# The Bay Area Hydrology Model – A Tool for Analyzing Hydromodification Effects of Development Projects and Sizing Solutions

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**Abstract**

The California Regional Water Quality Control Board, San Francisco Bay Region, is requiring stormwater programs to address the increases in stormwater runoff rate, volume, and duration created by new and redevelopment projects, known as hydromodification, where those increases could cause erosion of receiving streams. Municipal stormwater discharge permits in the San Francisco Bay area contain a requirement for stormwater programs to develop Hydromodification Management Plans (HMPs) that describe how each program's agencies will meet this requirement.

The hydromodification control standard established in municipal permits is that post-project runoff shall not exceed pre-project rates and/or durations, over a defined range of storm event sizes. Research has shown that, to develop effective measures for control of changes in flow duration, the changes in a project site's hydrology cannot be evaluated for a single storm event with traditional design storm approaches. The change in hydrology must be evaluated over a longer time frame using a continuous simulation hydrologic model, and the results used to size control measures to match pre-project flow duration patterns. These analysis methods require specialized expertise and are difficult for many developers' engineers to perform and for municipal staff to review.

During development of their HMPs, three stormwater programs in the southern San Francisco Bay area, the Santa Clara Valley Urban Runoff Pollution Prevention Program, the Alameda Countywide Clean Water Program, and the San Mateo Countywide Storm Water Pollution Prevention Program, recognized this problem and decided to jointly fund development of a tool to simplify the analysis of hydromodification effects and to help design flow control measures. The tool, known as the Bay Area Hydrology Model (BAHM), is a Bay area version of the Western Washington Hydrology Model developed by Clear Creek Solutions for the Washington State Department of Ecology. It consists of a user-friendly graphical interface through which the user inputs information about the project and desired control measure (e.g., detention basin or underground vault); an engine that automatically loads appropriate parameters and meteorological data and runs the continuous simulation model HSPF to generate flow duration curves; a module that sizes the control measure to achieve the hydromodification control standard; and a reporting module. The tool uses parameters that have been calibrated for two watersheds in Alameda County, and is in the process of being calibrated for two watersheds in Santa Clara County.

This paper describes the background and need for the BAHM, development of the BAHM and appropriate parameters for the southern Bay Area, and examples of the application of the tool to size hydromodification control facilities for two development projects.

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## Introduction

Urbanization of a watershed modifies natural watershed and stream processes by altering the terrain, modifying the vegetation and soil characteristics, introducing pavement and buildings, installing drainage and flood control infrastructure, and altering the condition of stream channels through straightening, deepening, and armoring. These changes affect hydrologic characteristics in the watershed (rainfall interception, infiltration, runoff and stream flows), and affect the supply and transport of sediment in the stream system. The change in runoff characteristics from a watershed caused by changes in land use conditions is called hydrograph modification, or simply hydromodification.

As the total area of impervious surfaces increases in previously undeveloped areas, infiltration of rainfall decreases, causing more water to run off the surface as overland flow at a faster rate. Storms that previously didn't produce runoff under rural conditions can produce erosive flows. The increase in the volume of runoff and the length of time that erosive flows occur ultimately intensify sediment transport, causing changes in sediment transport characteristics and the hydraulic geometry (width, depth, slope) of channels. The larger runoff durations and volumes and the intensified erosion of streams can impair the beneficial uses of the stream channels.

The California Regional Water Quality Control Board (Water Board), San Francisco Bay Region, is requiring stormwater programs to address the increases in runoff rate and volume from new and redevelopment projects where those increases could cause increased erosion of receiving streams. The Phase 1 municipal stormwater permits in the Bay Area contain requirements to develop and implement hydromodification management plans (HMPs) and to implement associated management measures.

The first Bay Area permit to include the new requirements was that of the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP)[4]. SCVURPPP conducted an assessment of hydromodification impacts on streams tributary to South San Francisco Bay and developed an HMP Report[5] that describes how SCVURPPP agencies will meet this requirement. On July 20, 2005, the Water Board adopted key provisions of the HMP Report and required implementation of the provisions within three months.

Other Bay Area stormwater permits that contain the requirement to develop and implement HMPs include those of the Alameda County, San Mateo County, Contra Costa County, and Fairfield-Suisun area stormwater programs[6]. The Contra Costa HMP was adopted by the Water Board on July 12, 2006. The other stormwater programs have submitted final HMPs to the Water Board and are awaiting review and approval.

## Permit Requirements

Provision C.3.f. of the NPDES permit, *Limitation on Increase of Peak Stormwater Runoff Discharge Rates*, describes the HMP requirements. Under Provision C.3.f., municipalities are required to develop an HMP to describe how they plan to manage increases in the magnitude, volume, and duration of runoff from new development and significant redevelopment projects in order to protect streams from increased potential for erosion or other adverse impacts. The

[4] SCVURPPP consists of the thirteen cities of Santa Clara Valley, Santa Clara County, and the Santa Clara Valley Water District (SCVWD), all of which are Co-permittees on a joint NPDES permit to discharge stormwater to South San Francisco Bay.
[5] SCVURPPP, *Hydromodification Management Plan, Final Report*, April 2005 (www.scvurppp.org)
[6] These programs together comprise about 60 additional municipal or county co-permittees.

requirements apply to development projects that create and/or replace 1 acre or more of impervious surface area.

In implementing the HMP, runoff controls[7] must be designed so that "post-project runoff shall not exceed estimated pre-project rates, durations, and volumes from the development site" (Provision C.3.f.i). Runoff controls are not required for projects that discharge stormwater runoff where the potential for erosion, or other impacts to beneficial uses, is minimal. Such situations may include: discharges into creeks that are concrete-lined or significantly hardened (e.g., with rip-rap, sack concrete, etc.) downstream to their outfall in San Francisco Bay; underground storm drains discharging to the Bay; and construction of infill projects in highly developed watersheds, where the potential for single-project and/or cumulative impacts is minimal (Provision C.3.f.ii).

The permit also requires: completion of a literature review; development of a protocol to evaluate hydromodification impacts to downstream watercourses; identification of an appropriate limiting rainfall event or range of events; a description of how municipal agencies will incorporate the HMP requirements into local approval processes; and guidance on management practices.

**Technical Analysis of Hydromodification Controls**

SCVURPPP and its consultant team completed a number of technical analyses to address key issues for the HMP, such as the effectiveness of various flow control techniques, the range of storm events to be considered for HMP criteria, and examples of flow duration basin sizing for local projects[8]. The key findings of these analyses, which served as the basis for developing performance criteria for the HMP, are described below.

Effective Design Approaches

It has been previously demonstrated that control of peak flows alone is not adequate for erosion control (MacCrae, 1996). SCVURPPP's studies (GeoSyntec, 2004, TMs #5 and 7) showed that hydromodification controls designed for discrete event volume control or design storm hydrograph matching do not provide adequate protection of receiving streams. The recommended effective method for hydromodification control is *flow duration control*. This approach involves maintaining the magnitude and duration of post-project flows at the same level as the pre-project flows (i.e., matching the long term pattern of flow rates and the number of hours they occur) via a flow duration control structure, for the full distribution of flows within a significant range. The flow duration approach considers the entire multi-year discharge record, as opposed to a single event. Flow controls should be supplemented by site design measures that reduce the amount of post-project runoff generated at the site.

Range of Storms to Manage

An evaluation was performed of the range of flows that are the most important for stream channel erosion and hydromodification impacts in Santa Clara Valley (GeoSyntec, 2004, TM#4). The evaluation was based on watershed assessments conducted for three subwatersheds in the Valley. The lower limit of the range is based on the critical flow (Qc) in each stream reach that initiates erosion of the stream bed or bank. For all three subwatersheds, Qc could be approximated as 10% of the 2-year pre-development peak flow. To partition this allowable flow

[7] This document uses the term runoff controls or flow controls to refer to Best Management Practices (BMPs) that reduce impacts of runoff volume, rate, and duration. Runoff controls that remove pollutants from stormwater will be referred to as treatment controls.

[8] Technical memoranda describing these analyses are available in Appendix C of the HMP Report (www.scvurppp.org).

among contributing land areas, an on-site project design criteria of 10% of the pre-project 2-year peak flow was proposed as the allowable low flow from a flow control facility.

The upper limit on the range of storms was determined by evaluating the contribution of different flow magnitudes to the total amount of erosive "work"[9] done on the stream bed and banks over a period of time. The low flows contribute the most work over time, whereas high flows contribute less work because they occur less frequently. Approximately 90-95% of the total work on the channel boundary is done by flows between Qc and the pre-development 10-year peak flow magnitude. Flows greater than the 10-year peak flow contribute less than 10% of the total work. Thus, the 10-year pre-project peak flow was selected as the practical upper limit for controlling erosive flows.

**Hydromodification Management Performance Criteria and Design Approach**

As stated earlier, Permit Provision C.3.f. requires that post-project runoff shall not exceed pre-project rates and/or durations, where the increased rates and durations will result in increased potential for erosion in the receiving stream. All of the Bay Area stormwater program HMPs include performance and applicability criteria to meet this requirement. These criteria will be used by local agencies as part of the development plan review process to manage hydromodification impacts of development projects.

A common theme among the various HMPs is that applicable projects with on-site flow control facilities that are designed to provide flow duration control to the pre-project condition are considered to comply with the HMP. Currently, most of the HMPs contain the following performance criterion: *Flow duration controls shall be designed such that post-project stormwater discharge rates and durations match pre-project discharge rates and durations from 10% of the pre-project 2-year peak flow up to the pre-project 10-year peak flow.*[10]

On-site flow controls include site design techniques, treatment controls that have the added effect of reducing flow (normally via infiltration), and flow control structures. Examples of site design features (also known as low impact development (LID) techniques) include minimizing impervious surface areas, preserving natural areas, limiting development especially where native soils have good infiltration characteristics, directing roof runoff to bioretention areas, and using vegetated swales in lieu of traditional underground storm drains. Flow control structures are generally detention/retention basins or underground vaults or tanks fitted with outlet structures such as weirs and/or orifices to control outflow rate and duration. Flood control and water quality treatment facilities can be combined with flow control structures; for example, water quality detention basins and wet ponds can be modified to provide hydromodification control.

The basic approach for design of flow control structures to meet hydromodification requirements 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[11]. The flow control structure is a detention facility 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

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[9] "Work" is a measure of the erosive hydraulic forces on the stream segment in excess of what the stream bed and bank materials can withstand (critical shear stress) before sediment movement occurs.

[10] The matching criterion is as follows: the post-project flow duration curve may not deviate above the pre-project flow duration curve by more than 10% over more than 10% of the length of the curve.

[11] See SCVURPPP, *Hydromodification Management Plan, Final Report*, April 2005, Appendix F (www.scvurppp.org) for more detailed guidance on how to design facilities for flow duration control.

post-project condition. This captured increase in volume must be discharged in one of several ways: 1) to the ground via infiltration (and/or evapotranspiration if vegetation is present) in the basin; 2) released at a very low rate to the receiving stream (at the critical flow for basin design, or 10% of the pre-project 2-year storm); and/or 3) diverted to a safe discharge location or other infiltration site, if feasible. Figure 1 shows a schematic pond facility in which the outlet structure is a standpipe riser with various openings.

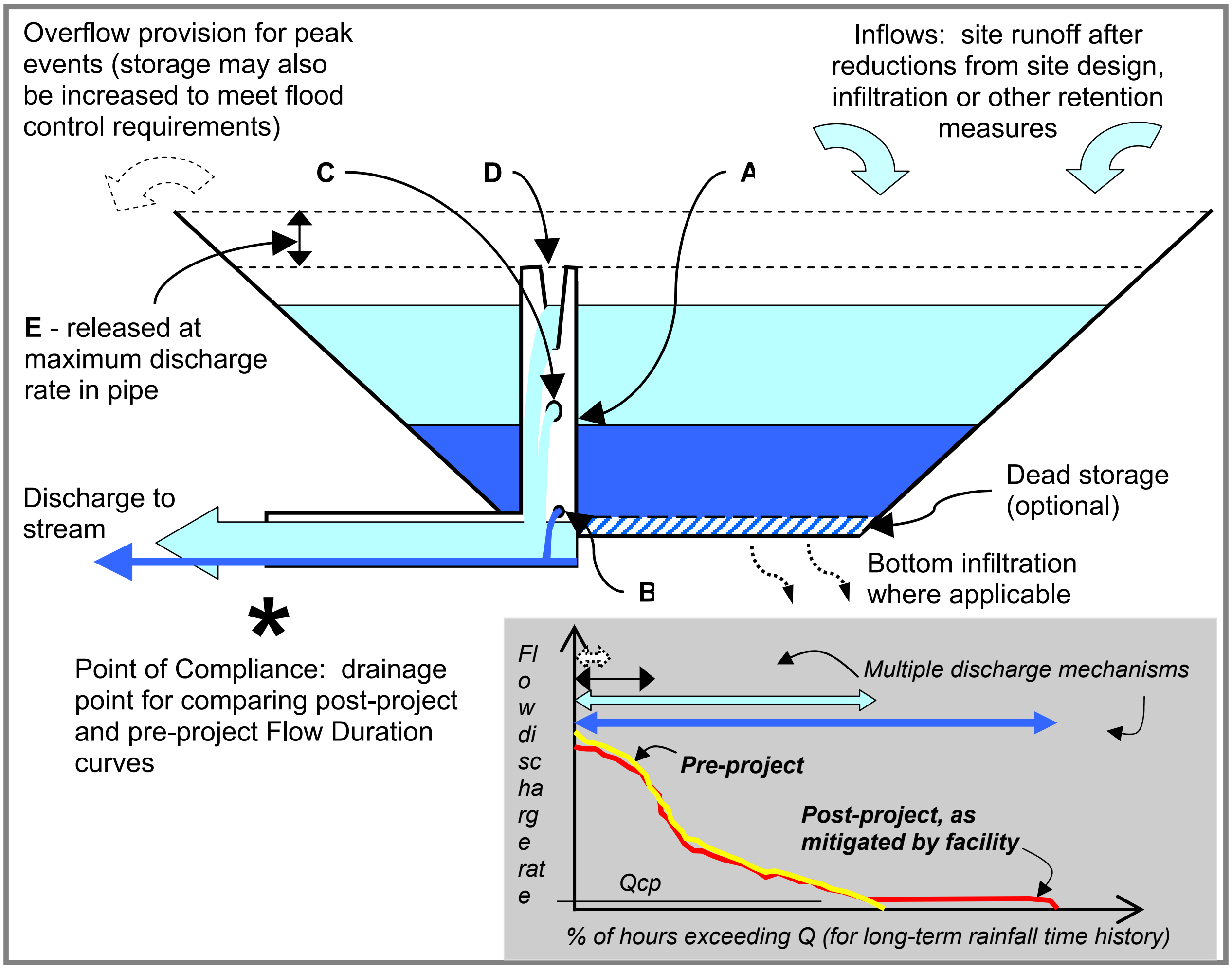


Figure 1. Schematic of flow duration pond and flow duration curves matched by varying discharge rates according to detained volume. Legend: A) outlet pipe riser; B) low flow orifice; C) intermediate orifice (1 shown); D) weir notch (V-type shown); E) freeboard above riser (typically 1 foot).

There are several public domain hydrologic models that can be used for simulating runoff for a continuous rainfall record and sizing flow control facilities. Examples are: 1) the Army Corps of Engineers' Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) which was used for the SCVURPPP analyses; 2) the U.S. Geological Survey and Environmental Protection Agency (EPA) software package called Hydrologic Simulation Program Fortran (HSPF); and 3) the EPA's Stormwater Management Model (SWMM).

## Design Challenges

The concept of designing a flow duration control facility is relatively new and, as described above, requires the use of a continuous simulation hydrologic model. Development, calibration and use of such models can be data intensive and time consuming, and there is a general lack of knowledge and experience with these models among the development community and municipal staff. An additional challenge is integrating flow controls with site design and treatment controls, i.e., estimating the flow reduction benefits of site design and treatment controls and accounting for this reduction in determining the size of the flow control facility, as well as evaluating the treatment capability of the flow control facility.

To address these design challenges, SCVURPPP investigated a user-friendly, automated modeling and flow duration control facility sizing tool called the Western Washington Hydrology Model (WWHM) and decided to jointly fund the adaptation of this tool, in collaboration with the Alameda County and San Mateo County stormwater programs, for use in the Bay Area. The WWHM was developed in 2001 for the Washington State Department of Ecology to support Ecology's *Stormwater Management Manual for Western Washington* (Washington State Department of Ecology, 2001) and assist project proponents in complying with the Western Washington hydromodification control requirements. The adapted tool, known as the Bay Area Hydrology Model (BAHM), is being calibrated to southern Bay Area watersheds and enhanced to be able to size other types of control measures and LID techniques for flow reduction as well.

## BAHM Overview

The BAHM software architecture and methodology is the same as that developed for the WWHM and uses HSPF as its computational engine[12]. Like WWHM, BAHM is a tool that generates flow duration curves for the pre- and post-project condition and then sizes a flow duration control basin or vault and outlet structure to match the pre-project curve. The software package consists of a user-friendly graphical interface with screens for input of pre-project and post project conditions; an engine that automatically loads appropriate parameters and meteorological data and runs continuous simulations of site runoff to generate flow duration curves; a module for sizing or checking the control measure to achieve the hydromodification control standard; and a reporting module.

The HSPF hydrology parameter values used in BAHM are based on calibrated watersheds located in the San Francisco Bay Area. The initial phase of calibration for two Alameda County watersheds (AQUA TERRA Consultants, 2005) is described later in this paper. Currently work is ongoing to calibrate two watersheds in Santa Clara County.

BAHM uses one or more long-term[13] local precipitation gages for each of the three South Bay counties and then scales the precipitation to the user's site using mean annual precipitation maps developed by local flood control districts or published as NOAA rainfall maps.

BAHM computes stormwater runoff for a site selected by the user. BAHM runs HSPF in the background to generate an hourly runoff time series from the available rain gauge data over a number of years. Stormwater runoff is computed for both pre-project and post-project land use conditions. Then, another part of the BAHM routes the post-project stormwater runoff through a stormwater control facility of the user's choice.

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[12] The Department of Ecology developed the present Version 2 of the WWHM to incorporate user comments. The BAHM is based on WWHM Version 3 which is currently in development.

[13] At least 30 years of record; 40 years or more are preferred.

BAHM uses the pre-project peak flood value for each water year to compute the pre-project 2- through 100-year flood frequency values[14]. The post-project runoff 2- through 100-year flood frequency values are computed at the outlet of the proposed stormwater facility. The model routes the post-project runoff through the stormwater facility. As with the pre-project peak flow values, the maximum post-project flow value for each water year is selected by the model to compute the developed 2- through 100-year flood frequency.

The pre-project two-year peak flow is multiplied by 10% to set the lower limit of the erosive flows, in accordance with the current HMP performance criteria[15]. The pre-project 10-year peak flow is the upper limit. A comparison of the pre-project and post-project flow duration curves is conducted for 100 flow levels between the lower erosive zone limit and the upper limit. The model counts the number of hours that pre-project flows exceed each of the flow levels during the entire simulation period. The model does the same analysis for the post-project mitigated flows.

### Using the BAHM

BAHM input is relatively simple. The user must locate the project site on the appropriate county map (Figure 2). The user can zoom in or out on the map to find the exact location. BAHM uses this information to select the appropriate precipitation record and multiplier for this location.

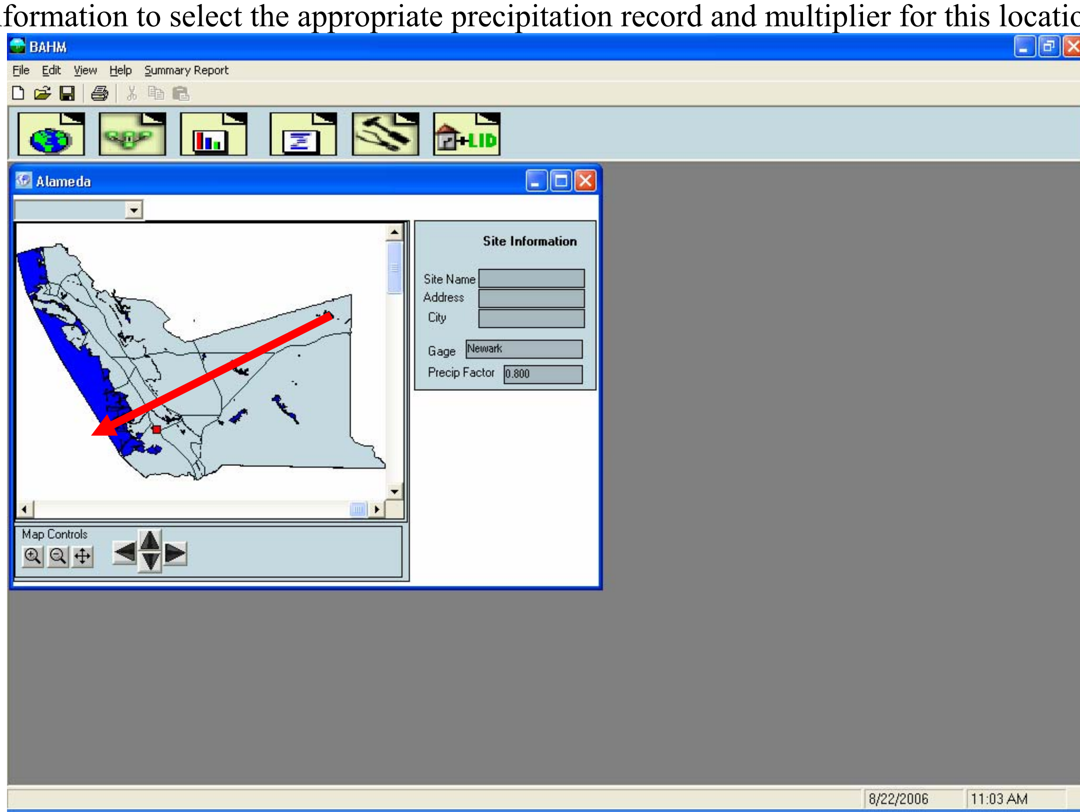


Figure 2. Example project site location.

[14] The actual flood frequency calculations are made using the federal standard Log Pearson Type III distribution described in Bulletin 17B (United States Water Resources Council, 1981). This standard flood frequency distribution is provided in U.S. Geological Survey program J407, version 3.9A-P, revised 8/9/89. The Bulletin 17B algorithms in program J407 are included in the BAHM calculations.

[15] In the BAHM, this low flow limit is a user-defined variable, to allow flexibility pending potential changes in regulatory requirements.

The user then goes to the Scenario Generator screen (Figures 3a and 3b) where the land use, vegetation, and soils information are specified. For the Bay Area counties, the vegetation categories are forest, shrub, grass, and urban landscape. Pre-project vegetation can be any of the first three categories. There are three major soil categories: SCS A, B, and C/D soils[16]. Post-project land use can include roofs, streets/sidewalks/parking, and pond in addition to the four vegetation categories.

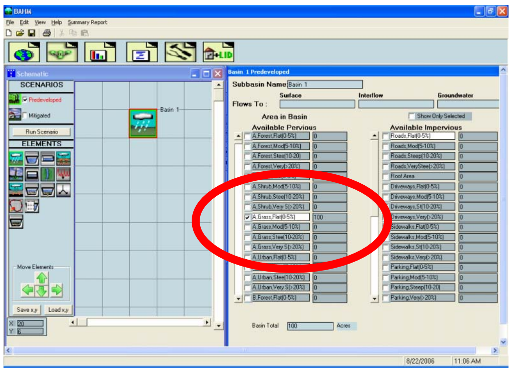

Figure 3a. Pre-project land use.

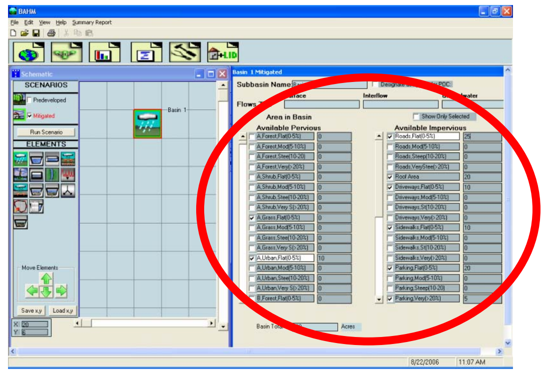

Figure 3b. Post-project land use.

The user inputs the number of acres of pre-project land use in each of the different land categories and does the same for the proposed development. For residential development there is the option to include low impact development (LID) practices such as roof runoff infiltration or dispersal and porous pavement. These LID practices reduce runoff and stormwater facility size. The user selects the type of stormwater control facility to include in the analysis. The available types are standard trapezoidal pond, tank (cylindrical, arched), vault, and irregular-shaped pond. The user can select one, two, or three orifices and a riser with a flat or notched weir (notch types include rectangular, V-shaped, and Sutro types). The facility can include infiltration, if appropriate for the site. The facility can be either manually sized to meet flow duration standards or the user can use the pond optimization feature (AutoPond) in BAHM to size the facility. An example of the BAHM pond information input form is shown in Figure 4.

[16] Soil groupings based on calibration work completed to date.

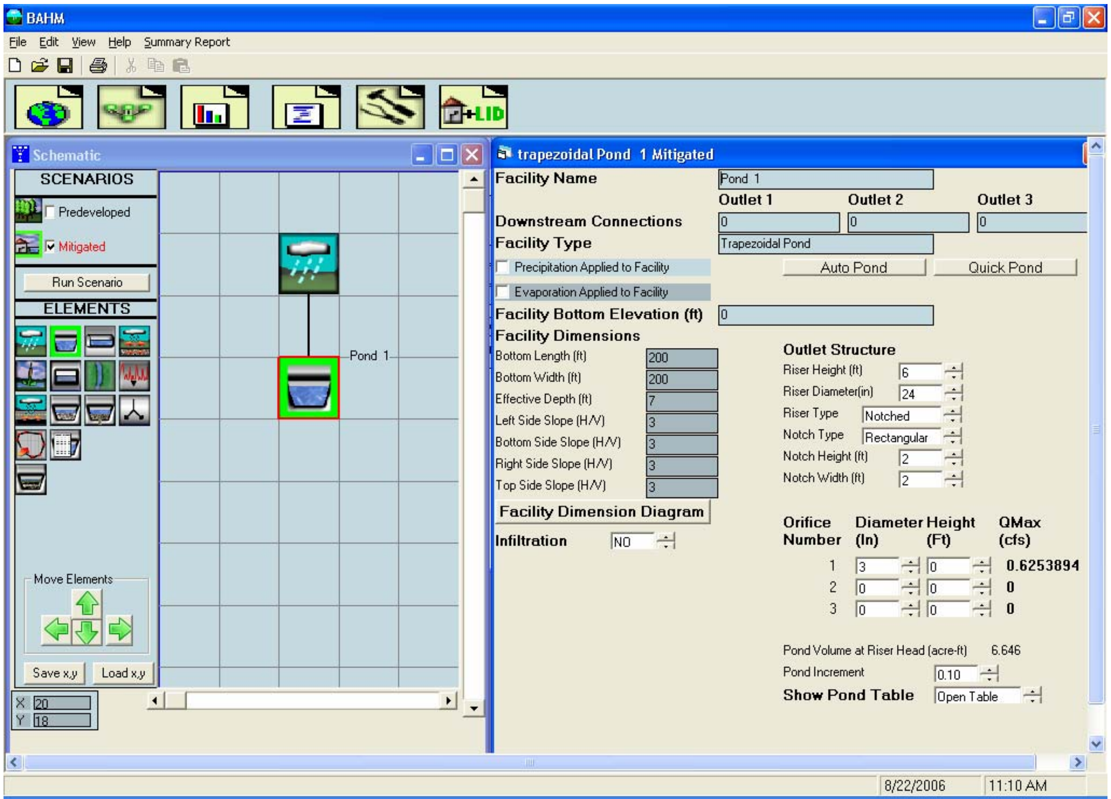


Figure 4. Pond information.

AutoPond uses a complex set of rules to select pond dimensions and outlet orifice diameters and heights. Once AutoPond has made an initial selection of pond and orifice sizes, BAHM runs HSPF to generate the long-term hourly runoff time series. The runoff is routed through the stormwater control facility and a flow duration comparison is made with the pre-project flows. If the post-project flow duration results do not pass the flow duration standard criteria then AutoPond changes dimensions and tries again. If the post-project flow duration results pass the standard then AutoPond tries to make the pond smaller. This produces the smallest (and most efficient) pond possible to meet the flow duration standard. Any time in this process the user has the option to stop AutoPond and make manual changes, if desired.

The user has the option of adding a water quality facility either upstream or downstream of the stormwater control facility. By placing the water quality facility upstream the user can take advantage of the flow moderation it provides to the control facility. This will result in a smaller stormwater control facility. Conversely, the water quality facility will have to be made larger to handle the greater variations in flows than if it is downstream of the control facility (which then moderates the flows to the water quality facility)[17].

BAHM produces model output in both graphical and tabular form. The major graphical output of interest is the flow duration plot of pre-project flow and mitigated post-project flow (Figure

[17] If the user wishes to design a flow control basin that will also accomplish stormwater treatment, the BAHM can be used to check the detention time in the basin to see if it meets design standards (typically 48 hours for settling fine-grained particulates).

5). All of the mitigated post-project flow values must be the same as or to the left of the pre-project values.

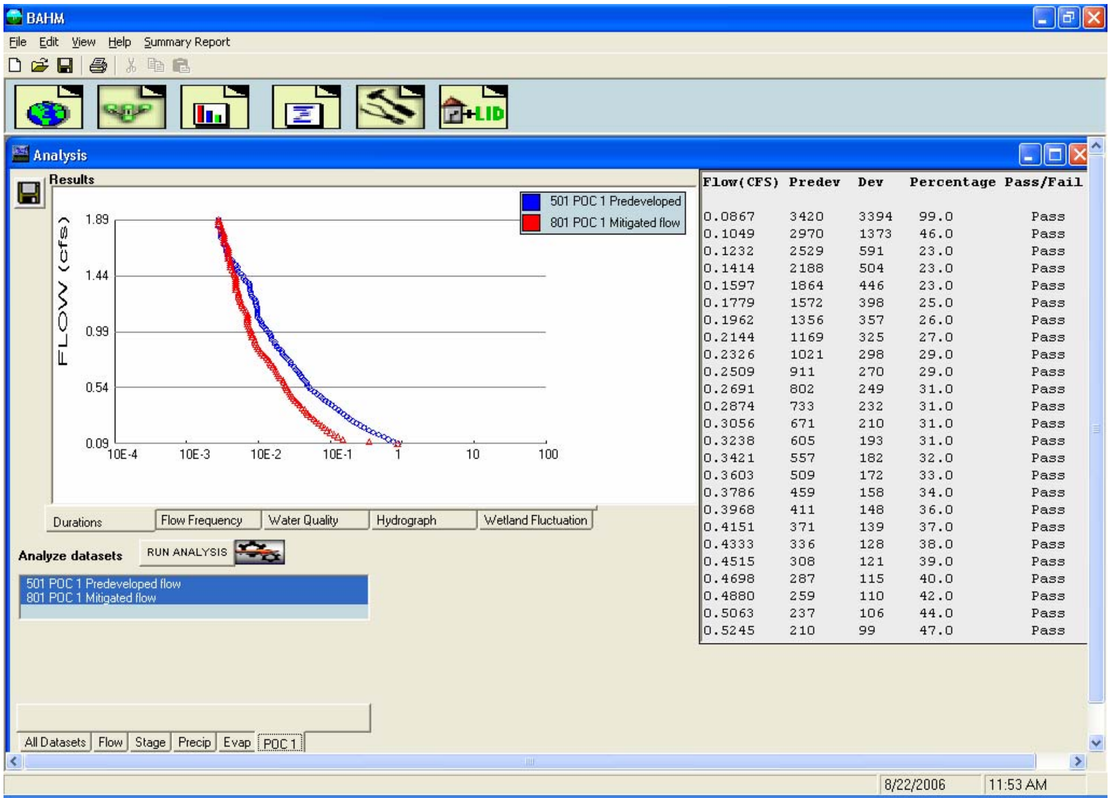

Figure 5. Flow duration comparison.

Numeric output is provided in tabular form. BAHM produces a project report that lists all of the input information. This includes the precipitation station and multiplier used, both pre- and post-project land use types and acreages, and dimensions and specifications of the flow control facility. This can be used by municipal staff to check the facility design. The user also has the option of saving the project file to disk. This project file can be later read into BAHM by the user or a reviewer to check or further modify the project.

The project report also lists the number of hours the pre- and post-project flows exceed each of the 100 flow duration levels and whether or not the flow control facility passes or fails the flow control standard for that level (Figure 5). Failure at any one of the 100 levels means the facility fails to meet the flow duration standard.

Low impact development (LID) practices have been recognized as opportunities to reduce and/or eliminate stormwater runoff at the source before it becomes a problem. They include compost-amended soils, bioretention, permeable pavement, green roofs, rain gardens, and spray irrigation. All of these approaches reduce stormwater runoff. BAHM can be used to determine the magnitude of the reduction and the amount of stormwater detention storage still required to meet HMP requirements.

BAHM explicitly includes the following LID practices:

- Roof runoff dispersion on adjacent pervious land
- Bioretention
- Green roofs

Other LID practices (such as pervious pavement and amended soils), can be implicitly modeled by adjusting parameters to represent these surfaces.

### BAHM Parameter Development

BAHM uses HSPF calibrated parameter values to accurately compute stormwater runoff for the range of land use, soil, topographic, and climatic conditions found in the southern Bay area counties. Since it is not appropriate to use parameter values from other parts of the country, the participating stormwater programs are sponsoring calibration activities to support BAHM development.

For the ACCWP-sponsored phase, a review of Alameda County watersheds with appropriate streamflow and meteorological records was conducted, and Castro Valley Creek and upper Alameda Creek were selected as calibration watersheds (see Figure 5)[18]. These two watersheds encompass an appropriate range of land use, soils, vegetation, and climatic conditions that represent a significant fraction of Alameda County. The Castro Valley Creek watershed is a highly developed urban and suburban area of about 5.5 square miles with moderate precipitation averaging 20-22 inches per year. Significant and continuous base flow reflects impacts of lawn and landscape irrigation, especially during summer months. In contrast, the modeled portion of the Alameda Creek watershed is a highly rugged and almost completely undeveloped area approximately 33.5 square miles in size. Most of the drainage originates in Santa Clara County and annual precipitation averages approximately 20-24 inches though rain gauge data is sparse. The objective for deriving calibrated HSPF parameter values from these watersheds is for the model to be usable for both urban and undeveloped areas throughout the county.

To provide local calibrated parameter values, HSPF model simulations were performed for a period of 10 years for Castro Valley Creek and 7.5 years for upper Alameda Creek. The Castro Valley simulation period was divided into a 5-year calibration period and a 5-year validation period.

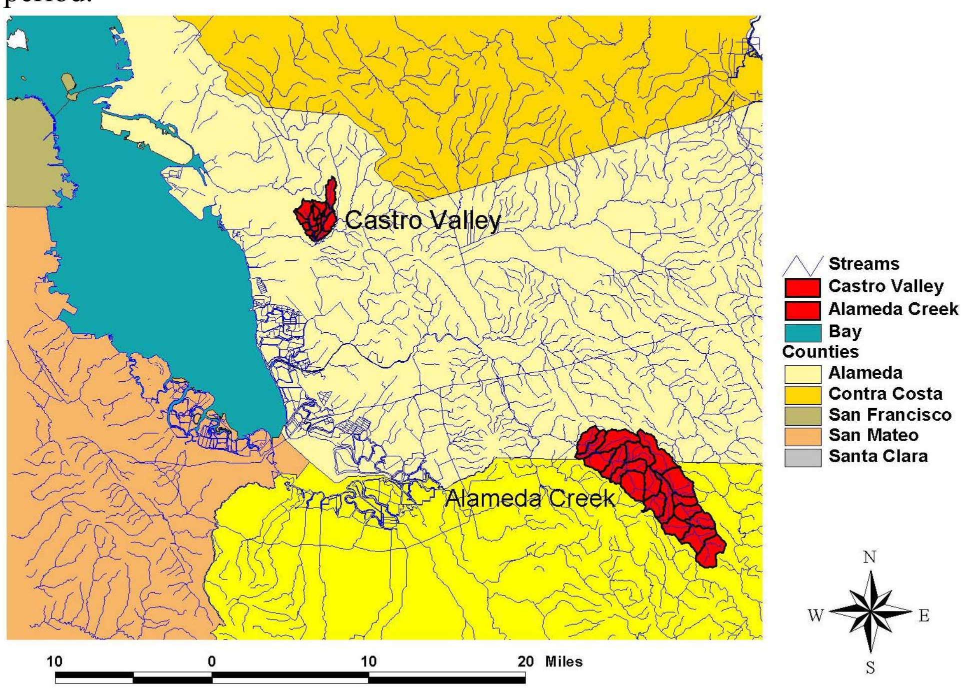


Figure 6. Castro Valley and Alameda Watersheds

[18] The ACCWP-sponsored calibration report and data memorandum can be found at www.cleanwaterprogram.org.

Calibration of a watershed with HSPF is a cyclical process of making parameter changes, running the model and producing comparisons of simulated and observed values, and interpreting the results. The procedures have been well established over the past 20 years as described in the HSPF Application Guide (Donigian et al., 1984) and recently summarized by Donigian (2002).

Hydrologic simulation combines physical characteristics of a watershed and observed meteorological data to produce a simulated hydrologic response. HSPF simulates flow to the stream network from four components: surface runoff from hydraulically connected impervious areas, surface runoff from pervious areas, interflow from pervious areas, and shallow groundwater flow from pervious areas. Because historic streamflow is not divided into these four units, the relative relationship among these components must be inferred from the examination of many events over several years of continuous simulation.

Figure 7 illustrates the mean daily flow over the simulation periods in log format for Castro Valley Creek and Alameda Creek, respectively. The daily patterns shown by the model clearly reflect the observations.

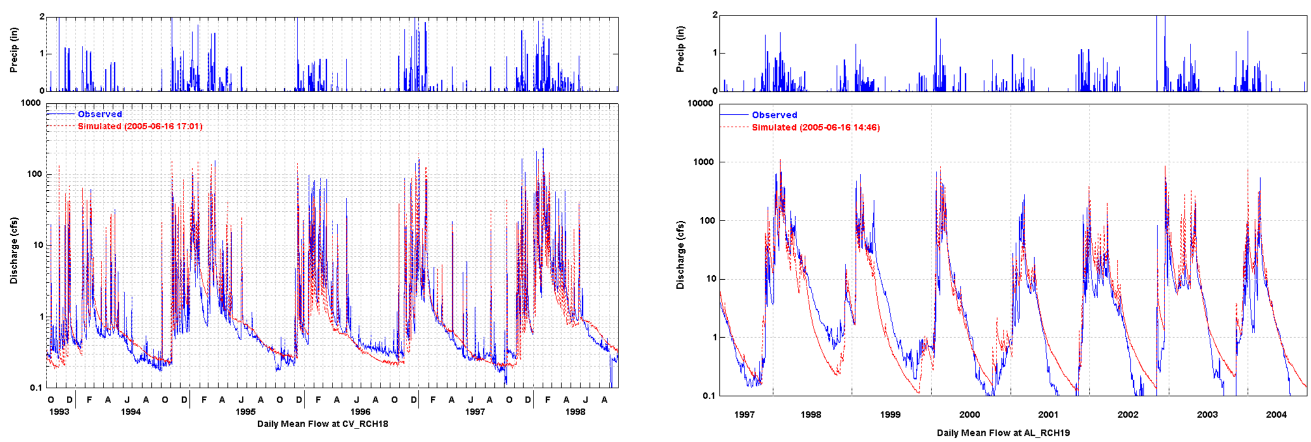


Figure 7. Calibration Daily Flow (simulated vs. observed) for Castro Valley Creek and upper Alameda Creek, with observed precipitation inputs.

Another way to look at the calibration results is to look at the statistics for different components of the streamflow record. For Castro Valley Creek, the percent differences between observed and simulated values are primarily less than 5%, with errors for some statistics in the 5-10% range but still indicating a very good calibration. Alameda Creek statistics show similar results and indicate a very good calibration for this watershed also.

Considering the quality of available data, the hydrographs and statistics indicate a very good calibration of HSPF parameter values for the Castro Valley Creek and upper Alameda Creek watersheds. The resulting model parameters were recommended for use in the Alameda County version of the BAHM. SCVURPPP has begun additional calibration modeling for two watersheds in Santa Clara County

## Application of the Tool

There have not been opportunities to demonstrate BAHM applications due to its recent adoption and introduction to the local engineering community. However, in Western Washington there is now considerable experience with using BAHM's cousin, WWHM.


In the Seattle metro area WWHM was used to size the stormwater control facilities for a new Costco store. Runoff from the site drains directly to adjacent Little Bear Creek, a salmon-spawning tributary of the Sammamish River. WWHM was used to design underground stormwater storage facilities.

The Costco store site is located on 14.38 acres between SR 522 and Highway 9. An additional 2.35 acres of Highway 9 improvements were built along the store's frontage. WWHM was used to size two stormwater systems for Costco. On-site stormwater runoff (from the store and parking lot) is routed to an underground storage facility consisting of 5,240 linear feet of 96-inch diameter pipe (6.04 ac-ft of storage). The runoff from off-site Highway 9 improvements is directed to a separate underground storage system with 1,140 linear feet of 96-inch pipe (1.31 ac-ft of storage). Both systems include 6 inches of dead storage for initial water quality treatment. Additional water quality treatment was provided by Stormwater Management, Inc.'s Stormfilter units. Costco was able to meet the Washington State Department of Ecology HMP requirements on a commercial site with limited space adjacent to critical salmon habitat.

Another example is Snoqualmie Ridge, a 1,343 acre planned community in Upper Snoqualmie Valley, 30 miles east of Seattle. Over 40 percent of the community has been set aside as open space, including parks, trails, preserved wetlands and a golf course. The community includes 2,200 homes plus a business park and retail space.

Ten stormwater detention ponds were designed using WWHM to control stormwater impacts. The ponds range in size from 2 acre-feet of storage to 20 acre-feet and have been incorporated into the adjacent residential neighborhoods and golf course. The community views these ponds as visual amenities.

## Conclusions

The WWHM methodology and software have been used extensively in major metropolitan areas and have been shown to be an effective tool for assisting project proponents meet regulatory requirements regarding hydromodification control. Its successor, the BAHM, will facilitate design of flow control facilities in the San Francisco Bay area, by providing a easier and more standardized way of using continuous simulation modeling and allowing computation of the benefits of site design/LID and treatment measures in reducing flows.

Furthermore, the BAHM will assist municipal agencies in their review of flow control facilities as part of development project approval.

**References**

AQUA TERRA Consultants. 2005. Hydrologic Modeling of the Castro Valley Creek and Alameda Creek Watersheds with the U.S. EPA Hydrologic Simulation Program – FORTRAN (HSPF). Mountain View, CA. www.cleanwaterprogram.org

Donigian, A.S., Jr., J.C. Imhoff, B.R. Bicknell and J.L. Kittle, Jr. 1984. Application Guide for the Hydrological Simulation Program - FORTRAN EPA 600/3-84-066, Environmental Research Laboratory, U.S. EPA, Athens, GA. 30613

Donigian, A.S. , Jr. 2002. Watershed Model Calibration and Validation: The HSPF Experience. WEF-National TMDL Science and Policy 2002, November 13-16, 2002. Phoenix AZ, WEF-2002 Specialty Conference Proceedings on CD-ROM.

MacRae, C.R. *Experience from Morphological Research on Canadian Streams: Is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection. Effects of Watershed Development and Management on Aquatic Ecosystems*, ASCE Engineering Foundation Conference, Snowbird, Utah, pg 144-162. 1996.

GeoSyntec Consultants, 2004. *Technical Memorandum #4: Evaluation of the Range of Storms for HMP Performance Criteria.* Prepared for the Santa Clara Valley Urban Runoff Pollution Prevention Program, April 1, 2004.

GeoSyntec Consultants, 2004. *Technical Memorandum #7: Flow Duration Control Example.* Prepared for the Santa Clara Valley Urban Runoff Pollution Prevention Program, April 1, 2004.

GeoSyntec Consultants, 2004. *Technical Memorandum #8: Sizing Flow-Duration Controls for a Small Development Project in San Jose.* Prepared for the Santa Clara Valley Urban Runoff Pollution Prevention Program, April 29, 2004.

SCVURPPP, 2005. *Hydromodification Management Plan, Final Report*. Prepared by EOA, Inc. and GeoSyntec Consultants. April 2005. www.scvurppp.org

United States Water Resources Council. 1981. Guidelines for Determining Flood Frequency. Bulletin #17B of the Hydrology Committee. Washington, DC.

Washington State Department of Ecology. 2001. Stormwater Management Manual for Western Washington. Volume III: Hydrologic Analysis and Flow Control Design/BMPs. Publication No. 99-13. Olympia, WA.