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An integrated stormwater management/GIS software system

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Abstract

Computing pollutant loadings are increasingly important for master planning flood control and environmental systems. In this paper, a stormwater pollutant estimation analog is coupled to a flood control master planning procedure linked to a GIS capability. The GIS functions develop land use versus area tabulations that readily input into pollutant loading equations. Because the linkage between the master plan of drainage databases and the pollutant loading equations is direct, an important advancement can be made in stormwater quantity and quality evaluation by a modest integration effort between software applications. For application in urban storm runoff management, a simple rainfall–runoff volumetric model can be linked to the stormwater pollutant model to estimate pollutant loadings on a storm event basis. Calibration of the model is achieved by matching mean annual loadings to NURP estimates.

Software availability

Program title:	PLM—Pollutant Loading Module
Developers:	Ted Hromadka and C. C. Yen
First available:	1993
Hardware:	IBM or Compatible
Source language:	FORTRAN 77
Program Size:	1.0 Meg
Cost:	$495

1. Introduction

In this paper, a Master Plan of Drainage, prepared using a Geographical Information System (GIS) (City of Yucaipa, 1993), is integrated with an urban stormwater quality model (State of California, 1993; US Environmental Protection Agency, 1983; Andrews, 1994; Driver and Tasker, 1988; Tasker *et al.*, 1990) for estimating the average annual pollutant loadings at strategic locations within the master planned area. The entire Storm Water Management Plan is represented by graphical layers in digital format, which allows for rapid communication between the master plan and other management systems, such as engineering, planing and flood control engineering and planning systems, stormwater quality management systems and database management systems, among others (Hromadka *et al.*, 1993).

1.1. Master Plan of Drainage and GIS analog

The Master Plan of Drainage and database system contains numerous elements and components that span several technical fields including database management, geographic information systems, hydrologic/hydraulic computer modeling, graphical database management, stormwater quality management, and flood control engineering and planning, among others.

In order to generate the data needed for the hydrologic models, a set of digital graphics layers may be used to represent each parameter and attribute associated with the system under study. Generally, several database layers will be required to develop a master plan study. These layers are created individu-

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ally; however, they may be viewed simultaneously to show coincidental hydrologic information. These layers include:

(1) Base map; consisting of topographic contours and streets right-of-way, or jurisdiction lines.
(2) Watershed boundary; to define particular hydrologic study boundaries.
(3) Drainage reservations; to define alignments within available rights of way.
(4) Existing facilities; to define alignments.
(5) Street flow patterns; to determine existing flow patterns.
(6) Alignments, defined by layers 3–5.
(7) Subarea boundaries; defined by layers 5 and 6.
(8) Overall mapping divides; for graphical displays and hard copy mapping.
(9) Land use map; for runoff properties.
(10) Hydrologic soil group map; for loss rates.
(11) Rainfall isohyetal map; for runoff estimates.
(12) Hydrologic nodal points; defined by layers 6 and 7.
(13) Hydrologic modeling element type; to define route parameters.

Primary hydrologic parameters used in the Master Plan of Drainage computer model include land use, hydrologic soil group, rainfall and hydrologic subarea topographic data such as area, length of water course, and elevation. In general, a study is discretized into subareas that are approximately 10–20 acres in size. These subareas require definition as to each of the parameters listed above. Additionally, maps are needed in order to effectively communicate these data. By obtaining, in digital form, or actually digitizing the land use maps, hydrologic soil group maps, rainfall maps, and subarea maps, not only is a digital/graphical representation available for display, but the data can then be processed by a 'polygon processor' in order to partition the subareas into the intersections of all the graphical layers. Geographic location is provided by use of street layout layers, right-of-way maps for reports, as well as graphical layers for display on the computer monitor.

1.2. GIS features

The use of geographic information systems (GIS) has become widespread in many facets of engineering and planning, among other fields. A key element of a GIS is the ability to intersect graphical layers, such as discussed above, so that the several forms of information are resolved into 'cells' wherein all parameters are homogeneous.

In the Master Plan of Drainage, each subarea requires definition of land use, hydrologic soil group, and rainfall, and the proportions of each within the subarea. The polygon processor performs this important task, and then develops a database for use in the Master Plan of Drainage computer model. The subarea data are stored in tabulated formats, on a subarea basis, indexed according to subarea number. Thus, tl retrieval of a specific subarea number will access these several data, automatically developed by the polygon processor.

The Master Plan of Drainage may be represented, in database form, as a collection of nodes (specific points along the catchment flood control system) and subareas (10–20 acres in size). All information computed by the Master Plan of Drainage, such as deficiency system mitigation needs, flow quantities, hydraulic properties, streetflow characteristics, flood control system characteristics, hydrologic parameters, cost-to-benefit indices and costs, among others, are stored in table form, and indexed according to node number, link number and subarea number. Data entered directly into the database such as flood control system history, age and so forth are also stored. Once the database is assembled, it may be linked to the graphical database, which displays the graphical layers constructed for the polygon processing (i.e. multiple use of a database form), while allowing easy access to the Master Plan of Drainage database.

1.3. Pollutant loading procedures

Pollutant loadings for specific pollutants in the National Pollutant Discharge Elimination Syste (NPDES) can be estimated (Andrews, 1994; Tasker and Driver, 1990; Tasker *et al.*, 1990), based upon the *State of California Storm Water Best Management Practice Handbook, 'Municipal'*, Appendix B, as:

$$R_L = [C_P + (C_I - C_P)\mathrm{IMP}_L]*I \tag{1}$$

where R_L = total average annual surface runoff from land use L (in yr^{-1}), IMP_L = fractional imperviousness of land use L (see Table 1), I = long-term average annual precipitation (in yr^{-1}), C_P = pervious area runoff coefficient = 0.10 and C_I = impervious area runoff coefficient = 0.95.

The nonpoint source pollution loads (expressed as lb yr^{-1}) vary by land use and the percent imperviousness associated with each land use. The pollution loading factor M_L is computed for land use L by the following equation:

$$M_L = \mathrm{EMC}_L * R_L * K * A_L \tag{2}$$

where M_L = loading factor for land use L (lb yr^{-1}), EMC_L = event mean concentration of runoff from land use L (mg l^{-1}); EMC_L varies by land and by pollutant (see Table 1), R_L = total average annual surface runof from land use L computed from Eq. 1 (in yr^{-1}), K = 0.2266, a unit conversion constant and A_L = area of land use L (acres).

Twelve constituents are modeled in the computer

Table 1
Event mean concentrations and impervious percentages

Land use	Percent impervious	Oxygen demand and sediment				Nutrients				Heavy metals			
		BOD (mg l^{-1})	COD (mg l^{-1})	TSS (mg l^{-1})	TDS (mg l^{-1})	TP (mg l^{-1})	SP (mg l^{-1})	TKN (mg l^{-1})	NO_2 and NO_3 (mg l^{-1})	Pb (mg l^{-1})	Cu (mg l^{-1})	Zn (mg l^{-1})	Cd (mg l^{-1})
Forest/Open	0.5%	8.0	51	261	100	0.23	0.06	1.36	0.73	0.00	0.00	0.00	0.00
Agriculture/Pasture	0.5%	8.0	51	216	100	0.23	0.06	1.36	0.73	0.00	0.00	0.00	0.00
Cropland	0.5%	8.0	51	216	100	0.23	0.06	1.36	0.73	0.00	0.00	0.00	0.00
Low-density residential	10.0%	10.8	83	140	100	0.47	0.16	2.35	0.96	0.18	0.05	0.18	0.002
Medium-density residential	30.0%	10.8	83	140	100	0.47	0.16	2.35	0.96	0.18	0.05	0.18	0.002
High-density residential	50.0%	10.8	83	140	100	0.47	0.16	2.35	0.96	0.18	0.05	0.18	0.002
Commercial	90.0%	9.7	61	91	100	0.24	0.10	1.28	0.63	0.13	0.04	0.33	0.002
Office/Light industrial	70.0%	9.7	61	91	100	0.24	0.10	1.28	0.63	0.13	0.04	0.33	0.002
Heavy industrial	80.0%	9.7	61	91	100	0.24	0.10	1.28	0.63	0.13	0.00	0.33	0.002
Water	100.0%	3.0	22	26	100	0.03	0.01	0.60	0.60	0.00	0.00	0.11	0.000
Wetlands	0.5%	8.0	51	216	100	0.23	0.06	1.36	0.73	0.00	0.00	0.00	0.00
Major highways	90.0%	9.7	103	142	100	0.44	0.17	1.78	0.83	0.53	0.05	0.37	0.002

Source: *State of California Storm Water Best Management Handbook, 'Municipal'*, Appendix B.

program; namely, BOD, COD, TSS, TDS, total-P, dissolved-P, NO_2 and NO_3, TKN, cadmium, copper, lead and zinc.

Table 1 contains the event mean concentration (EMC) values and the impervious percentages assigned for each land use designation.

From Eqs 1 and 2, the pollutant loading at any concentration point depends upon the tributary area land use designations (for example, Andrews, 1994). The land use designations at any nodal point within the master plan of drainage catchment are already summarized by the hydrologic computer model, and are available for use in estimating the pollutant loadings.

2. Application to a Master Plan of Drainage

The City of Yucaipa watershed, located in San Bernardino County, California, encompasses approximately 40 square miles (see Fig. 1), is used to demonstrate the stormwater pollutant loading calculation program. A Master Plan of Drainage for the City of Yucaipa was first prepared using the above discussed GIS/hydrologic procedures. Of key interest is the estimation of pollutant loadings in storm runoff at several locations in the City, and also the estimation of increase in pollution due to changing land use conditions in the watershed. The GIS Master Plan of Drainage facilitates rapid estimation of pollutant loadings at several locations in the Master Plan. The land use data required by the pollutant loading equatior (i.e. Eqs 1 and 2) were transported from the database management systems into the pollutant loading equations. Table 2 summarizes the average annual pollutant loadings at 40 locations within the study area (see Fig. 1 for node locations).

3. Application in rainfall–runoff model

The structure of the integrated rainfall–runoff/pollutant estimation computer model is depicted in Fig. 2. The first module is the rainfall–runoff model which estimates the 24-h runoff volume at the point of concern for each 24-h storm rainfall. The second module is the pollutant buildup model which tracks the accumulation of pollutants according to a prescribed buildup rate. The third module is the pollutant washoff model which approximates the pollutant washoff process based upon the runoff quantity estimated from Module #1. The fourth module estimates the long-term pollutant washoff rate. The fifth module computes average annual pollutant loadings based upon the National Urban Runoff Program (NURP) data (1993) and loading equations. The sixth module calculates the average pollutant loading for each storm event based

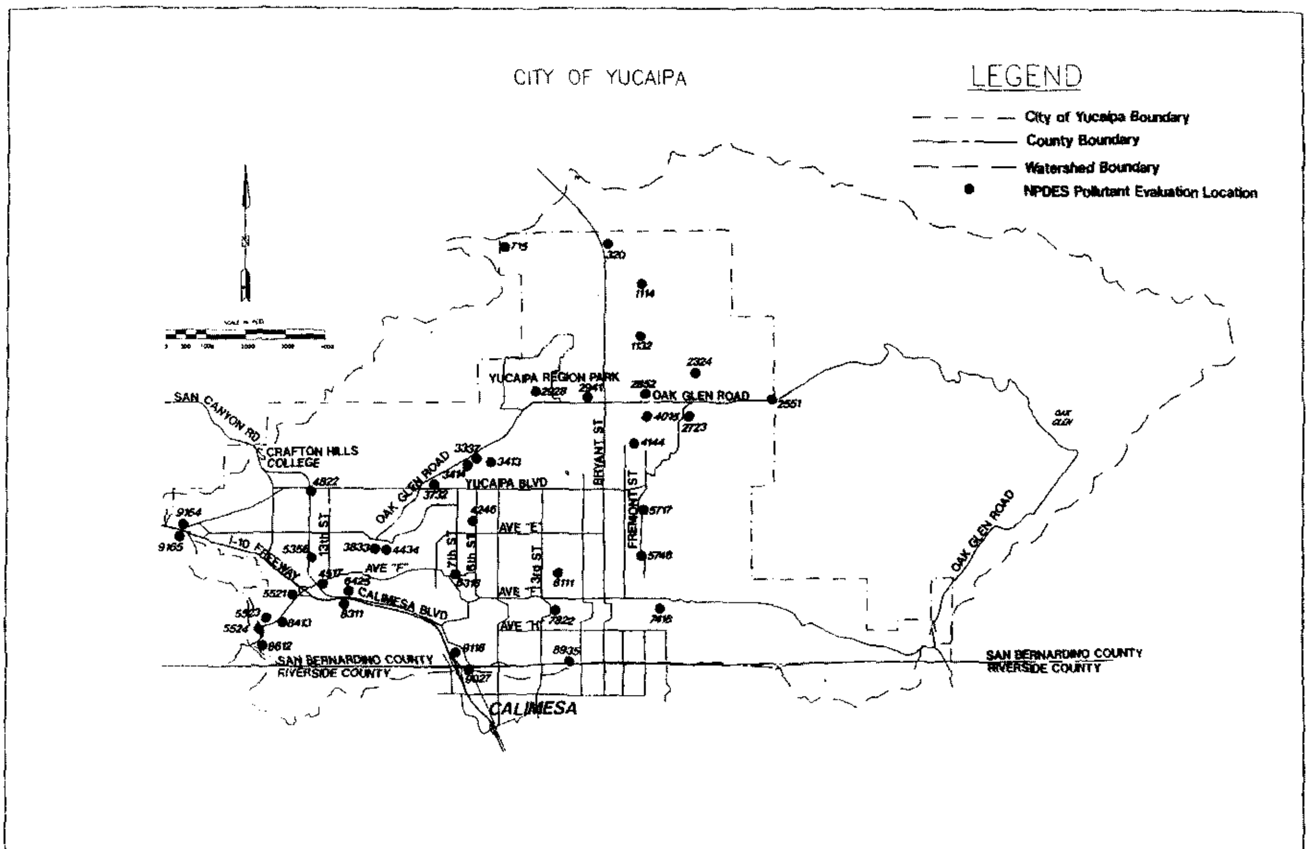

Fig. 1. City of Yucaipa NPDES pollutant evaluation location map.

Table 2
Summary of annual pollutant loadings

Node number	Annual pollutant loadings (lbs yr^{-1})											
	Oxygen demand and sediment				Nutrients				Heavy metals			
	BOD	COD	TSS	TDS	Total-P	Dissolved-P	TKN	NO_2 and NO_3	Lead	Copper	Zinc	Cadmium
5524	45,863	335,085	682,251	454,880	1784	660	9163	3968	620	174	730	7
5523	27,868	202,501	414,452	277,606	1069	360	5505	2396	372	105	452	4
8612	2533	18,680	35,750	24,682	100	34	512	219	37	10	43	0
8413	15,307	112,738	229,645	151,085	607	203	3113	1339	209	59	233	2
5521	27,541	200,028	409,857	274,466	1056	356	5435	2367	367	104	447	4
4517	26,834	195,471	402,008	267,267	1037	348	5335	2319	357	101	424	4
5356	5418	39,855	66,604	51,637	212	74	1071	452	85	24	111	1
4822	2963	22,124	37,694	28,046	120	42	607	254	47	13	56	1
8311	14,862	109,475	224,272	146,860	590	197	3025	1302	202	57	224	2
6425	6691	50,675	87,277	62,836	282	96	1415	585	108	30	116	1
9165	1104	7388	13,069	11,247	34	13	176	82	15	4	29	0
9164	731	5035	8250	7244	24	9	124	55	11	3	19	0
3833	20,958	152,311	330,917	211,232	808	268	4177	1829	265	74	303	3
4434	5422	40,114	66,865	51,443	215	75	1086	456	86	24	109	1
3732	14,073	101,712	242,485	145,084	538	174	2811	1250	160	45	170	2
3414	13,543	97,848	236,154	140,009	518	167	2709	1206	151	42	158	2
3337	5702	42,896	83,785	55,073	238	79	1207	508	83	23	83	1
3413	7575	52,904	148,915	82,470	269	84	1444	674	64	18	70	1
4246	3935	28,904	48,146	37,517	153	54	775	328	62	18	81	1
6316	5315	40,370	70,136	49,885	225	77	1132	468	86	24	90	1
8118	484	3398	5453	4720	17	6	86	38	7	2	12	0
9027	2305	17,282	30,629	21,906	95	32	476	200	36	10	40	0
8935	1220	9247	16,150	11,485	51	18	259	107	20	5	21	0
7822	5865	41,848	109,077	62,092	219	69	1156	525	58	16	60	1
132	575	4162	10,225	5965	22	7	116	52	6	2	6	0
2928	3201	24,075	47,099	30,932	133	44	677	285	47	13	47	1
4144	2291	17,102	28,970	21,670	93	32	469	196	37	10	43	0
6111	1805	13,628	25,229	17,218	76	26	382	160	28	8	28	0
2941	2875	20,058	55,291	31,163	102	32	544	254	25	7	29	0
2852	3226	21,636	74,820	37,570	105	30	586	291	14	4	15	0
4015	137	1054	1778	1270	6	2	30	12	2	1	2	0
715	1989	14,112	38,382	21,327	73	23	390	179	18	5	18	0
320	849	5660	20,221	9986	27	8	153	77	3	1	3	0
1114	546	3978	9422	5597	21	7	111	49	6	2	6	0
5717	213	1516	4084	2279	8	2	42	19	2	1	2	0
5746	414	3121	6031	3988	17	6	88	37	6	2	6	0
7416	4699	33,003	93,983	51,165	169	52	909	423	39	11	39	0
2723	2644	17,292	66,706	31,968	81	22	465	240	6	2	6	0
2324	1917	12,979	43,601	22,077	64	19	353	174	10	3	10	0
2551	2021	12,885	54,531	25,252	58	15	344	184	0	0	0	0

Source: *State of California Storm Water Best Management Practice Handbook, 'Municipal'*, Appendix B.

upon the results from Modules #4 and #5. Finally, the seventh module, which consists of the selected BMP performance relationships, examines the effectiveness in pollutant reduction on a daily storm basis. In the following sections, the above discussed modules will be examined in detail.

3.1. Rainfall–runoff module

The rainfall database consists of ordered pairs of {date, 24-h rainfall depth}, and in this application consists of about 50 yr of daily rainfall records. The Soil Conservation Service (SCS) storm runoff yield formula is used to compute 24-h storm runoffs from daily rainfalls. Other rainfall–runoff models can be used to replace the SCS storm runoff yield formula by straightforward algorithm replacement.

The SCS storm runoff yield formula is given by

$$Y_j = \frac{(P_{24} - I_a)^2}{(P_{24} - I_a + S)P_{24}} \tag{3}$$

where Y_j = 24-h storm runoff yield fraction for subarea A_j, P_{24} = 24-h storm rainfall (inches), I_a = initial abstraction and S = total soil capacity.

The initial abstraction, I_a, is a function of land

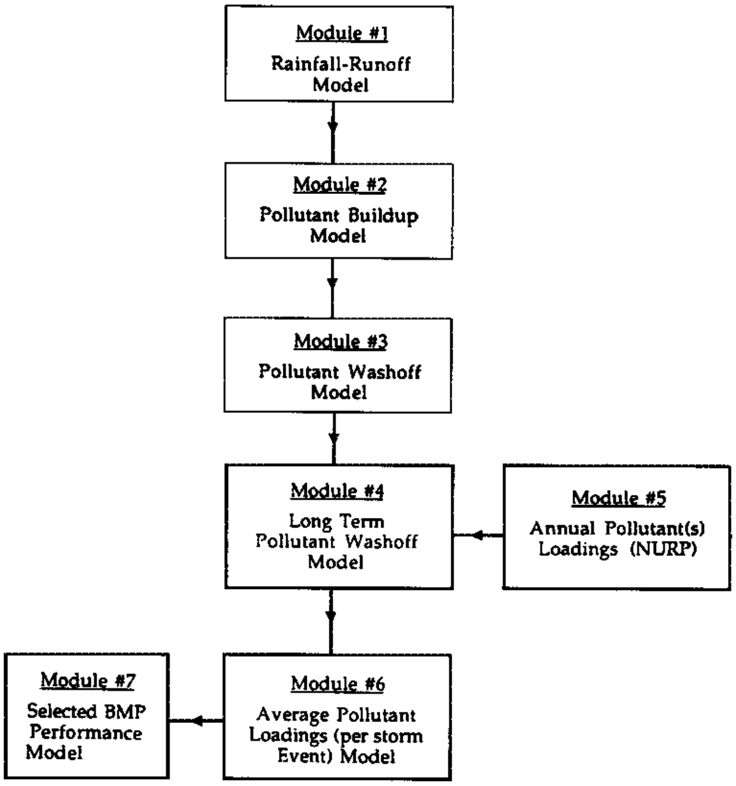

Fig. 2. Computer model structure.

use, cover treatment and antecedent soil moisture. An estimate for I_a is given by the SCS as

$$I_a = 0.2\,S \tag{4}$$

where S is an estimate of total soil capacity given by

$$S = \frac{1000}{\mathrm{CN}} - 10 \tag{5}$$

where CN is the SCS curve number (CN) which represents the runoff potential for a particular soil group and cover complex.

Table 3
Land use characteristics for example problem

Land use	SCS curve number	Area (acres)
Natural	66	189.6
Natural	77	763.8 (729.75)
Natural	83	300.6
5-7 DU/AC	69	3.3
5-7 DU/AC	75	7.6
Multiple family	56	11.6
Multiple family	69	70.0
Multiple family	75	48.2
Commercial	56	14.3
Commercial	69	5.7
Pavement	98	0.0 (34.05)

Values in parentheses indicate post-project conditions.

3.2. Definitions

Before discussing the pollutant buildup and washoff modules, the following terms are defined:

- *Pollutant recovery period* is defined as the time period (in days) wherein a pollutant accumulates from zero to its maximum buildup (100%). A straight-line buildup rate is assumed in this model.
- *Pollutant buildup rate* is defined as the reciprocal of the pollutant recovery period.
- *Total pollutant washoff runoff amount* is the runoff amount that will provide a 100% washoff of pollutants.
- *Pollutant washoff rate* is defined as the reciprocal of the total pollutant washoff runoff amount.

It should be noted that the above definitions are used for all the pollutants modeled. Of course, more complex definitions and relationships can be derived and implemented for each pollutant.

3.3. Pollutant buildup module

This model accumulates the pollutant buildup at the end of each rainfall record day. First, the number of days between rainfall events is calculated. Then th pollutant buildup between rainfall events is estimatea by multiplying the number of days between rainfall events by the pollutant buildup rate. Finally, by adding the pollutant buildup between rainfall events to the

Table 4
Portion of daily rainfall record for example problem

Date (month/day/year)	Precipitation (inches)
'01/22/43'	2.60
'01/23/43'	4.14
'01/24/43'	0.26
'01/27/43'	0.79
'02/03/43'	0.81
'02/08/43'	0.63
'02/21/43'	1.04
'02/22/43'	1.67
'02/24/43'	0.48
'03/03/43'	0.13
'03/04/43'	1.13
'03/05/43'	0.11
'03/10/43'	0.13
'03/11/43'	0.05
'03/17/43'	0.11
'03/24/43'	0.61
'04/06/43'	0.56
'04/07/43'	0.03
'04/14/43'	0.26
'05/26/43'	0.04
'10/19/43'	0.29
'11/02/43'	0.05
'11/18/43'	0.20
'11/23/43'	0.03
'12/07/43'	0.41
'12/10/43'	0.87
'12/11/43'	1.35
'12/21/43'	2.36
'12/28/43'	0.34
'12/30/43'	0.26
'01/04/44'	0.52
'01/11/44'	0.10
'01/25/44'	0.21
'02/01/44'	0.31
'02/08/44'	0.51
'02/15/44'	0.19
'02/20/44'	0.15
'02/21/44'	1.13
'02/22/44'	0.83
'02/23/44'	2.47
'02/24/44'	0.37
'02/26/44'	0.08
'02/27/44'	0.52
'02/29/44'	0.60
'03/07/44'	1.15
'03/14/44'	0.36

remaining pollutant loading corresponding to the end of the previous rainfall event, the total pollutant buildup at the end of the current rainfall event can be estimated.

It is assumed that the pollutant buildup can only ach a maximum value of 100%; after which, the pollutant will be transported by wind, moving vehicles, or by other means. Thus, the maximum pollutant buildup at the end of each rainfall event will not exceed 100%.

Table 5
Selected stormwater filter pollutant removal rates

Pollutant	Overall		
	Mean influent	Mean effluent	Mean % removal
Solids & nutrients (mg l^{-1})			
Total dissolved solids	113.50	155.50	+37.0%
(TDS)	231.23	15.35	93.4%
Total suspended solids	134.49	41.47	69.2%
(TSS)	1.000	0.584	41.6%
Chemical oxygen	0.105	0.354	+235.6%
demand (COD)	1.656	0.749	54.8%
Total Phosphorus (total	0.457	1.022	+123.6%
P)			
Soluble phosphorus			
(soluble P)			
Total Kjeldahl Nitrogen			
(KTN)			
Nitrite/nitrate (NO_3)			
Metals ($\mu g\ l^{-1}$)			
Copper (Cu)	25.68	8.81	65.7%
Lead (pt)	34.90	5.22	85.1%
Zinc (Zn)	173.62	27.12	84.4%

3.4. Pollutant washoff module

At the end of each rainfall recording date, the runoff amount is estimated from Module #1. By multiplying the runoff amount with the pollutant washoff rate, the potential pollutant washoff is estimated. The potential pollutant washoff cannot exceed 100% because the accumulated pollutant buildup is limited to 100%. The pollutant washoff is the minimum value between the potential pollutant washoff and the accumulated pollutant buildup. Finally, the remaining pollutant can be calculated by subtracting the pollutant washoff from the accumulated pollutant buildup.

3.5. Long-term average pollutant washoff rate

Program Modules 1–4 are repeated for each rainfall record, and the resulting pollutant washoff estimates are stored and accumulated to the end of the rainfall record. Next, the mean pollutant washoff (i.e. 100% of accumulated pollutant washoff) per year can be estimated by dividing the total record (e.g. 50 yr) of accumulated pollutant washoff by the number of years of rainfall record.

3.6. Long-term average annual pollutant loadings

Pollutant loadings for specific pollutants in the National Pollutant Discharge Elimination System (NPDES) can be estimated, based upon the *State of California Storm Water Best Management Handbook, 'Municipal'*, Appendix B (see previous section).

Table 6
Estimated storm event pollutant loadings for pre-project conditions

					Pollutant loadings (lb) for each runoff event												
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
01/22/43	2.60	0.78	100.0	100.0	0.0	644	4435	12854	7103	22	7	120	57	5	1	6	0
01/23/43	4.14	1.86	6.7	6.7	0.0	43	296	857	474	1	0	8	4	0	0	0	0
01/24/43	0.26	0.00	6.7	0.0	6.7	0	0	0	0	0	0	0	0	0	0	0	0
01/27/43	0.79	0.02	26.7	3.8	22.8	25	170	492	272	1	0	5	2	0	0	0	0
02/03/43	0.81	0.02	69.5	4.4	65.2	28	193	560	309	1	0	5	2	0	0	0	0
02/08/43	0.63	0.00	98.5	0.9	97.5	6	42	122	67	0	0	1	1	0	0	0	0
02/21/43	1.04	0.06	100.0	12.8	87.2	83	568	1648	910	3	1	15	7	1	0	1	0
02/22/43	1.67	0.28	93.8	56.0	37.9	361	2483	7198	3978	12	4	67	32	3	1	3	0
02/24/43	0.48	0.00	51.2	0.1	51.1	1	4	13	7	0	0	0	0	0	0	0	0
03/03/43	0.13	0.00	97.8	0.0	97.8	0	0	0	0	0	0	0	0	0	0	0	0
03/04/43	1.13	0.09	100.0	17.3	82.7	111	767	2223	1228	4	1	21	10	1	0	1	0
03/05/43	0.11	0.00	89.4	0.0	89.4	0	0	0	0	0	0	0	0	0	0	0	0
03/10/43	0.03	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
03/11/43	0.05	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
03/17/43	0.11	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
03/24/43	0.61	0.00	100.0	0.8	99.2	5	34	98	54	0	0	1	0	0	0	0	0
04/06/43	0.56	0.00	100.0	0.4	99.6	3	19	56	31	0	0	1	0	0	0	0	0
04/07/43	0.03	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
04/14/43	0.26	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
05/26/43	0.04	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
10/19/43	0.29	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
11/02/43	0.05	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0

(1) Storm event date, (2) 24-h rainfall (in), (3) Total daily runoff (in), (4) Pollutant buildup (%), (5) Pollutant washoff (%), (6) Pollutant buildup remaining (%), (7) BOD (lb), (8) COD (lb), (9) TSS (lb), (10) TDS (lb), (11) Total-P (lb), (12) Dissolved-P (lb), (13) TKN (lb), (14) NO_2 & NO_3 (lb), (15) Lead (lb), (16) Copper (lb), (17) Zinc (lb), (18) Cadmium (lb).

Table 7
Estimated storm event pollutant loadings for post-project conditions without selected stormwater filter system

					Pollutant loadings (lb) for each runoff event												
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
01/22/43	2.60	0.82	100.0	100.0	0.0	607	4470	11,657	6630	22	7	113	53	8	2	8	0
01/23/43	4.14	1.91	6.7	6.7	0.0	40	298	777	442	1	0	8	4	1	0	1	0
01/24/43	0.26	0.00	6.7	0.5	6.1	3	24	64	36	0	0	1	0	0	0	0	0
01/27/43	0.79	0.03	26.1	6.6	19.5	40	295	770	438	1	0	7	4	1	0	1	0
02/03/43	0.81	0.04	66.2	7.2	59.0	44	322	841	478	2	1	8	4	1	0	1	0
02/08/43	0.63	0.02	92.3	3.1	89.3	19	136	356	202	1	0	3	2	0	0	0	0
02/21/43	1.04	0.08	100.0	16.5	83.5	100	739	1928	1096	4	1	19	9	1	0	1	0
02/22/43	1.67	0.31	90.1	61.6	28.5	374	2753	7181	4084	13	4	69	33	5	1	5	0
02/24/43	0.48	0.01	41.9	1.5	40.3	9	69	180	102	0	0	2	1	0	0	0	0
03/03/43	0.13	0.00	87.0	0.1	86.9	1	6	15	9	0	0	0	0	0	0	0	0
03/04/43	1.13	0.11	93.5	21.3	72.2	129	953	2485	1413	5	1	24	11	2	0	2	0
03/05/43	0.11	0.00	78.9	0.1	78.8	1	4	10	6	0	0	0	0	0	0	0	0
03/10/43	0.03	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
03/11/43	0.05	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
03/17/43	0.11	0.00	100.0	0.1	99.9	1	4	10	6	0	0	0	0	0	0	0	0
03/24/43	0.61	0.01	100.0	2.8	97.2	17	124	324	184	1	0	3	1	0	0	0	0
04/06/43	0.56	0.01	100.0	2.2	97.8	14	100	260	148	0	0	3	1	0	0	0	0
04/07/43	0.03	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
04/14/43	0.26	0.00	100.0	0.5	99.5	3	24	64	36	0	0	1	0	0	0	0	0
05/26/43	0.04	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
10/19/43	0.29	0.00	100.0	0.7	99.3	4	29	77	44	0	0	1	0	0	0	0	0
11/02/43	0.05	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0

(1)–(18) are the same as in Table 6.

Table 8
Estimated storm event pollutant loadings for post-project conditions with selected stormwater filter system

					Pollutant loadings (lb) for each runoff event												
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
01/22/43	2.60	0.82	100.0	100.0	0.0	607	1377	769	9083	13	24	51	119	1	1	1	0
01/23/43	4.14	1.91	6.7	6.7	0.0	40	92	51	606	1	2	3	8	0	0	1	0
01/24/43	0.26	0.00	6.7	0.5	6.1	3	8	4	50	0	0	0	1	0	0	0	0
01/27/43	0.79	0.03	26.1	6.6	19.5	40	91	51	600	1	2	3	8	0	0	0	0
02/03/43	0.81	0.04	66.2	7.2	59.0	44	99	55	655	1	2	4	9	0	0	0	0
02/08/43	0.63	0.02	92.3	3.1	89.3	19	42	23	277	0	1	2	4	0	0	0	0
02/21/43	1.04	0.08	100.0	16.5	83.5	100	228	127	1502	2	4	8	20	0	0	0	0
02/22/43	1.67	0.31	90.1	61.6	28.5	374	848	474	5595	8	14	31	73	1	0	1	0
02/24/43	0.48	0.01	41.9	1.5	40.3	9	21	12	140	0	0	1	2	0	0	0	0
03/03/43	0.13	0.00	87.0	0.1	86.9	1	2	1	12	0	0	0	0	0	0	0	0
03/04/43	1.13	0.11	93.5	21.3	72.2	129	293	164	1936	3	5	11	25	0	0	0	0
03/05/43	0.11	0.00	78.9	0.1	78.8	1	1	1	8	0	0	0	0	0	0	0	0
03/10/43	0.03	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
03/11/43	0.05	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
03/17/43	0.11	0.00	100.0	0.1	99.9	1	1	1	8	0	0	0	0	0	0	0	0
03/24/43	0.61	0.01	100.0	2.8	97.2	17	38	21	253	0	1	1	3	0	0	0	0
04/06/43	0.56	0.01	100.0	2.2	97.8	14	31	17	203	0	1	1	3	0	0	0	0
04/07/43	0.03	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
04/14/43	0.26	0.00	100.0	0.5	99.5	3	8	4	50	0	0	0	1	0	0	0	0
05/26/43	0.04	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0
10/19/43	0.29	0.00	100.0	0.7	99.3	4	9	5	60	0	0	0	1	0	0	0	0
11/02/43	0.05	0.00	100.0	0.0	100.0	0	0	0	0	0	0	0	0	0	0	0	0

(1)–(18) are the same as in Table 6.

3.7. *Daily pollutant washoff estimate and calibration to NURP*

The average annual pollutant loading estimated from the previous module is used to calculate the pollutant loading for each complete pollutant washoff as follows:

$$\text{Pollutant loading (per one complete washoff)} = \frac{\text{Average annual pollutant loading (lb yr}^{-1})}{\text{Average complete pollutant washoff per year}} \quad (6)$$

By multiplying the pollutant loading per one complete washoff to each rainfall event response (for each pollutant), the daily pollutant loading (for each rainfall recording date) can be estimated. Thus, the daily pollutant simulation model is calibrated to statistically represent annual loadings estimated by the standard NURP equations.

3.8. *Example application*

A study site with approximately 50 years of daily rainfall data is used to demonstrate the subject computer model. A particular stormwater filter system is selected as one of the potential BMPs to offset the effects of a proposed large-scale land development project, and will be used as an example. At issue are pollutant removal efficiencies for using the stormwater filter. Table 3 shows the tributary watershed characteristics at the study site. Table 4 illustrates a portion of the daily rainfall data record (50 years total). Table 5 shows the pollutant removal rates for the selected stormwater filter system. Tables 1, 3, 4, and 5 are stored in four different database files as input files for the subject computer program. The estimated daily pollutant loadings for existing conditions (pre-project), post-project conditions, and post–project with BMP are shown in Tables 6–8. The summary of the 50-year simulation results for the pre-project conditions, post-project conditions, and post-project with BMP are shown in Tables 9–11. In this application, the complete pollutant washoff runoff depth is assumed to be 0.5 inch and the pollutant recovery period is 15 days.

The computer program approach to this type of problem is to conserve mass balance of the rainfall-runoff budgets with respect to the annual pollutant loading estimates. In other words, the 50-yr simulation in this example is used to fit the total pollutant washoff quantities to the sum of 50 yr of annual pollutant loadings. The resulting time series of pollutant washoffs can then be used for estimates of time variations.

4. Discussion

The purpose of implementing the integrated model is to consolidate all information necessary for analyzing and managing the Storm Water Management Plan, and to provide a mechanism for updating graphical and non-graphical data.

By managing all graphics in a graphical environment

Table 9
Mean annual pollutant loadings for pre-project conditions with 50 yr of rainfall record

Summary statistics		
Total rainfall (in)	=	595.54
Total runoff (in)	=	49.07
Total pollutant washoff (%)	=	7110.38
Total pollutant washoff (lb):		
BOD	=	45,784
COD	=	315,333
TSS	=	913,969
TDS	=	505,082
Total-P	=	1569
Dissolved-P	=	487
TKN	=	8502
NO_2 & NO_3	=	4034
Lead	=	354
Copper	=	100
Zinc	=	433
Cadmium	=	4

Table 10
Mean annual pollutant loadings for post-project conditions with 50 yr of rainfall record

Summary statistics		
Total rainfall (in)	=	595.54
Total runoff (in)	=	59.67
Total pollutant washoff (%)	=	8507.67
Total pollutant washoff (lb):		
BOD	=	51,641
COD	=	380,266
TSS	=	991,719
TDS	=	564,043
Total-P	=	1846
Dissolved-P	=	596
TKN	=	9586
NO_2 & NO_3	=	4532
Lead	=	709
Copper	=	133
Zinc	=	681
Cadmium	=	5

(e.g. AutoCAD environment) through the use of GIS, graphic and non-graphic data can be updated as conditions change. As new analysis is required, additional databases can be prepared, and linked to the current model, such as the stormwater quality model illustrated in this paper.

5. Conclusions

An integrated Storm Water Management Plan computer model is developed and used for the City of Yucaipa application. By the master planning process, the data needed to compute pollutant loadings are already developed by the GIS master planning process. The linkage is straightforward between the master plan

Table 11
Mean annual pollutant loadings for post-project conditions with selected stormwater filter system using 50 yr of rainfall record

Summary statistics		
Total rainfall (in)	=	595.54
Total runoff (in)	=	59.67
Total pollutant washoff (%)	=	8507.67
Total pollutant washoff (lb):		
BOD	=	51,641
COD	=	117,122
TSS	=	65,453
TDS	=	772,740
Total-P	=	1078
Dissolved-P	=	2000
TKN	=	4333
NO_2 & NO_3	=	10,133
Lead	=	106
Copper	=	46
Zinc	=	106
Cadmium	=	5

of drainage database and the pollutant loading estimator.

In the urban stormwater application, the subject computer program consists of seven interconnected modules. Each module consists of a simple relationship between variables which can be replaced by more complex relationships. The four database files can be modified to reflect other changes in the watershed lar use characteristics, or the NURP equation event mean concentrations, the selected BMP removal rates, or to include additional rainfall data.

As the effluent pollutant data becomes available, such as through water quality monitoring, the complete pollutant washoff runoff depths and the pollutant recovery period can be calibrated for future analysis.

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