13.0 Flood Attenuation

13.1 Introduction

One of the most fundamental requirements of stormwater management systems is to control flood discharges so that flood flows are released at pre-developed discharge rates to downstream properties. The pre-developed discharge rate is the rate at which stormwater was discharged when the property was in a natural condition prior to development. The most promising, and historically, the most effective, ways to manage flood discharges have been to avoid the artificial channelization of Major Drainageways and to construct stormwater flood attenuation facilities. The City of Greenwood Village (Village) requires the attenuation of the peak stormwater discharges to pre-development conditions from developed areas for the 5-year and 100-year frequency storms events.

The Village strongly discourages the artificial channelization of its Major Drainageways. Artificial channelization tends to accelerate velocities, increase peak flood discharges, and increase the costs for proper flood management for downstream property owners. The channelization of Major Drainageways is also inconsistent with the well-established policies of the Village to encourage recreation and the enhancement of the aquatic, terrestrial, and avian wildlife habitat along the Major Drainageways.

The Village strongly encourages the minimization of impervious areas to the maximum practical extent and the construction of on-site flood attenuation to minimize the inevitable increases in flood discharges caused by development. On-site flood attenuation also provides for sediment and debris collection near the source and away from the recreation areas along the Major Drainageways.

The Village will also consider and encourage regional detention facilities when it has been determined by the City Manager or designee that on-site detention is impractical or not in the best interest of the health, safety, and welfare of the Village. The City Manager or designee will prepare a rationale statement evaluating any proposal for regional detention. The rationale statement shall consider the same factors described in Section 3.3. The recommendations of the City Manager or designee may be appealed by the applicant or a resident of the Village in accordance with the procedures presented in Section 3.4.

13.2 Types of Stormwater Storage

Several types of stormwater storage can be constructed to meet the flood attenuation requirements of the Village.

13.2.1 Upstream Storage

The storage of runoff at the point of rainfall occurrence is known as "upstream storage." Upstream storage may take the form of rooftop storage, parking lot storage, and ponding in landscape areas. Upstream storage is particularly amenable to high-density commercial developments with large rooftop and parking areas. It is also amenable to parks and open space areas where short-term ponding does not excessively infringe upon the intended use of the property.

A well-designed upstream storage system can significantly reduce the requirements for the construction of stormwater facilities and flood-control improvements. It can also substantially enhance stormwater quality if the upstream storage area is landscaped with grasses or wetland vegetation and the stormwater is infiltrated into the ground.

13.2.2 Offstream Storage

Offstream storage usually occurs in depressed open areas outside of the main channel of the drainageway. Offstream storage can occur in constructed reservoirs or low-lying recreational fields where only storm hydrograph peaks are routed to the facility. These facilities usually require a side channel spillway or overflow from the main channel.

13.2.3 Underground Storage

Storage facilities can be built underground using large diameter pipes or other structures. These facilities tend to be expensive and are therefore usually used only for controlling runoff from commercial facilities with tight site limitations. A carefully designed access and maintenance program is a key element for the long-term success of these facilities.

13.2.4 Channel Storage

Low flow channels with wide bottoms can provide effective storage as an inherent part of their hydraulic characteristics. Wetland vegetation is particularly effective in slowing down peak discharge rates, thereby effectively providing storage and flood attenuation.

13.2.5 Retention Storage

The storage of runoff for a significant period of at least seven days is known as retention storage. Retention storage is frequently referred to as "wet storage" because of the relative permanence of the storage pool. A properly designed retention storage system can provide recreation and esthetic uses as well as providing for some enhancement of stormwater discharges from the retention storage basin.

13.2.6 Detention Storage

Detention storage is probably the most common form of stormwater storage. The flood discharges are typically held in a detention storage facility for several hours. Detention storage facilities are sometimes known as “dry ponds.”

Detention storage facilities are frequently designed to provide the multi-purpose functions of flood attenuation and water quality enhancement. A portion of the detention facility can be designed to include wetlands or an extended detention basin that slowly releases runoff over a few days. The extended detention time provides treatment for the water quality design storm. The water quality design storm is typically smaller than the design storm for flood attenuation.

13.3 Design Criteria

The analysis and design of storage facilities for flood attenuation purposes shall be completed in accordance with the criteria presented in the Storage Chapter, Volume 1 of the Urban Drainage and Flood Control District (UDFCD) Drainage Criteria Manual. Detailed design criteria and design procedures specific for the Village are highlighted in the following Sections.

The design policy of the Village is to provide guidelines that are consistent with regional stormwater drainage policy. The guidelines are intended to serve as a minimum standard and not intended to replace site-specific analysis and design requirements of individual projects.

Software packages for analysis and design shall be applied in accordance with the criteria presented in Chapter 17.0.

13.3.1 General Criteria

All flood attenuation facilities shall be designed in accordance with the following criteria:

1) Existing drainage courses shall be preserved.
2) All flood attenuation facilities shall be designed to provide control for the 5-year and 100-year design storms.
3) Unless otherwise specified, local detention shall be provided to control on-site runoff. Off-site runoff from upstream drainage areas shall be diverted around any proposed detention facility or the detention facility shall be designed to control the off-site runoff as if it were on-site runoff.
4) Flood attenuation storage volume shall be provided to reduce the peak discharge rate for developed site conditions to the peak discharge rate for pre-development site conditions. Developed site conditions shall include all anticipated future development that will impact the site drainage basin. Pre-development site conditions are defined as undisturbed natural conditions.

5) Channel conveyance facilities shall be designed with adequate hydraulic capacity to convey the combined off-site and on-site runoff through the property. The off-site peak discharge rate shall be determined in accordance with the most recent land-use planning maps or at the direction of the Village.
6) Drainage facilities shall incorporate design features to minimize, maintain, and enhance the physical aesthetics of the site. Design features may include proposed grading that mimics or improves the existing site profile and use of construction materials that visually integrate with the ambient environmental textures and patterns.
7) Properties served by an existing regional detention facility may only utilize the existing facility if the following conditions are met:
   a. Calculations shall be provided that show that the regional facility is adequate to mitigate the runoff from the property. The entire basin that drains to the facility shall be included in the calculations. The facility shall meet the requirements of this Drainage Criteria Manual.
   b. Calculations shall be provided that show that the drainage system between the property and the regional facility is adequate to convey the runoff from the property. The entire basin that drains to the drainage system shall be included in the calculations. The drainage system shall meet the requirements of this Drainage Criteria Manual.
8) Non-residential redevelopment. Non-residential redevelopment projects are encouraged to use regional solutions to meet the flood attenuation requirements of this Drainage Criteria Manual.

13.4 Design Procedures

Design procedures specific for the Village, which deviate from those presented in the UDFCD Drainage Criteria Manual are highlighted in the following Sections.

13.4.1 General

The construction of a swimming pool may or may not increase the effective impervious area on a site. If the pool is covered in such a way that it sheds runoff, the pool acts as if it was a new impervious surface and will increase the runoff from the site. If the pool is not covered, it will reduce runoff from the site. Because of the variation in the design of pool covers and the likelihood that a pool cover will be replaced with a different design sometime during the life of the pool, it is impractical to assign a specific permanent impervious area to a pool.
Therefore, it shall be assumed that the surface area of the pool will not create a change in the impervious area for the site. However, the impervious area created by the pool deck area shall be considered as new impervious area for the site.

Minor Development and Redevelopment projects will have minimal impact on stormwater runoff patterns and water quality. Minor Development and Redevelopment projects may submit

a design in accordance with the Simplified Method as described in Section 13.4.2. The Simplified Method includes both the flood attenuation and water quality management requirements for the increased impervious area.

Major Development and Redevelopment projects will have significant impact on stormwater runoff patterns and water quality. Major Development projects shall provide both flood attenuation and water quality management for the entire site. Major Redevelopment projects shall provide both flood attenuation and water quality management for the disturbed and increased area. Major Development and Redevelopment projects shall use one of the following methods:

1) To establish a hydraulically consistent and region-specific detention design, UDFCD adopted a set of empirical relationships to simplify sizing of detention facilities that provide flood attenuation. Required detention storage for projects with tributary areas smaller than 10 acres may be determined using the empirical relationships in accordance with the criteria presented in Section 13.4.3 Equation Detention Method.
2) The Colorado Urban Hydrograph Procedure (CUHP), a computer program written for the UDFCD, is widely used and accepted in the Denver region. The synthetic hydrograph parameters represent statistical precipitation averages derived from the historical period of record for watersheds of various sizes. Chapter 6.0 provides a detailed discussion of the applicability of the CUHP program in designing drainage facilities in the Village. Required detention storage for drainage areas larger than 10 acres in size shall be determined by routing through CUHP in accordance with the criteria presented in Section 13.4.4 Hydrograph Detention Method.
3) Major Development and Redevelopment projects that consist of a single family residential lot may submit a design in accordance with the Retention Method as described in Section 13.4.5.

13.4.2 Simplified Method

Minor Developments and Redevelopments can fulfill the requirements of this Drainage Criteria Manual using the Simplified Method. Projects using the Simplified Method must also meet the no net loss wetlands requirement of this Drainage Criteria Manual. The Simplified Method is based on the following assumptions:

1) All runoff calculations are based on impervious area and total lot size.
2) Stormwater flows are not separated into multiple downstream drainage basins.
3) The stormwater retention volume requirements are based on the Equation Detention Method (Table 13-1) for Type II (clay loam) soils.
4) The 60% phosphorus removal can be achieved with the retention of 0.45 inches of rainfall on-site based on Figures 6-2 and 6-4 for Type II (clay loam) soils.
5) A retention facility will be used. If a detention facility is used, then the facility

shall be designed by a professional engineer licensed in the State of Colorado.

Figure 13-1 shows the required retention volume based on lot size and amount of impervious area, with sufficient volume for both flood attenuation and water quality control, using the Simplified Method.

13.4.3 Equation Detention Method

The Equation Detention Method shall be used to size detention for drainage areas smaller than 10 acres in size. The equations presented in Table 13-1 shall be used to determine the minimum required detention volume and the maximum allowable release rates.

Table 13-1: Equation Detention Method

Design Storm Recurrence Interval	Minimum Detention Volume $V=KA^{(1)}$	Maximum Release Rates (cfs/ac) by Soil Type		
		I	II	III
5-yr	$K_5 = (0.77\ I – 2.65)/1000$	0.17	0.13	0.07
100-yr	$K_{100} = (1.78\ I – 0.002[I]^2 – 3.56)/1000$	1.00	0.85	0.50

where: V = minimum required storage volume (ac ft)
I = developed basin imperviousness (%)
A = tributary drainage area (ac)

13.4.4 Hydrograph Detention Method

The Hydrograph Detention Method shall be used to size detention for drainage areas larger than 10 acres in size using the CUHP as described in Chapter 6.0.

The applicant shall include sufficient documentation to clearly identify the design parameters. The maximum release rate shall be the rate specified in Table 13-1 or a rate approved by the Village determined based on an engineering analysis of site-specific pre-development conditions.

13.4.5 Retention Method

Major Development and Redevelopment projects that consist of a single family residential lot can fulfill the requirements of this Drainage Criteria Manual using the Retention Method. The Retention Method utilizes either full retention of the runoff or a combination of retention and detention. Developments using the Retention Method must also meet the no net loss wetlands requirement of this Drainage Criteria Manual. The Retention Method is based on the following

assumptions:

1) All runoff calculations are based on impervious area and total lot size.
2) Stormwater flows are not separated into multiple downstream drainage basins.
3) The stormwater retention volume requirement is based on 1.5 times the volume of runoff generated by a 24-hour, 100-year storm event using Type II (clay loam) soils.
4) The stormwater detention volume requirements are based on the Equation Detention Method (Table 13-1) for Type II (clay loam) soils.
5) The 60% phosphorus removal can be achieved by the retention of the runoff.

13.4.5.1 Full Retention with No Discharge

The goal of a pond designed for full retention with no discharge would be to retain all of the runoff from the site. This often creates a somewhat permanent pool of water depending on the amount of runoff and the time between the storm events. Figure 13-2 shows the required retention volume based on lot size and amount of impervious area for a retention pond that does not have an outlet.

13.4.5.2 Retention with Discharge

The goal of a pond designed with a combination of retention and detention would be to retain the volume of runoff from the site that exceeds the pre-developed volume. The pre-developed volume would then be detained and released at the rates shown in Table 13-1. Figures 13-3 and 13-4 show the required retention and detention volumes based on lot size and amount of impervious area for a retention pond that has an outlet. Figure 13-5 shows the width of the outlet weir depending upon the depth of the detention portion of the pond.

13.5 Open Space Storage

13.5.1 State Regulatory Criteria

Any embankment used for storing water that satisfies the criteria for surface area, volume, or height specified in Colorado Revised Statutes 37-87-105 as amended, shall be designed and constructed in accordance with state criteria and shall require plan approval by the State Engineer’s Office.

13.5.2 Detention Facility Volume

Control storage volumes for detention facilities designed to provide water quality treatment and peak attenuation for runoff control are shown schematically in Figure 13-6. It should be specifically noted that any portion of the storage facility that has been designed for water quality enhancement cannot be included in the storage volume required for flood attenuation. The water quality control volume usually contains stormwater for an extended period of time and it must be

assumed that the water quality control portion of the storage facility is full at the beginning of a design storm for flood attenuation.

13.5.3 Grading Requirements

Embankments five feet or less in height shall have a maximum slope of 4 (horizontal) to 1 (vertical), with even flatter slopes preferred. Embankments between five feet and ten feet in height shall have a maximum slope of 3:1. Embankments greater than ten feet in height shall be designed with slopes adequate to maintain structural stability. The minimum bottom slope for all open pond detention facilities shall be 2.0% measured perpendicular to the low flow channel. The minimum longitudinal slope of the low flow channel shall be 1.0%. The maximum side slope for rock-lined embankments shall be 3:1.

13.5.4 Freeboard Requirement

The minimum required freeboard for open space facilities is one foot above the 100-year water surface elevation.

13.5.5 Outlet Configuration

All outlet control structures for detention facilities shall conform to the details in Volumes 2 and 3 of the UDFCD Drainage Criteria Manual. Other configurations that satisfy required release rates must be approved by the City Manager or designee.

13.5.6 Emergency Overflow Structures

Emergency overflow structures to protect the embankment from catastrophic failure due to an extreme storm event that exceeds the design storage capacity or due to obstructions reducing the capacity of the outlet works shall be provided by an emergency overflow spillway.

The emergency overflow spillway shall be designed with a minimum capacity equal to the 100-year developed peak rate of flow into the facility. Structures shall not be permitted in the path downstream of the emergency overflow structure.

13.5.7 Vegetation Requirements

All open space detention facilities shall be vegetated using irrigated sod or natural dry-land grasses in accordance with the criteria adopted by the UDFCD. Additional landscaping that enhances the visual esthetics of the site is encouraged.

13.6 Parking Lot Storage

Detention design for parking lots shall conform to the general hydraulic criteria presented in Chapters 9.0 and 10.0 and to the specific criteria presented in this Section.

13.6.1 Depth Limitation

The maximum allowable ponding depth for the 100-year design storm is 12 inches.

13.6.2 Outlet Configuration

Inlets shall be designed with pipes having a minimum diameter of 18 inches. Weir outlets shall be designed having a minimum width of 3 inches.

13.6.3 Maintenance

The outlet shall be designed to minimize modifications that effect detention functions. The Village shall evaluate resurfacing activities for impact on volumes and release rates.

13.6.4 Flood Hazard Warning

All parking lot detention areas shall be identified by posting a minimum of two signs. The signs shall have a minimum area of 1.5 square feet and contain the following message:

WARNING:
This area is used to detain runoff
and is subject to periodic flooding
to a depth of (design depth).

Sign materials, geometry, and location are subject to approval by the City Manager or designee.

13.7 Underground Storage

Underground storage is considered to be one of the least preferred methods for storage due to the expense of these structures, difficult maintenance, and possible damage to other structures caused by leakage. Permanent structures shall not be placed directly above the underground detention.

13.7.1 Materials

Underground detention storage shall be constructed using corrugated metal aluminum pipe (CMP), reinforced concrete pipe (RCP) or reinforced concrete vaults. The pipe thickness, cover,

bedding, and backfill shall be designed for an AAHSTO H-20 loading condition or greater as required by the Village. The use of CMP shall require a soil analysis to ensure that the corrosivity of the soil will not shorten the design life of the culvert.

13.7.2 Pipe Storage Configuration

The minimum pipe diameter shall be 36 inches. Pipe segments shall be sufficient in number, diameter, and length to provide the required design storage volume. Pipe segments shall be placed side by side and connected at both ends by elbow and tee fittings as shown in Figure 13-7. The pipe segments shall be continuously sloped at a minimum of 0.25% to the outlet. Equivalent alternative configurations shall require approval by the City Manager or designee.

13.7.3 Inlet and Outlet Configuration

The inlets to the detention pipes shall be either surface inlets or subsurface connections within the local storm sewer system. The outlet from the detention pipes shall consist of a pipe with a minimum diameter of 18 inches and a maximum length of 25 feet. A two-pipe outlet may be required to control both the minor and the major design storms. For a two-pipe outlet, the invert of the lowest pipe must be set at the lowest invert of the storage pipes. If an orifice plate is required to control the release rates, the plate shall be hinged to open into the detention pipes to facilitate back flushing of the outlet pipe.

The outlet pipe shall discharge into a manhole or into a drainageway with erosion protection designed in accordance with the criteria presented in Chapter 12.0.

13.7.4 Maintenance Access

Access manhole locations for the detention facility shall be provided for cleaning the pipe segments and shall be located in accordance with the details shown on Figure 13-7. Maintenance of the pipe segments shall be in accordance with the schedule shown on Figure 13-7.

INSERT FIGURES 13-1 THROUGH 13-7

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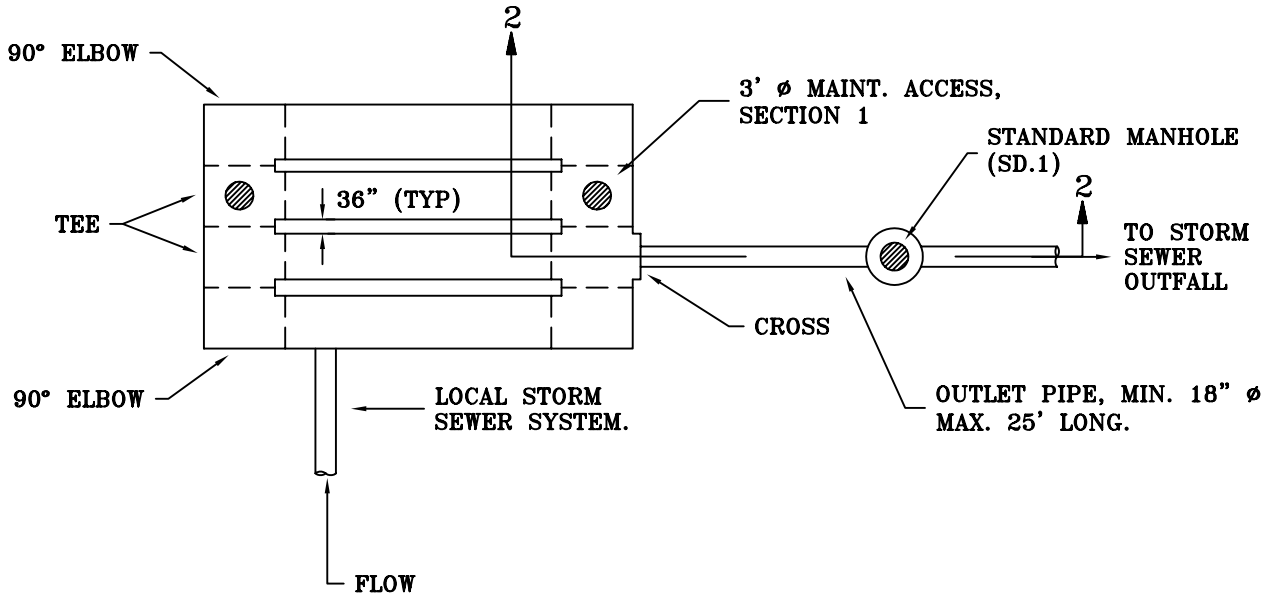
GENERAL PLAN
(NTS)



SECTION 2 OUTLET
(NTS)

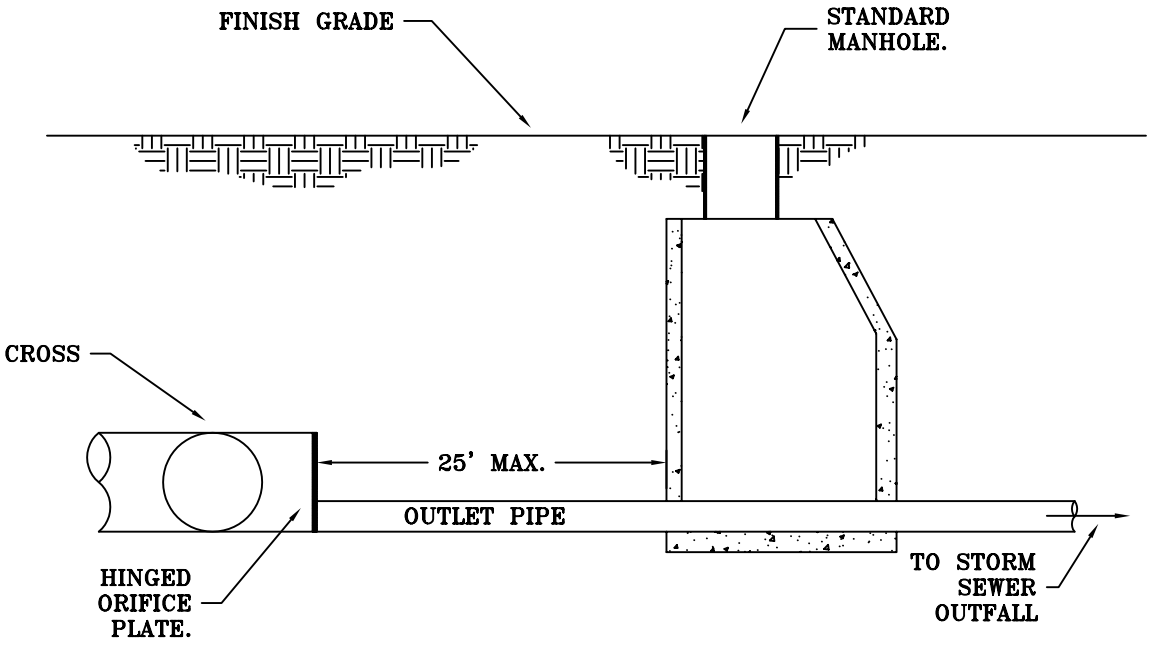


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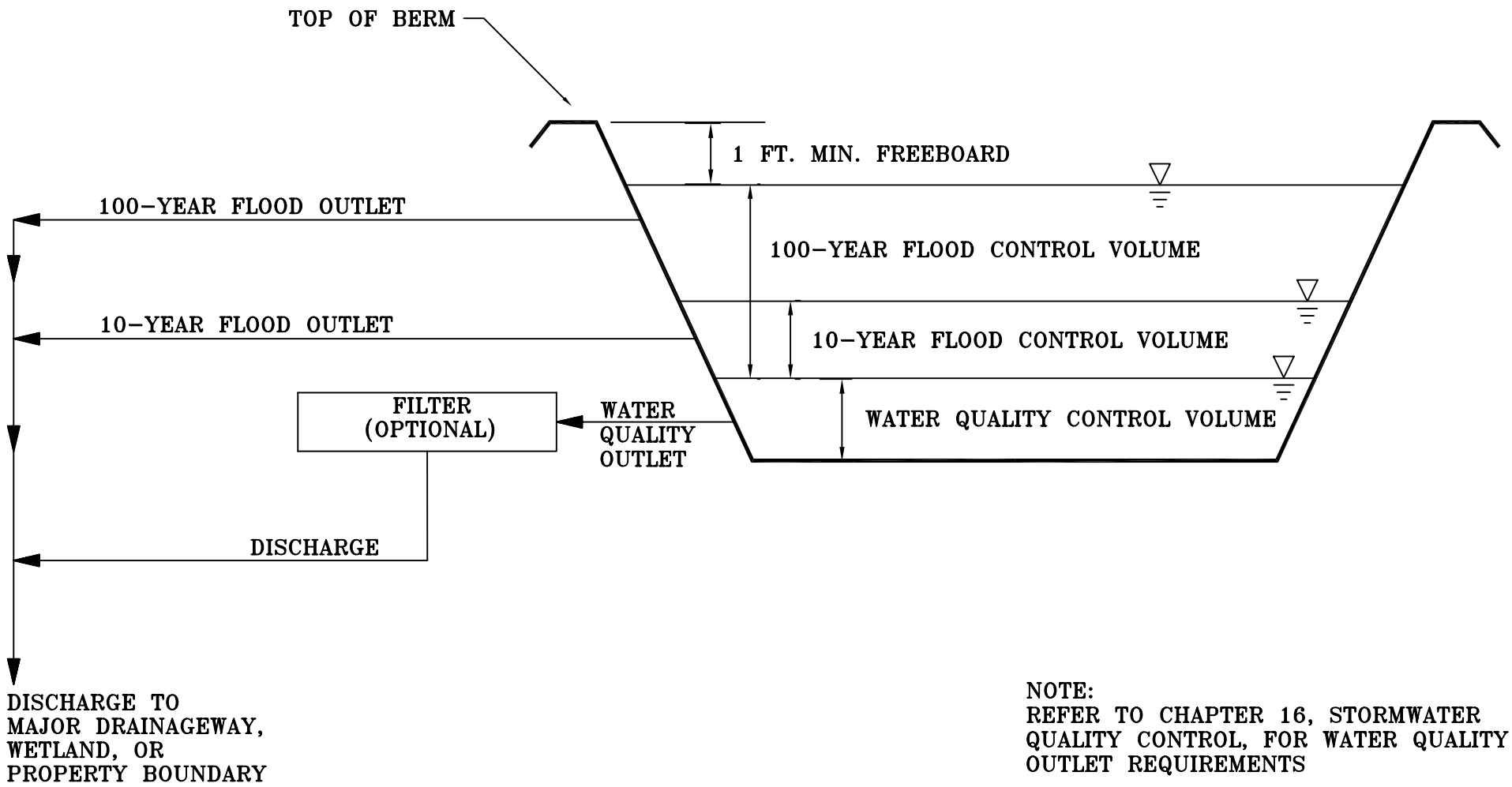
Figure 13-7
Underground Detention
Sheet 1 of 2

FIG13-7, SHEET 1.dwg



NOTE:
REFER TO CHAPTER 16, STORMWATER QUALITY CONTROL, FOR WATER QUALITY OUTLET REQUIREMENTS

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Figure 13-6
Required Distribution of
Detention Facility Volumes

FIG13-6.dwg

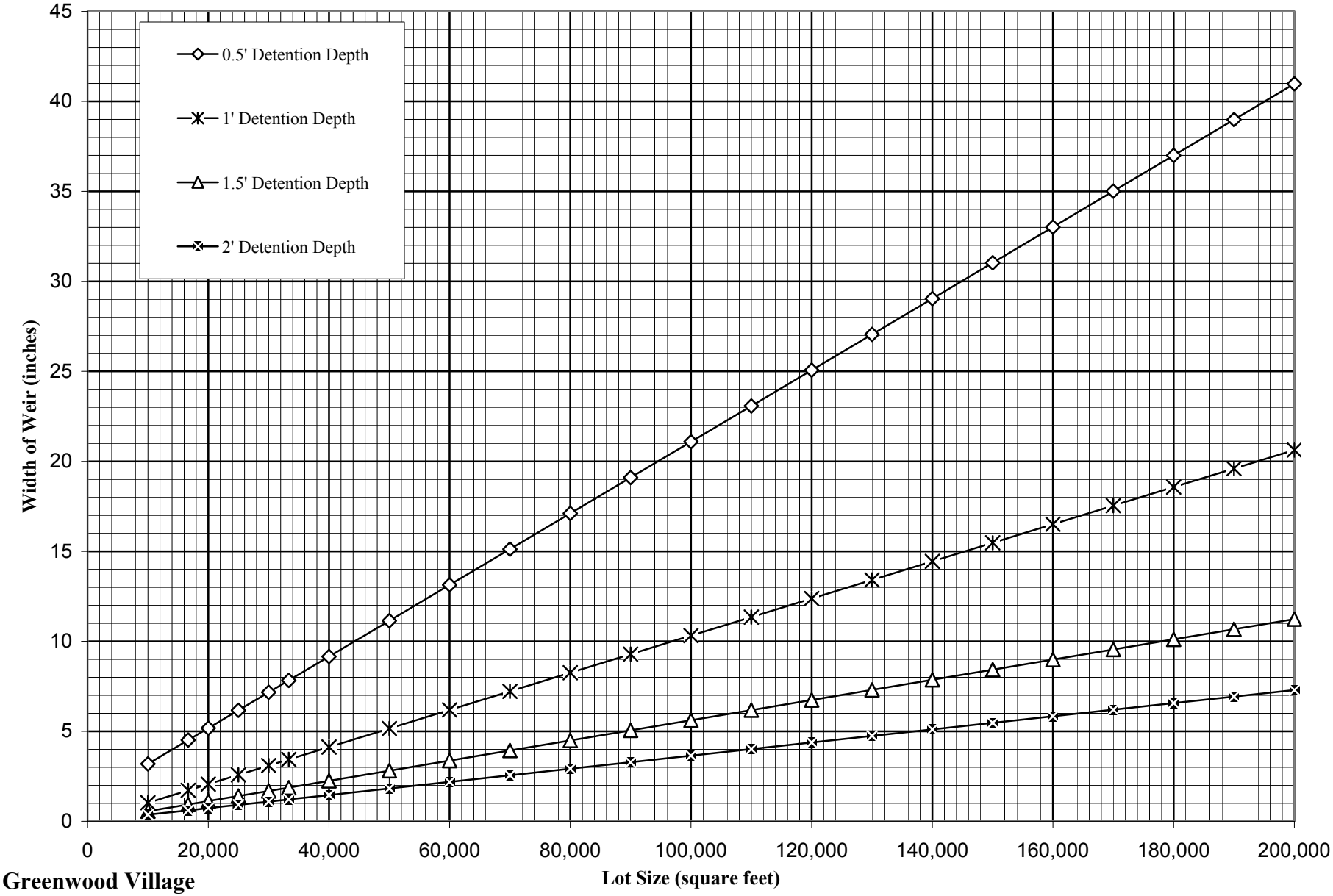

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Figure 13-5
Retention Method - Detention Weir Sizing

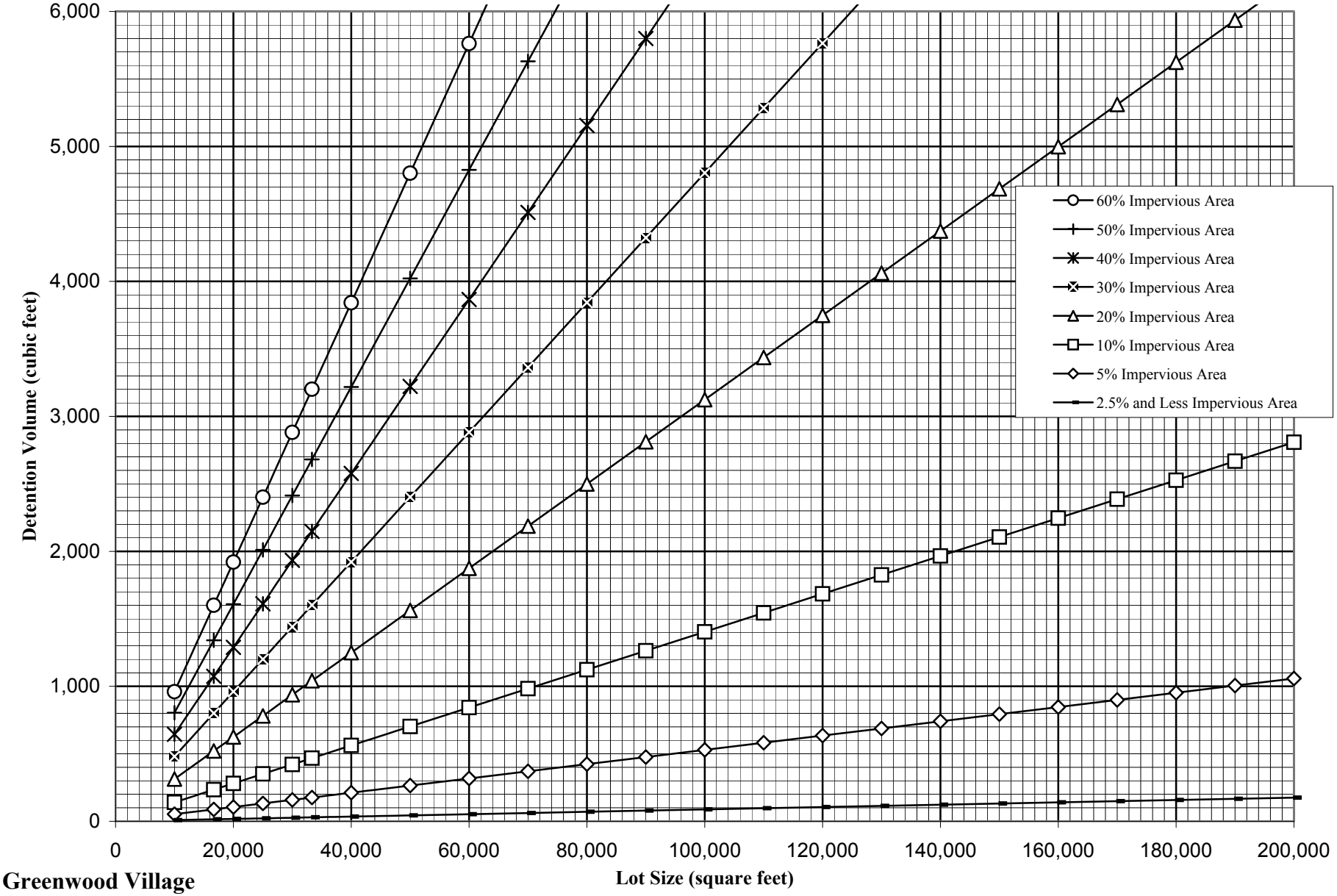

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Figure 13-4
Retention plus Detention Method - Detention Volume

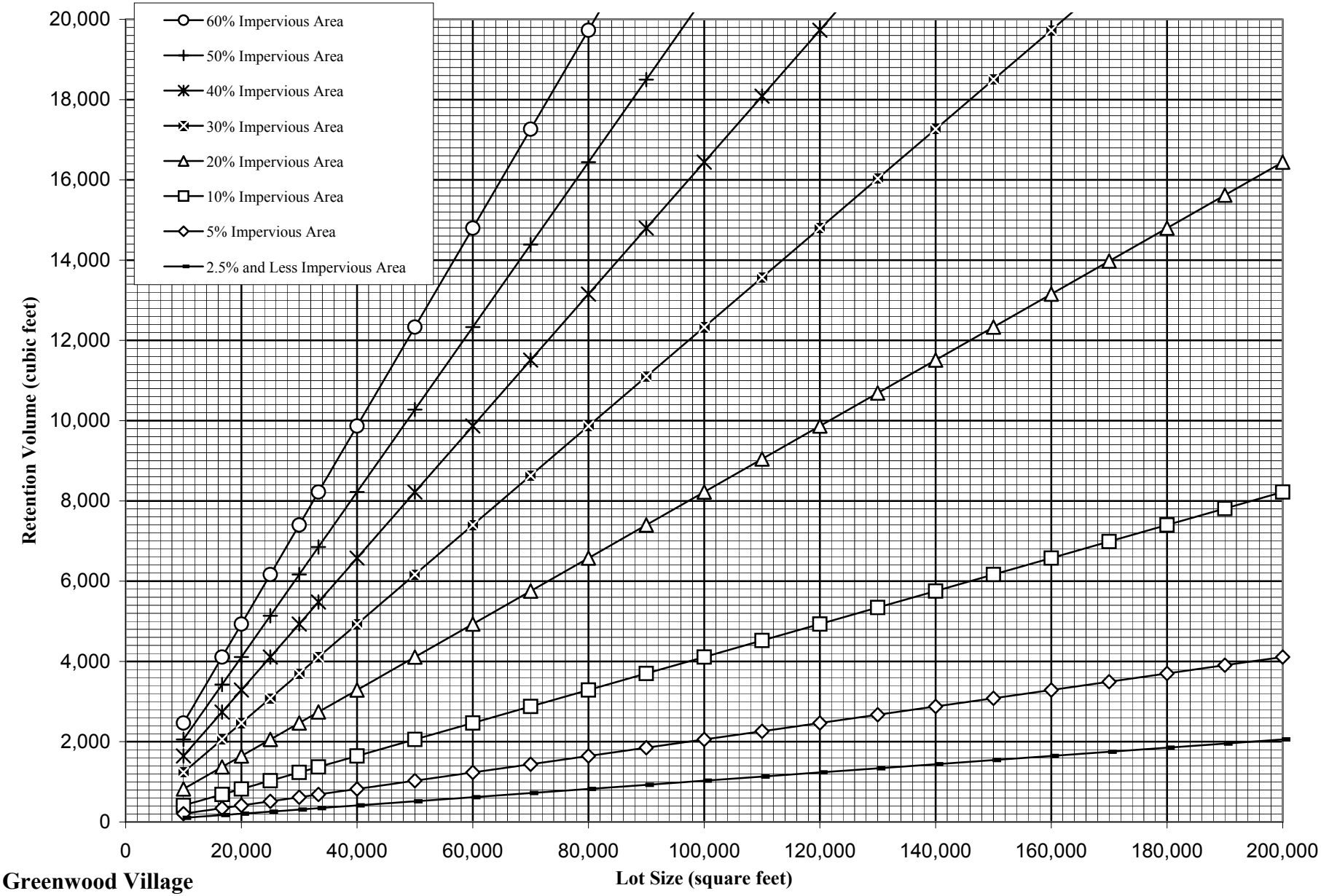

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Figure 13-3
Retention Method - Retention Volume with Discharge

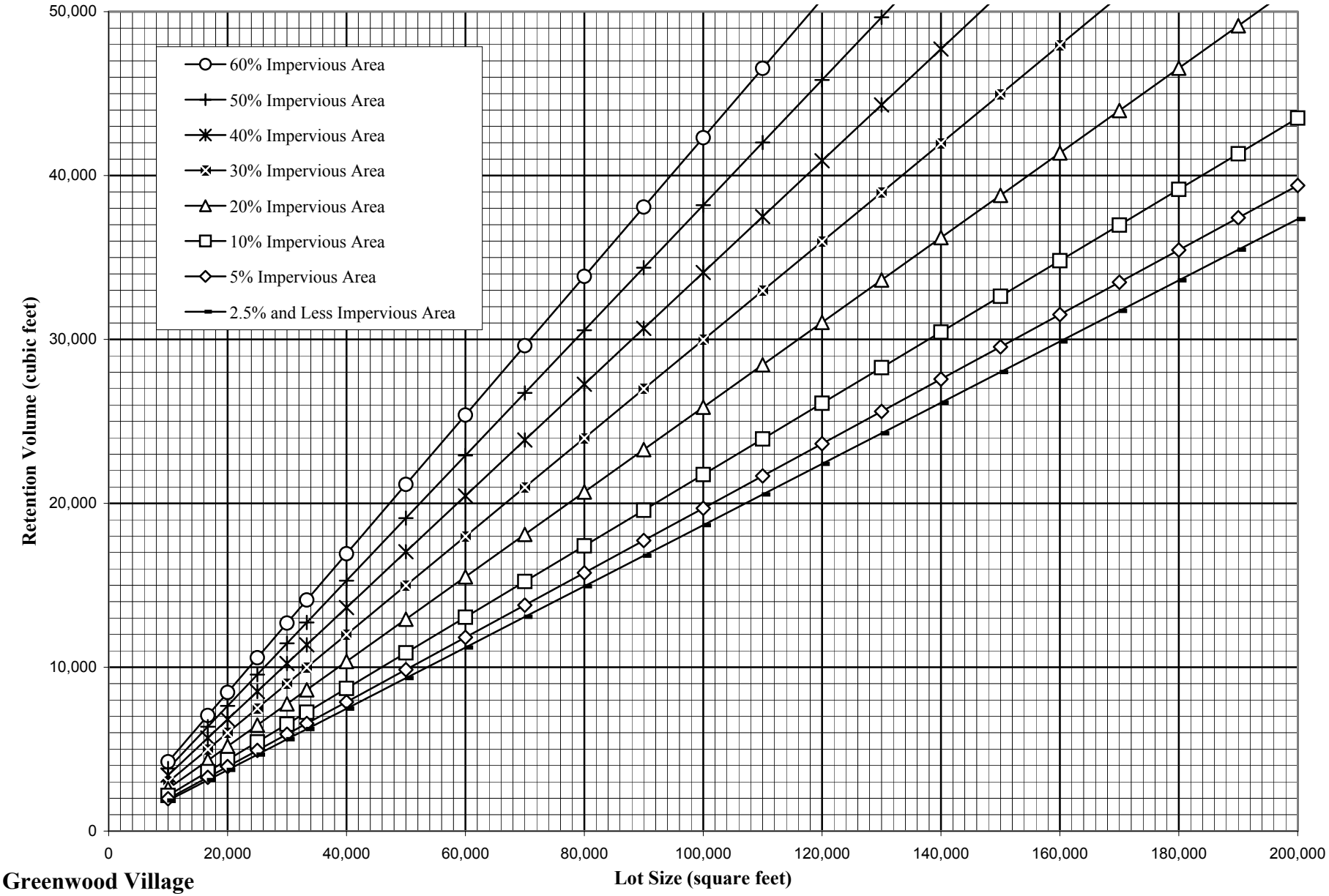

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Figure 13-2
Retention Method - Full Retention with No Discharge

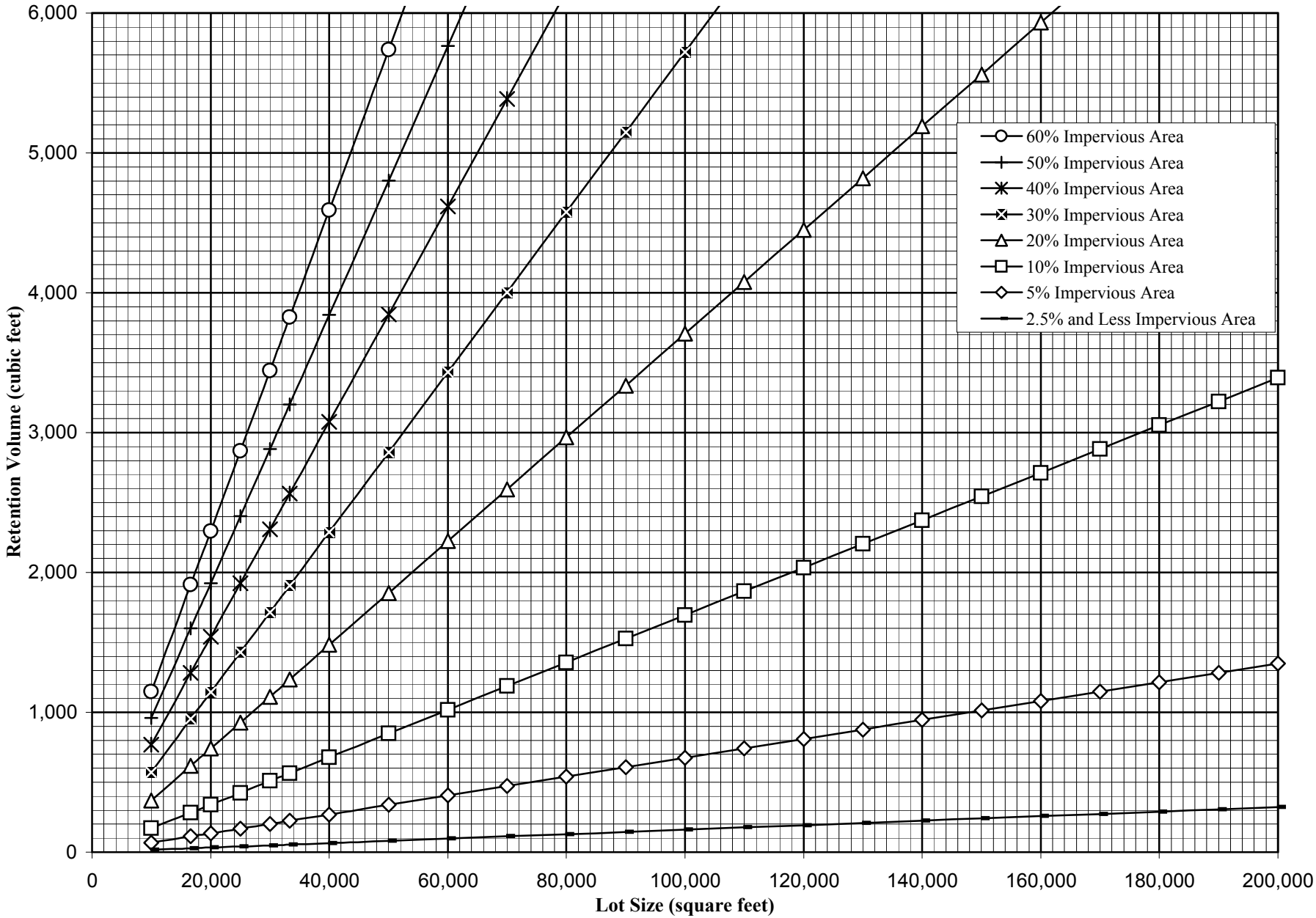

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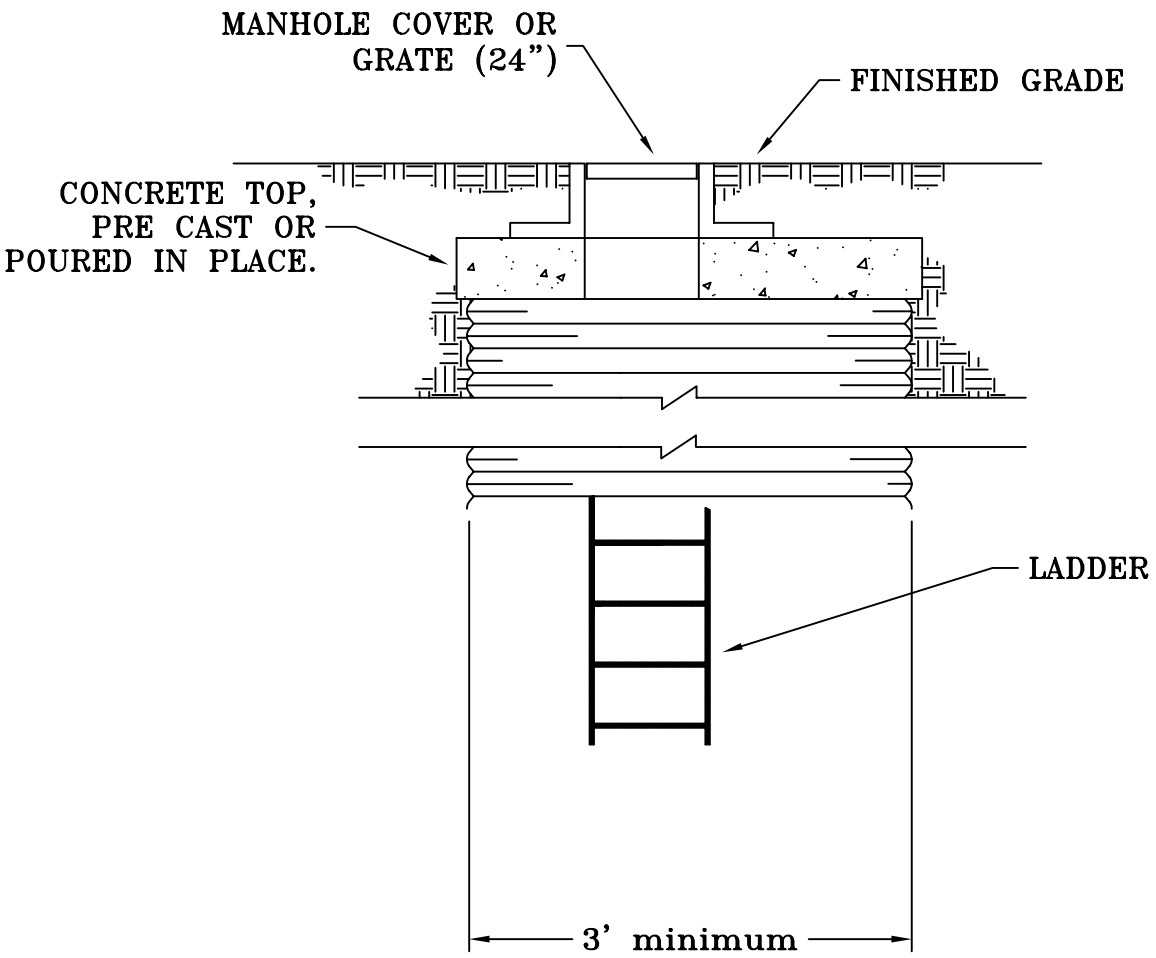
Figure 13-1
Simplified Plan
Retention Requirements

FIG 13-1 -Fig 13-1 Chart



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MAINTENANCE ACCESS REQUIREMENTS

DETENTION PIPE SIZE (INCHES)	MAXIMUM SPACING (FEET)	MINIMUM FREQUENCY
36 to 54	150	Every pipe segment
60 to 66	200	Every other pipe segment
>66	200	One at each of the battery pipes

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Figure 13-7
Underground Detention
Sheet 2 of 2

FIG 13-7, SHEET 2.dwg