Chapter 10: Enhanced Phosphorus Removal Supplement

Section 10.1 Introduction and Overview

The goal of this chapter is to address design standards for "enhanced phosphorus removal" for projects in phosphorus-limited watersheds. It has been determined that enhanced phosphorus removal is required to meet water quality objectives established for these watersheds. In addition, this chapter encourages the use of upstream controls as a primary means for reducing runoff volumes and their associated pollutant loads.

The discussion presented in this section of the supplement provides a short description of the sources, environmental fate and transport, and technical aspects of designing treatment systems for further reducing loads and concentrations of phosphorus in runoff beyond what would potentially be achieved based on the minimum statewide standards established in this Design Manual. This section also presents additional treatment performance standards for enhanced phosphorus removal.

10.1.1 Description and Properties of Phosphorus

Phosphorus is an essential nutrient for all life forms and can also be the limiting nutrient for the primary productivity of a body of water. However, increased amounts of phosphorus entering surface waters can stimulate excessive algae growth, and associated water quality problems such as decreased water clarity, large daily variations in dissolved oxygen, disagreeable odors, habitat loss and fish kills.

Phosphorus occurs in natural waters almost solely as phosphates. In rainfall runoff, the predominant (> 30%) phosphate forms are the orthophosphate anions HPO_4^{-2} and $H_2PO_4^{-1}$ and to a lesser degree (10%) magnesium phosphate ($MgHPO_4$ [aq]) and calcium phosphate ($CaHPO_4$ [aq]). Phosphorus is most often measured in one of two forms: total phosphorus (TP) and reactive dissolved phosphorus (RDP). While RDP is largely a measure of orthophosphate, TP includes inorganic and organic forms of phosphorus. The magnitude and phases/species are site, watershed and land-use specific. Depending on pH, hydrology, concentration of phosphate species, concentration of calcium and magnesium, particulate solids, redox and residence time, partitioning of phosphorus in rainfall runoff between the particulate-bound and dissolved fractions can vary from 20% to more than 90% particulate. Solubility of phosphorus species in rainfall runoff ranges from >80% at a pH of 6 to <1% at a pH of 8. Despite the wide range of speciation, partitionings, and solubility, phosphorus species are generally particulate bound, particularly within the settleable and sediment fractions. Approximately half the phosphorus in residential and commercial areas is particulate, with larger fractions of particulate bound phosphorus likely to be found in industrial and open space areas. The National Stormwater Quality Database (NSQD) reported total and dissolved phosphorus as follows:

Table 10.1 Phosphorus Concentrations by Land Use

	Residential	Commercial	Industrial	Open Space
Average Total P, mg/L (# of obs)	0.41 (963)	0.34 (446)	0.45 (434)	0.59 (46)
Average Dissolved P, mg/L (# of obs)	0.20 (738)	0.18 (323)	0.16 (325)	0.16 (44)
Approximate % Dissolved:	49	53	36	27
Approximate % Particulate:	51	47	64	73

Note: parentheses represent number of samples used to derive average.

Sources of Phosphorus

Natural phosphorus-bearing minerals are the chief source of phosphorus for industrial and agricultural purposes. The inorganic phosphate and organophosphate components of total phosphorus are typically derived from soil, plant and animal material. In nature, phosphorus has almost no gaseous forms, and so the major transport mechanism is typically by water flow. Nevertheless, significant amounts can be transported via the atmosphere, associated with dusts.

Significant traditional point sources of phosphorus include food-processing industries, sewage treatment plants, leachate from garbage tips and intensive livestock industries (e.g., animal feedlots, dairy operations, horse pastures and large poultry operations). Diffuse sources of phosphorus, although some (e.g., urban, industrial and construction) are now considered point sources from a regulatory standpoint, are often better described as nonpoint. Inorganic phosphate and organophosphate components of total phosphorus associated with undisturbed and agricultural land uses are primarily due to the use of fertilizers and manures and, to a lesser extent, the use of phosphorus-containing pesticides on agricultural lands.

In urban and suburban rainfall runoff, phosphorus sources include detergents, fertilizers, natural soil, flame retardants in many applications (including lubricants), corrosion inhibitors and plasticizers. In areas with high phosphorus content in soils, deposition of sediment due to construction or other land-disturbance activities can also represent a significant source. Automobile lubricant emissions, food products, lawn and garden fertilizers and various household cleaners, paints, fabrics and carpets contain phosphates which will be transported by runoff. The widespread use of products containing phosphorus in areas exposed to precipitation and runoff can contribute significantly to concentrations in receiving waters.

Finally, significant vegetation removal, land clearing, tilling or grading, soil compaction or the addition of impervious surfaces can result in increased phosphorus delivery due to higher runoff volume and intensity increasing the flushing of phosphorus from land surfaces or, potentially, increasing erosion of downstream water courses, which can be of concern in areas with high phosphorus contents in soils.

Environmental Fate and Transport of Phosphorus

The sources, dispersion, transport and fate of phosphorus in the environment is extremely complex, in some ways even more so than for nitrogen, because of the complexity of its forms and conversion pathways in the solid form. The oxidation-reduction status (usually expressed as redox potential) of the environment plays a critical role in the forms, and hence availability, of phosphorus. This status is critically dependant on microbial activity (which, if at a sufficient level, causes anaerobic conditions to develop) but in turn is dependent on the amount of readily assimilable organic matter present. High total phosphorus levels, together with high total nitrogen levels and in conjunction with other necessary nutrients and favorable physical characteristics of aquatic environments, can result in plant and algal blooms. (Burton, 2001)

Most total phosphorus is transported by processes such as runoff and stream flow and, to a lesser degree, in groundwater flow, although wind also transports components of total phosphorus around the landscape.

10.1.2 Enhanced Phosphorus Treatment Processes

Enhanced phosphorus treatment specifically refers to a measurable, significant improvement in phosphorus-treatment performance over the design methodology used for standard practices.

As receiving water quality is the ultimate measure of stormwater management practice performance, enhanced performance is best defined by the following:

1. Prevention of runoff can be a highly effective means for reducing the total loads of phosphorus generated as well as the size and, therefore, cost of downstream controls

while increasing the water quality efficiency. Reducing imperviousness and achieving hydraulic disconnection of impervious areas are both critical to reducing runoff volumes. Prevention is best addressed through hydrologic source control by maximizing evapotranspiration and infiltration. This could be achieved through small-scale distributed controls, such as raingardens, stormwater planter boxes, biofiltration areas, draining roof runoff to landscaped areas, draining driveways and walkways to landscaped areas, greenroofs, rainwater cisterns, use of porous pavements or minimization of site soil compaction.

2. Performance of a stormwater management practice is directly related to the quantity of water that is effectively treated by the system (i.e., the amount of flow that is not by-passed or that exceeds the system's effective treatment rates). This element of performance is as important as the effectiveness of the system itself. Stormwater management practices are rarely designed to control 100% of the runoff volume from all events. Therefore, effective bypass (which in this context includes flows diverted from the treatment system as well as discharges routed through the system in excess of the effective treatment flow rate) of some portion of the long-term hydrograph is expected. Analysis of the long-term continuous precipitation/runoff hydrology for a site can help optimize the hydraulic design of a treatment system in order to achieve the desired level of runoff capture. Target "capture rates" (e.g., the percentage of runoff that receives the desired treatment) may depend on several factors, including the sensitivity of receiving waters, desired water quality of discharge from the site (i.e., both treatment-system effluent and any bypass) or the level of downstream hydraulic control needed.

3. The ability of a treatment system to achieve low concentrations (for receiving waters that are concentration limited, such as rivers and streams) and/or low relative loading (for receiving waters that are mass limited, such as lakes and reservoirs) of target pollutants is an essential element of performance. The best means for evaluating this performance is through statistical quantification of observed effluent concentrations and loads. The expected effluent quality can be seasonally affected, as nutrient export can potentially occur as a result of decay of biological matter during winter months and can have a more significant effect on receiving waters when they are phosphorus limited relative to biological growth (i.e., during the summer).

4. The expansion of the classic definition of treatment-system performance to include hydrologic source control, hydraulic and hydrologic function and the ability of a system to achieve high-quality effluent are essential for providing sound information and direction on how to design treatment systems to minimize effects of phosphorus in runoff from new development, redevelopment and retrofits on receiving waters.

Furthermore, long-term phosphorus removal performance is particularly sensitive to proper maintenance; particularly important maintenance functions include:

- Sediment removal
- Vegetation control
- Landscaping practices

- Gross floatable organics, litter and garbage control
- Design consideration for vegetative systems.

These elements are key components in helping to achieve optimal phosphorus uptake and short and long term performance.

Treatability for Phosphorus

Treatability for phosphorus is a function of partitioning (particulate vs. aqueous). For particular-bound phosphorus, treatability is a function of particle distribution across the gradation of particle sizes and densities. Based on the best available data, it has been observed that particles less than 10 µm tend to have substantially higher associated phosphorus concentrations than larger particle sizes. This suggests that those practices capable of removing smaller particle sizes may provide greater treatment effectiveness overall. (Pitt, 2004)

In aqueous systems, treatability is a function of concentration and speciation. Phosphorus can readily undergo surface complexation reactions, be adsorbed or precipitated. Media or soils containing iron, aluminum or hydrated Portland cement can be very effective in separating phosphorus species through surface complexation or precipitation. However, complexation or partitioning to engineered media or particulate matter can be reversible, and particulate-bound phosphorus can be a chronic threat, especially in a cyclic redox environment.

When bound to organic or inorganic particles, viable unit operations include sedimentation and filtration, which may be augmented by pretreatment coagulation/flocculation where feasible. Management and maintenance of all unit operations, including physical, chemical and biological processes, is critical to ensure removal of phosphorus from stormwater.

Table 10.2 identifies the most appropriate unit operations or processes for treatment of particulate-bound or dissolved phosphorus. (Strecker, 2005)

Table 10.2 Treatment of Particulate Bound or Dissolved Phosphorus

Form	Unit Operation or Process For Treatment
Particulate bound	Sedimentation, filtration, coagulation-flocculation
Dissolved	Adsorption, surface complexation, precipitation, biological uptake and separation

10.1.3 Treatment Performance Goals

The design criteria provided in this supplement are based on extensive research into the relationship between design factors and performance and represent the state-of-the-practice in science and engineering. The following goals have been established as metrics for determining appropriate criteria for enhanced phosphorus removal:

Goal 1 - Reduce runoff volumes by requiring that each project assess the feasibility of hydrological source controls and, where feasible, implement those source controls. For each proposed plan, provide the reasons for acceptance and rejection of the various controls.

Goal 2 - Achieve less than 15% treatment bypass of the long-term runoff volume. This goal is defined by running a continuous simulation model that ensures that the SMP does not effectively bypass more than 15% of the runoff from the site.

Goal 3 - For flows that are treated by the system (i.e., flows that are not effectively bypassed), median effluent concentration of particulate phosphorus shall be at or below 0.1 mg/L. This effluent concentration of particulate phosphorus is equivalent to a net removal of particulate phosphorus of 80%, given a median influent concentration of 0.5 mg/L.

Goal 4 - For flows that are treated by the system (i.e., flows that are not effectively bypassed) the median effluent concentration of dissolved phosphorus shall be at or below 0.06 mg/L. This effluent concentration of dissolved phosphorus is equivalent to a net removal of dissolved phosphorus of 60%, given a median influent concentration of 0.15 mg/L.

Effluent quality goals for particulate and dissolved phosphorus are based on analysis of available empirical influent and effluent water quality data for a variety of treatment systems and operational conditions (e.g., catchment characteristics, climate). (Pitt, 2004)

The development of the design criteria is discussed in detail in Section 10.2 and is based on continuous simulation modeling of hydrology and hydraulics, as well as process-level analysis of the water quality performance of specific treatment systems when properly designed. The analysis is also based on particle size distributions from available data as well as the best available information on solid-phase phosphorus concentrations.

The alternative sizing criteria provided in Section 10.3 and design criteria provided in Section 10.4 are intended to serve as an acceptable means for achieving the above stated goals. Section 10.5 presents three design examples to demonstrate how the standards provided in this supplement can be used in engineering practice.

Section 10.2 Analysis of Methods and Summary of Conclusions for Sizing Standards

10.2.1 Introduction

The selection of alternate sizing standards for enhanced phosphorus treatment takes into account the expected impact on effluent quality relative to the defined performance goals, construction feasibility and the applicability of the alternate sizing criteria to a broad range of watershed types (e.g., highly impervious, highly pervious). These non-performance factors are used to help optimize the selection of alternate design standards. These design standards are suitable for enhanced phosphorus treatment and are similar in terms of implementation to those of standard practices. Design examples are provided in Section 10.5 of this supplement, to help clarify how the alternate sizing criteria may be incorporated into the existing design methodology.

10.2.2 Analysis of Existing and Alternate Design Standards

Separate analyses were performed for storage and flow-through systems to help assess the relative difference in treatment performance between systems sized according to the current standards as specified in this Manual and alternate sizing criteria.

Analysis of Storage Systems Treatment Performance

Storage systems are classified as those treatment practices that provide hydrologic and pollutant control via temporary storage of runoff volume and are typified by basins of various designs and configurations. While outlet design, basin geometry and other factors may differ, the overall hydraulic and treatment function of storage systems are generally similar.

It is well established that the primary treatment mechanism employed by storage systems is particulate settling, which is suitable for treatment of sediment and particulate-associated pollutants, including the particulate form of phosphorus. In terms of treatment practice design, particulate settling effectiveness in storage systems is governed in part by the depth of the water column and the duration over which water remains in the basin (under relatively quiescent conditions), among other factors. A number of non-design factors also influence particulate treatment performance, including the size and character of the suspended particulates. Select storage systems such as Wet Ponds (P-2) or Shallow Wetlands (W-1) are designed such that the WQ_v of the system remains full (i.e., 100% of the WQ_v is in the permanent pool), while others such as Wet Extended Detention Ponds (P-3) divide the WQ_v between permanent pool and an extended detention volume that drains following each runoff event.

It is important to note that large treatment systems may not always be appropriate for all sites. Sizing and design of large systems must take into account potential site constraints (e.g., height of water table relative to basin), construction and maintenance cost, site hydrology (e.g., need for flow control may require greater extended detention volume) and aesthetic criteria, among other factors. It is noted that the best means for reducing treatment system size is through the prevention of runoff as a part of the site-planning process.

Analysis of Flow-Through Systems Treatment Performance

Flow-through systems are different from storage systems in that these practices are not intended to capture and hold the runoff volume for a significant length of time, but rather they provide treatment through physical, chemical and/or biological mechanisms that act on the runoff as flows are routed through the system. As such, flow-through systems tend to be smaller in scale than storage systems and designed more for water quality treatment than flow attenuation.

The unit-process treatment mechanisms employed by various flow-through systems differ depending on their design and intended function, and the level of knowledge within the stormwater field of these mechanisms is still relatively limited. The factor that may be most relevant to the overall treatment performance of flow-through systems is hydraulic performance (i.e., the proportion of the total runoff volume treated). In the case of filtration and infiltration systems, the rate at which captured runoff is conveyed through the system is essentially constrained to the effective treatment flow rate of the system. A majority of flow-through systems are positioned as offline practices, equipped with a method for bypassing flows in excess of the treatment flow rate.

Analysis of the existing and alternate sizing methods for flow-through systems focused on the hydraulic performance as an approximation of overall treatment performance. As with the analysis of storage systems, continuous simulation models (incorporating long-term regional climatic data) were used to provide a relative comparison of performance.

10.2.3 Results of Analysis of Existing and Alternate Design Standards

The analysis of storage and flow-through systems provided a relative comparison of estimated overall treatment performance of stormwater management practices designed to the existing standards and to alternate standards. The results of this analysis indicate that the current method for sizing treatment systems is expected to yield stormwater management practices with WQ_v's that are insufficient to meet the enhanced phosphorus treatment performance goals.

Results of the continuous simulation analysis, as well as evaluation of empirical data reported for numerous different storage-type treatment practices nationwide, strongly suggest that sizing of the permanent pool is expected to have a significant influence on particulate treatment performance. Ponds with larger permanent pools relative to runoff volume result in improved settleable solids removal.

Analysis of runoff conditions for catchments with varying degrees of imperviousness reveals that, particularly during more intense storms or periods of frequent rainfall, the contribution of runoff volume from pervious areas can be significant. In addition, the 90% rainfall depth specified in the Design Manual may not provide sufficient storage to acceptably minimize reduced efficiency resulting from decreased detention time (in storage systems) or bypass (in flow-through systems).

The alternate approach to sizing the WQ_v presented in this supplement uses standard hydrologic calculations from the SCS Method (Technical Release 20 and Technical Release 55) to account for runoff from the entire catchment, as opposed to using the impervious fraction only. Several design storm criteria in addition to the selected sizing were evaluated, taking into account both estimated long-term performance and the variety of additional optimization factors previously noted.

The alternate WQ_v calculation for enhanced phosphorus treatment is considered to be suitable for both storage and flow-through systems and applicable to catchments that range from highly impervious to highly pervious. This alternate approach is as follows:

WQ_v = the estimated runoff volume (acre-feet) resulting from the 1-year, 24-hour design storm over the post-development watershed

Section 10.3 Stormwater Sizing Criteria

10.3.1 Introduction

Table 10.3 summarizes the stormwater sizing criteria to meet pollutant removal goals for enhanced phosphorus removal. The remainder of this section describes the modified sizing criteria in detail and presents instructions on how to properly compute and apply the standard to meet the performance goals.

Table 10.3 New York Stormwater Sizing Criteria for Enhanced Phosphorus Removal	
Water Quality (WQ_v)	WQ_v = estimated runoff volume (acre-feet) resulting from the 1-year, 24-hour design storm over the post development watershed (See Figure 10.1).
Runoff Reduction Volume (RRV)	Refer to existing requirements. (Chapter 4, Table 4.1) Runoff reduction applies to the WQv resulting from one-year, 24-hour storm . The minimum RRv is calculated using the one (1) year 24 hour storm and the Specified Reduction Factor (see minimum RRv formula on page 4-6 in Section 4.3).
Channel Protection (Cp_v)	Refer to existing requirements. (Chapter 4, Table 4.1)
Overbank Flood (Q_p)	Refer to existing requirements. (Chapter 4, Table 4.1)
Extreme Storm (Q_f)	Refer to existing requirements. (Chapter 4, Table 4.1)

10.3.2 Water Quality Volume (WQ_v) for Enhanced Phosphorus Removal

The Water Quality Volume (WQ_v) for enhanced phosphorus removal is designed to capture the estimated runoff resulting from the 1-year, 24-hour design storm over the post- development watershed. This alternate approach to sizing the WQ_v uses standard hydrologic calculations from the SCS Method (Technical Release 20 and Technical Release 55) to account for runoff from the entire catchment, both impervious areas and pervious areas. Contour lines for the 1-year, 24-hour design storm rainfall events are presented in Figure 4.2.

By implementing an environmental design approach and incorporating green infrastructure practices, a site's contributing impervious area can be reduced and the hydrology of the pervious areas altered. These practices will result in lower curve number (CN) and lower WQv.

10.3.3 Channel Protection Volume (Cp_v) for Enhanced Phosphorus Removal

Stream channel protection volume (Cpv) requirements are designed to protect stream channels from erosion. In New York State, the channel protection volume (Cpv) is accomplished by providing 24-hour extended detention of the one-year, 24-hour storm event. One way that this can be accomplished is by ensuring that the time difference between the center of mass of the inflow hydrograph (entering the SMP) and the center of mass of the outflow hydrograph (leaving the SMP) is a minimum of 24 hours (see Section 4.3 for complete discussion of channel protection volume).

For enhanced phosphorus removal, the WQ_v is sized for the one-year, 24-hour event. Therefore, the only additional requirement necessary to meet for Cp_v is to provide 24-hour extended detention of the WQ_v. In some SMPs (e.g., the Wet Extended Detention Pond), the Cp_v requirements are achieved through WQ_v sizing techniques (i.e., the extended detention orifice is sized to release the ED_v within 24 hours). In other SMPs (e.g., the Wet Pond) the requirements are not inherent in the design and must be achieved using other means (i.e., provided above the WQ_v).

Once a pond has been sized to meet the WQ_v requirement, a TR-55 and TR-20 (or approved equivalent) model may be used to determine center of mass detention time. By modifying the pond volume and the elevation and size of the outlet structure(s), in a trial and error fashion, the Cp_v requirement can be met. Alternatively, the methodologies in Appendix B can be followed to ensure Cp_v requirement is met.

10.3.4 Sizing to Meet Treatment Performance Goals

The method for sizing standard practices is expected to yield stormwater treatment systems with WQ_v insufficient to meet the enhanced phosphorus treatment goals. This section will explain what new design standards were implemented to meet the enhanced phosphorus treatment goals.

Goal 1. *Reducing Runoff Volumes*

For each project, the designer must assess the feasibility of hydrological source controls and reduce the total water quality volume by source control, implementation of runoff reduction techniques, or standard SMPs with runoff reduction capacity (RR), according to the process defined in Chapters 3 and 4 of this Design Manual. Each proposed plan must include a rationale for acceptance and rejection of the various controls.

Source controls include measures for reducing runoff generation and/or available phosphorus levels, as well as distributed controls located within the watershed that are designed to target specific sources of phosphorus in runoff before it is transported downstream. Effective use of source controls can help reduce or even eliminate the need for larger, more costly downstream structural controls and associated operation and maintenance obligations.

Runoff reduction is an effective means for preventing pollutant loads to receiving waters and has a number of positive effects on a site's water balance. Reducing runoff volume is the primary goal of green infrastructure approaches and structural infiltration practices (e.g., infiltration basins or trenches). In new development, where preservation of green space is possible and site configuration is flexible, runoff reduction techniques must be used to maximize infiltration and evapotranspiration. The process of planning and design according to runoff reduction techniques is defined in Chapter 3 of this Manual. Opportunities for and benefits of incorporating runoff reduction techniques can be gauged in part by assessing the hydrologic properties of native soils, specifically the hydrologic soil group (HSG).

Projects that cannot meet 100% of runoff reduction requirement due to site limitations that prevent the use of an infiltration technique and/or infiltration of the total WQv shall identify the specific site limitations in the SWPPP. Typical site limitations include: seasonal high groundwater, shallow depth to bedrock, and soils with an infiltration rate less than 0.5 inches/hr.

Construction activities that cannot achieve 100% reduction of the total WQv due to site limitations shall direct runoff from all newly constructed impervious areas to a RR technique or standard SMP with RRv capacity unless infeasible. In no case shall the runoff reduction achieved from the newly constructed impervious areas be less than the minimum runoff reduction volume (RRv_{min}) determined by the following equation:

$$RRv_{min} = \frac{P_{1yr} * \bar{R}_v * Aic * S}{12}$$

Where:

RRv_{min}	=	Minimum runoff reduction volume required from impervious area (acre-feet)
P_{1yr}	=	1-year storm event (in)
$\bar{R}_v$	=	0.05+0.009(I) where I is 100% impervious
Aic	=	Total area of new impervious cover
S	=	Hydrologic Soil Group (HSG) Specific Reduction Factor (*S*)

The specific reduction factor (S) is based on the HSGs present at a site. The following lists the specific reduction factors for the HSGs:

HSG A = 0.55
HSG B = 0.40

HSG C = 0.30
HSG D = 0.20

The remaining of WQv generated from 1-yr storm that exceeds the capacity of the implemented RR techniques or other SMPs with RRv capacity or both must be directed to a full treatment system, as specified in Chapter 4 of this Design Manual.

Given the design methodology in this chapter, green infrastructure approaches are effective means for reducing the WQv at sites in phosphorus restricted watersheds. Green infrastructure planning and design approaches can successfully mimic the preconstruction water balance by preserving existing water table elevations and maintaining the watershed hydrologic patterns, base flow of streams and wetlands and the evapotranspiration rates. Ultimately, reductions in post-development runoff are critical in order to minimize phosphorus loading to receiving waters. Section 10.3.5 discusses appropriate source-control approaches.

Goal 2. *Effective Bypass Treatment*

Practices should achieve less than 15% effective treatment bypass of the long term runoff volume. This goal is achieved by capture and treatment of runoff from the 1-year 24-hour storm. Based on this sizing, it is expected that the SMP will not effectively bypass more than 15% of the runoff from the site.

Goal 3. *Achieving Effluent Concentration for Particulate Phosphorus*

For flows that are treated by the system (i.e., flows that are not effectively bypassed), median concentration of particulate phosphorus shall be at or below 0.1mg/L. This effluent concentration of particulate phosphorus is equivalent to a net removal of particulate phosphorus of 80%, given a median influent concentration of 0.5mg/L.

This goal is achieved by designing in accordance with Section 10.4. In the case of storage systems, practices are designed to allow particles to settle out. These storage systems are governed by the depth of the water column and the duration during which the water remains in the basin. In this chapter, a minimum depth of 3 feet (above accumulated sediment) in the permanent pool is specified to allow for adequate detention of water in the pond for the particles to settle out. Depths of standing water should not exceed 8 feet. This provides enough water and oxygen under the ice in the winter while deeper water can have significant stratification issues and inadequate water exchange with deeper water in summer. Note that a minimum depth of 4-6 feet is required in pretreatment and 4 feet is required in the micropool at the outlet. For the enhanced phosphorus removal, the permanent pool is required to hold at least 50% (100% for wet ponds) of the WQ_v A minimum length-to-width ratio of 2:1 maximizes the flow path for which particles can settle out and minimizes scour of previously settled particulates. Complete performance criteria for all SMPs designed for enhanced phosphorus removal can be found in Section 10.4.

Stormwater wetlands can also be used to achieve these target concentrations. New design standards for the stormwater wetlands require that in deepwater zones (water depths of greater than 4 feet), 25% of the WQ_v must be met. The minimum depth allows sufficient time for particles to settle out.

Goal 4. *Achieving Effluent Concentration for Dissolved Phosphorus*

For flows that are treated by the system (i.e., flows that are not effectively bypassed), the median concentration of dissolved phosphorus shall be at or below 0.06mg/L. This effluent concentration of dissolved phosphorus is equivalent to a net removal of dissolved phosphorus of 60%, given a median influent concentration of 0.15 mg/L.

This goal is achieved by designing in accordance with Section 10.4. An acceptable concentration of dissolved phosphorus can be achieved by using systems that result in intimate contact between water and soils, engineered substrates or filtration media such that sufficient opportunity is provided for dissolved phosphorus to sorb to the appropriate substrates or media surfaces. Availability of iron, aluminum or hydrated Portland cement in soil or filtering media can accelerate surface complexation or precipitation, which results in separation of phosphorus species. Furthermore, by increasing and/or optimizing, as well as properly maintaining, vegetation in treatment trains, dissolved phosphorus concentration goals can be met. Systems which incorporate these features can effectively provide physical, chemical and/or biological treatment. Regular maintenance on these systems will allow the vegetation to have optimal living conditions and maintain flow rates. Proper maintenance of vegetation is important for preventing decaying matter from potentially contributing to phosphorus export from treatment systems.

10.3.5 Source Control Options

Hydrologic Source Controls

Hydrologic source control is best achieved through the reduction of the effective impervious surface area of the catchment and minimization of disturbed area. This is particularly the case where predevelopment soils demonstrate significant infiltration capacity. In addition, integrating a series of green infrastructure principles and practices uses micro management of runoff, allows groundwater recharge, increases losses through evapotranspiration and emulates the preconstruction hydrology, resulting in reduced water–quality-treatment volume.

This goal can be accomplished by following green infrastructure principles, as identified in Chapters 3 and 5. The green infrastructure principles are categorized in three major groups: Preservation of Natural Resources, Reduction of Impervious Cover, and green infrastructure techniques. From the hydrologic design standpoint, the first two categories result in reduction of curve numbers, increased flow path and time of concentration. This approach results in reduction of flow volume and peak discharge rate. The third category, however, provides an opportunity for distributed runoff control from individual sources, flow routing, infiltration, treatment and reduction of total water quality volume.

Possible approaches and techniques that may result in reduction of curve number and extension of time of concentration include:

- Minimizing disturbance to keep the ground cover in natural condition, preservation of vegetation, and maximizing evapotranspiration
- Disconnecting directly connected imperviousness
- Employing construction and development practices that minimize grading and compaction of soils (e.g., use of low-pressure or light grading equipment in future pervious areas)
- Employing methods to improve the soil hydrologic function, such as decompaction or soil amendments, to help maintain the natural hydrologic function of the site
- Using site-planning techniques that minimize disturbance and minimize siting of impervious cover on soils with high infiltration rates
- Maintaining the predevelopment time of concentration by methods such as increasing flow path, dispersing flow through natural drainage patterns reforestation, and flattening slopes (given does not occur on existing slopes that would not otherwise be disturbed);
- Increasing roughness by establishing vegetative or woody surfaces that result in increased time of concentration, filtration, pollutant uptake and retard velocity
- Using grass swales instead of closed channels (pipes) to increase infiltration, pollutant uptake and time of concentration

- Using vegetative filter and buffer strips to improve water quality, preserve riparian ecosystem, keep structures out of floodplain, increase times of concentration and reduce curve number

- Reducing curb and gutter to direct the flow onto vegetated or infiltration areas and reduce piped discharge

Practices by which a volumetric reduction may be achieved include:

- Using alternate materials such as porous pavements and paver systems in place of impervious surfaces

- Capturing runoff within the catchment using distributed systems such as soil-amended areas, rain gardens or infiltration, while maximizing evapotranspiration

- Maintaining predevelopment runoff volume through distributed on-site stormwater management by selecting appropriate techniques that mimic the hydrologic functions of the predevelopment condition, micro management of hydrology and siting retention on individual lots

- Providing retention and on-site reuse of runoff. For a listing of techniques refer to Chapter 5 of this Manual.

Please note:

- Acceptable green infrastructure techniques are described fully in Chapter 5, along with sample sizing calculations for each technique

- Reduction of water quality volume by routing the runoff through the above volumetric-reduction practices at maximum will result in a reduction equivalent to the storage volume of the practice.

- No infiltration for larger events may be assumed through source-control practices.

Pollutant Source Controls, Maintenance and Land Management

The available surface–runoff-characterization data indicate that high concentrations of phosphorus in urban and suburban areas tend to be associated with landscaped areas (e.g., residential and commercial lawnscapes, golf courses). Prevention of soil losses via effective stabilization of disturbed areas, maintenance of healthy ground cover and design of landscapes to minimize concentrated flow and maximize time of concentration, as well as controls on application of phosphate-based fertilizers, are primary methods for reducing the export of phosphorus.

References/Further Resources

Center for Watershed Protection. 1998. Better Site Design: A Handbook for Changing Development Rules in Your Community. Available from www.cwp.org

New York State Better Site Design Handbook, 2005. New York State Department of Environmental Conservation. (ftp://ftp.dec.state.ny.us/dow/stormdocuments/designguidance/BSD.pdf)

New York State Stormwater Management Design Manual, 2003. Chapter 9 (Jan. 2007). (http://www.dec.state.ny.us/chemical/29072.html (p 9-1, 9-43))

Prince George's County, MD. June 1999. *Low-Impact Development Design Strategies: An Integrated Design Approach.* Prince George's County, Maryland, Department of Environmental Resources, Largo, Maryland Available from www.epa.gov

10.3.6 Redevelopment Projects

Generally all the requirements for redevelopment projects, as presented in Chapter 9 of this Manual, are applied in the phosphorus-limited watersheds. The overriding factors in application of redevelopment criteria to such projects in the phosphorus-limited watersheds are the design-storm and practice selection. As an example, a redevelopment project in a phosphorus-limited watershed may provide treatment by selection of one of the practices listed in Section 10-4 of this Manual-sized to 25% of water quality volume based on the 1-year 24-hour storm event by the use of practices listed in Chapter 10. Use of alternative practice for treatment of 75% of water quality volume is also acceptable.

Section 10.4: Performance Criteria

Introduction

This section outlines the performance, sizing and design criteria for enhanced phosphorus removal for five groups of structural stormwater management practices (SMPs) to meet the treatment performance goals stated in this chapter. These five groups include stormwater ponds, stormwater wetlands, infiltration practices, filters and open channels.

Evidence suggests that storage systems can increase stream temperature. The use of stormwater ponds and wetlands with 24-hour detention time discharging to trout waters is strongly discouraged unless a second practice is used at the outlet of the pond to cool the effluent before it leaves the site. In the case of storage systems additional mechanisms such as rock radiator or cold water-release design can help reduce the outflow temperature. Sand filters are practices that have also proven to be effective for reduction of temperature.

Maintenance provisions must be developed to ensure the longevity and performance of all permanent stormwater management practices and associated conveyances.

How to Use This Section

This section will note the additional requirements for enhanced phosphorus treatment and how the new design criteria can be met. All criteria defined in this section shall be used as a supplement to the required elements and design guidance provided in chapter 6 of this Manual. This section does not repeat all the design criteria from chapter 6. Instead, this section supersedes the less conservative design criteria defined in chapter 6.

All the pond-design details not specified in this section shall, at minimum, meet the required elements and design guidance as stated in Chapter 6 of this manual.

10.4.1 Stormwater Ponds

Pond-design variants include four options:

- P-1 Micropool Extended Detention Pond (Figure 6.1)
- P-2 Wet Pond (Figure 6.2)
- P-3 Wet Extended Detention Pond (Figure 6.3)
- P-4 Multiple Pond System (Figure 6.4)

Treatment Suitability:

Pocket ponds are not acceptable options for effective phosphorus removal. In the presence of a high-water table, ground water intercept may be incorporated based on a flow-balance analysis on a case-by-case basis.

10.4.1.1. Feasibility

Required Elements

- Stormwater ponds will operate as online treatment systems.
- Location of pond designs within the surface waters of New York is not allowed.

10.4.1.2. Inlet Protection

Required Elements

- A forebay shall be provided at each pond inflow point. In the case of multiple inflow points, alternative pretreatment may replace a forebay at secondary inlets with less than 10% of the total design storm flow rate.
- The forebay depth shall be 4-ft. to 6-ft. deep.

10.4.1.3. Treatment

Required Elements

- Provide water quality treatment storage volume equivalent to the WQ_v, estimated to be the post construction 1-year, 24-hour runoff volume from the contributing area of the development.
- Although both CP_v and WQ_v storage can be provided in the same practice, providing Cp_v storage for the one-year storm can only be met in the wet ED design. In the design of wet ponds, additional storage is required to address channel protection criterion.

10.4.1.4. Minimum Pond Geometry

Required Elements

- The minimum length–to-width ratio for the pond is 2:1 (i.e., length relative to width).
- Minimum permanent pool depth shall be at least 3 feet above sediment storage. Sacrificial storage (an additional 1-2 feet depth) must be incorporated, depending on the pond maintenance plan.
- Maximum permanent pool depth is 8 feet due to the risk of anaerobic condition and phosphorus export.
- Minimum surface-area-to-drainage area ratio of 1:100 or 3% for all connected completely paved areas.
- Include 1-foot freeboard.

10.4.1.5. Landscaping

Required Elements

- Optimize the vegetation in pond for phosphorus uptake.
- Use native plants whenever possible. Natives are typically better suited to the local climate and are easier to establish than exotics. Natives also provide the highest benefit to the local ecosystem. Exotic species can also be considered based upon local guidance and desired attributes. Local conservation groups may provide recommendations on plant species suitable for the region, including natives. Vegetation should also be selected so as not to attract nuisance species.
- Avoid woody vegetation within 15 feet of the toe of the embankment, or 25 feet from the principal spillway.
- The safety bench and pond edges shall be heavily planted with vegetation and barrier riparian cover.
- Design landscaping in drainage area to minimize the use of fertilizer application, which is directly related to phosphorus concentrations.

Tables 10.4 and 10.5 provide useful information on the characteristics of vegetation for stormwater treatment and design consideration for vegetative systems. These elements are key components in helping to achieve optimal phosphorus uptake and short-and long- term performance.

Table 10.4 Useful Characteristics of Vegetation used for Stormwater Treatment*
Tolerant of site-specific and climatic conditions (temperature ranges, averages; total precipitation and duration of precipitation events and inundation, flow velocities, and humidity)
Not invasive or noxious
Tolerant of typical stormwater pollutant concentrations. Evaluating plants used in constructed wetlands for wastewater treatment (as well as established stormwater treatment systems) provides information about pollutant tolerance.
Can uptake, store or otherwise remove pollutants.
Easy to establish and resilient to stress.
Low maintenance requirements (e.g., disease resistant, low fertilization and mowing) Note, high growth rates may increase maintenance requirements.
Adequate growth rates, large surface area of roots, stems and leaves and deep rooted.
Salt-tolerant in areas with high concentrations of soluble salts (arid regions) or cold climates where deicing agents are used.
Aesthetically pleasing (e.g., attracts birds, provides visual interest).
Supports symbiotic associations with microbes (e.g., mycorrhizal fungi or rhizobacteria)
Plants are readily available.

* Table 5-23 from WERF Critical Assessment of Stormwater Treatment and Control Selection Issues (2005)

Table 10.5 General Design Consideration for Vegetated Systems*
Preserve existing natural vegetation whenever possible
Diversify plant species to improve wildlife habitat and minimize ecological succession.
Situate plants to allow access for structure maintenance.
Avoid plants with deep taproots where appropriate, as they may compromise the integrity of filter fabric and earth-dam or subsurface drainage facilities. Note, many native plants may have taproot systems.
Avoid plants that may overpopulate or become too dense-such as that vector issues arise (e.g., vegetation too dense for mosquito fish etc.).
Use seed mixes with fast germination rates under local conditions. Plant vegetation and seeds at appropriate times of the year.
Temporarily divert flows from seeded areas until vegetation is established.
Stabilize water outflows with plants that can withstand storm-current flows.
Shade inflow and outflow channels and southern exposures of ponds to reduce thermal warming.
Plant stream and water buffers with trees, shrubs, bunch grasses and herbaceous vegetation when possible to stabilize banks and provide shade.

* Table 5-24 from WERF Critical Assessment of Stormwater Treatment and Control Selection Issues (2005)

10.4.1.6. Maintenance

Required Elements

- Maintenance responsibility for a pond and its buffer shall be vested with a responsible authority by means of a legally binding and enforceable instrument that is executed as a condition of plan approval.
- Sediment removal in the forebay shall occur every 3 years or after 30% of total forebay capacity has been lost.
- Sediment removal from the main basin every 5 years or when the minimum water depth approaches 3 feet. More regular maintenance will help ensure that the system is achieving the highest removal of phosphorus.

10.4.2 Stormwater Wetlands

Stormwater wetlands shall meet all required elements and design guidance of stormwater ponds as required in this chapter, in addition to the following modifications. All the wetland design details not specified in this section shall, at minimum, meet the required elements and design guidance stated in Chapter 6 of this manual.

Design variants acceptable for enhanced phosphorus removal include:

- W-1 Shallow Wetland (Figure 6.7)
- W-2 ED Shallow Wetland (Figure 6.8)
- W-3 Pond/Wetland System (Figure 6.9)
- W-4 Pocket Wetland (Figure 6.10)

10.4.2.1. Landscaping

Pocket wetlands are the only acceptable options for treatment in the presence of a high water table. The groundwater intercept may be incorporated based on identification of the water table with a contribution less than the total volume of the permanent pool in small sites.

Optimize vegetation for phosphorus uptake. Native plants should be used whenever possible. Natives are typically better suited to the local climate and are easier to establish than exotics. Natives also provide the highest benefit to the local ecosystem. Exotic species can also be considered, based upon local guidance and desired attributes. Local conservation groups may provide recommendations on plant species suitable for the region, including natives. See Table 10.4 and Table 10.5.

- Donor plant material must not be from natural wetlands.

10.4.2.2. Maintenance

Required Element

- Maintenance responsibility for a pond and its buffer shall be vested with a responsible authority by means of a legally binding and enforceable instrument that is executed as a condition of plan approval

10.4.3 Stormwater Infiltration

All the infiltration design details not specified in this section shall, at minimum, meet the required elements and design guidance as stated in Chapter 6 of this Manual.

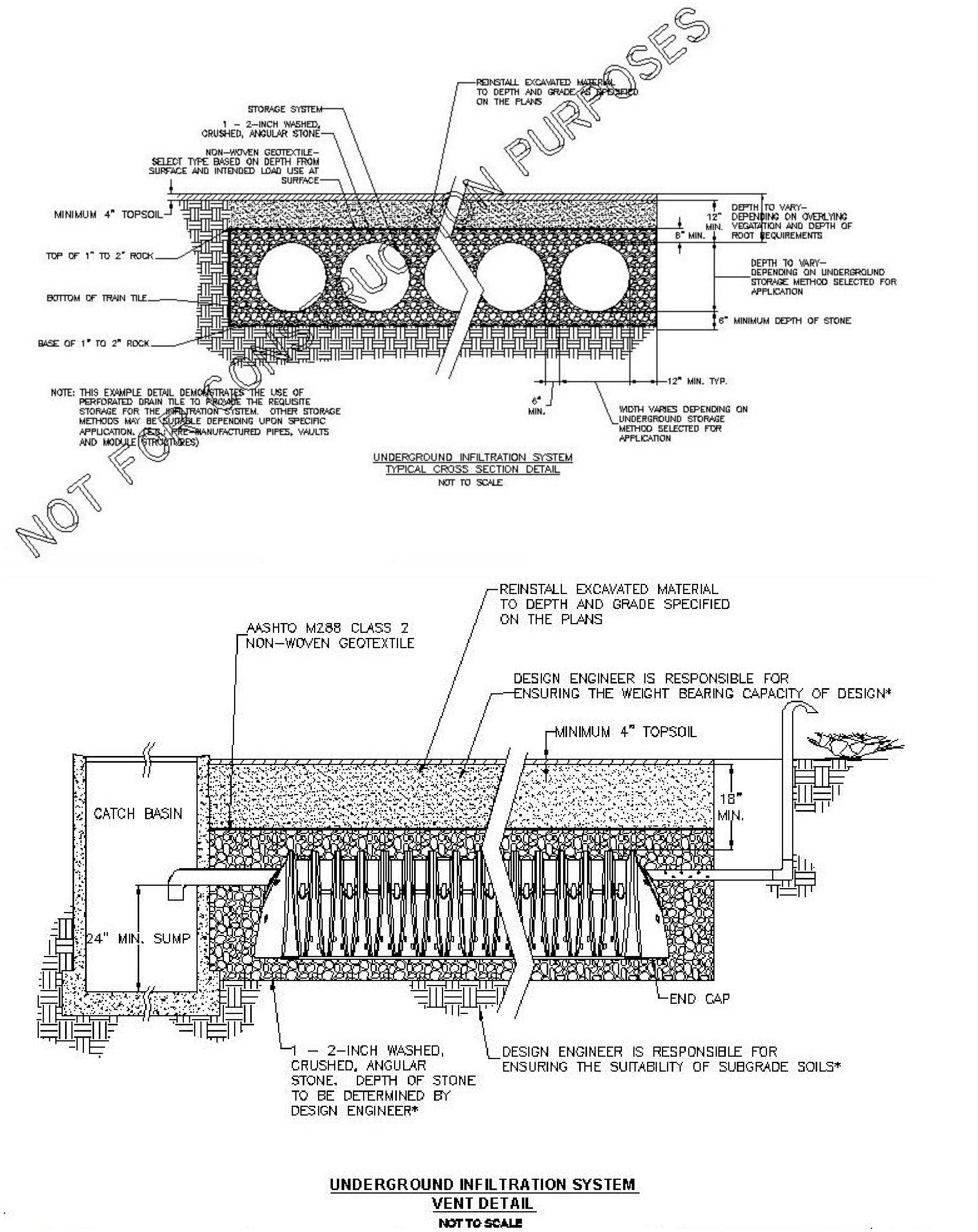
Stormwater infiltration practices capture and temporarily store the WQ_v before allowing it to infiltrate into the naturally permeable soil during a two-day period. Infiltration systems are good candidates for residential and other urban settings where elevated runoff volumes, pollutant loads, runoff temperatures and particulate and soluble phosphorus are a concern. By infiltration through underlying soil, chemical, biological, sorption and physical processes remove pollutants and delay peak stormwater flows. The design variations for stormwater infiltration systems include the following:

- I-1 Infiltration Trench (Figure 6.11)
- I-2 Infiltration Basin (Figure 6.12)
- I-3 Dry Well (Figure 6.13)
- I-4 Underground Infiltration Systems (Figure 10.1)

Treatment Suitability:

Infiltration practices sized for enhanced phosphorus removal automatically meet channel protection (CPv) requirements. Infiltration practices alone typically cannot meet detention (Qp), except on sites where the soil infiltration rate is greater than 5.0 in/hr. However, extended detention storage may be provided above an infiltration basin.

Figure 10.2 A generic display of underground infiltration systems (adapted from MN Stormwater Manual)



10.4.3.1. Feasibility

- Vertical and horizontal separation distances and setbacks are required from structures such as drinking water supplies, septic systems, foundations and pavements. The intent is for protection of human health, functional and structural integrity, prevention of seepage and frost-heave concerns respectively.

10.4.3.2. Conveyance

- Infiltration systems operate as an offline treatment system with bypass flowing to a stable downstream receptacle unless used as pretreatment to an online system.
- All infiltration systems shall be designed to fully de-water the entire WQ_v within 48 hours after a storm event.
- Exit velocities from pretreatment chambers shall be non erosive (3.5 to 5.0 fps during the two-year design storm) and less than 3 fps during the one-year design storm.

10.4.3.3. Treatment

Required Elements

- Water quality volume (WQ_v) is equivalent to the estimated 1-year, 24-hour post-construction runoff volume.
- Provide diversion for construction runoff and minimize construction traffic over infiltration area.
- Trench depth shall be less than 4 feet (I-2 and I-3). Infiltration basins (I-1) may be 2-to-12- feet deep.

Design Guidance

- Infiltration basin side slopes should be kept to a maximum 1:3 (V:H).
- Infiltration systems are not allowed on fill soil because they lack consistency and structural strength.
- Soil de-compaction is required for recovering infiltration capacity in disturbed areas. Information on de-compaction techniques is provided in a separate guidance document.
- Infiltration is not recommended in active karst formations without adequate geotechnical testing.
- To avoid designs that may conflict with the U.S. Environmental Protection Agency (EPA) Class V injection wells, defined as any bored, drilled or driven shaft or dug hole that is deeper than its widest surface dimension, or an improved sinkhole or a subsurface fluid-distribution system. Consult EPA's fact sheet on this issue for further information:

  - http://www.epa.gov/safewater/uic/class5/types_stormwater.html
  - http://yosemite.epa.gov/water/owrccatalog.nsf/1ffc8769fdecb48085256ad3006f39fa/87418a822b4ba98985256c9c005cb2bf!OpenDocument

- Underground Infiltration Systems - Several underground infiltration systems, including pre-manufactured pipes, vaults and modular structures, have been developed as alternatives to infiltration basins and trenches for space-limited sites and stormwater redevelopment applications. These systems are designed similar to infiltration basins or trenches, depending on site specific conditions, to capture, temporarily store and infiltrate the WQv within 48 hours. Underground infiltration systems are generally applicable to small development sites (typically less than 10 acres) and should be installed in areas that are easily accessible to maintenance. These systems should not be located in areas or below structures that cannot be excavated in the event that the system needs to be replaced (MN Design Manual, 2006).

10.4.3.4. Landscaping

Required Elements

- Design landscaping features in drainage area that minimize fertilizer application.
- Limit access of high-impact earth moving equipment, do not over-excavate, and use de-compaction practices to restore the soils original infiltration properties.

Design Guidance

- Infiltration trenches can be covered with permeable topsoil and planted with grass. Use deep-rooted plants such as prairie grass to increase the infiltration capacity of the underlying soils.

10.4.3.5. Maintenance

Required Elements

Maintenance responsibility for an infiltration system shall be vested with a responsible authority by means of a legally binding and enforceable instrument that is executed as a condition of plan approval. Remove sediment/gross solids from the infiltration surface annually, to ensure the maximum surface area for treatment.

- The vegetative cover needs to be regularly maintained. Grass cover may be mowed and bare areas should be reseeded
- Disc, aerate or scrape the basin bottom to restore original cross section and infiltration rate every one to five years.

- To avoid soil compaction concerns, infiltration areas should not be used for recreational purposes unless a soil amendment is used.

10.4.4 Stormwater Filtering Systems

Filtering systems designed with a recharge capacity must also meet the soil testing, separation distance and siting requirements of infiltration systems. Design variants include:

- F-1 Surface Sand Filter (Figure 6.15)
- F-2 Underground Sand Filter (Figure 6.16)
- F-3 Perimeter Sand Filter (Figure 6.17)
- F-4 Organic Filter(peat) (Figure 6.18)
- F-5 Bioretention (Figure 6.19)

Treatment Suitability: Stormwater bioretention areas are shallow stormwater basin or landscaped area which utilizes engineered soils and vegetation to capture and treat runoff. Bioretention practices are often located in parking lot islands, and can also be used to treat runoff in residential areas.

10.4.4.1 Conveyance

Required Elements

- Systems will operate as offline treatment systems with bypass to stable downstream conveyances, unless used as pretreatment to an online system.
- Conveyance to bioretention system is typically overland flow delivered to the surface of the system, usually through curb cuts or over a concrete lip.

10.4.4.2 Pretreatment

Required Elements

- Redundant pretreatment must be provided in areas with clay soils.

10.4.4.3 Treatment

Required Elements

- Water Quality Volume (WQ_v) is equivalent to the estimated 1-year, 24-hour post development runoff volume.

- Filter media vary 1.5-3 feet deep according to the design variation as specified in schematics (Figures 6-15 to 6-19). Filter media shall meet the following requirements:
- Inorganic fraction of filter media shall be ASTM C-33 sand.
- The organic fraction of filter media in F-4 and F-5 shall be a sand/peat mixture.
- Media in F-5 design should contain 5-15% organic matter. Select organic matter that is not a source of phosphorus. Peat is greatly preferred due to low phosphorus and high cation-exchange capacity. Composts are an unacceptable alternative to peat. They are a major source of phosphorus for the first several years of operation (to underdrain water or percolate water to groundwater). When the soils go anaerobic, compost easily loses any phosphorus (and metals) it has accumulated. Peat does not have this risk of leachate.
- The engineered media shall have a low phosphorus index (0-25). (Hunt, 2006)
- Media should contain 0% clay. Any clay greatly hastens failure, especially in the presence of geotextiles.
- A permeable non-woven filter fabric shall be placed between the gravel layer and the filter media.
- In the design of bioretention areas, surface overflows should be used instead of underdrains, where possible. (i.e., where head is available, systems can be designed to drain to surface features instead of sub-surface conveyances as they drain).

10.4.4.4 Landscaping

Required Elements

- Provide a detailed landscaping plan.
- Landscape to minimize the application and frequency of fertilizer in the drainage area.
- Optimize vegetation in the filter for maximum phosphorus uptake.
- Stabilize contributing area before runoff is directed to the facility.
- Provide detailed landscaping plan for bioretention area.
- Optimize vegetation in the bioretention for phosphorus uptake. See Table 10.4 and Table 10.5.

10.4.4.5 Maintenance

Required Elements

Maintenance responsibility for a filtering system shall be vested with a responsible authority by means of a legally binding and enforceable instrument that is executed as a condition of plan approval.

- Remove sediment/gross solids from sedimentation chamber and filter surface annually or when depth exceeds 3 inches.
- Remove sediment/gross solids from bioretention surface annually or when depth exceeds 3 inches.
- Keep the vegetation height limited to 18 inches in bioretention systems to facilitate routine maintenance and allow for observation of system function.
- Rehabilitate/replace mulch and bioretention media (top 6 inches minimum) when flow-through rate is reduced to <60% design treatment flow rate. This is determined by observing ponding in the facility following a storm event.
- Provide stone drop (at least 6 inches) at the inlet.

10.4.4.6 Drainage configuration

Required Elements

- Systems designed for recharge do not require use of underdrain pipe and geotextile fabric on the bottom of the facility. Systems designed for recharge and filtration do not need geotextile fabric on the bottom of facility, but require a gravel underdrain and perforated pipe.
- The areas above the pipe between the made soil and gravel must be covered by a non woven filter fabric.

A liner must be provided between the made soil and the in-situ soils to minimize the risk of groundwater contamination, when treating runoff from hotspot areas. A raised underdrain pipe in the stone reservoir may be incorporated for additional storage for quantity controls.

Section 10.4.5 Stormwater Open Channel Systems

All the open channel system design details, not specified in this section, shall at minimum meet the required elements and design guidance as stated in Chapter 6 of this Manual.

Design variants include:

- O-1 Dry Swale (Figure 6.20)

10.4.5.1. Feasibility

Open channels are not effective stand alone practices for enhanced removal of phosphorus due to their limited ability to provide 24-hour detention and trap smaller particulates under most conditions. They may be effective only during low flows with a shallow water depth.

Open channels have been found to be effective for the purposes of reducing runoff through infiltration and affecting runoff hydrology (i.e., reducing peak discharges), which can be a key component of site hydraulic source control. An open channel design is provided in this supplement only for application in linear projects redevelopment projects, or in combination with other practices.

10.4.5.2. Treatment

Required Elements

- The geometry of the design must be linear with limited ponding depth less than 3 times the height of the grass.
- Temporarily store the WQv within the facility during a minimum 30-minute period. Computation of travel time may be used to document meeting this requirement.
- Soil media for the dry swale shall meet the specifications of bioretention media specified in this section of the Manual.

10.4.5.3. Maintenance

Required Elements

- Maintenance responsibility for an open channel shall be vested with a responsible authority by means of a legally binding and enforceable instrument that is executed as a condition of plan approval

Section 10.5 Design Examples

10.5.1 Introduction

This section presents design examples for two hypothetical development sites in the State of New York. The first site, "Stone Hill Estates," is a pond design in a residential development and the second example is a filter design in a commercial site. Both sites are located in the New York City watershed (east-of-Hudson). Both examples incorporate several design features of the BSD principles and hydrologic source control.

Example 1 presents a pond design example similar to the hydrology calculated in Section 8.1 of this Manual (note the change in geographic location). This design example demonstrates the hydrologic and hydraulic computations to achieve water quality and, to a limited extent, water quantity control for stormwater management. Other specific dam design criteria such as soil compaction, structural appurtenances, embankment drainage, outlet design, gates, reservoir drawdown requirements, etc. are not included in the example, but are stated in Guidelines for Design of Dams; Appendix A of this Manual.

Example 1 requires an Article 15 Dam Permit from NYS-DEC since the dam is 15 feet high measured from the top of dam to the toe of slope at the downstream outlet, and the storage measured behind the structure to the top of the dam is 2.2 MG.

Design Example 1 is completed for both a Wet Pond (P2) and a Wet Extended Detention (P3) Pond. Both are designed based on the criteria for enhanced phosphorus removal discussed in this chapter.

Example 2 demonstrates water quality design calculations for a sand filter for a commercial site. Only calculations for water quality volume (WQ_v) and channel protection volume (Cp_v) are included because the design of flood controls and ultimate build-out conditions follow the same steps as sections 8.1 and 8.2 of this manual. Both examples present new developments, whose design is based on BSD principles and focuses on hydrologic source control. These scenarios demonstrate how hydrologic source control is best achieved through reduction of the effective impervious surface and minimization of disturbed area.

All other design calculation methodologies remain consistent with the Design Manual and can be found in Chapter 8 of this manual.

10.5.2 Hydrology Sizing Method Stone Hill Estates

See Chapter 8, Section 8.1 for the complete site information and figures. The following shows only the elements of the design prepared in accordance with the enhanced phosphorus removal sizing criteria.

As illustrated in Figure 8.1 of Section 8.1, "Stone Hill Estates" is a 45-acre residential development with 20 acres of off-site drainage, which is currently in a meadow condition. The site is on mostly C soils with some D soils.

Base Data

Location: New York City Watershed (East of Hudson)

Site Area = 45.1 acres; Offsite Area = 20.0 ac (meadow)

Total Drainage Area (A) = 65.1 ac

Measured Impervious Area = 12.0 ac

Site Soil Types: 78% "C", 22% "D"

Offsite Soil Type: 100% "C"

Zoning: Residential (½ acre lots)

1-yr 24-hr storm = 2.8 inches

Hydrologic Data

	Pre	Post	Ult.
CN	72	78	82
t_c(hr)	.44	.33	.33

The computations in Section 8.1 begin by 1) calculating the water Quality volume (WQ_v) for the site, and 2) establishing the hydrologic input parameters and developing the site hydrology. The WQ_v

required for enhanced phosphorus removal cannot be calculated until the latter of the two steps have been completed because it is dependent on these values.

Step 1. Establish Hydrologic Input Parameters and Develop Site Hydrology (see Tables 10.5.1 and 10.5.2)

Table 10.5.1 Hydrologic Input Parameters

	Area (ac)	CN	Tc (hr)
Pre-developed	65.1	72	0.44
Post-developed	65.1	78	0.33
Ultimate buildout*	65.1	82	0.33

*Zoned land use in the drainage area.

Table 10.5.2 Hydrologic Calculations

Condition	$V_{1\text{-yr}}$ in	$Q_{1\text{-yr}}$ cfs	$Q_{10\text{-yr}}$ cfs	$Q_{100\text{-yr}}$ cfs
Pre-developed	0.62	28	99	207
Post-developed	0.99	49	139	266
Ultimate buildout	NA	NA	NA	411

The rainfall for 1-year 24-hour storm is 2.8 inches. The time of concentration is dependent on the 2-year rainfall event, which is 3.5 inches in this location. (Figure 4.7 in Chapter 4 illustrates the 2-year, 24-hour rainfall map for New York). In addition, the site is located in the Type III rainfall map.

Step 2. Compute Water Quality Volume, (WQ_v)

Compute WQv for Enhanced Phosphorus Removal

WQ_v = Estimated runoff volume (acre-feet) resulting from the 1-year, 24-hour design storm over the post development watershed (includes contributing on-site and off-site drainage from impervious and pervious areas alike)

The hydrologic calculations show that the 1-year, 24-hour event results in 0.99 inches of runoff over the total contributing site area. Therefore, the WQ_v can be calculated as follows:

$$= (\text{Total Drainage Area})(V_{1\text{-yr}})$$

$$= (65.1 \text{ ac})(0.99 \text{ in})(1 \text{ ft}/12\text{in})$$

$$= 5.37 \text{ ac-ft}$$

In final stabilization of the site, soil-decompaction practices are applied to all disturbed area. Because of soil restoration practice, hydrologic soil group curve numbers applied to the grass areas are kept as those of pre-construction condition.

Table 10.5.3 Stone Hill Pre-Development Conditions

PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			SK
DRAINAGE AREA NAME:	PRE DEVELOPMENT			10/07/07
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D	Curve Number	AREA (In acres)
MEADOW		C	71	20.25 Ac.
MEADOW		D	78	7.95 Ac.
WOOD		C	70	15.09 Ac.
WOOD		D	77	1.81 Ac.
OFF-SITE MEADOW		C	71	20.00 Ac.
			AREA SUBTOTALS:	65.10 Ac.

Time of Concentration 2-Yr 24 Hr Rainfall = 3.5 In	Surface Cover Cross Section	Manning 'n' Wetted Per	Flow Length Avg Velocity	Slope Tt (Hrs)
Sheet Flow	dense grass	'n'=0.24	150 Ft.	3.80%
				0.26 Hrs
Shallow Flow	UNPAVED		1300 Ft.	2.70%
			2.65 F.P.S.	0.14 Hrs.
Channel Flow		'n'=0.040	1100 Ft.	2.70%
Hydraulic Radius =1.26	22.0 SqFt	17.5 Ft.	7.14 F.P.S.	0.04 Hrs.

Total Area in Acres =	65.10 Ac.	Total Sheet	Total Shallow	Total Channel
Weighted CN =	72	Flow=	Flow=	Flow =
Time Of Concentration =	0.44 Hrs.	0.26 Hrs.	0.14 Hrs.	0.04 Hrs.
Pond Factor =	1	RAINFALL TYPE III		
STORM	*Precipitation* (P) inches	*Runoff* (V)in	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.8 In.	0.69	28 CFS	162,217 Cu. Ft.
2 Year	3.5 In.	1.11	48 CFS	263,102 Cu. Ft.
10 Year	5.0 In.	2.19	99 CFS	516,360 Cu. Ft.
100 Year	7.8 In.	4.5	207 CFS	191,446 Cu. Ft.

Table 10.5.4 Stone Hill Post-Development Conditions

PEAK DISCHARGE SUMMARY				
JOB:	STONE HILL			SK
DRAINAGE AREA NAME:	POST DEVELOPMENT			10/07/07
COVER DESCRIPTION	SOIL NAME	GROUP A,B,C,D	Curve Number	AREA (In acres)
MEADOW		C	71	0.16 Ac.
MEADOW		D	78	0.14 Ac.
WOOD		C	70	3.09 Ac.
WOOD		D	77	1.81 Ac.
IMPERVIOUS			98	12.00 Ac.
GRASS		C	74	20.09 Ac.
GRASS		D	80	7.81 Ac.
OFFSITE MEADOW		C	71	20.00 Ac.
			AREA SUBTOTALS:	65.10 Ac.

Time of Concentration	Surface Cover	Manning 'n'	Flow Length	Slope
2-Yr 24 Hr Rainfall = 3.5 In	Cross Section	Wetted Per	Avg Velocity	Tt (Hrs)
Sheet Flow	dense grass	'n'=0.24	100 Ft.	3.80%
				0.19 Hrs
Shallow Flow	UNPAVED		100 Ft.	1.50%
(a)			1.98 F.P.S.	0.01 Hrs.
	PAVED		400 Ft.	1.00%
(b)			2.03 F.P.S.	0.055 Hrs.
Channel Flow (a)		'n'=0.013	1550 Ft.	1.00%
Hydraulic Radius =0.50	1.6 SqFt	3.2 Ft.	7.22 F.P.S.	0.06 Hrs.
(b)		'n'=0.030	350 Ft.	4.30%
Hydraulic Radius =1.42	12.0 SqFt	8.5 Ft.	13.01 F.P.S.	0.01 Hrs.
(c)		'n'=0.040	300 Ft.	3.30%
Hydraulic Radius =1.26	22.0 SqFt	8.5 Ft.	7.89 F.P.S.	0.01 Hrs.
Total Area in Acres =	65.10 Ac.	Total Sheet Flow=	Total Shallow Flow=	Total Channel Flow =
Weighted CN =	78			
Time Of Concentration =	0.34 Hrs.	0.19 Hrs.	0.07 Hrs.	0.08 Hrs.
Pond Factor =	1	RAINFALL TYPE III		

STORM	Precipitation (P) inches	Runoff (V)in	Qp, PEAK DISCHARGE	TOTAL STORM Volumes
1 Year	2.8 In.	0.99 In.	49 CFS	233,950 Cu. Ft.
2 Year	3.5 In.	1.49 In.	75 CFS	352,313 Cu. Ft.
10 Year	5.0 In.	2.7 In.	139 CFS	638,328 Cu. Ft.
100 Year	7.8 In.	5.19 In.	266 CFS	1,226,170 Cu.Ft

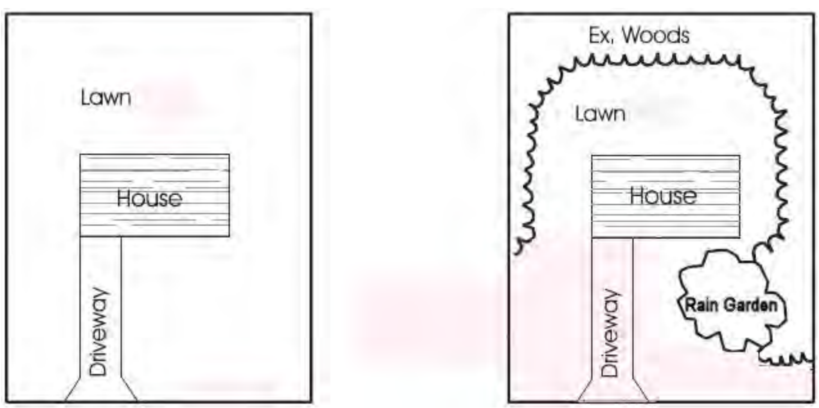
Step 3. Evaluate Source Control and Compute Flow Reduction

The conventional design (not incorporating BSD) WQ_v of 5.37 ac-ft results from a site design that includes 45 acres of disturbed area. A detention pond would need to be designed to treat the WQ_v on-site. The area required for this practice has a footprint of around 0.7 acres for treatment of runoff from 108 houses and roads.

To reduce the flow by source control, two Better Site Design (BSD) features are selected be incorporated in the site plan: vegetated buffers and rain gardens.

1. Vegetated Buffers – *Incorporating this feature would preserve about 4 acres of undisturbed natural area that in a conventional design would have been planned to be seeded as lawn areas. Instead, the area is preserved as forested conservation areas. This practice is applied in both soil types C and D and helps reduce the Curve Number from 78 to 77.*

Figure 10.5.1 Conventional versus BSD



2. Rain Gardens – *In this example, rain gardens are designed to receive runoff from a section of the rooftop on about half of the lots. Rain gardens are not intended to provide treatment for the entire water quality volume of the drainage area. Routing of the flow through rain gardens results in reduction of the WQv based upon the storage size of the rain garden. This practice is applied on the lots with soil type C. A rain garden's maximum allowable impervious area is 1000 ft2 (as specified in the rain garden profile sheet in Chapter 9 of this manual), designed to store and filter storm water within the planting media and to exfiltrate a fraction of the 1-year storm to the ground. A bypass also routes excess flow to the pond. An average size of 270 ft2 surface area is used for rain gardens which should be located within 30 ft. of the downspouts. The runoff volume to the rain gardens is primarily from driveways, lawns and disconnected rooftops. Roof leaders drain the rooftop runoff to the rain garden via a splash block and over a grass buffer that extends 20 ft. The rooftop runoff from half of the dwelling units (56 rooftops) is routed through rain gardens. Sites are graded so that the runoff volume reaches the rain garden, allowing infiltration of runoff volume equivalent to the storage capacity of the rain garden, while the outlet conveys excess flows of larger storms to the pond.*

Storage capacity of rain gardens is calculated based on the following parameters:

Table 10.5.5. Calculate Storage Capacity of Rain Gardens

WQv		56 units		
Solve for drainage layer and soil media storage volume:				
$V_{SM} = A_{RG} \times D_{SM} \times P_{SM}$				
$V_{DL} = A_{RG} \times D_{DL} \times P_{DL}$				
where:				Units
A_{RG} = proposed rain garden surface area (ft2)			270	ft^2
D_{SM} = depth soil media = 12 inches (ft)			1	Ft
D_{DL} = depth drainage layer = 6 inches (ft)			0.5	Ft
P_{SM} = porosity of soil media			0.2	
P_{DL} = porosity of drainage layer = 0.40			0.4	
V_{SM} = storage volume in soil media			50	ft^3
V_{DL} = storage volume in drainage layer			50	ft^3
D_P = ponding depth			0.50	Ft
$WQv = V_{SM}+V_{DL}+(D_P \times A_{RG})$			225	ft^3
Number of Units			56	
Reduction in WQv (ft^3)			13,608	ft^3

In modeling the hydrology of the site with source control, adding 56 rain gardens controls runoff from approximately 1.3 acres of roof top and 1.3 acres landscaped area, which results in control and reduction of 0.31 ac-ft of WQ_v. The runoff volume to the rain gardens is primarily from driveways, lawns and disconnected rooftops. From the runoff generated, 13,600 ft^3 (0.31 ac-ft) infiltrates into the native soil and does not reach the height of the rectangular weir outlet structure (1.5ft) designed to safely drain the overflow from the rain garden into the conveyance system. Source control results in around 6% reduction of final WQv. Table 10.5.6 provides a summary of source control reduction.

Table 10.5.6 Summary of Meeting Source Control Criterion	
Rooftop with BSD (ft^2)	1000
Number of Roof tops (1/2 of the dwelling units) tributary to rain gardens	56
Total Area (acre)	1.29
Total Imp. Area (acre)	12
% Imp. Area	0.11
Routing of 11% of impervious area through rain gardens meets the source control requirement (10% for HSG C)	

Step 4. Compute Stream Channel Protection Volume, (Cp_v)

The channel protection volume (Cp_v) requirement is achieved by detaining the 1-year, 24-hour storm to achieve a center of mass detention time (CMDT) of at least 24 hours. This can be achieved by adjusting the outlet structure (see Section 4.3 for complete discussion of Channel Protection Volume). In some cases, this will require reducing the extended detention orifice size and adjusting the overflow weir design.

Wet ponds are not designed for detaining flow; therefore, the difference between the inflow and outflow hydrographs is insignificant when sized purely for water quality control. The Cp_v requirement may be provided above the WQ_v in a wet pond (P2) or a stormwater wetland. Therefore, once a pond has been sized to meet the WQ_v requirement, a TR-55 and TR-20 (or approved equivalent) model may be used to determine center of mass detention Time. By modifying the pond volume and the elevation and size of the outlet structure(s), in a trial and error fashion, the Cp_v requirement can be met. Alternatively, the methodologies in Appendix B can be followed to ensure the Cp_v requirement is met. An example of this methodology is shown in Section 8.1 of Chapter 8.

It may be necessary to install detention ponds or underground vaults onsite to meet the Cp_v requirement of 24-hour extended detention if pond sizes become too large. Schematics of typical designs are shown in figures 4.2 and 4.3. Note that although these practices meet water quantity goals, they are unacceptable for water quality control because of poor pollutant removal and need to be installed subsequent to a practice in Section 10.2 of this chapter to ensure enhanced phosphorus removal.

Step 5. Additional Sizing Requirements

See Chapter 8, Section 8.1 for example procedures for computation of the Overbank Flood Protection Volume (Qp_{10}), the Extreme Flood Protection Volume (Q_f), and the Safe Passage of 100-Year Design Storm (Q_f).

10.5.3 Pond Design Example Stone Hill Estates

See Chapter 8, Section 8.2 Pond Design Example for the complete example, figures and calculations. The following shows only the elements of the example that have changed, in respect to this chapter, for enhanced phosphorus removal. The example provides calculations for both a Wet Pond and an Extended Detention Wet Pond.

Step 1. Compute Preliminary Runoff Control Volumes

The volume requirements were determined in Section 10.5.2. Table 10.5.7 provides a summary of the storage requirements.

Table 10.5.7 Summary of General Storage Requirements for Stone Hill Estates

Symbol	Category	Volume Required (ac- ft)	Notes
WQ_v	Water Quality Volume	5.06	Final WQv 5.37 - 0.31 = 5.06 ft^3
Cp_v	Channel Protection Volume	TBD	Wet Pond: See Below ED Wet Pond: N/A

Step 2. Determine whether the development site and conditions are appropriate for the use of a stormwater pond.

There are no additional requirements for this site. Procedures are identical to those presented in Chapter 8.

Step 3. Confirm local design criteria and applicability.

There are no additional requirements for this site. Procedures are identical to those presented in Chapter 8.

Step 4. Determine pretreatment volume.

Size wet forebay to treat 10% of the WQ_v. (10%)(5.1 ac-ft) = **0.51 ac-ft**

(Forebay volume is included in WQ_v as part of the permanent pool volume.)

Step 5. Determine permanent pool volume and ED volume.

Size permanent pool volume to contain 50% of WQ_v:

0.5 × (5.10 ac-ft) = **2.55 ac-ft**. (includes 0.51 ac-ft of forebay volume)

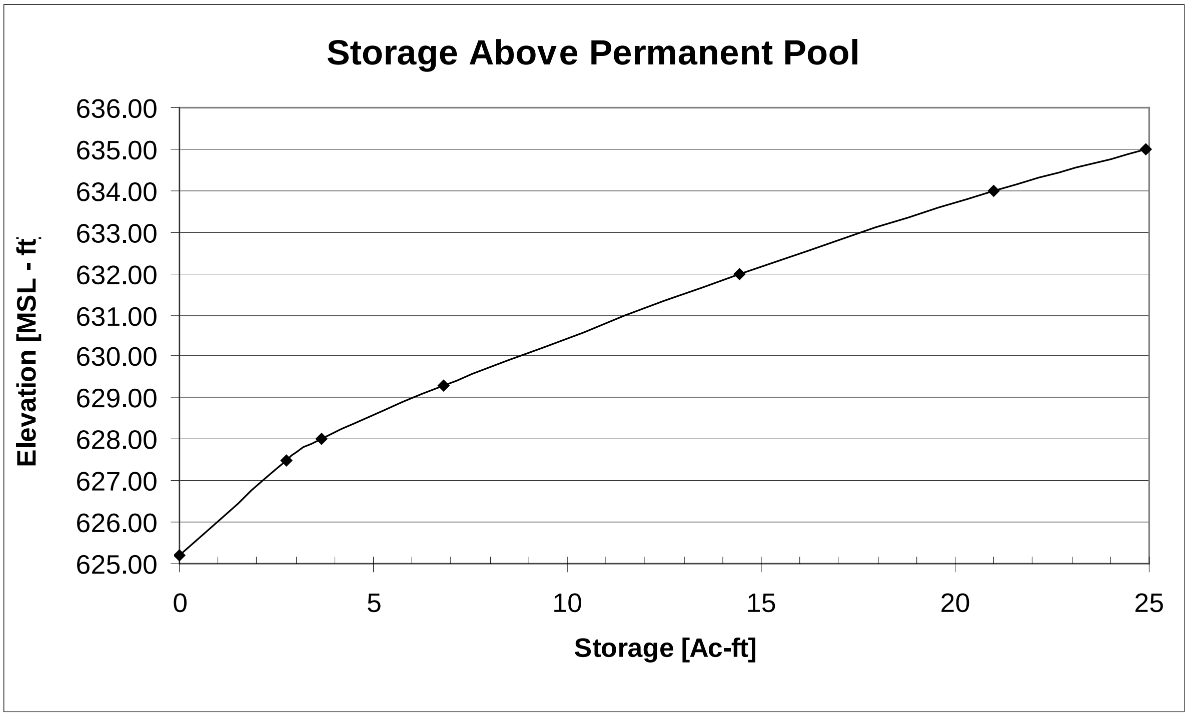
Size ED volume to contain 50% of WQ_v: 0.5 × (5.10 ac-ft) = **2.55 ac-ft**

Step 6. Determine pond location and preliminary geometry. Conduct pond grading and determine storage available for WQ_v permanent pool and WQ_v-ED (if applicable).

This step involves initially grading the pond (establishing contours) and determining the elevation-storage relationship for the pond. Storage must be provided for the permanent pool (including sediment forebay), extended detention (WQ_v-ED) and the Cp_v-ED. Calculations for the 10-year, and 100-year storms, plus sufficient additional storage to pass the ultimate condition 100-year storm with required freeboard can be found in Section 8.2 of Chapter 8. An elevation-storage table and curve is prepared using the average area method for computing volumes. See Figure 8.7 in Chapter 8 for pond location on site and Table and 10.5.8 for elevation-storage data and figure 0.10.5.2. for Stage Discharge Curve.

Table 10.5.8 Storage Elevation Table							
Elevation	**Area**	**Average Area**	**Depth**	**Volume**	**Cumulative Volume**	**Cumulativ e Volume**	**Volume Above Permanent Pool**
MSL	ft^2	ft^2	ft	ft^3	ft^3	ac-ft	ac-ft
621.00	13671						
624.00	36130	24901	3.0	74702	74702	1.71	0.00
625.20	45136	40633	1.2	48760	123461	2.83	0.28
627.50	60109	52623	2.3	121032	244493	5.61	2.96
628.00	94829	77469	0.5	38735	283227	6.50	3.85
629.30	114359	104594	1.3	135972	419200	9.62	6.97
632.00	132262	123311	2.7	332938	752138	17.27	14.62
634.00	154324	143293	2.0	286586	1038724	23.85	21.20
635.00	184321	169323	1.0	169323	1208046	27.73	25.08

Figure 10.5.2. Stage Discharge Curve



Set basic elevations for pond structures

- Set the pond bottom at elevation 621.0
- Provide gravity flow to allow for pond drain set riser invert at 620.5
- Set barrel outlet elevation at 620.0

Set water surface and other elevations

- Required permanent pool volume = 50% of WQ_v = 2.55 ac-ft. From the elevation-storage table, read elevation 625.2 (2.83 ac-ft > 2.55 ac-ft) site can accommodate it and it allows a small safety factor for fine sediment accumulation - OK
- Set permanent pool WSEL = 625.2
- Forebay volume provided in single pool with volume = 0.51 ac-ft – OK
- Add 1 ft to the depth of the forebay to account for sacrificial storage for sediment deposition.
- The pond pretreatment bottom is set at elevation 620.0

- Required extended detention volume (WQ_v-ED) = 2.55 ac-ft. From the elevation-storage table (volume above permanent pool), read elevation 627.5 (2.78 ac-ft > 2.55 ac-ft) OK. Set ED wsel = 627.5

- Check the pond surface area to drainage area ratio:

Perm. Pool V.	2.55		Surface area at WQv (sf)	52622.5
Drainage area (sf)	2835756		Surface area ratio 1:100	0.018557

NOTE: Total storage at elevation 627.5 = 5.61 ac-ft (greater than required WQv of 5.1 ac-ft)

Compute the required WQ_v-ED orifice diameter to release 2.55 ac-ft during 24 hours (for Wet ED Pond Only)

- Avg. ED release rate = (2.55 ac-ft)(43,560 ft^2/ac)/(24 hr)(3600 sec/hr) = 1.29 cfs

- Invert of orifice set at wsel = 625.2

- Average head = (627.5 - 625.2)/ 2 = 1.15'

- Use orifice equation to compute cross-sectional area and diameter

  - $Q = CA(2gh)^{0.5}$, for Q=1.29 cfs h = 1.15 ft; C = 0.6 = discharge coefficient Solve for A

  - A = 1.29 cfs / $[(0.6)((2)32.2\ ft/s^2)(1.15\ ft))^{0.5}]$ A = 0.25 ft^2, $A = \pi d^2 / 4$;

  - dia. = 0.57 ft = 6.76 inches

  - Use 8" pipe with a gate valve to achieve equivalent diameter.

Compute the stage-discharge equation for the 6.9" dia. WQ_v-ED orifice.

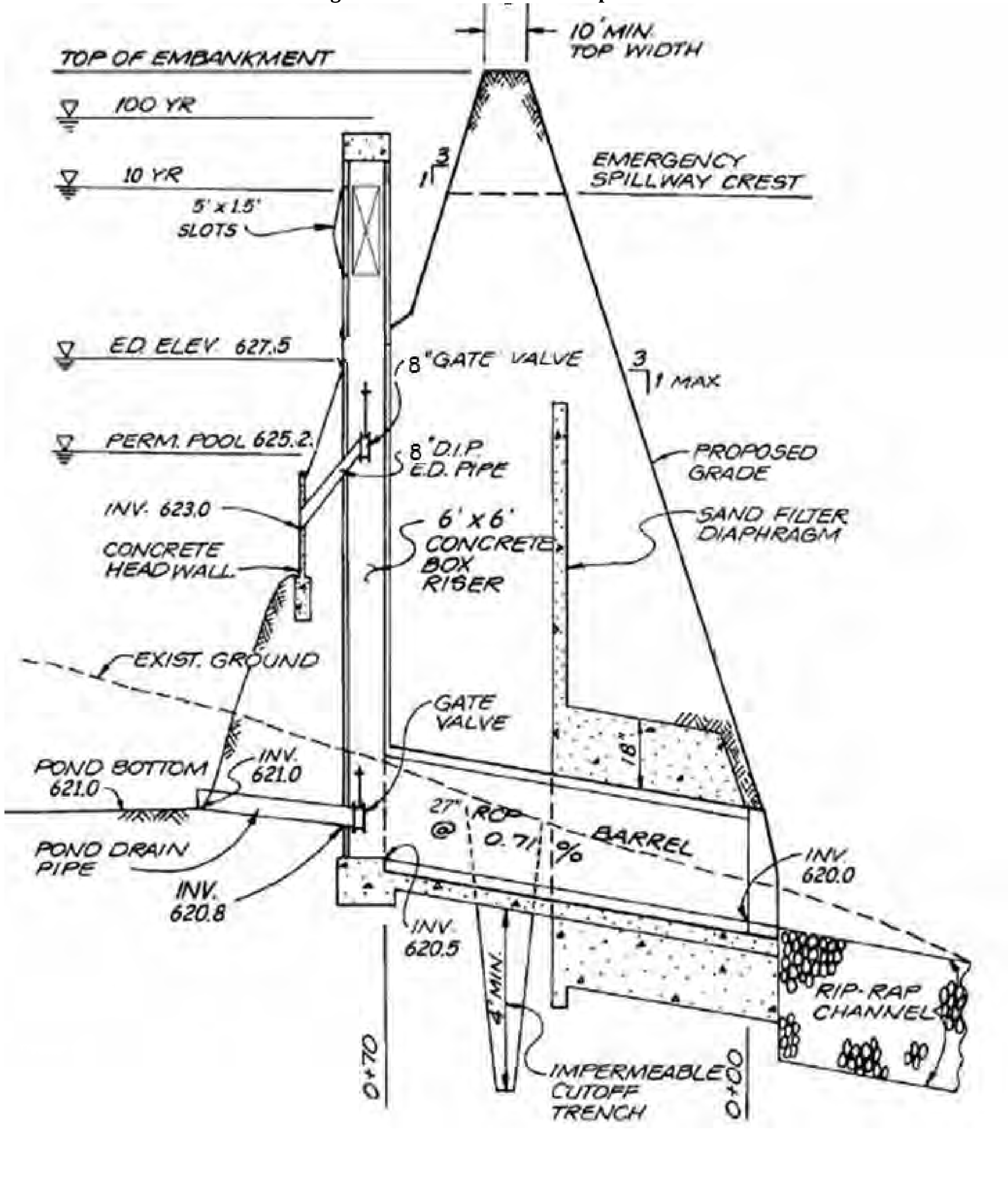
- $Q_{WQv\text{-}ED} = CA(2gh)^{0.5} = (0.6)\ (0.2\ ft^2)\ [((2)(32.2\ ft/s^2))^{0.5}]\ (h^{0.5})$

- $Q_{WQv\text{-}ED} = (1.25)\ h^{0.5}$, where: h = wsel - 625.65

(Note: Account for one half of orifice diameter when calculating head.)

NOTE: In Wet Pond design, there is no WQv-ED orifice. All of the 1-year, 24-hour volume is retained.

Figure 10.5.3- Outlet structure profile



Step 7. Set the Cp_v pool elevation. Compute Cp_v-ED orifice size, compute release rate for Cp_v control and establish elevation.

CPv Sizing for Wet Ponds:

To determine the required Cp_v, a TR-55 model was developed to demonstrate increasing the elevation of the pond and the sizing of a Cp_v outlet to achieve a center of mass detention time (CMDT) of at least 24 hours (24-hour extended detention of the 1-year, 24-hour storm event).

Based on the TR-55 output data:

- Required Cp_v storage to meet 24-hour CMDT = 3.09 ac-ft
- Diameter of Cp_v-ED orifice = 4.4 inches at an elevation of 627.5 (determined from TR-55 model)
- Overflow Weir = 100' wide earth spillway at 628.75 (not shown on the schematics)
- Reqiured CMDT = 25.2 hrs

CPv Sizing for Wet Extended Detention Pond:

The WQ_v for enhanced phosphorus removal is sized for the 1-year event and the WQ_v-ED orifice is sized to release the ED_v within 24 hours. According to step 6 the orifice diameter calculated to release the 2.55 ac-ft WQv within 24 hours (resulting in a release rate = 1.29 cfs). Therefore, the Cp_v requirements are essentially included in the design. No additional volume is recommended. Based on the TR-55 output data, a CMDT of 23 hours was achieved in this design. Additional detention may be achieved by either increasing pond volume or an additional practice or control at the outlet of the pond to meet the Cp_v requirement (not included in example).

See Chapter 8, Section 8.2 for example calculations for the remaining steps, which cover calculations for Step 8: calculate Qp_{10} (10-year storm) release rate and water surface elevations; Step 9: calculate Qp_{100} (100-year storm) release rate and water surface elevation, size emergency spillway, calculate 100-year water surface elevation, and Step 10: check for safe passage of Qp_{100} under ultimate build-out conditions and set top of embankment elevation.

10.5.4 Sand Filter Design Example

See Chapter 8, Section 8.3 Sand Filter Design Example for the complete example, figures, and calculations. The following shows only the elements of the example that have changed for enhanced phosphorus removal and does not address required water quantity controls.

This design example focuses on the design of a sand filter for a 4.5-acre catchment of Lake Center, a hypothetical commercial site located in the New York City watershed (east of Hudson). A five-story office building and associated parking are proposed within the catchment. The layout is shown in Chapter 8, Figure 8.14. The catchment has 3.05 acres of impervious cover (i.e., the site is 68% impervious). The pre-developed site is a mixture of forest and meadow. On-site soils are predominantly HSG "B" soils. Base data and hydrologic data are shown below and are available in Section 8.3.

Base Data

Location: New York City watershed (east-of-Hudson)

Site Area = Total Drainage Area (A) = 4.50 ac

Impervious Area = 3.05 ac; or I =3.05/4.50 = 68%

Soils Type "B"

Hydrologic Data

	Pre	Post
CN	58	85
t_c (hr)	0.44	0. 2

The storm distribution type falls under type III. The rainfall for different storm frequencies for this example also reflects the corresponding amount of rain for this location as described in Example 1 of this section. Calculation of the time of concentration is based on the 2-year rainfall event (3.5 inches).

This step-by-step example will focus on meeting the water quality requirements. Channel protection control, overbank flood control and extreme flood control are not addressed in this example. Therefore, a detailed hydrologic analysis is not presented. For an example of detailed sizing calculations, consult

Example 8.2 of Chapter 8. In general, the primary function of sand filters is to provide water quality treatment and not large storm attenuation. As such, flows in excess of the water quality volume are typically routed to bypass the facility. Where quantity control is required, bypassed flows can be routed to conventional detention basins (or some other facility such as underground storage vaults see Section 4.3).

The computations for the filter design for enhanced phosphorus removal begin with the site hydrologic input parameters and preliminary hydrologic calculations. These inputs are then used to obtain a WQ_v. Once the source control options are evaluated and incorporated in the site plan, a final WQv and flow rate is determined. Based on the discharge rate necessary, flow splitters are designed, and finally the filter design is completed.

Step 1. Develop Site Hydrologic Input Parameters and Calculate Water Quality Volume (see Table 10.5.9)

Water Quality Volume, WQ_v

The design storm is the 1-year, 24-hour, type III rainfall event. Consulting Figure 10.1, use 2.8-inches as the 1-year rainfall event based on the site location.

In final stabilization of the site, soil decompaction practices are applied to all disturbed area. Because of soil restoration practice, hydrologic soil group curve numbers applied to the grass areas are kept at their pre-construction value.

Using TR-55 and the post-development watershed, the resulting peak runoff rate is = 5.4 cfs.

The following provides a summary of TR-55 hydrologic calculation for WQv and discharge rate:

Table. 10.5.9			
Inputs	**Parameter**	**Value**	**Units**
Site Acreage	A	4.5	Acres
Impervious Area	IA	3.05	Acres
Impervious Cover %	I	67.78	%
1-yr Rainfall (type III)	P	2.8	Inches
Curve Number (CN)		85	
Runoff Volume	*WQv=Area*runoff depth*	22869.00	ft^3
Initial abstraction (Ia)	(200/CN)-2	0.35	
	Ia/P	0.13	
qu (from NRCS Exhibit 4-III)		550	csm/in
Qa (runoff depth TR-55)		1.42	Inch
		for tc = 0.2	Hour
Qwq=(qu csm/in) (area ac/640ac/sq mi.) (Qa")		5.41	Cfs
Volume		23,224.37	ft^3

Therefore:

WQ_v = 0.54 ac-ft or 23,224ft^3

Table 10.5.10 Site Hydrology

Condition	CN	$Q_{1\text{-yr}}$ cfs	$Q_{2\text{-yr}}$ cfs	$Q_{10\text{-yr}}$ cfs	$Q_{100\text{-yr}}$ Cfs
Pre-Developed	58	0.15	1.0	3.5	10.1
Post-Developed	85	5.4	8.2	13.6	23.8

Step 2. Evaluate the Development Site for Appropriate Source Control Practice and Application of Surface Sand Filter.

Grass swales and rain gardens are found to be suitable for this site. Infiltration capacity of the site (HSG B) allows infiltration and reducton of the runoff volume. The conventional plan identified 8 traffic islands which can be used for siting of a rain garden or bioretention area. A section of the conveyance system is also modified to collect the sheet flow and shallow concentrated flow into a grass swale. Grass swales allow some storage and infiltration. By incorporating these practices, the plan meets the source control requirement for routing 20% of impervious area through BSD practices.

3.05 acres * 43,560 * 0.2 = 26,572 ft^2

About 0.6 acre of the site will be connected to a bioretention area with infiltration capacity (without underdrain pipe) and a grass swale. Bioretention area calculations are similar to example 1 of this section. Swale capacity is calculated using standard open-channel hydraulic design calculations to maintain shallow depths and low velocities.

For the design of filters, head limitations are evaluated. Existing ground elevation at the practice location is 222.0 feet, mean sea level. Soil boring observations reveal that the seasonally high water table is at 211.0 feet. Adjacent drainage channel invert is at 213.0 feet. See Figure 10.5.4.

Step 3. Compute Source Control Flow Reduction

The site is designed to route the runoff from 0.6 acre of the impervious area through a bioretention area, overflow to an open channel and eventually flow to the proposed filter system. Bioretention storage is sized similar to the rain gardens in Example 1 provided in this Chapter. An overflow is designed to convey the overflow from the bioretention cell from larger storms into the swale.

Contributing areas consist of 0.6 acre of rooftop, and 1 acre of grass area. About 300 ft^2 of bioretention area is considered for each 1000 ft^2 of rooftop, which results in a total bioretention area of 6,500 ft^2. The rest of the impervious and landscaped areas discharge to a grass swale, which also conveys the overflow from the bioretention area. Table 10.5.11 shows the calculation for sizing of the bioretention areas.

Table 10.5.11. Summary of Bioretention Area Sizing				
Calculate storage capacity of bioretention area				
WQv		1 unit		
Solve for drainage layer and soil media storage volume:				
$V_{SM} = A_{RG} \times D_{SM} \times P_{SM}$				
$V_{DL} = A_{RG} \times D_{DL} \times P_{DL}$				
where:				units
A_{RG} = proposed rain garden surface area (ft2)			6500	ft^2
D_{SM} = depth soil media = 24 inches (ft)			2	ft
D_{DL} = depth drainage layer = 6 inches (ft)			0.5	ft
P_{SM} = porosity of soil media			0.2	
P_{DL} = porosity of drainage layer = 0.40			0.4	
V_{SM} = storage volume in soil media			2,600	ft^3
V_{DL} = storage volume in drainage layer			1,300	ft^3
D_P = ponding depth			0.50	ft
$WQv = V_{SM}+V_{DL}+(D_P \times A_{RG})$			7,150	ft^3
Units			1	
Reduction in WQv in Filter (ft^3)			7,150	ft^3

A grass swale is designed to convey the runoff from this sub-catchment. The grading of the site is planned to be less than 4% slope so no check dams are required and the swale provides conveyance with some infiltration and filtering of runoff. Routing the flow through the grass swale increases the time of concentration.

The final water quality volume for the filter can be found by subtracting the volume in the BSD components from the water quality volume in the traditional site design or:

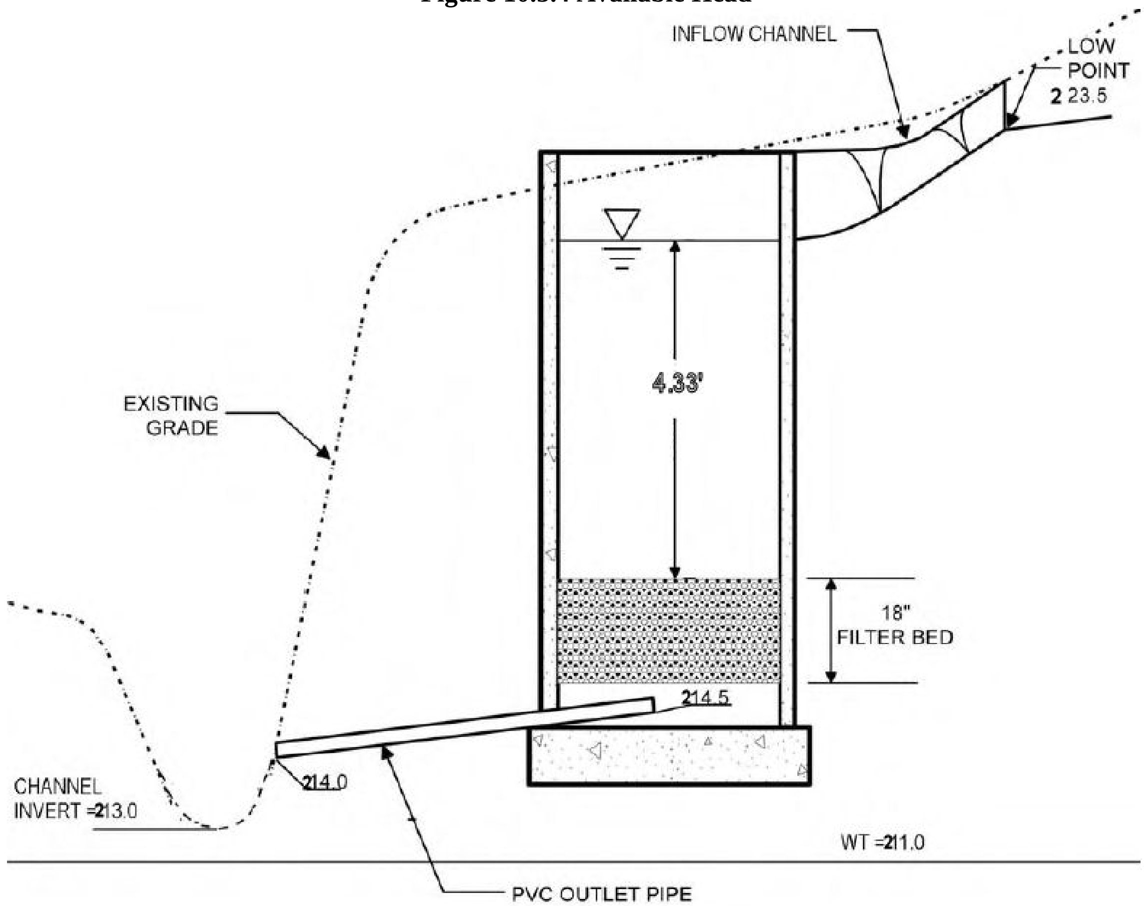
WQv = 23,224ft^3– 7,150 ft^3 = 16,074 ft^3

Step 4. Compute Available Head and Peak Discharge (Q_{WQ}).

Determine available head (See Figure 10.5.4):

The low point at the parking lot is 223.5. Subtract 2' to pass the Q_{10} discharge (221.5) and a half foot for the inflow channel to the facility (221.0). The low point at the channel invert, is 213.0. Set the outfall underdrain pipe 1.0’ above the drainage channel invert and add 0.5’ to this value for the drain slope (214.5). Add to this value 8" for the gravel blanket on top of the underdrains and 18" for the sand bed (216.67). The total available head is 221.0 - 216.67 or 4.33 feet. Therefore, the available average depth (hf) = 4.33' / 2 = 2.17 feet.

Figure 10.5.4 Available Head



Compute Peak Water Quality Discharge:

The peak rate of discharge for the water quality design storm is needed for the sizing of diversion structures. The discharge rate is derived from the hydrology calculation in Table 10.5.9. A similar calculation is performed to incorporate the flow reduction and increase time of concentration and peak reduction as a result of the BSD approach. The source control practices discussed above result in reduction of peak discharge by 12%. The flow splitter outlet structure is designed to convey the 1-year storm to the sedimentation chamber and filter and safely bypass the 10-year storm to the conveyance system.

Step 5. Sizing of Diversion Structure and Filtering System

At this point, all the steps are similar to steps 4 through 9 of Chapter 8.3 of this manual. The methodology for sizing of flow splitter outlet structure for diversion of the design storm (1-year), filter bed chamber volume within practice, filter bed overflow weir size and sedimentation chamber, all remain the same as defined in Chapter 8. The key equations include:

Orifice equation for sizing of diversion structure low flow orifice:

Q = CA(2gh)1/2 ;

Weir equation for sizing of the 10-year storm by pass weir:

Q = CLH3/2

Darcy's Law for sizing of the filter bed

$A_f = WQ_v (d_f) / [k (h_f + d_f) (t_f)]$

The requirement for enhanced phosphorus removal for sand filters is similar to conventional sizing of the filtering systems. As stated in Chapter 6, the entire treatment system (including pretreatment) shall be sized to temporarily hold at least 75% of the WQv prior to filtration. The following includes a summary of the design calculations for sand filter:

Table 10.5.12. Summary of Filter Bed Design			
Required Filter Bed Area filtration chamber Af = (WQv) (df) / [(k) (hf+df) (tf)]	Parameter	Value	Units
Design Volume (WQ_v)	WQv	16,074.00	ft^3
Filter Bed depth	d_f	1.5	ft
Coef. f Permeability of Filter media	K	3.5	ft/day
Avg. height of water above filter bed	h_f	2.18	ft
Design filter bed drain time	t_f	1.67	days
Surface Area	A_f	1120.94	ft^2
Width (Define L/W)	W	25	ft
Length	L	45	ft
Practice surface area		1125	ft^2
Porosity (n)		0.4 for sand	
Min. total volume Vmin=0.75Wqv		12055.5	ft^3
Pretreatment volume Pv=.25Wqv		4018.5	ft^3
pretreatment depth		2.5	ft
pretreatment surface area		1608	ft^2
Pretreatment length		65	ft
$Pvs=Pv+Pvh_f$		11,031	ft^3
Vf=Af(df)(n)		675	ft^3
$Vf\text{-}temp=2h_fA_f$		4905	ft^3
Vmin=Pv+Vf+Vf-temp		16,611	ft^3

References:

Burton, G.A. Jr., and R. Pitt, Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists, and Engineers. CRC Press, Inc., Boca Raton, FL. 911 pgs.

2002.

Cerrelli, G. A., "Stormwater Management Impacts Resulting from the Volumetric Abstraction of Runoff from Frequent Storms per PADEP CG-1." Villanova SWM Conference proceedings, 2007. 7pp.

Hunt, W. "Bioretention Performance, Design, Construction, and Maintenance." NC State Cooperative Extension, North Carolina A&T State University, Urban waterways. 2006. 10pp.

Minnesota Stormwater Manual, Minnesota Pollution Control Agency, 2005. http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html#manual visited 03/08.

Pitt, R. Maestre A., Morquecho R. "The National Stormwater Quality Database (NSQD, version 1.1)" 2004.

Pitt, R. E. Excerpt report, Particulate Phosphorus for Use in New York. 2005. 13pp.

Strecker, E.W ., W.C Huber, J.P. Heaney, D. Bodine, J.J. Sansalone, M.M. Quigley, D. Pankani, M. Leisenring, and P. Thayumanavan, "Critical Assessment of Stormwater Treatment and Control Selection Issues." Water Environment Research Federation, Report No. 02-SW-1. ISBN 1-84339-741-2. 290pp.

Wilks, D.S. & Cember, R.P. (1993). Atlas of Precipitation Extremes for the North-eastern United. States and South-eastern Canada. Publication No. Cornell University, Ithaca. RR 93-5