WAIKELE STREAM
HSPF MODEL DEVELOPMENT

NUTRIENT CALIBRATION REPORT
GSA contract GS-00F-168CA, Order EP-G159-00281

Prepared for:

Tetra Tech, Inc.

On behalf of:

United States
Environmental Protection Agency
Region 9
Honolulu, HI

September, 2017

NHC Ref. No. 2001168

nhc
northwest hydraulic consultants
water resource specialists

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Seattle, WA

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1 INTRODUCTION

The Waikele Stream TMDL working group, led by State of Hawaii Department of Health (DOH) and the U.S. Environmental Protection Agency (USEPA), is developing a TMDL for Waikele Stream. The primary tool for development of the TMDL is a Hydrologic Simulation Program Fortran (HSPF) model of the watershed, which is a modified version of the model created by Northwest Hydraulic Consultants (NHC) on behalf of the City and County of Honolulu Department of Facility Maintenance Stormwater Quality Branch (DFM-SWQ). Work on the original model included building the model framework (e.g. basin boundaries, land use segmentation, input data processing, etc.) and calibration to observed stream flows and sediment loads (NHC, 2017). DOH and EPA have engaged Northwest Hydraulic Consultants (NHC), as a sub-consultant to TetraTech Inc. (TetraTech), to activate the HSPF model's nutrient routines and calibrate the model to available observed total phosphorus (TP), total nitrogen (TN), and nitrate plus nitrite (NO_3 + NO_2) concentration data.

This report is limited to documentation of calibration of the HSPF model's nutrient routines to observed data. This work was initiated in early 2017 with funding provided by the EPA and DOH. Calculation of TMDL load and waste load allocations will be performed as a subsequent task and documented separately from this report.

Calibration Sequence and Quality Objectives for Modeling

Calibration is the process of adjusting model parameter values with the goal of achieving an acceptable level of agreement with observed data. Calibration of the HSPF model hydrology and sediment routines was previously documented in NHC (2017). Calibration of the model to observed nutrient measurements is the third calibration phase. The ability to achieve a good water quality calibration is dependent on the sediment calibration, and similarly, the sediment calibration was dependent on the hydrology calibration. The reader is referred to Section 4 of NHC (2017) for discussion of the quality objectives for modeling which were similarly applied to the nutrient calibration.

2 OBSERVED NUTRIENT MEASUREMENTS

Observed concentration data utilized for the nutrient calibration were previously summarized in Table 19 of NHC (2017). That tabulation and map showing the monitoring locations (Figure 1) are duplicated here for convenience. Additional discussion of the observed data are also included in TetraTech's draft report "Turbidity and Nutrient Total Maximum Daily Loads for the Waikele Watershed".

Table 1: Available Suspended Sediment and Nutrient Data (copied from NHC, 2017)

Location-Name	Site ID (USGS, DOH Oceanit, or USACE)	HSPF Reach	Suspended Sediment (SSC or TSS)	Total Nitrogen (TN)[3]	Total Phosphorus (TP)
Waikele Stream at Waipahu[1]	16213000 / STA 1	10	Daily (1972-1993), Periods of Seq. (2002), Inst. (2003-2004), Daily/Periods of Seq. (2007-2010)	Inst. (1973-2001), Periods of Seq. (2002), Inst. (2003 - 2004)	Inst. (1973-2001), Periods of Seq. (2002), Inst. (2003-2004)
Waikele Stream above H-1 Freeway near Waipahu[5]	21240215-8010501 / NA	10	Inst. (2000–2001)	Inst. (2000 – 2001)	Inst. (2000–2001)
Waikele Stream at Wheeler Field[1]	16212601 / NA	28	Daily/Periods of Seq. (2007-2010)	NA	NA
Waikakalaua Stream near Wahiawa	16212700 / STA 6	94 / 90[2]	Inst. (1999-2001, 2002)	Inst. (1999 - 2001, 2002)	Inst. (1999 - 2001, 2002)
Kipapa Stream at Waipahu	16212900 / STA 4	16	Inst. (1967-1968, 2002)	Inst. (2002)	Inst. (2002)
Kipapa Stream near Wahiawa[1]	16212800 / STA 7	84	Daily (1968-1982), Inst. (2002), Daily/Periods of Seq. (2007–2010)	Inst. (2002)	Inst. (1973 - 1977), Inst. (2002)
Mililani Storm Drain A at Mililani[1]	21260415-8012700 / NA	54	Periods of Seq. (2007–2010)	Inst. (1980 - 1982)	Inst. (1980 - 1982)
Upper Waikakalaua (upstream of Subdivision)	NA / STA 8	94	Inst. (2002)	Inst. (2002)	Inst. (2002)
Waikele Upstream of Kipapa Confluence	NA / STA 3	48	Inst. (2002)	Inst. (2002)	Inst. (2002)
Wheeler Near Stables	NA / STA 5A	24	Inst. (2002)	Inst. (2002)	Inst. (2002)
Waikele Stream, Training Area	SW-5	34	Inst. (2008)	Inst. (2008)	Inst. (2008)
Waikele Stream, Waianae Upland	SW-6	35	Inst. (2008 – 2011)	Inst. (2008 – 2011)	Inst. (2008 – 2011)
Waikele Stream, Below Wheeler Airfield	SW-11	28	Inst. (2008 – 2011)	Inst. (2008 – 2011)	Inst. (2008 – 2011)
Waikele Stream, Above Confluence with Waikakalaua[4]	SW-12	24	Inst. (2008 – 2011)	Inst. (2008 – 2011)	Inst. (2008 – 2011)

[1] Site currently operated under joint operating agreement between USGS and DFM-SWQ

[2] DOH Oceanit study location STA 6 is located below HSPF Reach 94 and 90 but above 22, reflects combined conditions from RCHRESs 90 and 94.

[3] Periods with Total Nitrogen Data typically also include Nitrate/Nitrate Samples but that data has been omitted from the table for brevity.[4]1980–1982 samples for Mililani Storm Drain B have been omitted from table.

[4] Concentrations reported by USACE (2016) for the SW-12 site were extremely high for all parameters (> 35,000 mg/L TSS, > 120 mg/L TN, and > 20 mg/L TP). Due to questions concerning these samples, these data were not targeted for model calibration. If further review concludes that these data are valid, the calibration and this report can be duly amended to include them.

[5] Waikele Stream above H-1 Freeway near Waipahu (USGS Station 21240215-8010501 is not shown in Figure 1.

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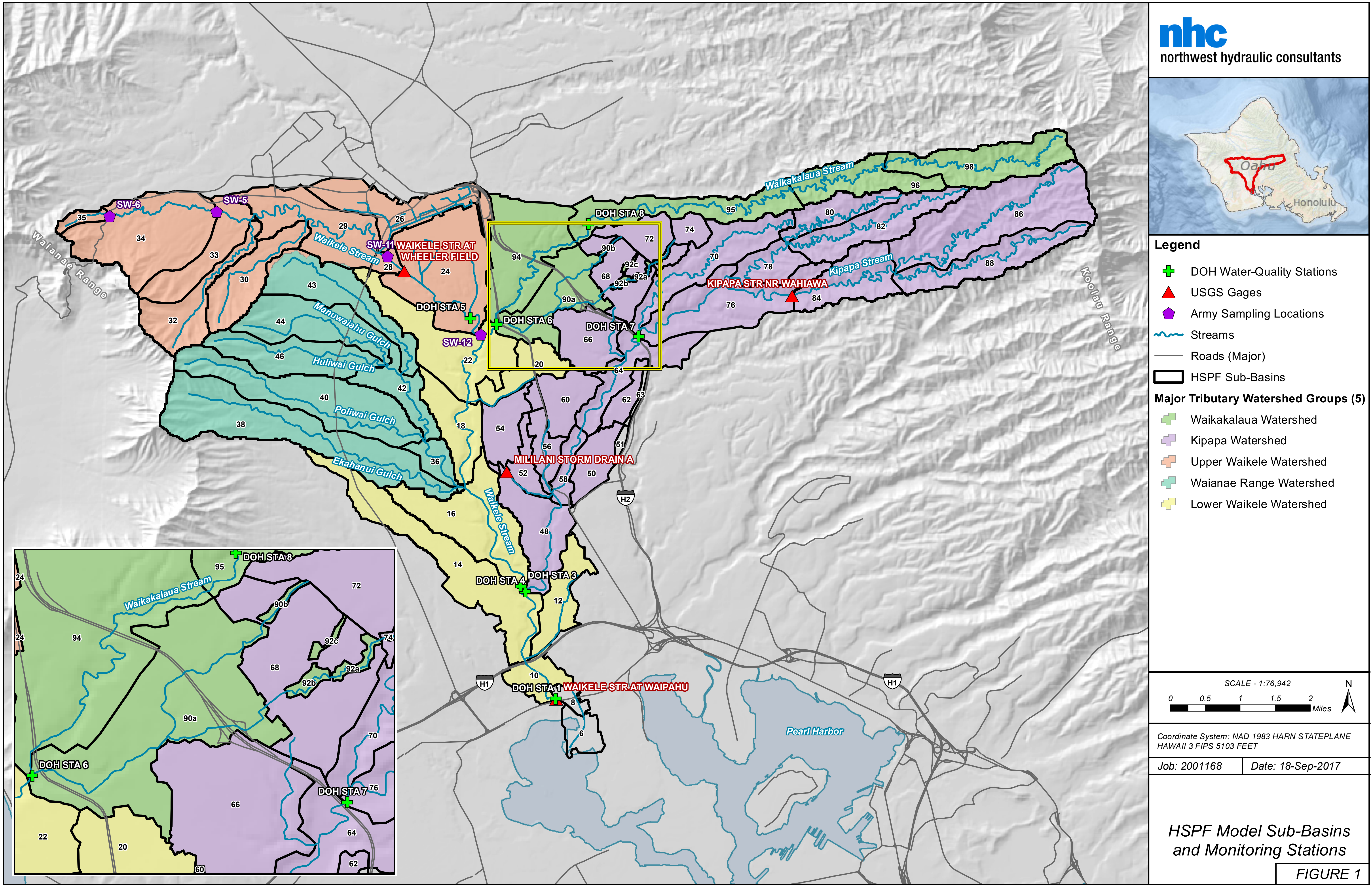

Coordinate System: NAD 1983 HARN STATEPLANE HAWAII 3 FIPS 5103 FEET

Job: 2001168	*Date: 18-Sep-2017*

HSPF Model Sub-Basins and Monitoring Stations

FIGURE 1

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3 NUTRIENT MODULE CALIBRATION

The HSPF model parameters controlling simulation of nutrient production, delivery and transport were calibrated by setting an initial set of parameters and modifying those to improve the match between simulated and observed data. Unlike flow and sediment load data, which was relatively abundant for four USGS gages (Waikele at Wheeler, Waipahu, Kipapa at Wahiawa, and Mililani Storm Drain), nutrient data are available at a larger number of sites but with fewer overall data values to calibrate to. Most of the nutrient data was collected by DOH between 1999 and 2004. A relatively small set of samples was also collected by the United States Army Corps of Engineers (USACE) on Upper Waikele Stream between 2008 and 2011. Periods of available instantaneous and sequential sample data are noted in Table 1 (prior page).

3.1 Modification of Model Framework and Calibration

The only change to the NHC (2017) HSPF model framework made as part of the work reported herein was activation of the HSPF nutrient modules followed by nutrient calibration. The model set-up and calibration parameters for water-quantity and sediment load remain unchanged.

The simulation period, October 1997 through September 2011[1], is identical to that used for the sediment calibration, however the period of observed data differs. Selection of this simulation period was previously discussed in NHC (2017). The simulation period is referred to as Water Years 1998 through 2012 throughout this report.

BMP Representation

Section 3.5 of NHC (2017) discussed three different model representations of existing stormwater Best Management Practices (BMPs) in the context of sediment removal. These included: street sweeping, structural BMPs represented as simple reduction factors (BMPRACs), and structural BMPs explicitly represented as storage volumes (FTABLES). Removal of nutrients via street-sweeping is not currently activated in the HSPF model[2]. IMPLNDs with and without street sweeping are defined with placeholders in the model for future use, but currently no street sweeping reduction of nutrients is activated. It is expected that street sweeping will be activated in the model as part of the TMDL implementation plan so that simulated loads will be reduced to reflect street sweeping. Nutrient removal from structural BMPs occurs in the model as a result of sediment removal (BMPRACs and FTABLES), but no removal of dissolved forms of nutrients is currently activated in the model (i.e. no nutrient BMPRACs). It is expected that these will also be activated as part of the TMDL implementation plan.

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[1] The model was also run for a short simulation period known as the model warm up, from January 1, 1989 to October 1, 1997. The warm up is necessary to establish the soil moisture condition at the beginning of the calibration period.

[2] Sediment removal is activated for HDOT roadways, but phosphorus delivery from impervious surfaces utilizes build-up and washoff algorithm parameters that do not vary between swept and non-swept surfaces and are independent of simulated sediment delivery.

Nutrient Calibration Priority

Several related criteria were used to guide nutrient calibration. In approximate priority order, these include:

1. Match cumulative distribution function curves of concentrations observed at eight DOH sites and three USACE sites.
2. Match dry season (May through October), wet season (November through April), and overall geomean concentrations observed at eight DOH sites and three USACE sites.
3. Match observed pollutographs of sequential samples collected at DOH Site 1 between 1999 and 2001.
4. Match event mean concentrations from runoff on a land use basis as reported in literature for studies in Hawaii and the U.S. mainland.

Land Surface Nutrient Loading Parameters

Sediment delivery depends strongly on rainfall-runoff, and stream flow processes and nutrient delivery depends strongly on both hydrology and sediment. The same hierarchy of dependencies applies to model calibration. That is, the nutrient calibration quality is dependent on the quality of both the water flow and sediment calibration. HSPF generates TP, TN, and NO_3+NO_2 from both pervious and impervious surfaces. Nutrient loading from the land surface (including shallow interflow and groundwater flow) is controlled using HSPF's IQUAL and PQUAL modules. TP delivery via surface runoff from pervious surfaces is directly associated with sediment transport, while TN, and NO_3+NO_2 surface loading (and TP loading from impervious surfaces) is simulated using nutrient build-up and washoff processes, independent of modeled sediment transport. HSPF representation of TN includes both dissolved and particulate forms of ammonia/ammonium[3] (NH_3+NH_4^+) + nitrate (NO_3) + nitrite (NO_2) and organic nitrogen. BOD loading and the instream growth and decay of plankton are also simulated by the model due to their secondary effect on nitrogen delivery. However, no observed data for these processes were available so default values were fixed and not varied during model calibration.

The output presented in the following sections was generated using the nutrient parameters listed in Table 2 and Table 3 [two pages ahead]. In order to simplify the parameterization of the model, and also due to a lack of data to further distinguish them, model Pervious Land Segments (PERLNDs) and Impervious Land Segments (IMPLNDs) were assigned the same set of values for all segments within the same land use (i.e. no variation due to soil or rainfall zone). However, nutrient loads generated by the HSPF model still vary by PERLND or IMPLND segment as a result of the different runoff response and sediment delivery that occurs within a single land use.

Loading generated from PERLND surface runoff was calibrated using build-up and washoff parameters (ACQOP, SQOLIM, and WSQOP) for nitrogen (NH_3 and NO_3 + NO_2) and sediment potency parameter

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[3] As a measure of convenience, for the remainder of this report the symbol (NH_3) is used to represent the sum of ammonia (NH_3) and ammonium (NH_4^+).

(POTFS) for TP. Interflow and groundwater loading of all nutrients were calibrated using parameters IOQC and AOQC respectively.

Impervious Land Segments (IMPLNDs) are fewer in number and they do not generate any sub-surface runoff, so the parameter sets are simpler than for their Pervious Land Segment (PERLND) counterparts. Loading from impervious surfaces, TP included, was calibrated using build-up and washoff parameters (ACQOP, SQOLIM, and WSQOP).

Table 2: Impervious Land Segment Nutrient Calibration Parameters

Land Cover	IMPLND IDs	TP			NH_3			NO_3+NO_2		
		ACQOP	SQOLIM	WSQOP	ACQOP	SQOLIM	WSQOP	ACQOP	SQOLIM	WSQOP
Low Pollution Generating Impervious Surface (LPGIS)	11-16	0.007	0.035	0.25	0.0013	0.009	0.5	0.01	0.05	0.15
Non-Swept High Pollution Generating Impervious Surface (HPGIS)	21-26	0.0266	0.133	0.2	0.0017	0.0135	0.4	0.015	0.05	0.1
Swept High Pollution Generating Impervious Surface (HPGIS)	31-46	0.0266	0.133	0.2	0.0017	0.0135	0.4	0.015	0.05	0.1

ACQOP: pollutant build-up accumulation rate (lbs/acre-day), SQOLIM: pollutant build-up limit (lbs /acre), WSQOP: the rate of surface runoff that will remove 90 percent of stored pollutant per hour (inches/hour).

Instream Nutrient Processes and Parameters

Nutrients associated with runoff that is routed from the land surface into stream and stormwater system routing reaches in HSPF are allowed to transform while being conveyed downstream. Total phosphorus is the only nutrient form that is allowed to adsorb and desorb from suspended sediment within the reach. Different adsorption and desorption coefficients are used for sand, silt and clay. When sediment settles in the reach adsorbed phosphorus is lost from the water column and sediment that scours from the bed has a phosphorus component that is added to the water column. Standard parameters for instream nutrient processes used for the initial model were not modified during calibration.

Table 3: Pervious Land Segment Nutrient Calibration Parameters

Land Cover	PERLND IDs	TP			NH_3				NO_3+NO_2			
		POTFS	IOQC	AOQC	ACQOP	SQOLIM	IOQC	AOQC	ACQOP	SQOLIM	IOQC	AOQC
Forest or Scrub-Shrub	101-216 401-497	0.168 - 0.672	0.02 - 1.95	0.035 - 0.099	0.0004 - 0.018	0.002 - 0.09	0.012 - 0.072	0.13 - 0.56	0.0002 - 0.004	0.0004 - 0.007	0.001 - 0.101	0.108 - 0.162
Grass Urban	201-346	0.945 - 0.945	0.059 - 5.85	0.055 - 0.21	0.037 - 0.05	0.185 - 0.25	0.12 - 0.15	0.08 - 0.1	0.005 - 0.018	0.009 - 0.036	0.015 - 1.25	0.9 – 3.0
Pasture	521-546	0.84 - 1.008	0.209 - 20.9	0.261 - 0.523	0.001 - 0.006	0.005 - 0.03	0.05 - 0.075	0.03 - 0.06	0.012 - 0.03	0.023 - 0.06	0.05 - 0.075	3.0 - 60
Golf Course	581-586	0.777 - 0.819	0.053 - 5.25	0.12 - 0.12	0.037 - 0.05	0.185 - 0.25	0.12 - 0.15	0.08 - 0.1	0.005 - 0.018	0.009 - 0.036	0.015 - 1.25	0.9 – 3.0
Bare Land	601-606	0.42 - 0.42	0.209 - 20.9	0.523 - 0.523	0.037 - 0.05	0.185 - 0.25	0.12 - 0.15	0.08 - 0.1	0.005 - 0.018	0.009 - 0.036	0.015 - 1.25	0.9 – 3.0
Ag. High Runoff	671-696	3.36 - 6.72	0.209 - 20.9	0.523 - 0.523	0.003 - 0.02	0.015 - 0.1	0.12 - 0.2	0.08 - 0.15	0.002 - 1.05	0.004 - 2.1	0.05 - 0.95	3.0 - 60
Fallow	721-726	0.84 - 0.84	0.209 - 20.9	0.523 - 0.523	0.001 - 0.006	0.005 - 0.03	0.12 - 0.2	0.03 - 0.06	0.001 - 0.003	0.002 - 0.006	0.01 - 0.75	0.6 - 1.8
Seed Corn	771-796	3.36 - 6.72	0.209 - 20.9	0.261 - 0.523	0.003 - 0.02	0.015 - 0.1	0.12 - 0.2	0.08 - 0.15	0.002 - 1.05	0.004 - 2.1	0.05 - 0.95	3.0 - 60
Wetland and Water	901-906	0.168 - 0.336	0.209 - 20.9	0.523 - 0.523	0.003 - 0.012	0.017 - 0.06	0.03 - 0.06	0.025 - 0.04	0.007 - 0.036	0.013 - 0.072	0.004 - 0.4	0.18 - 0.84

POTFS: Soil nutrient potency factor (mg/kg), ACQOP: pollutant build-up accumulation rate (lbs/acre-day), SQOLIM: pollutant build-up limit (lbs/acre), IOQC: interflow nutrient concentration (mg/L), and AOQC: groundwater nutrient concentration (mg/L).

3.2 Nutrient Calibration Results — Cumulative Distribution Function (CDF) Curves

The first comparison of the model's ability to match observed nutrient observations is the CDF curves. Simulated and observed concentration curves were developed by sampling the time-series of concentrations simulated for each monitoring location at the times corresponding to the available observed samples. In cases when there is zero simulated flow in a reach, the simulated concentration is not valid; these times have been excluded from the curves. The total number of observed samples, and number of observed samples corresponding to times of simulated flow, are both limited at many of the monitoring stations. CDF curves with fewer than ten simulated and observed pairs have been excluded as curves with so few points are judged to be too unreliable to characterize the distribution of nutrient concentrations at a site (e.g. SW-5 and SW-6). As stated previously, nutrient data from site SW-12 was determined questionable and was not utilized for calibration of the HSPF nutrient routines.

CDF curves for each parameter (TP, NO_3 + NO_2, and TN) are presented in Figure 2 through Figure 7. Plots for stations in the upper undeveloped portions of the watershed (STA 6, STA 7, and STA 8) and plots for stations in the lower developed portions of the watershed (STA 1, STA 3, STA 4, and SW-11) are presented in two separate groups. The upper watershed stations are reflective of conservation areas dominated by forest and scrub-shrub land covers while the lower stations reflect a mix of land uses that are dominated by agricultural and urban pollutant loads.

Total Phosphorus (TP) CDF Curves

TP CDF curves for the upper watershed stations, shown in Figure 2 (blue is observed and orange is simulated), illustrate that the model matches observed concentrations well in undeveloped conservation areas. All three of these stations have relatively few monitoring points.

TP CDF curves for the lower watershed stations, shown in Figure 3, illustrate that the model matches observed concentrations in the watershed well overall. STA 1, which is located at the most downstream reach in the model, reflects the cumulative nutrient loads from the watershed. This site has more observed samples than any other site, making it the most reliable observed CDF curve. The simulated curve at STA 1 matches well, with the exception of missing one observed sample at the highest point in the curve with a concentration of 5 mg/L.

STA 3 and STA 4 are located a relatively short distance upstream of STA 1 on Waikele Stream and Kipapa Stream; both stations are located immediately upstream of the confluence on the respective streams. The simulated CDF curves at these locations are slightly high (i.e. right) relative to the observed curve, but the curves could not be shifted left without degrading the calibration at STA 1. These two curves have few observed monitoring points relative to STA 1 (10 and 14 each vs. 99), so they were used as secondary calibration locations and the fits were considered acceptable.

At the SW-11 location on Upper Waikele Stream the simulated CDF curve slightly under estimates the observed curve and missed the peak observed sample, which exceeded 6 mg/L. This simulated curve could be shifted right by increasing TP loading from impervious surfaces in rainfall zone 4, but the current calibration was accepted to maintain a consistent set of calibration parameters across all of the rainfall zones. In NHC (2017) it was discussed that this reach of Waikele stream frequently is dry and the reaches in this area infiltrate to groundwater, bypassing the reach immediately downstream. This behavior provides some uncertainty about how TP moves through this reach as well. For example, dissolved forms may infiltrate while adsorbed forms may be temporarily stored and later transported downstream.

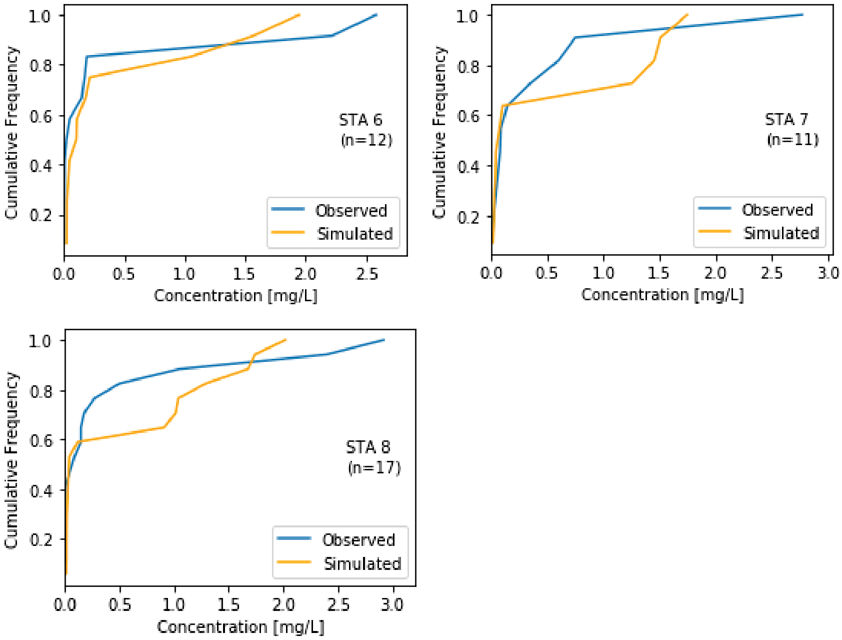

Figure 2: TP CDFs for Upper Watershed, STA 6 , STA 7 (upper right) and STA 8 (lower left)

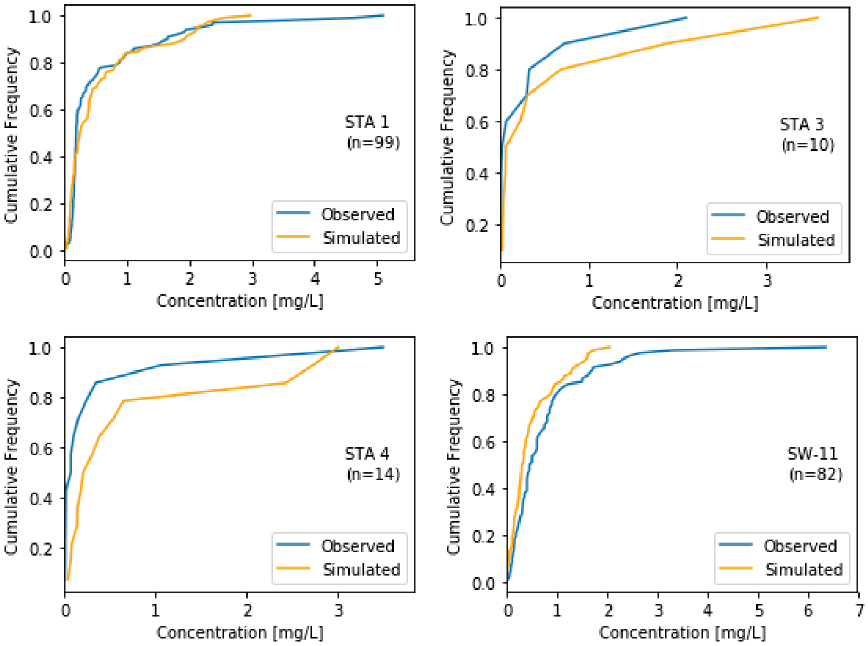

Figure 3: TP CDFs for Lower Watershed, STA 1 , STA 3 (upper right), STA 4 (lower left), and SW-11 (lower right)

Nitrate + Nitrite (NO_3 + NO_2)

Upper watershed station NO_3 + NO_2 CDF curves, shown in Figure 8, illustrate that the model matches observed concentrations moderately well in undeveloped conservation areas. All three of these stations have relatively few monitoring points. The error in the three curves are not in a consistent direction (STA 6 has high concentrations, STA 7 has low concentrations, and the STA 8 curve under estimates the lower half of the curve and over estimate the top half). The error in the STA 6 curve can be partly explained by considering the location of the STA 6 monitoring station, which is immediately upstream of a developed area. The HSPF model reach that was queried to get this output, RCHRES 95, includes some urbanized area immediately downstream of the monitoring station. Shifting the Sub-basin 95 boundary up gradient to exclude this urbanized area would be expected to improve the match between the simulated and observed concentrations. The STA 7 curve misses a single high sample of just below 0.4 mg/L, but this could not be matched without degrading the match at STA 8.

Lower watershed station NO_3 + NO_2 CDF curves, shown in Figure 9, illustrate how well the model matches observed concentrations in the watershed overall. The simulated curve at STA 1, which is again the most reliable curve due to the number of observed samples, matches the observed curve relatively well.

The simulated CDF curves at STA 3 and STA 4 are slightly high (i.e. right) relative to the observed curves, but like the TP curves at these stations, the NO_3 + NO_2 curve (i.e. shifting them left) does not match without degrading the calibration at STA 1. It is possible that the groundwater baseflow routed from upstream catchments in the study area, which is assumed to enter Waikele Stream at RCHRES 14, actually enters further upstream in RCHRES 16, thus affecting this site. However, observed flow data at the mouth of Kipapa Stream (RCHRES 48) indicated that reach is frequently dry (thus confirming that the assumption that baseflow enters at RCHRES 14 is accurate). The relatively poor matches at these stations STA 3 and STA 4 were considered acceptable due to the limited number of observed samples and the lack of an identified mechanism to improve the calibration.

At the SW-11 location on Upper Waikele Stream the simulated CDF curve follows the trend of the observed curve closely but slightly under estimates the peak observed sample, which approached 2 mg/L.

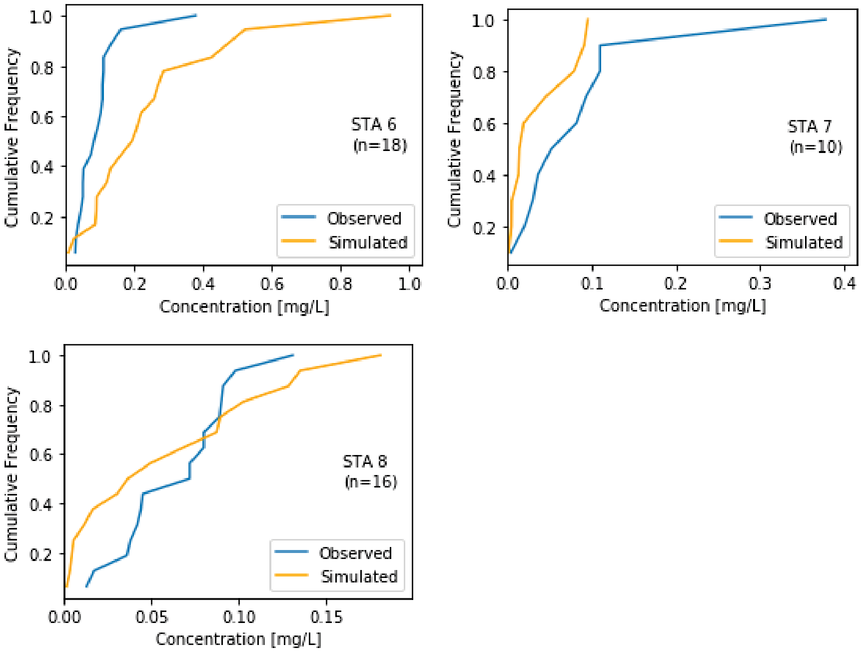

Figure 4: NO_3 + NO_2 CFD for Upper Watershed, STA 6 , STA 7 (upper right), and STA 8 (lower left)

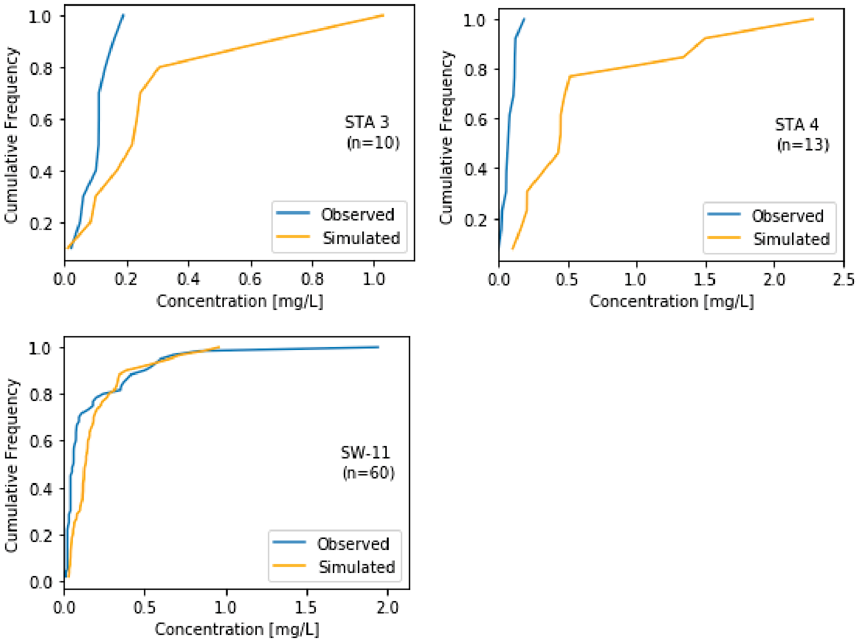

Figure 5: NO_3 + NO_2 CFD for Lower Watershed, STA 1 , STA 3 (upper right), STA 4 (lower left), and SW-11 (lower right)

Total Nitrogen (TN)

Upper watershed station TN CDF curves, shown in Figure 6, illustrate how well the model matches observed concentrations in undeveloped conservation areas. Given how few observed samples were available for these sites, the fit of the simulated and observed CDF curves are considered acceptable.

Lower watershed station NO_3 + NO_2 CDF curves, shown in Figure 7, illustrate how well the model matches observed concentrations in the watershed overall. The simulated curve at STA 1, which is again the most reliable curve due to the number of observed samples, matches the observed curve relatively well. The quality of the matches to the STA 3 and STA 4 CDF curves are comparable to that of STA 1 and are also considered acceptable.

At the SW-11 location on Upper Waikele Stream the observed TN concentrations are very high, frequently exceeding 10 and even 50 mg/L, while the simulated concentrations never exceed 10 mg/L. This is by far the biggest deviation of the model from the observed data across all parameters. Further review of the observed data at SW-11 reveals that nearly all of this TN is in an organic form. To increase the simulated concentrations to match these very high observed samples would require identifying and calibrating a source of organic nitrogen that has not yet been identified. The CDF curve for this site has been accepted as-is, but the <u>under-estimation of simulated TN at this location should be considered when making management decisions based on model output</u>.

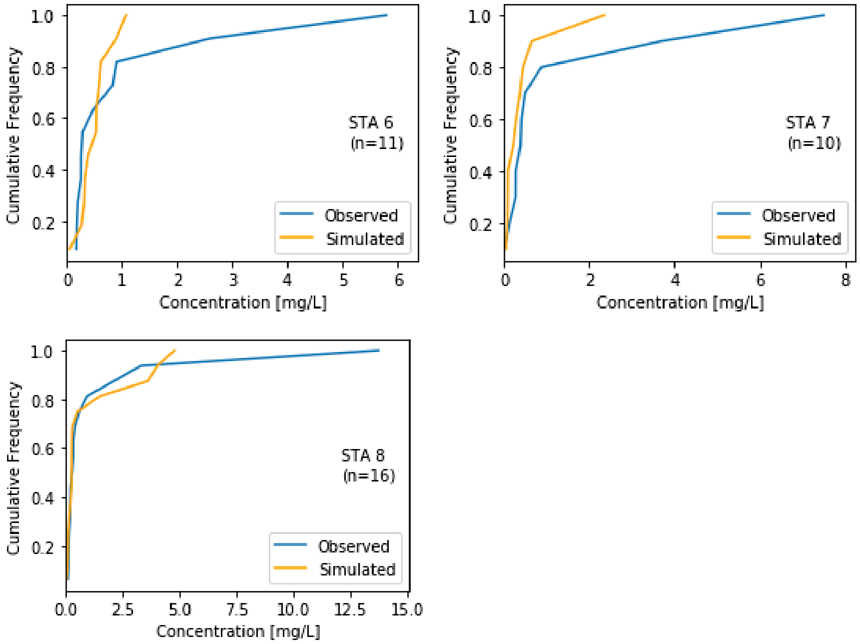

Figure 6: TN CFD for Stations STA 6 , STA 7 (upper right), and STA 8 (lower left)

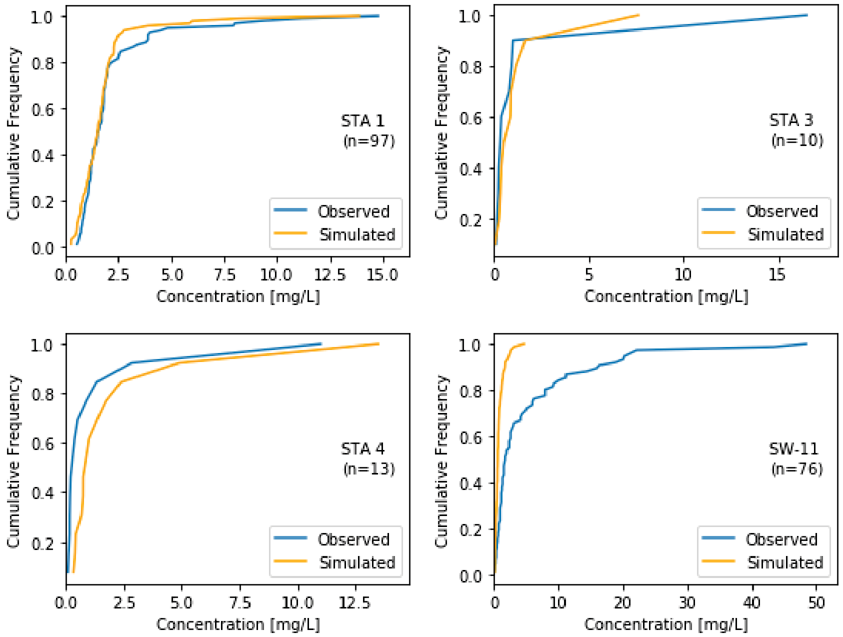

Figure 7: TN CFD for Stations STA 1 , STA 3 (upper right), STA 4 (lower left), and SW-11 (lower right)

3.3 Nutrient Calibration Results — Annual, Wet, and Dry Season Concentrations

Tabulations of observed and simulated concentrations, expressed as geometric means, are provided in Table 4 through Table 6. The values used to calculate these geometric means are identical to those used to generate the CDF curves in the prior section. That is, simulated concentrations were sampled from the simulated time-series at the same time intervals for which observed samples were collected. If there was no simulated discharge at the time an observed sample was collected then both the simulated and observed sample were ignored. This treatment of the data was of particular relevance when reviewing the data in Upper Waikele Stream, where the stream is typically dry. While the model's hydrology calibration discussed in NHC (2017) does a good job of matching the general runoff behavior in the system, there is not adequate rainfall data to fully capture the flashiness of this portion of the watershed. Additionally, it is not known if these samples might have been collected from pools or other areas of near standing water at times when the river was not flowing. As a result, many of the time-intervals for which samples were collected at stations SW-6, SW-11, and SW-12, have no simulated concentration for which to compare. The Sample Count columns on the table list both the number of samples used to calculate the geomean and the total number of observations available.

There is no commentary to accompany these tables. The reader is referred to Section 3.2 for commentary on the quality of the calibration at each site for each parameter.

Table 4: Simulated and Observed TP Concentrations

Station Name	HSPF RCHRES ID	Annual TP			Wet Season TP			Dry Season TP		
		Observed GeoMean (mg/L)	Simulated GeoMean (mg/L)	Sample Count[2]	Observed GeoMean (mg/L)	Simulated GeoMean (mg/L)	Sample Count[2]	Observed GeoMean (mg/L)	Simulated GeoMean (mg/L)	Sample Count[2]
STA 1	10	0.293	0.294	[99 of 99]	0.236	0.273	[55 of 55]	0.384	0.321	[44 of 44]
[1]Waikele Stream above H-1	10	0.044	0.070	[4 of 4]	0.052	0.033	[3 of 3]	0.026	0.650	[1 of 1]
STA 3	48	0.061	0.179	[10 of 10]	0.036	0.113	[8 of 8]	0.485	1.133	[2 of 2]
STA 4	16	0.061	0.321	[14 of 14]	0.037	0.166	[10 of 10]	0.216	1.666	[4 of 4]
STA 5A	24	1.031	0.701	[4 of 6]	1.031	0.267	[2 of 4]	0.363	1.844	[2 of 2]
STA 7	84	0.132	0.145	[11 of 11]	0.094	0.028	[5 of 5]	0.176	0.575	[6 of 6]
STA 6	90+94	0.050	0.138	[12 of 12]	0.014	0.048	[6 of 6]	0.181	0.394	[6 of 6]
STA 8	95	0.062	0.140	[17 of 17]	0.020	0.040	[10 of 10]	0.303	0.824	[7 of 7]
SW-6	35	3.891	0.030	[5 of 28]	3.891	0.030	[5 of 28]			[0 of 0]
SW-11	29	0.486	0.262	[82 of 141]	0.535	0.214	[63 of 90]	0.352	0.513	[19 of 51]

[1] USGS Station No. 212402158010501

[2] Sample Count is expressed as number of samples used to calculate geomean “of” the total number of observed samples. The difference originates from an inability to sample simulated concentrations when stream discharge equals zero.

Table 5: Simulated and Observed NO_2 + NO_3 Concentrations

Station Name	HSPF RCHRES ID	Annual NO^3			Wet Season NO^3			Dry Season NO^3		
		Observed GeoMean (mg/L)	Simulated GeoMean (mg/L)	Sample Count[2]	Observed GeoMean (mg/L)	Simulated GeoMean (mg/L)	Sample Count[2]	Observed GeoMean (mg/L)	Simulated GeoMean (mg/L)	Sample Count[2]
STA 1	10	0.638	0.522	[96 of 96]	0.693	0.448	[55 of 55]	0.571	0.643	[41 of 41]
STA 2	10	0.040	0.787	[4 of 4]	0.051	0.939	[3 of 3]	0.020	0.463	[1 of 1]
STA 3	48	0.091	0.179	[10 of 10]	0.087	0.273	[8 of 8]	0.107	0.032	[2 of 2]
STA 4	16	0.051	0.438	[13 of 13]	0.046	0.448	[10 of 10]	0.074	0.404	[3 of 3]
STA 5A	24	0.403	0.100	[4 of 6]	0.403	0.108	[2 of 4]	0.252	0.092	[2 of 2]
STA 7	84	0.052	0.018	[10 of 10]	0.051	0.019	[5 of 5]	0.054	0.017	[5 of 5]
STA 6	90+94	0.078	0.161	[18 of 18]	0.079	0.220	[13 of 13]	0.074	0.072	[5 of 5]
STA 8	95	0.055	0.065	[16 of 16]	0.057	0.085	[10 of 10]	0.052	0.041	[6 of 6]
SW-6	35	0.512	0.074	[5 of 28]	0.512	0.074	[5 of 28]			[0 of 0]
SW-11	29	0.074	0.136	[60 of 107]	0.078	0.1109	[41 of 62]	0.068	0.179	[19 of 45]

[1] STA 2 was ignored due to too few samples.

[2] Sample Count is expressed as number of samples used to calculate geomean "of" the total number of observed samples. The difference originates from an inability to sample simulated concentrations when stream discharge equals zero.

Table 6: Simulated and Observed TN Concentrations

Station Name	HSPF RCHRES ID	Annual TN			Wet Season TN			Dry Season TN		
		Observed GeoMean (mg/L)	Simulated GeoMean (mg/L)	Sample Count[2]	Observed GeoMean (mg/L)	Simulated GeoMean (mg/L)	Sample Count[2]	Observed GeoMean (mg/L)	Simulated GeoMean (mg/L)	Sample Count[2]
STA 1	10	1.635	1.380	[97 of 97]	1.738	1.426	[55 of 55]	1.508	1.322	[42 of 42]
STA 2	10	0.248	1.135	[4 of 4]	0.251	1.182	[3 of 3]	0.240	1.004	[1 of 1]
STA 3	48	0.549	0.668	[10 of 10]	0.485	0.791	[8 of 8]	0.900	0.341	[2 of 2]
STA 4	16	0.452	1.169	[13 of 13]	0.460	1.065	[10 of 10]	0.426	1.592	[3 of 3]
STA 5A	24	4.756	0.855	[4 of 6]	4.756	1.161	[2 of 4]		0.630	[2 of 2]
STA 7	84	0.451	0.236	[10 of 10]	0.824	0.184	[5 of 5]	0.247	0.303	[5 of 5]
STA 6	90+94	0.516	0.410	[11 of 11]	0.248	0.490	[6 of 6]	1.244	0.332	[5 of 5]
STA 8	95	0.436	0.452	[16 of 16]	0.383	0.352	[10 of 10]	0.540	0.688	[6 of 6]
SW-6	35	17.368	0.428	[5 of 28]	17.368	0.428	[5 of 28]			[0 of 0]
SW-11	29	2.428	0.628	[76 of 131]	2.464	0.542	[59 of 85]	2.320	1.051	[17 of 46]

[1] STA 2 was ignored due to too few samples.

[2] Sample Count is expressed as number of samples used to calculate geomean "of" the total number of observed samples. The difference originates from an inability to sample simulated concentrations when stream discharge equals zero.

3.4 Nutrient Calibration Results — Pollutographs for STA 1

During periods when frequent monitoring data is available pollutograph plots can be used to visualize and compare the timing and magnitude of simulated and observed pollutant concentrations. Location STA 1 is the only site within the study area that has data suitable for this comparison, and only a relatively short period between April 1999 and April 2004 is available at that location. Figure 8 presents this full period, and Figure 9 shows only the period February through June 2002, a period when (sub-daily interval) sequential samples were taken for three storms at STA 1. The data plotted in Figure 8 are individual concentrations (simulated concentrations as red circles and observed as blue plus signs), corresponding to the time-interval that observed samples were collected. In Figure 9 a grey dashed line has been added showing the complete simulated concentration pollutograph. The level of agreement between observed and simulated concentrations in these plots is good, which is expected given the quality of the match in the CDF plots presented previously for this station.

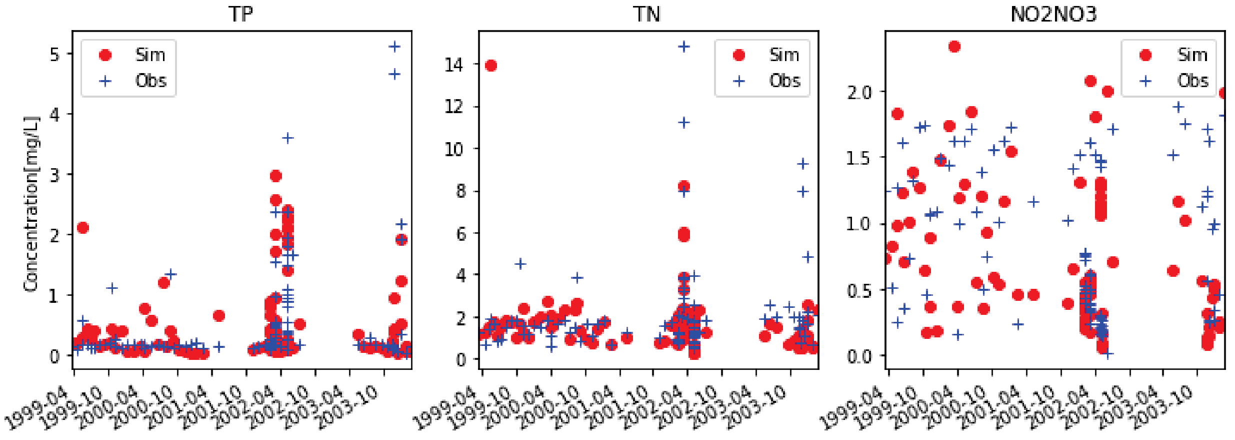

Figure 8: Simulated and Observed TP (left), TN (middle), and NO_2+NO_3 (right) Pollutographs for STA 1 (April 1999 to April 2004)

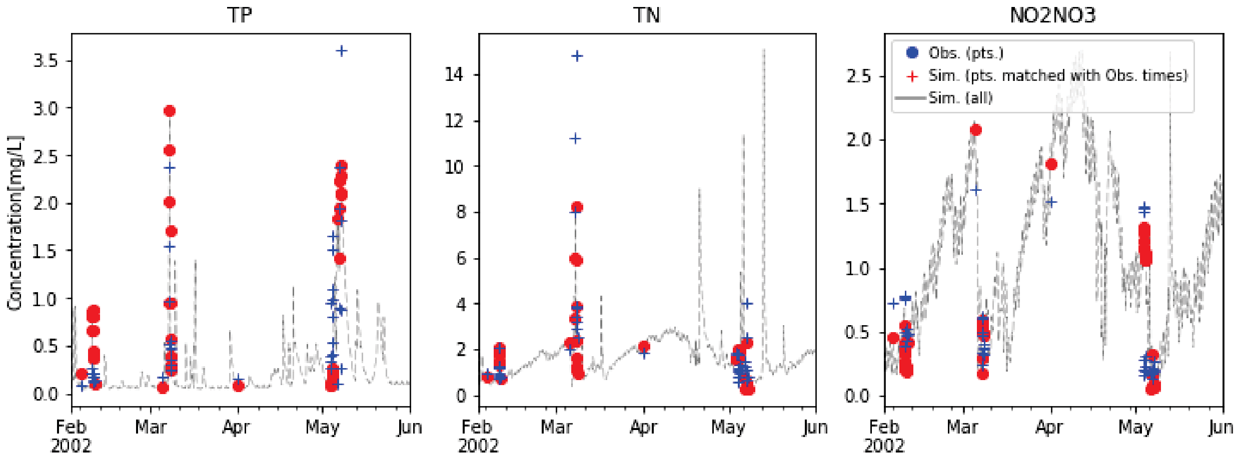

Figure 9: Simulated and Observed TP (left), TN (middle), and NO_2+NO_3 (right) Pollutographs for STA 1 (February to June 2002)

3.5 Nutrient Calibration Results — Loading Rate Per Land Use vs. Literature Values

Unlike some simple water-quality models that utilize a set of pollutant Event Mean Concentrations (EMCs) as inputs, the HSPF model user must define the parameters listed in Section 3.1 to simulate dynamic pollutant loading behavior. Then, the user can query the simulated load or concentration generated from each land use and check these values against expected concentrations of runoff based on watershed-specific monitoring of individual land uses or literature values. These comparisons are important because the model's representation loading rates from different land uses directly affects the distribution of concentrations within the watershed which in turn informs TMDL allocations and the associated management actions to achieve those allocations.

If reliable local, in-watershed data reflecting loading from specific land uses are available, they take highest priority in model calibration. Reliable data from nearby watersheds with similar physical characteristics are the next best source, while data reflecting similar land uses from more distant watersheds, or literature values representing national databases are of lower priority. There has not been a systematic local monitoring program that includes all of the land-uses included in the HSPF model. However, DFM-SWQ has been collecting stormwater samples from four residential areas on Oahu located in the Kaukonahua, Manoa, Mililani, and Pearl City districts. These data were assembled for this project and are summarized in Table 7. DFM-SWQ and their consultant, WSP USA (formerly Parsons Brinkerhoff) have not formally reported these results, so they should be considered draft. The volume and number of sites for which monitoring data has been collected is not adequate to fully characterize loading rates across the island, but they provide the best available information at this time. Residential is the dominant urban land use in the study area.

Table 7: Draft Oahu Stormwater Nutrient Characterizations (courtesy of DFM-SWQ)

Constituent	Season	Mean Concentrations (mg/L) by Monitoring Location						
		Pearl City	Kaukonahua	Manoa	Mililani	Minimum	Average	Maximum
TP	All	0.27	0.11	0.12	0.08	0.08	0.15	0.27
	Wet	0.16	0.18	0.13	0.10	0.10	0.14	0.18
	Dry	0.30	0.06	0.11	0.07	0.06	0.14	0.30
NO^3	All	0.20		0.14	0.10	0.10	0.15	0.20
	Wet	0.09		0.12	0.11	0.09	0.11	0.12
	Dry	0.23		0.16	0.08	0.08	0.16	0.23
TN	All	1.05	1.11	0.79	0.83	0.79	0.95	1.11
	Wet	0.70	1.43	0.84	1.03	0.70	1.00	1.43
	Dry	1.14	0.85	0.74	0.59	0.59	0.83	1.14

The local residential pollutant characterization data in Table 7 was supplemented with other literature sources characterizing pollutant runoff from the mainland U.S. to assign expected concentrations by land use to each of the dominant land uses in the study area. These other sources included data from Washington State Department of Ecology, the Center for Watershed Protection, and the NURP and NSQD databases.

The resulting stormwater pollutant concentration characterizations are tabulated along with the average seasonal simulated concentrations from the HSPF model in Table 8 through Table 10 for TP, NO^2 and NO^3, and TN, respectively. The simulated concentrations are reported by individual precipitation zone and also cumulatively for the entire study area (i.e. All Zones). The All Zones column includes the most data and should be the primary column used to evaluate model performance. Values for individual zones can vary significantly between these zones as a result of soil type, rainfall intensity, and the specific impervious area characteristics within these zones. In some zones the area of a land use within a precipitation zone may be very small, and an atypical distribution of impervious and pervious surface can cause these values to be higher or lower than expected. In an effort to aid the reader in interpretation of this table, the table cells have also been shaded a gradient of blue, white, and red with blue being low values, red being high values, and white values filling in the middle. The reader should note that not all land uses have literature based characterizations listed, and only the local data has the nutrient characterization differentiated by season.

HSPF simulated TP concentrations listed by land use in Table 8 show varying levels of consistency with literature values. For the low-medium residential category that most closely matches the land uses characterized by Table 7, simulated values fall close to the upper range observed elsewhere on Oahu for all but one precipitation zone during the dry season and most the precipitation zones during the wet season. The dry season exception, and the largest residential use deviation overall, is precipitation zone 4 (Central Valley) where dry season TP concentration 0.50 mg/L exceeds the maximum observed elsewhere (0.30 mg/L). The dry climate in this region, combined with the somewhat atypical residential land use on the Army base are possible explanations for this discrepancy. Among the other land uses, simulated average concentrations for commercial and conservation areas match literature values fairly closely, falling above the listed value in some rainfall regions and below in others. In addition to the listed literature values, model confidence in the calibration of conservation areas is bolstered by the fact that STA 7 and STA 8 receive drainage from areas that are almost exclusively in conservation use. The agricultural land use category is by far the largest contributor of TP within the watershed. This is not unexpected given the association of TP with sediment and the high sediment load contribution from agriculture identified in NHC (2017).

Simulated NO_2+NO_3 average concentrations by land use shown in Table 9 show a similar level of consistency with literature values found for TP for most land uses. Simulated Low-Medium density residential NO_2+NO_3 concentrations are consistently <u>above</u> the range observed elsewhere on Oahu (i.e. 0.11 and 0.16 mg/L wet and dry season averages from Table 7), but the observed values are <u>below</u> the range of those found in literature from sites in the mainland U.S (e.g. Washington State Department of Ecology reports low intensity residential event mean concentrations of 0.49 and 0.52 mg/L, wet and dry season). It is not surprising that concentrations observed on Oahu are different from those in

Washington State, but additional local monitoring data from both low and high intensity residential should be used to verify this trend when it becomes available. Simulated commercial and conservation values match literature values fairly closely. The agricultural land use category is also by far the largest contributor of NO_2+NO_3 within the watershed, but not to the same degree as TP.

Simulated TN concentrations shown in Table 10 are consistent with literature values at approximately the same level of consistency as that found for TP and NO_2+NO_3. For the Low-Medium density residential category the simulated wet season concentration across all zones (1.02 mg/L) is very close to the average observed elsewhere on Oahu (1.00 mg/L), however the dry season average of 0.28 mg/L is considerably lower than the 0.83 mg/L dry season concentration observed locally. The fact that the simulated residential land uses exclude roadways (or other differences from the limited number of local basins with monitoring data) is one reason simulated TN concentrations may be lower in some precipitation zones. Simulated wet season commercial land use TN concentrations (1.42 mg/L across all zones) is lower than the listed literature concentration of 1.8 mg/L, but not excessively so. This difference could be due to a generally small amount of commercial in most of the precipitation zones, allowing some atypical commercial uses to skew the simulated results. The agricultural land use category is also by far the largest contributor of TN within the watershed, especially during the dry season.

Table 8: Total Phosphorus, Mean Concentrations by Land Use and Precipitation Zone

Land Use	Season	Literature Target (mg/L)	Avg. Simulated Concentration by Precipitation Zone [mg/L]						
			All Zones	1	2	3	4	5	6
Commercial	Wet	0.30	0.34		0.44	0.39	0.33	0.29	
	Dry		0.65		1.06	0.69	0.82	0.57	
Multi-Family Residential + High Density Residential	Wet		0.20		0.22	0.15	0.24	0.16	
	Dry		0.31		0.30	0.24	0.47[2]	0.26	
Low-Medium Density Residential	Wet	0.10 -0.18 (avg. 0.14)	0.21		0.16	0.14	0.17	0.22	
	Dry	0.06 -0.30 (avg. 0.14)	0.33		0.29	0.24	0.50[2]	0.34	
Open Space	Wet		0.28	0.09	0.19	0.17	0.19	0.32	0.17
	Dry		0.70	0.73	0.52	0.25	0.69	0.75	1.22
Golf Course	Wet		0.64		1.11	0.36	0.37	1.03	
	Dry		0.56		0.37	0.24	0.56	0.73	
Conservation	Wet	0.08	0.11	0.11	0.10			0.18	0.13
	Dry		1.19	1.18	0.63			0.75	1.28
Roadway	Wet	0.30	0.41		0.49	0.53	0.43	0.38	
	Dry		0.81		1.19	0.97	1.09	0.71	
Pasture	Wet		0.99					0.99	
	Dry		1.55					1.55	
Fallow	Wet		0.73		0.88	0.86	0.65	0.52	
	Dry		2.62		0.87	0.42	5.86	2.15	
Pineapple	Wet		16.81		17.40	23.07	16.80	13.50	
	Dry		13.87		13.55	1.30	17.19	12.87	
Seed Corn	Wet		27.65		24.62	30.31			
	Dry		10.73		14.01	0.87			
Truck Crop	Wet		21.38		24.62	28.75	13.46	12.24	
	Dry		8.62		13.29	0.54	8.93	9.54	

[1] Cell colors for simulated values indicate relative ranking:
red (high), white (medium), and blue (low)

[2] Residential uses in precipitation region 4 include some bare earth land cover with higher concentrations of TP than typical of this use category.

Table 9: NO_2+NO_3, Mean Concentrations by Land Use and Precipitation Zone

Land Use	Season	Literature Target (mg/L)	Avg. Simulated Concentration by Precipitation Zone [mg/L]						
			All Zones	1	2	3	4	5	6
Commercial	Wet	0.50	0.23		0.22	0.29	0.27	0.20	
	Dry		0.32		0.50	0.39	0.42	0.27	
Multi-Family Residential + High Density Residential	Wet	0.23	0.24		0.26	0.21	0.31	0.17	
	Dry	0.57	0.28		0.44	0.36	0.39	0.24	
Low-Medium Density Residential	Wet	0.09 -0.12 (avg. 0.11)	0.22		0.24	0.22	0.24	0.22	
	Dry	0.08 -0.23 (avg. 0.16)	0.26		0.44	0.36	0.39	0.24	
Open Space	Wet		0.16	0.05	0.19	0.30	0.38	0.13	0.07
	Dry		0.19	0.02	0.34	0.37	0.37	0.19	0.02
Golf Course	Wet		0.47		0.48	0.35	0.54	0.36	
	Dry		0.35		0.48	0.38	0.39	0.28	
Conservation	Wet		0.07	0.07	0.03			0.07	0.07
	Dry		0.02	0.02	0.05			0.05	0.02
Roadway	Wet	0.50	0.20		0.23	0.23	0.21	0.19	
	Dry		0.34		0.51	0.39	0.46	0.30	
Pasture	Wet		0.34					0.34	
	Dry		0.29					0.29	
Fallow	Wet		0.33		0.35	0.27	0.41	0.15	
	Dry		0.32		0.43	0.38	0.30	0.20	
Pineapple	Wet		0.13		0.13	0.11	0.13	0.13	
	Dry		5.70		8.49	5.02	7.08	3.65	
Seed Corn	Wet		0.12		0.13	0.11			
	Dry		7.16		8.51	3.10			
Truck Crop	Wet		0.13		0.13	0.12	0.34	0.12	
	Dry		2.27		8.33	1.66	2.89	2.09	

[1] Cell colors for simulated values indicate relative ranking: red (high), white (medium), and blue (low)

Table 10: Total Nitrogen, Mean Concentrations by Land Use and Precipitation Zone

Land Use	Season	Literature Target	Avg. Simulated Concentration by Precipitation Zone [mg/L]						
			All Zones	1	2	3	4	5	6
Commercial	Wet	1.80	1.42		0.38	2.72	1.20	1.18	
	Dry		0.66		0.10	0.17	0.44	0.83	
Multi-Family Residential + High Density Residential	Wet	1.73	1.25		2.25	0.62	1.73	0.90	
	Dry		0.50		0.13	0.06	0.53	0.53	
Low-Medium Density Residential	Wet	0.70 -1.43 (avg. 1.00)	1.02		0.72	0.30	0.65	1.16	
	Dry	0.59 -1.14 (avg. 0.83)	0.28		0.06	0.05	0.28	0.30	
Open Space	Wet	0.90	1.60	1.01	1.74	1.45	1.15	1.70	0.76
	Dry		2.01	2.61	2.30	0.13	0.58	2.09	2.01
Golf Course	Wet		5.15		10.01	6.24	3.20	5.68	
	Dry		1.86		1.82	0.44	0.66	3.76	
Conservation	Wet	0.90	0.72	0.66	1.22			0.91	0.61
	Dry		1.81	1.65	5.74			1.96	1.55
Roadway	Wet	1.80	0.48		0.61	0.45	0.36	0.56	
	Dry		0.32		0.11	0.08	0.17	0.38	
Pasture	Wet		4.42					4.42	
	Dry		5.28					5.28	
Fallow	Wet		1.65		1.89	3.96	0.83	2.22	
	Dry		2.41		1.24	0.99	1.73	4.93	
Pineapple	Wet		6.58		7.11	9.72	6.01	5.19	
	Dry		50.97		80.83	66.99	56.09	32.60	
Seed Corn	Wet		8.42		7.27	9.44			
	Dry		69.73		79.79	39.43			
Truck Crop	Wet		6.55		7.25	8.97	3.77	3.63	
	Dry		20.38		78.27	18.71	21.09	18.16	

[1] Cell colors for simulated values indicate relative ranking: red (high), white (medium), and blue (low)

4 CONCLUSION

The HSPF water discharge and fine sediment model originally developed by NHC (2017) was modified to activate HSPF nutrient modules and calibrate the model to observed TP, NO_2+NO_3, and TN concentrations.

The resulting simulated nutrient concentrations were evaluated using four comparisons to observed concentrations, CDF curves, average geometric mean concentrations by season, and pollutographs at one location (STA 1), and published literature data. The results indicate that with two exceptions the model does a good job of predicting observed concentrations within the Waikele Stream watershed. The primary exception is the simulation of TN at station SW-11. At this location the observed nitrogen data includes upwards of 50 mg/L of organic nitrogen that is not replicated with the HSPF model. The second exception is the SW-12 location, located immediately downstream of SW-11. Data at SW-12 for all three parameters is not consistent with that observed at other locations within the study area. The author recommends that the USACE be contacted about these data to discover why they were not used in their prior analysis and what might explain the exceptionally high values reported for these locations. Given the high degree of spatial variability in local rainfall data, changing land use, and dynamic hydrologic processes active in the mountainous regions of this watershed, the calibration was considered adequate for the objectives of the project.

Additional monitoring data would help refine several areas of uncertainty within the model calibration. Gaging of agricultural sub-basins could provide a measure of concentrations from individual agriculture crop types and refine the loadings from those areas and would help with development of effective nutrient management strategies.

References

Northwest Hydraulic Consultants, Inc. (2017). *Central Oahu Watershed Studies, Waikele Stream HSPF Model Development.* Prepared for WSP USA (formerly Parsons Brinckerhoff, Inc.), on behalf of the City and County of Honolulu, Department of Environmental Services. Draft April, 2017.