Development of TMDL Modeling for Impaired Urban Watershed

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Abstract
The allocation of impaired load in the water bodies of urban watershed area is perhaps the most scientifically and potentially challenging aspect for water resources planners. The new concept of total maximum daily load (TMDL) has recently been introduced to design the sate of art to set the water quality standards for designated uses of water bodies loaded from point and nonpoint sources of pollution. This paper has described total maximum daily load understanding in urban watershed allocated from nonpoint pollution sources like agriculture and urban / storm runoff, and traditional point source pollution, like permitted sewage treatment plants and industrial discharges. Study is carried out in GIS framework PLOAD extension of BASINS watershed tool to determine total maximum daily load on the watershed from load allocation (LA) and waste load allocation (WLA) based on existing land uses and hydrological scenario. Results show the estimation of pollutants loading from all sources in a watershed upstream of and within the impaired segment, which have addressed to remedy the impairment. Support for this work is provided in the part by funding from the National Natural Science Foundation Committee (NNSFC) for the project No. 50239030

Key words
Arch/view GIS, nonpoint source, PLOAD, point sources, TMDL, urban watershed

INTRODUCTION

The TMDL program is simply the enforcement of rules provided in the Clean Water Act of 1972 (CWA, 1982). The CWA addressed point and nonpoint source pollution and mandated that water agenesis should set water quality standards for designated uses of water bodies, scrutiny water bodies not meeting set standards and develop total maximum load daily load understanding for them. The provisions in the CWA that called for non-point source pollution control and TMDLs were largely ignored for 20 years following the passage of the CWA partly due to our lack of knowledge concerning non-point source pollution and its control. Instead, lot of efforts was made to control water pollution on implementing best available technology to clean up point-source pollution. In this regards many challenges exist in the implementation of the TMDL program. Non-point source pollution, which is basically storm / urban water runoff that has been polluted by land use, is still not well understood. It is difficult to quantify loadings produced by non-point source pollution and to predict water quality responses water bodies due to these loadings. Also, the connection of non-point source pollution to land use means that it must be controlled through land use practices, or the implementation of Best Management Practices (BMPs) (Zaheer *et al*. 2002). For the same reasons, it is not easy to understand non-point source pollution, also fully understand the effectiveness of BMPs. Further more, many landowners are affected by the TMDL program and must be involved in the planning process. In order for the TMDL program to be effective, public awareness and stakeholder involvement will be key important. Monitoring is extremely important to measuring the effectiveness of the TMDL program in obtaining its goals, in monitoring BMPs to determine their effectiveness, and in determining the sources of pollutant loadings. Monitoring can also be used to fill in the gaps of knowledge that we lack concerning nonpoint source pollution by directly measuring concentrations of pollutants in water bodies and developing mass loadings of pollutants and pollution response curves (Waneilista, 1978). Modeling of non-point source pollution is still in its early stages. However, model such as the EPA's BASINS is beginning to bring a uniform approach to TMDL development (CH2M HILL, USEPA 2001). This is especially useful in economic analyses, since they allow different water pollution control scenarios to be evaluated to determine cost-effective solution. It shifts the focus from cleaning up point source pollution to improving the quality of water in the water body itself. According to USEPA with 43% of the impaired waters reported in 1998 being due to non-point source pollution alone, it is clear that a major focus of the TMDL program will be on cleaning up non-point source pollution (USEPA 1998). Therefore, if the TMDL program is to be a success, landowners must be involved and land use practices will be affected. The TMDL procedure and the watershed approach to water quality management involve an extremely diverse group of stakeholders (TNRCC 2001). For the TMDL program to be a success, it requires the cooperation of all of these stakeholders in the development and implementation of the TMDL (Jarrell, 1999). TMDL understanding in this study is defined as loading capacity (LC) of rivers flowing in the Xishan urban watershed of Taihu Lake Basin integrated with various land uses. The terms, LC is simply defined as maximum amount of pollutants that water body can receive under permissible limit set by Chinese Water Commission. Based on land use information, pollutants loading coefficient and range of high, low and average annual rainfall, non-point pollutants load is calculated.

MATERIAL AND METHODOLOGY

The allocation of loads to various polluters is understood to be social as well political aspect of the TMDL development in the Xishan urban watershed. Therefore, it is difficult to determine the effect of non-point source pollution on the actual water quality of the stream network of study area. Methodology is only adopted to calculate load allocations in stepwise, first it is determining the maximum allowable load that streams is tolerating and then dividing load by the flow rate of the stream. Waste load allocations (WLAs) from point sources is calculated and subtracted out, since the point source pollution loading is steady state and the below equations is used to simulate TMDL (Zaheer, 2003).

$$TMDL= WLA+LA+BL+MOS \tag{1}$$

The result is the sum of the load allocation (LA), waste load allocation (WLA), the background load (BL), and margin of safety (MOS). While, MOS is allocated as fairly as possible. Once a total LA and WLA are established to cover all non-point and point sources respectively in urban watershed covered by a TMDL, this LA is divided into individual allocations. BASINS (Better Assessment Science Integrating Point and Non-Point Sources) watershed management tool, developed by the USEPA is used to analysis by allowing multiple scenarios to be evaluated quickly. The PLOAD model extension is used to calculate non-point source (LA) pollution, which is a program that uses EMC (event mean concentrations) based on land use and an impervious factor to determine the typical load on an urban watershed (Cui *et al*. 2003). Point source pollution of stream network is calculated from water quality model integrated with PLOAD. It then provides a graphical display in GenScn for the watershed (complete with pollutant loads).

TMDL Process Evaluation

During TMDL development, process is carried out in the following steps;

(i) Examination of the problem setting described in term of watershed characterization.
(ii) Definition of target values of indicators, presenting achievement of WQS.
(iii) Estimation and identification of load allocation (LA) in the urban watershed.
(iv) Estimation of waste load allocation (WLA) and its components to examine impacts on receiving waters and quantify the loading capacity.
(v) Evaluation of the linkage between loading and response.
(vi) Selection of the loading allocation for MOS that results in the achievement of WQS.

Watershed Characterization. Watershed characterization is used including detail information regarding watershed boundary and area, land use type and their percentage values, stream network and waste discharge potential, hydrological and climatologically survey and digital elevation model (DEM) processing. Watershed characterization analysis and related data development is carried out using Arch/view GIS framework (Young *et al*. 1986).

Water Quality Standard (WQS). For defining target values of indicators, which is represented through the achievement of WQS that China has been established called as National Water Standard (GB 3838-88) for the surface water quality. Table 1 is showing the permissible limits for the various kinds of water quality parameters fall in five different classes in respect of various water uses. The values of standards are based on the classification of water in accordance with their particular use i.e.

Class I: Water resources and national protection areas.
Class II: Drinking water resources and protection areas (fishing).
Class III: Drinking water and class II protection areas (normal fishing).
Class IV: Industrial and recreation (swimming, boating etc).
Class V: Agriculture water use and visiting water resources.

Estimation and Identification of load Allocation. Load allocation component is included non-point source of pollution. Estimation of LAs is carried out from agriculture and domestic land uses in the urban watershed using PLOAD. For example, estimation of TN in agriculture and domestic land use is shown in Figure 1. Annual pollutants load is calculated on an annual average basis based on land use information, pollutants loading coefficient and annual rainfall from the watershed containing non-point source data. PLOAD model is designed for the LA estimation using two methods, called Export coefficient and Simple methods depending upon the availability and nature of input data. Present study used simple method with following expressions (USEPA 2001);

$$R_{VU} = 0.05+(0.009*L_U) \text{ and } LA = \Sigma U\,(P*P_j*R_{VU}*C_{EMC}*A_U) \quad (2)$$

Where R_{UV} is the runoff coefficient for land use type U (inches *runoff/inched rainfall),* and L_U is percent imperviousness for respective land use. Similarly, LA is pollutants load Allocation, P is precipitation (cm/*y*), P_j is ratio of storm producing runoff, R_{VU}, run off coefficient for land use type, C_{EMC} is EMC (mg/l) and A_U is area (*m*) of land use type U. LA is computed as; (a) watershed (kg/year or Ib/year), (b) watershed area (kg/ha/year or Ib/ac/year), and (c) EMC by pollutants (mg/l) (Table 2). LA sources are identified in the urban watershed using the developed artificial neural network model as described in Zaheer and Cui 2003.

Table 1. Chinese National Standard for surface water quality (GB 3838-88)

No	Categories Water Quality parameters	Concentration of water quality parameters (mg/l)				
		I	II	III	IV	V
1	pH			6.5~8.5		
2	DO	10	6	5	3	2
3	COD_{mn}	2	4	6	8	10
4	COD_{cr}	3	15	15	20	25
5	BOD_5	0.02	3	4	6	10
6	NH_3-N	0.01	0.02	0.02	0.2	0.2
7	NO_3-N	0.06	10	20	20	20
8	NO_2-N	0.02	0.1	0.15	1.0	1.0
9	Total P	0.02	0.02	0.02	0.2	0.2
10	TOP	0.05	0.1	0.1	0.2	0.2
11	Oil	0.05	0.05	0.05	0.5	1.0
12	Phenol	0.00	0.002	0.005	0.0	0.1
13	Coliform	-	-	1000	-	-

Site for Figure 1 PLOAD's TN estimation from agriculture and domestic land uses

Table 2. Computation of load allocation (LA) in all delineated watersheds of Xishan sub basins

ID	Pollutant Load by Watershed (kg/year)			Flow		Event Mean Concentration (EMC) (mg/l)			Pollutant Load By watershed area (kg/ha/y)		
	COD	TN	TP	(m^3/sec)	(m^3/y)	COD	TN	TP	COD	TN	TP
1	217155.3	49902.31	23977.75	0.67	20971408	51.5	12	5.7	2.95	0.62	0.30
2	243537.9	49125.11	25061.54	0.72	22493370.9	53.2	11.3	5.7	4.02	0.74	0.39
3	247031.2	63363.25	31231.27	0.82	25731201.2	47.7	12.3	6	2.54	0.60	0.31
4	203672.8	45987.46	21720.68	0.59	18947047.2	45.0	9.3	4.5	2.18	0.42	0.21
5	156434.2	40445.15	18168.45	0.48	15144307.8	40.3	10.9	4.9	2.01	0.49	0.22

Estimation of Waste Load Allocation. It is described as the amount of load, which can be assimilated without violating water quality standards. Identification and evaluation of waste load allocation (WLA) in term of point sources pollution is simulated in the urban watershed river network after the application of developed mathematical water quality model (Zaheer and Cui 2002). Model is applied for the point source pollutants computation after validation and calibration process. Model simulation is included the prediction, fate and diffusion of non-conservative pollutants and their transport in the direction of flow. WLA assessment is calculated based on two factors:

a) The diluting capacities, which cause to decrease the carrying capacity of river and it subsides the effect of pollutants and distributes the pollutants gradually in waters and bottom soil as described by the equation.

$$WLA = Q_o(C_S - C_O) + qC_S \, when \; x \to 0 \, and \; v \to 0, \quad (3)$$

b) The self-purification capacity or assimilation capacity causes the decrease of pollutants to harmless level under the influences of certain chemical, physical and biological processes in the river is calculated by the equation:

$$WLA = KVC_S$$
$$when,\ C_o = C_S\ and\ q << KV \quad (4)$$

Example of model simulation of COD in concentration term of WLA in mg/l along the River section on 10th day after the discharge of industrial effluent is shown in the Figures below (Figure 2 (a, b, c)).

Site for Figure 2 (a, b, c) Simulation of COD on the 10th day for Wang Yu River, Jui Li River and Yun River

Linkage between Loading and Response. For the simulation of water quality and pollution problem by a mathematical model, it is inevitable that modeling assumption and simplification have to be made. Naturally the assumption and modeling simplification that are made to simulate a real problem together with the error and uncertainties in the physical description of the system parameters will manifest themselves in the form of differences between analysis prediction and the true behavior of real system. Based on this concept the following assumption are established:

(i) The river flow is one direction, i.e. one-dimensional model.
(ii) Studies are made under the steady state of flow conditions.
(iii) The effluent discharge concentration is taken as point source pollution.
(iv) The discharge of pollutants load from the point sources is measured as pollution capacity or mass load (kg/year).
(v) Addition of oxygen by surface re-aeration is considered as first order reaction.
(vi) The removal of dissolved oxygen from the river is proportional to the addition of Oxygen demanding materials in the water.

Margin of Safety. It is a part of the load is allocated to MOS to account for limitations in the accuracy of model / analytical procedures or account for the uncertainty in determining the amount of pollutant load and its effect on water quality. MOS is typically considered:

A- *Explicit* definition based on evaluation of accuracy of TMDL estimation techniques
B- *Implicit* incorporation through conservative assumptions incorporated in analysis.

The MOS should not be used to account for allocation to future sources or to natural background sources. As in the case a comparative analysis is made to establish relation ship between total polluting load, as for example for EMC by COD in mg/l and permissible limit set according to Chinese water quality for COD of Class IV for the use of surface water in agriculture and recreational activities is shown in the Figure 3. This shows the impact of pollutants loading rate to harmful level in certain modeling units because the presence of WLA (industrial units). Therefore, MOS, and specifically uncertainty, are very important components of TMDL process, and it leads the adjustment of water quality standards with decrease by 10%. Under the condition, the TMDL is determined to wards safe side for any risk as impact of safety factor is shown in the Figure 4. This is because of loading allocations may affect many stack holders in TMDL understanding; therefore, MOS helps to make allocation decisions.

Site for Figure 3 EMC by COD in mg/l and permissible limit set according to Chinese water quality of Class IV for the use of surface water in agriculture and recreational activities.

Site for Figure 4 TMDL process leading the adjustment of water quality standards with decrease by 10%

Results and Discussion

The TMDL allocation process culminates in allocating pollutant loads among various nonpoint (LA), point (WLA) and natural background sources in the urban watershed. Calculation is made based on the following three steps using Equation 1;

(i) First, the model is simulated for the computation of COD for the period of ten days at various cross sections along the rivers using point sources inventory, effluent discharge and river discharge data. This modeling output is used to calculate WLA of river system at respective cross sections within the modeling units.

(ii) Secondly, nonpoint sources (LA) are calculated based on EMC concentration from land use type in the modeling units.

(iii) Finally, the computed results for LA and WLA are integrated for PLOAD model development to compute the TMDL process allocating to both point and nonpoint sources for Xishan urban fringe watershed.

Allocating pollutants (TMDL) is computed by watershed area (kg/year or Ib/day). Set of layout for the distribution of total COD daily load distribution of pollutants over the watershed area based on watershed (LD_COD) in kg/year, watershed area (AR_COD) in kg/ha/year) and even mean concentration (EMC_COD) in mg/L by the pollutants is shown in the Figures 5. The TMDLs are allocated to the LAs and WLAs with 10% of the allowable loading reserved as a margin of safety (MOS). The TMDLs cover 877 km^2 of Xishan urban watershed. The nonpoint load as LAs for TN, TP and COD are estimated as 11,846,30.47 kg/year, 48,030.69 kg/year and 15,674,53.35 kg/year, while point source as WLAs are calculated 8,485,29.13 kg/year, 1, 070,95.19 kg/year and 36,070,74.47 kg/year respectively. Nonpoint pollution is estimated, mainly contributed from agriculture and domestic sources in the Xishan urban fringe watershed. Moreover, load allocation as TMDL is estimated as 3,361,01.56 kg/year, 1,551,25.66 kg/year 737.71 and 51,744,93.19 kg/year for COD, TN and TP respectively. The whole results are summarized after conversion of pollutants load in ton/year in Table 3.

Table 3. Summary of TMDL in Xishan fringe urban watershed

Load allocation / Pollutants Load	TN Ton/year	TP Ton/year	COD Ton/year
Point load /WLA	1870.65	105.88	3455.58
Nonpoint load/LA	1000.34	236.10	7952.10
TMDL	2871.56	341.89	11407.65

Site for Figure 5 Profile of TMDL computation using WLA and LA data

CONCLUSIONS

This paper has described the total maximum daily load modeling process in impaired urban watershed using pollutant-loading allocation, which is defined as the sum of waste loading allocation (WLA), load allocation (LA), and margin of safety (MOS). This described the ability to simulate sediment, COD and nutrient (N and P) loadings from a watershed with variable size source loads, e.g., agricultural, forested, urban areas and developed land. Load allocations were estimated for sources of TN, TP and COD from agriculture, domestic and septic systems. While waste load allocation were made for sources like industries and sewage waste. In fact, TMDL understanding process is extremely complex and faces many challenges but present study will help to provide a guideline for carrying out TMDL program in future projects. Because, it involves complex process with staggering workload and cooperation of a diverse group of people, and integrated science that is not well understood. However, TMDL has realistic approach in attempting to make gains at the root of the water pollution problem. An urban watershed approach, which addresses nonpoint as well point source pollution control through the cooperation of the stack holders responsible for creating it, is the only way for pollution protection agencies to make meaningful progress towards the target for having clean waters that meet Chinese water quality standards. These are the only situation Federal agencies, Provincial environmental agencies, and NGO's can work for repairing the impaired environment. Only TMDL understanding process have the resources to compute load allocations, create a cost effective management plan, implement the management plan, and then monitor the results to determine the successful urban watershed management.

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