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STORMWATER POLLUTANT LOADING ESTIMATION: USING GIS AND MASTER PLANS OF DRAINAGE

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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 data bases 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.

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INTRODUCTION

In this paper, a Master Plan of Drainage, prepared using a Geographical Information System (GIS), is integrated with an urban stormwater quality model for estimating the average annual pollutant loadings at strategic locations within the master planned area. The entire Master Plan is represented by graphical layers in digital format, which allows for rapid communication of master plan with other management systems, such as engineering, planning and flood control engineering and planning systems, stormwater quality management systems, and data base management systems, among others.

Master Plan of Drainage and GIS Analog

The Master Plan of Drainage and data base system contains numerous elements and components that span several technical fields including data base management, geographic information systems, hydrologic/hydraulic computer modeling, graphical data base 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 data base layers will be required to develop a master plan study. These layers are created individually; 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, 4, and 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 to 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 of 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.

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 parameter 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 data base 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, the 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 data base form, as a collection of nodes (specific points along the catchment flood control system), and subareas (10 to 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 tabled form, and indexed according to node number, link number, and subarea number. Data entered directly into the data base such as flood control system history, age, and so forth are also stored. Once the data base is assembled, it may be linked to the graphical data base, which displays the graphical layers constructed for the polygon processing (i.e., multiple use of a data base form), while allowing easy access to the Master Plan of Drainage data base.

Pollutant Loading Procedures

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 Practice Handbook, "Municipal," Appendix B, as:

$$R_L = [C_p + (C_I - C_P)\, IMP_L] * I \qquad (1)$$

where:

R_L = total average annual surface runoff from land use L (in/yr)

IMP_L = fractional imperviousness of land use L (see Table 1)

I = long-term average annual precipitation (in/yr)

Table 1

Event Mean Concentrations and Impervious Percentages

Land Use	Percent Impervious	Oxygen Demand & Sediment				Nutrients				Heavy Metals			
		BOD mg/L	COD mg/L	TSS mg/L	TDS mg/L	TP mg/L	SP mg/L	TKN mg/L	NO23 mg/L	Pb mg/L	Cu mg/L	Zn m/L	Cd mg/L
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	0.189	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	0.004	0.33	0.002
Water	100.0%	3.0	22	26	100	0.036	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.

C_P = pervious area runoff coefficient = 0.10

C_I = impervious area runoff coefficient = 0.95

The nonpoint source pollution loads (expressed as lbs/yr) 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:

$$M_L = EMC_L * R_L * K * A_L \quad (2)$$

where:

M_L = loading factor for land use L (lb/yr)

EMC_L = event mean concentration of runoff from land use L (mg/L); EMC_L varies by land and by pollutant (see Table 1)

R_L = total average annual surface runoff from land use L computed from Equation 1 (in/yr)

K = 0.2266, a unit conversion constant

A_L = area of land use L (acres)

Twelve constituents are included in the module; namely,

- BOD
- COD
- TSS
- TDS
- Total-P
- Dissolved-P
- NO_2 and NO_3
- TKN
- Cadmium
- Copper
- Lead
- Zinc

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

From Equations (1) and (2), the pollutant loading at any concentration point depends upon the tributary area land use designations. 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.

APPLICATION

The City of Yucaipa watershed, located in San Bernardino County, California, encompasses approximately 40 square miles (see Figure 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. The land use data required by the pollutant loading equations (i.e., Equations 1 and 2) were transported from the data base management systems into the pollutant loading equations. Table 2 summarizes the average annual pollutant loadings at 40 locations within the study area (see Figure 1 for node locations).

DISCUSSION

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

By managing all graphics in a graphical environment (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 data bases can be prepared, and linked to the current model, such as the stormwater quality model illustrated in this paper.

CONCLUSIONS

An integrated Master Plan of Drainage and Environmental System 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 of drainage data base and the pollutant loading estimator.

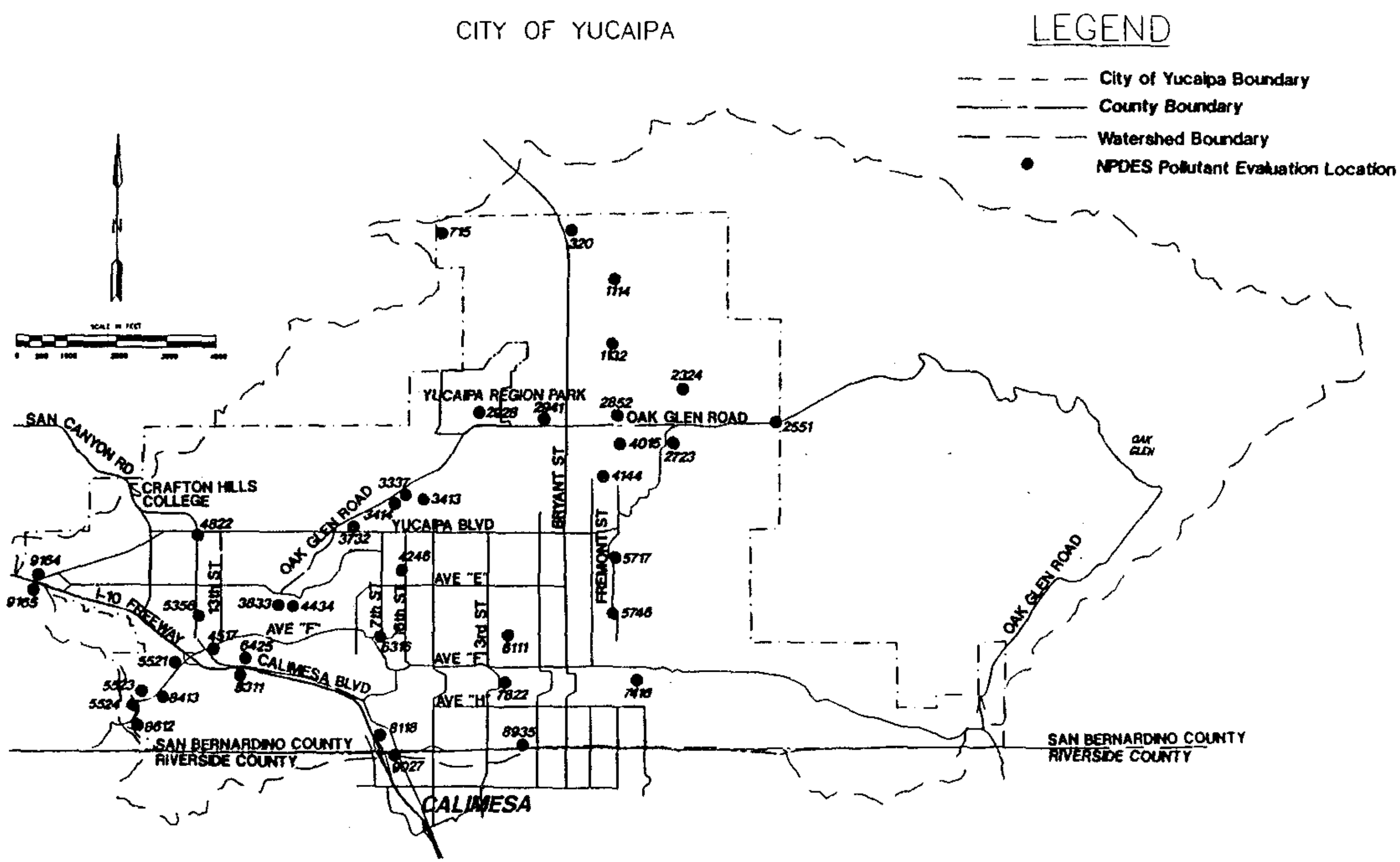

Figure 1. City of Yucaipa NPDES Pollutant Evaluation Location Map

Table 2

Summary of Annual Pollutant Loadings

*** ANNUAL POLLUTANT LOADING ***

(Ref. State of California Storm Water Best Management Practice Handbook -- Municipal, Appendix B)

LONG-TERM AVERAGE PRECIPITATION (IN/YR) = 3.10

	ANNUAL POLLUTANT LOADINGS (LBS/YR)											
	OXYGEN DEMAND & SEDIMENT				NUTRIENTS				HEAVY METALS			
NODE NUMBER	BOD	COD	TSS	TDS	TOTAL-P	DISSOLVED-P	TKN	N02&N03	LEAD	COPPER	ZINC	CADMIUM
5524	45863.	335085.	682251.	454880.	1784.	660.	9163.	3968.	620.	174.	730.	7.
5523	27868.	202501.	414542.	277606.	1069.	360.	5505.	2396.	372.	105.	452.	4.
8612	2533.	18680.	35750.	24682.	100.	34.	512.	219.	37.	10.	43.	0.
8413	15307.	112738.	229645.	151085.	607.	203.	3113.	1339.	209.	59.	233.	2.
5521	27541.	200028.	409857.	274466.	1056.	356.	5435.	2367.	367.	104.	447.	4.
4517	26834.	195471.	402908.	267267.	1037.	348.	5335.	2319.	357.	101.	424.	4.
5356	5418.	39855.	66604.	51637.	212.	74.	1071.	452.	85.	24.	111.	1.
4822	2963.	22124.	37694.	28046.	120.	42.	607.	254.	47.	13.	56.	1.
8311	14862.	109475.	224272.	146860.	590.	197.	3025.	1302.	202.	57.	224.	2.
6425	6691.	50675.	87277.	62836.	282.	96.	1415.	585.	108.	30.	116.	1.
9165	1104.	7388.	13069.	11247.	34.	13.	176.	82.	15.	4.	29.	0.
9164	731.	5035.	8250.	7244.	24.	9.	124.	55.	11.	3.	19.	0.
3833	20958.	152311.	330917.	211232.	808.	268.	4177.	1829.	265.	74.	303.	3.
4434	5422.	40114.	66865.	51443.	215.	75.	1086.	456.	86.	24.	109.	1.
3732	14073.	101712.	242485.	145084.	538.	174.	2811.	1250.	160.	45.	170.	2.
3414	13543.	97848.	236154.	140009.	518.	167.	2709.	1206.	151.	42.	158.	2.
3337	5702.	42896.	83785.	55073.	238.	79.	1207.	508.	83.	23.	83.	1.
3413	7575.	52904.	148915.	82470.	269.	84.	1444.	674.	64.	18.	70.	1.
4246	3935.	28904.	48146.	37517.	153.	54.	775.	328.	62.	18.	81.	1.
6316	5315.	40370.	70136.	49885.	225.	77.	1132.	468.	86.	24.	90.	1.
8118	484.	3398.	5453.	4720.	17.	6.	86.	38.	7.	2.	12.	0.
9027	2305.	17282.	30629.	21906.	95.	32.	479.	200.	36.	10.	40.	0.
8935	1220.	9247.	16150.	11485.	51.	18.	259.	107.	20.	5.	21.	0.

(Continued)

Table 2

Summary of Annual Pollutant Loadings

(Continued)

	ANNUAL POLLUTANT LOADINGS (LBS/YR)											
	OXYGEN DEMAND & SEDIMENT				NUTRIENTS				HEAVY METALS			
NODE NUMBER	BOD	COD	TSS	TDS	TOTAL-P	DISSOLVED-P	TKN	N02&N03	LEAD	COPPER	ZINC	CADMIUM
7822	5865.	41848.	109077.	62092.	219.	69.	1156.	525.	58.	16.	60.	1.
1132	575.	4162.	10225.	5965.	22.	7.	116.	52.	6.	2.	6.	0.
2928	3201.	24075.	47099.	30932.	133.	44.	677.	285.	47.	13.	47.	1.
4144	2291.	17102.	28970.	21670.	93.	32.	469.	196.	37.	10.	43.	0.
6111	1805.	13628.	25229.	17218.	76.	26.	382.	160.	28.	8.	28.	0.
2941	2875.	20058.	55291.	31163.	102.	32.	544.	254.	25.	7.	29.	0.
2852	3226.	21636.	74820.	37570.	105.	30.	586.	291.	14.	4.	15.	0.
4015	137.	1054.	1778.	1270.	6.	2.	30.	12.	2.	1.	2.	0.
715	1989.	14112.	38382.	21327.	73.	23.	390.	179.	18.	5.	18.	0.
320	849.	5660.	20221.	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.	33003.	93983.	51165.	169.	52.	909.	423.	39.	11.	39.	0.
2723	2644.	17292.	66706.	31968.	81.	22.	465.	240.	6.	2.	6.	0.
2324	1917.	12979.	43601.	22077.	64.	19.	353.	174.	10.	3.	10.	0.
2551	2021.	12885.	54531.	25252.	58.	15.	344.	184.	0.	0.	0.	0.

REFERENCES

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