第4單元：集水區水質模式的建立和應用
Session 4: Watershed Modeling

1. 集水區暴雨逕流量估算的模式分析
Modeling Watershed Rainfall-Runoff Process

2.集水區暴雨污染物負荷估算:國環保署BASINS模式
Modeling Watershed Pollutant Transport and US EPA BASINS

3. Ala Wai 集水區模式分析
Modeling Ala Wai Watershed Under BASINS

4. 實例分析和小組討論
Tutorial Session and Group Discussion

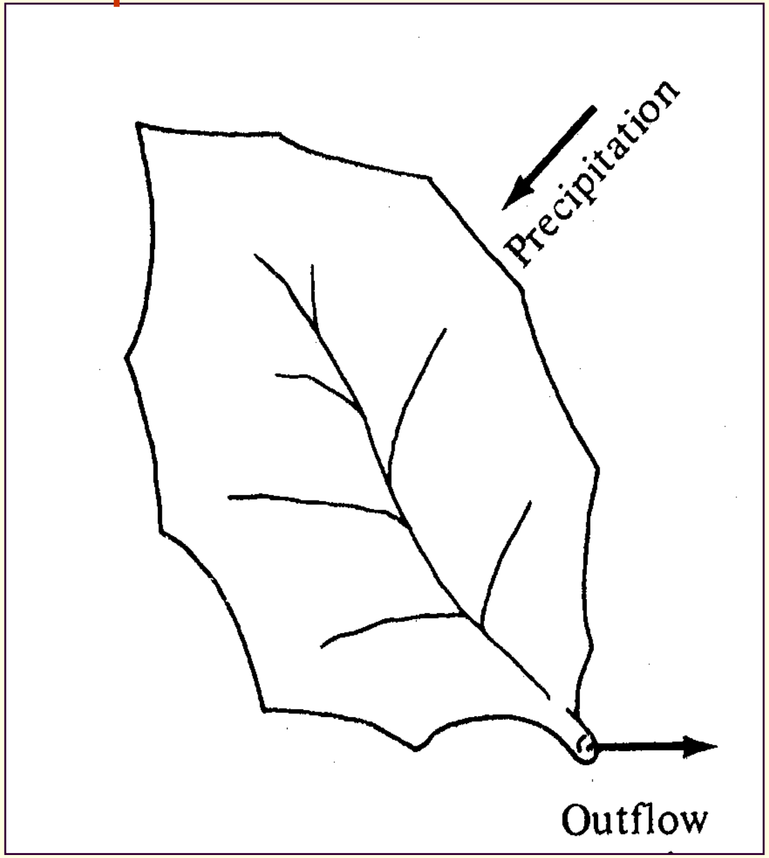
集水區的模式分析

- Watershed Modeling
  - Quantitative Watershed Hydrology
  - Qualitative Waste Loading Estimation

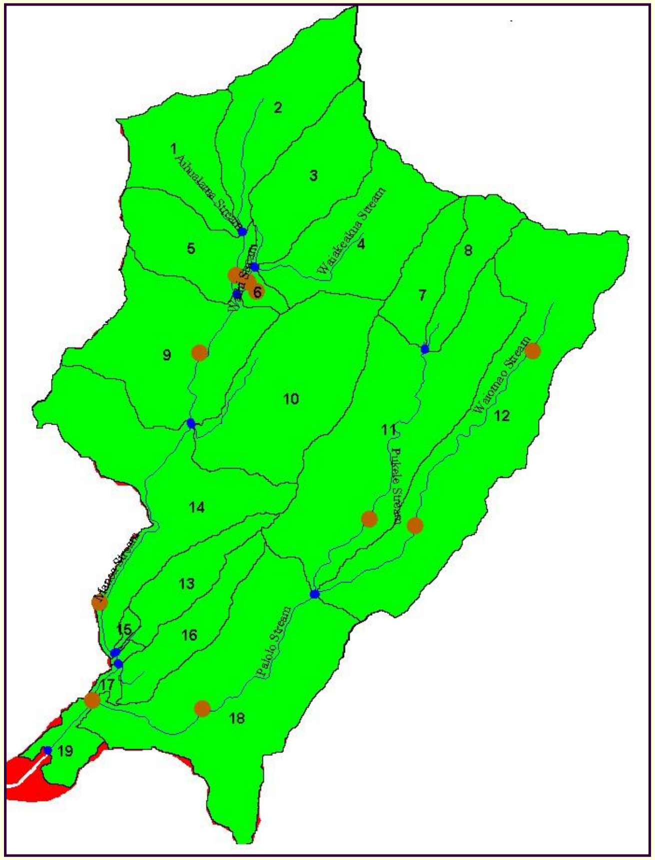
1.集水區暴雨逕流量估算的模式分析

Modeling Watershed Rainfall-Runoff Process

Watershed Rainfall-Runoff and transport Processes



Manoa Watershed and Drainage System



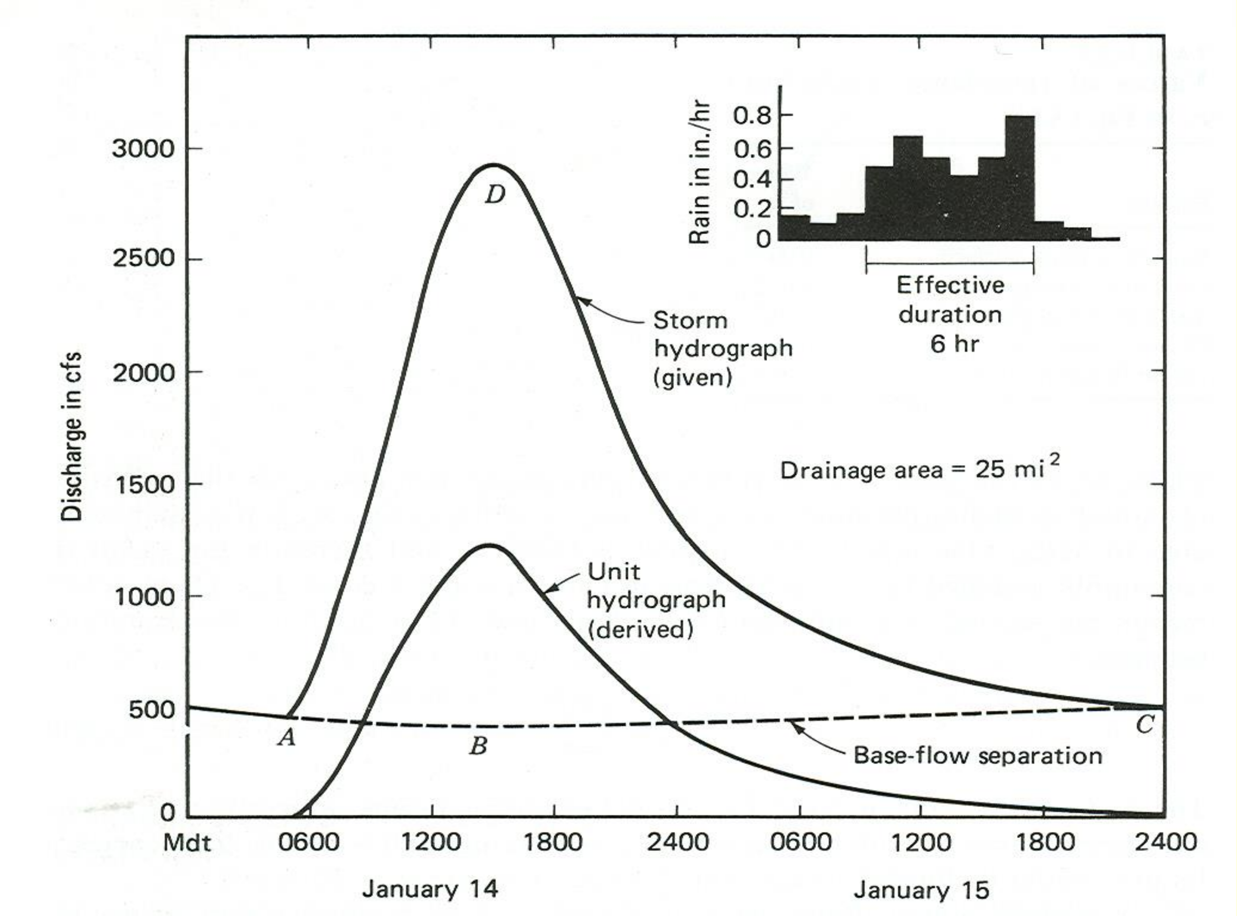
Watershed Rain-Runoff Modeling – A Short Review

Unit Hydrograph
Sherman, 1932

Instantaneous Unit Hydrograph
Huang, 1937; Clark, 1945; Nash, 1957

Nonlinear Watershed Modeling
Amorocho and Brandstetter, 1971; Diskin and Boneh, 1973; Liu and Brutsaert,1978

Sherman Unit Hydrograph Model



Reference: Sherman, L.K. (1932) Streamflow from rainfall by the unit-graph method, Engineering News Record, 108:501-505.

Linear Systems Theory and Sherman Unit Hydrograph Model

Although the Sherman unit hydrograph method considers the watershed as a linear system where the principle of superposition may apply, the unit hydrograph cannot be treated as the system impulse response function of a watershed rainfall-runoff system because it depends on the characteristics of watershed and rainfall.

Modern Unit Hydrograph Model

Modern unit hydrograph method takes a watershed as a linear system and the IUH of the watershed is the systems impulse response function. The effective rainfall is the systems input function and the storm hydrograph is the systems output function. According to the linear systems theory, the system output can be calculated by a convolution integral of the systems impulse response function and input function

$$y(t) = \int_0^t x(\tau)u(t-\tau)d\tau$$

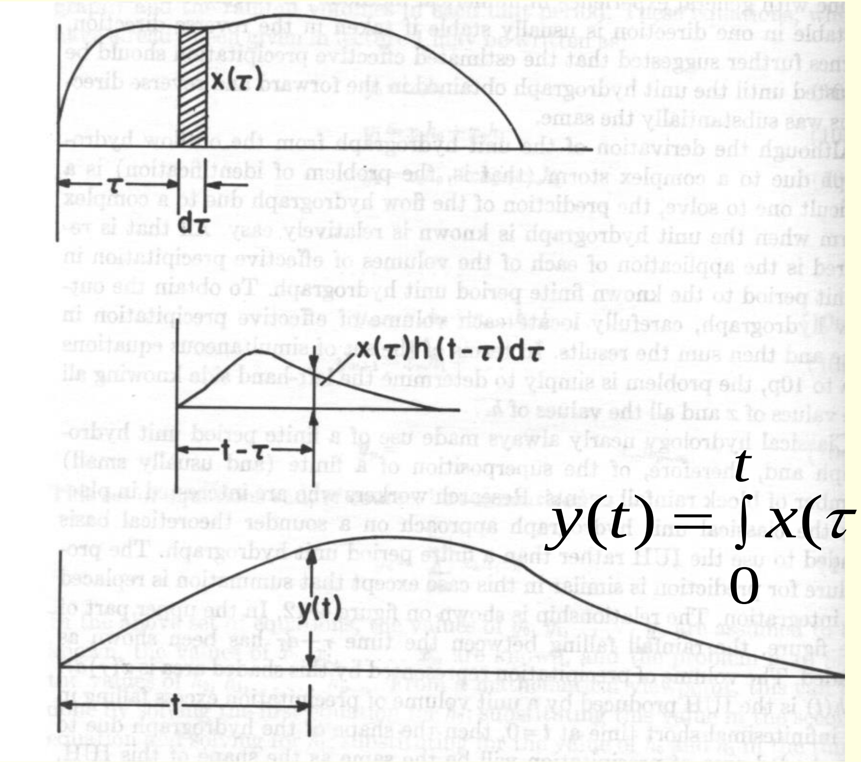
where

u(t) = system impulse response function or IUH

y(t) = the system output function or storm hydrograph

x(t) = the system input function or effective rainfall

Instantaneous Unit Hydrograph Model



$$y(t) = \int_0^t x(\tau)h(t-\tau)d\tau$$

Reference: Nash J.E. 1959. Systematic determination of Unit hydrograph parameters. *J. Geophysical Research* 64: 111-115.

Non-Linear Rainfall-Runoff Modeling

HYDROLOGIC SYSTEMS

Volume I

Rainfall-Runoff Modeling

Vijay P. Singh

Department of Civil Engineering
Louisiana State University

Prentice Hall, *Englewood Cliffs, New Jersey 07632*

17.1.4.6 The Liu-Brutsaert (LB) Method

Liu and Brutsaert (1975, 1978) employed Chebyshev polynomials for analysis of a second-order nonlinear system. These polynomials can be defined as (M. A. Snyder, 1966),

$$P_j(s) = \cos(j \cos^{-1} s), \qquad j = 0, 1, 2, \cdots \tag{17.95}$$

Clearly the polynomials of degree 0 and 1 equal unity. The polynomials of higher degrees can be generated from the recurrence relation

$$P_{j+1}(s) - 2sP_j(s) + P_{j-1}(s) = 0 \tag{17.96}$$

Chebyshev polynomials are orthogonal over the interval (−1, 1) with respect to the weighting function $(1 - s)^{-.5}$, that is,

$$\int_{-1}^{1} P_i(s)P_j(s)(1 - s)^{-.5}\, ds = c_j \delta_{ij} \tag{17.97}$$

where $c_0 = \pi$ and $c_i = \pi/2$ for $j \neq 0$ and δ_{ij} is Kronecker's delta. The first- and second-order kernels in equation (17.49) can be expressed in terms of these polynomials as

$$h_1(s) = \sum_{j=0}^{N_1} c_j P_j(s) \tag{17.98a}$$

$$h_2(s_1, s_2) = \sum_{i=0}^{N_2} \sum_{j=0}^{N_2} c_{ij} P_i(s_1) P_j(s_2) \tag{17.98b}$$

Reference: Singh, V.P. (1988). Hydrologic Systems – Rainfall-Runoff Modeling, Prentice Hall, New Jersey.

Non-Linear Watershed Modeling

A nonlinear watershed model can be formulated as a second order Volterra integral equation which was first introduced to the study of electronics by Wiener (1958).

Volterra integral equation

$$y(t) = x(t) + \int_{-\infty}^{t} h_1(t,s)\, x(s)\, ds$$

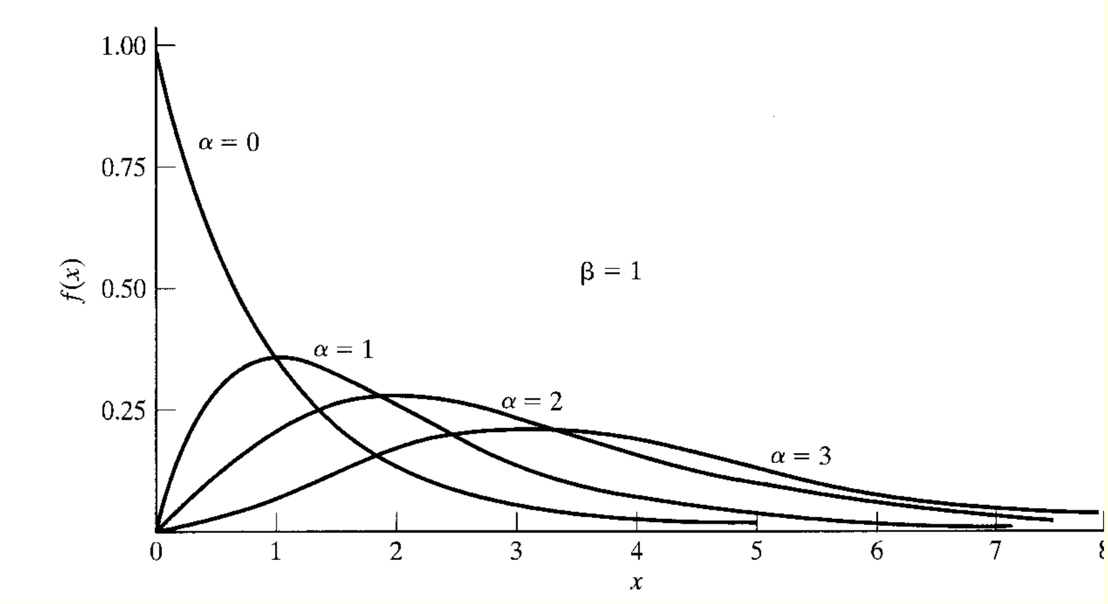
$$+ \int_{-\infty}^{t} \int_{-\infty}^{t} h_2(t,s_1,s_2)\, x(s_1)\, x(s_2)\, ds_1\, ds_2$$

$$+ \ldots + \int_{-\infty}^{t} \ldots \int_{-\infty}^{t} h_n(t,s_1 \ldots s_n) \prod_{i=1}^{n} x(s_i)\, ds_i$$

Reference: Wiener, N (1958). . Nonlinear Problems in Random Theory, The Techn. Press, John Wiley & Sons, NY

Nash IUH in the form of a Gamma Distribution Function

By considering a watershed as a series of linear reservoirs, the synthetic IUH would take the form of a Gamma distribution function, f(x).



$$h(t) = \frac{t^{\alpha} e^{-t/\beta}}{\beta^{\alpha+1}\Gamma(\alpha+1)}$$

where

α is a shape factor

and

β is a scale factor

Reference: Nash, J.E. (1957) The form of the instantaneous unit hydrograph, Proc. Gen. Assem. Toronto, Ins Ass. Sci. Hydrol. 3:144-12

Formulation of Nash IUH Parameters

Nash IUH

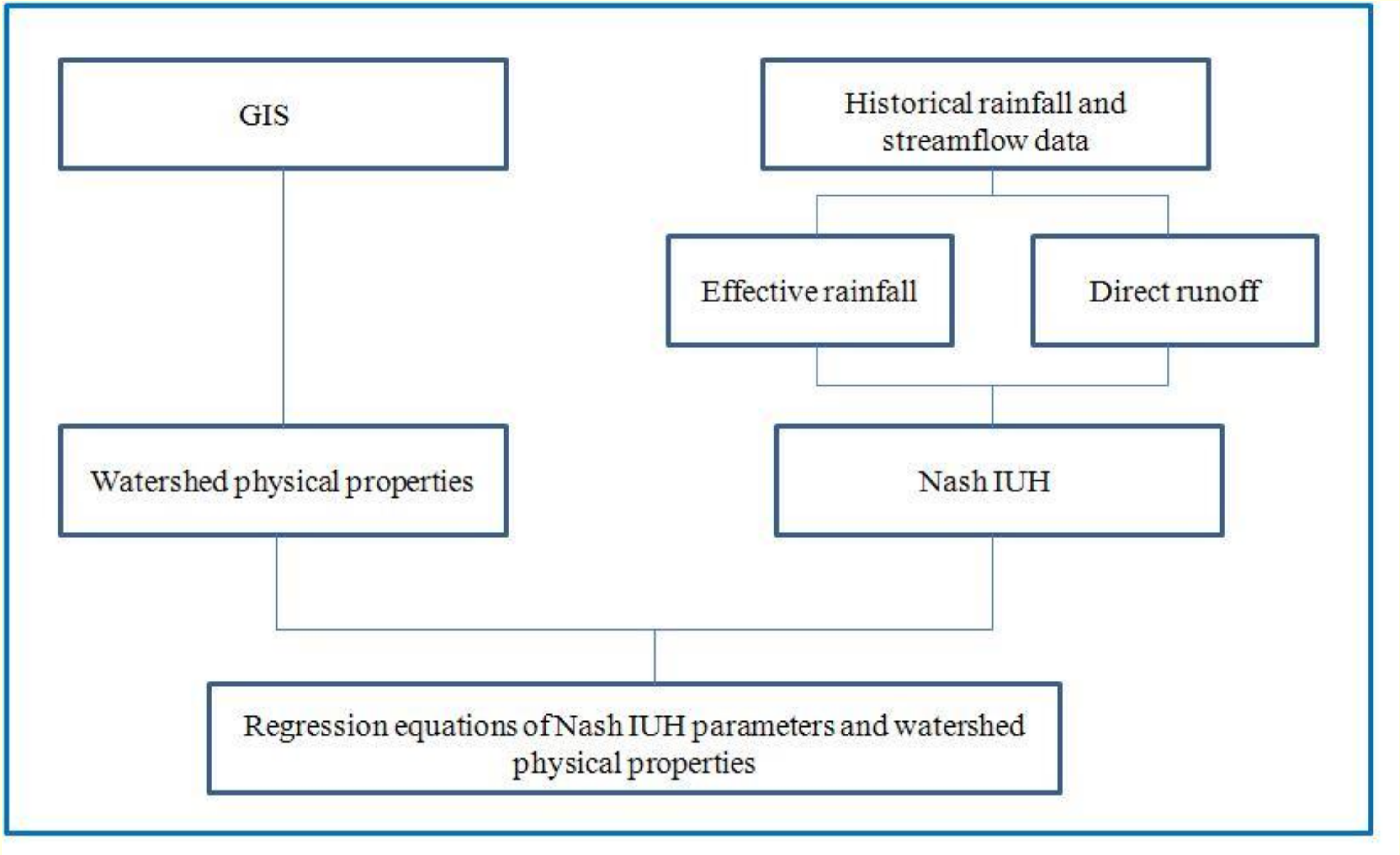
$$h(t) = \frac{1}{\Gamma(\alpha)} \frac{1}{\beta} (\frac{t}{\beta})^{\alpha - 1} \exp(-\frac{t}{\beta})$$

Regression Equations for Nash IUH

$$\alpha = a_0 \; S^{a_1} CN^{a_2} (\frac{A}{L^2})^{a_3}$$

$$\beta = b_0 \; S^{b_1} CN^{b_2} (\frac{A}{L^2})^{b_3}$$

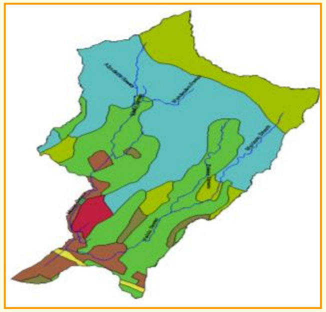
Deriving Regression Equations for Nash IUH Parameters



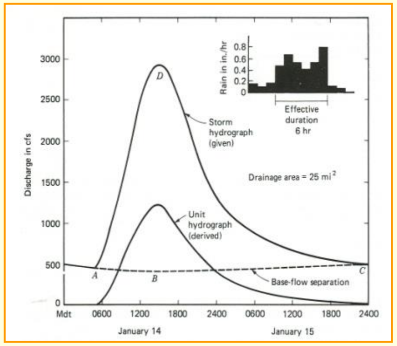
Latest Developments: GIS-Based Nash IUH

BASINS

Watershed characteristics



Historical Rainfall/Runoff Data



Regression Equation

〈 , ®

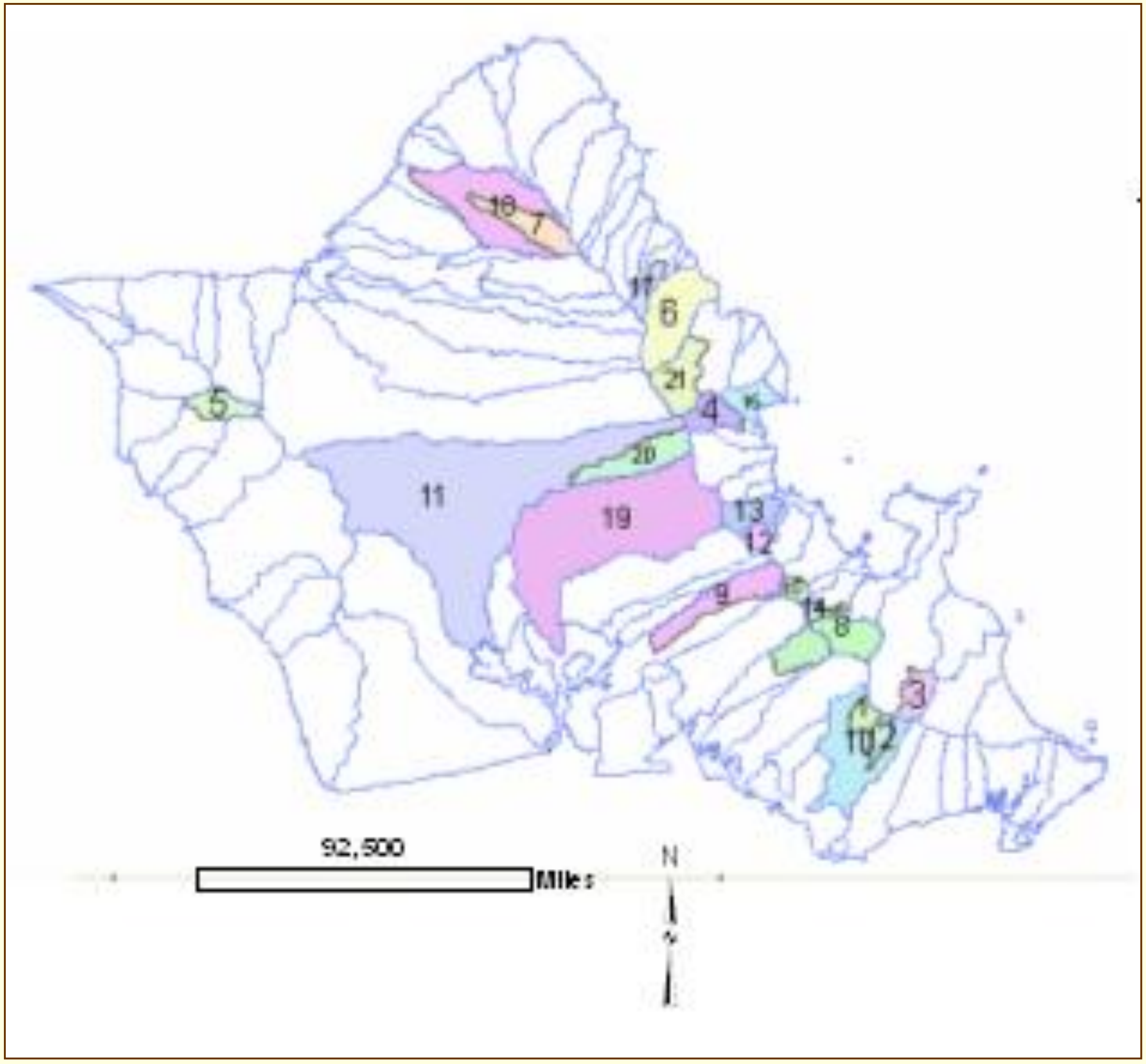
Storm Rainfall

Time-Variant Synthetic IUH

Flood Flow

Reference: Fernandes, K. and Liu, C.C.K. 2011. GIS-based flood hydrograph in Hawaii, (In preparation)

Application of GIS-Based Nash IUH in Hawaii



Regression Equations Derived for Hawaii Watersheds

Watershed	Watershed	USGS ID	By System Inversion		By Using Regression Equations	
Number	Name		λ	β	λ	β
1	Waikeakua	16240500	44.68	14.46	55.67	14.05
2	Puekele	16244000	60.44	32.94	37.98	24.74
3	Makuwo	16254000	24.62	12.13	22.36	13.91
4	Waikana	16294900	65.73	35.53	39.92	24.60
5	Makaha	16211600	71.33	39.41	60.08	36.14
6	Punalu	16303000	36.72	18.45	45.97	28.07
7	Pupukea	16325000	67.32	49.87	94.45	58.01
8	Kooamali	16272200	97.90	55.00	122.88	64.84
9	Halawa	16226400	41.67	21.37	43.57	28.23
10	Manoa	16242500	46.51	34.45	45.44	28.37
11	Waikele	16213000	128.32	72.91	118.36	67.83
12	Kahaluu	16283500	21.22	15.70	28.00	18.00
13	Waihee	16284200	21.71	27.83	37.72	23.47
14	Luluku	16270900	16.50	13.75	23.28	15.58
15	Haiku	16275000	36.00	23.84	26.83	17.00
16	Hakipu	16295300	32.75	15.90	44.90	28.14
17	kalanui	16304200	30.72	14.70	38.23	24.60
18	Waimea	16330000	67.63	37.16	89.93	53.13
19	Waiawa	16216000	138.83	77.56	78.22	46.22
20	Kippa	16212800	90.05	76.97	51.85	32.62
21	Kahana	16296500	65.83	36.17	61.23	37.48

Regression Equations Derived for Hawaii Watersheds

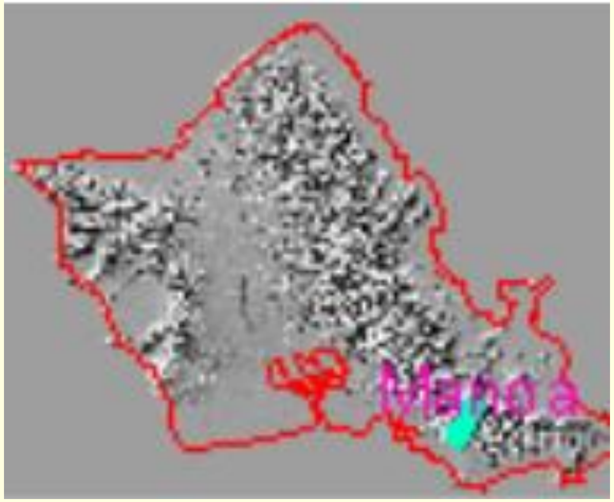
Watershed ID	Watershed Name	USGS ID	A, m^2	L, m	$(A/L)^2$	S	CN
1	Waikeakua	16240500	2.75E+06	1280.00	1.677	57.00	78.00
2	Puekele	16244000	3.06E+06	3525.00	0.246	67.10	79.60
3	Makuwo	16254000	5.29E+06	1146.00	4.026	45.61	71.00
4	Waikana	16294900	5.75E+06	3500.00	0.470	63.28	69.00
5	Makaha	16211600	5.96E+06	4600.00	0.282	50.10	72.00
6	Punalu	16303000	7.21E+06	4219.00	0.405	57.82	70.00
7	Pupukea	16325000	8.11E+06	12515.00	0.052	52.98	80.43
8	Kooamali	16272200	9.88E+06	3288.00	0.914	19.00	68.28
9	Halawa	16226400	1.21E+07	8296.00	0.176	66.78	80.00
10	Manoa	16242500	1.55E+07	6592.00	0.357	53.83	76.00
11	Waikele	16213000	1.18E+08	22072.00	0.243	24.00	82.00
12	Kahaluu	16283500	2.18E+06	1540.00	0.918	58.00	76.00
13	Waihee	16284200	2.51E+06	2200.00	0.519	61.30	71.00
14	Luluku	16270900	1.19E+06	1424.00	0.588	77.00	78.00
15	Haiku	16275000	2.51E+06	1690.00	0.880	71.00	69.00
16	Hakipu	16295300	2.20E+06	2464.00	0.363	53.00	77.00
17	kalanui	16304200	2.88E+06	3836.00	0.196	83.00	73.00
18	Waimea	16330000	3.27E+07	17095	0.112	48.89	74.6
19	Waiawa	16216000	6.84E+07	16666	0.246	39.1	75.23
20	Kippa	16212800	1.11E+07	7992.00	0.174	61.82	78.61
21	Kahana	16296500	9.69E+06	6966.00	0.200	52.18	75.27

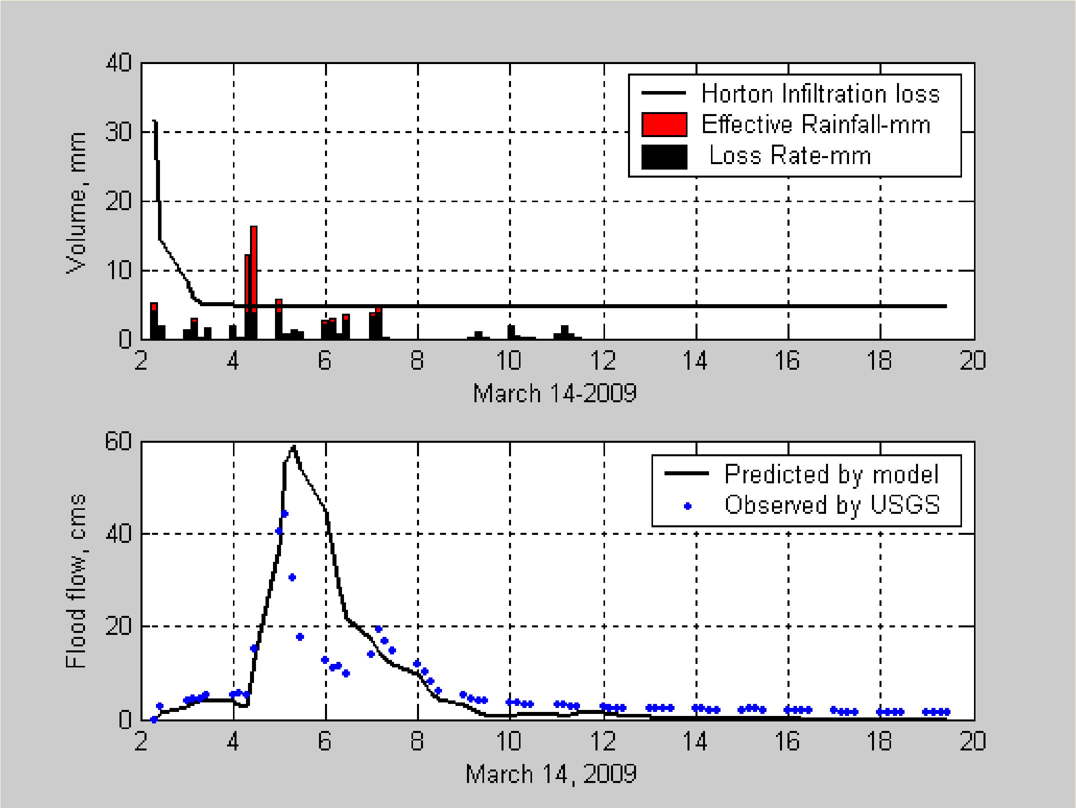
Regression Equations of GIS-Based Nash IUH for Hawaii Watersheds

$$\alpha = 6.57x10^{6}\ S^{-1.152} C_N{}^{-1.783} (\frac{A}{L^2})^{-0.422}$$

$$\beta\ = 3.0x10^{5}\ S^{-1.02} C_N{}^{-1.36} (\frac{A}{L^2})^{-0.397}$$

Application of GIS-Based Nash IUH in Hawaii: Manoa Watershed

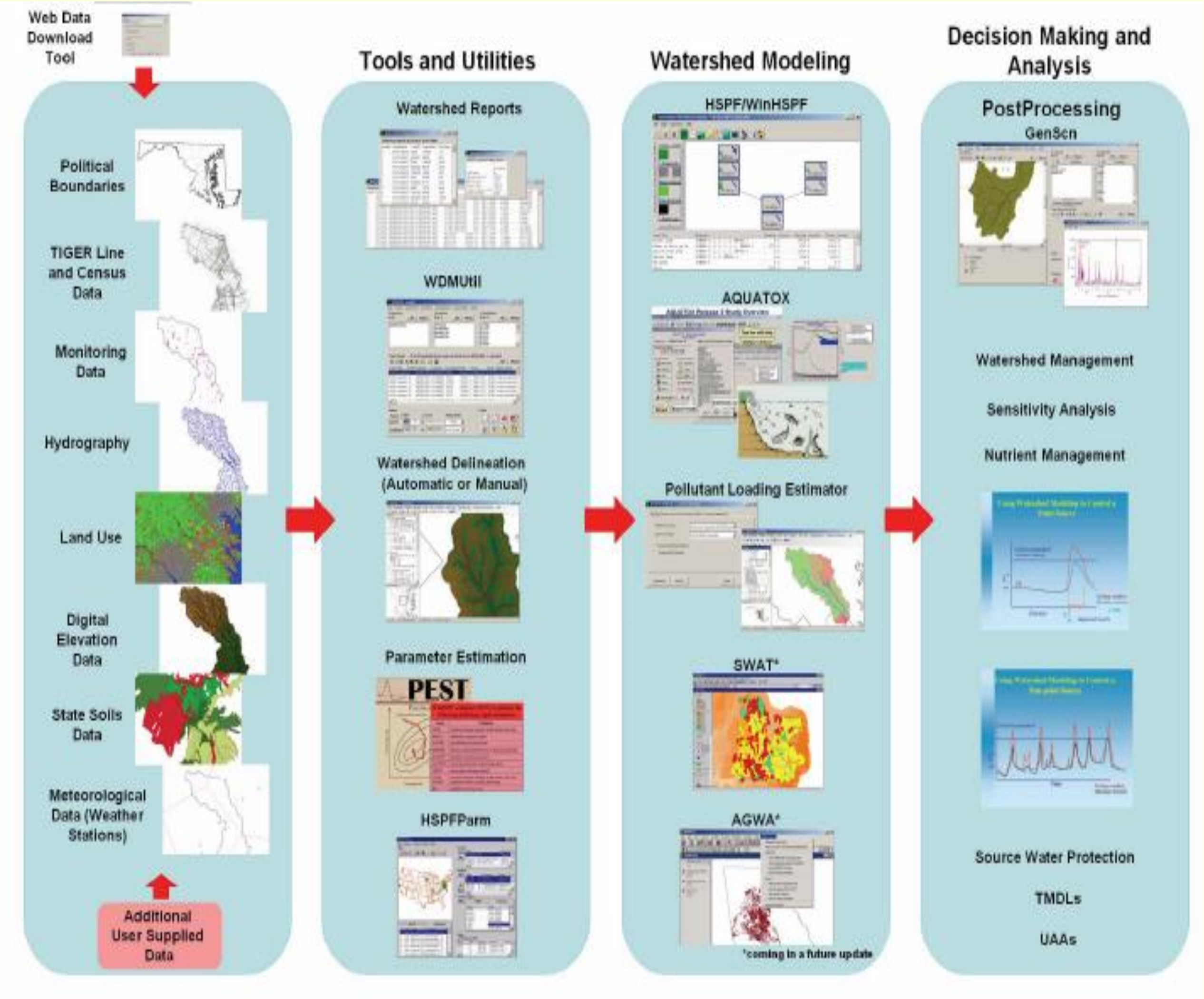




2.集水區暴雨污染物負荷估算:BASINS模式

Modeling Watershed Pollutant Transport and US EPA BASINS

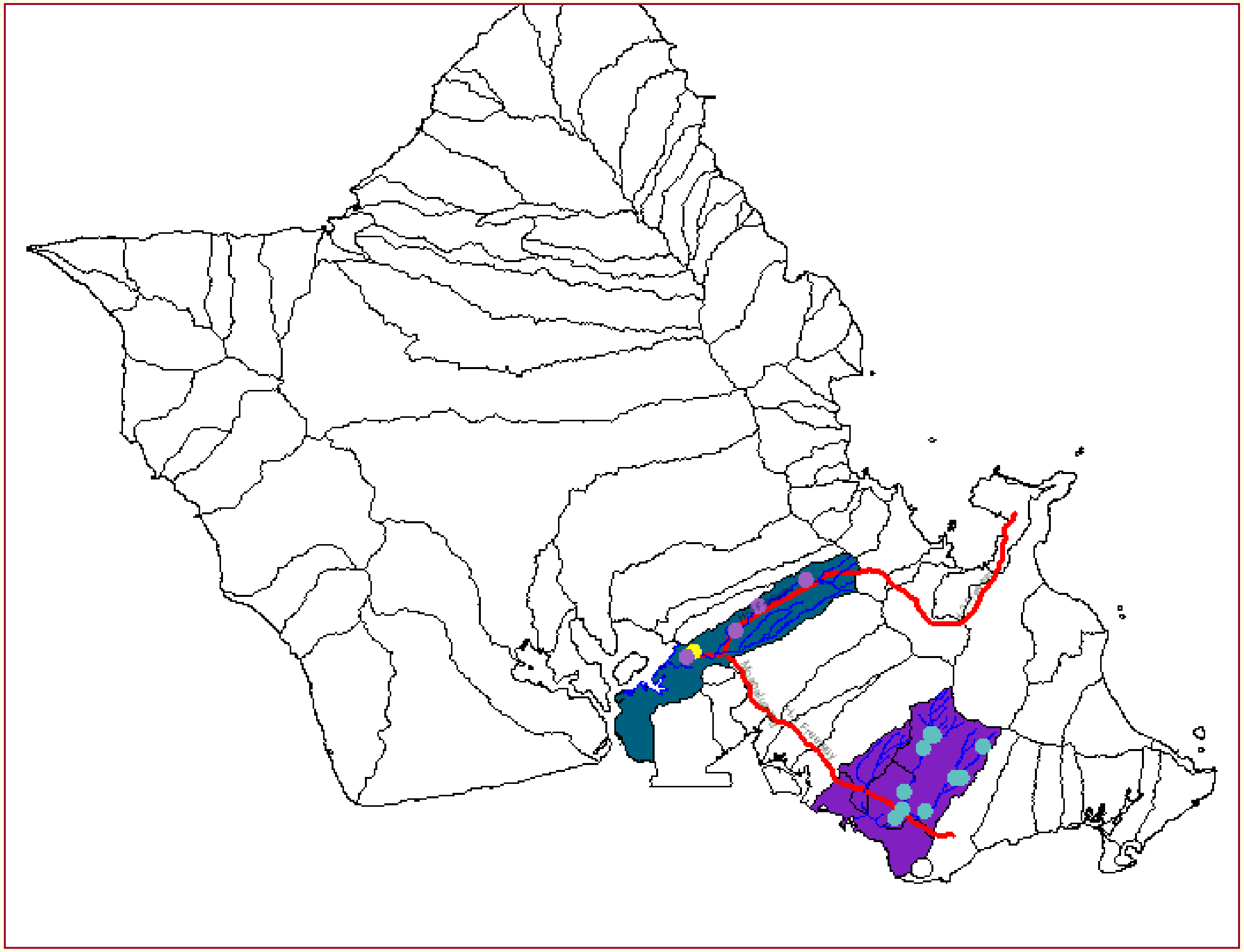
U.S. EPA BASINS Overview



3. Ala Wai 集水區模式分析

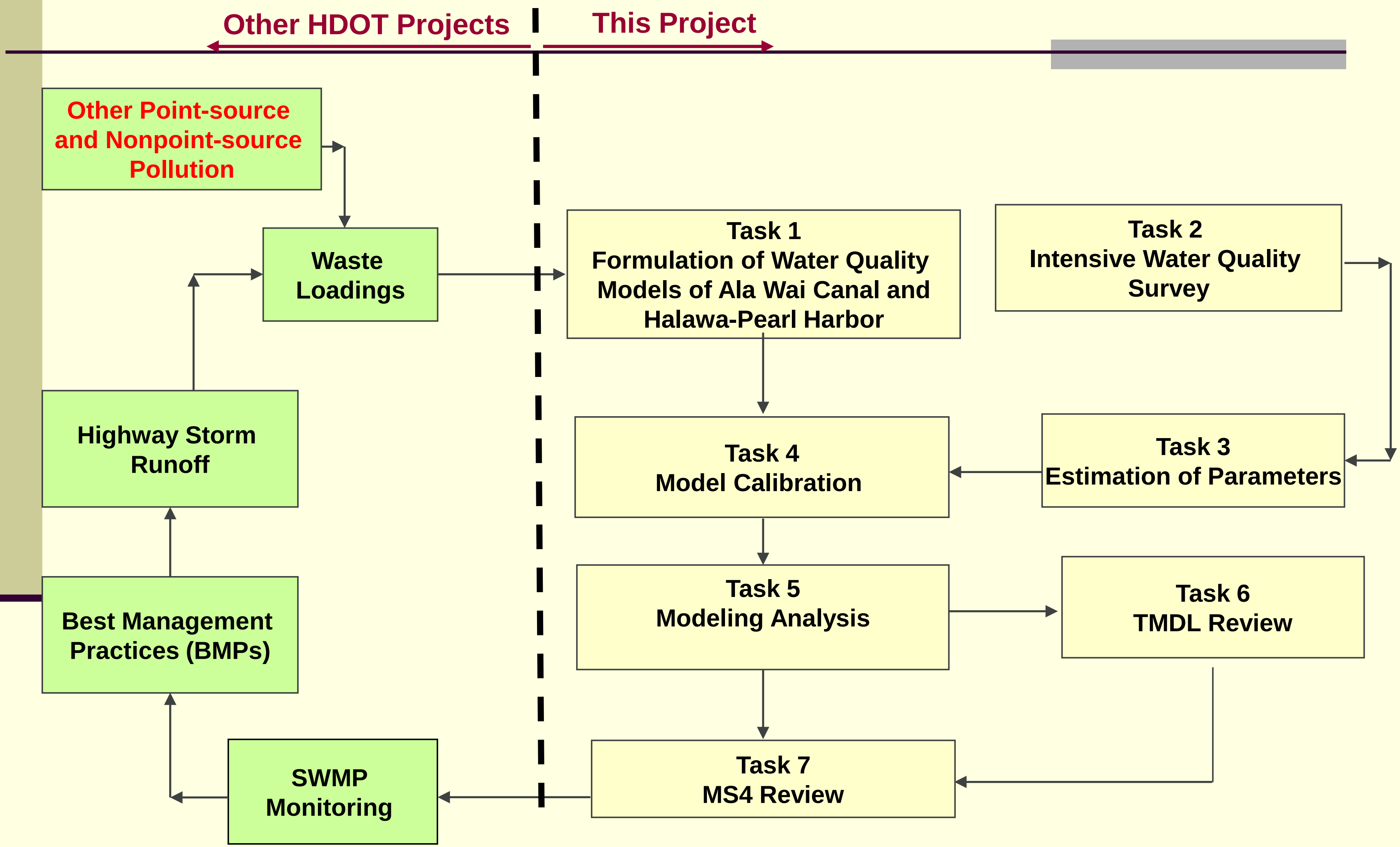
Modeling of Ala Wai Watershed

Hawaii Depart of Transportation project on Survey and Modeling Analysis of HDOT MS4 (Municipal Separate Storm Sewer System) Highway Storm Runoff

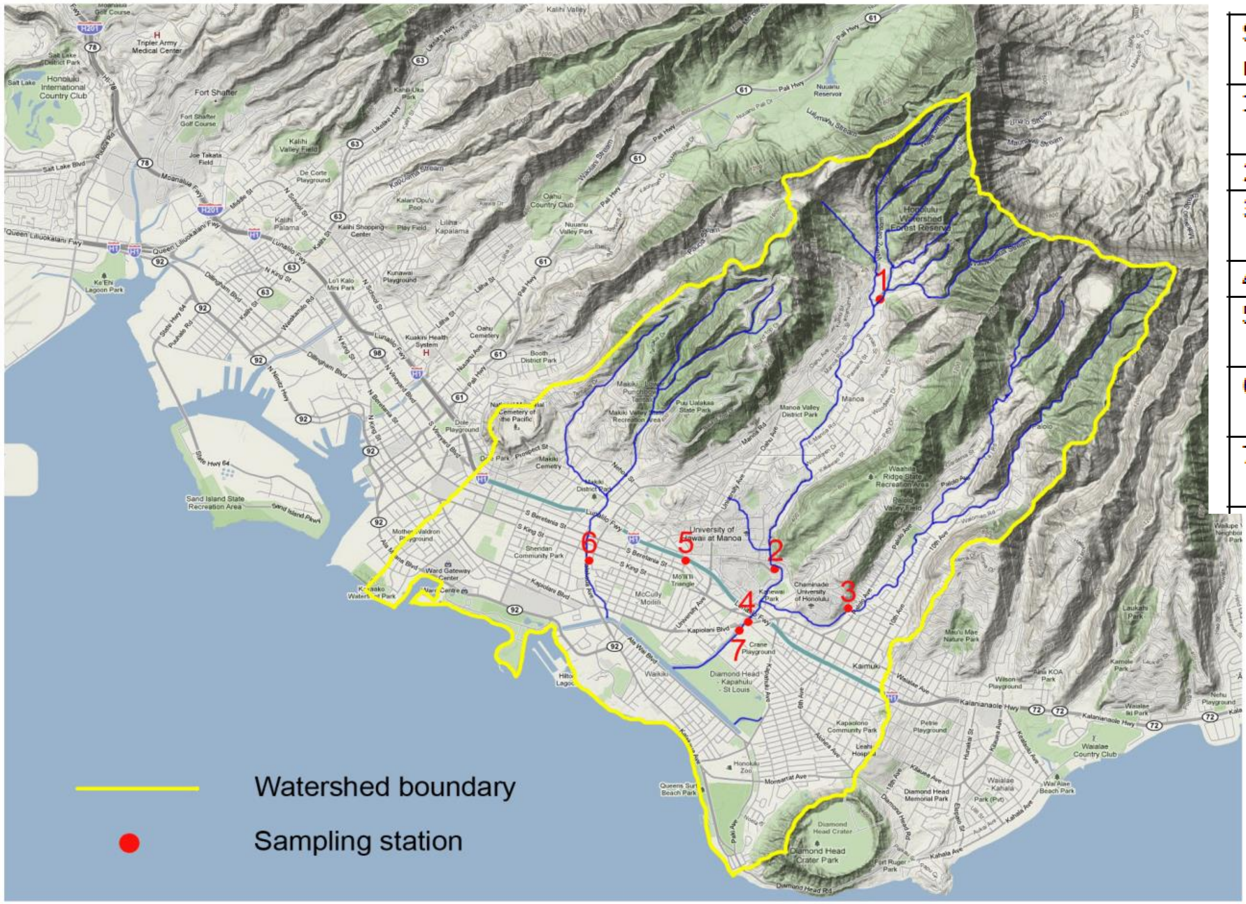


Hawaii Department of Transportaion Project

Approach and Methodology



Design and Construction of a Monitoring Network for the Ala Wai Drainage System



Station #	Site
1	Waiakeakua Stream – Upper Manoa
2	Manoa Stream at Kanewai
3	Palolo Stream Near Palolo Ave.
4	H1-storm drain at Kapiolani Blvd.
5	H1-storm drain at Isenberg St.
6	Makiki Stream
7	Manoa-Palolo Stream at Kaimuki HS School

Monitoring station of Manoa Stream at UH-Manoa Hawaiian Study Center

Monitoring station of Manoa-Palolo stream at Kaimuki High School.

Monitoring station of H1 freeway intake at Isenberg Street

Field Survey

Field Measurements

- Rainfall
- Flow
- Water Temperature
- Dissolved Oxygen

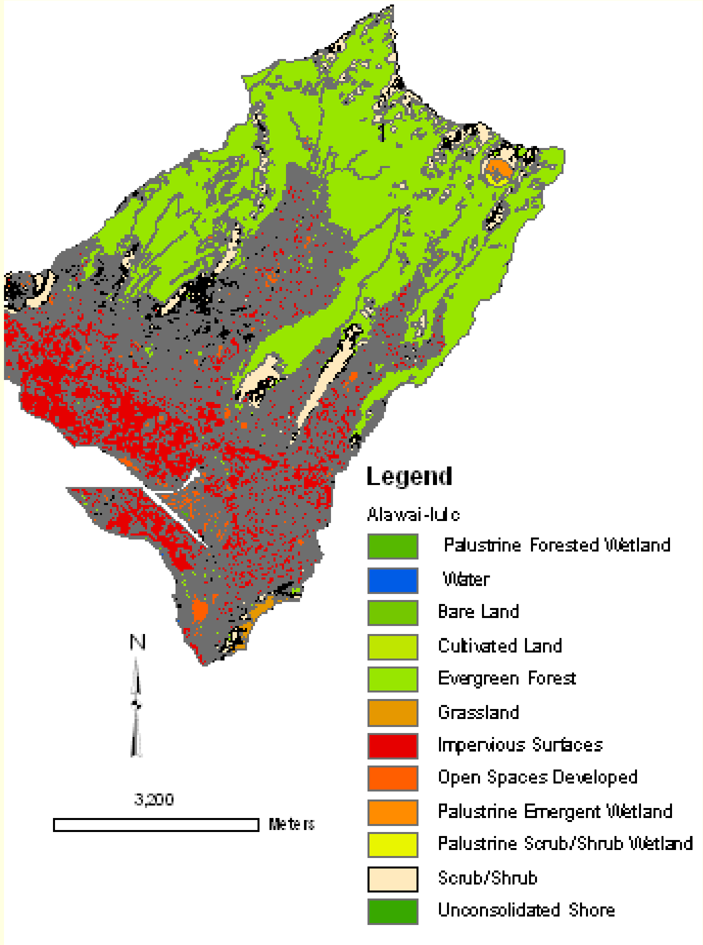
Field Samples analyzed at UH-Manoa Laboratory

- Total suspended Solids
- Total Nitrogen

Model Formulation

BASINS/PLOAD Model

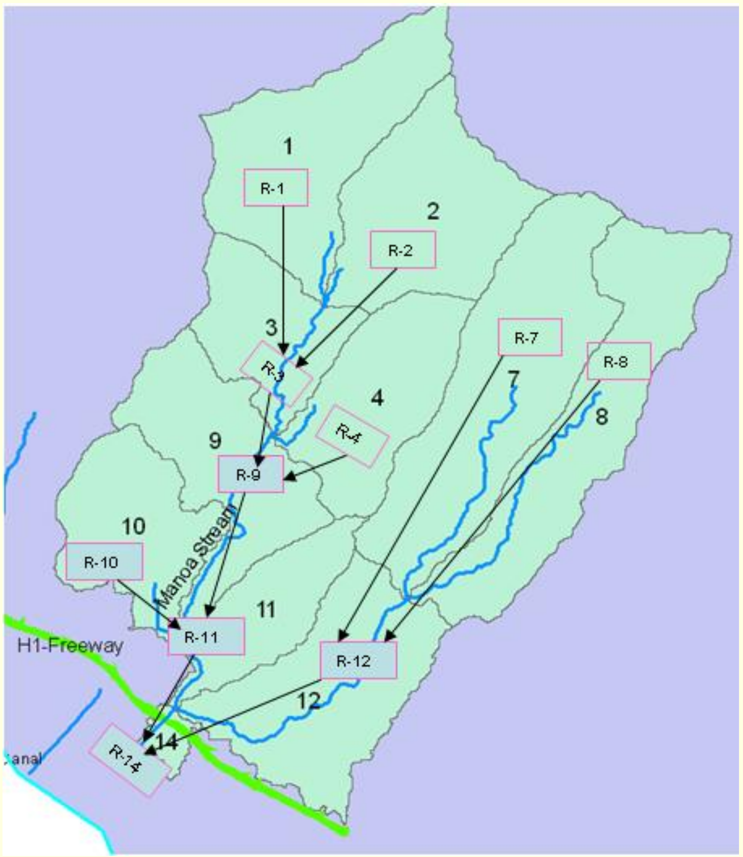
PLOAD is a simplified GIS based model for calculating average annual pollutant loads.

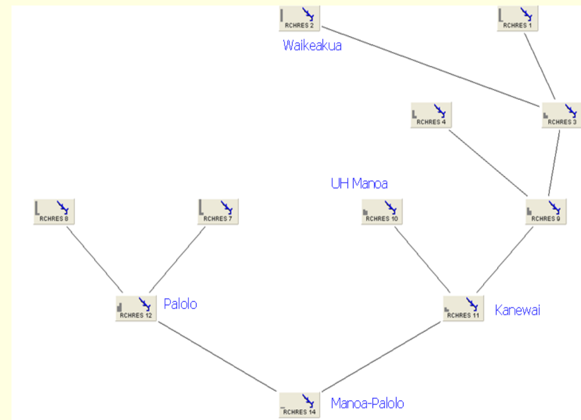


Model Formulation

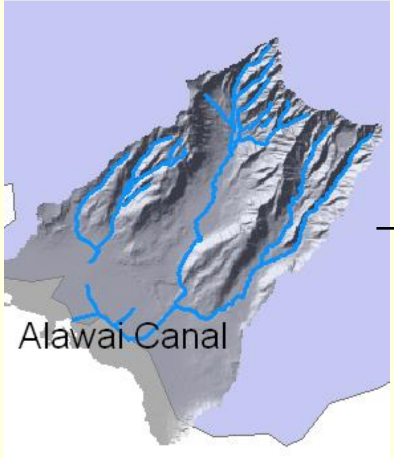
BASINS/HSPF Model

The HSPF model is developed to simulate time-variable flow and pollutant load. In HSPF model, a watershed is divided into several sub-watersheds. A sub-watershed consists of land segments and water bodies which can be either streams or reservoirs.

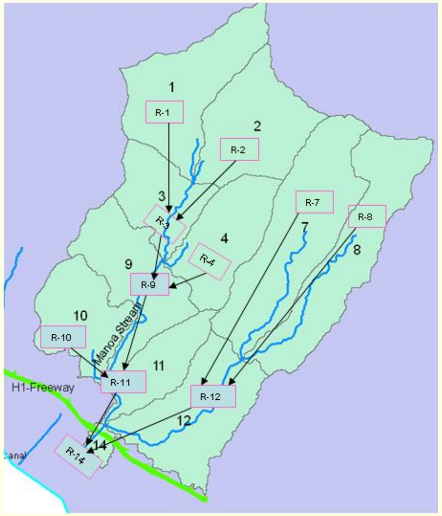




Watershed Characteristics and BASINS/HSPF modeling



Watershed

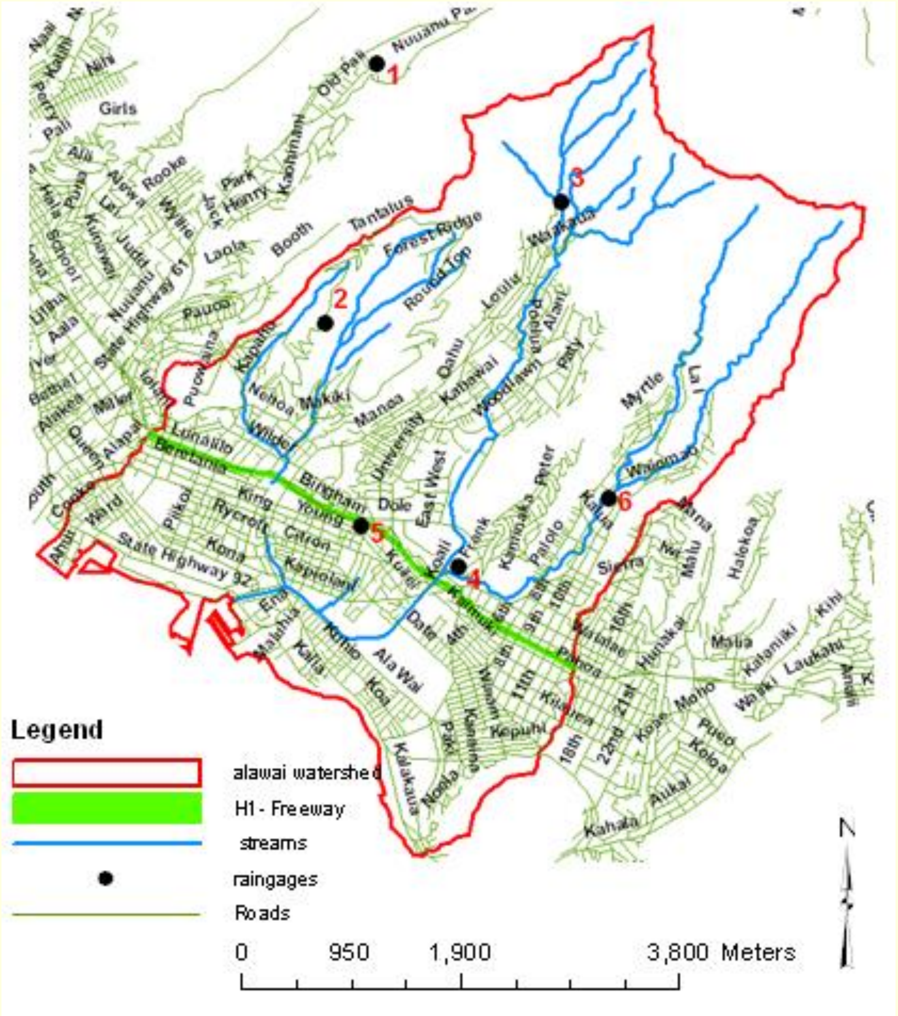


Sub-watershed

Sub-Watershed properties:
1. Hydrologic properties such *as L, A, S, FTABLE, n*, etc
2. Soil data
3. Land use data.
4. Other watershed indices parameters such as SCS curve numbers.

HSPF modeling

Rainfall (evaporation) Stations



Results of Dry-weather surveys

Dry- weather surveys are conducted monthly to provide baseline conditions of flow and pollutant loads.

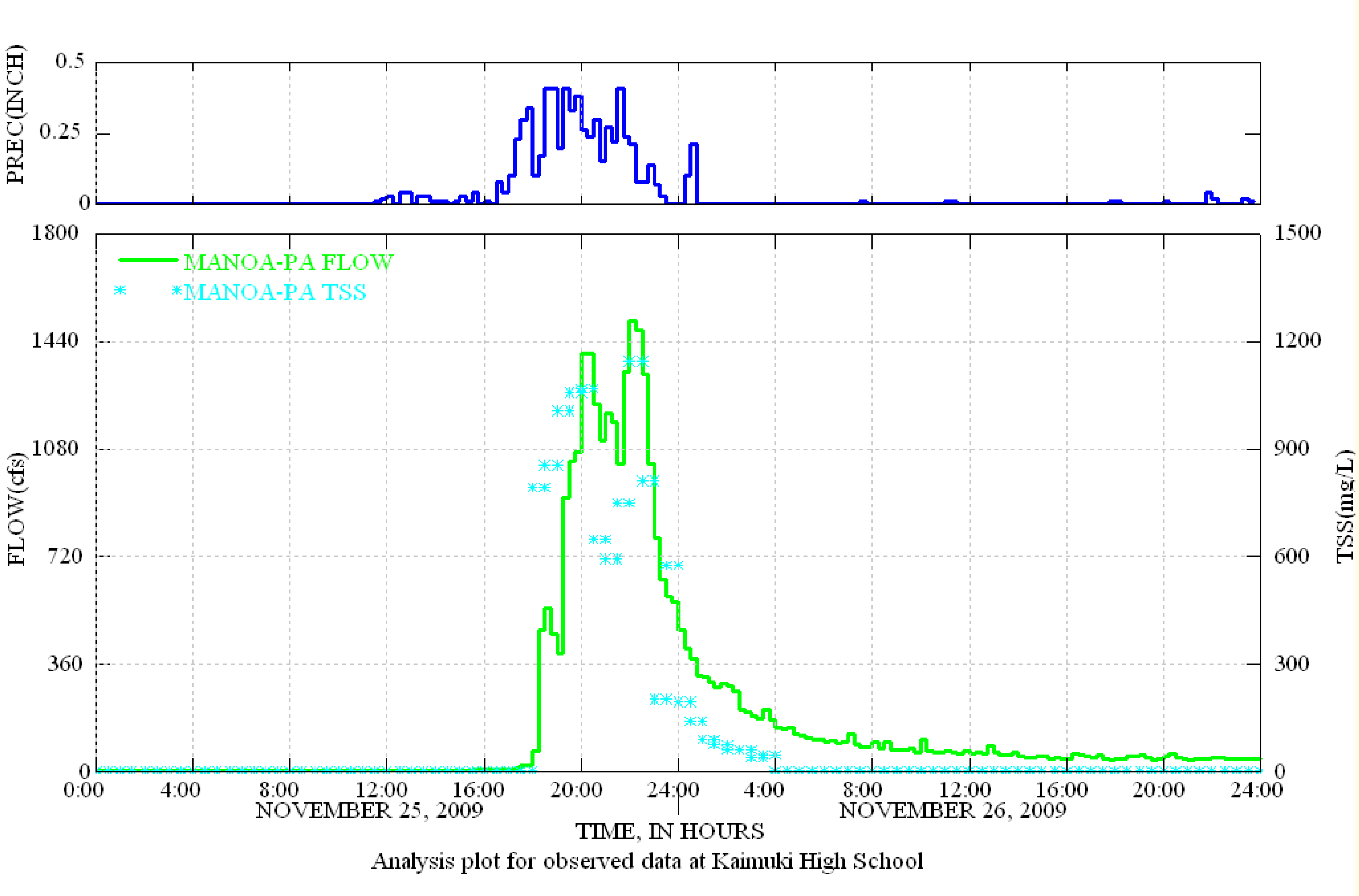
Station	Flow, cfs	TSS		TN	
		mg/L	Ton/yr	mg/L	Ton/yr
Waikeakua	4.6	2.85	0.41344	0.13	0.0189
Manoa Stream	9.1	2.9	0.83224	0.28	0.0804
Palolo Stream	4.02	7.23	0.91658	0.68	0.0862
Manoa-Palolo at KHS	13.5	8.25	3.51232	0.384	0.1635
H1-Freeway Isenberg	0	0	0.00000	0	0.0000
Makiki Stream	0.25	4.57	0.03603	0.684	0.0054
H1-Freeway at Kapilani	0	0	0.00000	0	0.0000
Alawai		13.56		1.69	

Storm water surveys

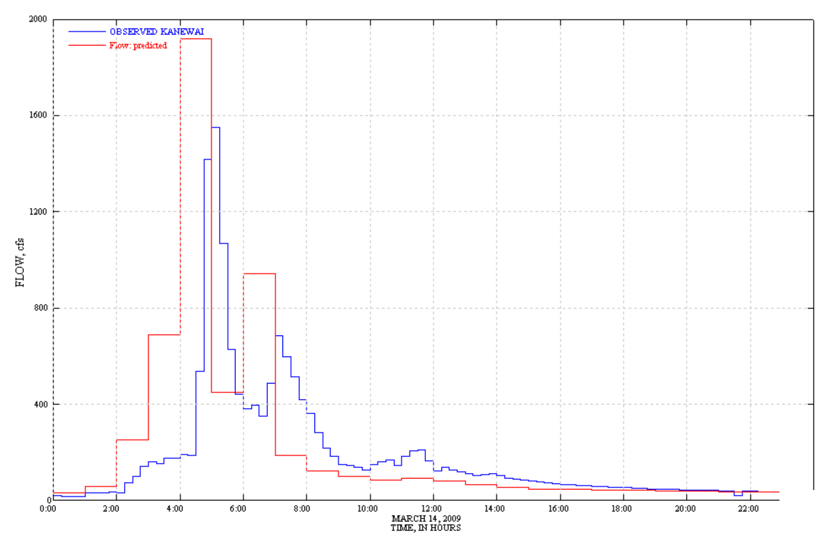
Because of the lack of major storms, our monitoring network didn't capture as many storm events of as large a size as we had originally hoped for.

	Monitoring Station						
Date	Waikeakua	Manoa Stream Kanewai	Palolo Stream	Manoa-Palolo at KHS	Makiki	H1-Isenberg	H1-Kapiolani
3/14/2009		√					
4/10/2009		√		√			
8/11/2009		√		√			
11/25/2009	√	√		√			
12/3/2009		√	√	√	√	√	
1/31/2010			√				
2/2/2010		Sampler	√		√	√	
3/8/2010		Moved to H1-					
3/15-16/10	√		√			√	√
4/3/2010		Kapiolani	√		√		√
4/4/2010			√		√		√
4/6/2010	√			√			

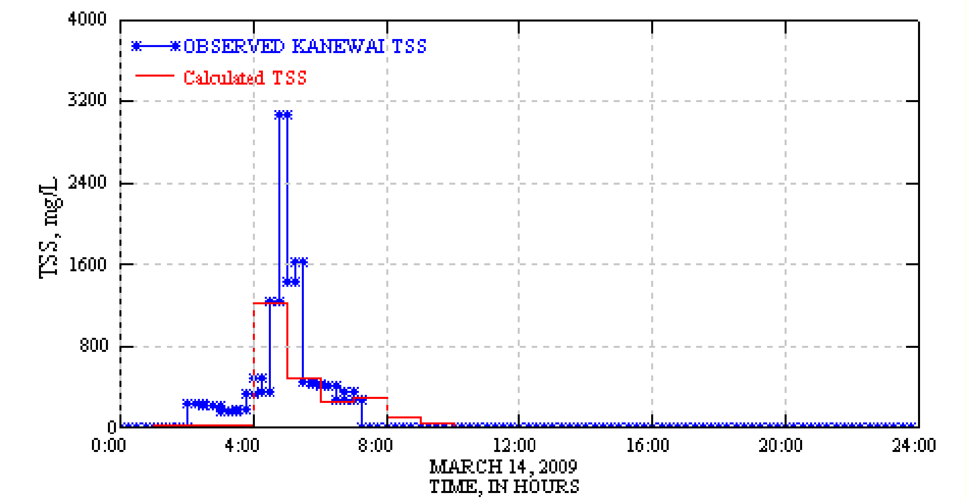
Rainfall, flow and TSS observed at Manoa-Palolo station during the November 26 rain storm.



Calibration of HSPF model of Manoa watershed at Kanewai

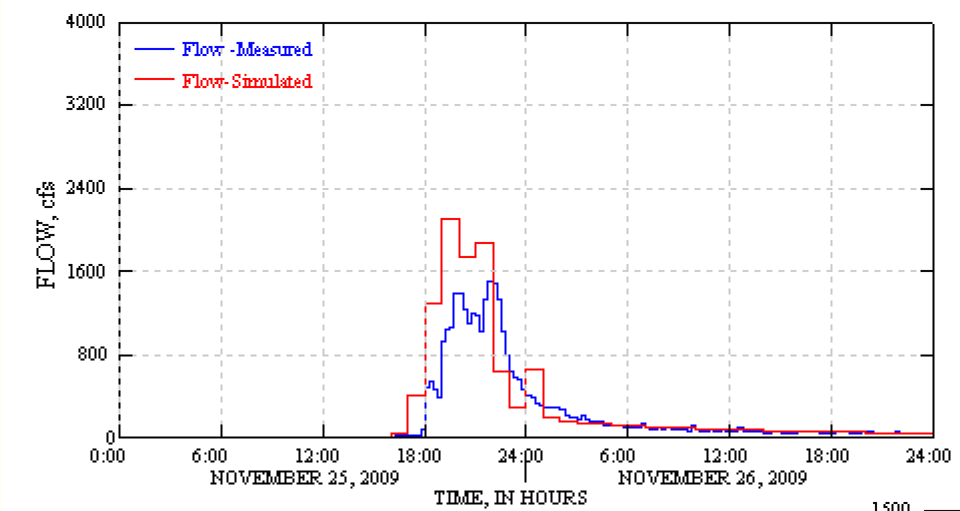


Analysis Plot for FLOW at Manoa stream: Kanewai

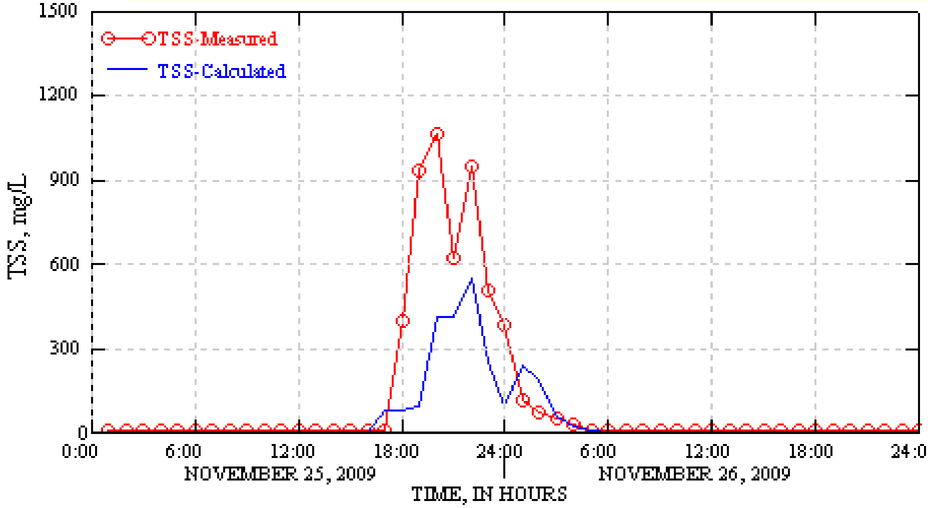


Calculated sediment concentration at Manoa stream: Kanewai

Calibration of HSPF model of Manoa-Palolo watershed at Kaimuki High School

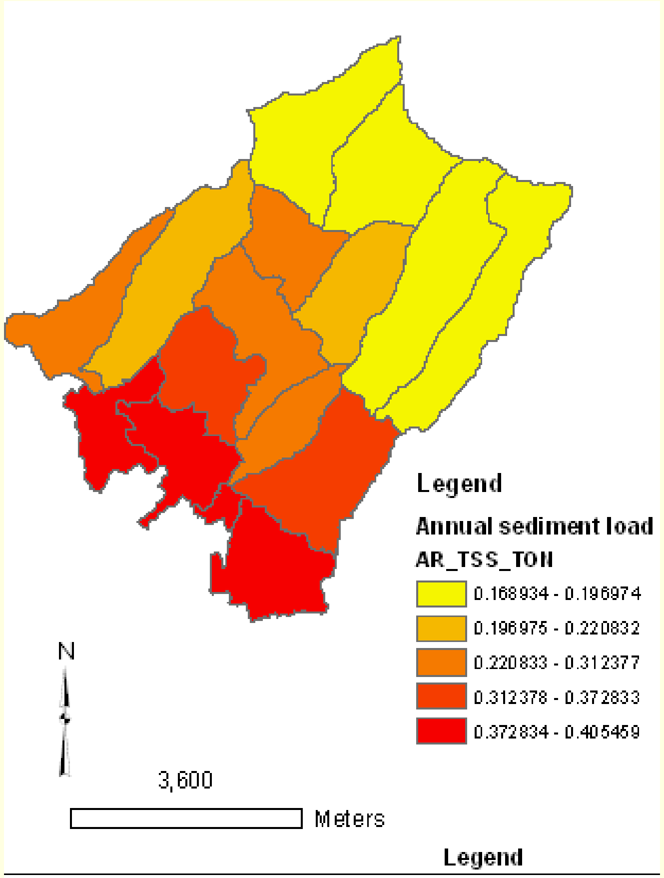


Analysis Plot for FLOW at Manoa-Palolo Stream



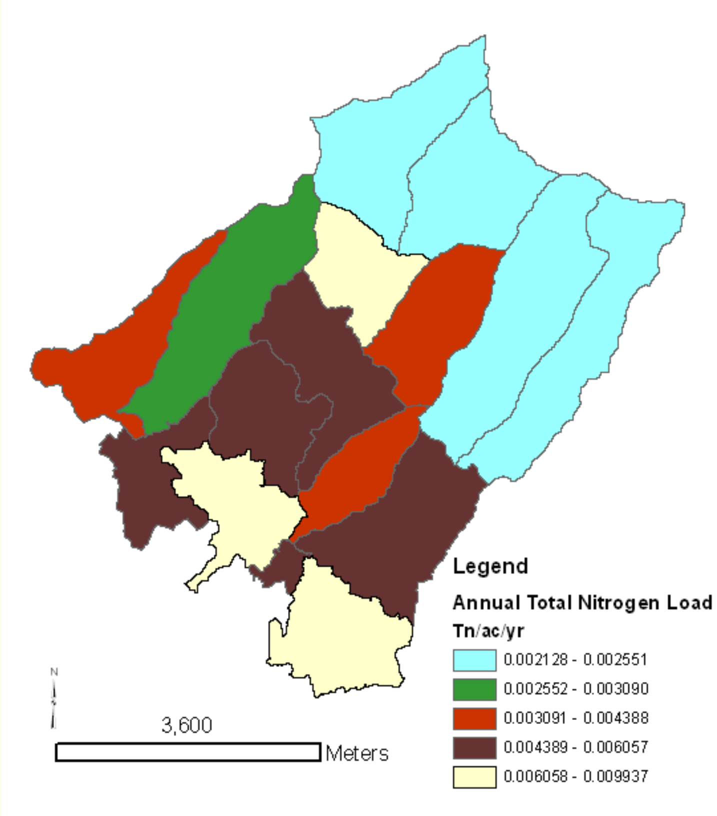
Analysis Plot for HOURLY MEAN Values: Manoa-Palolo Stream at Moilili

PLOAD modeling and the Average annual load from Ala Wai drainage system (a)TSS



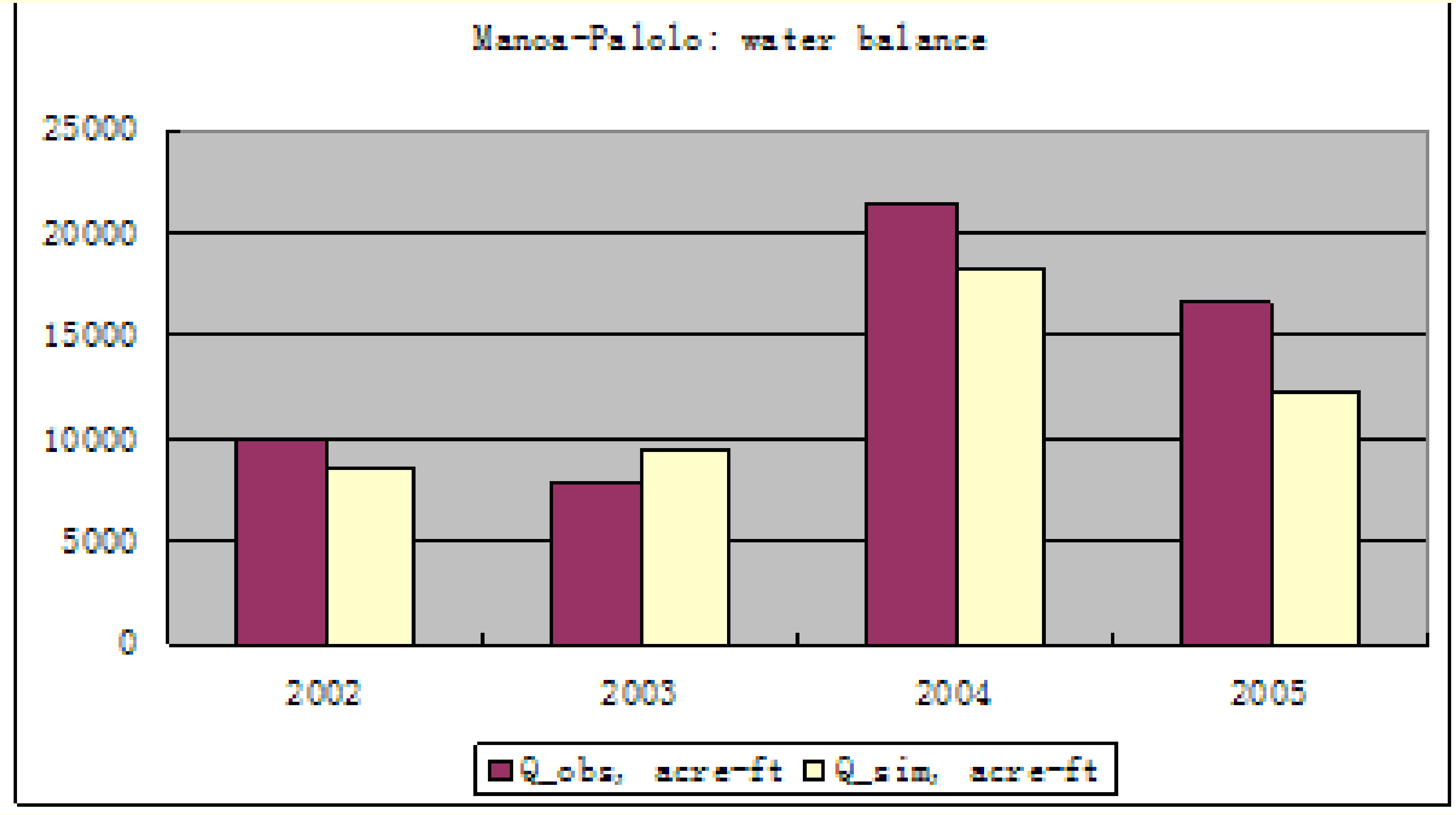
SUBBASIN	A, HA	AR_TSS_TON/ac/yr	Ton/yr
1	310.6000	0.172836864	131.5237
2	278.8800	0.168933948	115.4251
3	170.7600	0.285178250	119.3077
4	220.6500	0.215239605	116.3569
6	341.8200	0.220831826	184.9376
5	216.7400	0.312376743	165.8761
7	413.9000	0.196973795	199.7423
8	344.8100	0.193208820	163.2198
9	254.2900	0.289471147	180.3436
10	205.2600	0.364353965	183.2289
11	140.2700	0.295138849	101.4279
13	153.5600	0.399732698	150.3882
15	188.1700	0.397801500	183.3931
14	29.2300	0.390925748	27.99556
12	303.5200	0.372832775	277.2474
16	225.8800	0.405459192	224.3835

PLOAD modeling and the Average annual load from Ala Wai drainage system (B)TN

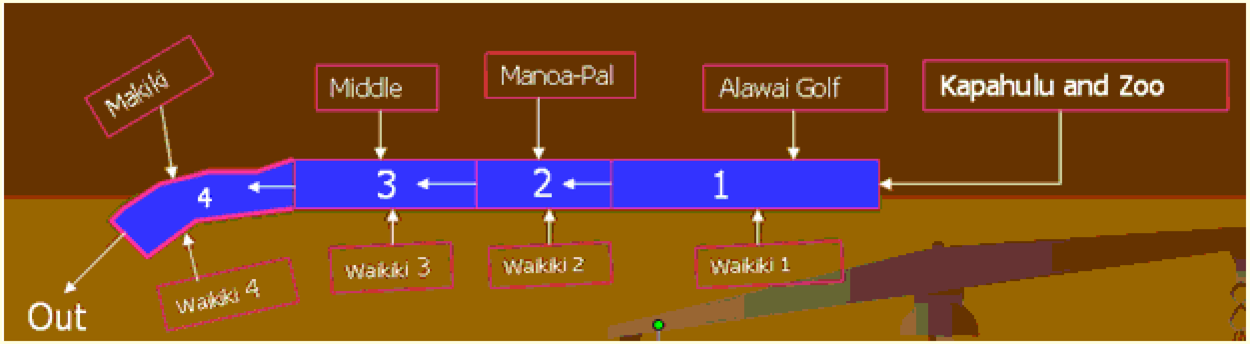


subbasins	Area,HA	TN/yr	TN/ac/yr
1	310.6	1.81	0.002413737
2	278.9	1.43	0.002127726
3	170.8	4.17	0.00954033
4	220.7	1.97	0.003642712
5	341.8	2.40	0.004388081
6	216.7	2.42	0.003089988
7	413.9	2.61	0.002550816
8	344.8	2.07	0.002488944
9	254.3	3.29	0.005217363
10	205.3	2.84	0.005818185
11	140.3	1.32	0.003847807
12	153.6	4.03	0.005398204
13	188.2	1.97	0.006057134
14	29.2	0.23	0.005000521
15	303.5	3.82	0.008245223
16	225.9	5.48	0.009936525

HSPF Flow Simulation on Manoa-Palolo Stream at Kaimuki High School



Basins/HSPF Modeling and Calculated Flow and TSS loadings to Ala Wai Canal during the Storm of December 3, 2009



Contribution Area	Flow	TSS
	m^3	kg
Makiki	77973	20849
Middle	16512	4057
Manoa Palolo	146376	74300
Alawai-Golf	51503	207
Kapahulu-Zoo	13291	3679
Waikiki	30221	6192

Estimated Annual Waste Loading into the Ala Wai Canal

Scenario	MIDDLE	MAKIKI	MANPAL	ZOO	WAIKIKI1	GOLF	WAIKIKI2	WAIKIKI4	ALAMOANA	Total	H1	
Location	RCH15	RCH30	RCH14	RCH60	RCH60	RCH50	RCH60	RCH63	RCH63	tn/yr	t/yr	
Constituent	ROSED4	ROSED4	ROSED4	ROSED4	ROSED4	ROSED4	ROSED4	ROSED4	ROSED4			
2002	32.9	2450	1220	252	252	27.3	231	35.3	67.4	4567.9	17.9134	0%
2003	27.3	927	2000	39.1	39.1	34.7	20.2	33.5	62.8	3183.7	28.7696	1%
2004	73.5	1080	4550	50.8	50.8	111	31.4	45.8	79.8	6073.1	48.177	1%
2005	44.7	1020	1360	46.8	46.8	24.8	22.7	34.3	65.8	2665.9	23.2408	1%
2006	40.7	898	4900	41.8	41.8	26.4	20.7	32.5	60.6	6062.5	36.3907	1%
2007	25.5	600	984	32	32	14	15.3	34.5	68	1805.3	11.83315	1%
2008	42.3	755	1990	31.9	31.9	17.4	15.6	38.4	69.9	2992.4	17.6746	1%
2009	26.6	795	1110	23.5	23.5	25.2	11.2	27.4	42.1	2084.5	7.6645	0%