Description of MassDOT's Application of Impervious Cover Method in BMP 7U

(MassDOT Application of IC Method)

Introduction

The Massachusetts Department of Transportation (MassDOT) operates storm water systems along its roadways to control runoff. Storm water systems in urbanized areas are regulated under a Municipal Separate Storm Sewer Systems (MS4) National Pollutant Discharge Elimination System (NPDES) general permit issued by the United States Environmental Protection Agency (USEPA).

MassDOT has created a program to assess impaired waters and determine where to retrofit BMPs to ensure that storm water discharges from MassDOT's urbanized roadways do not cause instream exceedances of water quality standards. This report outlines one method used by MassDOT to assess the impacts that its storm water systems have on the state's impaired water bodies (listed on MADEP's 303d list).

For some of these impaired water bodies, the Massachusetts Department of Environmental Protection (MassDEP) has developed Total Maximum Daily Loads (TMDLs) which quantify concentrations of existing pollutants and identify the reductions in pollutant loading required to meet current water quality standards. MassDOT uses the TMDLs to assess storm water discharges from their storm water systems and make necessary improvements to the systems to meet the required reduction in pollutant loading outlined in the TMDL.

Many Massachusetts water bodies are impaired, but currently have no TMDL. In these cases, MassDOT is left without quantitative guidance for assessing its discharges, but still must address possible contributions to impairments as part of permit compliance. MassDOT used USEPA's Impervious Cover (IC) Method as a basis for developing an approach to assess the impacts of its storm water systems on impaired receiving water bodies without TMDLs.

The following sections describe:

- The effects of impervious cover on receiving water bodies
- Approaches to mitigation of impervious cover
- USEPA's Impervious Cover Method
- MassDOT's application of the Impervious Cover Method

Effects of Impervious Cover

The effects of impervious cover on receiving waters have been researched and documented extensively for more than 10 years. Storm water-related water quality impairments in watersheds are typically due to a pattern of causes and effects starting with disruption of the hydrologic cycle. Historically, development activity (i.e., urbanization) leads to changes in land cover in which forest and grasslands areas are converted to urban and suburban use with less soil and vegetated surfaces and more hard, paved, or roofed surfaces. These changes in land-uses result in changes to the hydrologic cycle of adjacent receiving waters, primarily through reductions in infiltration and increases in surface runoff. Both the quantity and quality of water resources are affected by these hydrologic disruptions.

Figure 1 below illustrates a hypothetical water budget for a parcel of land with both pre- and post-development conditions. In the post-development scenario, infiltration and resulting baseflow (through the ground) decrease dramatically with increases in hard, unabsorptive, impervious surfaces (roofs, pavement). Simultaneously, runoff (over the ground) increases significantly, especially during larger storms, causing bankfull flow conditions and stream bed scouring to occur more frequently. Consequently, with more impervious cover, the receiving stream experiences lower low flows due to reduced baseflow, and higher high flows due to increased storm water runoff volumes. Furthermore, instead of being slowed and filtered as it moves through or over the soil, water picks up speed and pollutants as it flows over paved or hard surfaces.

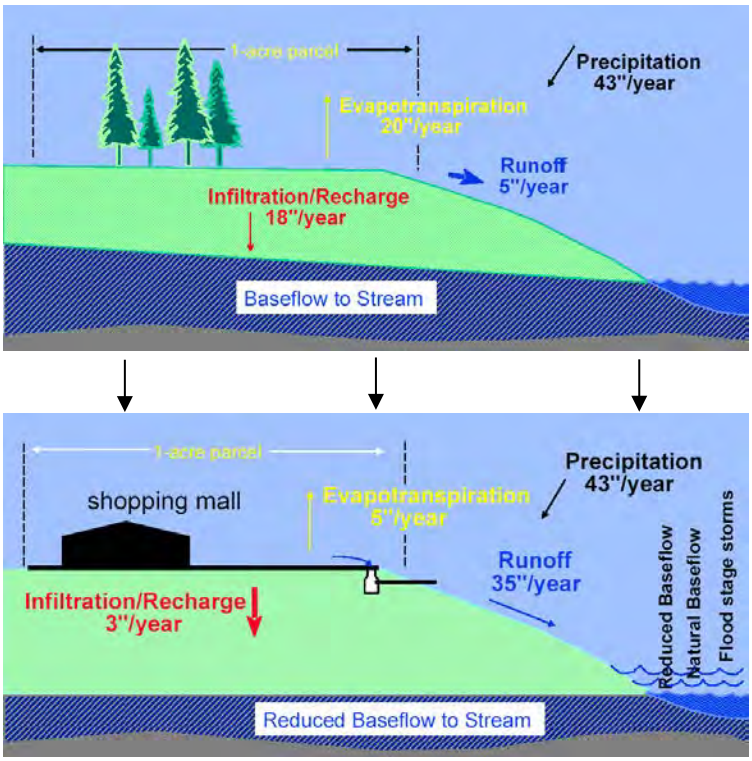


Figure 1: Water Budget under Pre- and Post-Development Conditions

These changes have important effects on receiving waters. As water flows more quickly over the ground, it enters water bodies in large volumes during rain events, and at much higher velocities, causing physical damage with its power. Streams are scoured, their physical structures and aquatic habitats are disrupted, sediment is deposited on fish spawning beds and benthic habitats, and aquatic life is carried away by the force of the large volumes of water that enter a water body at high speed. Storm water collection systems exacerbate the problem by collecting the diffuse runoff in storm water pipes and transmitting it at high velocity to water bodies in a concentrated and more powerful form. Consequently, impervious surfaces are not only a source of pollution, but are a source of stream erosion and stability and hydrology problems.

Urbanization, primarily through the construction of IC, causes progressive hydrologic, physical, water quality, and biological impacts to aquatic health. The relative portion of a watershed's IC can be used as an effective means of determining aquatic system health. Increased IC leads to increased loads of sediments, both from surface runoff and from in-stream disruption, and to increased loads of associated pollutants that are either applied to, or are on, the ground. CWP 2003 states that the unit area pollutant load delivered by storm water runoff to receiving waters increases in direct proportion to watershed IC. This is true for a wide range of pollutants typically associated with highway runoff and is summarized in Table 3 from CWP (2003).

Table 3: Summary of Urban Stormwater Pollutant Loads on Quality of Receiving Waters

Pollutants in Urban Stormwater	WQ Impacts To:					Higher Unit Load?	Load a function of IC?	Other Factors Important in Loading
	R	L	E	A	W			
Suspended Sediment	Y	Y	Y	N	Y	Y (ag)	Y	channel erosion
Total Nitrogen	N	N	Y	Y	N	Y (ag)	Y	septic systems
Total Phosphorus	Y	Y	N	N	Y	Y (ag)	Y	tree canopy
Metals	Y	Y	Y	?	N	Y	Y	vehicles
Hydrocarbons	Y	Y	Y	Y	Y	Y	?	related to VMTs and hotspots
Bacteria/Pathogens	Y	Y	Y	N	Y	Y	Y	many sources
Organic Carbon	N	?	?	?	Y	Y	Y	
MTBE	N	N	N	Y	Y	Y	?	roadway, VMTs
Pesticides	?	?	?	?	Y	Y	?	turf/landscaping
Chloride	?	Y	N	Y	Y	Y	?	road density
Trash/Debris	Y	Y	Y	N	?	Y	Y	curb and gutters

Major Water Quality Impacts Reported for:
R = River, L = Lake, E = Estuary, A = Aquifer, W = Surface Water Supply
Higher Unit Area Load? Yes (compared to all land uses) (ag): with exception of cropland
Load a function of IC? Yes, increases proportionally with IC

The relationship between these pollutants and impervious cover is central to the use of impervious cover as a surrogate for loading of pollutants to impaired waterbodies including streams, rivers, and lakes.

Effects of Impervious Cover on First, Second, and Third Order Streams

The Center for Watershed Protection (CWP) has performed extensive research linking impervious cover with 26 different urban stream indicators. Figure 2 illustrates the relationship between specific stream impacts associated with increasing IC. Physical impacts are directly related to modification in stream hydrology. For example, flooding causes channel enlargement and incision, while low flows can result in warmer in-stream temperatures. Water quality impacts are due primarily to direct conveyance of additional materials into the stream with storm water runoff. Lastly, biological impacts are the result of degradation of hydrological, physical, and water quality conditions in the stream ecosystem. The Center for Watershed Protection indicated that their research is based on first, second, and third-order streams. (CWP, 2003).

The typical pattern of effects caused by storm water includes some or all of the following factors:

- Modified land use with increased IC (paved surfaces and roofs).
- Modified stream hydrology, typically flashier streams with higher peaks and lower low flows.
- Modified physical stream conditions, including channelization and stream bed scouring;
- Increased sediment loading via surface runoff and stream bank erosion.
- Increased pollutant loading via surface runoff;.
- Degraded ambient water quality conditions.
- Degraded ambient biological conditions.

Land cover and stream hydrology modifications are the causes and reduced water quality, reduced aquatic habitat, and biological modification are the results in this process.

Hydrologic Impacts

- Increased runoff volume
- Increased peak flow rates
- Increased bankfull flow
- Decreased baseflow

Physical Impacts

- Modified sediment transport
- Channel enlargement
- Channel incision
- Stream embeddedness
- Loss of large woodsy debris
- Changes in pool/riffle structure
- Loss of riparian cover
- Reduced channel sinuosity
- Warmer in-stream temperatures

Water Quality Impacts

- Increased sediment concentrations
- Increased nutrient concentrations
- Increased trace metal concentrations
- Increased hydrocarbon concentrations
- Increased bacteria and pathogens
- Increased organic carbon concentrations
- Increased MTBE concentrations
- Increased pesticide concentrations
- Increased deicer concentrations

Biological Impacts

- Reduced aquatic insect diversity
- Reduced fish diversity
- Reduced amphibian diversity
- Reduced wetland plant diversity

Figure 2: Effects of Increased Impervious Cover (adapted from CWP, 2003)

Effects of Impervious Cover on Large Streams and Ponds

Research is also available linking impervious cover and the health of large streams and lakes. Water quality in rivers, lakes and ponds is a reflection of the characteristics of their watersheds (Wetzel 2001). The watersheds of these water bodies are comprised of a series of smaller headwater streams and their watersheds. The health of the downstream water bodies is a direct reflection of the aggregate water quality exhibited by the smaller watersheds that comprise the larger watershed. If the headwater streams have higher storm water pollutant concentrations as a result of impervious cover, downstream rivers and lakes will also have higher storm water pollutant concentrations.

A threshold of 10% impervious cover is suggested as a breakpoint beyond which impairments of these small streams are observed (CWP 2003). A clear, broadly applicable threshold of impervious cover has not been developed for larger water bodies. Processes of settling, transformation and biologic uptake of storm water pollutants are generally more significant as the size of a water body increases. At a minimum, instream channel erosion is likely to be a smaller contributor relative to other sediment and pollutant sources as stream size increases. Therefore, larger water bodies are likely able to assimilate more storm water pollutants per unit area of watershed than smaller headwater streams.

CWP research included the review of impervious cover's effect correlation to storm water pollutant loads to other waters larger than third order streams. Table 3 from CWP located on page 3, shows loads of suspended sediment, total phosphorus, total nitrogen, metals, hydrocarbons and pathogens to receiving water including lakes, rivers and estuaries increase as a function of watershed impervious cover. CWP states that lakes are especially sensitive to changes in watershed impervious cover and that reservoirs generally respond in a similar manner to lakes. In drinking water reservoirs, CWP recommends aggressive watershed treatment, if watershed impervious cover is above 10%. (CWP 2003)

A study conducted by the US Forest Service (Phelps and Hoppe 2002) concluded that as impervious surface cover increased above 10%, the overall stream water quality fell. This analysis included a comparison of stream water quality classification and the percentage of impervious surface cover on a HUC-11 watershed (area of approximately 50 square miles) basis for New Jersey basins, This analysis showed that those basins (including lakes) that were ranked as having the highest water quality had an impervious surface cover of 10% or less. Declines in water quality occurred in basins with higher proportions of impervious cover. These basins were larger than most of the watersheds included in the MassDOT assessments, supporting the contention that impervious cover is an adequate predictor of water quality in water bodies larger than headwater streams. In addition, New Hampshire has used impervious cover target of 20% for shorefront development on lakes and rivers (NHDES 2008) indicating that impervious cover is an important factor to receiving water quality in waters of all size.

The link between impervious cover and storm water pollutant loading to streams, and ultimately downstream lakes, is receiving increased attention (Bauer et al 2005 LCRA 2010, NHDES 2008, CWP and Tetra Tech 2005). While there is justification that 9% impervious cover (1 percentage point less than the 10% trigger) is appropriate as a threshold value in headwater streams, similar or higher values have been used as triggers for lakes and rivers (NHDES 2008, Phelps and Hoppe 2002). In the absence of a consistent impervious cover threshold for larger rivers and lakes, MassDOT conservatively used the generally accepted 9% threshold for headwater streams for all impaired waters as an indication that storm water may be causing the impairment of the water.

Mitigating Impervious Cover

Since the primary mechanism of IC impacts is hydrologic changes (which lead to physical, biological, and water quality impacts), an effective way to reverse those impacts is to restore the natural hydrology of the area of concern. IC causes higher runoff volume than natural conditions during all storm events. This runoff can destabilize rivers and streams, carry pollutants, and cause sedimentation in ponds and lakes, thereby compromising the water quality of the receiving water body. In addition, hydrologic changes induced by IC lead to higher storm event flows and lower base flows, which in turn lead to water body and habitat impairments from an array of impacts. Returning a watershed to its pre-development hydrologic condition involves either eliminating (or reducing) IC or mitigating the hydrologic effects of IC (by mimicking pre-development hydrologic conditions) through the use of site design strategies and storm water Best Management Practices (BMPs). These practices should be chosen to counter the effects of IC by increasing infiltration and retention, increasing times of concentration (time it takes storm water to reach a water body from the most distant point in the watershed), and matching runoff volumes and flow rates to pre-development conditions for smaller storms when possible.

The USEPA's IC Method uses the amount of effective IC within a watershed as surrogate for pollutant loading when evaluating water quality impairments. Effective IC is defined as IC that drains to a receiving water body without opportunity for infiltration or attenuation of flow rates or volumes. Effective IC may be mitigated by storm water BMPs or other practices. The following categories of BMPs may be employed to mitigate for the hydrologic impact of IC thereby reducing the amount of effective IC within a watershed:

- Recharge/infiltration BMPs
- Extended detention BMPs

The following paragraphs describe the performance characteristics for each of these mitigation practices.

Recharge/Infiltration BMPs

Recharge BMPs are designed to infiltrate collected storm water from the BMP into the ground. These BMPs mitigate IC impacts by allowing runoff to infiltrate to the groundwater slowly. This mitigates the higher runoff volumes caused by IC by recharging the groundwater instead of contributing to the receiving water during storm events. This also helps to provide low post-storm base flows in receiving waters because replenished groundwater ultimately feeds water body baseflows. Infiltration also provides pollutant removal via filtration and microbial action through the soil column. Because of these qualities, recharge/infiltration BMPs are the most preferred type of BMP to mitigate for IC and reach the goal of returning the watershed to pre-development hydrologic conditions. Infiltration BMPs include surface systems, such as infiltration basins and swales and filter strips, and underground systems, such as infiltration galleries and leaching catch basins. Some infiltration BMPs may be installed as an intermediary in a storm water system, such as infiltration swales and filter strips, while others are typically installed at the end of a storm water collection system, such as infiltration basins and underground systems. All infiltration BMPs operate by temporarily storing storm water and allowing it to percolate into the ground.

Extended Detention BMPs

Extended detention BMPs are designed to store storm water flows for an extended period following storm events and discharge it at a controlled rate over an extended period. These BMPs are not the preferred choice for IC mitigation because they only address the timing of the runoff instead of addressing runoff volume and infiltration. However, while recharge/infiltration type BMPs may be preferable from a groundwater recharge/runoff volume reduction standpoint, extended detention BMPs may be more suited to soil and groundwater conditions found at a given site.

Although extended detention BMPs do not actually reduce a watershed's runoff volume, if the detention time is long enough (days versus the typical hours), then the watershed's effective IC can be reduced. The long detention times can mimic the time water would spend traveling through a watershed under pre-existing conditions. Drawing out flows over a sufficiently long period of time will mimic the base flows provided by undeveloped watersheds. For example, vegetated wetlands are nature's extended detention BMPs. (USEPA/ENSR 2006)

Other BMPs

Other BMPs that do not mitigate for hydrologic impacts of IC, but that are designed to specifically mitigate for water quality or another target, may be employed to increase the effectiveness of the BMPs described above and are also useful for storm water management systems. For example, deep-sump hooded catch basins, water quality inlets, or sand filters may be used as "pretreatment" devices to remove entrained sediment and oils from runoff before it is routed to an infiltration BMP. Other BMPs, not fully described here, include planting trees, rehabilitation of compacted soils, and streamside buffers. These are also measures that can reduce run off and contribute to improved water quality while at the same time adding attractive features to a developed area.

USEPA's Impervious Cover Method

USEPA's IC Method uses the percent of IC in a watershed as a surrogate for storm water pollutant loading for the development of TMDLs. The method can be applied to determine whether a water body is likely to be impaired due to storm water or if other sources of pollutants are more likely to be the cause of the impairment. According to *Pilot TMDL Applications Using the Impervious Cover Method* (USEPA/ENSR 2005), "Based on extensive data and the best information available, it appears that if the IC target is met (by reducing actual IC, reducing directly connected IC, or other measures) storm water-impaired waters will be brought back into compliance with water quality standards (WQS)." In a recent memorandum, the USEPA affirmed this approach to assessing pollutant loading for waters impaired by storm water pollutants (USEPA 2010a).

USEPA's IC Method is based on the relationship between the portion of IC in a watershed and the receiving water body's water quality. The method is largely based on the work of The Center for Watershed Protection (CWP), which has compiled and evaluated extensive data relating watershed IC to hydrologic, physical, water quality, and biological conditions (CWP, 2003) as described in the previous section. The CWP research included the review of more than 225 research studies which included data on urbanization influences on hydrologic, physical, water quality, and biological indicators of aquatic health (CWP, 2003).

The USEPA recommends an IC target of 9% IC to guide implementation of best management practices (BMPs) (USEPA/ENSR 2006). USEPA cites research performed by the CWP, which indicates that a decline in stream quality occurs when impervious cover (IC) for a watershed exceeds 10% and that severe impairment can be expected when the IC exceeds 25%. CWP states that the influence of IC on the receiving water when the watershed is in the range of 1-10 percent impervious "is relatively weak compared to other potential watershed factors". They indicate that "numerous studies have suggested that other watershed and regional factors may have a stronger influence, such as the underlying geology, the amount of carbonate rock in the watershed, physiographic region, local soil types, and most important, the relative fraction of forest and crop cover in the subwatershed" (CWP, 2003). USEPA chose the 9% target as the value at which storm water impairments will be likely removed. (USEPA/ENSR 2006) Based on the supporting research and guidance from USEPA, MassDOT has also chosen to use 9% impervious cover as a target for its analysis, as described in detail in later sections of this document.

USEPA's Storm Water TMDL Implementation Support Manual includes guidance for identifying mitigation sites and techniques. The guidance begins by indicating that identification and prioritization of locations for specific storm water mitigation can be done by evaluating the percentage of impervious cover on both the "sub-watershed and site-specific level". In their example of analyzing Beaver Brook watershed, they indicated that watersheds with greater than 9% IC would "likely require storm water mitigation actions to remove impairments and are selected for further assessment" while the subwatersheds with less than 9% IC "mitigation is likely not required". (USEPA/ENSR 2006).

USEPA Region 1 has developed the IC Method as a TMDL development methodology. To date, several TMDLs have been completed using this methodology across Region 1. The method is used to facilitate TMDL development for storm water-impaired waters by providing an easily measured surrogate (impervious cover) to the impairment itself as well as providing an inherent target for implementation.

In addition to TMDL development, USEPA Region 1 has expanded its use of the IC Method and philosophy to planning and management applications. In April 2009, USEPA Region 1 developed a fact sheet entitled Restoring Impaired Waters: Total Maximum Daily Loads (TMDLs) and Municipal Storm Water Programs. This document is self-described as providing guidance on "how municipal storm water managers can help implement TMDLs for impaired waters and improve water quality by implementing storm water management programs required by MS4 permits". This document specifically guides permit-holders to use the IC methodology to address their impacts on impaired waters.

Quoted from the fact sheet:

> *Accordingly, MS4s might find it useful to create an inventory of existing structural/nonstructural BMPs and then determine the current storm water volume, pollutant load, or impervious cover reductions from these practices on the basis of estimated or modeled reduction estimates. It is also helpful to calculate the size of the drainage area served by the BMP. Impervious cover (IC) is a reliable and convenient measurement for municipalities because:*
>
> - *Research has shown there is a strong correlation between impervious land cover and in-stream water quality*
> - *IC is associated with increased storm water flows and pollutant loads*
> - *IC can be used for issuing credits for existing or new BMPs installed*
> - *IC can be used to track BMPs and interim progress for NPDES permits*
>
> *In summary, the information from a BMP inventory and tracking system will help document compliance with the TMDL and satisfy NPDES regulations that require MS4s to assess the effectiveness of the storm water BMPs used in reducing the storm water discharge.*

In conjunction with this fact sheet, USEPA Region 1 developed the following tools for MS4 permit holders to address impaired waters:

- 305(b)/303(d) Map - community-specific map showing the geographic extent of permit coverage and the surface water quality status
- 305(b)/303(d) Stats - community-specific statistics of surface water quality status
- IC Map - community-specific map showing the geographic extent of permit coverage and impervious area (IA)
- IC Statistics - community-specific statistics of impervious area (IA) and Directly Connected Impervious Area (DCIA)

USEPA indicates that these maps will provide tools for a long-term approach to reduce directly connected impervious cover and promote infiltration and evapotranspiration where appropriate. This level of support and focus on impervious cover shows USEPA's commitment to addressing storm water impairments and its faith in the IC methodology to do so.

MassDOT's Application of the IC Method

MassDOT has applied many aspects of USPEA's IC Method guidance to MassDOT's program to assess its impacts on the state's impaired water bodies and guide the implementation of retrofit improvements to its storm water systems.

MassDOT calculated the percentage of impervious cover for the subbasins of the impaired segments or impaired water bodies. As outlined in the USEPA/ ENSR 2006 document, watersheds with less than 9% IC were not further analyzed under this program, although MassDOT will continue to implement storm water best management practices in these areas during maintenance and construction projects. This 9% IC threshold is adequate and conservative for the purpose of assessing storm water related impacts to streams and rivers of all sizes as well as lakes and ponds. CWP clearly demonstrated that first, second, and third order steams start to become impaired when their contributing watersheds contain 10% or greater IC. (CWP, 2003) Larger streams and rivers larger have a higher tolerance to IC than head water streams, so 9% is more conservative for these waterbodies. Multiple sources, including CWP (2003) and NHDES (2008), have suggested watershed IC thresholds for impairment of 10% to 20% for lakes and reservoirs, therefore 9% IC would be a conservative threshold here has well.

MassDOT then evaluates further watersheds with greater than 9% IC. The subbasin reduction in IC necessary to achieve the 9% IC target is applied to MassDOT urban roads discharging to the water bodies to assess the level of IC mitigation needed to reach 9% effective IC. By applying this target amount proportionally to its properties, MassDOT is able to calculate the level of IC mitigation needed to address the impairment.

Appropriateness of MassDOT's IC Assessment Method

MassDOT's assessment methodology for impaired waters lacking a TMDL is based on extensive research, USEPA's methodology and guidance, and is consistent with accepted practices throughout the industry.

Research

As described, the link between impervious cover and impaired waters (streams, rivers, and lakes) is well documented through thorough research. The CWP's conclusion linking impervious cover and water impairments is supported by statistically documented correlations of 26 different urban stream indicators (CWP, 2003). In essence, their research concludes that impervious cover can be confidently used as a surrogate "pollutant" to address a range of impairments. Based on this research, it is clear that not all impairments should be addressed using impervious cover as a surrogate, but several are directly related and therefore appropriate to replace with impervious cover. The link between impervious cover and larger streams and lakes is also documented, including within the CWP's research and beyond. Therefore, unless existing data clearly indicate certain pollutants are not related to storm water, MassDOT will assess waters without TMDLs based on impervious cover.

In addition, in USEPA's pilot TMDLs, they presented specific pollutant loads and pollutant targets for the assessed waters in addition to impervious cover calculation and target 9% IC for demonstration. In all seven cases, the target specific pollutant load percent reductions were less than the resulting impervious cover percent reduction. This further supports that using impervious cover as a surrogate and 9% as a target is appropriate and even conservative.

USEPA Region I

USEPA has recognized the mounting research and has developed a methodology that uses the connection of impervious cover and impaired waters to develop TMDLs that address storm water impairments. From USEPA (2005), "The IC Method provides direct guidance toward removing impairments and evaluating management scenarios because this surrogate relates the cause of an impairment directly to the impairment. The IC Method is also relatively efficient to apply. Thus, it is suitable for evaluating the sub-watersheds of large watersheds and is capable of rapidly identifying problem areas (i.e., hot spots)."

USEPA acknowledges that all sources contributing to an impairment need to be identified and assessed in a TMDL analysis. MassDOT's application of the IC Method does not result in the development of a full TMDL for the water, which would include an analysis of all contributors and resulting waste load allocations. Although MassDOT does not have the resources to develop TMDLs for waters across the state, MassDOT's approach results in an analysis of the impervious cover storm water contribution to the impairment, and specifically MassDOT's direct contribution. MassDOT uses USEPA's methodology to perform the initial steps of the TMDL development (calculating subbasin impervious cover percentage) and uses these results to identify impaired waters that are linked to impervious cover, and therefore potentially MassDOT discharges.

In its Pilot TMDL study (2005), the USEPA stated that their IC method can be applied at various levels of detail. They recommend the following modifications to the IC method when more precise results are desired:

- Project-specific impervious cover datalayer
- Project-specific estimates of directly-connected impervious cover
- Incorporation of storm sewer networks to refine watershed delineation and directly connected impervious cover
- Accounting for existing BMPs in IC and load determinations

As described in the Assessment Method section of this document, MassDOT includes project-specific data for MassDOT's impervious cover direct discharges, the location and configuration of the storm water system to refine contributing watersheds, and accounting of existing BMPs in its assessment method.

In addition, MassDOT has adopted USEPA's methods for sizing BMPs in its method for both sizing new BMPs and determining how much IC mitigation existing BMPs provide. USEPA states that to replicate existing hydrologic conditions, and therefore mitigate the effects of impervious cover, runoff volumes must approximate natural conditions for most storms. They indicate a threshold rainfall value below which no runoff occurs (also known as the "initial abstraction") under pre-development conditions should be used as a design target for BMPs. In further description they indicate that 99% of rainfall events in the northeast are 2-inches or less and therefore a 2-inch storm is the logical target for BMPs volume reduction. (USEPA/ENSR, 2006) Therefore, as described in the following sections, both USEPA and MassDOT's methodologies use the following two volumes as target treatment volumes for BMPs that mitigate impervious cover:

- Volume of initial abstraction lost when converting pervious surfaces to impervious surfaces

- Volume of runoff generated by impervious cover during the 2-inch storm event

USEPA has affirmed impervious cover as a tool beyond TMDL development. In its Restoring Impaired Waters fact sheet, it specifically guides MS4 permit-holders to begin inventorying their impervious cover and estimating impervious cover reductions provided by existing and potential BMPs as steps towards addressing their permit requirement of addressing impaired waters. They indicate that the steps will "help document compliance with the TMDL and satisfy NPDES regulations that require MS4s to assess the effectiveness of the storm water BMPs used in reducing the storm water discharge". Under the assessment program, MassDOT is not only generating an inventory of its infrastructure and performance, but generating targeted recommendations for the improvement of their systems related to the specific waters they discharge to.

Industry Accepted Practices

MassDOT's approach is based on extensive research and practices provided by the USEPA and supported by industry accepted data and information. MassDOT uses subbasins delineated by USGS, impervious cover data available by MassGIS, and BMP categories standard throughout the storm water industry, including the MassDEP Storm Water Policy (2008). Many of the BMPs listed in USEPA's Stormwater TMDL Implementation Support Manual (2006) are taken directly from MassHighway (now MassDOT) storm water handbook.

MassDOT acknowledges that although some of the methodologies and data are available and standard, not all components of this application have been done before. The CWP states "researchers will need to develop standard protocols to define the extent and quality of watershed treatment." USEPA has provided the 9% target IC as the "extent" of treatment and has provided guidance on how to determine the "quality" of treatment via the goals of initial abstraction and 2-inch storm volume treatment. Under this application, MassDOT has taken these principles and developed quantitative means for evaluating the specific IC mitigation performance for both existing and new BMPs. As described in the following section, MassDOT gives IC reduction credits to infiltration BMPs based directly in the USEPA's Storm Water Best Management Practices Performance Analysis (2010c) results. Currently, there are no standard IC reduction values for extended detention practices. Therefore, based on detention BMP's ability to provide mitigation for both the pre-development initial abstraction and 2-inch storm event volume and on the principals outlined by USEPA, MassDOT developed IC reduction credits for these BMPs based on how they store and discharge these volumes.

In summary, MassDOT's implementation of the IC method provides an efficient and effective method to assess the impacts that its storm water systems have on impaired water bodies that do not have established TMDLs. The method also provides an effective, inherent target for mitigation; 9% or less effective impervious cover. Using the IC method as a surrogate for storm water impairment provides significant advantages over evaluating specific pollutants:

- Provides efficient and effective method for evaluating impacts and mitigation targets.
- May be consistently applied over a large range of watershed and receiving water conditions.
- More holistic evaluation of storm water impacts than single pollutant approaches.
- Consistent, conservative target is significantly more efficient to apply than a pollutant based approach which would require significant receiving water specific evaluations and other pollutant source data to establish targets.

- Efficiently identifies locations and targets for BMP implementation.

Assessment Method

MassDOT's protocol for using the IC Method is comprised of several steps, outlined in Figure 3. The following summarizes these steps:

- Step 1: Calculate the Percent of IC within the Total Contributing Watershed.
- Step 2: Calculate the Percent of IC within the Subwatershed.
- Step 3: Calculate the Amount of Effective IC Reduction Required in the Subwatershed.
- Step 4: Apply the Percent of Effective IC Reduction Required in the Subwatershed to MassDOT IC Areas Discharging to the Impaired Water Body.
- Step 5: Calculate the Effective IC Reduction Credit from Existing MassDOT BMPs.
- Step 6: Recommend Additional BMPs to the Extent Practicable to Reduce Effective IC to Target.

The following sections detail each step of MassDOT's application of the IC Method and provide sample calculations using this assessment method.

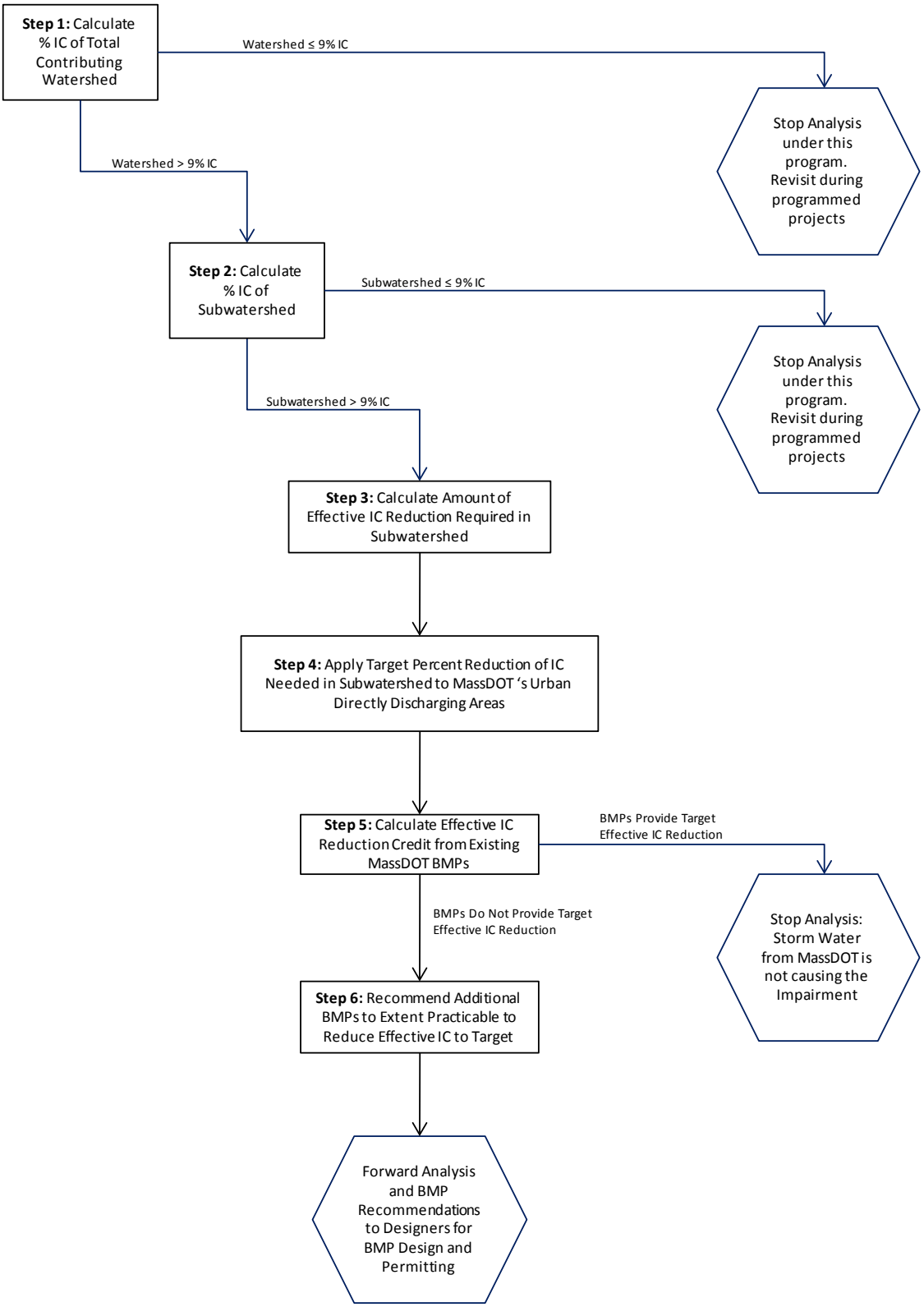


Figure 3: MassDOT's Application of the IC Method

Step 1: Calculate the Percent of IC within the Total Contributing Watershed

Delineate the total watershed to the subject water body or stream segment and calculate its area and percent IC. The total watershed should include the watershed of the impaired water or segment, the watersheds of its tributaries, and watershed of any upstream segments.

Delineate the total watershed within a geographic information system (GIS) environment using data layers from USGS Data Series 451, which includes a database of Massachusetts nested stream basins drawn at a scale finer than that of the existing 12-digit Hydrologic Unit Code basins (HUC-12s) of the national Watershed Boundary Dataset. This data was developed by USGS specifically to summarize IC across Massachusetts watersheds. When necessary, modify the USGS watershed boundary to represent only the subject water body or stream segment. USEPA also uses this subbasin dataset when presenting impervious cover data to the MS4 municipalities in their impervious cover statistics "IC Stats" worksheets (EPA 2010(b)).

Upon establishing the total watershed boundary and its area, use GIS spatial querying tools in conjunction with MassGIS's Impervious Surface data layer to calculate the area and percentage of IC. USPEA also uses this impervious cover dataset when presenting impervious cover data to the MS4 municipalities in their impervious cover statistics "IC Stats" worksheets (EPA 2010(b)). In situations where data layers from USGS Data Series 451 are used without modification, the watershed's area and percent IC may be taken directly from the attribute tables included with the USGS data set.

If the percent of IC over the total watershed is equal to or less than 9%, then stop the assessment under this program. MassDOT discharges from this area will be addressed during maintenance and construction projects. If the percent of IC is greater than 9%, proceed to Step 2 of the assessment.

Step 2: Calculate the Percent of IC within the Subwatershed

Delineate the subwatershed specific to the subject water body or stream segment and calculate its area and percent IC. The subwatershed includes the area that drains immediately to an impaired water body or stream segment and excludes watersheds of larger tributaries and any upstream segments.

Delineate the subwatershed within GIS using data layers from USGS Data Series 451. In general, the USGS sub-basin delineations should be used to define the subwatershed. Select those basins that contain the subject water body or stream segment to represent only the DCIA. If necessary, modify the USGS watershed boundary to represent only the subject water body or stream segment. As mentioned, USEPA also uses this subbasin dataset when presenting impervious cover data to the MS4 municipalities in their impervious cover statistics "IC Stats" worksheets (EPA 2010(b)).

Calculate the area and percent IC over the subwatershed using spatial querying tools within GIS in conjunction with MassGIS's Impervious Surface data layer. As mentioned, USPEA also uses this impervious cover dataset when presenting impervious cover data to the MS4 municipalities in their impervious cover statistics "IC Stats" worksheets (EPA 2010(b)). In situations where data layers from USGS Data Series 451 are used without modification, the watershed's area and percent IC may be taken directly from the attribute tables included with the USGS data set.

If the percent of IC over the subwatershed is equal to or less than 9%, then stop the assessment under this program. MassDOT discharges from this area will be addressed during programmed projects. If the percent of IC is greater than 9%, proceed to Step 3 of the assessment.

Step 3: Calculate the Percent of Effective IC Reduction Required in the Subwatershed

Calculate the amount of effective IC that would need to be mitigated or made pervious in the subwatershed to meet the 9% IC target.

For example, if a subwatershed of 50 acres has a total of 10 acres of IC, the calculation for the amount of effective IC reduction required in the subwatershed to meet the 9% target would be as follows:

Calculate the percent of IC within the subwatershed (from Step 2),

$$\frac{10\ acres\ of\ IC}{50\ acres\ total} \times 100 = 20\%\ IC$$

The sample subwatershed contains 20% IC. Next calculate the percentage of effective IC reduction required to meet the 9% target within the sample subwatershed,

$$\frac{20\% - 9\%}{20\%} = 55\%\ \text{IC Reduction}$$

In this example, 55% of the total 10 acres of IC must be mitigated or made pervious to meet the target 9% IC within the subwatershed. The amount of mitigation required for MassDOT's direct discharges is calculated in Step 4.

Mitigation practices for IC include the installation of storm water BMPs specifically designed to mitigate the hydrologic effects of IC by promoting infiltration and retention and attenuating peak flows and volumes. Mitigation provided by existing BMPs is calculated in Step 5.

Step 4: Apply the Percent of Effective IC Reduction Required in the Subwatershed to MassDOT IC Areas Discharging to the Impaired Water Body

First, calculate the amount of IC mitigation required for MassDOT urban IC areas discharging directly to the subject water body or stream segment. The IC areas assessed under this program include only those MassDOT impervious areas within the subwatershed that drain immediately to the impaired water body or stream segment. Do not include impervious areas that drain to other watercourses or segments upstream of the subject water body or stream segment. Under their NPDES permit and this program to assess impaired waters and retrofit BMPs, MassDOT is only assessing its direct discharges to impaired waters.

When performing this calculation, first delineate the MassDOT-owned urban areas (both pervious and impervious) contributing storm water directly to the subject water body or stream segment. Use construction plans, as-built plans, aerial imagery, and site visits to delineate these areas as accurately as possible. Then calculate the MassDOT-owned IC areas within this watershed using the MassGIS Impervious Cover data, which is used for consistency.

Multiply this MassDOT IC area directly discharging to the waterbody by the percent of effective IC reduction required in the subwatershed (calculated in Step 3) to obtain the amount of IC mitigation required for MassDOT-owned property.

Using the previous example, a subwatershed of 50 acres has a total of 10 acres of IC requiring a 55% reduction of effective IC to meet the 9% target in the subwatershed. If MassDOT owns 2 acres of IC urban MassDOT roadways that discharge directly into the receiving water body, the calculation for the amount of IC mitigation required for these areas would be as follows:

$$2\ acres\ \times 55\% = 1.1\ acres$$

In this example, 1.1 acres of IC MassDOT urban area that directly discharges to the water body must be mitigated or made pervious in order to reach the target 9%. This number may be reduced if credit can be assigned to existing BMPs mitigating the effects of IC from MassDOT areas discharging to the impaired water, as calculated in Step 5.

Step 5: Calculate the Effective IC Reduction Credit Provided by Existing MassDOT BMPs

Assign IC reduction credit to existing MassDOT-owned BMPs based on the ability of the BMPs to mitigate the impacts of IC on the receiving water body or stream segment. This step is broken up into five parts:

1. Desktop analysis of existing BMPs
2. Field-verification of existing BMPs
3. Characterizing existing BMPs
4. Assigning effective IC reduction credit to BMPs
5. Quantifying effective IC reduction provided by existing BMPs

The following section outlines each of these parts and how MassDOT calculated IC reduction credit provided by existing MassDOT-owned BMPs. These same credits are used for proposed BMPs as described in Step 6.

Desktop Analysis of Existing BMPs

Start by reviewing construction plans, as-built plans, and aerial imagery to locate existing MassDOT-owned BMPs contributing storm water to the subject water body. Create a data layer (shapefile) in GIS and draw a polygon for each identified BMP that accurately represents its geospatial location and approximate surface area. Focus primarily on locating infiltration and extended BMPs, although an inventory of all BMPs will be useful for understanding the storm water systems.

Review design plans, as-built plans, permit applications, and any other available documentation for the following BMP-specific information:

- BMP dimensions (depth, width, length, etc.)
- Inlet structures (type, orifice size, invert elevations, etc.)
- Outlet structures (type, orifice size, invert elevations, etc.)
- Contributing watershed information (size, land cover, etc.)

Record this information for field-verification and use in calculations in subsequent parts of this step.

Perform a desktop analysis of the soils at each BMP location using the United States Department of Agriculture's Natural Resources Conservation Service (NRCS) SSURGO-Certified Soils data, which can be obtained from the MassGIS website. Use the information included in the data layer to determine the soil type and associated Hydrologic Soil Group (HSG) at each location. Record this information for each BMP.

Finally, delineate the watersheds to each BMP using a combination of original construction plans or as-built plans, showing surface and subsurface conveyance system, aerial imagery, and USGS topographical maps. Create a data layer (shapefile) in GIS and draw a polygon for each watershed that accurately represents the catchment area draining to each existing BMP.

Field-Verification of Existing BMPs

Perform field visits to verify the data collected during the desktop analysis and gather additional information. Begin by locating existing BMPs identified during the desktop analysis and other existing BMPs not previously documented. Verify the drainage patterns and watershed boundaries delineated during the desktop analysis and evaluate the watersheds of newly identified BMPs. Then record the location of all existing BMPs and points of interest using a GPS device. Observe each BMP, making note of the following:

- Size. Record the dimensions of the BMP including surface area and depth.
- Inlet and outlet structures. Record orifice sizes and relative inverts.
- Wetness. Record whether the BMP is wet or dry when observed and type of vegetation growing on the bottom (i.e., grass vs. wetland vegetation).
- Condition. Record the relative structural condition of the BMP.

Characterizing Existing BMPs

Using the data obtained through the desktop analysis and field verification, characterize existing BMPs according to approximate type, approximate volume of storm water treated by the BMP, and soil infiltration rate.

For this characterization, use the following types of BMPs:

- Infiltration Basin
- Infiltration Swale
- Vegetated Filter Strip
- Extended Detention Basin
- Other

MassDOT classifies infiltration basins, infiltration swales, and vegetated filter strips as infiltration BMPs. Infiltration BMPs are designed to infiltrate runoff and therefore mimic the ability of undeveloped vegetated soils to absorb storm water runoff. This serves to mitigate the hydrologic effects of runoff from IC by reducing runoff volumes and rates and restoring base flows to the receiving water body (ENSR, 2005).

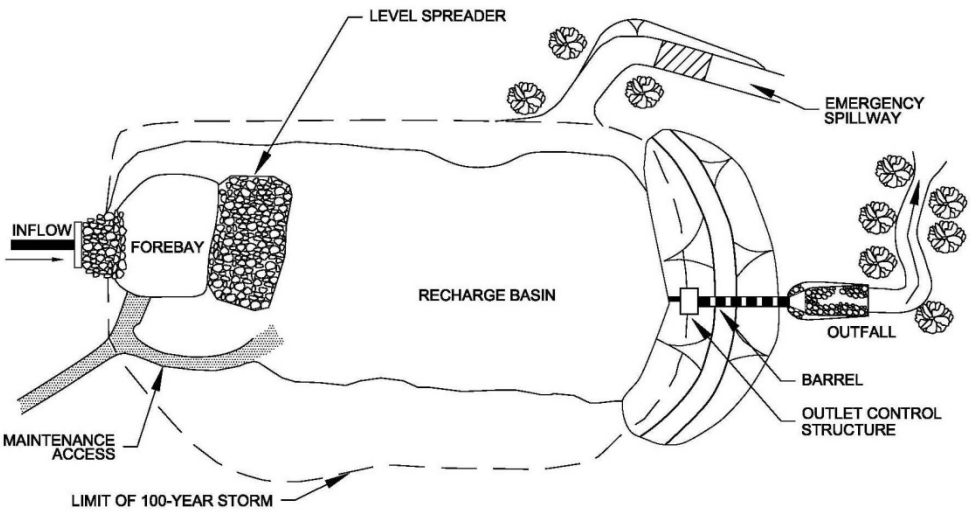
Infiltration Basin: The infiltration basin is a pond designed to intercept runoff and provide both retention and infiltration. Infiltration basins are constructed in permeable soils and should be dry when observed in the field unless recent rain has occurred. Infiltration basins should not have a low

level outlet. The storage volume provided by an infiltration basin is calculated as the volume between the floor of the basin and its lowermost outlet. See Figure 4.

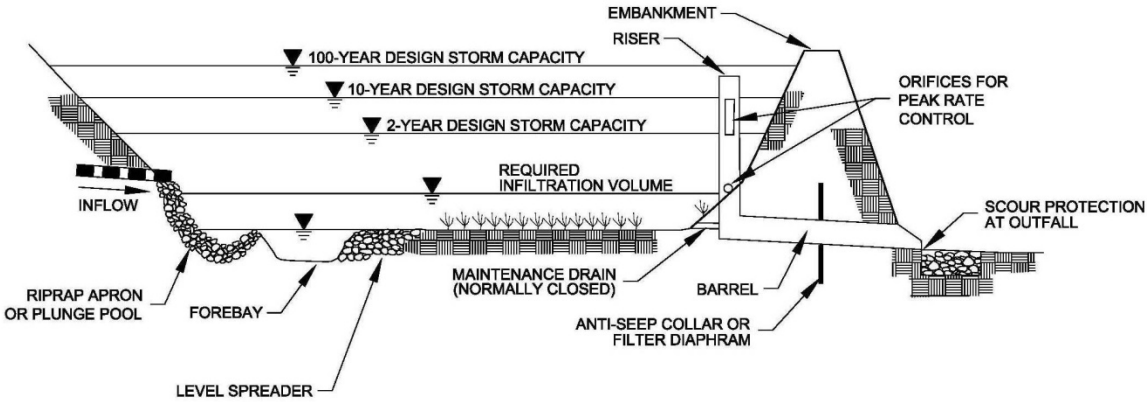
Infiltration Swale: The infiltration swale is a vegetated, flat or gently sloped channel designed to provide retention and infiltration within cells defined by impermeable check dams or other structures. Infiltration swales should also be constructed in permeable soils. The storage volume provided by an infiltration swale consists of the volume stored behind the check dam within each cell, therefore conveyance swales with no outlet control or check dams would not be characterized as infiltration swales. See Figure 5.

Vegetated Filter Strip: The vegetated filter strip is a flat or gently sloping vegetated area that receives sheet flow from impervious cover. A vegetated filter strip should be between 25 and 75 feet in length (MassDEP Storm Water Handbook, 2008), and should be as wide as the area contributing to the filter strip. See Figure 6.

Extended Detention Basin: The extended detention basin is a wet or dry pond that intercepts and stores runoff and slowly releases it over an extended period. Extended detention basins and their outlet control structure should be sized to store a relatively large volume of runoff and draw down over a period of several days to mimic pre-development contribution to base flows to a receiving water body. An extended detention basin should include a small low-level outlet that discharges runoff at a controlled rate. Observe the level of water in the pond above the lowest outlet. This level should be appropriate relative to the magnitude of recent rain events and time since the last event. For example, if it has not rained for a week or more, the pond level should be near the low level outlet and conversely if significant rain occurred in the past 24-hours, the pond level should be close to the overflow outlet. The extended detention storage volume provided by this type of basin consists of the volume between the low level outlet of the basin and its overflow, or flood controls outlet. See Figure 7.

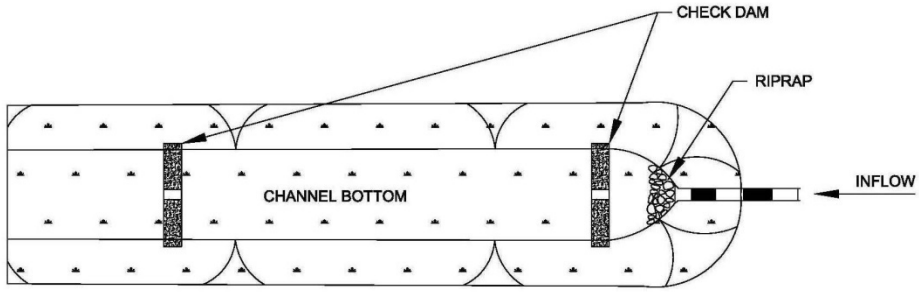


Infiltration Basin Plan View

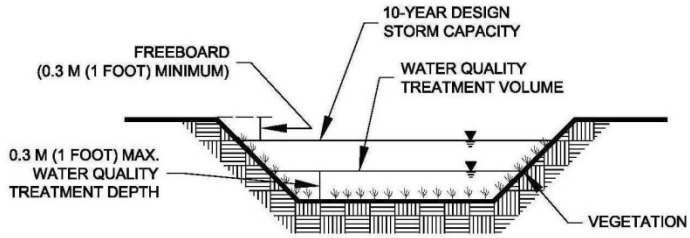


Infiltration Basin Profile View

Figure 4 Typical Infiltration Basin, from MassHighway Storm Water Handbook 2003



Swale Plan View



Swale Profile View

Figure 5 Typical Water Quality Swale with Check Dam, from MassHighway Storm Water Handbook 2003

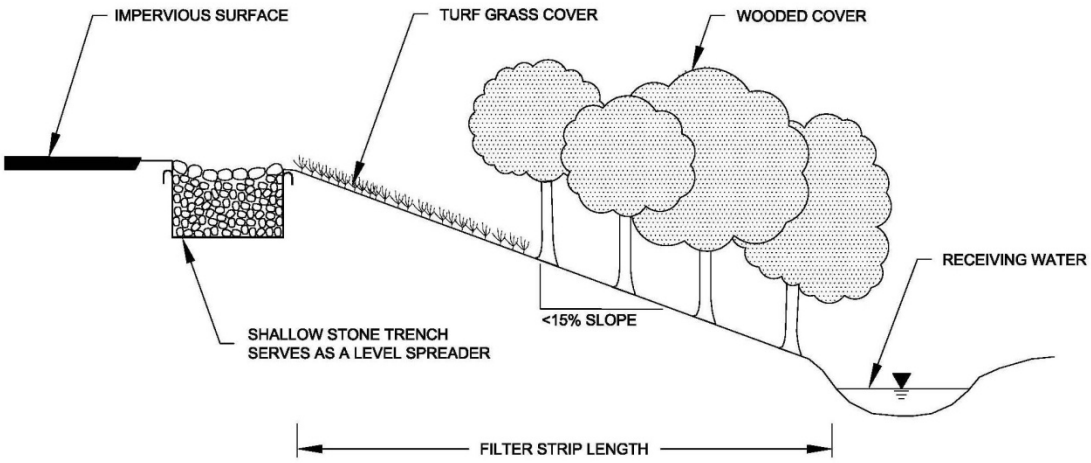
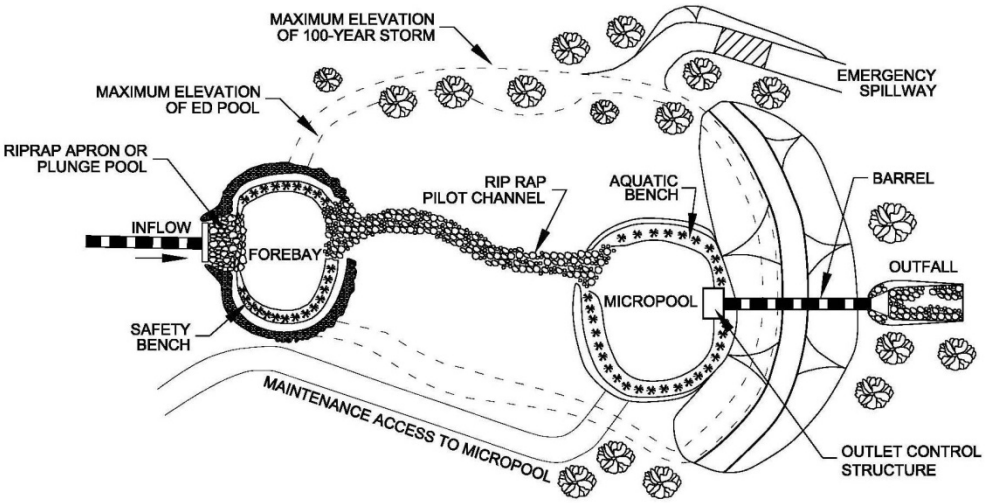
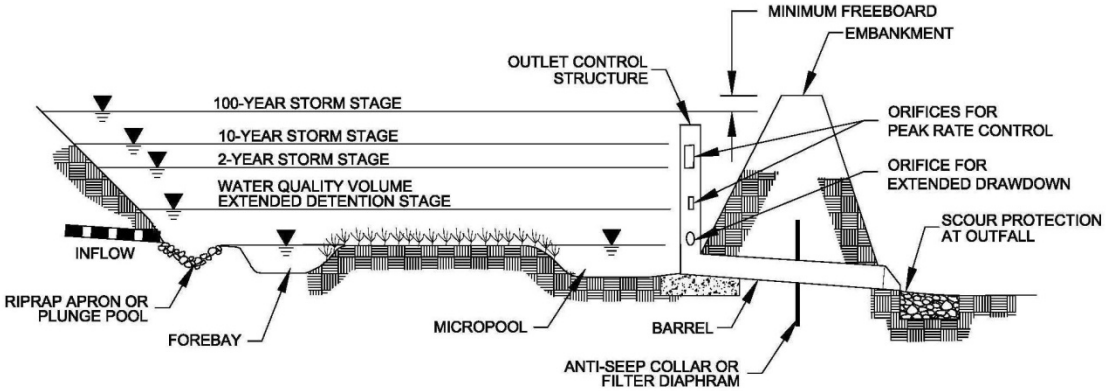


Figure 6 Typical Filter Strip, from MassHighway Storm Water Handbook 2003



Extended Detention Plan View



Extended Detention Profile View

Figure 7 Typical Extended Detention, from MassHighway Storm Water Handbook 2003

Using the above descriptions, classify each existing BMP. Characterize additional BMPs that provide infiltration or extended detention (eg. infiltration galleys, leaching catch basins) based on their function. If a BMP does not fit any of the descriptions (does not provide infiltration and/or extended detention), it is assumed to provide no mitigation for the effects of IC and should not be assigned IC reduction credit.

Calculating Depths of Storm Water Treated for BMPs: For infiltration BMPs (infiltration basin, infiltration swale and filter strip), calculate the depth in inches of storm water runoff treated by each BMP to mitigate the effects of IC. The depth of storm water runoff treated will be used to evaluate the infiltration BMP's effectiveness of mitigation runoff and therefore the effects of impervious cover. For an infiltration basin, an infiltration swale, or an extended detention basin, perform this calculation by dividing the total storage volume of the BMP (defined above) by the area of IC draining to the BMP.

For a BMP with a storage volume of 1,000 cubic feet and 1.5 acres of contributing IC area, this calculation is as follows:

$$\frac{1{,}000\ cubic\ feet}{1.5\ acres\ \times \left(\frac{43{,}560\ square\ feet}{1\ acre}\right)} \times \frac{12\ inches}{1\ foot} = 0.184\ inches$$

For a filter strip, the depth of storm water runoff treated is performed by first calculating the initial abstraction (Ia) of the filter strip using the equation below. Estimate the CN using a land cover of open space in good condition (grass cover >75%) for the applicable hydrologic soil group. These CN values from TR-55 are listed in Table 1.

$$Ia = 0.2 \times \left(\frac{1000}{CN} - 10\right)$$

This Ia is the depth of runoff that is initially absorbed by the filter strip. Then multiply the Ia by the area of the filter strip to calculate the volume of water absorbed or treated by the filter strip:

$$Volume\ Treated\ by\ Filter\ Strip = Ia \times Area\ of\ Filter\ Strip$$

Divide this volume by the total contributing area (area of the filter strip plus the area of the contributing IC) to obtain the depth of storm water treated by the filter strip, as follows:

$$Depth\ Treated\ by\ Filter\ Strip = \left(\frac{Volume\ Treated\ by\ Filter\ Strip}{Area\ of\ Contributing\ IC + Area\ of\ Filter\ Strip}\right)$$

For a filter strip that is 75 feet long and 20 feet wide with 1.5 acres of contributing IC area and Hydrologic Soils Group (HSG) A soils, this calculation as follows:

$$Ia = 0.2 \times \left(\frac{1000}{39} - 10\right) = 3.13\ inches$$

$$\begin{aligned} Volume\ Treated\ by\ Filter\ Strip &= 3.13\ inches \times 75\ feet \times 20\ feet \\ &= 391\ cubic\ feet \end{aligned}$$

$$\begin{aligned} Depth\ Treated\ by\ Filter\ Strip &= \left(\frac{391\ cubic\ feet}{65{,}340\ square\ feet + (75\ feet \times 20\ feet)}\right) \\ &= 0.07\ inches \end{aligned}$$

After calculating the depth of storm water in inches treated by each existing BMP, assign an infiltration rate to each BMP using the data summarized in Table 1. To be conservative, unless specific soil evaluation data is available, use the slowest infiltration rate (least infiltration ability) for a given HSG. In areas where several HSGs are present within an existing BMP, use the most conservative (slowest) infiltration rate among those present. If no soil information is available, use HSG C.

Table 1 Hydrologic Soil Properties Classified by Soil Texture

Texture Class	NRCS Hydrologic Soil Group (HSG)	Infiltration Rate (inches/hour)	CN (Open Space, Good Condition)
Sand	A	8.27	39
Loamy Sand	A	2.41	39
Sandy Loam	B	1.02	61
Loam	B	0.52	61
Silt Loam	C	0.27	74
Sandy Clay Loam	C	0.17	74
Clay Loam	D	0.09	80
Silty Clay Loam	D	0.06	80
Sandy Clay	D	0.05	80
Silty Clay	D	0.04	80
Clay	D	0.02	80

Assigning Effective IC Reduction Credit to Infiltration BMPs

For infiltration BMPs (Infiltration Basin, Infiltration Swale, and Vegetated Filter Strip), assign a percentage of effective IC reduction (removal efficiency) to each BMP based on type, treatment depth, and soil infiltration rate using the removal efficiencies summarized in Table 2. Calculate intermediate values using linear interpolation.

Table 2 Infiltration BMPs Effective IC Reduction Credit

BMP Type	Infiltration Rate	BMP Storage Over Impervious Area (inches)								
		0	0.1	0.2	0.4	0.6	0.8	1	1.5	2
Infiltration Basin	A - Sand 8.27 in/hr	0%	55%	77%	93%	98%	99%	100%	100%	100%
Infiltration Basin	A - Loamy Sand 2.41 in/hr	0%	33%	54%	78%	88%	93%	96%	99%	100%
Infiltration Basin	B - Sandy Loam 1.02 in/hr	0%	24%	42%	66%	79%	87%	91%	96%	98%
Infiltration Basin	B - Loam 0.52 in/hr	0%	20%	36%	58%	73%	81%	87%	94%	97%
Infiltration Basin	C - Silt Loam - 0.27 in/hr	0%	16%	30%	51%	66%	76%	82%	91%	95%
Infiltration Basin	C - Sandy Clay Loam - 0.17 in/hr	0%	13%	25%	44%	59%	71%	78%	89%	94%
Infiltration Basin	D	0%	10%	20%	37%	52%	66%	74%	87%	93%
Vegetated Filter Strip	A - Sand 8.27 in/hr	0%	55%	77%	93%	98%	99%	100%	100%	100%
Vegetated Filter Strip	A - Loamy Sand 2.41 in/hr	0%	33%	54%	78%	88%	93%	96%	99%	100%
Vegetated Filter Strip	B - Sandy Loam 1.02 in/hr	0%	24%	42%	66%	79%	87%	91%	96%	98%
Vegetated Filter Strip	B - Loam 0.52 in/hr	0%	20%	36%	58%	73%	81%	87%	94%	97%
Vegetated Filter Strip	C - Silt Loam - 0.27 in/hr	0%	16%	30%	51%	66%	76%	82%	91%	95%
Vegetated Filter Strip	C - Sandy Clay Loam - 0.17 in/hr	0%	13%	25%	44%	59%	71%	78%	89%	94%
Vegetated Filter Strip	D	0%	10%	20%	37%	52%	66%	74%	87%	93%
Infiltration Swale	A - Sand 8.27 in/hr	0%	55%	77%	93%	98%	99%	100%	100%	100%
Infiltration Swale	A - Loamy Sand 2.41 in/hr	0%	33%	54%	78%	88%	93%	96%	99%	100%
Infiltration Swale	B - Sandy Loam 1.02 in/hr	0%	24%	42%	66%	79%	87%	91%	96%	98%
Infiltration Swale	B - Loam 0.52 in/hr	0%	20%	36%	58%	73%	81%	87%	94%	97%
Infiltration Swale	C - Silt Loam - 0.27 in/hr	0%	16%	30%	51%	66%	76%	82%	91%	95%
Infiltration Swale	C - Sandy Clay Loam - 0.17 in/hr	0%	13%	25%	44%	59%	71%	78%	89%	94%
Infiltration Swale	D	0%	10%	20%	37%	52%	66%	74%	87%	93%

Note: Derived from performances for runoff reduction for Infiltration Basin, *Storm Water Best Management Practices (BMP) Performance Analysis* (USEPA, March 2010c).

Removal efficiencies for infiltration BMPs (Infiltration Basin, Infiltration Swale, and Vegetated Filter Strip) are derived from results for Infiltration Basin in the study titled *Storm Water Best Management Practices (BMP) Performance Analysis* (USEPA, March 2010c). This study analyzed the long-term ability of several BMPs, to treat for pollutants characteristic of storm water runoff, including Total Phosphorus (TP), Total Suspended Solids (TSS), and Zinc (Zn). Additionally, the report analyzed the long-term ability of infiltration systems to reduce runoff volumes.

The use of this study for estimating effective reduction in IC was recently affirmed in a fact sheet published by EPA titled Restoring Impaired Waters: Total Maximum Daily Loads (TMDLs) and Municipal Storm Water Programs. The document provides municipalities with information on the tools available to assist with TMDL compliance, one of the provisions of their storm water permit. One aspect of TMDL compliance discussed is the use of IC "for issuing credits for existing or new BMPs installed." For issuing credits to infiltration basins and infiltration trenches, USEPA refers to their BMP performance study ,"EPA developed runoff volume reduction curves to provide an estimate of effective reduction in IC" (USEPA, 2009). Therefore, runoff volume reductions have been used as IC reductions.

The range of removal efficiencies summarized in Table 2 is the same for each infiltration BMP because each acts as an infiltration basin in that they store and infiltrate storm water and are a direct function of the depth of runoff treated. Calculating the depth of runoff treated for each existing BMP, as outlined above, will provide the appropriate credit regardless of whether it is an infiltration basin, infiltration swale, or vegetated filter strip.

Assigning Effective IC Reduction Credit to Extended Detention BMPs

MassDOT based its method for assigning mitigation credit to extended detention basins on guidance provided in USEPA's Storm Water TMDL Implementation Support Manual (USEPA/ENSR 2006). The following passage from the manual describes criteria for designing extended detention basins to mitigate for impervious cover impacts:

"Extended detention BMPs do not exfiltrate runoff but instead slowly release stored runoff over a period of time (days). Detention BMP should be sized to store the full difference between existing and pre-existing 2-inch storm runoff volume. The detention BMP outlet should be designed to draw the full mitigation volume down over a period of 7 to 10 days and to draw down the initial abstraction mitigation volume over a period of 3 to 4 days. These extended drawdown periods are intended to maximize attenuation of flows while allowing for recovery of storage volume for future events."

MassDOT has adapted this guidance to develop a method for estimating the mitigation credits for existing and proposed extended detention BMPs. The guidance is clear that extended detention basins that store a large volume of water and release it over several days provide significant mitigation of impervious cover impacts. Storing and releasing runoff very slowly after rain events can achieve similar benefits to infiltration-type BMPs, including:

- Control of peak runoff rates
- Replenishment of base flow via extended surface discharges
- Preventing increased frequency of bank full flows
- Minimizing runoff volume impacts
- Water quality enhancement through significantly extended detention times

For extended detention basins, assign a percentage of effective IC reduction (removal efficiency) to each BMP based on the method outlined below. This method uses two parameters to assess the

percentage of effective IC reduction to be applied to each extended detention basin: storage capacity (Storage Credit) and drawdown time (Drawdown Credit) with each parameter assigned a percentage of the optimal (100%) credit. Multiplying two percentages together to provides an overall extended detention IC mitigation credit:

Extended Detention Mitigation Credit = Storage Credit X Drawdown Credit

These factors represent the extended detention BMP's ability to store significant volumes of runoff and then release it slowly over several days. Basins that both store large volumes and release them over several days receive high relative credits, while basins that store small volumes or release stored volumes quickly would receive little or no mitigation credit.

Storage Credit

Using the TMDL Implementation Support Manual (2006) as the standard, basins that can store the full 2-inch storm volume receive full (100%) Storage Credit. The 2-inch storm in Massachusetts represents 98 to 99% of all storm events, recurring every one to two years. This recurrence interval is also associated with bank full/channel forming flows. Basins that can store a 2-inch storm have the means to mitigate the hydrologic impacts of impervious cover, including increased runoff rates, increased bank full discharges, and decreased base flows. Also, while these basins do not reduce total runoff volumes, spreading outflows over several days provides a very similar effect. MassDOT considered two other critical storms to establish Storage Credits for basins that store less than the 2-inch storms:

- Initial abstraction storm: equal to the initial abstraction depth for pre-development conditions, the storm for which no runoff would result under natural conditions. Basins that store this storm provide the ability to mitigate many of the IC-related hydrologic impacts (increased runoff rates, reduced base flow, increased runoff volume), but not for all storms. The initial abstraction storm (0.5 to 1.5 inches, depending on soils) represents 75 to 95% of all storms. MassDOT established a relatively conservative Storage Credit of 50% for basins able to store this volume.
- 0.5-inch storm: The 0.5-inch storm represents approximately 75% of rainfall events in Massachusetts. Basins that store this storm still provide the ability to mitigate many of the IC-related hydrologic impacts (increased runoff rates, reduced base flow, increased runoff volume), but for a smaller fraction of storms. MassDOT established a relatively conservative Storage Credit of 25% for basins able to store this volume.

To determine the Storage Credit portion of the Extended Detention Mitigation Credit, first calculate the pre-development initial abstraction (Ia) runoff depth for the total area of IC contributing to the subject BMP. Estimate the pre-development curve number (CN) using a land cover of woods in good condition for the applicable hydrologic soil group (HSG). Use the following equation or Table 3 for this calculation:

$$Ia = 0.2 \times \left(\frac{1000}{CN} - 10\right)$$

Table 3 Initial Abstraction for Woods in Good Condition

Hydrologic Soil Group	CN (woods, good condition)	Ia (inches)
A	30	4.25
B	55	1.45
C	70	0.78
D	77	0.53

Next multiply the Ia by the surface area of IC contributing to the subject BMP to obtain the pre-development Ia volume. This represents the volume of water normally infiltrated into the subsurface before creating runoff under pre-development conditions. Calculate the basin's detention volume and assign the Storage Credit based on the ability of the BMP to hold the volumes specified in Table 4. Take no Storage Credit for basins that store less than 0.5-inch storm volume.

Table 4 Storage Credit for Extended Detention Basins

Storage Volume of IC Area	Storage Credit
< 0.5 inch	0%
0.5 inch	25%
Ia depth	50%
2 inch	100%

Drawdown Credit

Based on the TMDL Implementation Support Manual (2006) as the standard, basins that release the Ia storm over 4 days receive full (100%) drawdown credit. Given an average inter-storm interval of 3 days (see Table 5), a 4 day drawdown time is optimal for maximizing detention times but still providing sufficient storage for future storms. Longer times could result in too frequent overtopping, therefore not providing impervious cover mitigation, unless very large detention volumes are provided. Shorter drawdown times would increase periods of no outflow and diminish the benefit of spreading flows over long periods. MassDOT established 1 and 8 day as respective minimum and maximum drawdown times to provide some extended detention benefit, assigning these a storage credit of 25% and then linearly interpolating for other drawdown times between 1 and 4 and 4 and 7 days.

Table 5 Average Storm Information for Massachusetts

Rainfall Depth (inches)	0.01	0.1	0.5	1.0	2.0
Average annual occurrences	122	80	31	11	2
Avg. annual interstorm interval (days)	3.0	4.6	12	32	187
Percentage of storms this depth or smaller (%)	-	35	75	91	98

Source: http://www.nrcc.cornell.edu/page_nowdata.html, 1971-2000 for Massachusetts rainfall stations, Boston Area, Amherst, Ashburnham, Birch Hill Dam, Nantucket, Natick, Newburyport, Northbridge, Sunderland, Tully Lake, and Walpole

For the Drawdown Credit, first calculate the volume of storm water produced by an Ia storm for the area of IC draining to the subject extended detention basin. For basins that store less than the Ia volume (calculated for the Storage Credit), use the 0.5-inch storm. Then use the extended detention drawdown plots included in Appendix A to calculate the drawdown time for this volume. When using the extended detention drawdown plots, calculate head by dividing the drawdown volume by the estimated BMP surface area. Assign Drawdown Credit based on the calculated drawdown specified using the credits values listed in Table 6.

Table 6. Drawdown Credit for Extended Detention Basins

Drawdown Time* (days)	Drawdown Credit
< 1	0%
1	25%
2	50%
3	75%
4	100%
5	75%
6	50%
7	25%
>7	0%

** Drawdown time for smaller of Ia storm or largest storm basin holds.*

Calculate Extended Detention Mitigation Credit

Finally, multiply Storage Credit and the Drawdown Credit together to obtain the total effective IC reduction credit for the subject extended detention basin. Basins that store relatively large volumes and draw these down over several days are credited well, while basins that only do well in one aspect will receive little or no credit. For example, a basin that stores the Ia volume and draws it down over 4 days would receive a mitigation credit of (50% X 100% =) 50% whereas a basin that stores 0.5-inches and draws down in 1 day would receive a credit of (25%X 25% =) 6%.

Quantifying Effective IC Reduction Provided by Existing BMPs

After assigning percentages of effective IC reduction to each BMP, calculate the amount of reduction provided by each. For an infiltration basin treating 0.1 inch of storm water over its DCIA and HSG A soils, the corresponding removal efficiency based on Table 2 is 33%. Using this percentage applied to a watershed with 1.5 acres of IC, the calculation for effective IC reduction credit is as follows:

$$1.5\ acres\ IC \times 33\% = 0.495\ acres$$

In cases where a cumulative reduction in effective IC achieved by the existing BMPs equal to or greater than the target reduction, no further measures are taken and the analysis ends. However, if the reduction in effective IC achieved by existing BMPs is less than the target reduction, the analysis continues to Step 6.

Step 6: Recommend Additional BMPs to the Extent Practicable to Reduce Effective IC to Target

After calculating IC reduction credit from existing BMPs, determine whether it is practicable to construct additional BMPs to treat runoff from MassDOT's impervious urban area that directly discharges to the impaired water body. In some instances it may not be practicable to construct additional BMPs due to site constraints such as lack of available space, incompatible soils, etc. When this is the case, document the constraints.

If the possibility exists to construct additional BMPs, calculate the IC reduction credit from the these additional BMPs. Perform this calculation in the same manner outlined in Step 5 for existing BMPs. Add the reduction in effective IC provided by proposed BMPs to the reduction in effective IC provided by the existing BMPs to obtain a total reduction in effective IC. If the total amount effective IC reaches the 9% threshold, end the analysis and forward recommendations for proposed BMPs to the design consultant for design and permitting. If the total amount effective IC does not meet the 9% threshold, document constraints and forward recommendations for proposed BMPs to a consultant for design and permitting.

Conclusion

As part of their NPDES MS4 storm water permit, MassDOT is required to address the discharge of pollutants from their storm water systems. Some of the impaired water bodies to which MassDOT's storm water systems discharge already have a TMDL, which provides a target for the allowable concentration of various pollutants entering an impaired water body. In these cases, MassDOT can more easily assess whether or not their storm water discharges meet the target concentrations of pollutants outlined in the TMDL.

However, in cases where no TMDL for a water body exists, MassDOT is left without target concentrations of pollutants and has no reference for assessing the impact of the discharges from their storm water systems. To provide an efficient and relevant method to perform these assessments under the current schedule, MassDOT developed an application of the IC Method that has allowed MassDOT to quantify the impacts of its IC on receiving water bodies and stream segments and develop the improvements needed to mitigate the effects of storm water runoff from its IC. This method will allow MassDOT to identify the urbanized areas where existing storm water BMPs are not adequately addressing the water quality impairments and where installation of additional BMPs is an effective use of taxpayer dollars.

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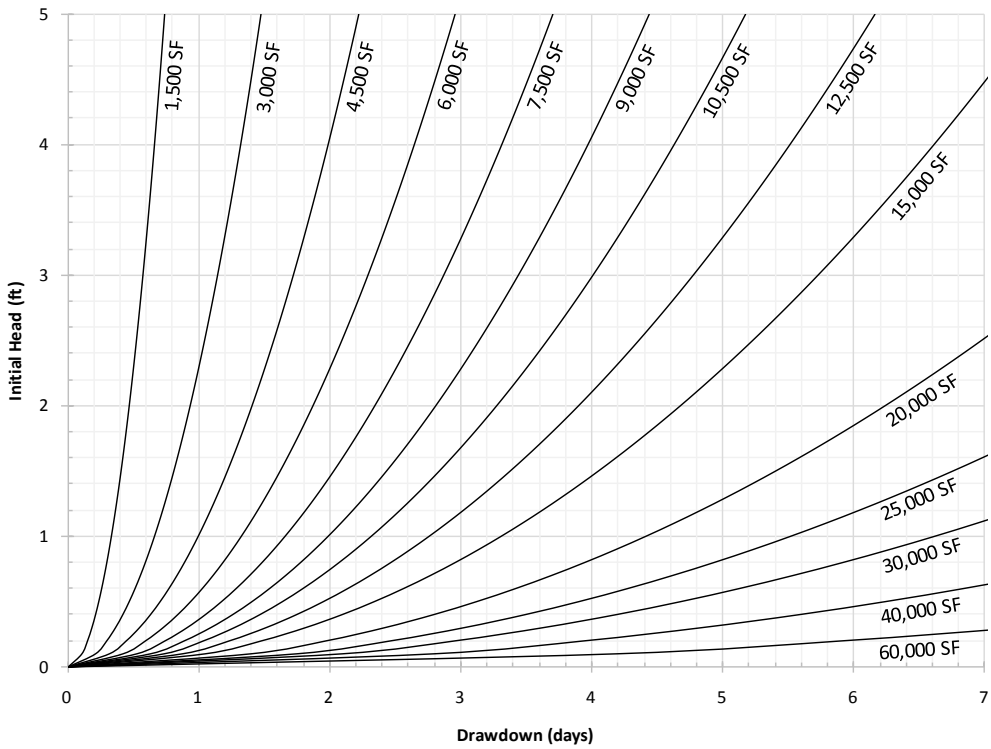
Appendix A – Extended Detention Drawdown Plots

2" Orifice



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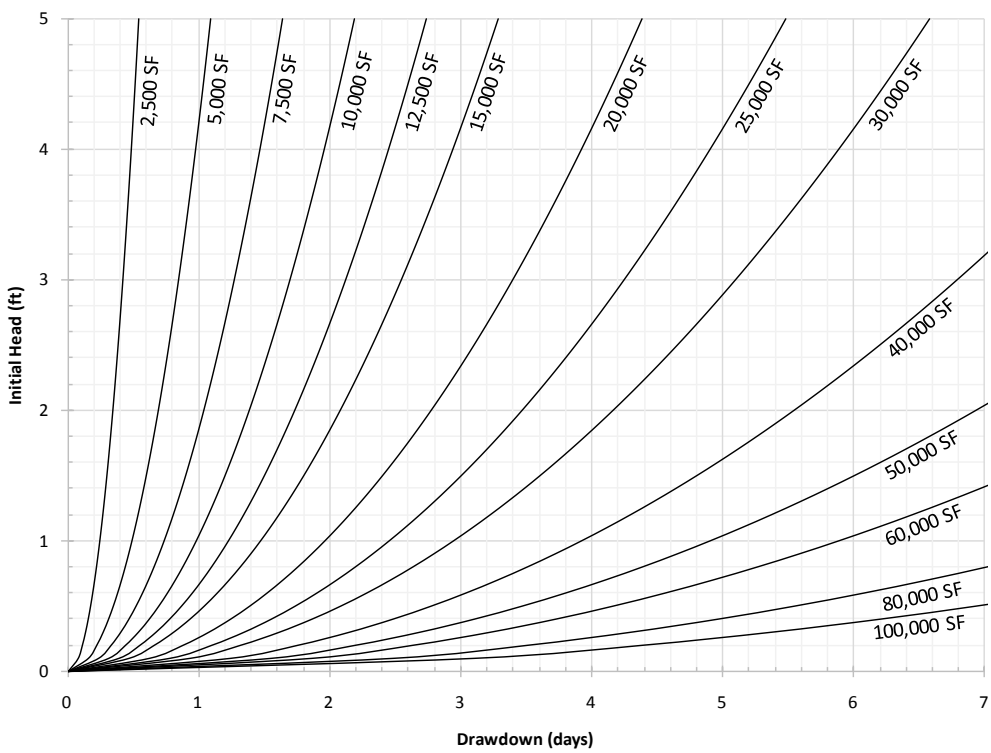
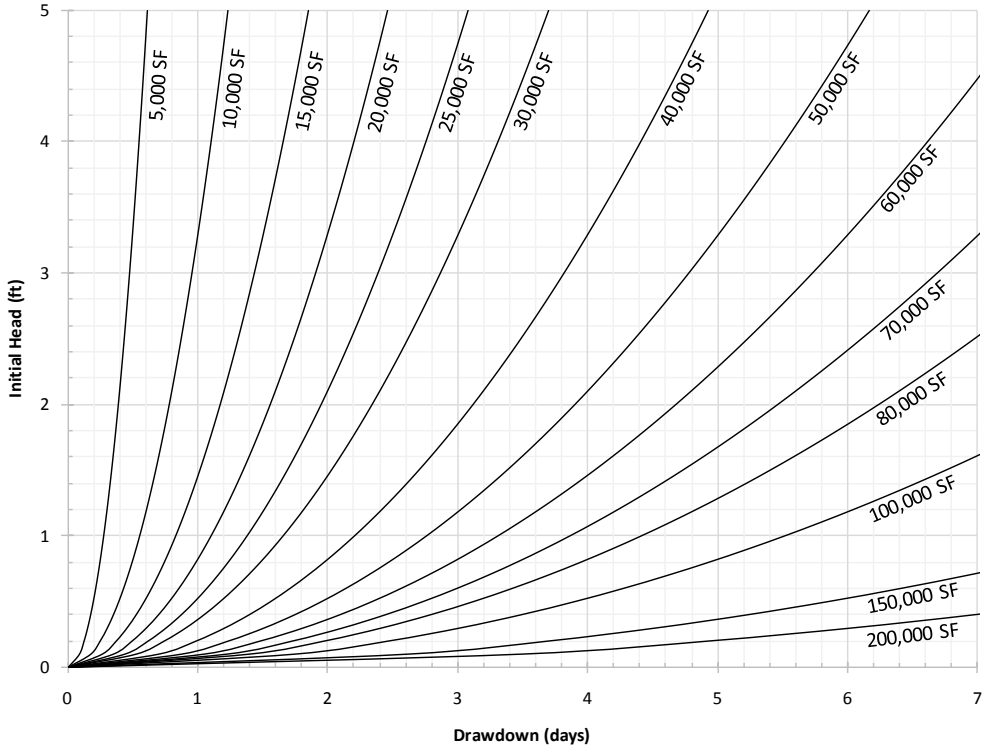
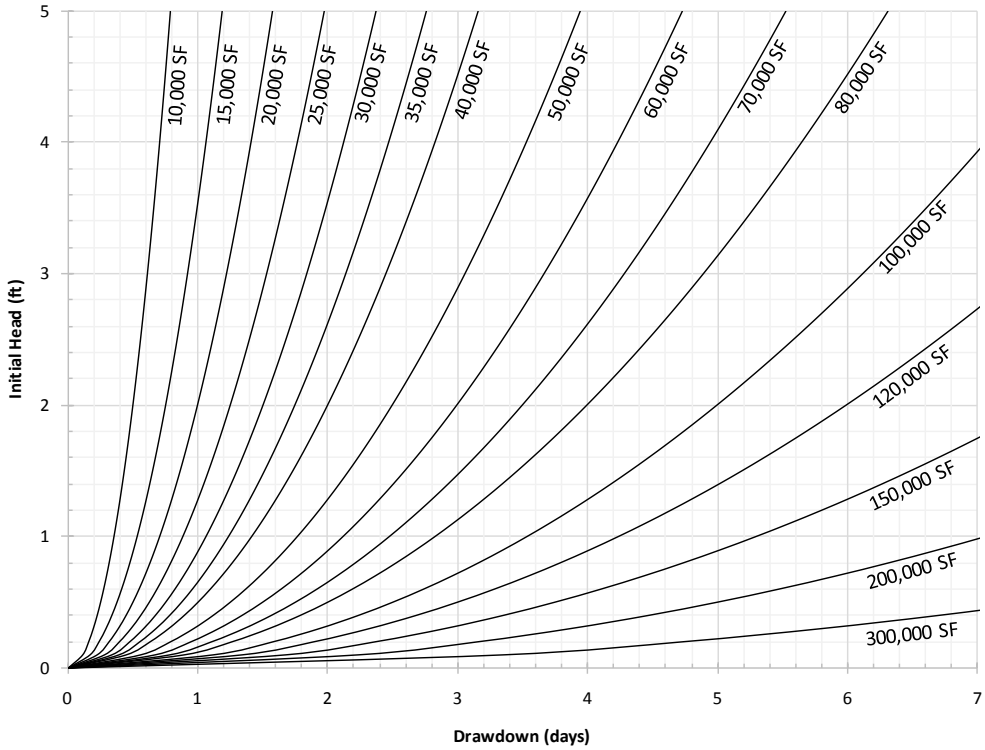


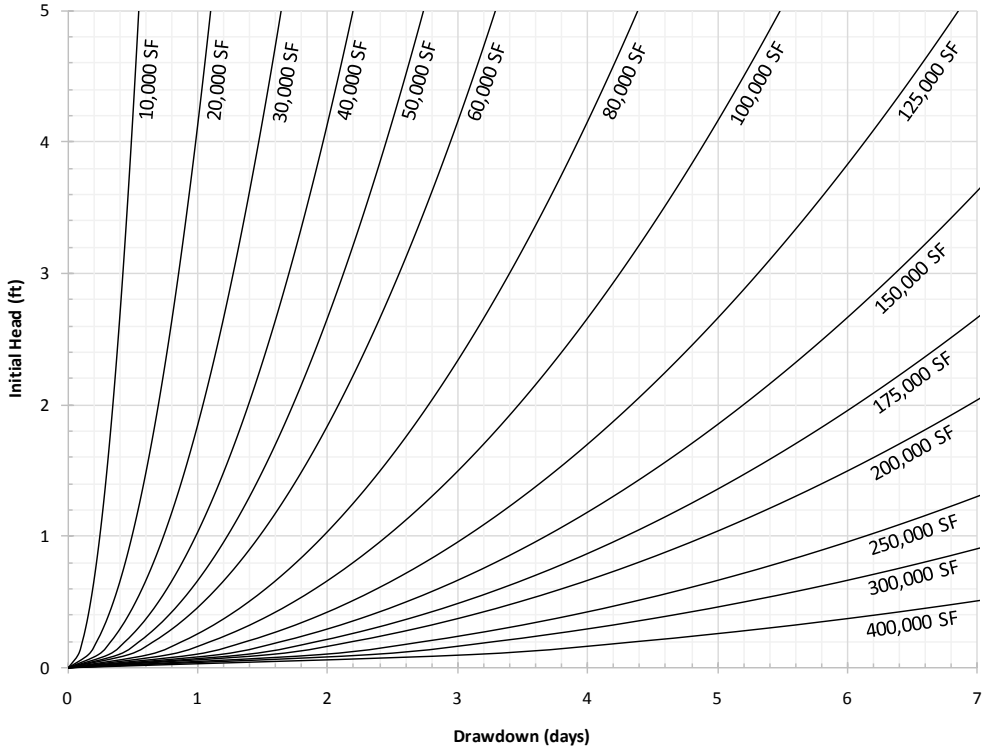
4" Orifice



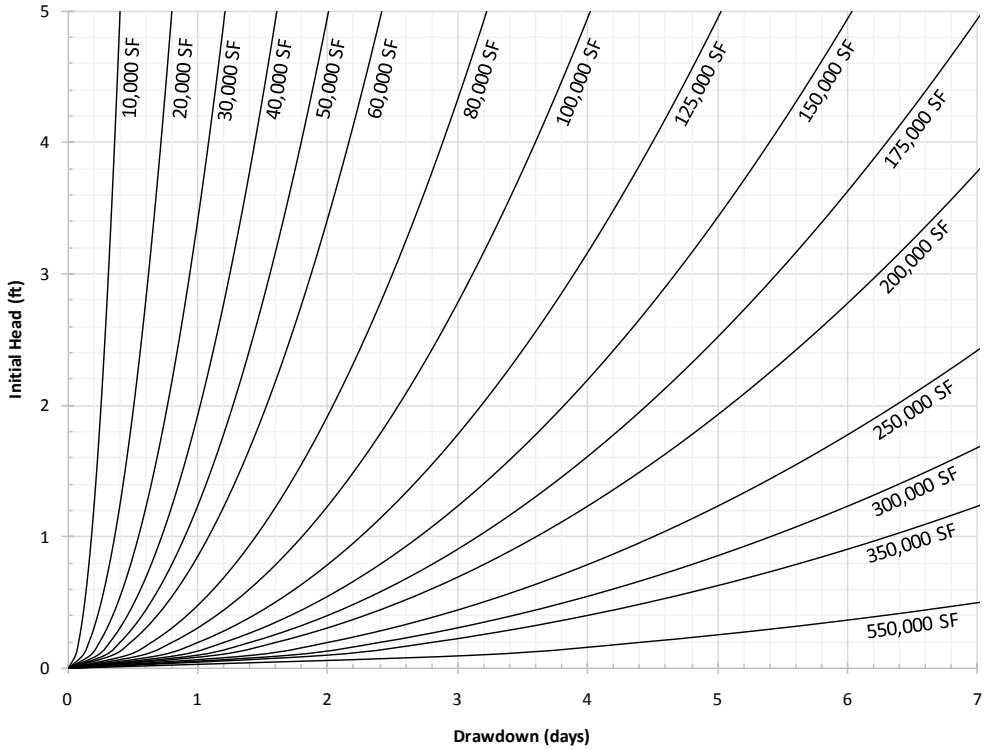
5" Orifice



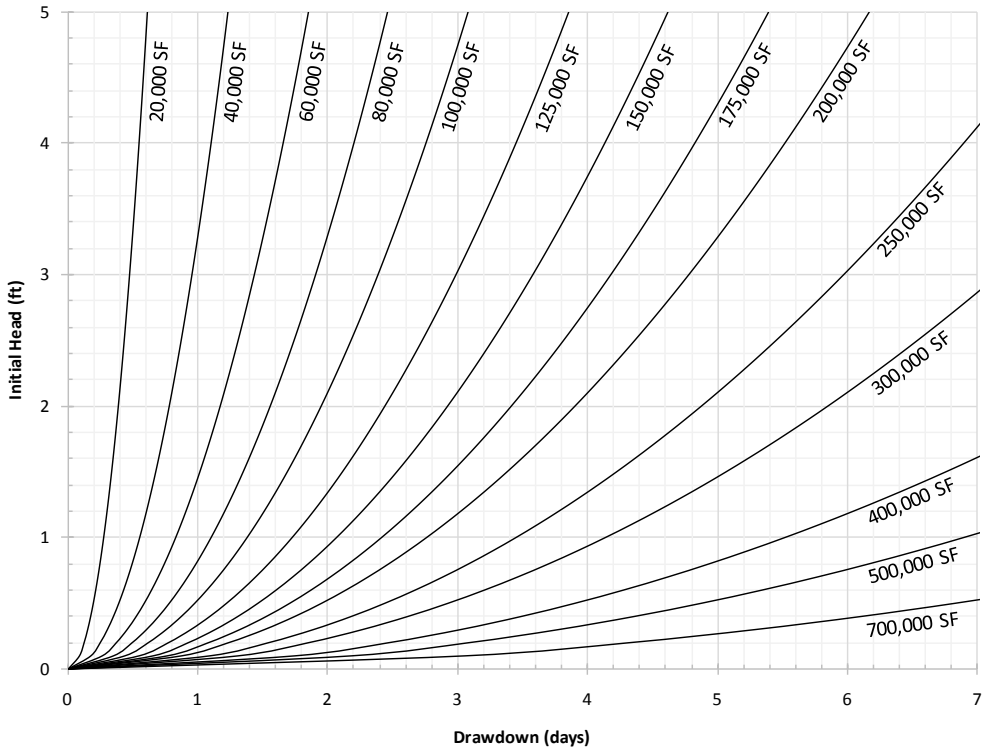
6" Orifice



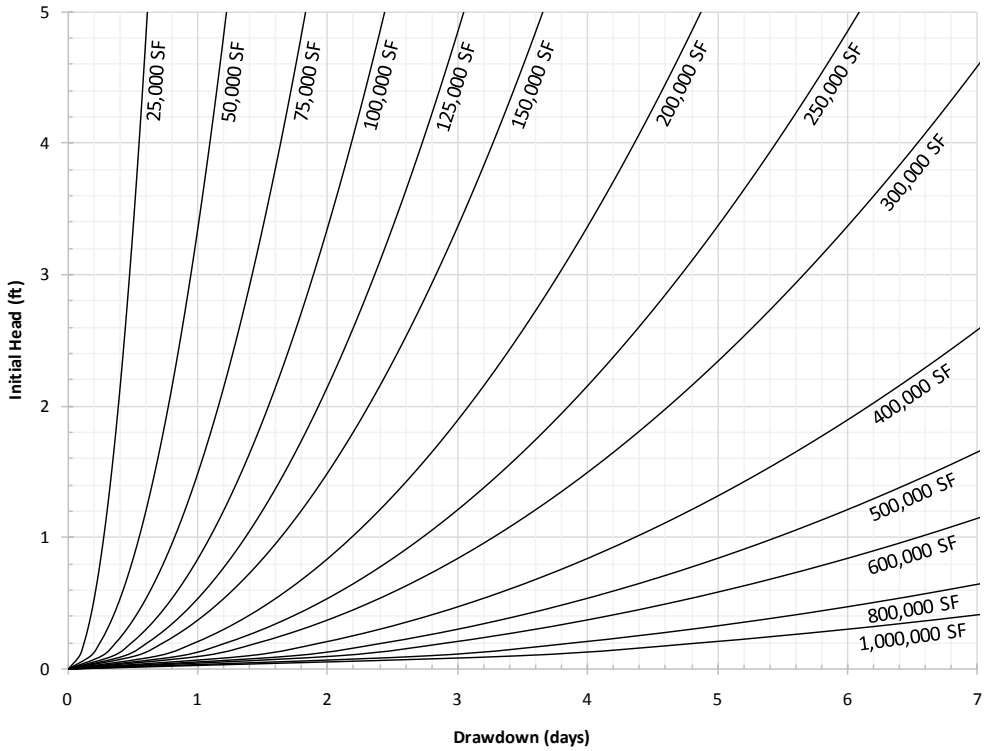
7" Orifice



8" Orifice



9" Orifice



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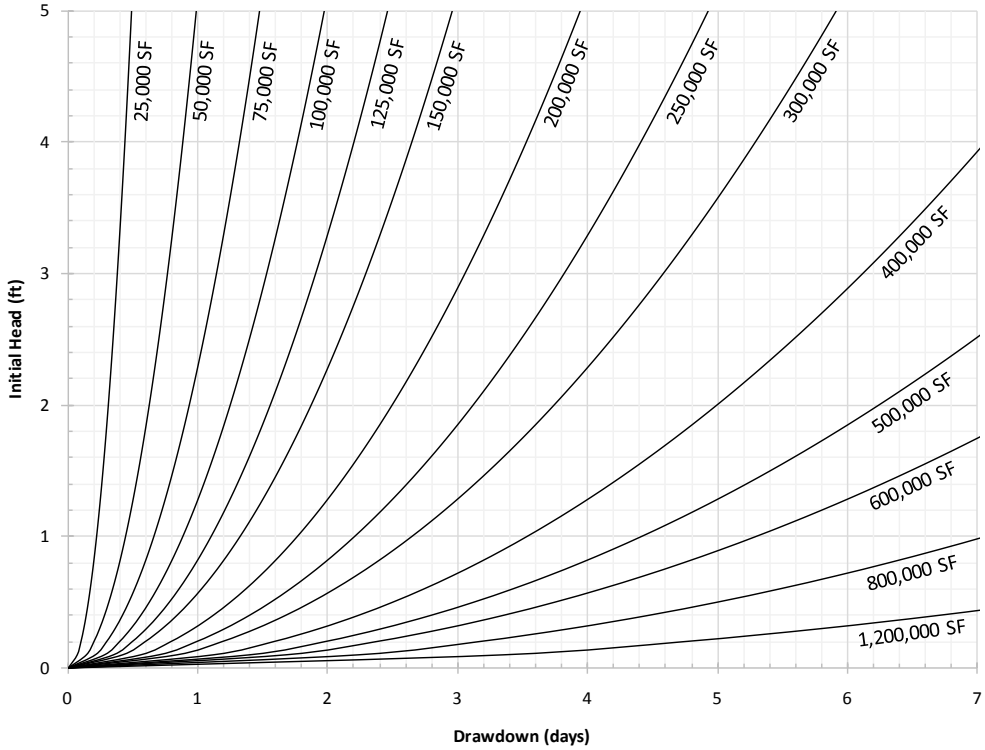

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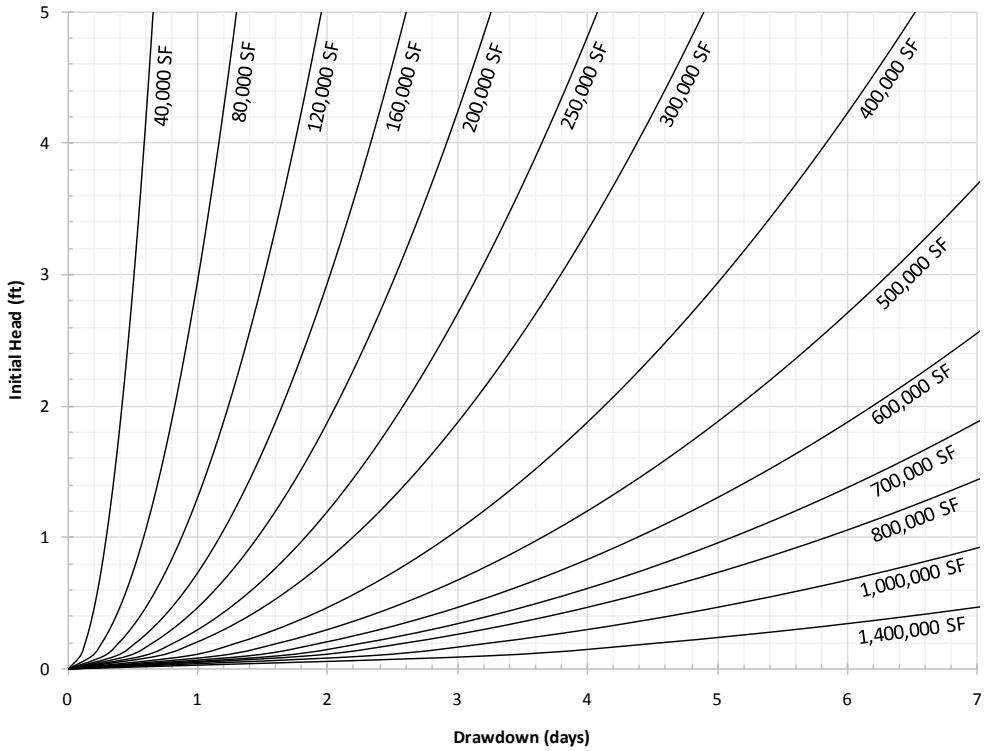
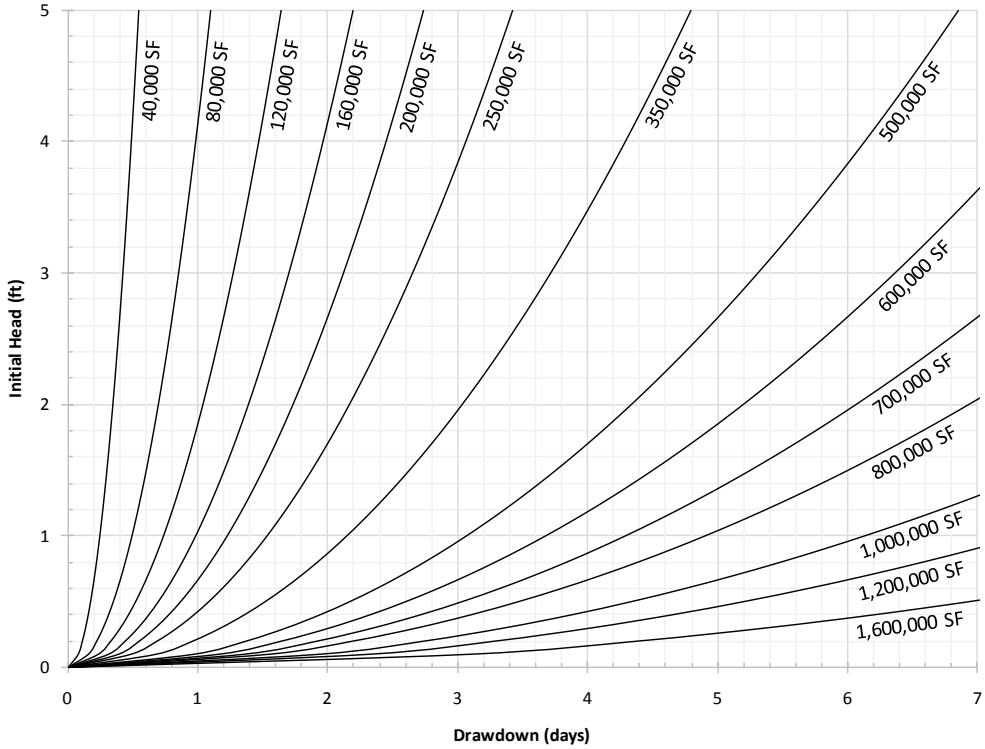


12" Orifice


40,000 SF
80,000 SF
120,000 SF
160,000 SF
200,000 SF
250,000 SF
350,000 SF
500,000 SF
600,000 SF
700,000 SF
800,000 SF
1,000,000 SF
1,200,000 SF
1,600,000 SF
Initial Head (ft)
Drawdown (days)
0
1
2
3
4
5
6
7