6.0 Runoff

6.1 Introduction

The timing, peak rates of discharge, and volume of stormwater runoff are the primary considerations in the design of drainage facilities for the management of flood discharges and water quality in drainage systems. The purpose of this Chapter is to provide a dependable and consistent methodology for estimating storm runoff in the City of Greenwood Village (Village). It depends to a great degree on the general methods developed by the Urban Drainage Flood Control District (UDFCD) that are applicable to the entire region. This Chapter includes refinements that are necessary to address the local physical conditions, including soil types and typical drainage basin size, and water quality goals of the Village. The methodologies for estimating storm runoff described in this Chapter are to be used for all drainage studies submitted to the Village. Whenever there is a conflict between the methodologies described in the UDFCD Drainage Criteria Manual and this Drainage Criteria Manual, the methodologies described in this Drainage Criteria Manual shall be used.

6.2 Flood Control Design Runoff

6.2.1 Basin Size Criterion

The Rational Method and the Colorado Unit Hydrograph Procedure (CUHP) are the two methods that have been widely adopted as the preferred methods for estimating runoff patterns in the Denver metropolitan region. The Rational Method is a simplified approach that has proven to be reliable for the design of storm sewers and determining runoff from small drainage basins. The CUHP is a more sophisticated approach and is generally recommended for larger basins with more complex design needs. The UDFCD recommends the use of CUHP for basins larger than 90 acres. For smaller basins, the UDFCD has developed a modified CUHP method that can be applied to basins in the 10 to 90 acre range.

Most of the drainage basins within the Village are in the range of 10 to 90 acres and require relatively sophisticated drainage improvements to meet the land use, recreation, flood control, and water quality goals of the Village. The optimum design of these facilities requires significantly more study, thought, and judgment than can be obtained using the Rational Method. For these reasons, the Village requires the use of the more sophisticated CUHP for estimating runoff from any basin larger than 10 acres.

The CUHP provides a higher degree of dependability for estimating the peak runoff rates and the time of distribution of runoff. Both of these parameters can have a significant impact on the design of a flood control facility such as a detention facility or grass-lined drainage channel. The requirement to use CUHP for all drainage basins larger than 10 acres is a reasonable

application of this technology. It is likely that the critical rainfall pattern for determining the peak rate of runoff for basins in the 10 to 90 acre range will be the 1-hour storm because the times of concentration for basins this size in the Village are typically between 10 and 45 minutes.

Use of the Rational Method for storm sewer design is a well-established local and regional practice that is appropriate for drainage design with multiple, small basins. The Village will continue to permit use of the Rational Method for estimating runoff in storm sewer design.

6.2.2 Application of Design Methods

The first step in applying the various analysis and design methods is to obtain a representative topographic map of the drainage basin and to define the boundaries of all the relevant drainage basins. Basins to be defined include all basins tributary to the area of study and sub-basins in the study areas. Field checks and possibly field surveys should be completed for each basin. At the preliminary stage of planning, the possibility of the diversion of transbasin waters into the study basin should be investigated. Such imports of drainage water could be a result of drainage improvements by others or overflows from irrigation canals such as the Highline Canal.

Transbasin diversions out of the study area should also be kept in mind. The engineer should be very cautious when reducing a design flow due to a transbasin export, particularly for the major storm analysis. This approach could cause significant drainage problems in the basin receiving the exported flows.

The boundaries of the major storm drainage basin frequently, but do not always, coincide with the boundaries of the minor storm drainage basin. This is often the case in urban areas where low flows from the minor storm will remain contained by the curb and gutter and follow the grade, but when a large flow occurs, the water will be deep enough to cause part of the water to overflow street crowns and flow into a new sub-basin.

When analyzing the major runoff event occurring on an area that has a storm sewer system sized for the minor storm, care must be used when determining the time of concentration. Normally, the design of storm sewers assumes that all of the runoff is collected by the storm sewer or gutter. For the minor storm design, the time of concentration is, in part, dependent upon the flow time in the storm sewer. However, during the major runoff event, the storm sewers are likely to be at capacity and cannot accept all the runoff flowing to the inlets. This additional runoff then bypasses the inlets and continues overland, generally at a significantly lower velocity than the runoff in the storm sewers. This requires an analysis of different times of concentration between underground flow and overland flow.

This difference in travel times allows for the storm sewer to continue flowing full for a longer period and, in effect, carry significant portions of the major runoff. The basis for this increased benefit is that the excess runoff from one inlet will flow to the next inlet downhill, using the

overland route. If that inlet also at capacity, the runoff will often continue on until capacity is available in the storm sewer. The analysis of this aspect of the interaction between the storm sewer system and the major storm runoff is complex. The most useful procedure for this analysis is the routing of the major and minor storm runoff hydrographs through the overland and storm sewer routes concurrently.

6.2.3 Rational Method

As discussed in Section 6.2.1, the Rational Method can only be used for drainage studies in the Village with basins smaller than 10 acres. The Rational Method is based on the Rational Formula as presented in the Runoff Chapter, Volume 1 of the UDFCD Drainage Criteria Manual. The assumptions and limitations presented in the UDFCD Drainage Criteria Manual should be reviewed to ensure that the use of the Rational Method is appropriate.

6.2.3.1 Time of Concentration

The UDFCD provides a methodology for estimating the times of concentration for both urban and rural areas in the Runoff Chapter, Volume 1 of its Drainage Criteria Manual. This method shall be used to estimate times of concentration for use with the Rational Method in the Village. The initial flow time shall be used for sheet flow conditions only. Once the flow becomes concentrated by a swale, ditch, gutter, or storm sewer, then the travel time equations shall be used.

The minimum time of concentration shall be 5 minutes for urban areas and 10 minutes for rural areas. The maximum time of concentration for urbanized areas shall not exceed that discussed in the UDFCD Drainage Criteria Manual.

6.2.3.2 Intensity

The intensity, I, is the average rainfall rate, in inches per hour, for the period of maximum rainfall of a given frequency having a duration equal to the time of concentration.

After the design rainfall has been selected (i.e., 2-yr, 5-yr, or 100-yr frequency occurrence) the intensity can be determined for the selected time of concentration using Figure 5-1.

6.2.3.3 Runoff Coefficient

The runoff coefficient, C, represents the integrated effects of infiltration, evaporation, retention, flow routing, and interception all of which effect the time distribution and peak rate of runoff. Determination of the runoff coefficient requires judgment and understanding by the engineer.. The coefficients presented in the Runoff Chapter, Volume 1 of the UDFCD Drainage Criteria Manual shall be used. Because the coefficients vary with frequency, no further adjustments are needed for large storms.

The determination of the percent of impervious area is an important parameter for determining the runoff coefficient. Surface area is either considered pervious or impervious. Pervious areas are those surface areas where water can readily infiltrate into the ground. Impervious areas are those surface areas where the infiltration of water into the ground is restricted. Examples of impervious areas are parking lots, sidewalks, roads, pool deck areas, and structures. As an area is developed, i.e., the land use changes from undeveloped to commercial, industrial, and/or residential use, the amount of impervious area typically increases. As the percent of impervious area increases, generally less water infiltrates into the ground. This will cause the stormwater runoff volumes to increase, the time to the runoff peak to decrease, and the stormwater peak runoff rates to increase.

The proposed development conditions shall be used to estimate the percent impervious area. The estimated imperviousness presented in the Runoff Chapter, Volume 1 of the UDFCD Drainage Criteria Manual provides general guidance for estimating the percent impervious area during the early planning stages for a project. The estimates present typical values for the Denver region. For lots greater than ½ acre, Figure 6-1 shall be used. Figure 6-1 is based on a survey of actual percent impervious area for modern low-density residential subdivisions in the Village and Lakewood, Colorado. The estimates on probable impervious area are to be used in the early stages of planning for a project and can be used only for a Conceptual and Preliminary Drainage Study. As soon as a site layout has been prepared by the applicant, a more accurate estimate of the impervious area for the project will be required to be used. Impervious area estimates based solely on the information contained in UDFCD Drainage Criteria Manuals and Figure 6-1 will not be acceptable for inclusion in a Final Drainage Study.

6.2.4 CUHP Method

As discussed in Section 6.2.1, the CUHP shall be used for all drainage studies in the Village with basins larger than 10 acres.

6.2.4.1 CUHP Rainfall Patterns

The CUHP was designed to be used with the NOAA 1-hour rainfall depths for the Denver region. The temporal distribution to be used in the Village can be derived using the Village's rainfall depths and the methodology described in the Rainfall Chapter, Volume 1 of the UDFCD Drainage Criteria Manual.

6.2.4.2 CUHP Effective Rainfall

Effective rainfall is that portion of precipitation which runs off land into a drainageway closely following a precipitation event. Those portions of precipitation that do not result in runoff are called abstractions. Abstractions include interception by vegetation, evaporation, infiltration, storage in all surface depressions, and long-time surface retention.

The abstractions for pervious areas tend to be substantially larger than those for impervious areas. Any reasonable estimate of effective rainfall must be based on a reasonably accurate estimate of the impervious area. Refer to Section 6.2.3.3 for a discussion of impervious area and the acceptable methods for estimating impervious area.

Precipitation that is collected and held in small surface depressions and does not become a part of general surface runoff is called depression storage. Most of this water is eventually infiltrated or evaporated. The CUHP method requires values for retention losses as input in calculating effective rainfall. The actual input to the CUHP can be an area-weighted average for the basin.

Infiltration is the flow of water into the soil surface. Soil type and soil moisture content are the most important factors for determining infiltration rates. Fine-grain soils, clays and clay loams, exhibit slower infiltration rates and coarse-grained soils, sands, exhibit faster infiltration rates. As soil moisture increases, the rate of infiltration decreases. If the soil has several layers or horizons, the least permeable layer will control the maximum infiltration rate. Vegetation, lawn grass in particular, tends to increase infiltration by loosening the soil on the surface. Other factors that affect infiltration rates include slope of land, quality of water, age of lawn, and soil compaction.

As the rainfall continues, infiltration rates decrease. When a rainfall event occurs on dry soil, the infiltration rate is higher than if it occurs on a wet soil, such as irrigated lawn grass. This changing rate of infiltration is more important for small rainfall events which carry a majority of the stormwater pollution than it is for larger rainfall events such as the 100-year storm.

The UDFCD uses Horton's Equation for estimating infiltration abstractions for the CUHP. The CUHP Method described in the Runoff Chapter, Volume 1 of the UDFCD Drainage Criteria Manual shall be used for estimating runoff hydrographs in the Village.

6.3 Water Quality Control Design Runoff

Urbanization typically leads to a decrease in pervious land areas. This, in turn, causes an increase in the volume of runoff and typically allows accumulated pollutants to more easily wash off the surface quickening their conveyance through the watershed. Human activities such as lawn fertilization, use and disposal of chemicals, and ice control on streets also increases the potential pollutant loads on receiving streams during a storm.

The concept of a "first flush" of stormwater pollutants has been studied for a number of years with mixed conclusions. The first flush refers to the initial higher concentrations of pollutants contained in the runoff at the beginning of a rainfall event. Although there is a high degree of certainty that the concentrations of pollutants in the runoff are higher at the beginning of the storm, there is less certainty concerning the relative importance of this first flush when compared with the lower concentrations of pollutants which occur as the storm continues. Understanding

these differences can be important if a stormwater quality management facility is designed to focus only on the treatment of the first flush.
The Village requires the design of stormwater quality management systems for an entire design storm. The focus of the design effort then shifts to the consideration of the size of the runoff event to be included. The following Sections define a procedure for selecting the size of the storm to be managed by the water quality-related improvements in a drainage system. Chapter 16.0 defines the procedures for estimating the effectiveness of alternative control measures for removing pollutants from the selected design storm. Based on an analysis of the relative annual contribution of pollutants for the design storm conditions and the effectiveness of the proposed improvements to remove the pollutants for the design storm, the overall effectiveness of the proposed system can be evaluated and compared with the stormwater quality goals of the Village.

6.3.1 Precipitation Patterns

The UDFCD has studied precipitation patterns for the Denver region based on many years of record at Stapleton Airport. Based on that analysis, it was concluded that the average storm in the region has an 11-hour duration with an average time interval between storms of 11.5 days. It was further noted that only about 30 storms per year are large enough, with more than 0.1 inches total precipitation, to cause significant runoff. Of these runoff events, approximately 75 percent or 22 events are the result of storms with a total depth of 0.1 to 0.5 inches. Thus, it was concluded that facilities designed to treat runoff from a 0.5-inch event would be “very effective.”

Later, more detailed studies, considered the effects of impervious areas, time intervals between storms, and alternative sizes for capture volumes. These studies concluded that facilities designed to capture the 80th percentile runoff event would remove 80 % to 90 % of the annual total suspended solids load in the stormwater, while doubling the capture volume was estimated to only increase removal rates by 1% to 2 %.

The determination of an optimum design storm for water quality management will depend upon a number of factors, including but not limited to:

1) Type of land use,
2) percent impervious areas,
3) effectiveness of the selected water quality control measures, and
4) water quality goals of the receiving stream.

With this wide range of factors, it is not possible to determine a design storm for water quality control purposes without considering site specific conditions.

To assist in this analysis, the Village has studied in detail the precipitation and runoff patterns that are likely to occur within the Village. Table 6-1 summarizes the precipitation patterns

recorded at the Cherry Creek Reservoir gauge from 1952 through 1997. The total average annual precipitation is 16.37 inches and the average number of runoff events, with precipitation greater than 0.1 inches, is 35.

Table 6-1: Average Annual Precipitation Patterns in Greenwood Village

Precipitation Event Rage (in)	Average Event (in)	Events Per Year (number)	Annual Precipitation (in)	Accumulative Annual Precipitation (in)	Accumulative Annual Precipitation (%)	Accumulative Annual Measurable Events (number)	Accumulative Annual Measurable Events (%)
0.00				0.00	0.00	0.00	0.00
	0.00	294.71	0.00				
0.01				0.00	0.00	0.00	0.00
	0.05	35.39	1.77				
0.10				1.77	10.81	35.39	50.38
	0.15	12.50	1.88				
0.20				3.65	22.30	48.89	68.17
	0.25	6.41	1.60				
0.30				5.25	32.07	54.30	77.30
	0.35	3.85	1.35				
0.40				6.60	40.32	58.15	82.78
	0.45	3.26	1.47				
0.50				8.07	49.30	61.41	87.42
	0.55	2.00	1.10				
0.60				9.17	56.02	63.41	90.26
	0.65	1.50	0.98				
0.70				10.15	62.00	64.91	92.40
	0.75	1.33	1.00				
0.80				11.15	68.11	66.24	94.29
	0.85	0.90	0.77				
0.90				11.92	72.82	67.14	95.57
	0.95	0.62	0.59				
1.00				12.51	76.42	67.76	96.46
	1.05	0.43	0.45				
1.10				12.96	79.17	68.19	97.07
	1.15	0.35	0.40				
1.20				13.36	81.61	68.54	97.57
	1.25	0.28	0.35				
1.30				13.71	83.75	68.82	97.96
	1.35	0.22	0.30				
1.40				14.01	85.58	69.04	98.28
	1.45	0.22	0.32				
1.50				14.33	87.54	69.26	98.59
	1.55	0.20	0.31				
1.60				14.64	89.43	69.46	98.88
	1.65	0.17	0.28				
1.70				14.92	91.14	69.63	99.12
	1.75	0.13	0.23				
1.80				15.15	92.55	69.76	99.30
	1.85	0.10	0.19				
1.90				15.34	93.71	69.86	99.44
	1.95	0.07	0.14				
2.00				15.48	94.56	69.93	99.54
	2.125	0.07	0.15				
2.25				15.63	95.48	70.00	99.64
	2.375	0.07	0.17				
2.50				15.80	96.52	70.07	99.74
	2.625	0.04	0.11				
2.75				15.91	97.19	70.11	99.80
	2.875	0.04	0.12				
3.00				16.03	97.92	70.15	99.86
	3.25	0.08	0.26				
3.50				16.29	99.51	70.23	99.97

	3.75	0.02	0.08				
4.00				16.37	100.00	70.25	100.00
Total		364.96	16.37				

Based on total precipitation records at US Army Corps of Engineers gage at Cherry Creek Reservoir (1952 - 1997).

6.3.2 Determination of Runoff for the Water Quality Design Storm

The runoff for each precipitation event will depend primarily upon the percent imperviousness and the soil type. The runoff for various size precipitation events were estimated for different ranges of percent imperviousness for the three major soil types in the Village using the CUHP Method described in Section 6.2.4. Figures 6-2 and 6-3 show the runoff results from a selected design storm for different soil types and percent imperviousness conditions. These curves shall be used to estimate the runoff volume for a selected water quality design storm.

The peak rate of runoff for the selected design storm shall be based on the Rational Method for basins smaller than 10 acres and the CUHP Method for basins larger than 10 acres as described in Section 6.2.

6.3.3 Determination of Design Storm Runoff for Calculating Annual Phosphorus Loads

The phosphorus removal rate will be estimated based on the design storm conditions used to design the water quality control facility. For storms larger than the selected design storm, it can be reasonably assumed that a well-designed facility will remove at least the same mass of phosphorus that was removed for the design storm condition. It can also be assumed that the total phosphorus loading in a given storm is proportional to the volume of runoff. This is a conservative assumption that essentially ignores the higher concentrations of phosphorus that occur during the first flush.

Figures 6-4 and 6-5 provide the percent captured in a facility based on the assumptions presented above, the percent imperviousness of a site, and the soil type of the site. These figures shall be used to estimate the percent captured in a facility for a selected design storm. This percent captured and the effectiveness of the selected control measure as calculated following the procedures described in Chapter 16.0, shall be used to estimate the phosphorus removal efficiency of the proposed facility.

INSERT AND FIGURES 6-1 THROUGH 6-5

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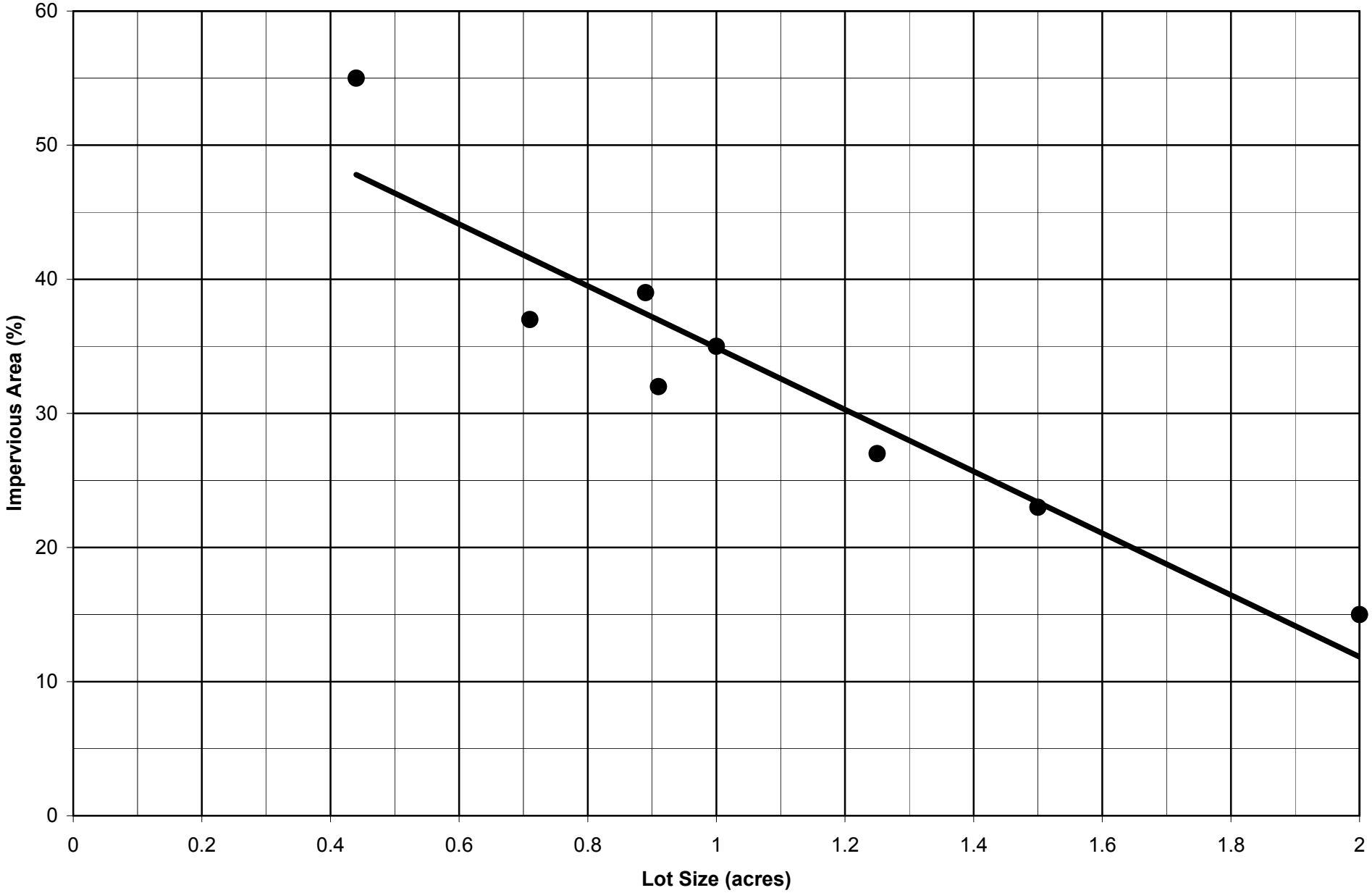

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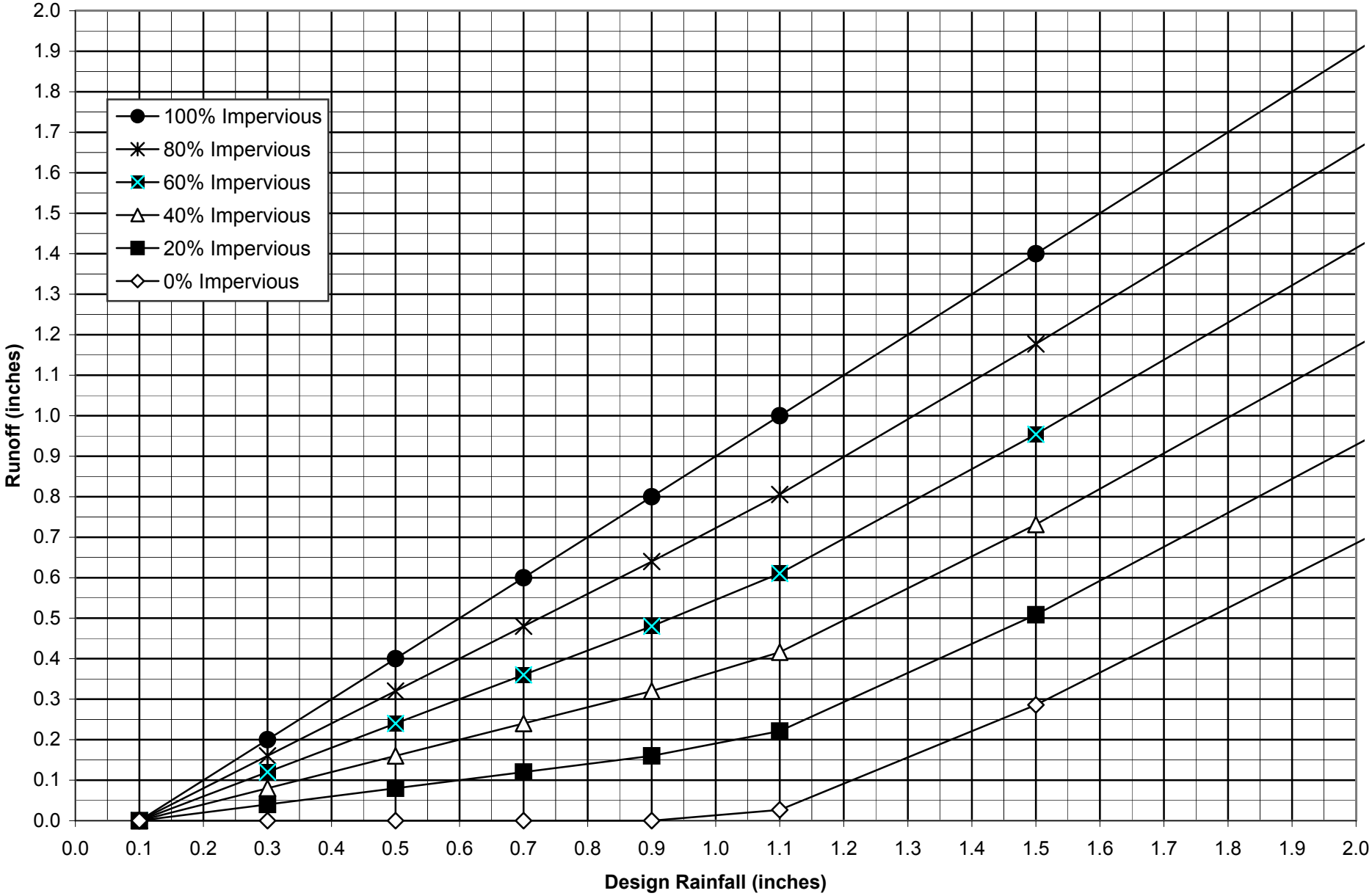
Figure 6-1
Percent Imperviousness for
Low Density Residential Housing

2003 Figures 6-1 to 6-3.xls-Figure 6.1



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2003 Figures 6-1 to 6-3.xls-CLAY&LOAMS WQ fig6.2

Figure 6-2
Rainfall-Runoff-Imperviousness for
Type I and II Soils - Clays and Clay Loams

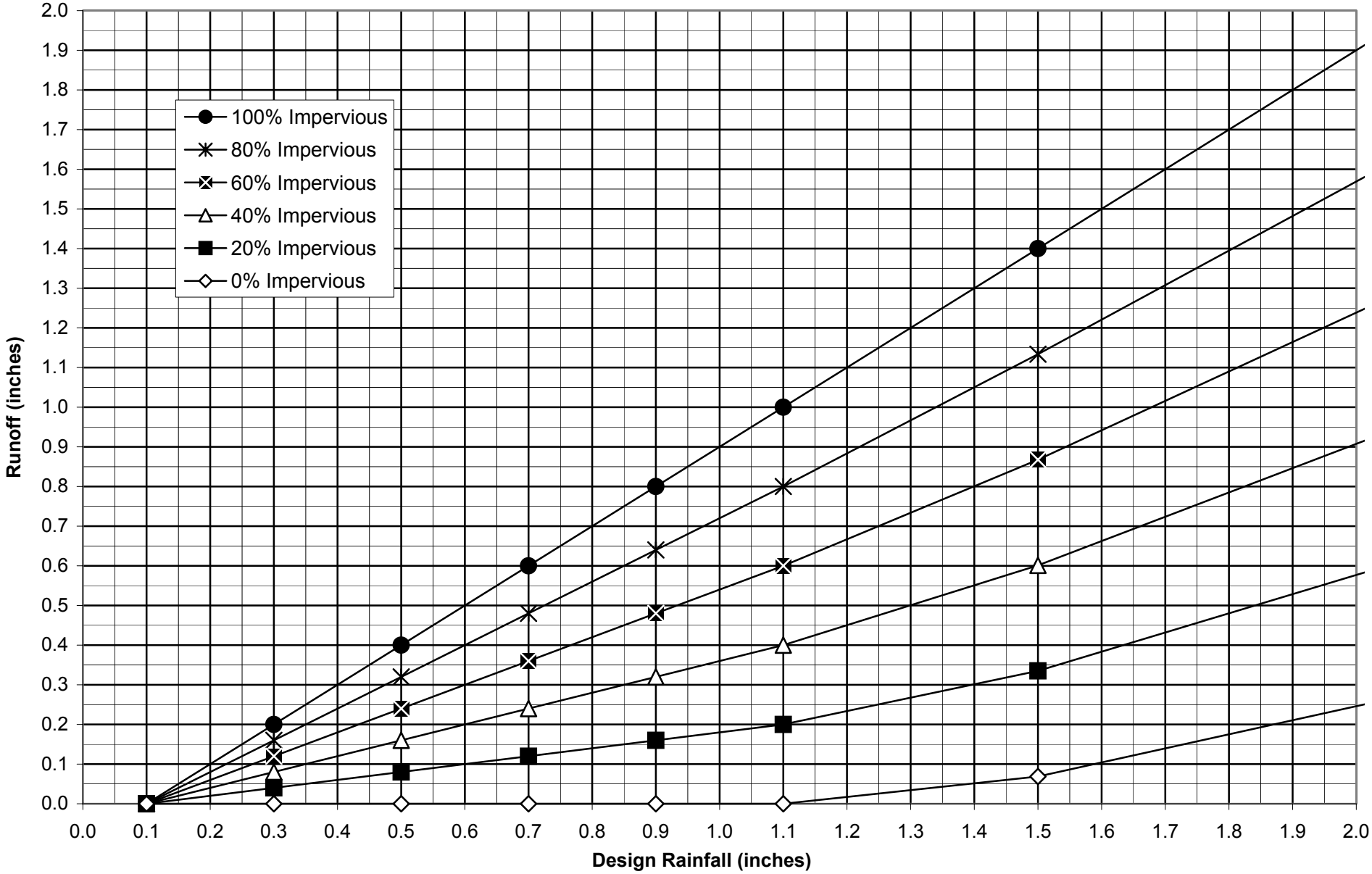

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Figure 6-3
Rainfall-Runoff-Imperviousness for Type III Soils - Sand and Gravels

2003 Figures 6-1 to 6-3.xls-S&GR WQ fig6.3

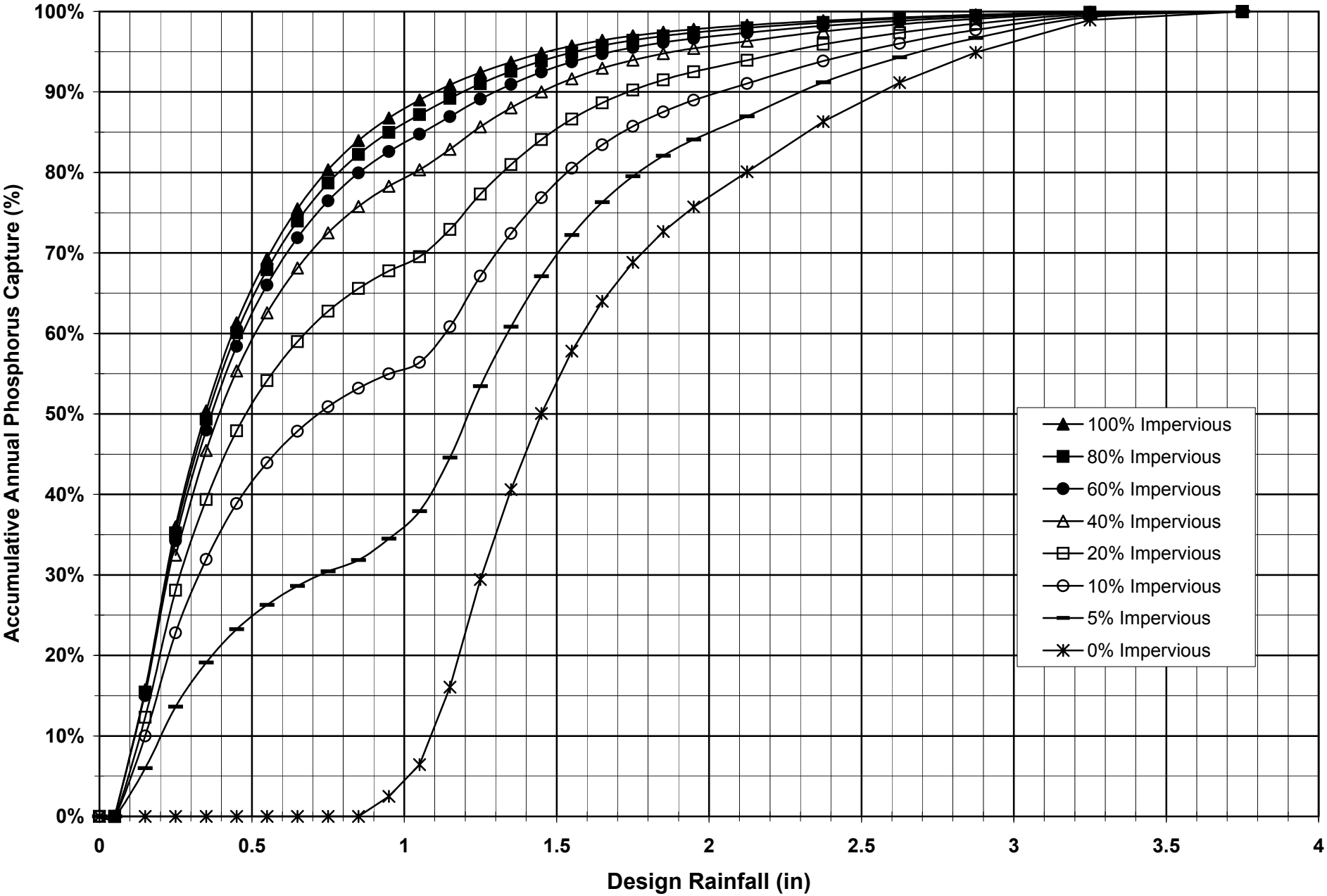

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Figure 6-4
Percent Annual Stormwater Phosophorus Capture
Type I and II Soils (Clay and Clay Loams)

2003 Figures 6-4 to 6-5.xls-FIG 6_4

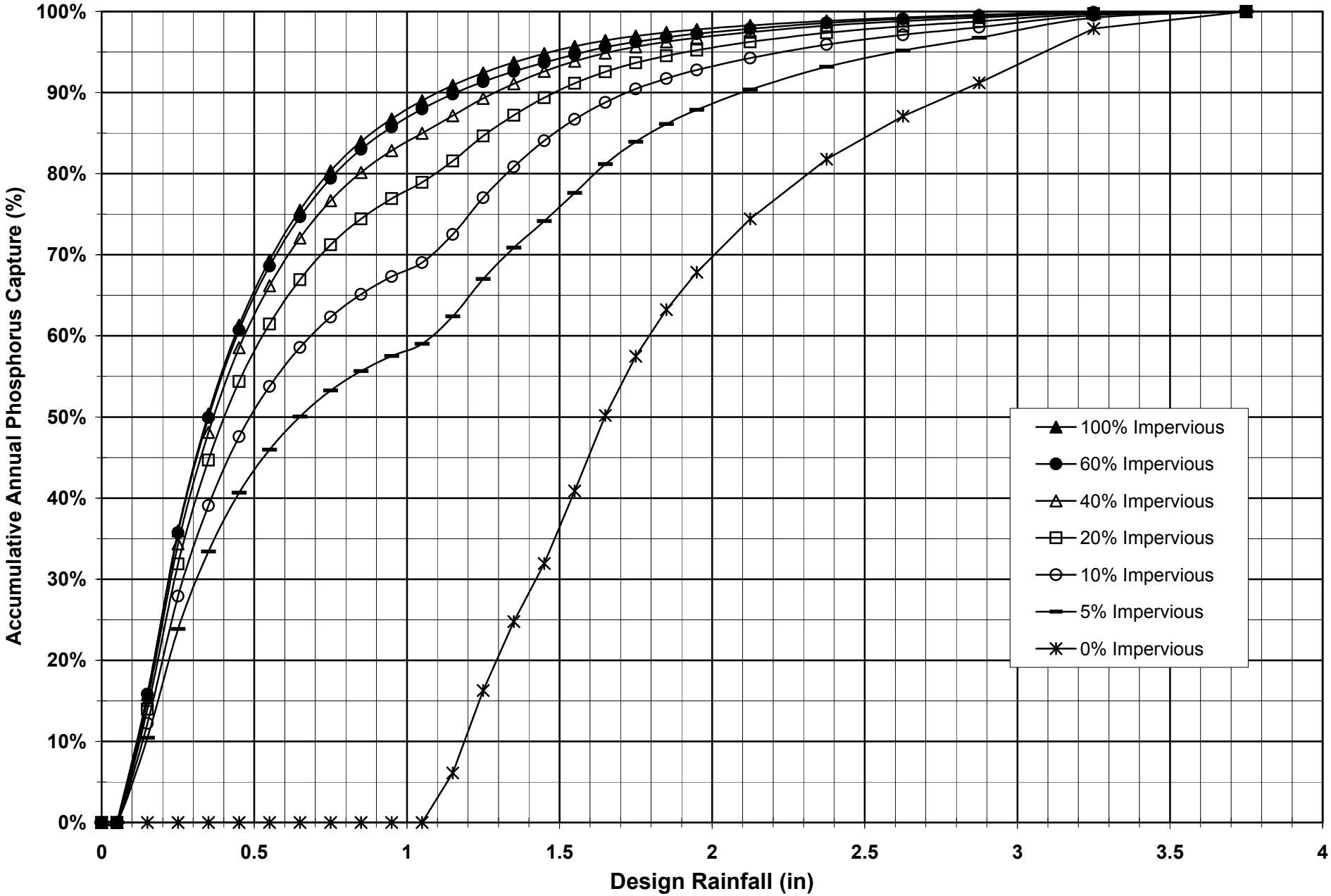

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Figure 6-5
Percent Annual Stormwater Phosophorus Capture
Type III Soils (Sand and Gravel)