalls Parallel (Extensions of Sides)	0.7

TABLE 6-8: FHWA CHART AND SCALE NUMBERS FOR CULVERTS		
Chart No.	**Scale No.**	**Description of Culvert and Entrance Configuration**
Box Culverts with Flared Wingwalls		
8	1	Wingwalls Flared 30 to 75 Degrees
	2	Wingwalls Flared 90 or 15 Degrees
	3	Wingwalls Flared 0 Degrees (Sides Extended Straight)
Concrete Pipe Culverts		
1	1	Square Edge Entrance with Headwall
	2	Groove End Entrance with Headwall
	3	Groove End Entrance, Pipe Projecting from Fill
Corrugated Steel Culverts		
2	1	Headwall
	2	Mitered to Conform to Fill Slope
	3	Pipe Projecting from Fill

Sloping abutment and pier data for bridges can be entered into the Sloping Abutment Data Editor and Pier Data Editor, respectively. The sloping abutment data requirements consist of station- elevation data, while the pier data requirements consist of elevation-width data as well as upstream and downstream centerline stations. The floating debris around a pier or piers can also be entered into the Pier Data Editor. In addition, the Bridge Design Editor within HEC-RAS can be used to facilitate the design of new bridges.

The Bridge Modeling Approach Editor requires the selection of low flow and high flow (pressure and/or weir) computation methods. Low flow occurs when water passes under a bridge or through a culvert without submerging the low chord of the bridge structure or the top of the culvert. Pressure flow occurs whenever the low chord of the bridge or the entire culvert is submerged, and weir flow occurs when water overtops the roadway. Available low flow methods include: Energy (Standard Step), Momentum, Yarnell, and WSPRO. The Energy method should be selected for culvert analyses. Although a single low flow method may be selected for bridges, it is recommended that the Energy method as well as one or more other applicable methods be selected and that the highest energy answer be used. If the Momentum or Yarnell methods are selected for bridges, the user must enter a value for the pier loss coefficient that corresponds to that method. A list of representative coefficients can be obtained within the Bridge Modeling Approach Editor. If the WSPRO method is selected, the user must press the WSPRO Variables button and enter additional information that is required for that method. The available high flow methods are Energy (Standard Step) and Pressure and/or Weir. It is recommended that both of these methods be selected and that the highest energy answer be used.

6.2.9 Floodway Analysis

A floodway analysis is required if modifications are made to HEC-RAS models of streams that were studied by the Federal Emergency Management Agency (FEMA). As previously described, the floodway is a corridor of effective flow that includes the channel and any adjacent land areas required to pass the 100-year peak discharge rates without increasing the WSEL at any point along the channel more than 1-foot above the 100-year base flood elevations (BFE). The floodway is a regulatory concept that is intended to prevent encroachments (i.e., fill, structures, or other obstructions) from being placed too close to the channel without extensive analysis and mitigation measures. Additional information on FEMA requirements for floodway analysis can be obtained from FEMA's website (http://www.fema.gov), the HEC-RAS program documentation.

SECTION 7 – HYDRAULIC ANALYSIS, CRITERIA, AND METHODOLOGY FOR SECONDARY DRAINAGE FACILITIES

7.1 GENERAL DESIGN CRITERIA FOR SECONDARY DRAINAGE FACILITIES

This section describes the general design requirements for storm sewers, which include all conduit systems and may consist of either storm sewer pipes or box culverts; however, culverts and bridges within open channels shall be designed and analyzed using the criteria contained in Section 6.

7.1.1 Design Storm Frequencies

The following design storm frequencies shall be used for analysis and design of storm sewers:

- Street gutters along residential streets should carry peak runoff rates from a 10-year storm event without overtopping curbs while maintaining the hydraulic grade line (HGL) at an elevation below the gutter line at inlets and below the rim elevation at manholes. Major thoroughfares should accommodate 10-year peak runoff rates with a minimum 10-foot dry travel lane and 25-year peak runoff rates without overtopping curbs.
- For systems draining less than 100 acres, storm sewers should be designed to convey 10-year peak runoff rates while maintaining the HGL at an elevation below the gutter line at inlets and below the rim elevation at manholes. Peak 25-year runoff rates shall be accommodated with a maximum of 6 inches of flow depth above the crown of the roadway.
- For systems draining more than 100 acres but less than 200 acres, storm sewers should be designed to convey 10-year peak runoff rates while maintaining the HGL at an elevation below the gutter line at inlets and below the rim elevation at manholes. Peak 50-year runoff rates shall be accommodated with a maximum of 6 inches of flow depth above the crown of the roadway.
- For systems draining more than 200 acres, storm sewers should be designed to convey 25-year peak runoff rates while maintaining the HGL at an elevation below the gutter line at inlets and below the rim elevation at manholes. Peak 100-year runoff rates shall be accommodated with a maximum of 6 inches of flow depth above the crown of the roadway.

7.1.2 General Design Requirements

- Storm sewer systems shall be designed to accommodate fully developed peak runoff rates associated with the design storm frequency requirements specified in Section

6.1.1 while maintaining the HGL at an elevation below the gutter line at inlets and below the rim elevation at manholes.

- The minimum and maximum allowable velocities for the design peak runoff rates are 2 feet per second and 8 feet per second, respectively, assuming full pipe flow.
- The minimum allowable culvert pipe size is 18 inches diameter, provided a continuous culvert length does not exceed 30 feet.
- The minimum allowable storm sewer pipe size is 24 inches any time the continuous sewer pipe length or culvert exceeds 30 feet.
- Manholes or junction boxes shall be placed where changes in pipe size, shape, and slope occur; at storm sewer junctions; and at intervals less than or equal to 300 feet in long storm sewer segments where the size or direction has not changed.
- All storm sewers located within the public right-of-way (ROW) and/or easements should be constructed of reinforced concrete pipe (RCP). Other pipe materials in compliance with the District's Manual may be used for storm sewer systems.
- Structural requirements for storm sewer systems shall adhere to those specified for culverts in Section 6.1.4.
- All outfall structures for secondary drainage facilities shall conform to the requirements described in Section 8.5.

7.1.3 Extreme Event Design

The capacity of the storm sewer system may be exceeded during rainfall events that are more intense than the design storm. For example, a storm sewer system designed to convey the 5-year peak runoff rates from a drainage area will not have adequate capacity to convey the 100-year peak runoff rates from that area. Ponding may occur in streets, roadside ditches, and adjacent low-lying areas when the capacity of the storm sewer system is exceeded. In order to eliminate or reduce potential flooding on adjacent properties, street layout and pavement grades shall be designed to direct stormwater runoff into channels or drainage systems without flowing through private property. The street grading plan shall be developed to prevent 100-year ponding levels in the streets from exceeding the lowest of the following:

- 1-foot above natural ground;
- 6-inches over the top of curb or crown of road, whichever is lower;
- the lowest finished floor elevation of adjacent habitable structures and critical facilities.

In areas where streets cannot be graded to carry sheet flows directly to an open channel, an extreme event overflow structure must be provided to collect sheet flow and convey it to a channel. This structure should consist of storm sewer and inlets designed to convey the

100- year peak runoff rate from the developed drainage area plus a grass or concrete-lined emergency overflow swale located within a drainage easement between two residential lots

7.2 HYDRAULIC ANALYSIS AND DESIGN OF STORM SEWERS

This section describes the requirements for the hydraulic analysis of storm sewer systems.

7.2.1 Acceptable Storm Sewer Design Methods

Hydraulic analysis of storm sewers may be performed using manual calculations, a spreadsheet, or other storm sewer design methods approved by the District. Intensity calculations for Rational Method analyses must utilize the Orange County *rainfall intensity* parameters shown in Table 5-5.

7.2.2 Peak Runoff Rates

The following methods shall be used to determine the peak runoff rates from the drainage area served by the storm sewer system:

- The Rational Method discussed in Chapter 5 may be used to determine peak runoff rates for storm sewer systems serving drainage areas up to 200 acres.
- The HEC-HMS methodology discussed in Chapter 5 shall be used to compute peak discharge rates for storm sewer systems serving drainage areas greater than 200 acres.

7.2.3 Storm Sewer Slopes

As indicated in Section 7.1.2, the minimum allowable velocity for storm sewers flowing full is 2 feet per second and the maximum allowable velocity for storm sewers flowing full is 8 feet per second. Manning's equation (Equation 7-1) can be rearranged as indicated below to solve for the maximum and minimum pipe slopes required to maintain flow velocities within the acceptable range.

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

Equation 7-1

where: Q = flow rate (cubic feet per second);
n = Manning's roughness coefficient from Table 6-4;
A = cross-sectional area of flow, assuming full flow in pipe or box (square feet);
R = hydraulic radius, cross-sectional area divided by wetted perimeter (feet);
S = slope of the pipe or box (feet per foot).

As indicated in the Continuity Equation (Equation 7-2), the flow rate can be expressed as a function of velocity and area:

$$Q = V \times A$$ **Equation 7-2**

where: V = velocity (feet per second).

Incorporating the Continuity Equation into Manning's Equation yields Equation 7-3***:***

$$V = \left(\frac{1.49}{n}\right) R^{2/3} S^{1/2}$$

Equation 7-3

where: R = Hydraulic radius (see Equation 7-4)

The hydraulic radius can be expressed as a function of the diameter for circular pipes flowing full:

$$R = \frac{D}{4}$$ **Equation 7-4**

where: D = pipe diameter (feet).

Substituting Equation 7-4 into Equation 7-3 and rearranging to solve for slope of the pipe yields Equation 7-5:

$$S = \left[\frac{Vn}{1.49\left(D/4\right)^{2/3}}\right]^2$$

Equation 7-5

The *n* values used to obtain these slopes were obtained from Table 7-1. Equation 7-5 should be used to determine the range of acceptable slopes for other pipe materials, sizes, *n* values, and shapes.

TABLE 7-1: MINIMUM AND MAXIMUM ALLOWABLE SLOPES FOR STORM SEWERS						
Pipe Diameter (inches)	Pipe Slopes (%)					
	RCP (n = 0.013)		HDPE (n = 0.012)		CMP (n = 0.027)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
18	0.11	1.802	0.096	1.535	0.486	7.771
21	0.092	1.467	0.078	1.250	0.395	6.327
24	0.077	1.228	0.065	1.046	0.331	5.296
27	0.066	1.049	0.056	0.894	---	---
30	0.057	0.912	0.049	0.777	0.246	3.933
36	0.045	0.715	0.038	0.609	0.193	3.084
42	0.036	0.582	0.031	0.496	0.157	2.511
48	0.030	0.487	0.026	0.415	0.131	2.102
54	0.026	0.416	0.022	0.355	0.112	1.796
60	0.023	0.362	0.019	0.308	0.098	1.561
66	0.020	0.319	0.017	0.271	0.086	1.374
72	0.018	0.284	0.015	0.242	0.076	1.224
78	0.016	0.255	0.014	0.217	0.069	1.100
84	0.014	0.231	0.012	0.197	0.062	0.997
90	0.013	0.211	0.011	0.180	0.057	0.909
96	0.012	0.193	0.010	0.165	0.052	0.834
102	0.011	0.178	0.009	0.152	0.048	0.769
108	0.010	0.165	0.009	0.141	0.045	0.713
120	0.009	0.144	0.008	0.122	---	---

7.2.4 Friction Losses

Friction losses in storm sewer systems may be computed using the following form of the Manning's Equation:

$$H_F = \frac{\left(n^2 Q^2 L\right)}{\left(2.22 A^2 R^{4\beta}\right)}$$ **Equation 7-6**

where: H_F = friction loss (feet);

7.2.5 Minor Losses

Minor losses are those losses that result from changes in velocity or direction of flow. Although minor losses in storm sewer systems are usually insignificant, they may exceed the H_F in relatively short storm sewer segments. In addition, the cumulative effect of minor losses may be significant in relatively flat areas like Orange County. Minor losses include those associated with: pipe entrances, pipe exits, pipe bends, pipe elbows, junctions, manholes, expansions, contractions, and appurtenances such as valves and meters. It is important to note that minor losses can be minimized by careful design. For example, severe pipe bends can be replaced by gradual curves if sufficient right-of-way is available and costs are manageable. Furthermore, well designed manholes and inlets without sharp or sudden transitions or flow impediments do not cause significant minor losses.

Minor losses are typically computed using a loss coefficient and flow velocities in upstream and downstream pipe segments. Although entrance losses, exit losses, and losses at inlets and manholes are discussed in detail in this section, it may be necessary to account for other minor losses depending on project specific considerations. For additional information on minor losses refer to TxDOT's *Hydraulic Design Manual* or other hydraulic reference manuals. Equation 7-7 can be used to compute entrance losses:

$$H_E = K_e \frac{V^2}{2g}$$ **Equation 7-7**

where: H_E = entrance loss (feet);
K_e = the entrance loss coefficient, from Table 6-7, or 1.25 for inlets or manholes at the beginning of a storm sewer segment;
V = velocity in the pipe (feet per second);
g = the acceleration of gravity (32.2 feet per second^2).

For this calculation, the velocity upstream of the pipe entrance is assumed to be zero. Table 6-7 provides a summary of entrance loss coefficients for a number of culvert entrance configurations. Equation 7-7 can also be used to compute exit losses and the exit loss coefficient may be assumed to be equal to 1.0 for most applications. Minor losses at inlets and manholes can be computed with Equation 7-8. Table 7-2 lists typical Minor loss coefficients for various inlet and manhole configurations.

$$H_{I/M} = \frac{\left(V_1{}^2 - KV_2{}^2\right)}{2g}$$

Equation 7-8

where:
$H_{I/M}$ = loss at inlet or manhole (feet);
K = the minor loss coefficient, from Table 7-2;
V_1 = velocity in the upstream pipe (feet per second);
V_2 = velocity in the downstream pipe (feet per second);
g = the acceleration of gravity (32.2 feet per second^2).

TABLE 7-2: MINOR LOSS COEFFICIENTS FOR INLETS AND MANHOLES

Type of Structure	Coefficient (K)
Inlet on Main Line	0.50
Inlet on Main Line with Branch Lateral	0.25
Manhole on Main Line with 22.5-Degree Lateral	0.75
Manhole on Main Line with 45-Degree Lateral	0.50
Manhole on Main Line with 60-Degree Lateral	0.35
Manhole on Main Line with 90-Degree Lateral	0.25

7.2.6 Hydraulic Grade Line

As indicated previously, the HGL shall be maintained at an elevation below the gutter line at inlets and below the rim elevation at manholes during the design storm frequency determined from Section 7.1.1.

The tailwater elevation in the receiving channel or storm sewer system shall be determined using the Frequencies of Coincidental Occurrence methodology described in Section 6.2.5 and Table 6-3. This value will be the starting WSEL or HGL at the downstream end of the storm sewer system (outfall node). The HGL elevation at the upstream end (node) of each storm sewer segment can be estimated using Equation 7-9.

Equation 7-9

$$HGL_u = HGL_d + h_f + h_m$$

where:
- HGL_u = HGL at upstream end (node) of storm sewer segment (feet);
- HGL_d = HGL at downstream end (node) of storm sewer segment (feet);
- h_f = headloss due to friction (feet);
- h_m = sum of Minor losses (feet).

The HGL at the downstream end (node) of the next storm sewer segment upstream can be estimated as the upstream HGL calculated for the downstream segment of storm sewer from this node or the top of the upstream pipe, whichever is greater.

The HGL computations should proceed in an upstream direction into all branches of the storm sewer system. If the HGL elevation is above the gutter line at any inlets or the rim elevation at any manholes, the storm sewer system must be adjusted so that the HGL does not exceed these elevations. This can typically be accomplished by increasing the capacity of the storm sewer segments with the most significant losses. However, adjustments to storm sewer flowline elevations may also be required.

7.3 HYDRAULIC ANALYSIS AND DESIGN OF ROADSIDE DITCHES

This section describes the general design requirements, design storm frequencies, and peak runoff rates for storm sewers.

7.3.1 Design Storm Frequencies

The following guidelines must be followed in the design of roadside ditches and associated culverts to be placed in roadside ditches.

- For drainage areas up to 50 acres, roadside ditches and culverts in those ditches should be designed to convey 10-year peak runoff rates at maximum water levels not exceeding top of bank elevations. Peak 25-year runoff rates shall be accommodated with a maximum flow depth of 6 inches above the crown of the roadway.
- For drainage areas between 50 acres and 100 acres, roadside ditches and culverts in those ditches should be designed to convey 10-year peak runoff rates at maximum water levels not exceeding bank elevations. Peak 50-year runoff rates shall be accommodated with a maximum flow depth of 6 inches above the crown of the roadway.
- For drainage areas greater than 100 acres, roadside ditches will be considered as open channels. Refer to Chapter 6 for open channel design requirements.

7.3.2 General Design Requirements for Roadside Ditches

The following general requirements shall be applied to the designs of all roadside ditches.

- Roadside ditches shall be designed with side slopes no steeper than 3 horizontal to 1 vertical (3:1).
- The minimum Manning's roughness coefficient for roadside ditch design shall be 0.04.
- The minimum grade for roadside ditches shall be 0.1-percent.
- Hydraulic computations which demonstrate that the ditch design is sufficient to carry design flow rates for the frequencies specified in Section 6.3.1 will be required.
- The ditch should be vegetated immediately after construction or repair to minimize erosion.
- Flow velocities are to be maintained at non-erosive levels. In areas where erosive velocities are anticipated, slope protection measures will be employed (see Chapter 9).
- The depth of roadside ditches shall be maintained between 1.5 feet and 4 feet. Roadside ditches greater than 4 feet in depth will be subject to the design requirements for open channels.
- The minimum culvert size for roadside ditches shall be 18 inches.
- The maximum head loss for a driveway culvert shall be limited to 0.1 feet for the applicable design storm.

7.3.3 Peak Runoff Rates

Peak design flow rates for secondary drainage facilities may be computed using the Rational Method for drainage areas up to 200 acres. HEC-HMS shall be used to compute the peak flow rates for drainage areas greater than 200 acres. Complete peak flow calculations must be submitted in support of all proposed structure designs.

7.4 LOT GRADING AND DRAINAGE

Individual lots should be graded in accordance with the following guidelines:

- Lots should be graded to drain to a street, swale, road or outfall ditch at a minimum slope of 1-percent.
- Wherever possible, sheet flow from individual lots should not cross adjacent lots before entering a street, swale, ditch, or other drainage facility.

- All finished floor elevations should be at least 12 inches above the highest finished ground elevation immediately adjacent to the slab.
- For lots draining to a street, the finished floor elevation should be at least 12 inches above the highest point along the top of the curb or crown of road, whichever is highest, immediately adjacent to the building.
- All finished floor elevations should be at least 1-foot above the design water surface elevation or computed base flood elevation in any adjacent drainage facility.

SECTION 8 – DETENTION ANALYSIS

The purpose of this section is to provide criteria and guidelines to be used in the analysis of detention facilities. Detention facilities are intended to mitigate increases in peak flows and changes in the timing of runoff associated with urbanization so that surrounding properties and the receiving body of water are not adversely impacted by increases in peak flows or water surface elevations (WSELs). Refer to Section 4 for additional information on the effects of urbanization.

It is important to note that detention will be required for the following types of improvements: new development; redevelopment; roadway expansion; drainage system improvements; and any other improvements that increase the impervious cover, decrease the time of concentration (T_C), or increase the peak flows from a drainage area. Additional information on impervious cover, T_C values, and peak flows is provided in Section 5.

The civil engineering industry's standard of care for detention analysis is the 100-year event, which is typically used by public entities requiring detention. In addition, the 100-year rainfall event is used by the Federal Emergency Management Agency (FEMA) to define the level of flooding risk within communities that participate in the National Flood Insurance Program (NFIP). Therefore, the 100-year design storm event will be used as the basis for detention analysis within the District's boundaries and jurisdiction. In some instances, 5-year and 10-year design storm events will also need to be analyzed to ensure that the proposed detention facility does not cause adverse impacts during more frequent rainfall events.

8.1 GENERAL DESIGN REQUIREMENTS

The following design requirements are discussed in this section: design storm frequencies, detention basin location and geometry, maintenance berms, maintenance, pumped detention facilities, multi-purpose design, and extreme event overflow structures.

8.1.1 Design Storm Frequencies

The following design storm frequencies should be used for detention analysis and design.

- The required storage volume for detention basins serving up to 200 acres (that are analyzed using the simplified methodology described in Section 8.7) shall be designed for a 100-year design storm event.
- Detention basins serving drainage areas greater than 200 acres and areas up to 200 acres that are analyzed using the methodology described in Section 8.8 shall be analyzed for the 10-year and 100-year design storm events.

8.1.2 Detention Basin Location and Geometry

In order to facilitate pavement and storm sewer drainage, detention basins should typically be located in the lowest portion of the drainage area contributing to the basin. In addition, detention basins should be located immediately adjacent to the receiving drainage system where feasible. This will minimize the required length of outfall pipe and decrease maintenance strip requirements (see Section 8.1.3), which may decrease overall drainage system costs. The following criteria shall be used in detention basin design:

- Generally, side slopes of detention basins shall be no steeper than three horizontal to one vertical (3:1); however, the use of these side slopes should be verified by a geotechnical report. If soil conditions are conducive to slope instability, flatter side slopes may be required.
- A minimum transverse slope of 0.50-percent shall be used on the bottom of the detention basin.
- A minimum of 1-foot of freeboard shall be provided in the detention basin.
- A 6-foot wide concrete pilot channel with a depth of 6 inches shall be provided in the bottom of the basin to facilitate drainage and avoid erosion problems. A minimum slope of 0.10-percent shall be used for concrete pilot channels.
- Earthen pilot channels with a minimum depth of 2 feet may be substituted for concrete pilot channels for aesthetic reasons or to facilitate multi-purpose use of a detention facility. The minimum slope for earthen pilot channels is 0.20-percent and the side slopes of earthen pilot channels shall be no steeper than three horizontal to one vertical (3:1).
- The minimum allowable outfall pipe size is 24 inches. If the detention analysis shows that a smaller pipe is required to restrict discharges, then a restrictor shall be placed inside the upstream end of the 24-inch diameter pipe.
- The use of parking lot detention storage is acceptable provided that the maximum ponding depth does not exceed 6 inches. It is recommended that preliminary approval be obtained from the District's Staff prior to beginning a detailed design of any parking lot detention facility.

8.1.3 Maintenance Berms

For all detention basins, a minimum 25-foot wide maintenance strip shall be provided around the entire detention basin. Detention basins located immediately adjacent to a drainage channel with a dedicated right-of-way (ROW) and a maintenance strip wide enough to satisfy channel design criteria may share the adjacent channel maintenance strip. The combined total width of the common maintenance strip serving both the channel and detention basin maintenance shall not be less than 30-foot wide under any circumstances.

For detention basins located adjacent to parking lots, the parking areas may satisfy 10-feet of the maintenance strip. Adequate access for maintenance equipment must be provided.

8.1.4 Detention Facility Outlet Structure

The outlet structure for a detention facility is subject to erosive velocities for prolonged periods of time. For this reason, the erosion protection measures are very important.

Reinforced concrete pipe used in the outlet structure should conform to ASTM C-76 Class III with compression type rubber gasket joints conforming to ASTM C-443. HDPE may also be used. Pipes, culverts, and conduits used in the outlet structures should be carefully constructed with sufficient compaction of the backfill material around the pipe structure as recommended in the geotechnical analysis. Generally, compaction density should be the same as the rest of the structure. Place bentonite around pipes to seal them and headwalls, concrete lining or concrete stabilized sand (CSS) surfaces for erosion protection. The use of seepage cutoff collars is not recommended since such collars are often inadequately installed and prevent satisfactory backfills compaction. A concrete control structure with a grate area equal to ten (10) times the outfall pipe area shall be constructed. Concrete or approved equal paving extending from the outfall area into the pond a distance of ten (10) feet shall be placed on the bottom of the facility for maintenance of the structure. Adequate steel grating around the outfall pipe intake must be designed to prevent clogging of the pipe from dead or displaced vegetation.

The concrete spillway for the 100-year discharge or greater flows shall extend down the bank to the bottom of the channel and up the far side of the receiving outfall ditch.

8.1.5 Extreme Event Overflow Structures

Unless otherwise directed by the District, all detention basins shall be designed so that stormwater runoff in excess of the 100-year rainfall event is conveyed to the nearest drainage channel without flooding structures. Overflow depths up to 1-foot above basin top of bank elevations should be considered. Grass-lined earthen swales, weirs, concrete-lined overflow sections, and other structures may be utilized to convey these overflows.

8.1.6 Maintenance

A. Required Maintenance. All detention facilities shall be located in readily accessible areas and two access routes should be provided where possible. The following maintenance activities should be performed on a regular basis: mowing, slope repairs, removal of accumulated sediments, and repairs to intake and discharge structures. In addition, a maintenance schedule should be prepared and submitted in conjunction with the Drainage Plan. The detention facilities include all intake and discharge culverts and ditches, related maintenance berms and right of way, pilot channels, and drainage ditches and/or underground pipes that lead from the detention facilities to the drainage ditches or other drainage outfall within or outside of the subdivision.

B. Maintenance Solely the Obligation of the Developer, Owners and/or the Property Owner's Association. With regard to residential subdivision developments, the Developer shall be responsible for preparing and filing a sufficient declaration of covenants, conditions and restrictions (hereinafter, the "covenants") which provide the following requirements: (1) the covenants shall describe the required maintenance activities as set forth in Section 8.1.6.A. above and shall provide that such maintenance activities shall be the sole responsibility of the Developer, the Owners, and/or an HOA required to be created, and must be performed properly and on a regular basis; (2) a requirement for sufficient assessments for the performance of such maintenance on a regular basis to be paid by the Owners of each lot in the residential subdivision to the HOA, for the duration of the existence of such detention facilities; (3) that a mandatory HOA will be created pursuant to Section 1.5 – Definitions – Property Owner's Association, of this Manual, and in compliance with the requirements therein set out; (4) a requirement that all subsequent purchasers of lots in the residential subdivision must be members of the HOA; (5) that the Developer shall convey by warranty deed to the Owners of all lots in the residential subdivision and/or the HOA the property which includes the detention facilities including all intake and discharge culverts and ditches, related maintenance berms, pilot channels, drainage ditches and/or underground pipes that lead from the detention facilities to any drainage ditches or drainage outfalls outside of the subdivision and including sufficient right of way for the performance of maintenance; (6) Deeds from the Developer to each Owner of lots in the residential subdivision must be accompanied by a Notice of Obligations Related to Membership in Property Owners Association as required by Section 5.012 of the Tex. Property Code which must describe the requirement of maintenance activities to be performed for the detention facilities as set forth in Section 8.1.6.A. of this Manual and as well, identify the initial amount of assessments, as determined by the Developer, required to perform such maintenance on a regular basis; (7) provide for the dedication to the public and public entities of a sufficient detention drainage easement in compliance with Section 1.5 – Definitions – Detention Drainage Easement, of this Manual; and (8) in the event of any violation or breach, or attempted violation or breach, of any of the requirements of the covenants herein stated by any lot Owner or by the HOA, any other Owner and/or the HOA, and/or any public entity with jurisdiction concerning drainage or flood mitigation shall be authorized to enforce the terms of the covenants by any proceedings at law or in equity against the person(s) or entity violating or breaching, or attempting to violate or breach such covenants including actions for prohibitive or mandatory injunctive relief; and, it shall not be prerequisite to the granting of any such injunctive relief that there be any showing that irreparable damage or harm will result if such injunctive relief is not granted; rather, that irreparable damage or harm shall be presumed. Additionally, any person or entity entitled to enforce the requirements of such covenants may recover the full extent of such damages, both actual and punitive, as such person or entity may show entitlement by reason of any such violation or breach. In any action for enforcement of such covenants, whether for injunctive relief or damages, if the party prosecuting such action is successful, they shall be entitled to recover, in addition to any damages awarded, reasonable attorney's fees and all costs.

With regard to all other private, commercial, industrial or municipal developments, the Developer or Owner-Entity shall be responsible for the maintenance of the detention facilities.

C. District Not Responsible for the Operation, Performance and/or Maintenance of Private Detention Facilities and District's Reservation of Rights. The District will not be responsible for the operation, performance and/or maintenance of detention facilities designed and/or constructed by Developers and/or Owners including such detention facilities designed and/or constructed in accordance with a Drainage Plan approved by the District for the purpose of drainage mitigation for the development of residential subdivisions, individual private projects, the construction of infrastructure improvement projects intended to serve private developments, public facilities, or commercial or industrial developments. Further, the District does not assume any liability, obligations or responsibilities regarding the design and/or construction of detention facilities by reason of the promulgation of criteria and regulations set forth in this Manual, or the approval of a Drainage Plan. The design and/or construction of detention facilities by a Developer or Owner, and the operations, maintenance and/or performance of such detention facilities, shall be the sole responsibility of such Developer, Owner or the HOA. The District reserves the right to reject approval of a Final Plat for a residential subdivision development until compliance with the requirements of the Drainage Manual and the HOA is formally created and filed of record in the Official Public Records of Orange County, Texas, and the right to reject concept approval and final approval of the Drainage Plan for all other developments until the Owner/Developer agrees in writing to assume the responsibility for the permanent maintenance of the detention facilities.

8.2 MULTI-PURPOSE DESIGN

The District encourages multi-purpose features in detention facilities provided that the stormwater management function of the facility is not compromised. In addition, the multi-purpose detention facilities must be designed to accommodate the maintenance activities discussed in Section 8.1.6 and to provide safety features. Potential multi-purpose features include wetlands, playgrounds, soccer fields, and hiking or biking trails.

8.3 TYPES OF DETENTION FACILITIES

Stormwater detention can be accomplished in a variety of facilities to support the District's "No Adverse Impact" Policy. Developers and project owners are encouraged to evaluate the best method, or combination of methods, for their particular needs. Prior to final selection of the drainage system for a project, the developer should contact the District for a Pre-Submittal Meeting.

8.3.1 Pumped Detention Facilities

All stormwater detention facilities requiring mechanical pumping systems are generally prohibited, with the exception of pumping of dead storage (maintenance or amenity water stored at or below the discharge pipe control level). Pumped detention may be allowed, at the sole discretion of the District, under the following conditions and with the following stipulations:

a) A combination pump and gravity systems shall be constructed.

b) The minimum detention rate shall be 1.0 ac-ft/ac for developed projects.

c) The selected outfall rate shall not increase the elevation or the flow within the receiving system.

d) The discharge delivery system shall not have peak discharge and / or peak stages that exceed the pre-developed values at any point in time for the 5-year, 10-year, and 100-year design storm events.

e) A redundant pump system, with a minimum of 2 pumps shall be required, each capable of providing the design discharge rate. If 3 pumps are provided, any 2 pumps in combination must be capable of providing the design discharge rate.

f) Fencing of the control panel must be provided to prevent unauthorized operation and vandalism pursuant to the Texas Commission on Environmental Quality Standards. The District must be provided access.

g) Adequate assurance must be provided that flooding would not occur in the event of loss of power during a 100-year flood

h) Sensors must be placed so that the pumps would remain off during a rain event.

i) Sensors must be placed so that pumping will not occur when the level of water in the receiving system is at or above 1/4 of its full depth.

j) The Operator shall provide the District with a quarterly operational report that shall indicate the operational times, total hours of operation, and the amount pumped. Said report shall be delivered to the District office on or before 20th day of the month after the end of each quarter.

k) District shall have the right to enter the property and inspect the operation of the system at any time for any reason.

l) Failure to maintain the pump station in working order is a violation of these rules, regulations, and guidelines and may be grounds for regulatory intervention by the District.

m) The pump station must be accessible by an all-weather road.

The use of a pumped detention system must be approved by the District prior to the Drainage Plan being submitted.

8.3.2 Natural (and Naturalized) Detention Facilities

The District recognizes, and may allow in its sole discretion, natural detention facilities in low lying areas subject to flooding during high rainfall events and capable of draining slowly after a rain event has passed. Use of natural detention facilities will require detailed surveying and analysis to determine capacity and function. Furthermore, use of natural detention will require permanent dedication of the property for the sole purpose of stormwater detention. Natural detention facilities are more sensitive to modifications in the upstream watershed. Any future development which may affect the function or capacity of the dedicated natural detention facility, including development in any portion of the contributing watershed, shall require detailed analysis of the facility.

"Naturalized" detention facilities may also be constructed with the intention of supporting natural vegetation. For constructed, naturalized detention facilities, the bottom of a detention facility should be designed as flat as practical to still maintain positive drainage to the outfall structure. Side slopes should be designed to allow for regular maintenance and be grass-lined with a minimum 4 to 1 side slope. The bottom flowline should be graded toward the outfall structure at a minimum transverse slope of 0.002 feet per foot. The remainder of the pond bottom shall be graded toward the flowline of the pond at a minimum slope of 0.01 feet per foot. Selected vegetation may be introduced to the bottom of the facility to encourage a particular habitat. Other design requirements for channels should be followed, including backslope drains, and erosion protection measures. A maintenance plan to remove trash debris and excessive siltation must be provided to and approved by the District. Additional storage volume may be required by the District to offset predicted siltation based on experiences with nearby drainage facilities.

8.3.3 Manicured Dry Detention Facilities

Manicured, dry detention facilities are man-made features intended to temporarily detain excess stormwater flows and prevent adverse impacts of the associated development in either the upstream or downstream watershed in response to a future design storm event. Manicured, dry detention facilities are preferred by the District. This type of facility lends itself to ease of maintenance, best hydraulic management, and multi-purpose utilizations.

The design of the detention facility bottom to remain dry and aesthetically manicured is very important from the standpoint of long-term maintenance. A pilot channel is required to facilitate complete drainage of the basin following a runoff event. A concrete lined pilot channel should have a minimum depth of 6 inches (6”), a minimum bottom width of 6 feet (6’) and a minimum flowline slope of 0.001 feet per foot.

Bottom slopes of the detention basins should be graded towards the low-flow pilot channel or outfall. The transverse slope of the bottom should be a minimum slope of 1%.

Detention basins which make use of a channel section for detention storage may not be required to have pilot channels but should be built in accordance with the requirements for channels, including side slopes, maintenance berms, back slope drains and erosion protection measures previously discussed.

8.3.4 “Wet” Detention Facilities

“Wet” detention facilities and ponds which maintain a level of water at all times. These facilities may include neighborhood amenity ponds, lakes, etc. The space/volume which is intended to hold water during dry periods shall not be considered in the calculations of stormwater detention capacity.

Wet detention ponds must be approved by the District prior to the design and preparation of construction plans. Any detention pond which is designed to hold water for any reason shall be considered to be a wet detention pond. It will be the responsibility of the Developer, MUD or Homeowners Association to own and maintain any wet detention ponds. The District strongly recommends the use of ripple protection barriers at the static water edge in wet detention ponds. Wet detention facilities are not allowed within the jurisdiction of any City which prohibits such wet detention facilities.

8.3.5 Underground Detention Systems

With prior approval of the District, underground detention systems may be utilized. All pipes are recommended to be at least forty-eight (48) inches in diameter.

All underground detention systems must be accessible for inspection and cleaning. No such system may be used in conjunction with a pump system and shall have separate criteria and requirements. Concrete overflow structures are required for all underground detention systems.

No underground detention system of any kind will be accepted by the District for maintenance.

No storage volume credit will be given for void space between stone backfill on underground detention systems.

8.4 EXTREME EVENT OVERFLOW STRUCTURES

All detention basins shall be designed so that stormwater runoff in excess of the 100-year rainfall event may be conveyed to the nearest drainage channel without flooding structures. Overflow depths up to 1-foot above basin top of bank elevations should be considered. Grass-lined earthen swales, weirs, concrete-lined overflow sections, and other structures may be utilized to convey these overflows.

8.5 PEAK DISCHARGE RATES

The following items related to peak discharge rates are discussed in this section: methodology, allowable peak discharge rates, and off-site flows.

8.5.1 Methodology

As described in Section 5, the Rational Method may be used for drainage areas up to 200 acres, and HEC-HMS shall be used for drainage areas greater than 200 acres to determine peak discharge rates consistent with the aforementioned criteria. For drainage areas greater than 200 acres or for smaller drainage areas being analyzed with the detention routing methodology described in Section 8.8, inflow hydrographs shall be computed by HEC-HMS.

8.5.2 Allowable Peak Discharge Rates

For detention facilities of any nature, the maximum allowable peak discharge rate shall be limited to the existing, pre-development, conditions 10-year and 100-year peak discharge rates for the 10-year and 100-year design storm events, respectively.

It is important to note that limiting discharges during the two rainfall events may require multiple outfall structures (i.e., a low-flow pipe with a larger diameter pipe or weir stacked above).

8.5.3 Off-Site Flows

An investigation of off-site flows shall be completed as part of every drainage study or detention analysis. Off-site flows that drain through a project must be accommodated by the proposed drainage plan. When off-site (run-on) flows are routed through a detention basin, the allowable peak discharge rates shall be based on the entire contributing (project and off-site) drainage area. For this case, regardless of acreage, the detailed detention analysis methodology described in Section 8.8 must be used.

A downstream off-site drainage facility may be required to convey the stormwater from the project site to the receiving system, with sufficient 100-year capacity based upon contributing upstream acreage under existing conditions. This off-site drainage facility shall have sufficient drainage easement for conveyance and maintenance purposes. For the width of the ROW required for channels, see Section 6.1.2 for earthen channels and Section 6.1.3 for concrete-lined channels. For enclosed systems, the minimum ROW width is equal to the widest dimension of the underground conduit plus two times the maximum depth from finished ground to the invert of the conduit, or 30 feet, whichever is greatest.

8.6 DETENTION FACILITIES FOR PROJECTS 2 ACRES OR SMALLER

Small Projects are defined as those projects that are two (2) acres or smaller. To minimize the expense of extensive engineering, simplified accepted design methodologies may be utilized for capacity and outfall assessment of a project of this size.

8.6.1 Detention Analysis for Projects No Larger Than 2 Acres

For small projects, no larger than two acres, on-site detention capacity may be sized to accommodate 0.75 ac-ft. per acre without further capacity analysis.

8.6.2 Design of Outfall Structures for Projects No Larger Than 2 Acres

The outlet for such a detention facility may be sized based on the orifice equation (Equation 8-1) presented below. In this case the volume calculated using 0.75 ac-ft per acre shall be considered to be the 100-year volume. The 10-year and 5-year volumes will be considered to be 55% and 40% of the 100-year volume, respectively. The generation of runoff hydrographs and the routing of flood flows are not required for these Small Projects.

$$Q = CA\sqrt{2gH}$$

Equation 8-1

where: Q = entrance loss (feet);
C = Pipe Inlet Coefficient (see Table 5-7);
A = Outfall restrictor cross-sectional area;
g = the acceleration of gravity (32.2 feet per second^2)
H = Elevation difference between the water surface in the detention pond and the receiving system for a given storm. If the receiving system has the potential to be tidally influenced, contact the District to determine the appropriate water surface elevation of the receiving system for use in this equation.

For ponds discharging into creeks or ditches, the outfall structure shall be designed to ensure that the allowable flow is not exceeded during a 5-year, 10-year and 100-year event. This may be achieved using a combination of pipes and or weirs. The flowline of each pipe or weir level shall be set based upon the 5-year, 10-year, and 100-year water surface elevations in the detention pond.

8.7 DETENTION ANALYSIS FOR DRAINAGE AREAS UP TO 200 ACRES

This section describes the methodology to be used in determining the required detention storage volume and outfall structure size for drainage areas up to 200 acres.

8.7.1 Detention Analysis for Drainage Areas Up to 200 Acres

The simplified detention analysis methodology developed for drainage areas up to 200 acres is based on the triangular hydrograph method. Equations 8-2 through 8-4 can be used to compute the required detention storage volume as the area between triangular inflow and outflow hydrographs for the basin. In this method, the outflow hydrograph is assumed to intersect the receding limb of the inflow hydrograph at a flow rate equal to the maximum allowable peak discharge rate from the detention facility. Equation 8-2 can be used to calculate the time base of the triangular inflow hydrograph (B):

$$B = \frac{43{,}560 V_R}{0.5 Q_I}$$

Equation 8- 2

where: B = time base of the triangular inflow hydrograph (seconds);
V_R = the detention inflow volume in (acre-feet);
Q_I = the proposed 100-year peak inflow rate (cubic feet per second).

The detention inflow volume (V_R) can be computed using Equation 8-3:

$$V_R = A(XS)$$

Equation 8- 3

where: A = drainage area served by detention basin (acres);
XS = rainfall excess, from Table 8-1 (feet).

The rainfall excess shall be determined from Table 8-1 based on the soil type and proposed impervious cover of the drainage area. If the proposed impervious cover falls between the values listed in this table, then the rainfall excess should be estimated by interpolation.

TABLE 8-1: 100-YEAR RAINFALL EXCESS VALUES FOR ORANGE COUNTY, TEXAS				
% Impervious Cover	Rainfall Excess by Soil Groups (inches)			
	A	B	C	D
0	0.34	4.88	9.19	10.78
10	1.59	5.79	9.64	11.12
20	2.95	6.58	10.10	11.34
30	4.20	7.49	10.44	11.57
40	5.56	8.28	10.89	11.80
50	6.92	9.19	11.34	12.14
60	8.17	9.98	11.80	12.37
70	9.53	10.98	12.14	12.59
80	10.78	11.68	12.59	12.93
90	12.14	12.59	13.05	13.16
100	13.39	13.39	13.39	13.39

Equation 8-4 can be used to estimate the detention storage requirement (V_S) for drainage areas up to 200 acres.

$$V_S = \frac{0.5B(Q_I - Q_O)}{43{,}560} \qquad \textbf{Equation 8- 4}$$

where: V_S = detention storage requirement (acre-feet);
Q_O = maximum allowable peak discharge rate (cubic feet per second).

The minimum detention requirements shall never be less than 0.65 acre-ft/acre.

8.7.2 Design of Outfall Structures for Drainage Areas up to 200 Acres

Detention outfall structures shall be designed to limit discharges to the allowable peak discharge rates described in Section 8.5.2. If requested by the District or if tailwater conditions in the receiving system warrant, the detention routing analysis and outfall structure sizing described in Section 8.8 shall be used. Otherwise, the required outfall pipe diameter for drainage areas up to 200 acres can be estimated by trial and error calculations using the procedure described in this section. Equation 8-5 is an acceptable head loss equation for pipe culverts flowing full that can be used to solve for pipe diameter:

$$H_T = \left[\frac{2.52(1 + K_e)}{D^4} + \frac{466n^2L}{D^{16/3}}\right]\frac{Q^2}{100}$$

Equation 8-5

where: H_T = available head (feet);
K_e = entrance loss coefficient, typically 0.5;
D = diameter of pipe (feet);
n = Manning's roughness coefficient, from Table 6-6;
L = length of culvert (feet);
Q = design discharge rate (cubic feet per second).

If a HEC-RAS model of the receiving channel exists, then the Frequencies of Coincidental Occurrence methodology described in Chapter 6 shall be used to determine the constant tailwater in the receiving channel and to calculate the available head (H_T) for the 100-year analysis using Equation 8-6. Otherwise, an H_T of 2 feet can be assumed for the 100-year design storm event. In addition, an H_T of 2 feet should be used for the 10-year design storm event.

$$H_T = h_{\mathrm{basin}} - h_{channel}$$

Equation 8-6

where: H_T = available head (feet);
h_{basin} = 100-year design WSEL in detention basin (feet);
$h_{channel}$ = tailwater elevation in channel from Frequencies of Coincidental Occurrence (feet).

Once a pipe diameter is selected, Equation 8-7 shall be used to calculate the design peak discharge rate for the design storm event specified in Section 8.1.1 to ensure that the maximum allowable discharge rate is not exceeded.

$$Q = \sqrt{\frac{100H_T}{\frac{2.52(1 + K_e)}{D^4} + \frac{466n^2L}{D^{16/3}}}}$$

Equation 8-7

If the HEC-HMS detention routing methodology described in Section 8.8 is used to analyze a detention basin with a drainage area less than or equal to 200 acres, then the outfall structure shall also be sized using the methodology for drainage areas greater than 200 acres.

8.8 DETENTION ANALYSIS FOR DRAINAGE AREAS GREATER THAN 200 ACRES

A detailed detention routing analysis is required for detention basins serving drainage areas greater than 200 acres. As indicated previously, this method may also be used for drainage areas less than 200 acres. Detention routing shall be performed for the 10-year and 100-year rainfall events and the allowable peak discharge rates shall be determined from Section 8.5. Sections 8.8.1 through 8.8.4 discuss the hydrologic and hydraulic data required to develop detention routing models.

8.8.1 Acceptable Detention Routing Software Programs

The detention routing may be performed in HEC-HMS, HEC-RAS unsteady flow, Stormwater Management Model (SWMM), a detention routing spreadsheet, or other generally accepted detention basin routing programs approved by the District. The HEC-HMS and HEC-RAS manuals referenced in Chapters 5 and 6 should be consulted for additional information regarding the detention routing capabilities of these programs.

8.8.2 Inflow Hydrographs

Proposed conditions inflow hydrographs for the various design storm events should be developed in HEC-HMS using the hydrologic criteria presented in Chapter 5.

8.8.3 Stage-Storage Relationship

A stage-storage or stage-area relationship should be developed from the detention basin grading plan and entered into the detention routing model.

8.8.4 Outfall Structure

Detention outfall structures shall be designed to limit discharges to the allowable peak discharge rates described in Section 8.5. Depending on the detention routing software program, the outfall structure will either be input directly into the model or simulated with a stage-discharge relationship calculated independently and entered into the model. For HEC-HMS, the outfall structure is described using a stage-discharge relationship. For HEC-RAS unsteady flow or other unsteady flow models, the size and material of the outfall structure along with tailwater conditions within the receiving channel are entered into the model and a stage-discharge relationship is computed automatically. In either case, the required size of the outfall structure is dependent on tailwater conditions within the receiving channel.

A constant tailwater elevation in the receiving channel shall be estimated using the Frequencies of Coincidental Occurrence methodology described in Chapter 6. This constant tailwater elevation can be used to develop a stage-discharge relationship for an outfall structure of a specific diameter using Equation 8-7 or other hydraulic modeling program. The calculated stage-discharge relationship can then be incorporated into HEC-HMS or another acceptable model. In areas where tailwater conditions are a concern (i.e., detention basins located in 100-year flood plains, channels where WSELs remain high for long periods, channels with steeply rising WSELs, and areas with existing flooding problems), a stage hydrograph (elevation versus time) shall be developed for the receiving channel and used in a HEC-RAS unsteady flow model or other acceptable software that allows stage hydrographs as a downstream boundary condition.

As indicated in Section 8.4, an extreme event overflow structure must be provided in all detention basins to accommodate stormwater runoff in excess of the 100-year event without flooding structures. Standard hydraulic methods shall be used to determine the required dimensions of the overflow structure.

8.8.5 Acceptable Results

Once preliminary detention routing results are obtained, the peak discharge rate from the proposed detention basin shall be compared to the allowable peak discharge rate for each design storm event being analyzed. If the peak discharge rate for any of the design storm events exceeds the allowable peak discharge rate for that event, the size and/or configuration of the outfall structure shall be adjusted until acceptable results are obtained. In addition, the detention basin grading plan may also need to be revised to ensure that adequate volume is provided to maintain 1-foot of freeboard is the basin. If the grading plan is revised, an updated stage-storage relationship will need to be developed and incorporated in the detention routing model.

8.9 DOWNSTREAM IMPACTS

For drainage areas greater than 640 acres or if requested by the District for smaller drainage areas, a HEC-HMS downstream impacts analysis shall be performed to demonstrate that the proposed detention facility does not cause any impacts (increases in peak flows) downstream of the detention facility. If prior approval is obtained from the District, other standard software may be used for the downstream impacts analysis. The District has the option to request a downstream impacts analysis for drainage areas located in the lower half of the respective watershed. If a downstream impacts analysis is requested for drainage areas up to 200 acres, then the hydrologic methodology for drainage areas over 200 acres (see Chapter 5) and the detention routing method for drainage areas over 200 acres (Section 8.8) shall be used. The downstream impacts analysis shall be performed for the 10- and 100-year rainfall events. At a minimum, the downstream impacts analysis shall compare peak discharges downstream of the site to the mouth of the receiving channel. However, the District's staff has the option to request that the downstream impacts analysis be continued further downstream.

The routed outflow hydrograph from the detention basin should be incorporated into a detention conditions HEC-HMS model of the receiving channel. The resulting peak discharge rates downstream of the proposed detention shall be compared to the existing conditions peak discharges rates prior to development of the project site. If the drainage area served by the proposed detention basin is part of a larger drainage area, then the larger area should be subdivided to create revised existing and detention conditions models where the area served by the detention basin is represented by a stand-alone sub-basin. If the analysis indicates that there are increases in peak flows downstream of the proposed detention facility, then the discharge structure and/or detention basin shall be modified to eliminate these increases. This process is illustrated in Figure 8-1.

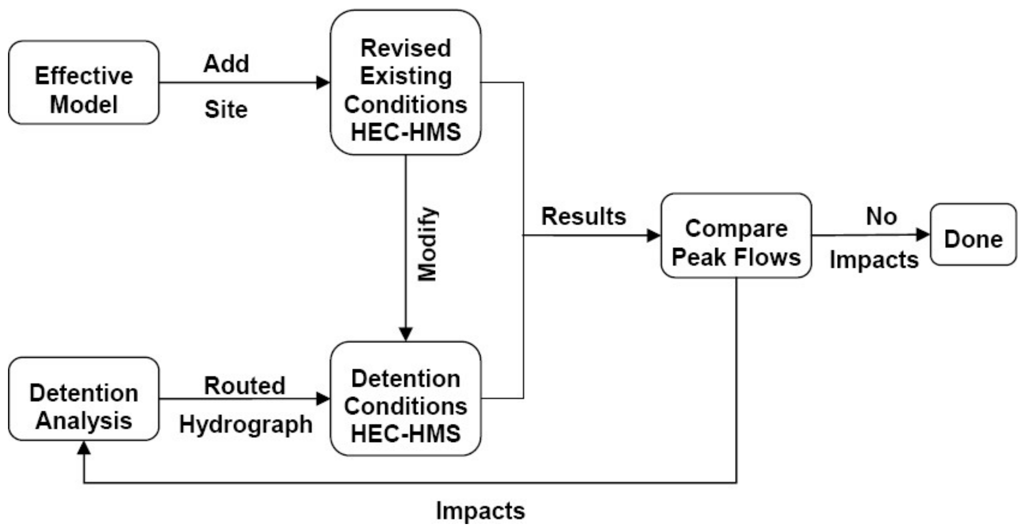

Figure 8-1*:* Downstream Impacts Analysis Process

SECTION 9 – EROSION AND SEDIMENT CONTROL

This section of the Manual describes methods for controlling erosion and sediment deposition in drainage facilities within the District's boundaries.

9.1 EFFECTS OF EROSION AND SEDIMENTATION

Erosion and sedimentation can have very serious effects on stormwater drainage. Some of these effects are summarized below:

- **Integrity of Drainage Facilities:** Erosion can cause slope failures, increase roughness coefficients, and generally reduce the efficiency of drainage channels. However, sediment deposition can clog drainage culverts and reduce the available conveyance in open channels.
- **Maintenance:** Erosion can significantly reduce the maintainability of drainage facilities and increase the cost of maintenance by increasing the frequency with which repairs are required.
- **Water Quality:** Erosion and sedimentation can increase the turbidity of water and may cause other water quality problems associated with pollutants attached to soil particles.

9.2 AREAS WITH HIGH EROSION POTENTIAL

Areas with relatively high erosion potential include the following:

- In channel bends, especially where the radius of curvature is less than three times the top width of flow in the channel.
- Around bridges and culverts where channel transitions and reduced flow areas create increased flow velocities.
- In steep sections of channels and ditches and on steep, unprotected slopes where flow velocities may reach erosive levels.
- Along grass-lined channel side slopes where significant amount of stormwater runoff flows over the channel bank and down the sides of the channel.
- At confluences where flows in tributary channels, storm sewers, or roadside ditches enter a receiving channel.
- In areas where non-cohesive soils are particularly prone to erosion.

9.3 SLOPE PROTECTION METHODS

The following sections describe some of the most common slope protection methods.

9.3.1 Turf Establishment

The establishment of grass on exposed earthen side slopes is the most common method for protecting the slopes from erosion. Grass establishment should be initiated as quickly as possible after channel construction or repair work is completed. The grasses used for this purpose should be of hardy varieties which do not require repeated watering and excessive amounts of care once they are established. Grasses with deep root systems are preferable to those with shallower root systems because they are more resistant to drought.

9.3.2 Slope Paving

Concrete slope paving is an effective slope protection method but is generally considered too expensive to apply over large areas. Therefore, slope paving is most commonly used in limited areas where the potential for erosion is very high. Table 9-1 provides a summary of slope paving requirements for varying channel side slopes.

TABLE 9-1: MINIMUM THICKNESS AND REINFORCEMENT FOR CONCRETE SLOPE PAVING

Channel Side Slope (H:V)	Minimum Thickness (inches)	Minimum Reinforcement	
		Material	Dimensions
3:1	4 inches	welded wire fabric	6 x 6 x W2.9 x W2.9
2:1	5 inches	welded wire fabric	6 x 6 x W4.0 x W4.0
1.5:1	6 inches	reinforcement	4 x 4 x W4.0 x W4.0

Minimum requirements for concrete slope paving are as follows.

- All concrete slope paving shall consist of Class A concrete.
- The side slopes of the channel shall be no steeper than 1.5 horizontal to 1 vertical (1.5:1).
- All slope paving shall include a toe wall at the top and sides with a minimum depth of 18 inches. Toe walls shall also be included along the bottom of the channel with a minimum depth of 24 inches for clay soils and 36 inches for sandy soils.

- Weep holes shall be used to relieve hydrostatic pressure behind lined channel sections. The specific type, size, and placement of the weep holes shall be based on the recommendations of the geotechnical report.
- Where construction is to take place under muddy conditions or where standing water is present, a seal slab of Class C concrete shall be placed in the channel bottom prior to placement of the concrete slope paving.
- Control joints shall be provided at a maximum spacing of 25 feet. A sealing agent shall be utilized to prevent moisture infiltration at control joints.

9.3.3 Rip-Rap

Rip-rap consists of rock or broken concrete pieces with a minimum dimension of about six inches and a maximum dimension of 18 to 24 inches. Rip-rap is normally hand-placed as a layer which extends 18 inches below the finished channel grade. Minimum requirements for rip-rap are as follows.

- The minimum mat thickness shall be 18 inches.
- Well-graded blocks weighing from 40 pounds to 265 pounds shall be used.
- The maximum steepness of slopes protected by rip-rap shall be 2 horizontal to 1 vertical.
- Filter fabric bedding is required in areas where rip-rap is placed on sandy or silty soils. On cohesive clay soils with very little sand content (less than 20-percent sand), filter fabric is not required.

Sacks of ready-mix concrete may not be used as rip-rap because lack of gradation allows water penetration and undermining of the soil under the installation.

9.3.4 Acceptable Velocities for Various Slope Treatments

The maximum allowable velocity in open channels and at bridges or culverts shall be analyzed for the design storm event. As shown in Table 9-2, the maximum allowable velocity is related to the type of channel, the slope treatment, and the soil structure throughout the open channel section. If the maximum velocities listed in this table are exceeded during the design storm event, then the channel design shall be modified until acceptable velocities are attained.

TABLE 9-2: MAXIMUM ALOWABLE VELOCITIES IN OPEN CHANNELS		
Soil Description	**Slope Treatment**	**Maximum Velocity (feet per second)**
Fine Sand	None	1.50
Sandy Loam	None	1.75
Silt Loam	None	2.00
Clay Loam	None	2.50
Stiff Clay	None	3.75
Sandy Soils (Easily Eroded)	Grass	4.00
Clay Soils (Erosion-Resistant)	Grass	5.00
Sandy Soils (Easily Eroded)	Rip-Rap	6.00
Clay Soils (Erosion Resistant)	Rip-Rap	8.00
Sandy Soils (Easily Eroded)	Concrete	8.00
Clay Soils (Erosion Resistant)	Concrete	10.00
Bridges and Culverts	----	8.00

9.4 REQUIREMENTS FOR CHANNEL BENDS AND CONFLUENCES

Erosion protection is required for all channel bends with a radius of curvature (measured along the channel centerline) less than three times the top width of flow in the channel. When required, erosion protection must extend along the outside bank of the bend and at least 20 feet upstream and downstream of the tangent points. Slope protection on the channel bottom and the inside bank is required only if anticipated flow velocities are above non-erosive levels.

Table 9-3 may be used to determine whether erosion protection is needed given the angle of intersection between the channels and the anticipated 25-year flow velocity in the tributary channel. Table 9-4 summarizes the minimum extent of erosion protection upstream and downstream of the confluence.

TABLE 9-3: MINIMUM EROSION PROTECTION FOR CHANNEL CONFLUENCES		
25-Year Velocity in Tributary Channel (feet per second)	Angle of Intersection (θ)	
	15 to 45 degrees	45 to 90 degrees
≥ 4.0	Protection Required	Protection Required
2.0 – 4.0	No Protection Required	Protection Required
≤ 2.0	No Protection Required	No Protection Required

TABLE 9-4: MINIMUM EXTENT OF EROSION PROTECTION AT CONFLUENCES	
Location	Minimum Distance (feet)
Receiving channel, upstream of confluence	20
Receiving channel, downstream of confluence	larger of 50 or $0.75T_m/\tan\theta$
Tributary channel, upstream of confluence	20

For both bends and confluences, the top edge of erosion protection shall extend at least as high as the 25-year design water surface elevation in the channel or two-thirds of the way up the channel side slopes, whichever is lower. A healthy grass cover must be established on the channel slope above the concrete lining.

9.5 REQUIREMENTS FOR STORM SEWER OUTFALLS

Storm sewer outfalls shall be designed and constructed to minimize potential for erosion in the receiving channel. The minimum slope stabilization material to be used at outfalls shall be 2 sacks per ton cement stabilized sand (2sk CSS).

No outfall pipe or culvert shall be less than 24" diameter. For outfalls using 24" to 48" diameter pipes discharging to the receiving channel, contact the District to determine if additional erosion protection measures must be installed in the receiving channel. For outfalls larger than 48" diameter, erosion protection must be installed in the receiving channel. Erosion protection shall be extended from the end of the outfall pipe for a distance of 6 pipe diameters into the receiving channel, or across the channel bottom and up the outfall pipe flowline elevation on the opposite bank, whichever is less. Acceptable erosion protection measures will vary by location and must be coordinated with the District.

A standard manhole shall be installed on the line immediately upstream of the location where the outfall pipe enters the District's ROW.

All CMP and HDPE outfall pipes and culverts shall be bedded in 2-sack per ton cement stabilized sand bedding and bedding shall, at a minimum, extend from 6” below the pipe up to the spring line.

The outfall flowline shall be set no lower than 1’ above the normal water surface of the receiving channel. If the receiving channel is dry during dry weather, the outfall discharge shall be set no lower than 1’ above the flowline of the receiving channel. All outfall pipes shall be laid in accordance with acceptable flow velocity requirements.

9.6 CHANNEL BACKSLOPE DRAIN SYSTEMS

Backslope drain systems intercept sheet flow which otherwise would flow over the banks of drainage channels leading to erosion of the side slopes. The following minimum requirements shall be applied to all backslope drainage systems.

- The minimum backslope drain pipe diameter shall be 24 inches.
- The maximum spacing between backslope drains shall be 300 feet.
- The center-line of the backslope drainage swale shall be located 5 feet inside the channel right-of-way (ROW) line when 25-foot maintenance berms are used. When a 30-foot maintenance berm width is used, the backslope drainage swale shall be located 7.5 feet inside the ROW line.
- The minimum depth for backslope drainage swales shall be 0.5 feet. The maximum depth shall be 2 feet.
- The minimum invert slope for backslope drainage swales shall be 2-percent.
- The maximum side slope for backslope drainage swales shall be 1.5 horizontal to 1 vertical (1.5:1).

9.7 INTERCEPTOR STRUCTURES

Interceptor structures are designed to convey stormwater from secondary drainage facilities such as roadside ditches into receiving channels. The main purpose of the interceptor is to prevent stormwater runoff from flowing over the channel banks and down the channel side slopes.

9.8 STORMWATER POLLUTION PREVENTION PLANS

Stormwater pollution prevention plans shall be developed for all projects involving drainage improvements. These plans should focus primarily on the prevention of erosion and sediment deposition. Pollution control plans should be simple, easy to implement, and easy to maintain through the life of the construction project. A rock berm is one of the most effective measures for preventing sediments from being carried into a creek or channel. The rock berm reduces flow velocities in small ditches, causing suspended sediments to settle out. Sediments accumulating in the area immediately upstream of the rock berm must be removed periodically in order to preserve the effectiveness of the berm and the hydraulic capacity of the ditch. A filter fabric fence is another effective measure for containing sediments.

9.9 SPECIAL ENERGY DISSIPATION STRUCTURES

Special energy dissipation structures such as baffled chute spillways, energy dissipation basins, drop structures, and other features meant to dissipate energy in a controlled manner to mitigate erosion risks shall be designed in accordance with procedures developed by the U.S. Bureau of Reclamation set forth in *Design of Small Dams* (U.S. Department of the Interior, Bureau of Reclamation).

APPENDIX A – FEE SCHEDULE

Review of Preliminary Submittals including Pre-submittal Meeting,
Drainage Report, Preliminary Drainage Plans, Preliminary Plat
Review of Construction Plans, Details, and Specifications $850*

(* Fee due with submission of the “Submission Form and Checklist for District Review of Development”.)

Review of Final Submittals $350

APPENDIX B – DRAINAGE PLAN/PLAT NOTES

A. SPECIAL NOTES

The following notes and clarifying statements shall be entered on the Drainage Plan (and Plat if required) including any deed restrictions to ensure compliance with all drainage regulations and requirements.

1. Any governmental body for purposes of drainage work may use drainage easements and fee strips provided the District is properly notified.

2. Permanent structures, including, but not limited to, fences, buildings, and permanent landscaping, shall not be erected in a drainage easement or fee strips.

3. Maintenance of detention facilities is the sole responsibility of the owner of the property and/or a homeowner's association created for the purpose of ownership and/or maintenance of drainage facilities.

4. The Developer shall notify the District in writing at least two (2) regular business days before placing any concrete for drainage structures.

5. The District's personnel shall have the right to enter upon the property for inspection at any time during construction or as may be warranted to ensure the detention facility and drainage system are operating properly.

6. Appropriate cover for the side slopes, bottom and maintenance berm shall be established prior to approval of the construction by the District. A minimum of 95% germination of the grass must be established prior to approval of construction by the District.

7. No building permit shall be issued for any lot within this development until all required drainage facilities, including, but not limited to any required detention facility, has been constructed and approved by the District.

8. The District's approval of the Final Drainage Plan (and Final Plat if required) does not affect the property rights of third parties. The developer is responsible for obtaining and maintaining any and all easements, fee strips and/or any other rights-of-way across third parties' properties for purposes of moving excess runoff to the District's drainage facilities as contemplated by the Final Drainage Plan and Final Plat.

9. All drainage features associated with any construction within the subdivision (or other development) shall be constructed in accordance with the Drainage Plan and/or Drainage

Report for __<name of subdivision>__, dated ________ as prepared by ________________ and approved by the Orange County Drainage District on ___<date>___.

B. SIGNATURE BLOCK—FINAL DRAINAGE PLAN AND PLAT

The following signature block shall be included on the FINAL PLAT for approval by the District's Board of Directors.

"APPROVED BY THE ORANGE COUNTY DRAINAGE DISTRICT BOARD OF DIRECTORS ON THIS THE ___ DAY OF _________, _____.

______________________________	______________________________
DIRECTOR, PRECINCT 1	DIRECTOR, PRECINCT 4
______________________________	______________________________
DIRECTOR, PRECINCT 2	DIRECTOR-AT-LARGE
______________________________	______________________________
DIRECTOR, PRECINCT 3	GENERAL MANAGER

The above have signed this plat based on the recommendation of the District's Engineer who has reviewed all sheets provided and found them to be in general compliance with the District's rules, regulations, and guidelines."

Approval by the District shall not be construed to mean that all the calculations provided in these plans and/or plats have been fully checked and verified, or that construction in accordance with the approved plans provide assurance against any future flood risks. Submittals provided to the District shall constitute a representation by the owner/developer that: plans submitted have been prepared, signed and sealed by a Professional Engineer licensed to practice engineering in the State of Texas and plat has been signed and sealed by a Registered Professional Land Surveyor, licensed to practice in the State of Texas, which conveys the engineer's and/or surveyor's responsibility and accountability.