Chapter 7: Hydromodification Management Measures

7.1 What is Hydromodification?

Changes in the timing and volume of runoff from a site are known as "hydrograph modification" or "hydromodification". When a site is developed, much of the rainwater can no longer infiltrate into the soils, so it flows offsite at ***faster rates and greater volumes***. As a result, erosive levels of flow occur more frequently and for longer periods of time in creeks and channels downstream of the project. Hydrograph modification is illustrated in Figure 7-1, which shows the stormwater peak discharges after rainstorms in an urban watershed (the red, or dark, line) and a less developed (the yellow, or light, line). The axes indicate the volume of water discharged, and the time over which it is discharged.

Definition

Hydromodification refers to changes in timing and volume of runoff from a site.

Examples of causes: increase in imperviousness, etc.

Examples of consequences: erosion, etc.

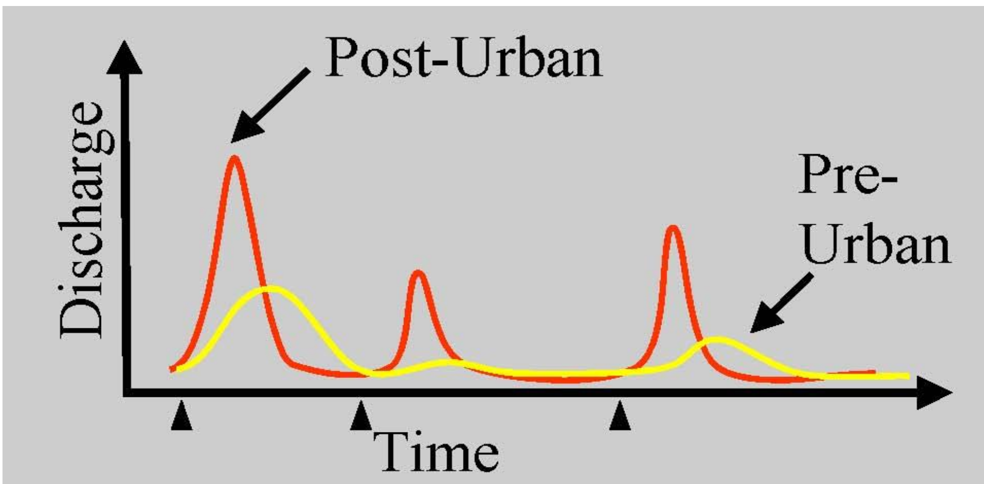

Figure 7-1: Stormwater Peak Discharges in Urban (Red) and Less Developed (Yellow) Watersheds (Credit: NEMO-California Partnership)

In watersheds with large amounts of impervious surface, the larger volumes, faster rates and extended durations of flows that cause erosion often cause natural creeks or earthen channels to erode and become incised, as the channel enlarges or deepens in response to the increased flows. ***Problems from this additional erosion*** often include private property and public infrastructure damage, degradation of stream habitat and water quality; these issues have not been addressed by traditional detention designs. Figures 7-2 and 7-3 illustrate the effect of increasing urbanization on stormwater volumes.

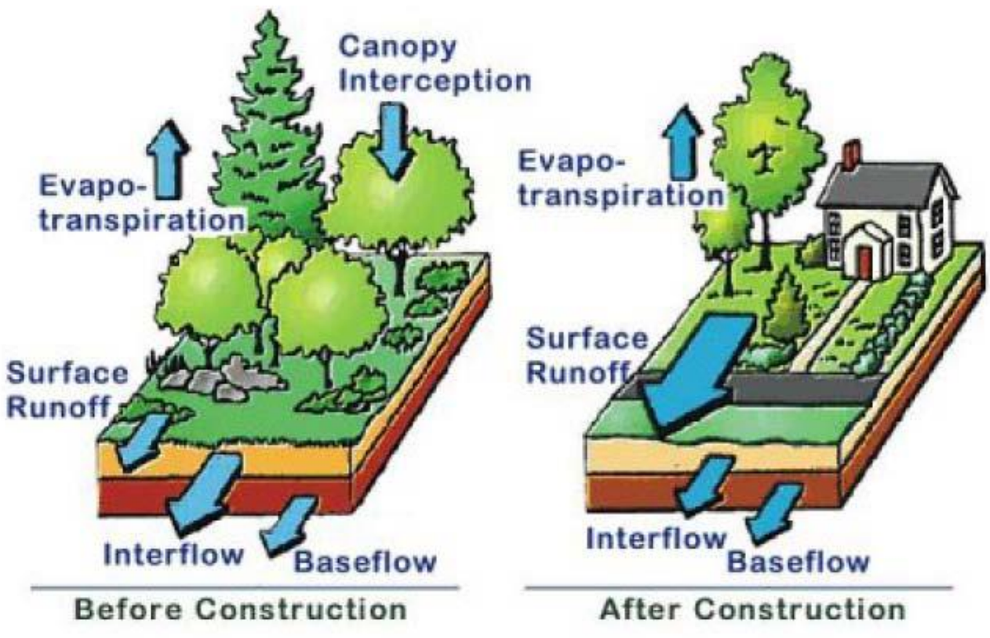

Figure 7-2: Effects of Urbanization on the Local Hydrologic Cycle (Source: Maryland Stormwater Design Manual, 2000)

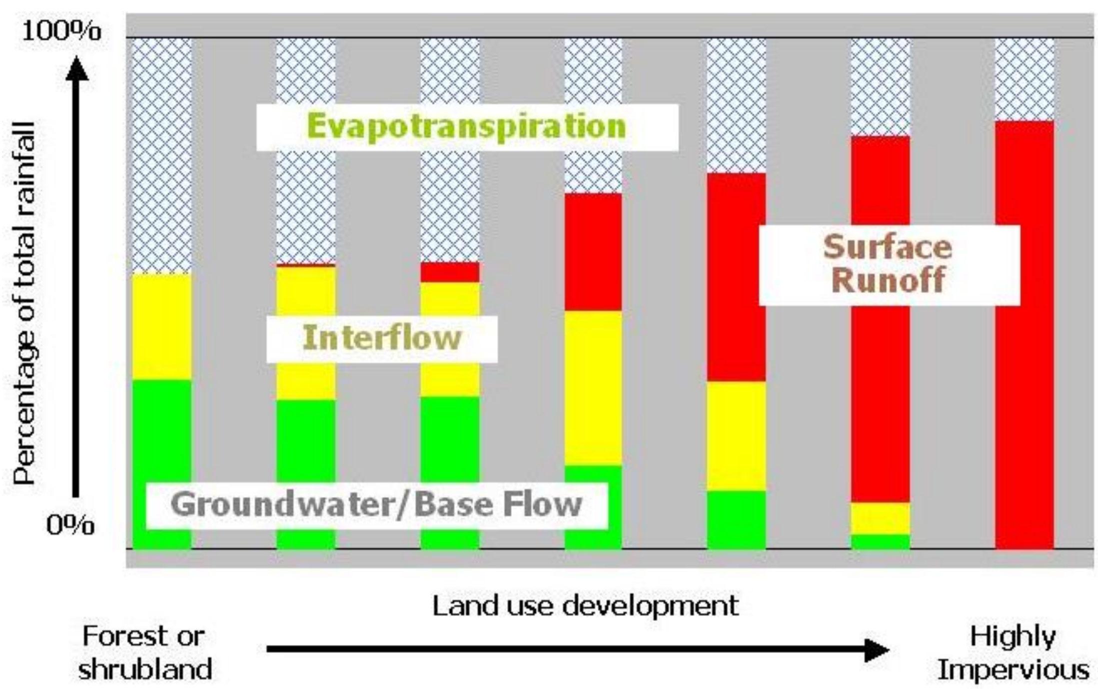

Figure 7-3. Variation in rainfall contribution to different components of the hydrological cycle for areas with different intensity of urban development (Courtesy of Clear Creek Solutions)

7.2 Hydromodification Management (HM) Controls

Since 2007, new hydromodification management (HM) techniques have been required in areas across the San Francisco Bay Area that are susceptible to hydromodification. These techniques focus on ***retaining, detaining or infiltrating runoff*** and matching post-project flows and durations to pre-project patterns for a specified range of smaller, more frequent rain events, to prevent increases in channel erosion downstream. Within San Mateo County, a simple map-based approach is used to determine which parts of the drainage network are susceptible to hydromodification impacts. Projects that meet certain criteria, and from which runoff passes through the susceptible areas, are be required to incorporate one or more HM measures in the design in order to reduce erosive flows from a wide range of runoff conditions. HM measures can be grouped into three types:

> Key Point
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> Hydromodification management (HM) techniques focus on retaining, detaining or infiltrating runoff.

Site design and hydrologic source control measures, which are generally distributed throughout a project site. These types of measures minimize hydrological changes caused by development beginning with the point where rainfall initially meets the ground. Examples include minimizing impervious area, disconnecting roof leaders and providing localized detention. ***LID treatment measures also serve as hydrologic source control measures*** because they reduce runoff volumes and peak flows by retaining and detaining runoff.

Flow duration control measures are used to manage excess runoff from the site after hydrologic source control measures are applied. Stormwater is temporarily detained, and then the runoff is gradually discharged at a rate calculated to avoid adverse effects. Examples of storage facilities include extended detention basins, underground vaults, and oversized storm drainpipes. The discharge is controlled by outlet structures containing weirs and/or orifices designed to allow certain flow rates.

> Key Point
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> Flow duration control measures are sized to control the flow and duration of stormwater runoff according to a Flow Duration Control standard, which is often greater than size requirements for volume-based treatment.

Please note that there is a difference between the design approach for sizing measures to remove pollutants from stormwater and the approach for designing flow duration controls to prevent an increase in the potential for creek bank erosion. The treatment of stormwater pollutants targets capture of 80% of average runoff volume, which means that treatment measures will be bypassed every one to two years. Flow duration controls must be sized to control the statistical duration of a wide range of flow levels under simulated runoff conditions. Depending on pre-project and post project conditions, the required detention volume is ***likely to be greater*** than the capture volume required for treatment. Flow duration controls are typically used on-site, but larger facilities, such as detention basins, may be sized to control runoff from a regional drainage area. LID treatment measures can also be designed to achieve flow duration control and meet HM requirements.

In-stream or restorative measures are used to modify susceptible watercourses to withstand projected increases in runoff flows and durations without increasing erosion or other impacts to beneficial uses. In-stream measures are more complicated to use than other types of controls and are best suited for creeks or channels that have ***already received impacts*** from previous development and have only localized channel instability. Examples include biostabilization techniques using roots of live vegetation roots to stabilize banks and localized structural measures such as compost socks, rock weirs, boulder clusters or deflectors. An example of a compost sock installation that combines a localized structural measure and a biostabilization measure is shown in Figure 7-4 below. These measures will not automatically provide HM protection for channel reaches farther downstream and may require longer planning timelines and cooperation among multiple jurisdictions compared to flow duration controls.

Figure 7-4: In-stream restorative measure using compost socks and vegetation (Credit: Filtrexx)

7.3 Which Projects Need to Implement HM Controls?

Unless it is a single-family home that is not part of a larger of development, a project will be required to comply with the HM requirements if it meets all of the following applicability criteria:

- The project creates and/or replaces one acre or more of impervious surface,
- The project will increase impervious surface over pre-project conditions, AND
- The project is located in a susceptible area, as shown on the HM Control Area Map.

Appendix H contains the Countywide HM Control Area Map. The boundary between areas that are subject to HM requirements and areas that are not generally follows major roadways, such as El Camino Real and Alameda de Las Pulgas. Appendix H includes a series of maps that show more detail for locations in which the boundary does not follow major roadways. Areas exempt from HM requirements tend to be ***heavily developed areas of the bayside***, while the more open and residential hillside, and coastal areas are generally subject to the HM requirements. Four municipalities -- East Palo Alto, Foster City, Daly City, and Colma – are totally exempt (except for some small areas of parkland in which no development is expected to occur). All of the other municipalities have some portions of their jurisdictions where development may occur that would be subject to HM requirements.

Please note that Attachment E of the MRP allows for the ***following exceptions to the HM control area boundary*** shown on the map:

- A project located on one or more parcels in the exempt area that drain into the HM control area would be subject to HM requirements.
- A project in the HM Control Area from which runoff drains only through a hardened channel and/or enclosed pipe along its entire length before directly discharging into a waterway in the exempt area or into tidal waters would be exempt from HM requirements, if the project applicant demonstrates, in a statement signed by an engineer or qualified environmental professional, that this condition is met.

Also note that projects located in susceptible areas are encouraged to include hydrologic source control measures for HM if they are likely to cause hydrograph changes, ***even if they create and/or replace less than one acre of impervious surface.***

7.4 Hydromodification Management (HM) Requirements

The HM objective is to control stormwater discharges from non-exempt development projects so that these discharges do ***not increase the erosion potential*** of the receiving creek over the pre-project (existing) condition. This is accomplished by implementing four performance criteria:

Projects shall ***provide hydromodification management (HM) controls*** as needed to maintain the pre-project creek erosion potential. These controls may include a combination of on-site or off-site (regional drainage area and/or in-creek) control measures. An erosion potential (Ep) of up to 1.0 shall be maintained for creek segments downstream of the discharge point. Ep can be expressed as the ratio of post-project to pre-project erosive "work" done on the creek.

On-site stormwater controls that are designed to provide ***flow duration control*** to the pre-project condition shall comply with the HM requirements. Flow duration controls shall be designed so that the post-project stormwater discharge rates and durations match those of the pre-project condition, from 10 percent of the pre-project two-year peak flow up to the pre-project 10-year peak flow.

Key Point

Flow Duration Control looks at the full range of flows in a simulated long-term history, and is not directly comparable to approaches based on one or a few synthetic "design storms".

Projects may use ***off-site control measures*** in lieu of or in combination with on-site controls, where an approved plan – including an appropriate funding mechanism – is in place and accounts for the creek changes expected to result from changes in project runoff conditions. The off-site control measures or combination of controls shall be designed to achieve the management objective of keeping the erosion potential (Ep) at 1.0 or less, from the point of discharge to the creek as far down stream as potential impacts will occur.

7.5 How to Implement HM Requirements

Projects subject to HM requirements need to consider HM at every stage of project development, following the step-by-step instructions for C.3 submittals in Chapter 3. The most effective use of land and resources may require a combination of IMPs, flow duration control facilities and in-creek measures, which are described in Section 7.2. In general, the strategy for designing HM measures should:

Start with site design to minimize the amount of runoff to be managed (see Chapter 4).

Where possible, ***maximize infiltration*** to further reduce detention requirements. Note that infiltration is limited by site constraints such as slope stability concerns, low-permeability soils or groundwater protection constraints.

Use ***flow duration controls*** to detain the remaining calculated runoff from the site enough to ***control its release*** in a way that meets the remaining runoff design requirements. For some project locations, off-site options may be available to reduce or eliminate the need for onsite detention.

7.5.1 Flow Duration Control

> Key Point
>
> The duration of channel flows below the "critical flow" may be increased indefinitely without significant contribution to hydromodification impacts.

Flow Duration Control (FDC) differs from traditional "design storm" approaches used to design detention facilities for flood control or water quality treatment. Instead of specifying static holding times for one or a few discrete events, the Flow Duration standard manages runoff discharge over the full range of runoff flow levels predicted through continuous hydrologic simulation modeling, based on a long-term precipitation record. Flow Duration Control requires that the increase in surface runoff resulting from new impervious surfaces be ***retained on-site with gradual discharge*** either to groundwater through infiltration, losses by evapotranspiration, and/or discharge to the downstream watercourse at a level below the critical flow that causes creek channel erosion. ***Critical flow,*** or Qc***,*** is the lower threshold of in-stream flows that contribute to sediment erosion and sediment transport or effective work. The duration of channel flows below Qc may be increased indefinitely without significant contribution to hydromodification impacts.

7.5.2 Application of Flow Duration Control to Project Areas

The Flow Duration approach involves a continuous model that applies a time series of at least 30 years of rainfall records to a watershed area or project site to generate a simulated stormwater runoff record based on two sets of inputs, one representing future development and the other representing pre-project conditions. The 30-year precipitation record is the minimum length necessary to capture the range of runoff conditions that are cumulatively responsible for most of the erosion and sediment transport in the watershed, primarily flow levels that would recur at average intervals of 10 years or less in the pre-project condition. The design objective is to ***preserve the pre-project cumulative frequency*** distribution of flow durations and sizes under post-project flows. This is done with a combination of site design, infiltration and detention. Typically the post-project increase in surface runoff volume is routed through a ***flow duration control basin*** or other structure that detains a certain portion of the increased runoff and discharges it through a ***specialized outlet structure*** (see Figure 7-5).

Key Point

Flow Duration facilities are subject to Operations and Maintenance reporting and verification requirements similar to those for numerically sized treatment measures.

The flow duration basin, tank or vault is designed conceptually to incorporate multiple pools that are filled with different frequencies and discharge at different rates. The low-flow pool is the bottom level designed to capture and retain small to moderate size storms, the initial portions of larger storms, and dry weather flows. These flows are discharged through the lowest orifice which allows continuous ***discharge below the critical flow rate*** for a project (Qcp). Successively higher-flow pools store and release higher but less frequent flows through other orifices or graded weir notches to approximate the pre-project runoff durations. In practice the multiple pools are usually integrated into a

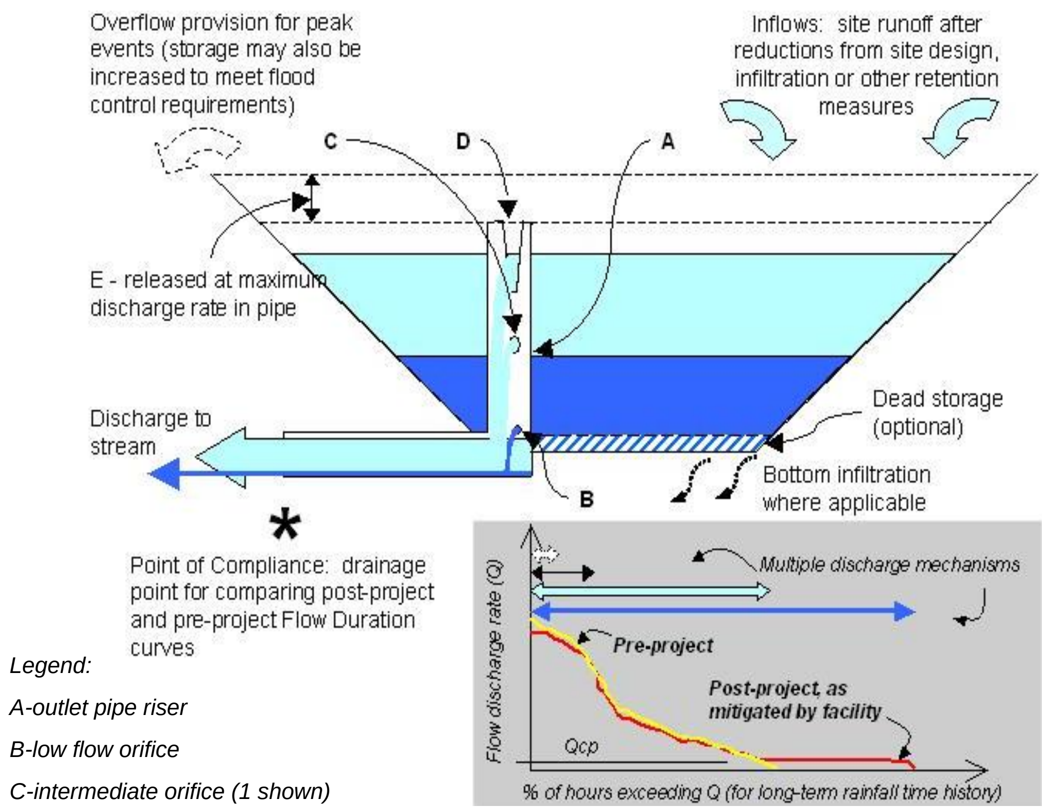

Figure 7-5: Schematic flow duration pond and flow duration curves matched by varying discharge rates according to detained volume. (Source: ACCWP, 2006)

single detention basin, tank or vault that works as a unit with the specialized outlet structure. Matching the pre-project flow durations is achieved through fine-tuning of the number, heights and dimensions of orifices or weir notches, as well as depth and volume of the basin, tank or vault.

As shown in the example chart of Figure 7-5, the post-project flow duration curve (red, or dark line) is reduced by the facility to remain ***at or below the pre-project curve*** (yellow, or light line), except for flows less than Qcp. Minor exceedances are permissible at a limited number of higher flows since at other flow levels the post-project duration is actually less than the pre-project condition.

Adequate maintenance of the low-flow orifice or notch is critical to proper performance. The outlet may be in a protective enclosure to reduce risk of clogging. Please note that Flow Duration facilities are subject to Operations and Maintenance verification requirements similar to those for numerically sized treatment measures.

7.5.3 Bay Area Hydrology Model (BAHM)

To facilitate the simulation modeling aspect of FDC for project applicants and their engineers, the Countywide Program collaborated with the Santa Clara and Alameda counties' stormwater programs to develop a Bay Area Hydrology Model (BAHM) ***software package***[46] that is adapted from the Western Washington Hydrology Model (WWHM) developed by Clear Creek Solutions for the State of Washington Department of Ecology (WDOE). The WWHM was specifically developed to help engineers design facilities to meet a Flow Duration Control standard for development projects.

The BAHM includes:

- Databases to automatically assign default rainfall conditions for a project location selected within the County boundary.
- A user interface for developing a ***schematic drainage model*** of the project site, with forms for entering areas of land use or impervious surface for multiple sub-basins.
- Continuous simulation modeling of ***pre-project and post-project runoff*** from the site using actual long-term rainfall records appropriately scaled for the project location.
- Simulation of ***LID site design and treatment measures***, to estimate the reduction in runoff flow and volume achieved by these measures.
- A design module for sizing a ***FDC detention facility*** and designing the discharge structure to meet the Flow Duration standard for matching post-project and pre-project duration-frequency curves. Pre-project and post-project runoff are compared at a "point of compliance" selected by the designer, usually near the point where runoff leaves the project area.
- Standardized output ***report files*** that can be saved in Word format, and include all information about data inputs, model runs, facility design, and summary of the hydrological statistics showing the compliance of post-project flow duration curves with the Flow Duration standard. Project input and output data can also be saved in Excel and other formats for other uses.

[46] The most recent version of the BAHM and the BAHM User Manual are available for download at: https://clearcreeksolutions.info/sample-page/

7.6 HM Control Design Process

If the project is not exempt from HM requirements, it has the potential to cause hydromodification impacts on the receiving stream and must use the HM standards to determine how it will meet the management objective. Implement the following steps to design HM controls for non-exempt projects.

1. ***Compare pre- and post-development runoff patterns.*** Use the BAHM to perform a detailed analysis comparing pre-project and post-project runoff patterns for the project site. If a more detailed or site-specific approach is preferred, as an alternative to using the BAHM, then flow duration curves must be generated, illustrating the distribution of flows resulting from a continuous rainfall record for the pre- and post-project conditions. This is accomplished using a continuous simulation hydrology model or a sizing tool based on a continuous simulation model. ***The input data and results of the BAHM or other model analyses and the flow duration matching curves must be submitted to the municipality as part of the project's Stormwater Management Plan.***
2. ***Incorporate the flow duration control measures into the project design.*** Use the BAHM to design flow control facilities to meet the flow duration control criteria, so that the discharge pattern produced by the proposed flow duration control measures matches the pre-development flow duration curve. As an alternative to using the BAHM, a continuous simulation hydrology model or sizing tool based on a continuous simulation model must be used, preferably the same model or tool used in step 1, above. Achieving the flow duration control criteria generally requires some type of above- or below-ground detention and/or infiltration facilities that reduce the volume and control the rate of post-project discharge.
3. ***If necessary, consider alternatives to on-site HM control.*** On-site stormwater detention and infiltration facilities may not be suitable for the project site due to space limitations, soil conditions, depth to groundwater, and other factors. If the on-site HM control alternatives are constrained for the project, then a combination of on-site, off-site, and/or in-stream measures may need to be considered to meet HM requirements. Remember that site design measures and LID treatment measures will help meet HM requirements by reducing post-project runoff volumes and peak flows.
4. ***Optimize the orifice of the HM facility***. The diameter of the low-flow (bottom) orifice is an important design parameter for flow duration facilities, since flows discharged from this outlet must be at or below the critical flow rate for the project (Qcp). However, maintenance and/or other considerations may dictate a practical limit to how small this orifice may be. In Western Washington, which has been implementing HM control requirements since 2001, the minimum orifice diameter specified in its Stormwater Management Manual is 0.5 inches, for orifices that have protective screens and a sump below that collects sediment[47]. If the BAHM or other model indicates that the flow duration matching criteria cannot be achieved with an orifice diameter of 0.5 inches, design options include:
    a. Increasing the drainage area to the HM facility (e.g. combining flows from two or more drainage management areas);
    b. Reducing the depth of the detention facility (that is, increase the surface area) to reduce the head on the orifice;
    c. Adding a flow throttling device such as an elbow restrictor; and/or

[47] Washington State Department of Ecology, Feb. 2005. *Stormwater Management Manual for Western Washington*, Volume III – Hydrologic Analysis and Flow Control Design. http://www.ecy.wa.gov/programs/wq/stormwater/manual.html

d. Add an infiltration measure downstream of the detention facility to further mitigate flows from the low-flow orifice.

Appendix D of the BAHM User Manual provides more information on how to size a flow duration facility with a specified minimum orifice size[48]. The Western Washington Manual provides more detail on orifice design.

5. ***Design for maintenance of the HM facility.*** HM facilities, like treatment measures, should be designed with maintenance considerations in mind. Design guidance for detention basins is provided in Chapter 6. Detention basins and underground vaults need safe access for personnel and equipment to perform required maintenance. Detention basins typically require a maintenance ramp leading to the bottom of the basin and a perimeter access road. Underground vaults require sufficient manhole openings and spacing with appropriate railings and ladders for access.

   Adequate maintenance of the low-flow orifice is critical to proper performance. Outlet protection, such as a screen, is recommended to reduce risk of clogging. For example, Caltrans detention basin design standards call for a welded stainless steel wire mesh attached to a frame that wraps around the outlet riser[49]. Note that HM facilities are subject to the MRP operations and maintenance verification requirements and will be inspected by municipal staff. Property owners should be familiar with maintenance requirements and perform activities routinely. More information on maintenance of detention basins is provided in Chapter 8.

[48] Clear Creek Solutions, 2013. *Bay Area Hydrology Model User Manual*. Prepared for the Alameda Countywide Clean Water Program, the San Mateo Countywide Water Pollution Prevention Program, and the Santa Clara Valley Urban Runoff Pollution Prevention Program. https://www.clearcreeksolutions.info/ftp/public/publications/BAHMUserManualJuly2007.pdf

[49] Ibid.

7.7 HM Control Submittals for Review

Determine the potential applicability of the HM requirements to the proposed project, using the guidelines in Section 7.3 and the applicability maps in Appendix H, and indicate HM applicability on the municipality's C.3 and C.6 Development Review Checklist (or equivalent form). Then prepare an HM Control Plan as part of the project's Stormwater Management Plan.

Table 7-1 provides a model checklist of submittal requirements for the HM Control Plan. Information on site design and LID treatment measures should also be included, if they are part of the HM Control Plan, along with any modeling analyses. The local jurisdiction should be consulted to determine the specific requirements for the project.

Table 7-1: HM Control Plan Checklist

Required?*		Information on Plan Sheets
Yes	No	
☐	☐	Soil types and depth to groundwater.
☐	☐	Existing and proposed site drainage plan and grades.
☐	☐	Drainage Management Area (DMA) boundaries
☐	☐	Amount of existing pervious and impervious areas (for total site and each DMA)
☐	☐	Amount of proposed impervious area (for total site and each DMA)
☐	☐	Amount of proposed pervious area (for total site and each DMA)
☐	☐	Proposed site design measures to minimize impervious surfaces and promote infiltration**
☐	☐	Proposed locations and sizes of stormwater treatment measures and HM controls
☐	☐	Stormwater treatment measure and HM control measure details
		Additional Submittal Information
☐	☐	BAHM Report with input and output data files in native software format, PDF format and additional files as required by municipality
☐	☐	If different model is used, description of the model, input and output data
☐	☐	Description of any changes to standard parameters (for example, scaling factor, duration criteria)
☐	☐	Comparison of HM facility sizing per model results vs. details on plan
☐	☐	Description of any unique hydraulic conditions due to HM facility location
☐	☐	Description and details of orifice/weir sizing, outlet protection measures, and drawdown time
☐	☐	Preliminary maintenance plan for HM facility

* Municipal staff may check the boxes in the "Required" column to indicate which items are required for the project.

** Site design, treatment and HM measures that promote infiltration should be designed consistent with the recommendations of the project geotechnical engineer.

7.8 Area-Specific HM Provisions

Individual municipalities may have special policies or ordinances for creek protection applicable in all or part of their jurisdictions. ***Local municipal staff should be contacted*** to identify any special local jurisdictional provisions that may encourage or affect specific forms of HM implementation. Examples of area-specific HM provisions can include:

- Watershed-based land-use planning measures, such as creek buffers, which may be incorporated in local General Plans, zoning codes or watercourse ordinances.
- Special permitting provisions for project design and review of projects on streamside properties.
- Specific plans for regional HM measures or in-stream restoration projects.

Contact

Some municipalities may have special policies or ordinances for creek protection.

Contact the local jurisdiction to learn more.