Technical Report Documentation Page

1. REPORT No.
CA/TL-89/07

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Comparison of Estimated Runoff Pollutant Loads Calculated by Three Models

5. REPORT DATE
June 1989

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
Nelle Marino

8. PERFORMING ORGANIZATION REPORT No.
647375

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Office of Transportation Laboratory
California Department of Transportation
Sacramento, CA 95819

10. WORK UNIT No.

11. CONTRACT OR GRANT No.
E89TL63

12. SPONSORING AGENCY NAME AND ADDRESS
California Department of Transportation
Sacramento, CA 95807

13. TYPE OF REPORT & PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report applies the pollutant runoff models developed by the Federal Highway Administration (FHWA), California State Department of Transportation (Caltrans), and the Washington State Department of Transportation (WSDOT) to test sites in Sacramento, CA. Predictions of pollutant loads are made for the maximum design storm, an average storm and a light storm with minimal runoff by applying the appropriate equations for each model. It was found that the pollutant loads predicted by the WSDOT and FHWA runoff models do not fall within the 95 percent confidence limits of the Caltrans model. All models should be further examined to determine if they are too site specific to accurately predict pollutant loads in general locations. It is recommended that the predicted pollutant concentrations given in this report be compared to field measurements.

17. KEYWORDS
Pollutant loads, pollutant concentrations, runoff models

18. No. OF PAGES:
74

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1989-1996/89-07.pdf

20. FILE NAME
89-07.pdf

This page was created to provide searchable keywords and abstract text for older scanned research reports.
November 2005, Division of Research and Innovation

State of California
Department of Transportation
Division of New Technology and Research
Office of Transportation Laboratory

COMPARISON OF ESTIMATED RUNOFF POLLUTANT LOADS CALCULATED BY THREE MODELS

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89-07

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TECHNICAL REPORT STANDARD TITLE PAGE

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17. KEY WORDS	18. DISTRIBUTION STATEMENT
Pollutant loads, pollutant concentrations, runoff models	No restrictions. This document is available to the public through the National Technical information Service, Springfield, VA 22161

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified		

DS-TL-1242 (Rev.6/76)

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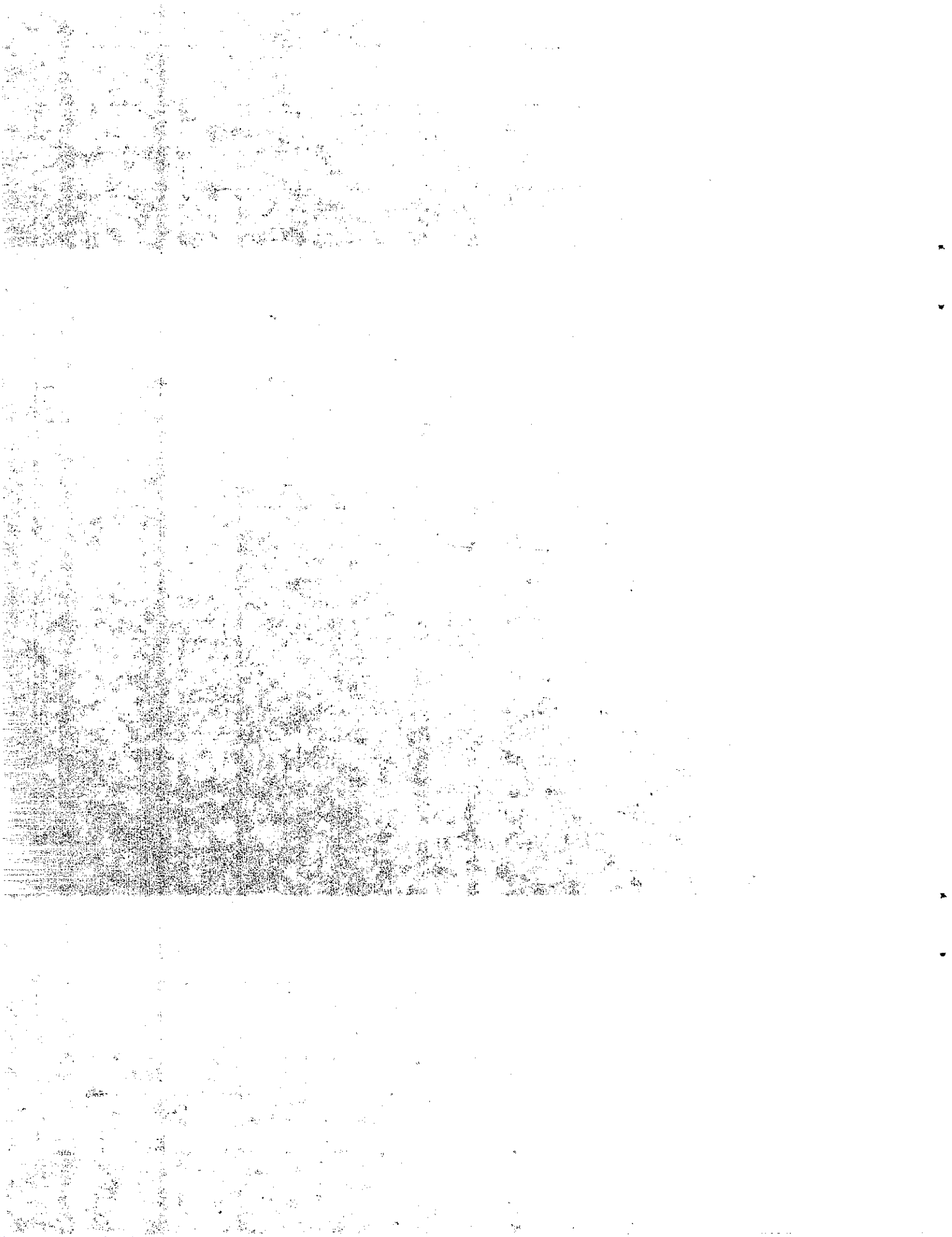

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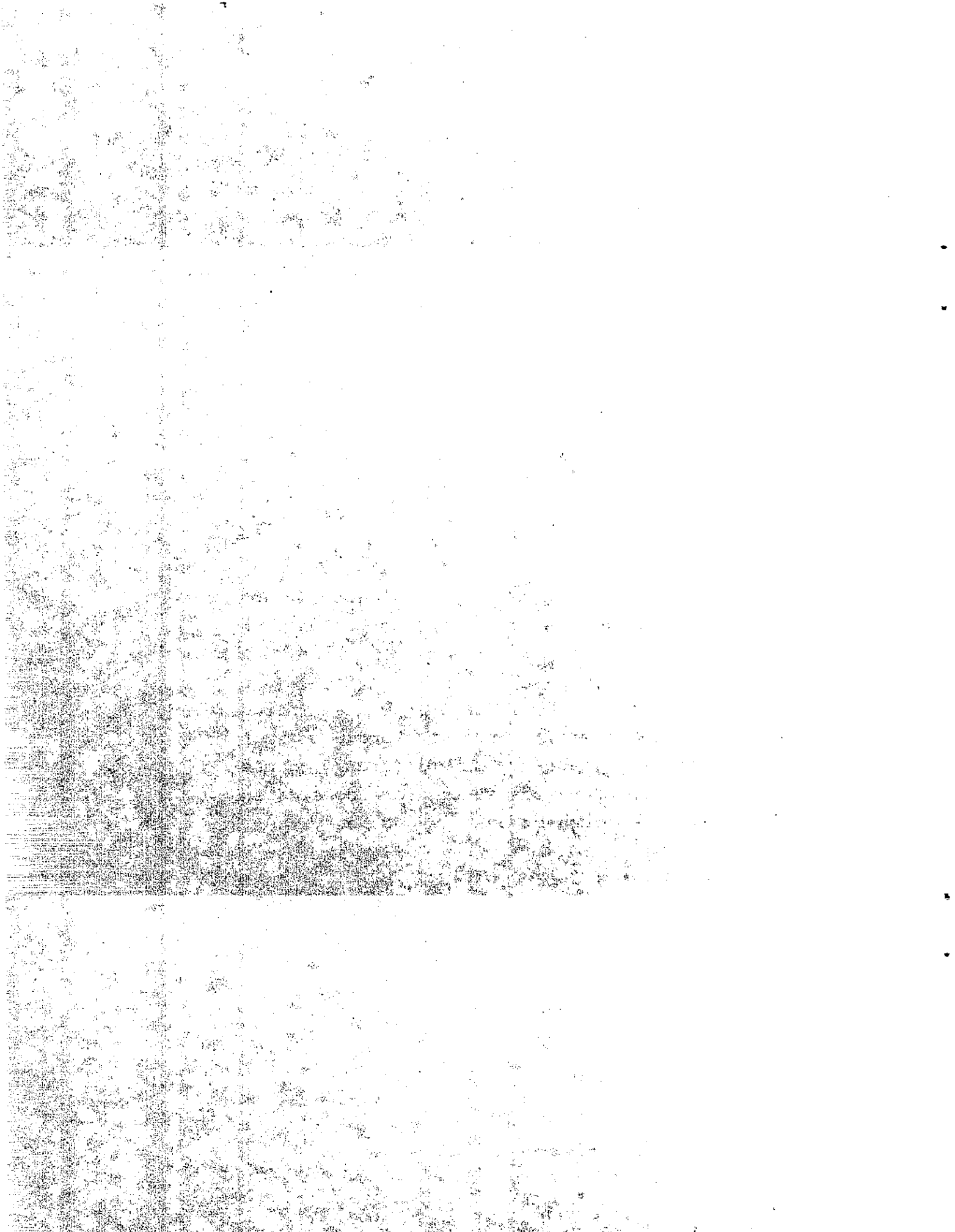

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litre (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs)	4.448	newtons (N)
	(1000 lbs) kips	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (in-lbs)	.1130	newton-metres (Nm)
	foot-pounds (ft-lbs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

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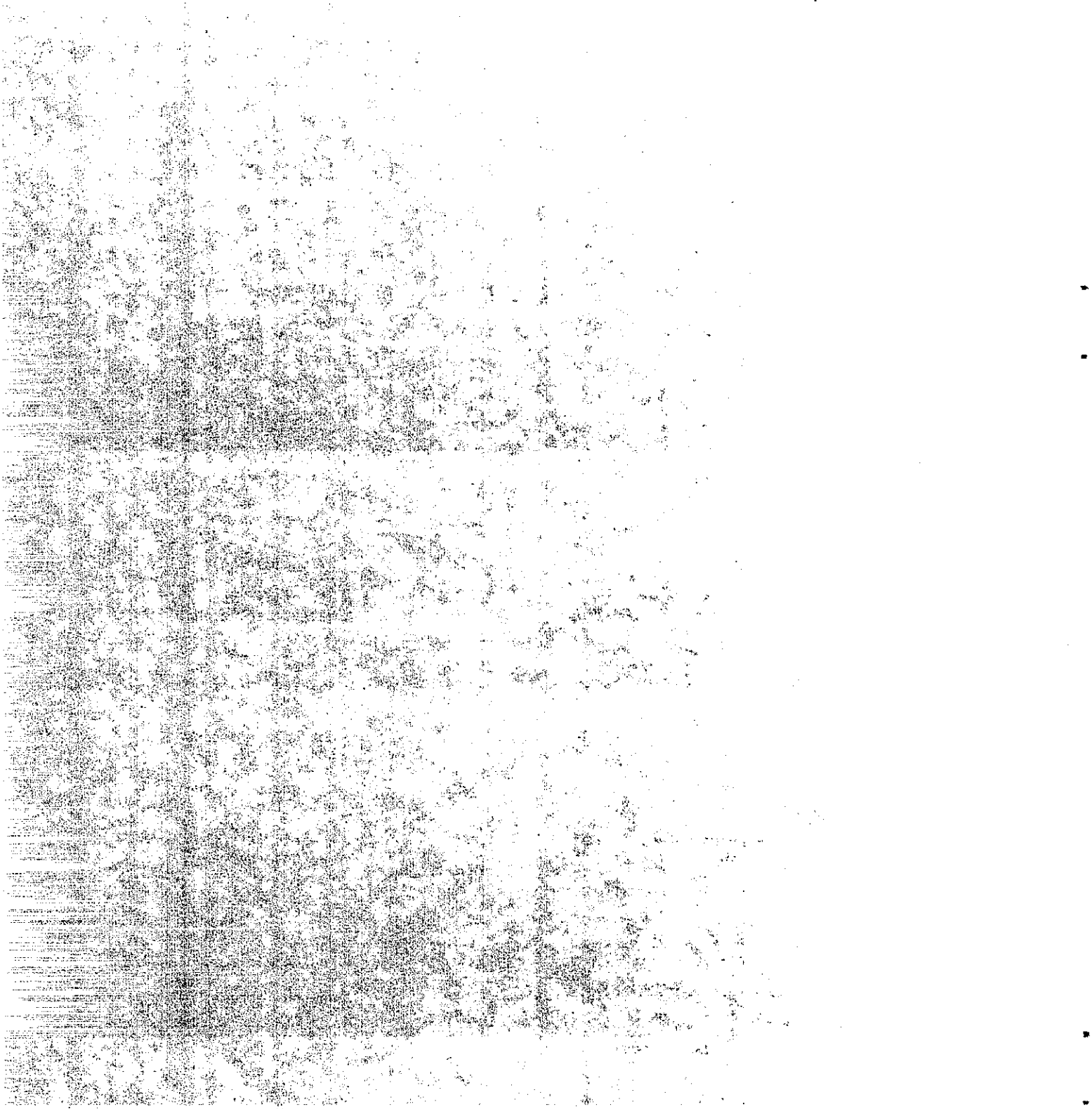

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PROBLEM STATEMENT

Three models that predict pollutant loads in highway runoff have been developed by FHWA funded research. These models have had little or no testing to determine their applicability to cismontane regions of California. (Cismontane California is that part of California west of the main Sierra Crest as opposed to the deserts.) A thorough knowledge of the current models is necessary if one or more of the models will be adopted or modified for use in the enviromental process.

INTRODUCTION AND BACKGROUND

Water runoff from highway surfaces has the potential to carry harmful pollutant loads to nearby water sources. Therefore, models that forecast pollutant loads in highway runoff have been developed by various agencies. This research paper applies the models developed by the Federal Highway Administration (FHWA) (1) California State Department of Transportation (Caltrans) (2),(3), and the Washington State Department of Transportation (WSDOT) (4) to test sites (5) in Sacramento, California.

Pollutant loads in highway runoff from three different storm sizes are predicted. The maximum design storm, an average storm, and a light storm with minimal runoff are applied to two different urban highway test sites. Predictions are made for each storm size using FHWA, Caltrans, and WSDOT models for forecasting pollutant loads.

One possible mitigation measure which will reduce the concentration of pollutants in highway runoff is vegetated channels. Vegetated ditch surfaces lower pollutant concentrations by reducing the velocity of runoff, enhancing sedimentation, filtering suspended solids, and increasing

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infiltration. The University of Washington has developed an empirical table of pollutant treatment efficiencies for various lengths of vegetated channels. (See Appendix A) This is applied to the sites and situations described in the previous paragraph to predict pollutant concentration reductions for the test sites with vegetated drainage ditches.

The two test sites are located along westbound U.S. 50. Refer to Appendix B on pages B-1 to B-5 for site details and location map. At each test site, three samplers are situated along the drainage channel. The first sampler is located at the outlet culvert entrance which initially drains runoff into the channel. A second sampler is placed approximately midway through the channel. The final sampler is located at the end of the channels to determine pollutant levels in the runoff as it is released to receiving waters. Data on the effects of vegetated channels from University of Washington studies are combined with the three runoff models individually to estimate pollutant concentrations at the three sampler locations. Refer to Appendix B for details on sampler locations.

OBJECTIVE

The purpose of this research was to determine what pollutant loads that each of the models will estimate for typical cismontane California freeway locations.

CONCLUSIONS AND RECOMMENDATIONS

- It is recommended that the predicted pollutant concentrations given in this report be compared to field measurements from the test sites.

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- The general trend found through application of the models to the Howe and Watt Avenue test sites is as follows:

	HOWE AVE	WATT AVE
FHWA:	concentrations fall between CALTRANS and WSDOT levels	
CALTRANS:	lowest concentrations	highest concentrations
WSDOT:	highest concentrations	lowest concentrations

- The pollutant loads predicted by the WSDOT and FHWA runoff models do not fall within the 95% confidence limits of the Caltrans model.

- The WSDOT runoff model cannot be used in California due to geographical and climatic differences between the two states.

- The FHWA model is too general and did not give consistent results when the model was applied to two similar test sites.

- It is recommended that a study be done which applies the runoff models on an annual basis rather than to single storm events to determine if the models show more consistent trends on a long-term basis.

- The Caltrans model should be further examined to determine if it is too site-specific to accurately predict pollutants in general locations as indicated by the inconsistent trends noted previously.

- Currently, the only data on pollutant reduction due to vegetated channels are from WSDOT. These data are applied to

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all three models in this report. These data may not necessarily be accurate for the Caltrans and FHWA models.

- All models should be further examined to determine if all three models oversimplify a complex system, thereby giving unreliable results.

BENEFITS

This research report will assist enviromental personnel in selecting an appropriate model for estimating pollutant loads in highway runoff. In the future, pollutant concentration estimates in this report will be compared to actual pollutant concentrations measured in samples taken from the test sites.

IMPLEMENTATION

1. A copy of this report will be sent to the environmental staff in each of the Districts and in the appropriate Headquarters' offices.

2. The pollutant loads predicted by the models in this study will be compared to actual field measurements.

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SECTION 1: POLLUTANT LOADS AND CONCENTRATIONS PREDICTED BY FHWA, CALTRANS, AND WSDOT RUNOFF MODELS

The following tables contain the pollutant loads and concentrations predicted by the FHWA, CALTRANS, and WSDOT runoff models. Data input into each model is listed above the table. Rainfall intensity is indicated at the top of each column. Highway lengths and drainage areas are obtained from as-built plans of the highway. Average daily traffic is available from the Division of Traffic Engineering. Refer to Reference 5 for a detailed history of the Howe and Watt Avenue test sites and sampling devices. Refer to Appendix C for a summary of each model. Sample calculations are included in Appendix D. These tables predict pollutant levels assuming no mitigation measures such as vegetated channels. (See Section 2 for the effects of grass lined channels on pollutant levels.)

The FHWA model input includes site type, accumulation time, and dry days. Refer to Appendix C for a description of the various site types. Accumulation time is the time since the last storm of sufficient intensity to wash accumulated pollutants from the roadway. Dry days is the time since the last storm of any intensity. For this analysis it is assumed that the accumulation time is equal to dry days. An average value of 10 days is assumed.

The Caltrans input includes a runoff coefficient. This study used the default value of 0.90. The WSDOT input includes a runoff factor for impervious and pervious drainage areas, TSS loading factor, total annual rainfall, and site type. This study used default values of 0.70 and 0.45 as recommended by the WSDOT runoff model for impervious and pervious drainage areas. Site types are classified as either western or eastern Washington. The model gives equations and TSS loading factors for eastern and western Washington. The eastern Washington value of 0.026 lbs /

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mi-VDS is used for inland areas and the western Washington value of 0.0064 lbs / mi-VDS is used for coastal sites. Therefore this study used the eastern Washington value to apply the model to the inland sites of Howe and Watt Avenue. For comparison purposes only, the Washington model was also applied using western Washington equations. (See Section 1, Table D) Rainfall data are available from several sources including the Department of Water Resources Publications (6). Weather data used in this study are included in Appendix E.

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SECTION 1

TABLE A: POLLUTANT LOADS PREDICTED FROM FHWA MODEL

Site: Howe Avenue
Site Type: I (100 % paved)
Highway Length: 4210 ft or 0.80 mile
Average Daily Traffic: 64,500 vehicles/day
Accumulation Time = Dry Days = 10 days
Site Drainage Area: 202,118 sq ft

PARA-METER	MINIMAL STORM 0.1" in 2 hrs		2-YEAR RETURN 1.98" in 24 hrs		100-YEAR RETURN 4.39" in 24 hrs	
	LOAD	CONC	LOAD	CONC	LOAD	CONC
TS	60,599	1,624	141,239	150	259,780	124
TSS	30,645	822	73,404	78	136,231	65
VSS	11,657	313	27,066	29	49,709	24
TVS	19,418	521	37,249	39	63,444	30
TKN	272	7.3	540	0.57	930	0.44
BOD	2,073	56	3,928	4.2	6,654	3.2
TOC	3,815	102	8,414	8.9	15,173	7.2
COD	14,714	395	31,012	33	54,957	26
TN	136	3.6	249	0.26	408	0.19
TPO_4	59	1.6	141	0.15	259	0.12
Cl	3,234	87	5,978	6.3	10,006	4.8
Pb	327	8.8	780	0.83	1,442	0.69
Zn	58	1.6	127	0.13	227	0.11
Fe	1,175	32	2,386	2.5	4,164	2.0
Cu	18	0.48	41	0.043	77	0.037
Cd	17	0.45	19	0.020	36	0.017
Cr	11	0.29	23	0.024	42	0.020
Hg	0.35	0.0094	0.25	0.00026	0.40	0.00019

LOAD = Pollutant Load in Grams / Storm
CONC = Pollutant Concentration in Milligrams / Liter

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POLLUTANT LOADS PREDICTED FROM FHWA MODEL

Site: Watt Avenue
Site Type: I (100 % paved)
Highway Length: 400 ft or 0.076 mile
Average Daily Traffic: 59,500 vehicles/day
Accumulation Time = Dry Days = 10 days
Site Drainage Area: 19,166 sq ft

PARA-METER	MINIMAL STORM 0.1" in 2 hrs		2-YEAR RETURN 1.98" in 24 hrs		100-YEAR RETURN 4.39" in 24 hrs	
	LOAD	CONC	LOAD	CONC	LOAD	CONC
TS	5,339	1,178	12,456	139	22,906	115
TSS	1,379	304	5,148	57	10,691	54
VSS	1,111	245	2,468	28	4,468	22
TVS	7,212	1,592	8,786	98	11,095	56
TKN	91	20	113	1.3	150	0.75
BOD	803	177	966	11	1,207	6.1
TOC	667	147	1,075	12	1,669	8.4
COD	3,561	786	4,999	56	7,108	36
TN	64	14	73	0.81	86	0.43
TPO_4	5.4	1.2	13	0.14	23	0.12
Cl	1,356	299	1,597	18	1,955	9.0
Pb	19	4.2	59	0.66	118	0.59
Zn	11	2.4	17	0.19	25	0.13
Fe	349	77	454	2.1	612	3.1
Cu	1.9	0.42	3.9	0.043	6.8	0.034
Cd	0.11	0.024	1.1	0.012	2.6	0.013
Cr	1.4	0.31	2.5	0.028	4.2	0.021
Hg	0.39	0.086	0.39	0.0043	0.40	0.0020

LOAD = Pollutant Load in Grams / Storm
CONC = Pollutant Concentration in Milligrams / Liter

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TABLE B: POLLUTANT LOADS PREDICTED FROM CALTRANS MODEL

Site: Howe Avenue
Site Drainage Area: 202,118 sq ft
Average Daily Traffic: 64,500 vehicles/day
Runoff Coefficient: 0.90

PARA-METER	MINIMAL STORM 0.1" in 2 hrs		2-YEAR RETURN 1.98" in 24 hrs		100-YEAR RETURN 4.39" in 24 hrs	
	LOAD	CONC	LOAD	CONC	LOAD	CONC
TR	7,455	174	65,703	77	65,703	35
NR	4,086	95	41,947	49	41,947	22
FR	6,113	142	14,390	17	14,390	7.6
Pb	25	0.57	136	0.16	136	0.072
Zn	18	0.41	53	0.062	53	0.028
COD	4,778	111	17,845	21	17,845	9.5
TKN	168	3.9	371	0.44	371	0.20

LOAD = Pollutant Load in Grams / Storm
CONC = Pollutant Concentration in Milligrams / Liter

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POLLUTANT LOADS PREDICTED FROM CALTRANS MODEL

Site: Watt Avenue
Site Drainage Area: 19,166 sq ft
Average Daily Traffic: 59,500 vehicles/day
Runoff Coefficient: 0.90

PARA-METER	MINIMAL STORM 0.1" in 2 hrs		2-YEAR RETURN 1.98" in 24 hrs		100-YEAR RETURN 4.39" in 24 hrs	
	LOAD	CONC	LOAD	CONC	LOAD	CONC
TR	7,045	1,731	60,779	753	60,779	340
NR	3,819	938	38,746	480	38,746	216
FR	6,054	1,487	13,690	170	13,690	76
Pb	24	5.8	127	1.6	127	0.71
Zn	17	4.2	50	0.62	50	0.28
COD	4,686	1,152	16,740	207	16,740	94
TKN	167	41	353	4.4	353	2.0

LOAD = Pollutant Load in Grams / Storm
CONC = Pollutant Concentration in Milligrams / Liter

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TABLE C: POLLUTANT LOADS PREDICTED FROM WSDOT MODEL

Site: Howe Avenue
Site Type: inland (Eastern Washington)
Total Drainage Area: 19,166 sq ft
Impervious Drainage Area: 19,166 sq ft
Pervious Drainage Area: 0 sq ft
Runoff Factor of Impervious Drainage Area: 0.70
Runoff Factor of Pervious Drainage Area: 0.45
Length of Highway: 4,210 ft
Average Daily Traffic: 64,500 vehicles/day
TSS Loading Factor: 0.026
Total Annual Rainfall: 17.87 in

PARAMETER	MINIMAL STORM 0.1" in 2 hrs		2-YEAR RETURN 1.98" in 24 hrs		100-YEAR RETURN 4.39" in 24 hrs	
	LOAD	CONC	LOAD	CONC	LOAD	CONC
TSS	35,498	1,063	425,975	644	425,975	291
COD	14,197	425	170,391	258	170,391	116
Pb	25	0.76	303	0.46	303	0.21
Zn	740	22	8,877	13	8,877	6.1
Cu	9.0	0.27	108	0.16	108	0.074
TKN	43	1.3	511	0.78	511	0.35
TP	75	2.2	895	1.4	895	0.62
NO_3+NO_2-N	71	2.2	852	1.3	852	0.58

LOAD = Pollutant Load in Grams / Storm
CONC = Pollutant Concentration in Milligrams / Liter

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POLLUTANT LOADS PREDICTED FROM WSDOT MODEL

Site: Watt Avenue
Site Type: inland (Eastern Washington)
Total Drainage Area: 19,166 sq ft
Impervious Drainage Area: 19,166 sq ft
Pervious Drainage Area: 0 sq ft
Runoff Factor of Impervious Drainage Area: 0.70
Runoff Factor of Pervious Drainage Area: 0.45
Length of Highway: 400 ft
Average Daily Traffic: 59,500 vehicles/day
TSS Loading Factor: 0.026
Total Annual Rainfall: 17.87 in

PARA-METER	MINIMAL STORM 0.1" in 2 hrs		2-YEAR RETURN 1.98" in 24 hrs		100-YEAR RETURN 4.39" in 24 hrs	
	LOAD	CONC	LOAD	CONC	LOAD	CONC
TSS	3,103	81	37,213	49	37,213	22
COD	1,243	33	14,887	20	14,887	8.9
Pb	2.16	0.06	25.9	0.034	25.9	0.016
Zn	60	1.6	716	0.95	716	0.43
Cu	0.74	0.019	8.9	0.012	8.9	0.0054
TKN	3.7	0.98	45	0.059	45	0.027
TP	6.5	0.17	78	0.10	78	0.046
NO_3+NO_2 -N	6.2	0.17	74	0.097	74	0.044

LOAD = Pollutant Load in Grams / Storm
CONC = Pollutant Concentration in Milligrams / Liter

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TABLE D: POLLUTANT LOADS PREDICTED FROM WSDOT MODEL

Site: Howe Avenue
Site Type: (for comparison purposes, coastal (Western Wash) equations are used)
Total Drainage Area: 19,166 sq ft
Impervious Drainage Area: 19,166 sq ft
Pervious Drainage Area: 0 sq ft
Runoff Factor of Impervious Drainage Area: 0.70
Runoff Factor of Pervious Drainage Area: 0.45
Length of Highway: 4,210 ft
Average Daily Traffic: 64,500 vehicles/day
TSS Loading Factor: 0.0064
Total Annual Rainfall: 17.87 in

PARA-METER	MINIMAL STORM 0.1" in 2 hrs		2-YEAR RETURN 1.98" in 24 hrs		100-YEAR RETURN 4.39" in 24 hrs	
	LOAD	CONC	LOAD	CONC	LOAD	CONC
TSS	8,738	262	104,855	159	104,855	72
COD	3,494	105	41,943	63	41,943	29
Pb	50	1.5	604	0.91	604	0.41
Zn	18	0.54	218	0.33	218	0.15
Cu	2.2	0.067	27	0.04	27	0.018
TKN	24	0.71	283	0.43	283	0.15
TP	18	0.54	220	0.34	220	0.19
NO_3+NO_2 -N	17	0.53	210	0.32	210	0.14

LOAD = Pollutant Load in Grams / Storm
CONC = Pollutant Concentration in Milligrams / Liter

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POLLUTANT LOADS PREDICTED FROM WSDOT MODEL

Site: Watt Avenue
Site Type: (for comparison purposes, coastal (West Wash) equations are used)
Total Drainage Area: 19,166 sq ft
Impervious Drainage Area: 19,166 sq ft
Pervious Drainage Area: 0 sq ft
Runoff Factor of Impervious Drainage Area: 0.70
Runoff Factor of Pervious Drainage Area: 0.45
Length of Highway: 400 ft
Average Daily Traffic: 59,500 vehicles/day
TSS Loading Factor: 0.0064
Total Annual Rainfall: 17.87 in

PARA-METER	MINIMAL STORM 0.1" in 2 hrs		2-YEAR RETURN 1.98" in 24 hrs		100-YEAR RETURN 4.39" in 24 hrs	
	LOAD	CONC	LOAD	CONC	LOAD	CONC
TSS	762	20	9,160	12	9,160	5.5
COD	304	8.0	3,663	4.9	3,663	2.2
Pb	4.1	0.11	49	0.065	49	0.029
Zn	1.46	0.038	17	0.024	17	0.011
Cu	0.18	0.0048	2.2	0.0029	2.2	0.0013
TKN	2.1	0.054	25	0.033	25	0.015
TP	1.5	0.042	19	0.025	19	0.011
NO_3+NO_2 -N	6.2	0.041	18	0.024	18	0.011

LOAD = Pollutant Load in Grams / Storm
CONC = Pollutant Concentration in Milligrams / Liter

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SECTION 2: POLLUTANT CONCENTRATIONS PREDICTED BY FHWA, CALTRANS AND WSDOT RUNOFF MODELS USING GRASS CHANNELS

The tables that follow contain the pollutant concentrations predicted by the FHWA, CALTRANS, and WSDOT runoff models when drainage channels are vegetated with grass. The pollutant concentration at the first sampler location is not effected by the grass channel as it is located at the outlet culvert entrance which initially drains into the channel. This produces a sample of runoff as it comes directly from the highway. The second sampler concentration is a measure of the reduction in toxicity of the runoff after traveling half the distance of the channel through the grass. The third sampler concentrations represents the runoff as it is released to receiving waters.

The data developed by Washington State on the effect of vegetated channels on pollutant concentrations are presented in Appendix A.

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TABLE A: POLLUTANT LOADS PREDICTED FROM FHWA MODEL USING GRASS CHANNELS

Site: Howe Avenue
Site Type: I (100% paved)
Highway Length: 4210 ft or 0.80 mile
Average Daily Traffic: 64,500 vehicles/day
Accumulation Time = Dry Days = 10 days

PARA-METER	MINIMAL STORM 0.1" IN 2 hrs			2-YEAR RETURN 1.98" IN 24 hrs		
	S1	S2	S3	S1	S2	S3
TS	1624	374	324	150	35	30
TSS	822	189	164	78	18	16
VSS	313	72	63	29	6.7	5.8
TVS	521	120	104	39	9.0	7.8
TKN	7.3	1.7	1.5	0.57	0.13	0.11
BOD	56	13	11	4.2	0.97	0.84
TOC	102	23	20	8.9	2.0	1.8
COD	395	91	79	33	7.6	6.6
TN	3.6	83	0.72	0.26	0.060	0.052
TPO_4	1.6	0.34	0.32	0.15	0.035	0.030
Cl	87	20	17	6.3	1.4	1.3
Pb	8.8	2.0	1.8	0.83	0.19	0.017
Zn	1.6	0.37	0.32	0.13	0.030	0.026
Fe	32	7.4	6.4	2.5	0.58	0.50
Cu	0.27	0.062	0.054	0.043	0.0099	0.0086
Cd	0.21	0.048	0.042	0.020	0.0046	0.0040
Cr	0.29	0.067	0.058	0.024	0.0055	0.0048
Hg	0.0094	0.0022	0.0019	0.0026	0.000060	0.000052

S1 = Parameter Concentration at Sampler #1 (Milligrams / Liter)
S2 = Parameter Concentration at Sampler #2 (Milligrams / Liter)
S3 = Parameter Concentration at Sampler #3 (Milligrams / Liter)

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POLLUTANT LOADS PREDICTED FROM FHWA MODEL USING GRASS CHANNELS

Site: Howe Avenue
Site Type: I (100% paved)
Highway Length: 4210 ft or 0.80 mile
Average Daily Traffic: 64,500 vehicles/day
Accumulation Time = Dry Days = 10 days

PARA-METER	100-YEAR RETURN 4.39" in 24 hrs		
	S1	S2	S3
TS	124	29	25
TSS	65	15	13
VSS	24	5.5	4.8
TVS	30	6.9	6.0
TKN	0.44	0.10	0.088
BOD	3.2	0.74	0.64
TOC	7.2	1.7	1.4
COD	26	6.0	5.2
TN	0.19	0.044	0.038
TPO_4	0.12	0.028	0.024
Cl	4.8	1.1	0.96
Pb	0.69	0.16	0.14
Zn	0.11	0.025	0.022
Fe	2.0	0.46	0.40
Cu	0.037	0.0085	0.0074
Cd	0.017	0.0039	0.0034
Cr	0.020	0.0046	0.0040
Hg	0.00019	0.000040	0.000038

S1 = Parameter Concentration at Sampler #1 (Milligrams / Liter)
S2 = Parameter Concentration at Sampler #2 (Milligrams / Liter)
S3 = Parameter Concentration at Sampler #3 (Milligrams / Liter)

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POLLUTANT LOADS PREDICTED FROM FHWA MODEL USING GRASS CHANNELS

Site: Watt Avenue
Site Type: I (100% paved)
Highway Length: 400 ft or 0.076 mile
Average Daily Traffic: 59,500 vehicles/day
Accumulation Time = Dry Days = 10 days

PARAMETER	MINIMAL STORM 0.1" IN 2 hrs			2-YEAR RETURN 1.98" IN 24 hrs		
	S1	S2	S3	S1	S2	S3
TS	1,178	353	271	139	42	32
TSS	304	91	70	57	17	13
VSS	245	74	56	28	8.4	6.4
TVS	1,592	478	366	98	29	23
TKN	20	6.0	4.6	1.3	0.39	0.30
BOD	177	53	41	11	3.3	2.5
TOC	147	44	34	12	3.6	2.8
COD	786	236	181	56	17	13
TN	14	4.2	3.2	0.81	0.24	0.19
TPO_4	1.2	0.36	0.27	0.14	0.042	0.032
Cl	299	90	69	18	5.4	4.1
Pb	4.2	1.3	0.97	0.66	0.20	0.15
Zn	2.4	0.72	0.55	0.19	0.057	0.044
Fe	77	23	18	2.1	0.63	0.48
Cu	0.42	0.13	0.097	0.043	0.013	0.0099
Cd	0.024	0.0072	0.0055	0.012	0.0036	0.0028
Cr	0.31	0.093	0.071	0.028	0.0084	0.0064
Hg	0.086	0.026	0.020	0.0043	0.0013	0.00099

S1 = Parameter Concentration at Sampler #1 (Milligrams / Liter)
S2 = Parameter Concentration at Sampler #2 (Milligrams / Liter)
S3 = Parameter Concentration at Sampler #3 (Milligrams / Liter)

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POLLUTANT LOADS PREDICTED FROM FHWA MODEL USING GRASS CHANNELS

Site: Watt Avenue
Site Type: I (100% paved)
Highway Length: 400 ft or 0.076 mile
Average Daily Traffic: 59,500 vehicles/day
Accumulation Time = Dry Days = 10 days

PARA-METER	100-YEAR RETURN 4.39" in 24 hrs		
	S1	S2	S3
TS	115	35	26
TSS	54	16	12
VSS	22	6.6	5.1
TVS	56	17	13
TKN	0.75	0.23	0.17
BOD	6.1	1.8	1.4
TOC	8.4	2.5	1.9
COD	36	11	8.3
TN	0.43	0.13	0.099
TPO_4	0.12	0.036	0.028
Cl	9.0	2.7	2.1
Pb	0.59	0.18	0.14
Zn	0.13	0.039	0.030
Fe	3.1	0.93	0.71
Cu	0.034	0.010	0.0078
Cd	0.013	0.0039	0.0030
Cr	0.021	0.0063	0.0048
Hg	0.0020	0.00060	0.00046

S1 = Parameter Concentration at Sampler #1 (Milligrams / Liter)
S2 = Parameter Concentration at Sampler #2 (Milligrams / Liter)
S3 = Parameter Concentration at Sampler #3 (Milligrams / Liter)

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TABLE B: POLLUTANT LOAD PREDICTED FROM CALTRANS MODEL USING GRASS CHANNELS

Site: Howe Avenue
Site Drainage Area: 202,118 sq ft
Average Daily Traffic: 64,500 vehicles/day
Runoff Coefficient: 0.90

PARA-METER	MINIMAL STORM 0.1" in 2 hrs			2-YEAR RETURN 1.98" in 24 hrs		
	S1	S2	S3	S1	S2	S3
TR	174	40	35	77	18	15
NR	95	22	19	49	11	9.8
FR	142	33	28	17	3.9	3.4
Pb	0.57	0.13	0.11	0.16	0.037	0.032
Zn	0.41	0.094	0.082	0.062	0.014	0.012
COD	111	26	22	21	4.8	4.2
TKN	3.9	0.90	0.78	0.44	0.10	0.088

PARA-METER	100-YEAR RETURN 4.39" in 24 hrs		
	S1	S2	S3
TR	35	8.1	7.0
NR	22	5.1	4.4
FR	7.6	1.7	1.5
Pb	0.072	0.0064	0.0056
Zn	0.028	6.4 E-3	5.6 E-3
COD	9.5	2.2	1.9
TKN	0.20	0.046	0.040

S1 = Parameter Concentration at Sampler #1 (Milligrams / Liter)
S2 = Parameter Concentration at Sampler #2 (Milligrams / Liter)
S3 = Parameter Concentration at Sampler #3 (Milligrams / Liter)

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POLLUTANT LOAD PREDICTED FROM CALTRANS MODEL USING GRASS CHANNELS

Site: Watt Avenue
Site Drainage Area: 19,166 sq ft
Average Daily Traffic: 59,500 vehicles/day
Runoff Coefficient: 0.90

PARA-METER	MINIMAL STORM 0.1" in 2 hrs			2-YEAR RETURN 1.98" in 24 hrs		
	S1	S2	S3	S1	S2	S3
TR	1,731	519	398	753	226	173
NR	938	281	216	480	144	110
FR	1,487	446	342	170	51	39
Pb	5.8	1.7	1.3	1.6	0.48	0.37
Zn	4.2	1.3	0.97	0.62	0.19	0.14
COD	1,152	346	265	207	62	48
TKN	41	12	9.4	4.4	1.3	1.0

PARA-METER	100-YEAR RETURN 4.39" in 24 hrs		
	S1	S2	S3
TR	340	102	78
NR	216	65	50
FR	76	23	17
Pb	0.71	0.21	0.16
Zn	0.28	0.084	0.064
COD	94	28	22
TKN	2.0	0.60	0.46

S1 = Parameter Concentration at Sampler #1 (Milligrams / Liter)
S2 = Parameter Concentration at Sampler #2 (Milligrams / Liter)
S3 = Parameter Concentration at Sampler #3 (Milligrams / Liter)

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TABLE C: POLLUTANT LOADS PREDICTED FROM WSDOT MODEL USING GRASS CHANNELS

Site: Howe Avenue
Type: inland
Ai: 202,118 sq ft
Ap: 0 sq ft
Atot: 202,118 sq ft
Rtot: 17.87
L: 4210 ft or 0.80 mile
Ki: 0.70
Kp: 0.45
P: 0.026
ADT: 64,500 vehicles / day

PARA-METER	MINIMAL STORM 0.1" in 2 hrs			2-YEAR RETURN 1.98" in 24 hrs		
	S1	S2	S3	S1	S2	S3
TSS	1063	245	213	644	148	129
COD	425	98	85	258	59	52
Pb	0.76	0.17	0.15	0.46	0.11	0.092
Zn	22	5.1	4.4	13	3.0	2.6
Cu	0.27	0.062	0.012	0.16	0.037	0.032
TKN	1.3	0.30	0.26	0.78	0.18	0.16
TP	2.2	0.51	0.44	1.4	0.32	0.28
NO_3+NO_2 - N	2.2	0.51	0.44	1.3	0.30	0.26

PARA-METER	100-YEAR RETURN 4.39" in 24 hrs		
	S1	S2	S3
TSS	291	67	58
COD	116	27	23
Pb	0.28	0.048	0.042
Zn	6.1	1.4	1.2
Cu	0.074	0.017	0.015
TKN	0.35	0.081	0.070
TP	0.62	0.14	0.12
NO_3+NO_2 - N	0.58	0.13	0.12

S1 = Parameter Concentration at Sampler #1 (Milligrams / Liter)
S2 = Parameter Concentration at Sampler #2 (Milligrams / Liter)
S3 = Parameter Concentration at Sampler #3 (Milligrams / Liter)

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POLLUTANT LOADS PREDICTED FROM WSDOT MODEL USING GRASS CHANNELS

Site: Watt Avenue
Type: inland
Ai: 19,166 sq ft
Ap: 0 sq ft
Atot: 19,166 sq ft
Rtot: 17.87

ADT: 59,500 vehicles / day
L: 400 ft
Ki: 0.70
Kp: 0.45
P: 0.026

PARA-METER	MINIMAL STORM 0.1" in 2 hrs			2-YEAR RETURN 1.98" in 24 hrs		
	S1	S2	S3	S1	S2	S3
TSS	81	24	19	49	2.5	11
COD	33	9.9	7.6	20	6.0	4.6
Pb	0.060	0.018	0.014	0.034	0.0102	0.0078
Zn	1.6	0.48	0.37	0.95	0.29	0.22
Cu	0.019	0.0057	0.0044	0.012	0.0036	0.0028
TKN	0.98	0.29	0.23	0.059	0.018	0.014
TP	0.17	0.051	0.039	0.10	0.030	0.023
NO_3+NO_2 - N	0.17	0.051	0.039	0.097	0.029	0.022

PARA-METER	100-YEAR RETURN 4.39" in 24 hrs		
	S1	S2	S3
TSS	22	6.6	5.1
COD	8.9	2.7	2.0
Pb	0.016	0.0048	0.0037
Zn	0.43	0.13	0.099
Cu	0.0054	0.0016	0.0012
TKN	0.027	0.0081	0.0062
TP	0.046	0.014	0.011
NO_3+NO_2 - N	0.044	0.013	0.010

S1 = Parameter Concentration at Sampler #1 (Milligrams / Liter)
S2 = Parameter Concentration at Sampler #2 (Milligrams / Liter)
S3 = Parameter Concentration at Sampler #3 (Milligrams / Liter)

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DISCUSSION

The FHWA, Caltrans, and WSDOT runoff models were all developed using research sites at different locations and, therefore, with varying site characteristics. When applying the models to sites other than the research site, similar site characteristics are obviously desireable. These include climatic patterns, site drainage area, percent of drainage area that is paved, and average traffic volumes.

The ideal application for the Caltrans runoff model is an arid or semiarid region of the United States with the median, travelled lanes, and shoulders 100 percent paved. The drainage area should be between two and four acres to correspond to the drainage areas used to develop the model. Storm duration time should be 24 hours. (The Caltrans model was developed from from data at research sites in Placerville, Sacramento, Walnut Creek, and Redondo Beach.)

The FHWA model allows for more varied site characteristics. Different equations and constraints exist for three different site types. The Howe and Watt Ave test sites fit the profile of the Type I site best. Ideally Type I sites are bridges and overpasses. Our test site is not a bridge or overpass, but the other site characteristics of the Howe and Watt Avenue sites match Type I sites more closely than Type II and Type III sites. Site Type I has a drainage area that is 100 percent paved. Site Type II is generally 30 to 40 percent paved. Type III is a rural site with flush shoulders and a drainage area that is 20 to 30 percent paved.

The WSDOT runoff model is broken down into two site catagories, eastern and western Washington. Western Washington refers to coastal areas with frequent light rainfall. Average daily traffic ranges from 2000 to 17,000 ideally. For this report,

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annual Washington pollutant concentrations are divided by the average annual number of wet hours and multiplied by the number of hours for the three storm events being analyzed so Washington results can be compared to the two other models on a storm-by-storm basis.

Tables I and II on Page 26 & 27 compare concentrations predicted from five different constituents. The five pollutants were selected for discussion because they are the only five constituents that all three models predict. Table III on Page 28 shows the 95% confidence limits for the Caltrans model. The FHWA loads fall within Caltrans confidence limits only 23% of the time. The WSDOT loads fall within the limits only 33% of the time. This lack of consistency in pollutant load predictions suggests that the models may be valid for specific sites, but are not general enough to give reliable results for different geographic locations. The models also may be using equations which oversimplify a situation which is actually very complex. The FHWA runoff model showed a pattern of predicting values falling somewhere between those of Caltrams and WSDOT. Caltrans and WSDOT results show opposite trends for the Howe and Watt Ave sites. Caltrans predicts lowest pollutant concentrations for Howe Avenue and highest for Watt Avenue. One possible explanation for this trend may be that the Caltrans model is giving false high readings for the Watt Ave site because of the test site drainage area. As stated earlier, the Caltrans model was developed for use in an area that is from two to four acres. The Watt Ave site is only 0.44 acres. When the parameter loading is divided by a smaller area, the resulting concentration is higher. Alternatively, this may be an indication that the models are too site-specific and do not accurately predict pollutants for general locations. A third hypothesis is that the models show more consistant trends on a annual basis rather than on single storm events.

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TABLE I

COMPARISON OF POLLUTANT CONCENTRATIONS

	Pollutant Concentration (mg / liter)				
	TSS (NR)	TKN	Pb	Zn	COD
Howe Ave:					
R = 0.1 "					
FHWA	822	7.3	8.8	1.6	395
CALTRANS	95	3.9	0.57	0.41	111
WSDOT-east	1063	1.3	0.76	22	425
R = 1.98"					
FHWA	78	0.57	0.83	0.13	33
CALTRANS	49	0.44	0.16	0.062	21
WSDOT-east	644	0.78	0.46	13	258
R = 4.39"					
FHWA	65	0.44	0.69	0.11	26
CALTRANS	22	0.20	0.072	0.028	9.5
WSDOT-east	291	0.35	0.21	6.1	116
Watt Ave:					
R= 0.1"					
FHWA	304	20	4.2	2.4	786
CALTRANS	938	41	5.8	4.2	1152
WSDOT-east	81	0.98	0.06	1.6	33
R = 1.98"					
FHWA	57	1.3	0.66	0.19	56
CALTRANS	480	4.4	1.6	0.62	207
WSDOT-east	49	0.059	0.034	0.95	20
R = 4.39"					
FHWA	54	0.75	0.59	0.13	36
CALTRANS	216	2.0	0.71	0.28	94
WSDOT-east	22	0.027	0.016	0.43	8.9

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TABLE II

COMPARISON OF POLLUTANT LOADS

	Pollutant Load (grams)				
	TSS (NR)	TKN	Pb	Zn	COD
Howe Ave:					
R = 0.1 "					
FHWA	30,645	272	327	58	14,714
CALTRANS	4,086	168	25	18	4,778
WSDOT-east	35,498	43	25	740	14,197
R = 1.98"					
FHWA	73,404	540	780	127	31,012
CALTRANS	41,947	371	136	53	17,845
WSDOT-east	425,975	511	303	8,877	170,391
R = 4.39"					
FHWA	136,231	930	1,442	227	54,957
CALTRANS	41,947	371	136	53	17,845
WSDOT-east	425,975	511	303	8,877	170,391
Watt Ave:					
R= 0.1"					
FHWA	1,379	91	19	11	3,561
CALTRANS	3,819	167	24	17	4,686
WSDOT-east	3,103	3.7	2.2	60	1,243
R = 1.98"					
FHWA	5,148	113	59	17	4,999
CALTRANS	38,746	353	127	50	16,740
WSDOT-east	37,213	45	26	716	14,887
R = 4.39"					
FHWA	10,691	150	118	25	7,108
CALTRANS	38,746	353	127	50	16,740
WSDOT-east	37,213	45	26	716	14,887

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TABLE III

95% CONFIDENCE LIMITS FOR CALTRANS MODEL *

Upper & Lower Confidence Limits For Pollutant Load in Grams					
	TSS (NR)	TKN	Pb	Zn	COD
Howe Ave:					
R = 0.1"	0	28	0	5	2,052
	12,967	308	56	31	7,504
R = 1.98"	33,066	231	105	40	15,119
	50,828	511	167	66	20,571
R = 4.39"	33,066	231	105	40	15,119
	50,828	511	167	66	20,571
Watt Ave:					
R = 0.1"	0	38	0	5	2,163
	11,984	296	52	29	7,209
R = 1.98"	30,581	224	99	38	14,218
	46,911	482	155	62	19,263
R = 4.39"	30,581	224	99	38	14,218
	46,911	482	155	62	19,263

* Confidence limits were calculated using the procedure outlined in Reference No. 7

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APPENDIX A

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EFFECT OF VEGETATED CHANNELS ON POLLUTANT CONCENTRATIONS (Ref #6)

CHANNEL LENGTH		APPROXIMATE FRACTION OF POLLUTANT REMAINING
METERS	FEET	
< 10	< 33	1.00
10 - 20	33 - 66	0.50
20 - 30	66 - 98	0.40
30 - 40	98 - 131	0.30
40 - 50	131 - 164	0.26
50 - 60	164 - 197	0.23
> 60	> 197	0.20

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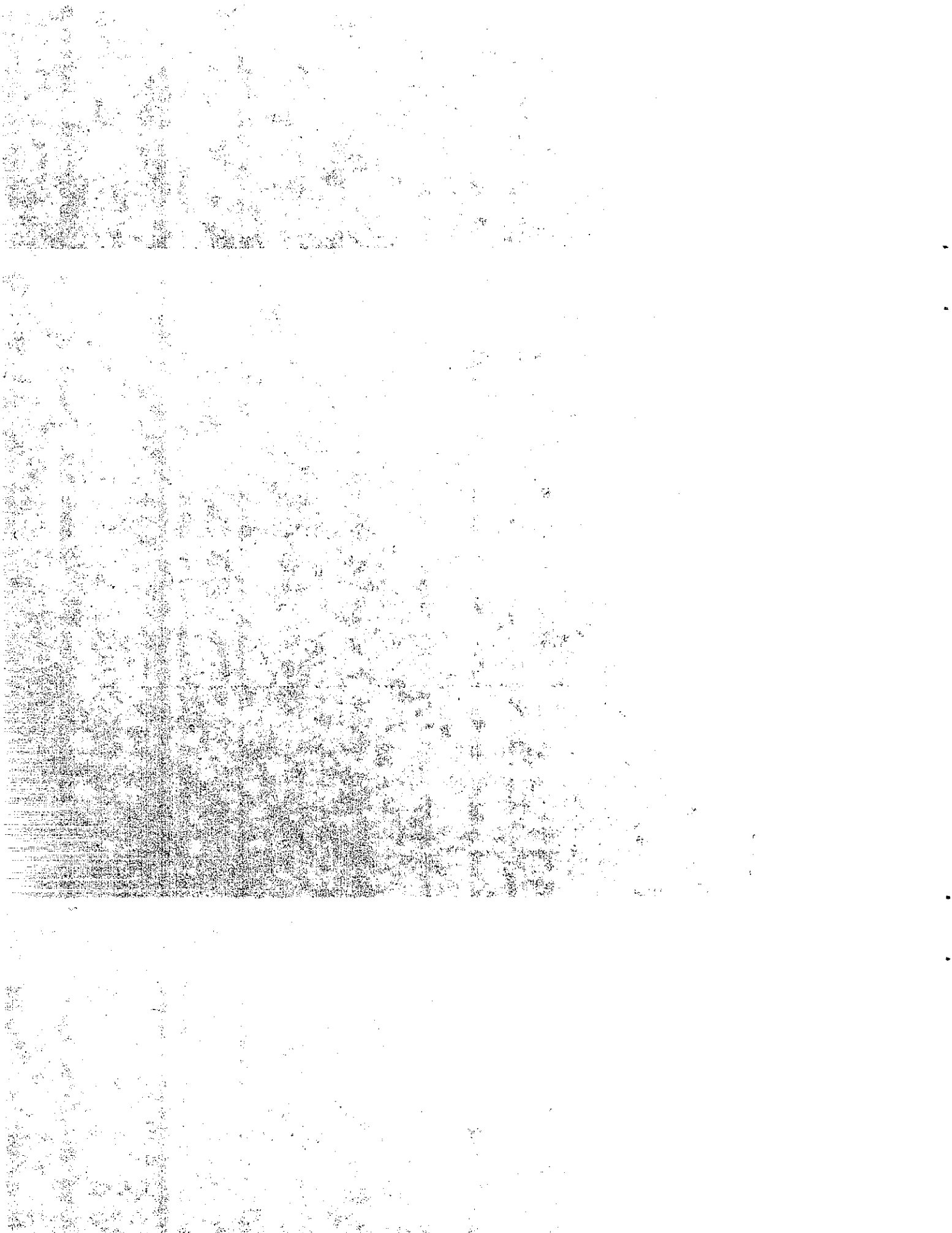

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APPENDIX B

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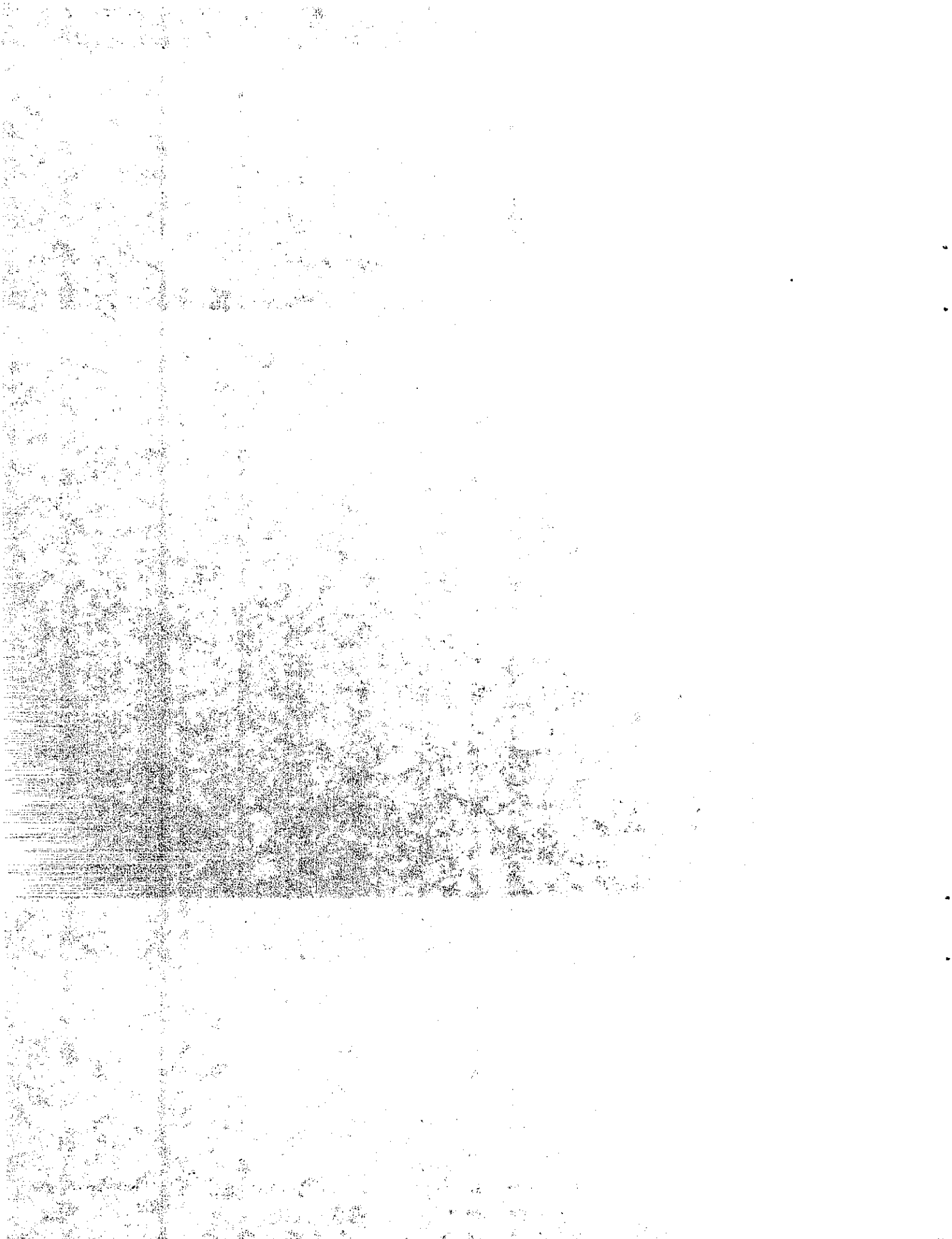

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SITE 1: HOWE AVENUE, U.S. 50

Site I is located along westbound U.S. 50 near P.M. 3.67. Westbound U.S. 50 is a four lane freeway which has a portland cement concrete pavement. Approximately 4.64 acres of freeway contribute runoff into the channel. The runoff sheet flows to a ditch which parallels the freeway and the Howe Avenue off-ramp on the north side. A portion of the runoff also drains into drop inlets located in the median. The runoff from each source flows through an 18-inch asbestos cement pipe and discharges into an earth-bottomed channel approximately 344 feet in length. The runoff then flows into an 18-inch culvert which traverses under the westbound U.S. 50 on-ramp leading to the vegetated channel. The vegetated channel is approximately 363 feet long. The average daily traffic is 129,000 vehicles (eastbound and westbound). The research area is landscaped with various trees and shrubs. Some of the trees and shrubs include Raywood Ash, Honey Locust, Coast Redwood, Coffee Berry, Ceanothus and Western Redbud.

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SITE 2: WATT AVENUE, U.S. 50

Site 2 is located along westbound U.S. 50 near P.M. R5.4. Approximately 0.44 acres of freeway area contribute runoff into the channel. Westbound highway U.S. 50 is a four lane freeway which has a portland cement concrete pavement. The runoff flows into two consecutive drop inlets (Type G1) located within the 8-foot paved shoulder to the north side of the freeway. The runoff travels through an 18-inch asbestos concrete pipe (ACP) and discharges the runoff into the vegetated channel which is approximately 181 feet in length. The runoff exits the channel through a 24-inch reinforced concrete pipe. There is a third culvert located to the west of the culvert at the end of the channel. The third culvert also contributes runoff to the channel. Therefore, the third sampler is placed before the point where the runoff enters the channel. This will insure that the runoff sampled by the third sampler will not include the runoff from the third culvert. The annual average daily traffic is 119,000 vehicles (eastbound and westbound). The area is landscaped with various trees and shrubs. Some of the trees and shrubs include the Honey Locust, Coast Redwood, Interior Live Oak, Cork Oak, and Western Redbud.

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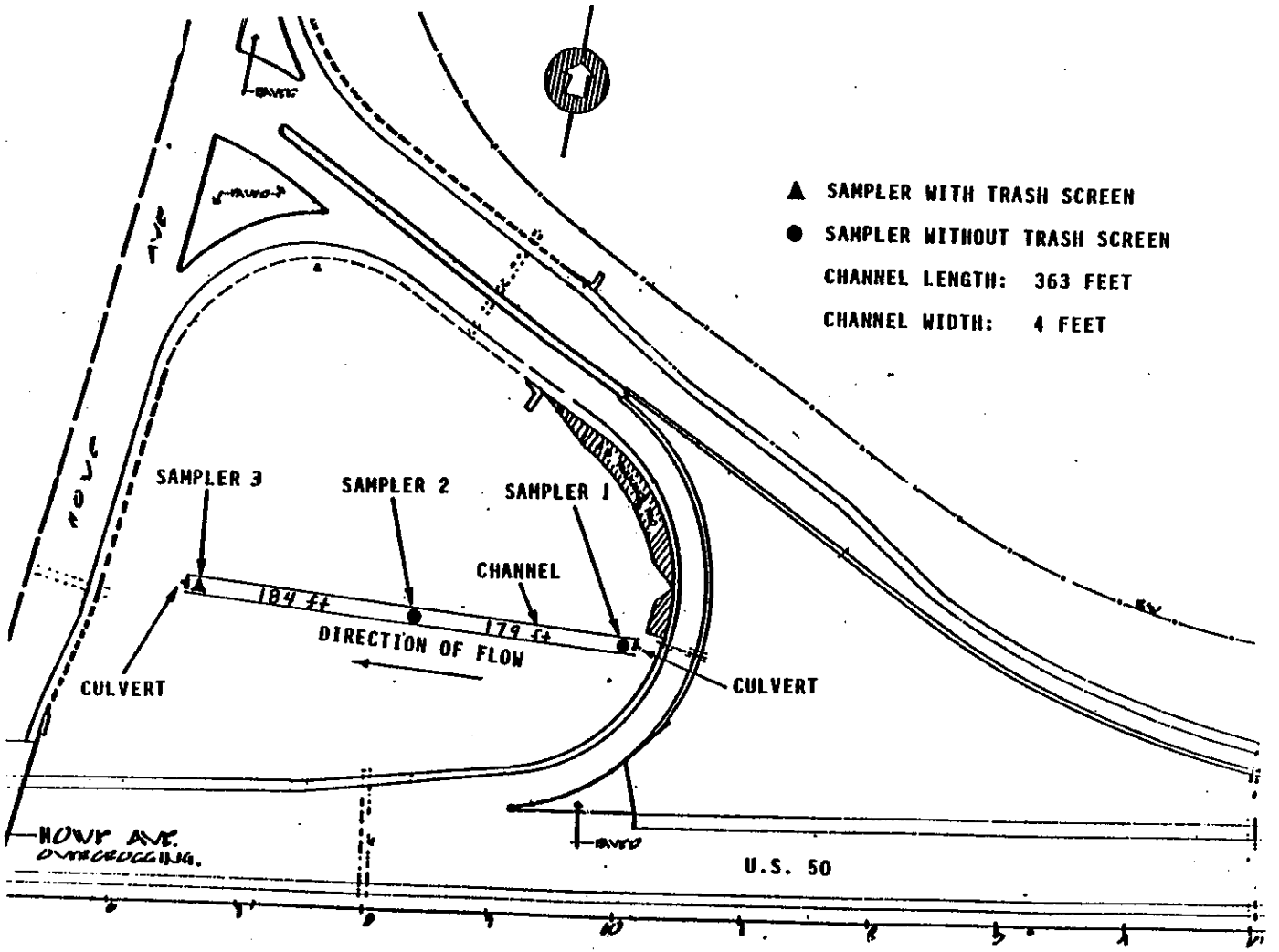

SITE 1 MAP

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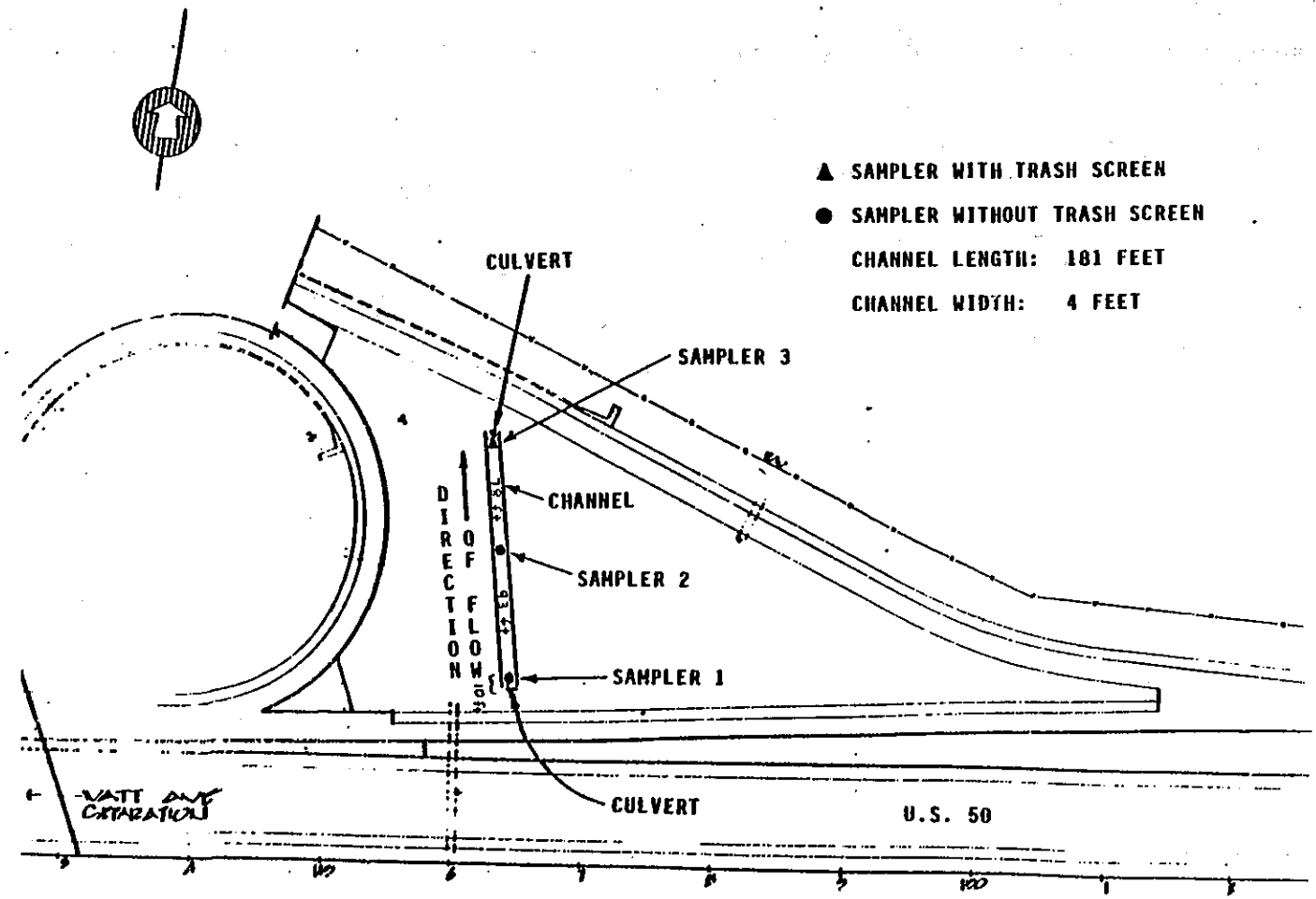

SITE 2 MAP

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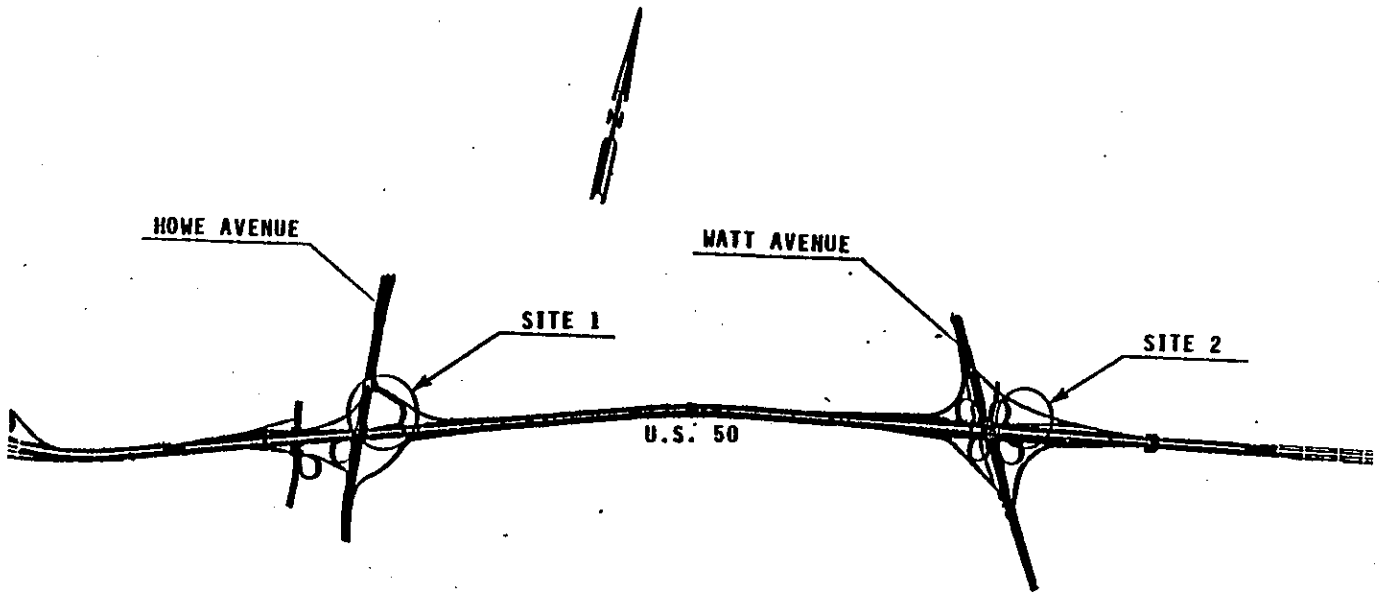

LOCATION MAP

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APPENDIX C

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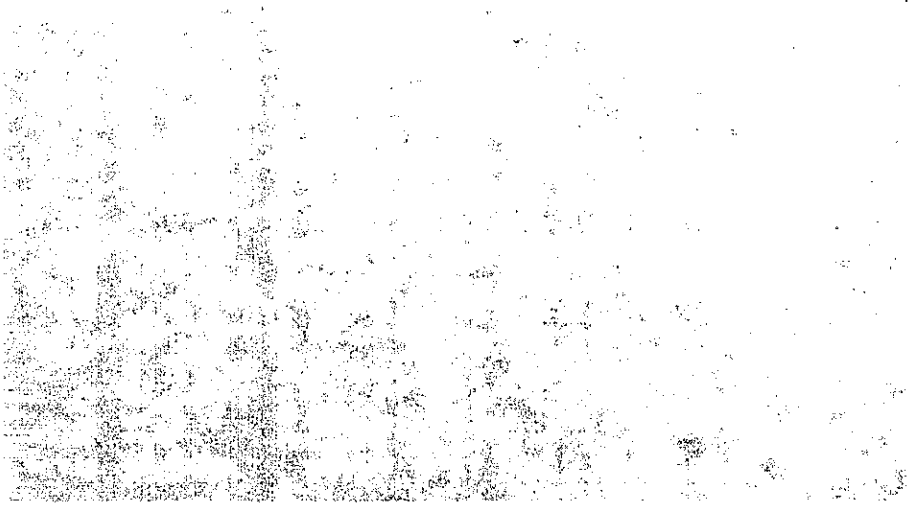

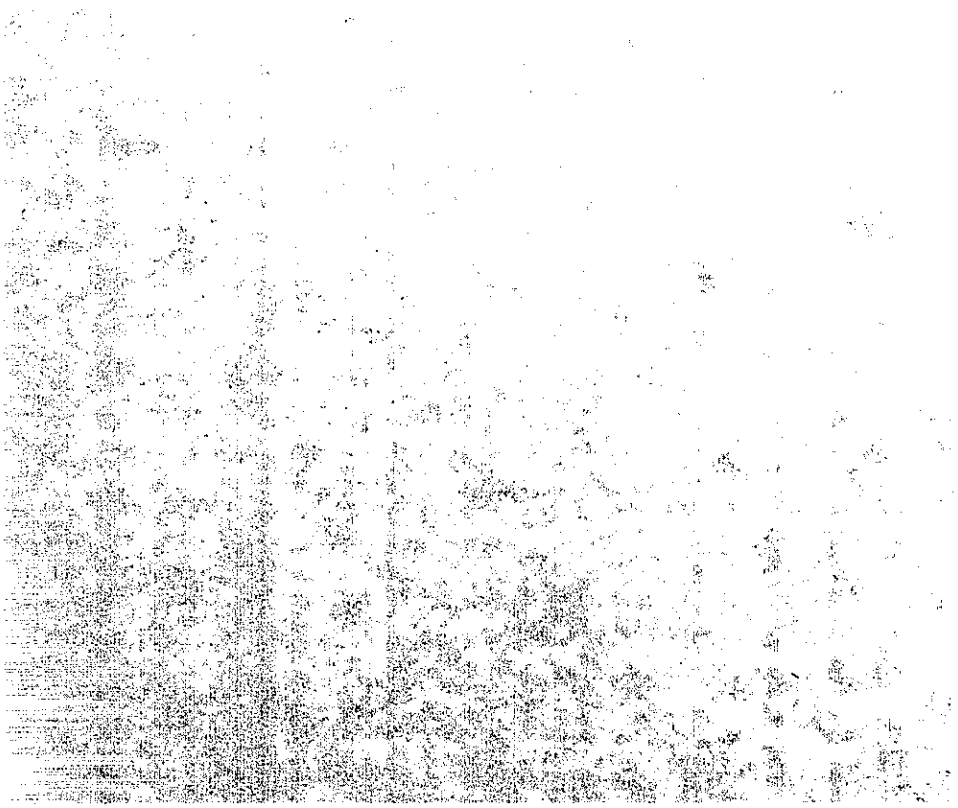

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FORMULAS FOR RUNOFF MODELS

FHWA MODEL (Input, Output, and Equations)

FHWA MODEL - INPUT

ADT,	Average Daily Traffic (vehicles / day)
R,	Rainfall (inches)
DD,	Dry Days Since Last Rainfall (days) Min = 1 day
RD,	Rainfall Duration (hours)
HL,	Highway Length (miles)
T,	Time of Accumulation (days) Max = 20 days
A.	Site Drainage Area (sq ft)
Site Type,	I, II, or III:
Type I Site =	Urban, elevated bridge deck, 100% paved with impact barriers containing each set of lanes
Type II Site =	Mountable curb with paved and nonpaved drainage area. Generally 30-40% paved
Type III Site =	Rural sites with flush shoulders, paved and nonpaved runoff through ditches

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FHWA MODEL - OUTPUT

Q,	Runoff (inches)
FD,	Runoff Duration (hours)
r,	Average Runoff Rate (inches / hour)
Kl,	Pollutant Accumulation Rate (lbs / mile-day)
Po,	Initial Surface Pollutant Load (lbs)
P,	Pollutant Level After Build-up (lbs)
PD,	Pollutant Load Discharged (lbs)
TS,	Total Solids (lbs)
Cp,	Constituent Concentration (mg / liter)
Pp,	Constituent Load (grams / storm)
TSS,	Total Suspended Solids (lbs)
VSS,	Volatile Suspended Solids (lbs)
TVS,	Total Volatile Solids (lbs)
TKN,	Total Kjeldahl Nitrogen (lbs)
BOD,	Biological Oxygen Demand (lbs)
TOC,	Total Organic Chemicals (lbs)
COD,	Chemical Oxygen Demand (lbs)
TN,	Total Nitrogen (lbs)
TPO_4,	Total Phosphate (lbs)
Cl,	Chlorine (lbs)
Pb,	Lead (lbs)
Zn,	Zinc (lbs)
Fe,	Iron (lbs)
Cu,	Copper (lbs)
Cd,	Cadmium (lbs)
Cr,	Chromium (lbs)
Hg,	Mercury (lbs)

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FHWA MODEL - EQUATIONS

TYPE I SITES:

$Q = 0.969R - 0.0187$

$FD = 1.12RD + 0.69$

$K2 = 5.0$

TYPE II SITES:

$Q = 0.470 * R^{1.369} * DD^{-0.0858}$

$FD = 1.06RD + 1.79$ if $DD > \text{or} = 10$

$FD = 1.27RD + 2.16$ if $DD < 10$

$K2 = 6.5$

TYPE III SITES:

$Q = 0.845 * R^{1.892} * DD^{-0.654}$

$FD = 1.92RD + 4.18$ if $DD > \text{or} = 10$

$FD = 1.48RD + 8.28$ if $DD < 10$

ALL SITES:

$r = Q / FD$

$K1 = 0.007 * (ADT^{0.89})$

$P = Po + (K1 * HL * T)$

$Po = 0$ if a storm of rainfall intensity > 0.5 inches per hour occurs at the beginning of the initial accumulation period

$Po = K * HL * T$ for all other cases

$PD = P * (1 - e^{(-K2 * r)})$

$TS = PD$

$Cp = (192{,}222.37 * Pp) / (Q * A)$

Pp = See tables on page C-4 and C-5 for individual constituent load equations

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FHWA MODEL - EQUATIONS

CONSTITUENT EQUATIONS FOR SITE TYPE I AND SITE TYPE II

PARAMETER	TYPE I	TYPE II
TSS =	0.53TS - 3.2	0.63TS - 188
VSS =	0.191TS + 0.2	0.152TS + 13.5
TVS =	0.221TS + 13.3	0.263TS + 243
TKN =	0.0033TS + 0.16	0.00546TS + 1.28
BOD =	0.023TS + 1.5	0.030TS + 28.3
TOC =	0.057TS + 0.80	0.056TS + 25.2
COD =	0.202TS + 5.47	0.193TS + 275.3
TN =	0.00137TS + 0.12	0.0013TS + 0.713
TPO_4 =	0.0010TS + 0.00030	0.00225TS - 0.32
Cl =	0.034TS + 2.59	0.042TS + 87
Pb =	0.0056TS - 0.024	0.00102TS + 0.04
Zn =	0.00084TS + 0.014	0.000584TS + 0.103
Fe =	0.015TS + 0.59	0.0196TS - 5.0
Cu =	0.00029TS + 0.00073	0.000316TS + 0.064
Cd =	0.00014TS - 0.0014	(4.16×10^{-5})TS + 0.021
Cr =	0.00016TS + 0.0012	(4.3×10^{-5})TS + 0.036
Hg =	(-7.6×10^{-7})TS + 8.8×10^{-4}	(2.44×10^{-6})TS + 1.006×10^{-6}

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FHWA MODEL - EQUATIONS

CONSTITUENT EQUATIONS FOR SITE TYPE III

PARAMETER	TYPE III
TSS =	0.32TS - 36.8
VSS =	0.061TS - 3.3
TVS =	0.32TS - 32.3
TKN =	0.0031TS + 0.55
BOD =	N / A
TOC =	0.068TS - 5.85
COD =	0.087TS + 0.65
TN =	0.00183TS + 0.054
TPO_4 =	0.00215TS - 0.245
Cl =	0.135TS + 2.6
Pb =	0.00041TS - 0.029
Zn =	0.000267TS - 0.011
Fe =	0.014TS - 1.61
Cu =	0.000074TS + 0.00878
Cd =	0.000040TS + 0.007
Cr =	0.00023TS - 0.028
Hg =	(-5.8×10^{-6})TS + 0.015

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CALTRANS MODEL (Input, Output, and Equations)

INPUT

ADT,	Average Daily Traffic	(vehicles / day)
R,	Rainfall	(inches)
RD,	Rainfall Duration	(hours)
A,	Site Drainage Area	(sq ft)
K,	Runoff Coefficient	(default value: K = 0.90)

OUTPUT

Cp,	Constituent Concentration	(mg / liter)
Pp,	Constituent Load	(grams / storm)
VDS,	Vehicles During Storm	(vehicles / storm)
Pb,	Lead Load	(grams / storm)
Zn,	Zinc Load	(grams / storm)
FR,	Filterable Residue Load	(grams / storm)
COD,	Chemical Oxygen Demand Load	(grams / storm)
TKN,	Total Kjeldahl Nitrogen Load	(grams / storm)
NR,	Total Nonfilterable Residue Load	(grams/storm)
TR,	Total Residue Load	(grams / storm)

EQUATIONS

Pb = 14.3 + 0.00189(VDS)	Zn = 11.5 + 0.00064(TR)
Zn = 14.3 + 0.00060(VDS)	COD = 3600 + 0.214(TR)
FR = 5360 + 0.140(VDS)	NR = -760 + 0.65(TR)
COD = 3590 + 0.221(VDS)	VDS = (ADT / 24) * RD
TKN = 150 + 0.00342(VDS)	Note: 423.78 is the conversion factor from g/in-sq ft to mg/liter
Cp = (423.78 * Pp) / (K * R * A)	

(Units are as indicated in input table)

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WSDOT MODEL (Input, Output, and Equations)

INPUT

ADT,	Average Daily Traffic (vehicles / day)
Ai,	Impervious Drainage Area (sq ft)
Ap,	Pervious Drainage Area (sq ft)
Atot,	Total Drainage Area (sq ft)
Ki,	Runoff Coefficient of Impervious Drainage Area
Kp,	Runoff Coefficient of Pervious Drainage Area
L,	Length (ft)
p,	TSS Loading Factor
R,	Rainfall (inches)
Rtot,	Total Annual Rainfall (inches)
D,	Duration of Storm Event (hours)

OUTPUT

K,	Runoff Factor of Total Drainage Area
Pl,	Constituent Load (lbs)
r,	Runoff Volume (cu ft)
rtot,	Total Annual Runoff Volume (cuft)
VDS,	Annual Vehicles During Storm (veh during storm / year)
X,	Ratio of Impervious Area to Total Area
COD,	Chemical Oxygen Demand (lbs)
Cp,	Pollutant Concentration (mg / liter)
SH,	Average Annual Storm Hours (hours / year)

Constituents:		TSS,	Total Suspended Solids (lbs)
Pb,	Lead (lbs)	TKN,	Total Kjeldahl Nitrogen (lbs)
Zn,	Zinc (lbs)	NO_2,	Nitrite (lbs)
Cu,	Copper (lbs)	NO_3,	Nitrate (lbs)
N,	Nitrogen (lbs)	TP,	Total Phosphorus (lbs)

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WSDOT MODEL - EQUATIONS

$X = Ai / Atot$

$K = X * (Kp + (Ki - Kp))$

$SH = (20.7 * Rtot) + 158$

$VDS = ADT / 24 * SH$

$TSS = VDS * K * P * L * (D / SH)$

$r = (R/12) * Atot * K$

$Cp = (Pl / r) * 16{,}019$

Default Values:

$Ki = 0.70$ $\quad$ $P(\text{east Wash}) = 26 \times 10^{-3}$ lbs / mi-VDS

$Kp = 0.45$ $\quad$ $P(\text{west Wash}) = 6.4 \times 10^{-3}$ lbs / mi-VDS

CONSTITUENT EQUATIONS FOR EASTERN WASHINGTON (inland):

$COD = 0.4 * TSS$

$Pb = (5.3 * 10^{-4} + (2.80 * 10^{-9} * ADT)) * TSS$

$Zn = (2.0 * 10^{-4} + (3.20 * 10^{-7} * ADT)) * TSS$

$Cu = (7.9 * 10^{-5} + (2.70 * 10^{-9} * ADT)) * TSS$

$TP = 2.1 * 10^{-3} * TSS$

$TKN = 1.2 * 10^{-3} * TSS$

$(NO_3 + NO_2\text{-}N) = 2.0 * 10^{-3} * TSS$

CONSTITUENT EQUATIONS FOR WESTERN WASHINGTON (coastal):

$COD = 0.4 * TSS$

$Pb = (1.5 * 10^{-4} + (8.70 * 10^{-8} * ADT)) * TSS$

$Zn = (1.4 * 10^{-4} + (3.00 * 10^{-8} * ADT)) * TSS$

$Cu = (7.9 * 10^{-5} + (2.70 * 10^{-9} * ADT)) * TSS$

$TP = 2.1 * 10^{-3} * TSS$

$TKN = 2.7 * 10^{-3} * TSS$

$(NO_3 + NO_2\text{-}N) = 2.0 * 10^{-3} * TSS$

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APPENDIX D

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SAMPLE CALCULATIONS - FHWA MODEL (Howe Ave Site)

Input:

Site Type I
ADT = 64,500 vehicles / day
R = 0.1 inch
DD = 10 days
RD = 2 hours
HL = 0.80 mile
T = 10 days
A = 202,118 sq ft

Output:

$Q = 0.969R - 0.0187 = 0.969\ (0.1\text{ in}) - 0.0187 = 0.0782$ inches

$FD = 1.12RD + 0.69 = 1.12\ (2\text{ hrs}) + 0.69 = 2.93$ hours

$K2 = 5.0$

$r = Q / FD = 0.0782\text{ in} / 2.93\text{ hrs} = 0.0267\text{ in / hr}$

$K1 = 0.007 * (ADT^{0.89})$
$= 0.007 * (64{,}500^{0.89}) = 133.54$ lbs / mi-day

$Po = 0$

$P = Po + (K1 * HL * T)$
$= 0 + (133.54\text{ lbs / mi-day} * 0.80\text{ mi} * 10\text{ days} = 1068.32$ lbs

$PD = P * (1 - e^{(-K2 * r)})$
$= 1068.32\text{ lbs} * (1 - e^{(-5.0 * 0.0267)}) = 133.51$ lbs

$TS = PD = 133.51$ lbs

$TS = PD = (133.51\text{ lbs}) * (453.59\text{ grams / lb}) = 60{,}559$ grams

$Cp = (192{,}222.37 * Pp) / Q * A$
$= (192{,}222.37 * 133.51\text{ lbs}) / (0.0782\text{ in} * 202{,}118\text{ sq ft})$
$= 12.16 * Pp = 12.16 * 133.51 = 1624$ mg / liter

$TSS = 0.53TS - 3.2 = (0.53 * 133.51) - 3.2 = 67.56$ lbs
$= 30{,}645$ grams

$VSS = 0.191TS + 0.2 = (0.191 * 133.51) + 0.2 = 25.70$ lbs
$= 11{,}657$ grams

$TVS = 0.221TS + 13.3 = (0.221 * 133.51) + 13.3 = 42.81$ lbs
$= 19{,}416$ grams

$TKN = (3.3 \text{ X } 10^{-3} * TS) + 0.16 = (3.3 \text{ x } 10^{-3} * 133.51) + .16$
$= 0.60$ lbs $= 272$ grams

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BOD = 0.023TS + 1.5 = (0.023 * 133.51) + 1.5 = 4.57 lbs
= 2,073 grams

TOC = 0.057TS + 0.80 = (0.057 * 133.51) + 0.80 = 8.41 lbs
= 3,815 gr

COD = 0.202TS + 5.47 = (0.202 * 133.51) + 5.47
= 32.44 lbs = 14,714 grams

TN = 0.00137TS + 0.12 = (0.00137 * 133.51) + 0.12 = 0.30
= 0.30 lbs = 137 grams

TPO_4 = 0.0010TS + 0.00030 = (0.0010 * 133.51) + 0.00030
= 0.13 lbs = 61 grams

Cl = 0.034TS + 2.59 = (0.034 * 133.51) + 2.59 = 7.13 lbs
= 3,234 grams

Pb = 0.0056TS - 0.024 = (0.0056 * 133.51) - 0.024
= 0.72 lbs = 328 grams

Zn = 0.00084TS + 0.014 = (0.00084 * 133.51) + 0.014
= 0.13 lbs = 57 grams

Fe = 0.015TS + 0.59 = (0.015 * 133.51) + 0.59
= 2.59 lbs = 1,176 grams

Cu = 0.00029TS + 0.00073 = (0.00029 * 133.51) + 0.00073
= 0.039 lb = 18 grams

Cd = 0.00029TS - 0.0014 = (0.00029 * 133.51) - 0.0014
= 0.037 lb = 17 grams

Cr = 0.00016TS + 0.0012 = (0.00016 * 133.51) + 0.0012
= 0.023 lb = 10 grams

Hg = (-7.6×10^{-7})TS + 8.8×10^{-4} = (-7.6×10^{-7} *
133.51) + 8.8×10^{-4} = 0.00078 lb = 0.35 grams

Cp (TSS) = 12.16 * Pp = 12.16 * 67.56 = 822 mg / liter

Cp (VSS) = 12.16 * Pp = 12.16 * 25.70 = 313 mg / liter

Cp (TVS) = 12.16 * Pp = 12.16 * 42.81 = 521 mg / liter

Cp (TKN) = 12.16 * Pp = 12.16 * 0.60 = 7.3 mg / liter

Cp (BOD) = 12.16 * Pp = 12.16 * 4.57 = 56 mg / liter

Cp (TOC) = 12.16 * Pp = 12.16 * 8.41 = 102 mg / liter

Cp (COD) = 12.16 * Pp = 12.16 * 32.44 = 395 mg / liter

Cp (TN) = 12.16 * Pp = 12.16 * 0.30 = 3.6 mg / liter

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$Cp\ (TPO_4) = 12.16 * Pp = 12.16 * 0.13 = 1.6$ mg / liter

Cp (Cl) = 12.16 * Pp = 12.16 * 7.13 = 87 mg / liter

Cp (Pb) = 12.16 * Pp = 12.16 * 0.72 = 8.8 mg / liter

Cp (Zn) = 12.16 * Pp = 12.16 * 0.13 = 1.6 mg / liter

Cp (Fe) = 12.16 * Pp = 12.16 * 2.59 = 32 mg / liter

Cp (Cu) = 12.16 * Pp = 12.16 * 0.039 = 0.48 mg / liter

Cp (Cd) = 12.16 * Pp = 12.16 * 0.037 = 0.45 mg / liter

Cp (Cr) = 12.16 * Pp = 12.16 * 0.023 = 0.28 mg / liter

Cp (Hg) = 12.16 * Pp = 12.16 * 0.00078 = 0.0095 mg / liter

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SAMPLE CALCULATIONS - CALTRANS MODEL (Howe Ave Site)

Input:

ADT = 64,500 vehicles / day
R = 0.1 inch
RD = 2 hours
A = 202,118 sq ft
K = 0.90

Output:

VDS = (ADT / 24) * RD = (64,500 / 24) * 2 hrs = 5375 veh / storm

Pb = 14.3 + 0.00189 (VDS) = 14.3 + 0.00189 (5375 veh) = 24.46 g

Zn = 14.3 + 0.00060 (VDS) = 14.3 + 0.00060 (5375 veh) = 17.52 g

FR = 5360 + 0.140 (VDS) = 5360 + 0.140 (5375 veh) = 6,112.50 g

COD = 3590 + 0.221 (VDS) = 3590 + 0.221 (5375 veh) = 4,777.88 g

TKN = 150 + 0.00342 (VDS) = 150 + 0.00342 (5375 veh) = 168.38 g

Zn = 11.5 + 0.00064 (TR) ---> 17.52 = 11.5 + 0.00064 (TR)
---> TR = 9,406.25

COD = 3600 + 0.214 (TR) ---> 4,777.88 = 3600 + 0.214 (TR)
---> TR = 5,504.11

TR = (9,406.25 + 5,504.11) / 2 = 7,455.18 g

NR = -760 + 0.65 (TR) = -760 + 0.65 (7,455.18 g) = 4085.87 g

Cp = (423.78 * Pp) / (K * R * A)
= (423.78 * Pp) / (0.90 * 0.1 * 202,118) = 0.0232966 * Pp

Cp (TR) = 0.0232966 * 7,455.18 = 173.68 mg / liter

Cp (NR) = 0.0232966 * 4,085.87 = 95.19 mg / liter

Cp (FR) = 0.0232966 * 6,112.50 = 142.40 mg / liter

Cp (Pb) = 0.0232966 * 24.46 = 0.569 mg / liter

Cp (Zn) = 0.0232966 * 17.52 = 0.408 mg / liter

Cp (COD) = 0.0232966 * 4,777.88 = 111.308 mg / liter

Cp (TKN) = 0.0232966 * 168.38 = 3.923 mg / liter

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SAMPLE CALCULATIONS - WSDOT (Howe Ave Site)

Input:

Site:	Howe Avenue	ADT:	64,500 vehicles / day
Type:	inland	L:	4210 ft or 0.80 mile
Ai:	202,118 sq ft	Ki:	0.70
Ap:	0 sq ft	Kp:	0.45
Atot:	202,118 sq ft	P:	26 X 10^{-3}
Rtot:	17.87	D:	2 hours

Output:

X = Ai / Atot = 202,118 sq ft / 202,118 sq ft = 1

K = X * (Kp + (Ki - Kp)) = 1 * (0.45 + (0.70 - 0.45)) = 0.70

SH = (20.7 * Rtot) + 158 = (20.7 * 17.87 in) + 158
= 528 wet hours / year

VDS = (ADT / 24) * SH = (64,500 veh/day / 24) * 528 hrs/yr
= 1,419,000 veh/year (during storm hrs)

TSS = VDS * K * P * L * D / SH
= (1,419,000 veh/yr * 0.70 * 26 X 10^{-3} lbs/mi-VDS * 0.80 mi * 2 hrs) / (528 hrs/yr)
= 78.26 lbs = 35,498 grams

r = R * Atzot * K = (0.1 inch / 12) * 202,118 sqft * 0.70
= 1179 cuft

COD = 0.4 * TSS = 0.4 * 78.26 lbs = 31.30 lbs = 14,199 grams

Pb = (5.3 X 10^{-4} + (2.80 X 10^{-9} * ADT)) * TSS
= (5.3 X 10^{-4} + (2.80 X 10^{-9} * 64,500)) * 78.26
= 0.056 lbs = 25 grams

Zn = (2.0 X 10^{-4} + (3.20 X 10^{-7} * ADT)) * TSS
= (2.0 X 10^{-4} + (3.20 X 10^{-7} * 64,500)) * 78.26
= 1.63 lbs = 740 grams

Cu = (7.9 X 10^{-5} + (2.70 X 10^{-9} * ADT)) * TSS
= (7.9 X 10^{-5} + (2.70 X 10^{-9} * 64,500)) * 78.26
= 0.020 lbs = 9.0 grams

TP = 2.1 X 10^{-3} * TSS = 2.1 X 10^{-3} * 78.26
= 0.16 lb = 75 grams

TKN = 1.2 X 10^{-3} * TSS = 1.2 X 10^{-3} * 78.26
= 0.094 lb = 43 grams

NO_3 + NO_2 - N = 2.0 X 10^{-3} * TSS = 2.0 X 10^{-3} * 78.26
= 0.16 lb = 71 grams

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Cp (Pl) = (Pl / r) * 16,019 = (Pl / 1179) * 16,019 = 13.59 * Pl

Cp (TSS) = 13.59 * 78.26 lbs = 1063 mg / liter

Cp (COD) = 13.59 * 31.30 lbs = 425 mg / liter

Cp (Pb) = 13.59 * 0.056 lb = 0.76 mg / liter

Cp (Zn) = 13.59 * 1.63 lbs = 22 mg / liter

Cp (Cu) = 13.59 * 0.020 lb = 0.27 mg / liter

Cp (TP) = 13.59 * 0.16 lb = 2.2 mg / liter

Cp (TKN) = 13.59 * 0.094 lb = 1.3 mg / liter

Cp (NO_3 + NO_2- N) = 13.59 * 0.16 lbs = 2.2 mg / liter

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APPENDIX E

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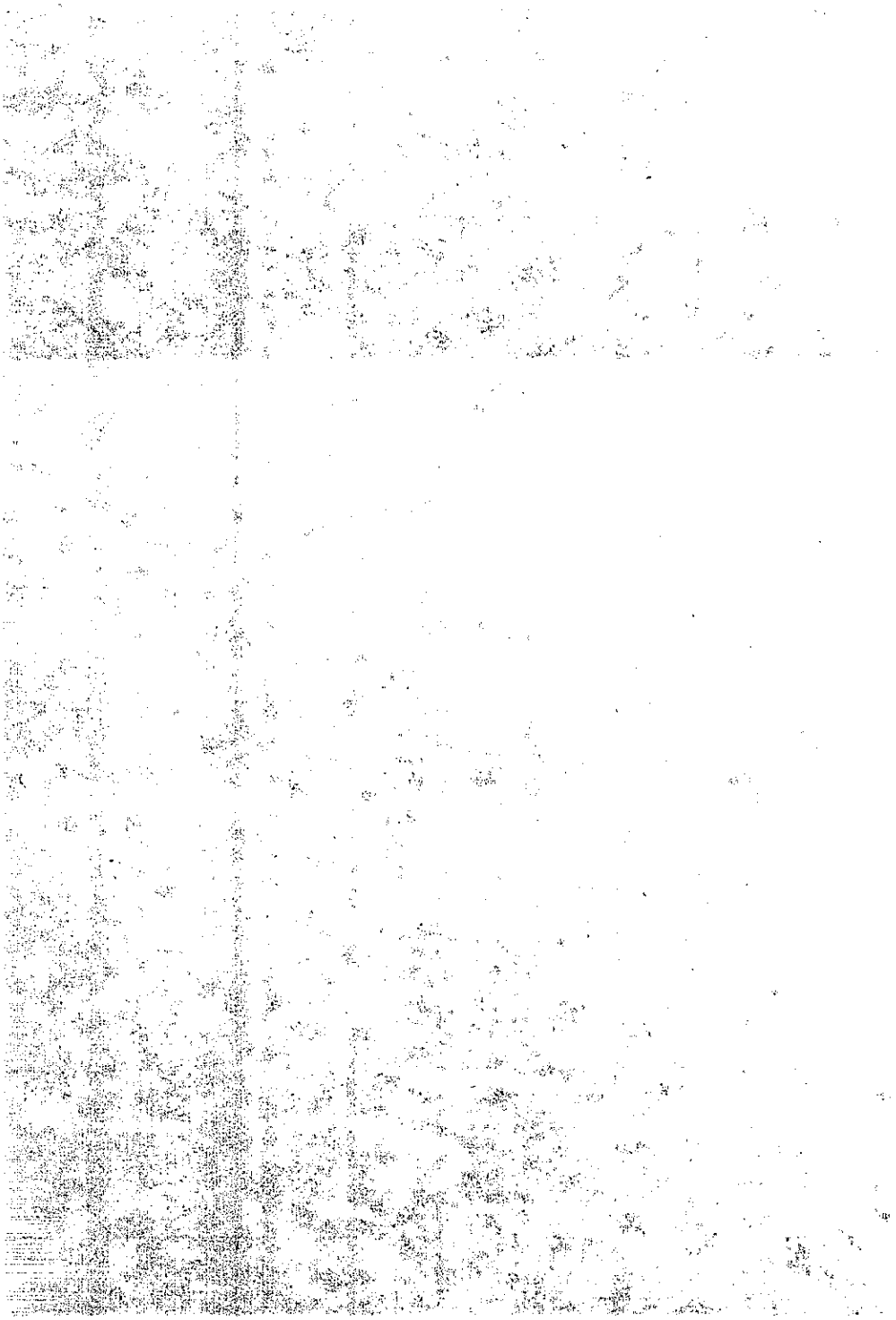

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CALIFORNIA

PRECIPITATION NORMALS (INCHES)

STATION		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
SACRAMENTO CITY WSO	R	4.18	2.94	2.18	1.44	.35	.13	.05	.09	.30	.90	2.31	3.00	17.87
SAINT HELENA		8.82	5.91	4.00	2.24	.55	.23	.07	.14	.39	1.96	4.30	6.63	35.24
SAINT MARYS COLLEGE		6.47	4.41	3.61	2.23	.58	.17	.06	.09	.33	1.64	3.51	5.11	28.21
SALINAS FAA AP		2.78	2.08	1.74	1.24	.24	.08	.04	.06	.26	.50	1.51	2.48	13.01
SALINAS DAM		4.73	3.98	3.08	2.01	.36	.03	.01	.04	.34	.53	2.38	3.51	21.00
SALT SPRINGS PWR HOUSE		6.72	6.52	5.96	4.08	2.07	.66	.25	.41	.86	2.08	5.20	7.51	44.32
SAN BERNARDINO CO HOSP		3.49	2.77	2.50	1.32	.54	.08	.04	.13	.49	.52	1.62	2.18	15.68
SAN CLEMENTE DAM		4.73	3.91	3.18	1.83	.38	.08	.05	.06	.24	.67	2.25	3.72	21.10
SANDBERG PTL FC130B		3.06	3.38	2.33	1.52	.47	.04	.03	.13	.41	.29	2.38	1.86	15.92
SANDBERG WSO	//R	2.52	2.81	1.57	1.04	.33	.04	.03	.10	.35	.26	1.99	1.90	12.94
SAN DIEGO WSO	R	2.11	1.43	1.60	.78	.24	.06	.01	.11	.19	.33	1.10	1.36	9.32
SAN DIMAS FIRE HD FC95		4.18	3.46	2.89	1.57	.39	.07	.03	.13	.33	.43	1.87	2.46	17.81
SAN FRANCISCO WSO	R	4.65	3.23	2.64	1.53	.32	.11	.03	.05	.19	1.06	2.35	3.55	19.71
S F FEDERAL BLDG. WSO	R	4.48	2.83	2.58	1.48	.35	.15	.04	.08	.24	1.09	2.49	3.52	19.33
SAN GABRIEL CANYON PH		5.44	4.44	3.52	1.81	.60	.15	.03	.13	.39	.46	2.26	2.86	22.09
SAN GABRIEL DM FC425BE		7.02	5.70	4.30	2.38	.66	.08	.02	.10	.41	.57	3.04	3.93	28.21
SAN GABRIEL FIRE DEPT		4.48	3.74	2.81	1.44	.27	.06	.01	.05	.30	.39	2.00	2.21	17.76
SAN JOSE	R	3.00	2.23	2.03	1.19	.30	.07	.05	.13	.21	.67	1.71	2.27	13.86
SAN LUIS OBISPO POLY		5.46	4.39	3.18	2.02	.39	.04	.04	.05	.33	.78	2.47	3.85	23.00
SAN RAFAEL		9.20	6.14	4.24	2.43	.54	.25	.06	.09	.43	2.10	4.77	7.23	37.48

PRECIPITATION DEPTH-DURATION-FREQUENCY TABLE

STATION NO. BSN ORDER SUB	STATION NAME	ELEV	SEC	TWP	RNG	LOT	BSN	LATITUDE	LONGITUDE	COUNTY CODE
A88 7633 0	SACRAMENTO CITY NWS	25	01	08N	04E	C	N	38.58	121.483	34

MAXIMUM PRECIPITATION FOR INDICATED DURATION D=DAYS H=HOURS

RETURN PERIOD IN YEARS	10	20	30	40	50	60	80	100	150	200	300	600	3650
2	1.98	2.87	2.98	3.17	3.41	3.68	4.06	4.46	5.17	5.73	6.86	9.74	17.74
5	2.64	3.34	3.98	4.34	4.62	4.94	5.49	6.00	6.92	7.73	9.25	13.22	22.92
10	3.18	4.18	4.69	5.09	5.40	5.78	6.38	6.95	7.95	8.94	10.59	15.31	25.88
20	3.51	4.79	5.35	5.78	6.13	6.53	7.20	7.80	8.87	10.06	11.97	17.17	28.41
25	3.64	4.96	5.56	6.00	6.36	6.76	7.45	8.07	9.16	10.48	12.36	17.74	29.17
40	3.78	5.37	5.99	6.11	6.47	7.24	7.96	8.60	9.76	11.09	13.16	18.90	30.71
50	4.02	5.55	6.19	6.65	7.04	7.46	8.19	8.85	9.96	11.41	13.53	19.43	31.41
100	4.39	6.12	6.80	7.28	7.70	8.13	8.91	9.59	10.73	12.37	14.63	21.03	33.49
200	4.75	6.67	7.39	7.90	8.34	8.78	9.61	10.31	11.47	13.30	15.68	22.57	35.45
1000	5.55	7.92	8.74	9.28	9.79	10.24	11.15	11.89	13.07	15.35	18.00	25.94	39.64
10000	6.67	9.67	10.40	11.10	11.77	12.23	13.24	14.03	15.20	18.11	21.11	30.45	45.13
PMP	13.15	18.33	20.40	22.27	23.36	24.88	27.73	30.14	34.58	38.98	44.82	67.81	100.23
MEAN	2.115	2.792	3.138	3.461	3.642	3.905	4.292	4.686	5.364	6.828	7.164	10.189	18.127
CLOCK HR. COR.	1.148	1.070	1.048	1.028	1.018	1.018	1.000	1.000	1.000	1.000	1.000	1.000	1.000
CALCULATED SKEW	1.300	1.831	1.477	1.150	.931	.815	.964	.959	.774	.908	1.109	.818	.601
REGIONAL SKEW	1.100	1.300	1.200	1.100	1.100	1.000	.900	.800	.600	.800	.700	.700	.400
SKEW USED	1.100	1.300	1.200	1.100	1.100	1.000	.900	.800	.600	.800	.700	.700	.400
KURTOSIS	4.588	9.674	7.283	5.876	4.595	3.861	4.719	4.372	3.435	3.958	4.891	3.434	3.144
N	105	105	105	105	105	105	105	105	105	105	105	105	105
RECORD YEAR	1880	1880	1880	1880	1880	1880	1880	1880	1862	1862	1862	1862	1862
RECORD MAXIMUM	5.280	8.370	8.810	9.170	9.170	9.170	11.080	11.440	12.070	14.780	19.380	24.730	35.540
NORMALIZED MAX	3.788	4.743	4.653	4.283	3.974	3.491	3.990	3.554	3.069	3.472	4.058	3.446	2.822
CALC. COEF. VAR	.396	.421	.487	.396	.382	.386	.396	.406	.487	.419	.420	.415	.340
REGN. COEF. VAR	.348	.371	.372	.370	.361	.358	.364	.363	.363	.365	.369	.377	.324
USED COEF. VAR	.348	.371	.372	.370	.361	.358	.364	.363	.363	.365	.369	.377	.324
MEAN/A	.1167	.1540	.1727	.1876	.2009	.2154	.2368	.2582	.2960	.3321	.3952	.5621	1.0000
RP10/A	.1711	.2305	.2588	.2807	.2981	.3188	.3521	.3834	.4341	.4941	.5894	.8448	1.4266
RP20/A	.2068	.2748	.3044	.3310	.3567	.3736	.4107	.4450	.5044	.5737	.6828	.9788	1.6692
RP50/A	.2216	.3004	.3414	.3670	.3883	.4115	.4529	.4881	.5495	.6295	.7462	1.0726	1.7327
RP100/A	.2428	.3375	.3758	.4018	.4247	.4485	.4916	.5291	.5921	.6826	.8069	1.1604	1.8474
RP1000/A	.3044	.4372	.4828	.5128	.5398	.5649	.6149	.6580	.7211	.8446	.9931	1.4389	2.1878
RP10000/A	.3678	.5334	.5844	.6169	.6494	.6748	.7385	.7737	.8384	.9990	1.1643	1.6796	2.4894
PMP/A	.7297	1.0111	1.1363	1.2287	1.2987	1.3723	1.5295	1.6640	1.9078	2.1588	2.5026	3.7468	5.5696

PRECIPITATION DEPTH-DURATION-FREQUENCY TABLE

STATION NO. BSN ORDER SUB	STATION NAME	ELEV	SEC	TWP	RNG	LOT	BSN	LATITUDE	LONGITUDE	COUNTY CODE
A88 9288 0	VACAVILLE	184	14	06N	01E	N	N	38.366	121.949	48

MAXIMUM PRECIPITATION FOR INDICATED DURATION D=DAYS H=HOURS

RETURN PERIOD IN YEARS	10	20	30	40	50	60	80	100	150	200	300	600	3650
2	2.88	3.58	4.08	4.47	4.88	5.14	5.82	6.42	7.58	8.13	9.51	13.73	24.04
5	3.88	4.92	5.68	6.11	6.62	6.95	7.88	8.65	10.04	10.90	12.83	18.43	31.87
10	4.51	5.81	6.68	7.16	7.74	8.09	9.15	10.01	11.53	12.71	14.82	21.57	35.88
20	5.11	6.66	7.53	8.14	8.79	9.14	10.32	11.24	12.88	14.26	16.68	24.19	38.51
25	5.29	6.92	7.82	8.44	9.11	9.46	10.67	11.62	13.28	14.76	17.18	24.99	39.54
40	5.58	7.47	8.42	8.89	9.57	10.13	11.41	12.38	14.07	15.74	18.28	26.62	41.63
50	5.85	7.73	8.78	9.36	10.09	10.64	11.78	12.74	14.44	16.28	18.76	27.38	42.58
100	6.30	8.31	9.36	10.25	11.03	11.38	12.78	13.81	15.56	17.56	20.29	29.63	45.39
200	6.91	9.28	10.39	11.12	11.95	12.29	13.77	14.84	16.82	18.88	21.78	31.79	48.85
1000	8.68	11.63	12.28	13.06	14.02	14.33	15.98	17.12	18.98	21.78	24.97	36.84	53.76
10000	9.76	13.48	14.98	15.74	16.87	17.12	18.98	20.28	22.83	25.71	29.27	42.89	61.17
PMP	19.14	25.80	28.96	31.25	33.46	34.81	39.75	43.43	50.14	55.33	64.94	95.52	143.99
MEAN	3.877	3.884	4.401	4.786	5.219	5.468	6.153	6.739	7.779	8.544	9.937	14.383	24.572
CLOCK HR. COR.	1.148	1.070	1.048	1.028	1.018	1.018	1.000	1.000	1.000	1.000	1.000	1.000	1.000
CALCULATED SKEW	1.081	1.276	.877	.861	1.179	1.105	.716	.685	.437	.372	.428	.723	.416
REGIONAL SKEW	1.100	1.300	1.200	1.100	1.100	1.000	.900	.800	.600	.800	.700	.700	.400
SKEW USED	1.100	1.300	1.200	1.100	1.100	1.000	.900	.800	.600	.800	.700	.700	.400
KURTOSIS	3.672	5.341	3.708	3.474	5.129	5.127	3.815	3.444	2.441	2.215	2.485	3.283	2.875
N	76	76	76	76	76	76	76	76	76	76	76	76	76
RECORD YEAR	1940	1943	1943	1943	1956	1956	1956	1956	1956	1956	1916	1941	1941
RECORD MAXIMUM	6.160	9.890	9.670	9.980	13.360	14.080	14.630	15.310	15.840	16.880	19.830	32.160	48.860
NORMALIZED MAX	2.282	3.314	3.841	2.719	3.795	3.841	3.488	3.198	2.514	2.338	2.441	2.941	2.923
CALC. COEF. VAR	.431	.484	.394	.399	.411	.407	.398	.398	.412	.414	.408	.422	.338
REGN. COEF. VAR	.348	.371	.372	.370	.361	.358	.364	.363	.363	.365	.369	.377	.324
USED COEF. VAR	.348	.371	.372	.370	.361	.358	.364	.363	.363	.365	.369	.377	.324
MEAN/A	.1282	.1581	.1791	.1948	.2124	.2224	.2504	.2743	.3166	.3478	.4044	.5841	1.0000
RP10/A	.1637	.2366	.2684	.2914	.3152	.3291	.3726	.4073	.4692	.5174	.6033	.8776	1.4264
RP20/A	.2193	.3017	.3182	.3436	.3798	.3886	.4344	.4727	.5394	.6008	.6978	1.0172	1.6692
RP50/A	.2379	.3145	.3541	.3816	.4161	.4248	.4781	.5185	.5877	.6592	.7635	1.1141	1.7327
RP100/A	.2696	.3444	.3889	.4172	.4496	.4631	.5199	.5621	.6332	.7148	.8257	1.2689	1.8474
RP1000/A	.3289	.4467	.4999	.5316	.5707	.5832	.6563	.6968	.7712	.8666	1.0162	1.4870	2.1878
RP10000/A	.3948	.5478	.6043	.6408	.6866	.6967	.7726	.8228	.8986	1.0441	1.1913	1.7458	2.4894
PMP/A	.7798	1.0378	1.1788	1.2737	1.3624	1.4167	1.6178	1.7674	2.0403	2.2519	2.6427	3.8873	5.8608

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WHERE N IS SMALL RESULTS ARE NOT DEPENDABLE

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