**Bay Area Hydrologic Model Development**

By Jing Wu, 05/2017

1. **INTRODUCTION**

Bay Area Hydrologic Model (BAHM) was originally developed by AQUA TERRA Consultants for Brake Pad Partnership (BPP) to estimate the copper from brake pad wear debris released to the Bay (Donigian and Bicknell, 2007). The model is built upon HSPF, a continuous simulation model capable of estimating flow and pollutant loads for mixed land use watersheds. The model delineated Bay area into 22 watersheds and simulated flow and sediment and copper loads from 1980 to 2005.

This modeling effort aims to update the model for broad use. Specially, the effort includes: 1) further delineated watershed into finer scale; 2) updated land use to most recent data; 3) extended model simulation period to 2016; 4) recalibrated model hydrology after the above changes were made; and 5) produced flow time series as inputs to bay hydrodynamic model. Below are the description of these efforts.

1. **WATERSHED DELINEATION**

The original model had the entire bay area delineated into 22 sub-basins. Current effort further delineated the areas directly draining into the bay into finer resolutions in order to meet the need of the Bay hydrodynamic model. The total sub-basins in the updated model are now 63.

1. **LAND USE UPDATES**

The 1992 National Land Cover Dataset (NLCD) was used in the original model, and grouped into six land use categories: Forest, Shrub/Wooded, Grass/Wetland, Developed Landscape, Impervious, and Agriculture. The land use data was updated to 2013 NLCD, classified in the same categories.

1. **MODEL SIMULATION PERIOD**

The model simulation period was updated from 1980-2005 to more recent period of 1999-2016 to be compatible with current needs. To do so, the model input data, including precipitation, evaporation, and urban irrigation, were collected and processed into model format.

**Precipitation**

The HSPF model requires hourly precipitation. The precipitation from 20 NOAA weather stations across the Bay area were used in the model (Table 1). Of these 20 stations, complete hourly data are available at only three stations and the rest of them have only daily data. The daily data were disaggregated into hourly data based on the rainfall patterns at nearby stations.

Table 1. Weather stations and major sub-basins



\* Hourly stations

* **Data sources**

All precipitation were downloaded from NOAA’s weather data center website:

Hourly data: <https://gis.ncdc.noaa.gov/maps/ncei/cdo/hourly>

Daily data: <https://gis.ncdc.noaa.gov/maps/ncei/cdo/daily>

* **Missing records**

As common with weather data, there are missing records in most of weather stations (Table 2). The missed data were filled by using data at nearby stations adjusted for average annual rainfall total. The annual rainfall for pertinent stations were obtained from PRISM. Table 2 lists the stations with missing data, and the filling in stations, annual rainfall, and the adjusting factor.

Table 2. Weather stations and fill-in stations



* **Data disaggregation**

Since HSPF requires hourly meteorology data, the daily data need to be disaggregated into hourly data. To do so, hourly data were collected at additional stations that are not part of model stations (Table 3). Given that the hourly data are available at different time periods for different stations and do not necessarily cover the full extent of a particular watershed, the disaggregation of most daily stations was based on the rainfall patterns at multiple nearby stations to improve accuracy. Table 3 shows the daily stations and corresponding hourly stations that were used for disaggregation.

Table 3. Daily stations and corresponding hourly stations for disaggregation



**Evaporation**

Another key meteorologic input for HSPF is evaporation. For evaporation, HSPF generally uses measured pan evaporation to derive an estimate of lake evaporation, which is considered equal to the potential evapotranspiration (PET) required by the model, i.e., PET = (pan evap) X (pan coefficient.) The actual simulated evapotranspiration is computed by the program based on the model algorithms that calculate dynamic soil moisture conditions, as a function of the rainfall, model ET (evapotranspiration) parameters, and the input PET data.

The original model used Pan evaporation data from the Los Alamitos gage in San Jose and adjusted it for using in other watersheds by the ratios of the CIMIS (California Irrigation Management Information System, <http://wwwcimis.water.ca.gov/cimis/data.jsp>) values for the corresponding zones. However, it is concluded that using just one set of data for the entire bay area with very distinctive micro-climates zone created too much uncertainty in the estimated evaporation data. Therefore, a different approach was employed to derive evaporation data for current model, as described below.

Hourly evapotranspiration data from 1999 to 2015 at 5 CIMIS stations were downloaded from CIMIS website (<http://www.cimis.water.ca.gov/Stations.aspx>). The evapotranspiration from CIMIS is considered equivalent to PET in HSPF model. These stations fall into 5 different (ETO) zones (Table 4). For watersheds within these 5 zones, the hourly time series was directly used, and for those in different zones, the ratios of the CIMIS values for the corresponding ETO zones (<http://wwwcimis.water.ca.gov/App_Themes/images/etozonemap.jpg>) was used to adjust the data set. In the end, each zone within the Bay area has its own hourly evapotranspiration data, which was then applied to each watershed within that zone.

Table 4. CIMIS stations for hourly evapotranspiration



As with precipitation, there were also missing data in CIMIS record. For each station, the data gap was filled by using monthly regression equation between evapotranspiration and temperature. The regression was carried out from all available data for each month, and the missed data were estimated using its monthly equation.

**Urban irrigation**

The developed urban and agricultural land use receives irrigation applications. With Bay Area’s semi-arid climates, supplemental irrigation can and does have a significant impact on the hydrologic regime and stormwater runoff, potentially changing ephemeral streams into perennial ones. Often the irrigation applications will exceed annual rainfall by 50% to 100% or more (Donigian and Bicknell, 2007).

Current model used the same approach as the original model to calculate urban and agricultural irrigation applications, which was based on prior modeling studies both in the Bay Area in Alameda County (AQUA TERRA Consultants, 2006) and in Ventura County of Southern California (AQUA TERRA Consultants, 2005). The approach assumes that irrigation systems would be used to make up monthly lawn and crop evapotranspiration (ET) demands that exceed available rainfall. The calculation requires rainfall, evapotranspiration, crop coefficient, and efficiency of irrigation system.

For calculating irrigation applications, the Bay area watersheds were lumped into six regions - Marin, East Bay, East Bay Inland, South Bay, Peninsula, and North Bay. The daily irrigation application was calculated for each region and applied to urban and agricultural land uses for every watershed within that region. Table 5 lists the weather stations and CIMIS zone that were used for calculation for each region. The steps of calculating daily irrigation applications are:

1. Estimate mean rainfall region-wide
2. Use the CIMIS zones for ETo; use average when there are 2 zones
3. Use a crop coefficient, Kc= 0.70, as an average for urban and agriculture
4. Calculate the ratio of the rain gage mean (from the timeseries) to the region mean (Step 1)
5. Using the region rainfall, region Eto, and Kc, calculate the irrigation demand timeseries
6. Use an irrigation efficiency of 0.80 (account for loss), midway between the urban and agriculture values to calculate irrigation need
7. Estimate the amount of irrigation applied based on Irrigation needed while applying antecedent rain condition for previous 7 days. Within the model input file, a reduction factor of 0.65 for urban and 0.85 for agriculture was used to reduce the irrigation amount by the fraction of the area that was assumed to be irrigated.

Table 5. Irrigation groups, rain gages and CIMIS zones



1. **MODEL CALIBRATION**

The updated model was calibrated at 8 USGS stations where long-term flow data are available (Table 6). The calibration period is 1999-2016. HSPF calibration procedure involved a ‘weight of evidence’ approach with multiple graphical and statistical comparisons of observed and simulated flows. Overall, model calibration was fair to good for 6 of 8 stations, judged by two key statistics that measure model performance –error in total volume and Nash model efficiency. The two stations - Guadalupe River at San Jose (discontinued at 2003) and Coyote Creek above highway 237 at Milpitas, CA, were not well calibrated. Both are large watersheds with reservoirs and complex water supply systems that intake and divert water in and out of the watersheds, which are not included and addressed in the current model. It is anticipated that model calibration will be improved if future updates take all important sources and sinks into account.

Table 6. Calibration stations and model statistics



After model calibration, the model parameters from calibration watersheds were assigned to the rest of watersheds that were not calibrated. The assignment was based on the principals of the paired watersheds should be fairly close to each other and generally in the same micro-climate. Table Y shows how the watersheds were paired for assigning model parameters.

1. **MODEL RESULTS**

The daily timeseries of flow from 1999 to 2016 for each sub-watersheds that directly drains to the Bay were generated, as an input to the Bay hydrodynamic model.

1. **REFERENCE**

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