

6. GUIDANCE FOR SELECTION AND DESIGN OF HYDROMODIFICATION CONTROL MEASURES

6.1 SELECTION OF CONTROL MEASURES

Types of Control Measures

Hydromodification controls are measures designed to meet the hydromodification control standards in Chapter 5. Hydromodification controls can be classified into the following categories:

- On-site controls (also referred to as project controls)
- Regional controls (including drainage-area controls and larger scale facilities)
- In-stream controls

On-Site (Project) Controls. Project controls are applied to individual projects when the site is developed or redeveloped. Project controls include site design features that are integrated into the development and are intended to reproduce, to the extent feasible, the natural processes of infiltration, evapotranspiration, and delayed runoff response. These are also known as “hydrologic source controls” because they have the effect of reducing runoff volumes resulting from development. Examples of such site design features include minimizing impervious surface areas, preserving natural areas, limiting development especially where native soils have good infiltration characteristics, directing roof runoff to bioretention areas, using vegetated swales in lieu of traditional gutter inlets and underground storm drains, and using soil amendments to improve infiltration and evapotranspiration.

Project controls also include flow control structures such as retention/detention basins and underground detention vaults and tanks. These may be needed to supplement the site design techniques for runoff volume and flow duration control to meet the hydromodification control standards. The two types of on-site controls are discussed in more detail below.

Site Design Techniques. Site design may be incorporated into the standard features of a development with only small to moderate changes in the project design. Appropriately applied, site design control techniques can reduce the runoff volume, duration and flow rate, and can reduce the infrastructure necessary to control and convey stormwater. Site design controls can be very effective at controlling geomorphically significant flows (i.e., erosive flows) and can be used to fulfill both water quality and flow control objectives. However, since site design controls

retain water on site through infiltration, evapotranspiration, and/or detention, their effectiveness depends on soil properties, groundwater levels, topography, and other site conditions.

The first step in this strategy is using design features that minimize the changes in the pre-project hydrograph by reducing impervious surfaces, breaking up impervious areas with pervious areas, disconnecting roof drains from direct connection to storm drains, and other options. Once all the strategies for minimizing the increase in runoff have been considered, then management practices that retain the excess runoff volume are employed (e.g., depressions in landscaping or “rain gardens”, infiltration, and vegetated filters). These should be distributed throughout the development site. Where site design and retention in landscaping are not enough to meet hydromodification control standards, detention is then employed, where some of the excess runoff is held in storage and later released at a slower rate.

Following are examples of site design techniques:

Decrease Impervious Surface Area

1. Minimize the impervious footprint by increasing building density (e.g., increasing the number of stories above or below ground, or adding parking below ground).
2. Conserve natural areas, especially riparian corridors, by concentrating or clustering development on the least environmentally sensitive portions of a site while leaving the remaining land in a natural, undisturbed condition.
3. Construct walkways, trails, patios, parking lots, driveways, low-traffic streets and other low-traffic areas with open-jointed paving materials or permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials.
4. Construct streets, sidewalks and parking lots to the minimum widths necessary, provided that public safety and a walkable environment for pedestrians are not compromised. Incorporate landscaped buffer areas between sidewalks and streets.
5. Maximize canopy interception and water conservation by preserving existing native trees and shrubs, and planting additional native or drought tolerant trees and large shrubs.
6. Design driveways with shared access, flared layout (single lane at street widening to double lane at garage) or wheel strips (paving only under tires).
7. Use natural drainage systems to the maximum extent practicable.

Promote Infiltration and Evapotranspiration

1. Where native soils have good infiltration characteristics (say, infiltration rates of 0.5 in/hr or greater), consider using shallow infiltration trenches for infiltration of roof runoff, or eliminating downspouts and extending roof eaves over pervious areas. Where less infiltrative soils are present, amend the soils and disperse roof runoff through landscaping or swales sloped away from buildings.
2. Construct on-site ponding areas in landscaping (small depressions or rain gardens) to increase opportunities for infiltration.

3. Incorporate landscaping into parking areas and drain the impervious surfaces to the landscaped area.
4. Drain impervious driveways, sidewalks, walkways, trails, and patios into adjacent landscaping.
5. Drain roads to vegetated drainage swales in lieu of curb and gutter.
6. Pave uncovered temporary or guest parking on private residential lots with a permeable surface.
7. Design bioretention areas¹ into parking lots in landscape islands, around the parking perimeter, or in strips between parking stalls.

Alternative Site Design Concepts

1. Vegetated rooftops, also known as green roofs or eco-roofs, are veneers of living vegetation that are installed on top of conventional roofs. A green roof is an extension of the existing roof, which involves a special root repelling membrane, a drainage system, a lightweight growing medium, and plants.
2. Runoff storage systems on top of roofs (“blue roofs”) can be used to detain and evaporate runoff volume. A flat roof with a large surface area can store a large quantity of water at a shallow depth.
3. A cistern is a vessel that provides storage of roof runoff for irrigation of landscaped areas. Cisterns may be either an above ground vessel with a manually operated valve or permanently open outlet, or a below ground vessel with a pump for water distribution.

Flow Control Structures. As described above, project controls also include retention/detention basins and underground detention vaults and tanks that are sized and fitted with outlet structures to control outflow duration. Flood control and water quality treatment facilities can be combined with flow control structures; for example, wet ponds and constructed wetlands can be modified to provide hydromodification control. Such control facilities are often located just before the point where project runoff leaves the development site. Design guidance for flow duration basins is provided in Appendix F.

Regional (Drainage-Area) Controls. Drainage-area controls intercept runoff from a drainage area before runoff is discharged to a creek. Drainage-area controls include larger detention and/or retention basins and bypass pipelines. They are designed to reduce flows, volume and durations and/or divert runoff so it is discharged at a less-sensitive location. In some cases, bypasses are used to intercept flow at outfalls and redirect a portion of that flow to a nearby detention basin. In other cases, bypass pipelines redirect flows away from a more-erosive stream segments to a less-erosive downstream segment or to an existing downstream impoundment (e.g., flood control basin or lake).

¹ Bioretention is a practice to manage and treat stormwater runoff by using a conditioned planting soil bed (3 to 4 feet deep) and planting materials to filter runoff stored within a shallow depression.

The benefits of drainage-area controls are: 1) they can be economical for serving several development projects; 2) they allow for efficient maintenance in one location; and 3) they can serve dual uses as multi-purpose facilities during the dry season. However, the use of drainage-area controls can be significantly constrained in urban areas due to lack of space and land costs.

In-Stream Modifications. In-stream modifications are applied within the riparian corridor to stabilize channels under an altered hydrologic regime. These measures improve channel stability and prevent erosion by increasing the channel's flow capacity and reducing the erosive forces, according to fluvial geomorphic principles. Examples include reducing channel slope (e.g., by increasing channel sinuosity or installing grade control structures), providing terraces and/or bypass channels, stabilizing banks (e.g., by grading slopes back, re-vegetation and providing structural measures where needed), and installing rock drop structures.

In-stream controls can be used to stabilize a stream channel that has already been impacted by hydromodification. For streams that are somewhat impacted or where delayed impacts are anticipated (after an area is developed, the impacts of increased runoff may take years to become evident), in-stream controls can improve the stream condition or minimize impacts that would otherwise continue. Where possible, the least-intrusive, most-environmentally sensitive in-stream controls should be used, such as re-vegetating banks or biotechnical bank stabilization techniques. For stable healthy streams, project controls or drainage area controls are preferable since they do not require disturbing the stream channel.

Selection Process

The selection process should follow a progressive control strategy that integrates: land use planning, distributed on-site control measures, followed by regional solutions and stream rehabilitation. Land use planning involves preserving the natural hydrologic conditions and protecting sensitive hydrologic features, sediment source and sensitive habitats, and helps to avoid the need to mitigate for hydromodification. On-site control measures are focused on minimizing the effects of development through conscientious design and through the implementation of distributed volume reduction BMPs (e.g., infiltration swales, infiltration gardens, etc.). After land use planning and on-site BMPs are maximized, then attention can be turned to managing the stream corridor itself by implementing in-stream controls and providing allowances for the modified stream flow characteristics to enhance the beneficial uses of streams.

In summary, three principles form the framework for implementing hydromodification control:

1. *AVOID* stormwater impacts and preserve existing natural channels, wetlands and riparian vegetation through hydrologic source controls. These measures can include such things as land use planning, regulation and site design practices to limit changes in quantity and quality before it enters the storm drain system.
2. *MINIMIZE* impacts to natural waterways by using structural controls to reduce or delay stormwater runoff, and intercept and/or remove pollutants after entering the storm drain system.
3. *MANAGE* the receiving water body itself by using bed and bank stability techniques, treatment measures, and stream maintenance programs.

In some cases, a regional stormwater management system may be more cost effective than individual project controls in achieving the second principle above. These strategies could include regional floodplain management, secondary collection and drainage systems, and large-scale detention and infiltration basins.

The following three-step process is recommended for selecting hydromodification control measures:

Step 1: Select Appropriate Site Design Measures: A list of site design techniques is provided earlier in this section. Additional techniques and design information is provided in the BASMAA “Start at the Source” Manual (1999). The companion document, “Using Site Design Techniques to Meet Development Standards for Stormwater Quality” (BASMAA, 2003) illustrates how various site planning concepts can be used to help minimize quantities of runoff from the site.

Step 2: Select Treatment Control Measures to Help Reduce the Volume and/or Rate of Runoff: After selecting appropriate site design measures, the second step in the selection process is to utilize treatment controls that also provide hydromodification benefits. All Provision C.3. Group 1 new development and significant redevelopment projects require stormwater quality treatment measures. Chapter III of the C.3 Stormwater Handbook lists treatment controls that may be appropriate for conditions in Santa Clara Valley and the considerations that apply in selection. These considerations include the land uses associated with the proposed development, the pollutants commonly associated with those land uses, the treatment processes that have been found effective for selected constituents, and the type of BMPs that utilize those treatment processes. In many cases, this selection process results in more than one candidate treatment control. In such situations, additional consideration should be made to select those treatment controls that also provide hydromodification benefits. Such benefits can be in the form of runoff volume reduction as achieved for example by treatment measures utilizing retention (e.g., bioretention facility) or measures that can achieve flow control as part of detention (e.g., extended detention basins). In general, retention facilities would be considered superior to detention facilities, but constraints on infiltration devices as described in Section III.4 and Attachment III-3 of the C.3 Stormwater Handbook may in some cases preclude retention facilities.

Step 3: Select Additional or Modify Measures to Meet Hydromodification Standard: The third step in the selection process would be to consider the need for additional controls or modification of controls selected in Step 2 that might still be required to meet the hydromodification control standard. Such controls would likely be similar to the treatment controls considered above, but could include increasing the size or capacity of the facilities, and modifying the outlet structure to manage the discharge to meet the hydromodification standard for flow duration control.

Design Issues

Issues that must be addressed in developing the initial design concepts for hydromodification control facilities include the following:

Capacity and Costs of Hydromodification Facilities. The capacity of the hydromodification basin (or equivalent storage volume associated with alternative controls such as bioretention or green roofs) is dependent on the nature of the development and site conditions, especially the infiltrative capacity of the soils. Where soils are more infiltrative, the pre-project runoff is low and matching such runoff conditions requires a larger basin. On the other hand, infiltrative soils also allow for infiltrating excess runoff. Basin size in terms of capacity and area are concerns for the land developer who may need to dedicate additional land for a hydromodification facility. This additional cost may be reduced or even eliminated if, instead of an end-of-pipe basin, low impact development type alternatives (e.g., utilizing existing landscaped areas) are feasible.

Basin Water Balance. A key design issue is how to best manage water in the basin. Water in a flow duration basin can be released through an outlet and, depending on soils and vegetation, infiltrated and evapo-transpired. Discharge via an outlet must be such as to match pre-project flow duration and at a rate that will not contribute to additional erosive flows in the stream.

Infiltration Conditions and Constraints. A key design issue in the Santa Clara Valley is whether soil and groundwater conditions are conducive for infiltration and if so, whether infiltration can be accomplished without adversely affecting groundwater quality. The C.3 provisions call for caution with regard to groundwater quality impacts. In some cases where the tributary area is considered a significant source of pollutants (e.g., heavy industrial site), pre-treatment or lining the flow duration basin may be required. Infiltrative soils also may clog over time, requiring removal of fine sediment.

Potential Impacts from Infiltration on Slope and/or Foundation Stability. Infiltration near the foundation of buildings can cause uneven settlement, and infiltration near steep slopes can cause or contribute to slope failures. Infiltration near buildings may be feasible through the utilization of designs that isolate the infiltrating area from the foundation and maintaining a 2% slope away from the building.

Mosquito Concerns. Drain times of 3 days and less are recommended to prevent mosquito production. However, recent communication with the Santa Clara County Vector Control District and the RWQCB indicates that infrequent events that cause drain times of up to 5 days would be acceptable. Most of the time when the basin exceeds the 3-day drain time is in the winter when temperatures are cold and mosquito production is reduced. Also, the exceedence occurs only when the basin is full, which is caused by large infrequent storm events.

Vegetation Choices for BMPs that Incorporate Vegetation. Vegetation type can enhance the performance of a basin by increasing evapotranspiration losses. Deep-rooted vegetation also can enhance infiltration. Where vegetation is desirable, a water balance analysis is necessary to ensure that there is adequate water to support the vegetation during dry periods. Vegetation must also be able to tolerate water inundation for up to 3 days.

Safety Considerations. Basin depths and side slopes can be a concern for public safety. Chain link fencing may be required for basin with large depths and steep side slopes. Moderate side

slopes and safety benches also can be employed to avoid the use of fencing. If the basin is to be part of a multi-purpose facility, consideration must be given to public safety as well as ease of use.

Flow Duration Control. Any facility that can retain and infiltrate runoff from impervious surfaces could be considered hydromodification control. However, the last facility in the train of controls must match the flow duration curve of the pre-project condition in order for the controls to be protective of streams and minimize erosion and channel adjustment. For example, infiltration swales along roadsides or between houses can reduce the runoff volume from the development, but measures must be taken to match the pre-project flow duration curve before final discharge to the drainage system.

Outlet Operation and Clogging. To discharge at flow rates necessary to match flow duration curves, or to discharge at Q_c , small orifice diameters may be required. These small openings will be subject to clogging if not properly protected. Basin designs must include features to help prevent clogging, such as screens, filter fabric and gravel barriers. This is particularly true for small developments where flow rates are small and less true for larger basins (such as regional basins). Outlet weir designs may also be considered.

Cost for On-Site Measures

Estimated costs for on-site measures include design, material, construction, maintenance, and land costs. Local conditions such as available head, soils, depth to groundwater, and slope can greatly affect costs. In urban areas, clearances and tie-ins to existing infrastructure also can lead to design changes and increased costs. Estimated construction and maintenance costs for on-site and treatment measures are summarized in Chapter III of the C.3. Stormwater Handbook as part of the selection matrices for choosing site design and treatment control measures (Attachment III-2).

Figures 6-1 and 6-2 show the construction cost curves for a surface basin (such as a flow duration basin) and a sub-surface facility (such as a bioswale/infiltration trench), respectively. These curves were derived from detailed cost spreadsheets, including such elements as site preparation, earthwork, structures, piping, re-vegetation and so forth. Costs do not include soil disposal fees, hauling, or contaminated soil testing, mitigation, or disposal. In addition, land costs have been excluded from this analysis. These are applied to the example problem in Section 6.3.

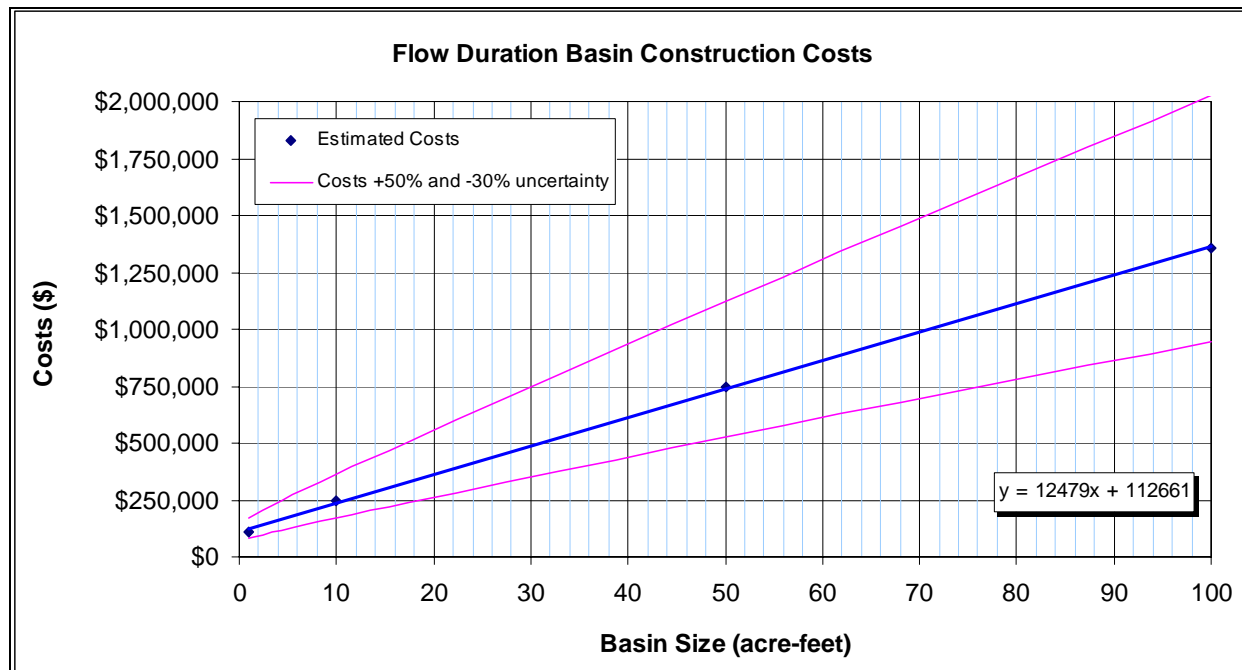


Figure 6-1 Estimated Cost for Surface Basin

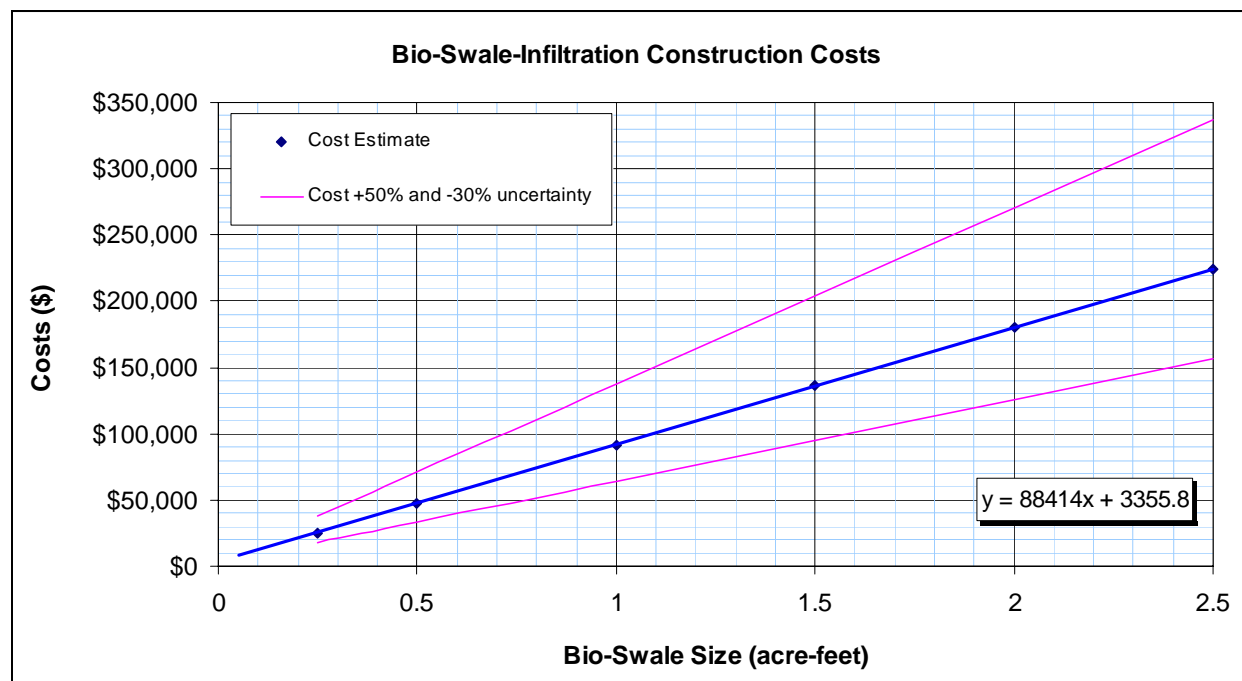


Figure 6-2 Estimated Costs for Sub-Surface Facility

6.2 HYDROMODIFICATION CONTROL DESIGN GUIDANCE

In Section 6.1, several types of hydromodification control measures were discussed, including site design techniques (hydrologic source control), use of treatment controls to achieve reductions in runoff volume, and flow control structures such as flow duration basins. Guidance on the sizing and design of site design and treatment measures is provided in several existing references: the C.3. Stormwater Handbook (SCVURPPP, 2004); “Start at the Source” (BASMAA, 1999); “Using Site Design Techniques to Meet Development Standards for Stormwater Quality” (BASMAA, 2003); and the California Stormwater Best Management Practice Handbooks, New and Redevelopment (CASQA, 2003). As a result, this section of the report focuses on the design of flow control structures. This report does not cover design of regional facilities (other than flow duration basins) or design of in-stream modifications to mitigate hydromodification effects.

Hydromodification control facilities are detention/retention and infiltration facilities engineered to meet a specified discharge performance. These facilities can be described as detention facilities, retention facilities, and infiltration facilities, or retention/detention (R/D) facilities. A detention facility temporarily stores surface water runoff and discharges it at a reduced rate. A retention facility retains stormwater and effectively has no outflow (outflow occurs by evaporation or soaking into the ground). Infiltration facilities are retention facilities that rely on the infiltration to soak water into the ground.

Any facility that can retain and infiltrate runoff from impervious surfaces could be considered hydromodification control. However, if the goal is to achieve hydromodification control on-site, the last facility in the “train” of controls must match the flow duration curve of the pre-project condition in order for the controls to be protective of streams. For example, vegetated swales along roadsides or between houses can reduce the runoff volume from the development, but additional measures must be taken to match the pre-project flow duration curve before final discharge to the stream system.

There are three primary types of detention facilities: basins, tanks, and vaults. Detention basins are built above ground; tanks and vaults are below-ground structures. Outlet control structures are used for controlling outflow from the facility to meet the desired discharge performance (flow duration control). In general, basins are preferred because of the relative ease of maintenance and the water quality treatment that surface soil and vegetation provide. Commonly R/D basins take the form of parks, athletic fields, duck ponds, golf courses, and other multi-purpose areas.

Infiltration facilities may be used where soils have suitable infiltration rates² for disposing of the increased runoff from development. Such facilities usually have a detention volume component to allow for temporary storage of runoff while it is being infiltrated. The detention volume is typically dependent on the infiltration capacity of the soils and the required facility performance. Infiltration facilities should be designed to protect ground water quality (see SCVURPPP C.3. Stormwater Handbook, Chapter III, and SCVWD design guidance).

² In the flow duration basin sizing examples in Section 6.3 and TMs #6, 7, and 8 (Appendix C), infiltration of stormwater from the basin was determined to be feasible for infiltration rates of 0.1 in/hour and greater.

Flow Duration Basin Design

The flow duration control approach involves: 1) simulating the runoff from the project site, pre- and post-project, using a continuous rainfall record; 2) generating flow-duration curves from the results; and 3) designing a flow control facility such that when the post-project time series of runoff is routed through the facility, the discharge pattern matches the pre-project flow-duration curve. The flow control facility is a detention basin that diverts and retains a certain portion of the runoff. The portion to be retained is essentially the increase in surface runoff volume created between the pre-project and post-project condition. This captured increase in volume must be discharged to the ground via infiltration (and/or evapotranspiration if vegetation present) in the basin, released at a very low rate to the receiving stream (at the critical flow for basin design, Q_{cp} , or 10% of the pre-project 2-year storm), and/or diverted to a safe discharge location or other infiltration site, if feasible.

As shown in Figure 6-3, the flow duration basin is designed to have two pools, a low flow pool (Zone A) and a high flow pool (Zone B). The low flow pool is designed to capture the difference in volume of runoff between the pre- and post-project conditions. It will also capture small to moderate size storms, the initial portions of larger storms, and dry weather flows. The high flow pool is designed to store and release higher flows to maintain, to the extent possible, the pre-project runoff conditions. The flow duration basin can also serve as a water quality treatment facility and can be designed to treat dry and wet weather flows using a combination of extended detention and natural treatment processes. Most dry weather “nuisance flows” will also infiltrate in the basin depending on the infiltration rate.

The flow duration basin is sized using an iterative process of adjusting basin storage as well as selecting and adjusting orifice sizes in the outlet structure. The low flow pool within the basin is initially sized to capture the increase in runoff volume that is generated from the development project. This capture volume is dependent on the development characteristics, the soil types, and the magnitude of increase in impervious surfaces. Previous analyses have shown that area requirements have less to do with the range of storms selected for management and more to do with site and development characteristics.

Once the lower pool is sized to capture the correct volume of runoff, the upper pool of the basin is sized to detain and discharge larger flows through an outlet structure in such a way as to reproduce the flow duration curve. Figure 6-4 illustrates an outlet structure consisting of a series of orifices at set elevations above the basin bottom. The number, diameter, and elevation of these orifices are determined by a trial and error approach (King County, 1998). The number, size and placement will vary from basin to basin depending on project conditions. The combination of sizing the lower portion of the basin and the upper portion to detain and discharge high flows has the affect of capturing the correct volume of runoff and matching the pre-project distribution of hourly flows. A weir and orifice combination could also be designed to accomplish the same level of control.

Separate flow duration and infiltration basins may be needed for water quality reasons, or a bypass pipeline could carry the excess runoff to a safe discharge location, if feasible. Combining flow duration and treatment into a single facility reduces the overall land requirements for stormwater management.

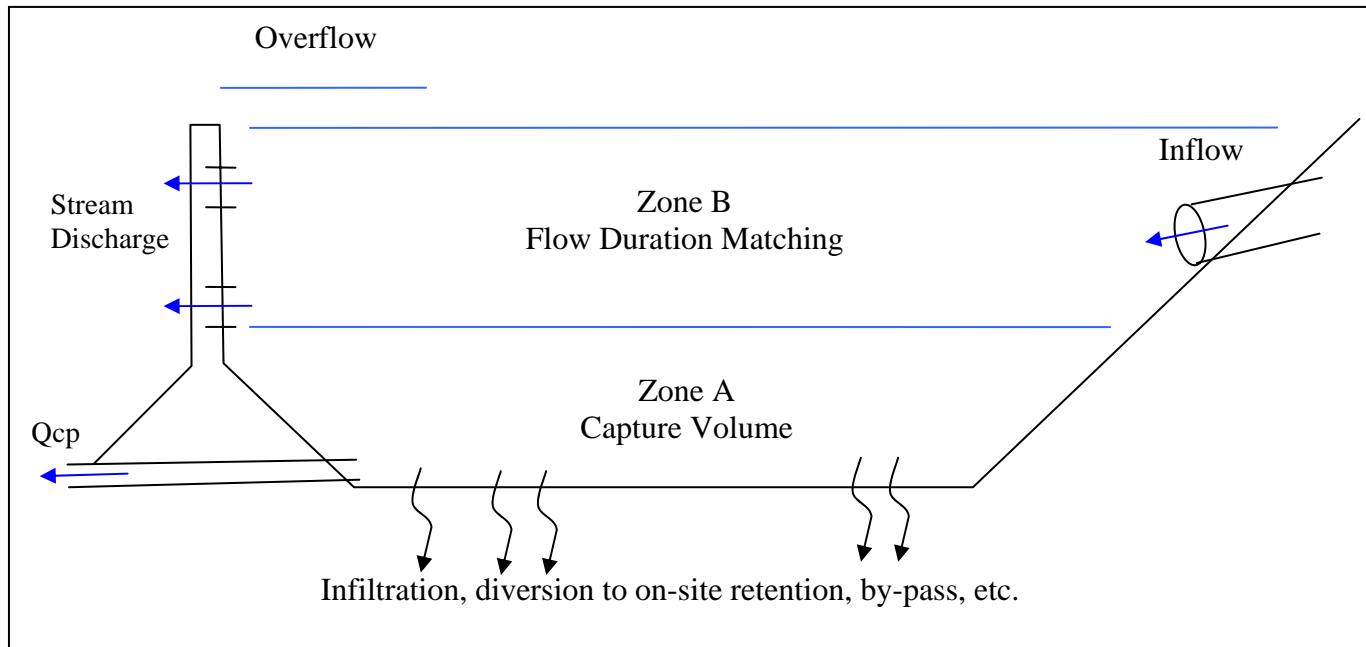


Figure 6-3
Generalized Configuration of Flow Duration Basin

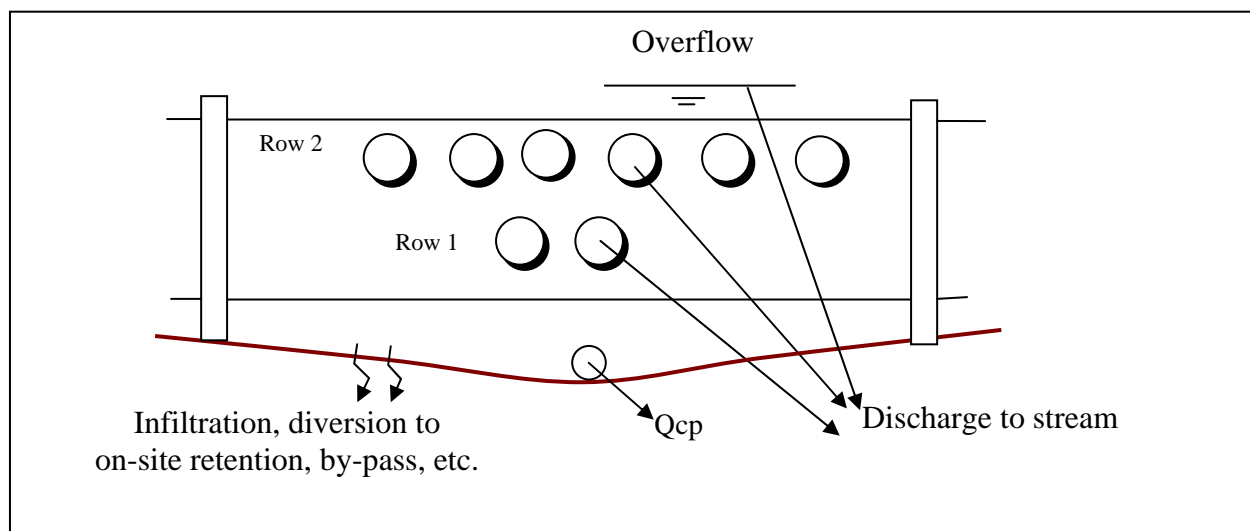


Figure 6-4
Generalized Configuration of Orifice-Type Outlet Structure

6.3 Examples of Application of Hydromodification Control Standard to Several Case Studies

The flow duration control design concept has been applied to several development scenarios in Santa Clara County and in Alameda County. The results are summarized in this section. Flow duration control has been used in western Washington as a hydromodification control measure for several years. Flow duration basin designs have also been used recently in Orange County, California.

Thompson Creek Large Site Example

This section summarizes the flow duration basin sizing results for an example development in the Thompson Creek subwatershed. This example sizes flow duration controls for an existing 716-acre residential development between Yerba Buena Creek and upper Thompson Creek, as if HMP controls were required when the project was constructed. This developed area is 71% impervious. Existing land uses are predominantly single-family residents, streets, parks and golf course properties. The infiltration rate for soils at the basin site is 0.2 inches/hour and the critical flow for the basin (Q_{cp}) is 2.4 cfs (10% of the pre-project 2-year peak flow).

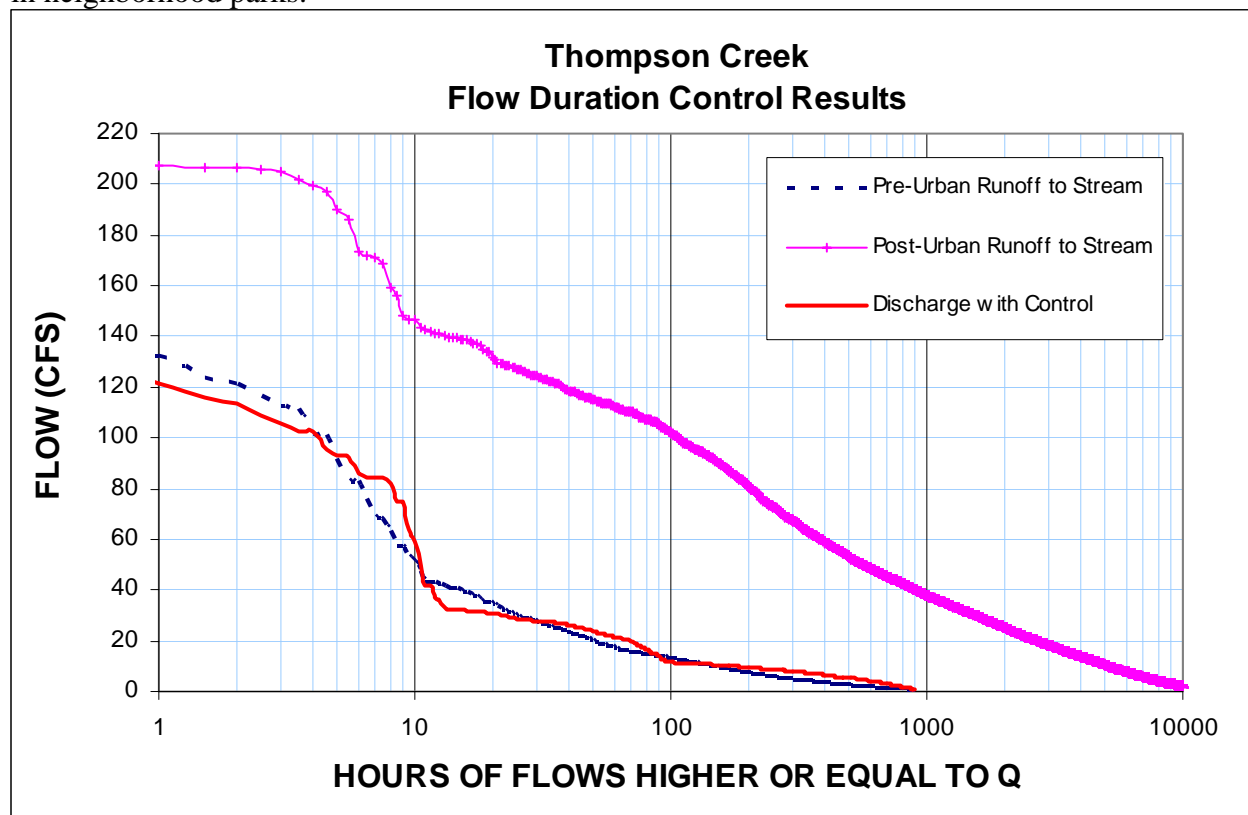
Figure 6-5 presents the pre-project flow duration curve, post-project (future) curve and post-project curve with controls at the site outlet point, using the 50-year continuous simulation results from the Thompson Creek hydrologic model. The post-project curve illustrates that the effect of development is to increase the duration of flows; that is, the flow duration curve moves to the right, indicating that both volume and duration of flows increase. (Note the logarithmic scale on the horizontal axis, so small changes along the axis may indicate large changes in volume and duration.) The effect of the flow control BMP is to reduce the durations to closely replicate the pre-project condition. This means that the magnitude of hourly runoff and the number of hours (duration) that flows occur at those magnitudes are nearly the same between pre- and post-project conditions.

For the 716 acres of development, the resulting basin characteristics are as follows:

- Basin volume is 120 acre-feet.
- Basin surface area is 15 acres (2% of the catchment area), assuming a maximum basin depth of 10-feet and 3:1 side slopes, and $Q_{cp} = 0$ cfs
- If the basin depth were limited to 6 feet and $Q_{cp} = 2.4$ cfs, the required surface area would be 20 acres, or 2.8% of the drainage area.
- If the basin depth were limited to 4 feet and $Q_{cp} = 2.4$ cfs, the required surface area would be 30 acres, or 4% of the drainage area.
- Fifteen orifices having diameters of 9-inches each discharge to the creek.

For simplicity, this example assumes that no individual lot on-site control measures or low impact site design techniques were used. These options would be strongly encouraged if an actual project like this was implementing HMP requirements, and would result in a smaller flow control basin. In addition, in a large development area like this, the required flow control basin

volume would be divided into a number of smaller basins distributed throughout the area, such as in neighborhood parks.



**Figure 6-5
 Flow Duration Curves for Thompson Creek Example**

When comparing the pre-project curve to the post-project with BMP curve, the results shown in Figure 6-5 would be considered a very good match. Design of flow duration basins is somewhat of a trial and error process, and some design configurations match pre-project curves better than others. Western Washington hydromodification control standards allow no more than a 10% deviation between the curves over no more than 10% of the curves' length, or range of flows (WDOE, 2001). Appendix F provides more guidance on flow duration curve matching.

The shape of the post-project with BMP curve is dependent on the type of outlet structure. In this case, orifice holes in a headwall are used, following Western Washington's guidelines. Orifice holes create the convex shaped sections of the curve, where each section represents the change in flows from adding the next row of orifice holes. In the example in Figure 6-5, there are three convex curve sections between zero and 51 cfs. Above 51 cfs, flows are spilling over the overflow structure.

A summary of the results of this analysis for the Thompson Creek development is presented in Table 6-1. The table lists the results for a variety of conditions varying allowable depth, the soil infiltration rate and the rate of Q_{cp} . Basin size is reported as a function of the total catchment

area (project drainage area) and the total directly connected impervious surface area (DCIA). The infiltration rate is also expressed as a loss rate (cfs) to compare to Qcp and to evaluate the importance of Qcp and infiltration in basin sizing.

As would be expected, the basin area requirements are controlled by the depth limitation imposed on the design. Shallower allowable depths require more surface area to contain the right storage volume. The ability to discharge the runoff volume to be controlled (infiltrated and/or discharged at Qcp) also affects the resulting basin size.

**Table 6-1
Summary of Basin Sizing Results for Thompson Creek Large Site (716 Acres) Example**

	10-foot Maximum Depth	6-foot Maximum Depth	6-foot Maximum Depth	4-foot Maximum Depth
Basin Size in Acres	15 acres	20 acres	25 acres	30 acres
Basin Size as % of Catchment Area	2%	2.8%	3.4%	4%
Basin Size as % of DCIA (1)	2.8%	3.9%	4.8%	5.7%
Drain time (2)	Not available at this time	3 days 80% of the time	3 days 75% of the time	3 days 90% of the time
Qcp	0	2.4 cfs	2.4 cfs	2.4 cfs
Infiltration Rate (Loss rate through wetted bottom)	0.2 in/hr (2.7 cfs)	0.2 in/hr (4.0 cfs)	0.1 in/hr (2.5 cfs)	0.2 in/hr (5.5 cfs)

- Notes: 1. DCIA = Directly Connected Impervious Area
2. Goal for drain time is 3 days, to minimize mosquito production. Regional Board staff and Vector Control District staff have indicated that 5 days' drain time is acceptable, given the type of mosquito prevalent in Santa Clara County and that mosquito production rates drop during cold winter weather.

Cost Results for Thompson Example. Table 6-1 above presented the construction cost curves for a surface basin infiltration facility. This curve was derived from detailed cost spreadsheets, including such elements as site preparation, earthwork, structures, piping, re-vegetation and so forth. Costs do not include soil disposal fees, hauling, or contaminated soil testing, mitigation, or disposal. Land costs are not included. The cost estimates presented in this section represent a planning level cost estimate with an accuracy of + 50% to -30%. The Thompson Creek example construction costs are estimated to be approximately \$1.6 million for the basin itself not including design, environmental documents, or land costs. The \$1.6 million construction cost is equivalent to \$2,300 per acre of development area. Assuming 4 houses per acre in this location, the flow duration basin construction would cost approximately \$600 per lot, excluding land costs.

San Jose Small Site Example

This section summarizes the application of the flow duration basin sizing technique to a small 12-lot residential subdivision in San Jose. The site is located near Alum Rock, has a moderate slope, and discharges to South Babb Creek through the storm drain system. The objective was to apply the flow duration control strategy to a small project and determine how well this approach would work on a small scale.

Project Description. The catchment area is 3.6 acres, with twelve residential lots of 3,000 square feet each. Run-on from the adjacent hill slopes is assumed to be zero. According to the City of San Jose, a ditch will be constructed along the upper boundary of the property to collect hill slope runoff and route it around the development to the storm drain system.

The pre-project and post-project percent imperviousness are estimated to be 9 and 45 percent, respectively. The post-project impervious surface includes paved roads and the driveways, patios and roofs of the 12 houses.

The soil type in this area is classified as “D” type soils using the SCS classification system. The infiltration rates for this soil type range from 0.06 to 0.20 in/hr. For hydrologic modeling purposes, an average infiltration rate of 0.13 in/hr was used over the project site. An infiltration rate of 0.20 in/hr was assumed for the basin location.

Results. Table 6-2 summarizes the results of the small project example. The resulting basin area requirements range from 1.3% to 2.1% of the total project area (3.6 acres), or 2.8% and 4.6% of the directly connected impervious area (45% imperviousness). For comparison, a water quality basin would be about 2% of the total project area (the facilities could be combined). Basin depths range from 1.75 feet to 2.25 feet. During the sizing procedure, basin depth was limited to a maximum of 3 feet. Because the scale of this project is small, the resulting flows, basin sizes, and orifice sizes are all small. Orifice sizes are 3 inches in diameter.

**Table 6-2
Summary of Basin Sizing Results for San Jose Small Site (3.6 Acres) Example**

Parameter	Discharge of extra volume at infiltration rate only	Discharge of extra volume at infiltration rate plus Qcp	Basin size with Roofs Disconnected
Basin Size -- % catchment area	2.1%	1.7%	1.3%
Basin Size -- % DCIA (1)	4.6%	3.7%	2.8%
Basin Depth	1.75 ft	2.25 ft	2.5 ft
Drain time (2)	3.7 days	<1 day	3.6 days
Qcp	0	0.1 cfs	0
Infiltration Rate (Loss rate through wetted bottom)	0.2 in/hr (0.015 cfs)	0.2 in/hr (0.012 cfs)	0.2 in/hr (0.009 cfs)

- Notes:
1. DCIA = Directly Connected Impervious Area
 2. Goal for drain time is 3 days, to minimize mosquito production. Regional Board staff and Vector Control District staff have indicated that 5 days’ drain time is acceptable, given the type of mosquito prevalent in Santa Clara County and that mosquito production rates drop during cold winter weather.

Figure 6-6 presents the pre-project flow duration curve and post-project curves under two scenarios: 1) with no individual lot BMPs and 2) with each lot assumed to have runoff controls. Each lot is assumed to have its roof and patios disconnected from the storm drain system and runoff from those areas controlled with a bioswale/infiltration trench or similar BMP designed to maintain pre-project runoff conditions on the lot. The figure shows that, with the individual lot BMPs, there is a much smaller difference between pre- and post- flow duration curves. The resulting flow duration basin area and volume are 62% and 77% smaller, respectively, than when the basin sized to collect both roof runoff and pavement runoff.

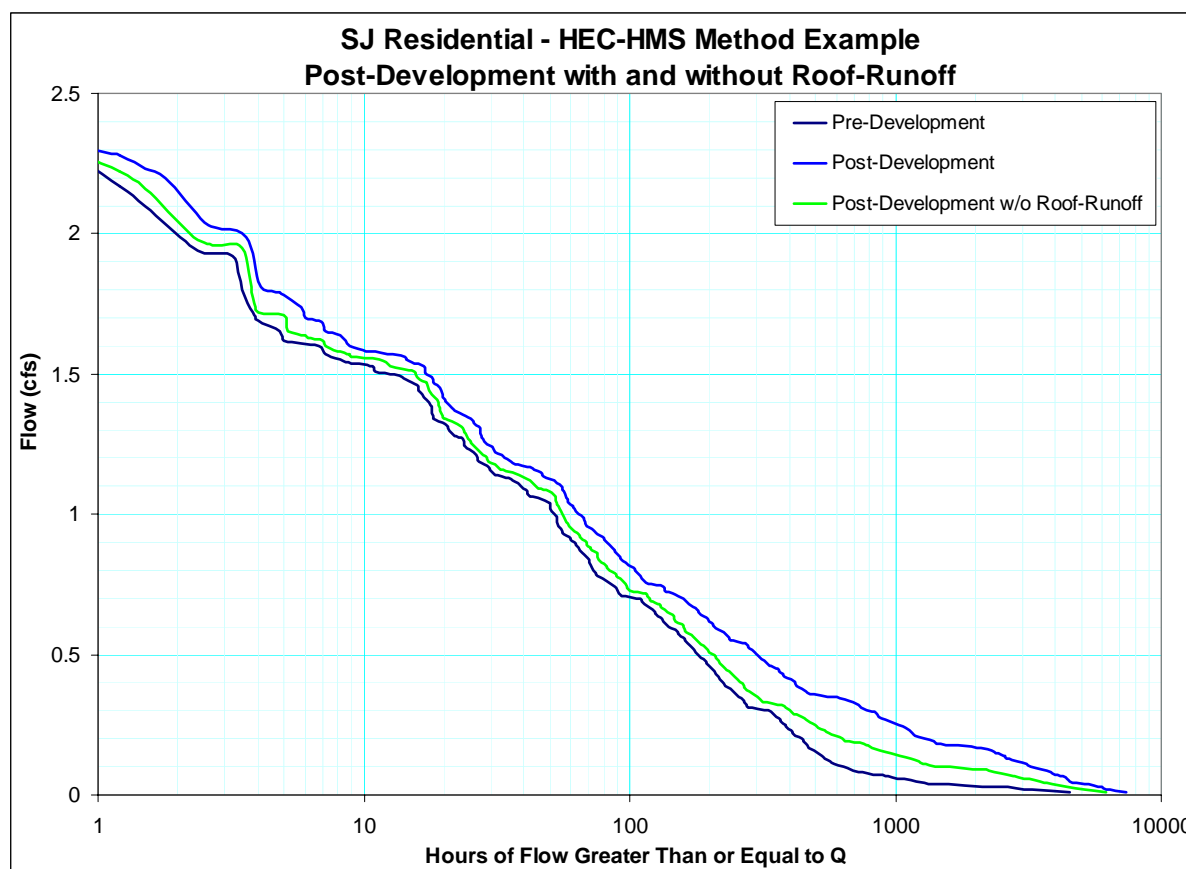


Figure 6-6
Post-Project Flow Duration Curves with and without Roof Runoff for
San Jose Residential Example

The flow duration basin sizing was re-computed after adding an allowable discharge equal to a Q_{cp} value of 0.10 cfs. Q_{cp} is computed as 10% of the 2-year pre-project peak flow. The 2-year peak flow was determined by performing a flood frequency analysis of the HMS model results and was estimated to be 1.0 cfs. Figure 6-7 presents the resulting matched flow duration curves under this scenario.

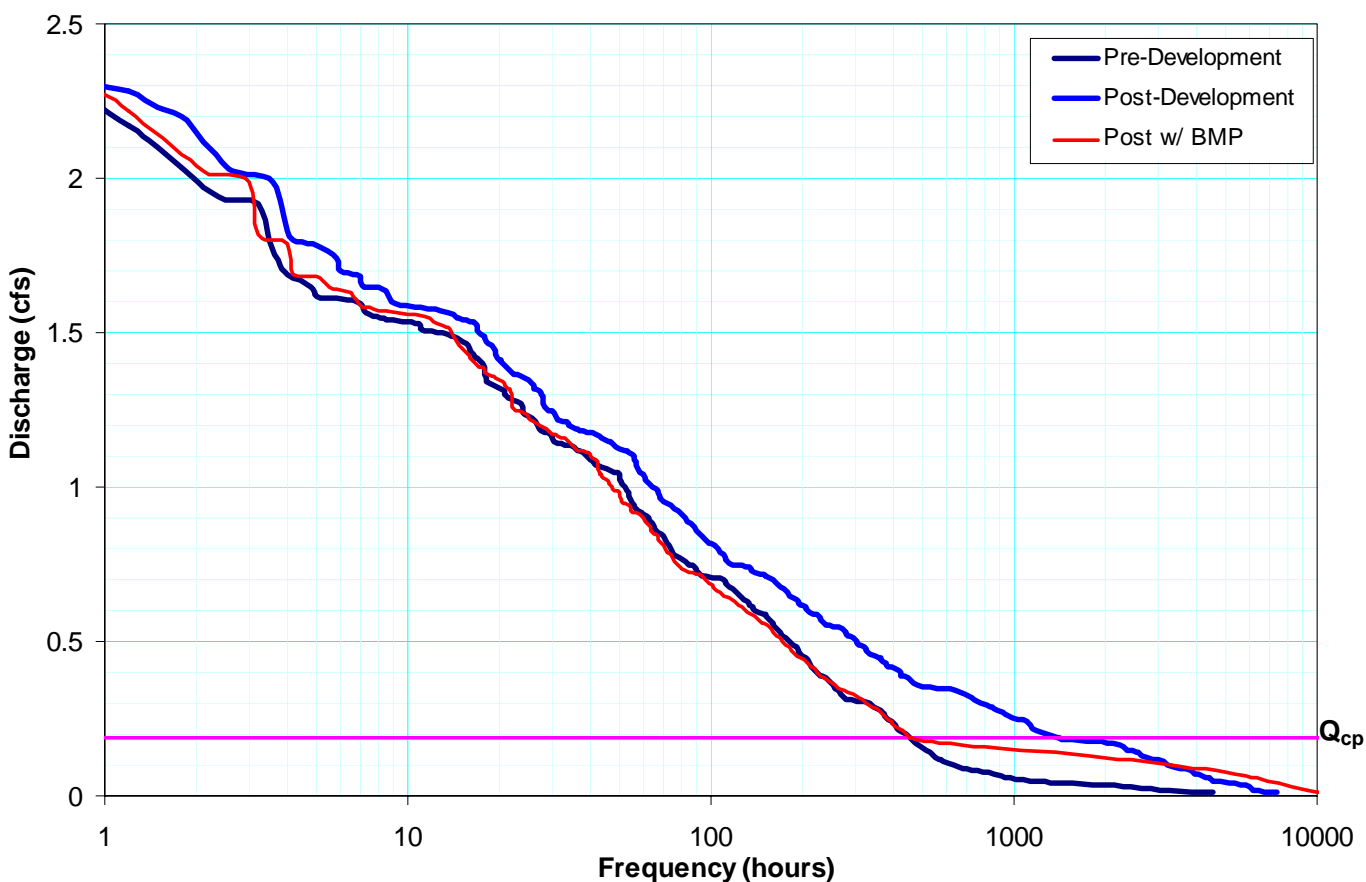


Figure 6-7
Post-Project Curve for San Jose Residential with Allowable Q_{cp}

Cost Results for San Jose Small Site Example. This curve was derived from detailed cost spreadsheets, including such elements as site preparation, earthwork, structures, piping, re-vegetation and so forth. Costs do not include soil disposal fee, hauling, or contaminated soil testing, mitigation, or disposal. Land costs are not included. The cost estimates presented in this section represent a planning level cost estimate with an accuracy of + 50% to -30%. The San Jose small site example construction costs are estimated to be approximately \$60,000 for the basin itself not including pipelines to the facility, design, environmental documents, or land costs. The \$60,000 construction cost is equivalent to \$5,000 per lot, excluding land costs.

Alameda County Commercial Example

This section summarizes the application of the flow duration basin sizing technique to a conceptual plan for a commercial development in Alameda County³. The objective was to apply the flow duration methodology to a small size project in Alameda typical of the developments expected in the future.

Project Description. This section summarizes relevant project information required for hydrologic modeling purposes.

- The catchment area is 12.2 acres. The pre-developed project site has zero impervious surface area and is covered with short grass with an average slope of 1.1 percent.
- The post-project percent imperviousness is estimated to be 67 percent. This includes building roofs, parking lots, paved roads, and sidewalks.
- The mean annual precipitation for the site is 22 inches. Precipitation records used in this continuous simulation analysis are from the NCDC gage ID# 040693 in Berkeley, covering the period from July 1, 1948 through January 1, 1991.
- The soil type in this area is classified as “B” type sandy loam soils using the SCS classification system. Infiltration rates for this soil type range from 0.5 to 1.0 in/hr. For hydrologic modeling purposes, an infiltration rate of 0.5 in/hr was used.

Results. Figure 6-8 presents the resulting matched flow duration curves. Under pre-project conditions, the model is only predicting 200 hours of flow due to the relatively high infiltration rate and flat slope. However under post-project conditions, more than 10,000 hours of runoff now occurs. The figure also shows the post-project flow duration curve with the BMP (flow duration basin). The pre-project flow duration curve is matched beginning from Q_c up to about 4 cfs and 10 hours. At this point the curve deviates from the pre-project curve, which is acceptable in this case because it is less than the pre-project curve. The reason it deviates is because the basin storage is large relative to runoff affecting peak discharges estimated by the continuous model and basin overflows. The post-project flow duration curve has an increase in the hours of flows below the Q_c . This is, of course, the allowable low flow discharge.

Table 6-3 presents the resulting flow duration basin size information, compared to a water quality basin sized using the CA BMP Handbook Method. This comparison is provided to give the reader perspective on the resulting flow duration basin sizes. In this case, with good pre-project soil infiltration capacity (0.5 in/hr) the required flow duration basin storage is 1.6 acre-feet, or 7% of the project area. The water quality basin is about 3% of the total project area. The continuous simulation model results suggest that the increase in surface runoff volume between class “D” soils (typically 0.06-0.2 in/hr infiltration rate) and impervious surfaces is smaller than the same comparison between class “B” soils (0.5-1.0 in/hr infiltration rate) and impervious surfaces. In the current example, the flow duration basin ends up large because of the large increase in runoff volume between the pre- and post-project conditions.

³ ACCWP Technical Memorandum #1, GeoSyntec Consultants, May 25, 2004. SCVURPPP acknowledges the Alameda Countywide Clean Water Program for the use of this example.

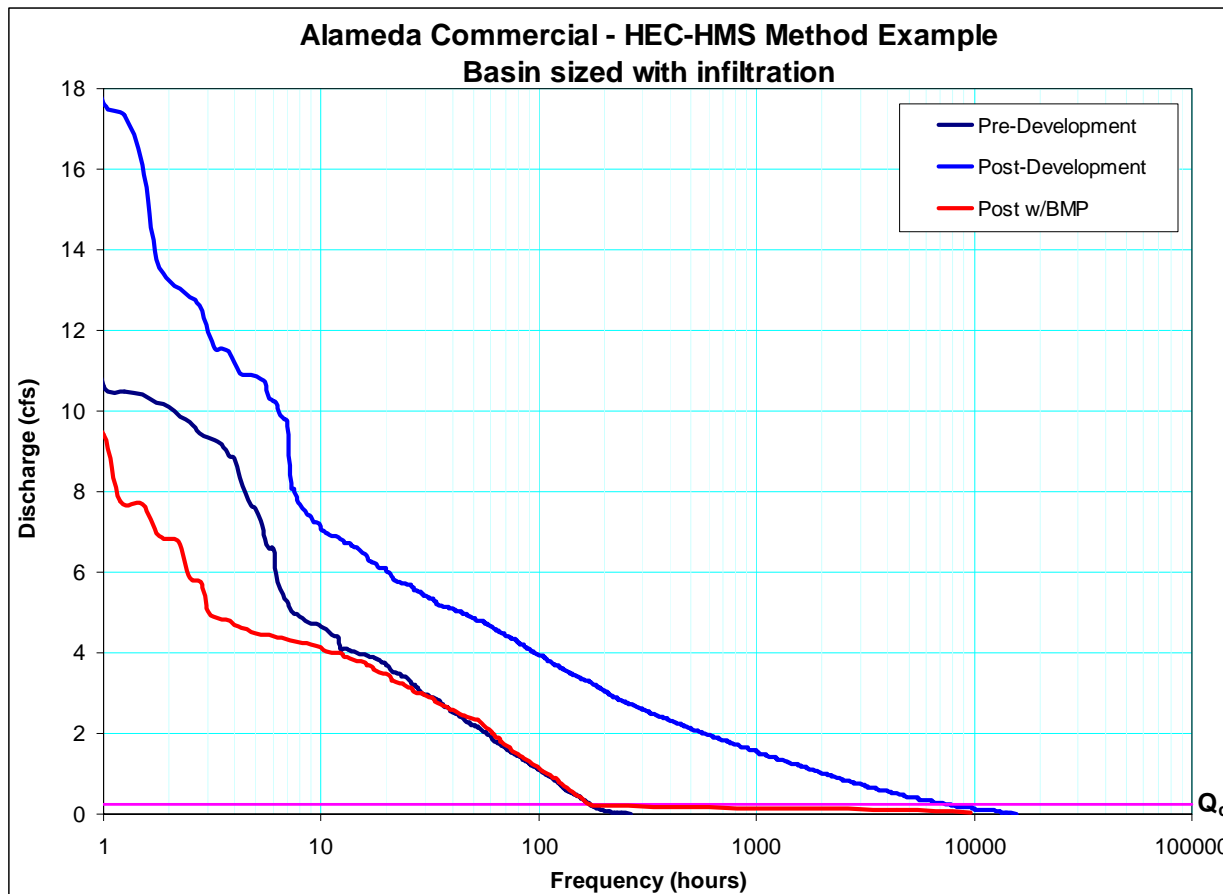


Figure 6-8
 Basin Sized with Infiltration for Alameda Commercial Development Example

Table 6-3
 Comparison of Basin Sizing for Alameda County Commercial Example

	GeoSyntec Analysis Based On Flow Duration Control (assumes infiltration and low flow release at Q_{cp})	Water Quality Basin using CA BMP Handbook Method
Basin Volume	1.6 acre-ft	0.7 acre-ft
Basin Depth	2 ft	2 ft
Basin Area	0.8 acres	0.36 acres
Basin Area (% of site)	7%	3%
Drain time	1 day	2 days
Qcp	0.25 cfs	N/A

The outlet structure for the flow duration basin was assumed to consist of a concrete or steel headwall with small diameter holes drilled into the wall. While the basin size is controlled by the runoff volume change between pre- and post-project conditions, the flow duration curve matching is primarily accomplished through design of the headwall structure. Because the scale of this project is relatively small, the resulting flows, basin sizes, and orifice sizes are all small. The orifice size to release the Q_{cp} flow is less than 3 inches in diameter. Adequate protection from clogging using screens and gravel will be required. A multi-stage weir could be used, but would also require small openings subject to clogging.

Cost Results for Alameda Commercial Example. This curve was derived from detailed cost spreadsheets, including such elements as site preparation, earthwork, structures, piping, re-vegetation and so forth. Costs do not include soil disposal fee, hauling, or contaminated soil testing, mitigation, or disposal. Land costs are not included. The cost estimates presented in this section represent a planning level cost estimate with an accuracy of + 50% to -30%. The Alameda commercial example construction costs were estimated to be approximately \$115,000 for the basin, not including, design, environmental documents, or land costs.

Discussion of the Application of Q_{cp}

The importance of Q_{cp} appears to vary depending on the area of the basin and the soil infiltration rates. In the flow duration basin examples for Thompson Creek (Table 5-1), increasing Q_{cp} from zero to 2.4 cfs had a limited effect on basin design because the drainage area to the basin and the basin size were so large. Q_{cp} is more important when sizing small flow duration basins like the ones sized for the small development examples. Because Q_{cp} and infiltration are the primary means of discharge from the basin for the extra volume of runoff caused by the impervious surfaces, their relative values are important in determining which is the controlling factor for basin size.

For large basins like the one in Thompson Creek, the surface area is large (29 acres) and thus the infiltration loss rate ($I_f * \text{area} = 5.5$ cfs) is also large. When compared to the Q_{cp} rate of 2.4 cfs (10% of the pre-project 2-year peak flow of 24 cfs), the infiltration loss rate is twice as important and Q_{cp} has little affect on basin size. For small basins, the area is small (0.06 acres) and the infiltration loss rate ($I_f * \text{area} = 0.01$ cfs) is also small. The estimated Q_{cp} for this small basin is 0.10 cfs and much more important for basin sizing.

Conclusions

The flow duration basin sizing approach can be applied to development sites of different sizes and land use types. The area required for flow duration basins seems to be between 2 to 7 percent of the contributing catchment area, depending on the infiltration capacity of the soil and the basin depth. Where projects have good soil infiltration rates and utilize low-impact development strategies, less land area may be required (1.5 to 2 percent).

Basin size can be reduced by applying volume reduction or low impact design strategies. For example, disconnecting impervious area such as roof drains and discharging runoff to landscaping, swales and/or infiltration trenches reduces the difference in volume between pre- and post-project runoff that need to be controlled in the basin.

Qcp should be incorporated in every basin design but its relative impact on basin sizing is dependent on project size and soil infiltration rates. The Qcp rates for small basins may require small orifice diameters as small as 2 inches.