Survey and Modeling Analysis of HDOT MS4 Highway Storm Runoff on Oahu, Hawaii

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Introduction

As a mid-course correction of the 1972 Federal Clean Water Act (CWA), the water quality-based approach for heavily polluted waters was introduced (USGAO 1989). Under this approach, water quality standards needed for planned uses of receiving waters were determined; if a receiving water does not meet these standards, plans must be developed to achieve this goal. The water quality-based approach considers pollution from both point and nonpoint sources. The basic steps to apply the water quality-based approach of pollution control are given in Section 303(d) of the CWA.

To implement Section 303(d) of the CWA, states need to identify the quality of each body of water within its jurisdiction and compare it with established water quality standards. If a receiving water doesn't meet water quality standards, even after technology-based minimum treatment has been implemented, the receiving water is designated as "water quality limited" or "water quality impaired." This designation can be given to an entire water body or to a segment of the water body. A list of water quality impaired water bodies in Hawaii was prepared by the State of Hawaii Department of Health (HDOH). For each water quality limited water body, the CWA required the state to establish and submit to the USEPA the total maximum daily loads (TMDLs) for the water. The Ala Wai Canal is a water quality impaired water body and a TMDL report for the canal was prepared by HDOH and approved by USEPA.

Under the CWA, the Hawaii Department of Transportation (HDOT) must apply for and receive from the USEPA a National Pollutant Discharge Elimination System (NPDES) permit concerning the storm runoff from its Municipal Separate Storm Sewer System (MS4). Water quality requirements in the current HDOT MS4 permit, relative to the Ala Wai Canal, were determined primarily by the canal TMDL report (HDOH 2002). However, the principal results of the Ala Wai Canal TMDL report were derived based on simple mass balance analysis without considering the environmental fate and transport of pollutants in the canal. Also, the report did not differentiate between runoff and waste loads generated by the HDOT MS4 and the City and County of Honolulu (CCH) MS4.

The principal objectives of this project were (1) to conduct a water quality survey and modeling of the contributing watersheds of the Ala Wai Canal in order to assess the amount of storm runoff and pollutant loads entering the canal from the HDOT MS4 facilities and other sources, and (2) to conduct a water quality survey and modeling of the Ala Wai Canal to evaluate the impacts of waste loads on the water quality of the canal as a receiving water.

Toward this end, water quality monitoring networks were installed to measure storm runoff and pollutant loads generated in the Ala Wai and Halawa drainage systems, including those generated by the H-1 & H-3 Freeways, and HDOT MS4 facilities (Figure 1). The data collected were used for the calibration of watershed models of both drainage systems. The calibrated watershed models were then used to evaluate the HDOT MS4 contributions to pollutant loads during major storm events, relative to other sources of pollution.

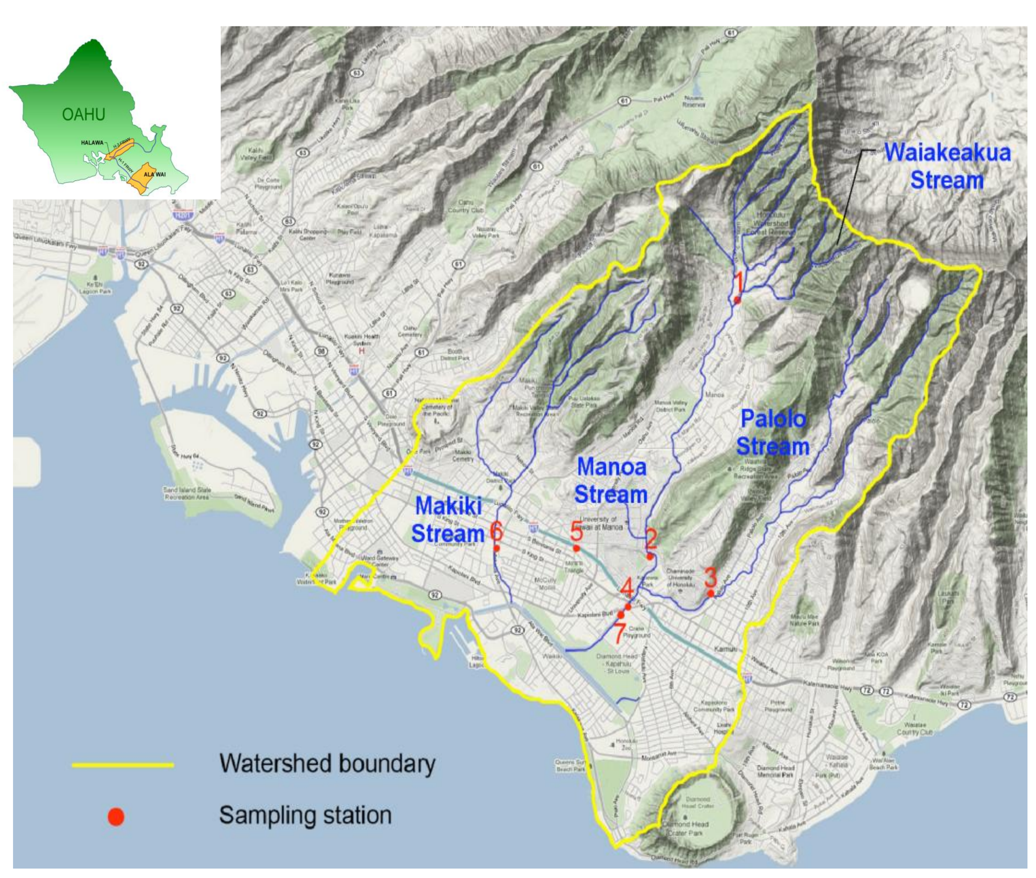


Figure 1, Network of 7 samplers installed in the Ala Wai basin

A water quality model was developed for the Ala Wai Canal to predict its water quality conditions under varying inputs of storm runoff and pollutant loads. Modeling results provided a basis for the re-evaluation of the principal provisions of the existing TMDL report of the Ala Wai Canal. The receiving water of the Halawa drainage system is Pearl Harbor, which is also a water quality impaired water body. Since the Pearl Harbor TMDL report is currently unavailable, the receiving water quality model for Pearl Harbor was not developed.

Materials and Methods - Sampling

The flow and water quality data collected by two monitoring networks were used to (1) estimate the baseline of flow and pollutant load generated by the Ala Wai watershed and its sub-watersheds under dry-weather conditions, and (2) provide a database for calibrating and testing the USEPA's Better Assessment Science Integrating Point and Non- point Sources (BASINS) and Hydrological Simulation Program FORTRAN (HSPF) models of the Ala Wai watershed system under wet-weather or storm conditions. Stream flow data was obtained from existing US Geological Survey (USGS) flow gages and from area velocity modules on three of the samplers. Sampling was triggered according to a programmed rate of flow to capture storm events.

Dry-weather data was collected from low-flow background grab samples from the sites each month in order to compare baseline (non-storm) concentrations of the two parameters measured (total suspended solids [TSS] and total nitrogen [TN]) to those in samples taken during storm conditions. The automatic samplers were programmed to take composite samples of storm water at intervals whenever stream stage exceeded a certain level. Once the water receded below those levels, sampling terminated. The samplers had the capacity to automatically take 24 discreet composite samples.

Rainfall data were obtained from six currently active gauges in the Ala Wai and three in the Halawa basin.

Methods - Modeling

The watershed modeling was conducted under USEPA's BASINS framework. BASINS consists of several geographic information system (GIS) based computer tools and databases for watershed analysis. These GIS tools and databases were integrated with several built-in models. Data collected by field surveys were used to calibrate two watershed models under the BASINS framework: the Pollutant Loading (PLOAD) model and the Hydrological Simulation Program FORTRAN (HSPF) model. Both the Ala Wai and Halawa drainage basins contain several sub- drainage basins. The PLOAD and HSPF models were developed individually for these sub-drainage basins. The calibrated watershed models were then used to estimate storm-produced pollutant loadings in the two drainage systems. This poster presents only the results of the Ala Wai watershed investigation.

The results of the HSPF model were then used as the input to a receiving water quality model of the Ala Wai Canal, in order to evaluate their impact on water quality conditions in the Canal and its **waste assimilative capacity**.

BASINS Loading Model/PLOAD

The watershed modeling analysis was first conducted using a simple BASINS/PLOAD model. Later, a more comprehensive watershed modeling analysis was conducted using the BASINS/HSPF model. The PLOAD is a simplified GIS-based model for calculating the average-annual runoff and pollutant loads from a watershed under particular land use patterns. The PLOAD application requires only pre-processed GIS and tabular input data including (a) GIS land use data, (b) GIS watershed data, (c) pollutant loading rate data tables, and (d) impervious terrain factor data tables. The equation used to calculate the annual load is similar to that associated with the universal soil loss equation.

BASINS Loading Model/HSPF

In BASINS/HSPF modeling, a watershed is divided into several sub-watersheds or reach. Each reach comprises several land segments and water bodies, which can be either streams or impoundments. Each land segment contributes discharge from municipal and industrial treatment facilities and other point and non-point sources to a reach. Land segments are further divided into pervious and impervious lands. For this study, land uses were divided into urban, non-urban , and H-1 Freeway or other HDOT MS4 facilities for storm water collection and disposal. The BASINS/HSPF model simulates rainfall-runoff and pollutant transport processes in terms of process-based algorithms, which consist of hydrologic and transport parameters. The hydrologic parameters are related to the water budget, hydrograph, peak flow, and timing of the hydrograph. The transport parameters are related to sediment production, sediment concentration, and load in a stream reach. The water quality constituents (mainly nutrients) were estimated applying a simple correlation factor to the runoff and sediment yield.

Results – Loading Models

The BASINS/PLOAD modeling indicates that the dry weather contributions to total annual loading were relatively small. This is not unexpected as the stream flow during dry-weather is mainly from base flow or groundwater recharge, which is generally of good quality.

The BASINS/HSPF model of Ala Wai Watershed was further calibrated by adjusting model parameters within a range of values, model calibration is completed when model simulated storm runoff and water quality conditions are reasonably close to the observed ones. Figure 2 shows the simulated TSS at one of the sampling station – Manoa-Palolo Stream at Kaimuki High School – during a November 2009 storm, along with the observed data.

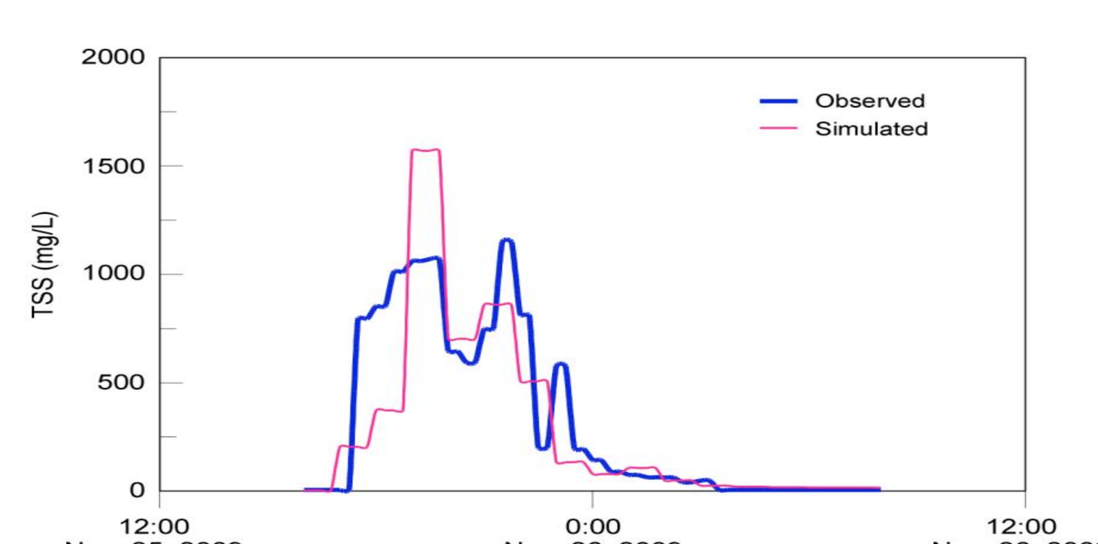


Figure 2, Calibration of BASINS/HSPF model for Manoa-Palolo watershed, with observed and simulated TSS data from Manoa-Palolo Stream at Kaimuki High School during a November 2009 storm

The calibrated BASINS/HSPF model was then used to simulate the waste loading entering the Ala Wai Canal during the wet (from October through March) and dry (from April through September) seasons .

Total nitrogen (TN) loading rates (g/h) of four segments

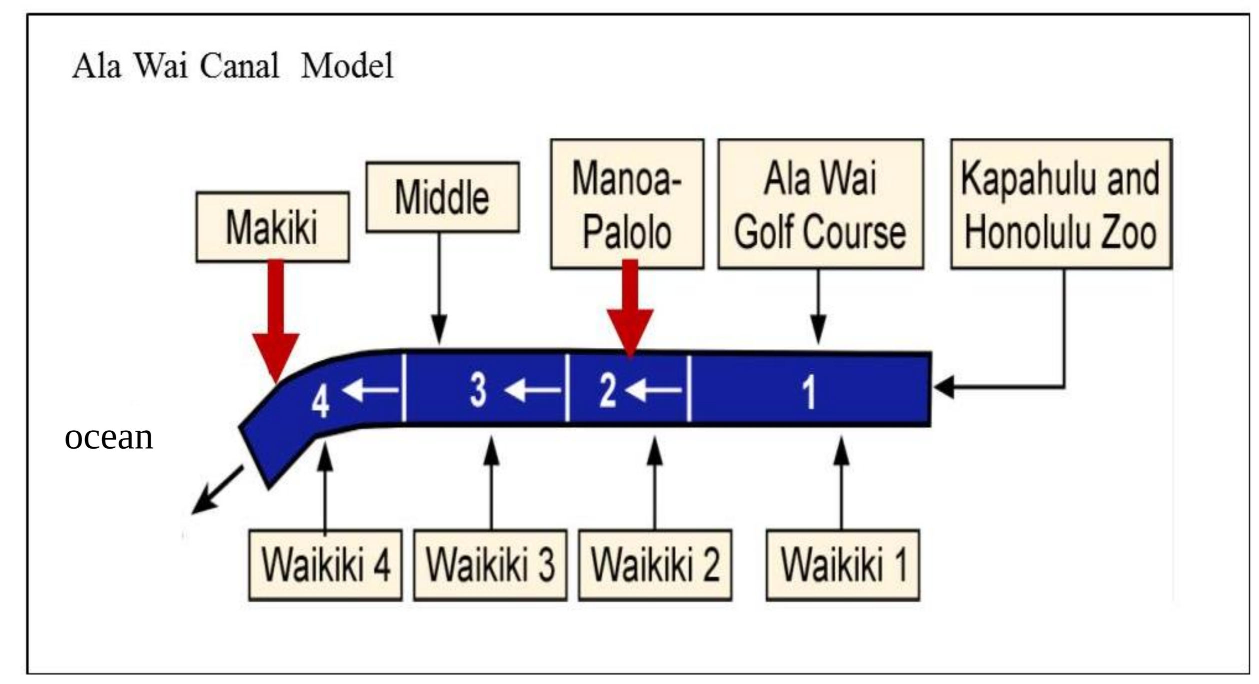
Segment No.	Dry Season Loading (g/h)	Wet Season Loading (g/h)
1	534	569
2	1,535	2,505
3	353	503
4	507	829

The results of the HDOT MS4 runoff survey and modeling analysis indicate that the combined HDOT and CCH contribution of storm runoff and pollutant loads is expected to be much smaller than those suggested by the existing Ala Wai TMDL report (HDOH 2002). Major portions of storm runoff and pollutant loads most likely originate in the upland areas.

Formulation and Application of an Ala Wai Canal Receiving Water Model

In this study, the Ala Wai Canal model was formulated by taking the canal as a series of four completely stirred tank reactors (CSTR) (Figure 3).

Figure 3, The Ala Wai Canal model consisting of a series of four CSTRs



Each CSTR simulated a segment of the canal with relatively constant salinity by the following equation:

$$\frac{dC}{dt} + \lambda C = \frac{W(t)}{V}$$

where:

C = pollutant concentration

λ = *eigenvalue which characterizes the CSTR system

W(t) = pollutant loading

V = volume of the CSTR system

*For the Ala Wai Canal model, as for any receiving water, the eigenvalue defines its waste assimilative capacity. Eigenvalues are determined by hydrodynamics and reaction kinetics. In this study the eigenvalue incorporated the effects of flushing time, water depth, decay coefficients, and settling velocity.

Results – Ala Wai Canal WQ Model

Modeling analysis indicates that Segment 2 with the large nitrogen loading from Manoa-Palolo stream contained the highest concentration of nitrogen of the four segments, and a reduction of up to 47% of nitrogen loadings would be necessary to meet water quality standards.

The survey and modeling analysis also indicated that a large increase in chlorophyll concentrations occurred after an influx of nutrients from storm runoff. Thus, the canal is nutrient-limiting. Further study on nutrient loading to the Ala Wai Canal and the associated eutrophication problem is needed for a more rational determination of the TMDL requirements.

Significance of this Study

Water pollution occurs when the waste loading to a water body exceeds its waste assimilative capacity. Water quality limited water bodies are those that are not in compliance with water quality standards even after measures required under the Clean Water Act were implemented. TMDL regulations were developed to address the issue of these quality limited water bodies. However many water bodies were identified as being water quality limited, without in-depth evaluation. There is a need for an objective means to identify water quality limited water bodies and their allowable loadings. The current study provides a methodology by which a more scientifically defensible assessment of these water bodies can be made.

Acknowledgements

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