GIS-BASED INFLUENCE ANALYSIS OF GEOMORPHOLOGICAL PROPERTIES ON POLLUTANT WASH-OFF IN AGRICULTURAL AREA

M. S. Bae and S. R. Ha

Department of Urban Engineering, Chungbuk National University, 48 Gaeshindong Heungdukgu, Cheongju, Chungbuk, 361-763, Korea (E-mail: mysoba@orgio.net)

ABSTRACT
This study was undertaken to improve the self-purification coefficient of the previous study for runoff analysis of pollution load using geomorphological factors. In the previous study, the assimilative capacity, K was estimated using single geomorphological factor, which is Horton's watershed form ratio, S_f. The assimilative coefficient, K was divided into two factors, namely, a watershed self-purification coefficient (k) and a watershed form ratio (S_f). The watershed form ratio, S_f is the equivalent density of stream of a watershed and considered as index of accessibility of pollution load to water body. Even though the S_f had shown a clear reciprocal relationship with the k, in agricultural area, there is a limitation that the k, estimated by using a S_f only, can't reflect the change of land coverage characteristics and/or land use of watershed. To overcome this limitation, in this study, a new geo-characteristic index (GCI), S_R, which is composed of S_f and weighted flow accumulation ratio (F_r), was suggested. GIS and remote sensing technique were used to calculate the S_f and F_r. The result of this study showed the relationship between a basin-wide self-purification coefficient, k and S_R. Interestingly, a clear reciprocal relationship exists between the two, and this relationship seemed to be more strong for the agricultural area, as the urbanized area has easier wash off due to the sewer network or paved surfaces.

Keywords: Diffuse pollution, geo-characteristic index, geomorphological properties, GIS, pollution load runoff

INTRODUCTION
Total maximum daily load (TMDL) has performed for watershed-based water quality management in Korea since 1998. To achieve water quality standards of TMDL at specific water quality monitoring station (WQMS), the comprehensive and rational pollution runoff analysis must be preceded. Pollution runoff model based on watershed depends upon the factors attributed to the geological characteristics of the watershed and/or the pollution elements of the ecosystem. Physically, it is impossible to incorporate all the relevant parameters into such an environmental model. Hence, many previous studies have treated reduction factors by using a single coefficient, called the assimilative capacity or purification coefficient, especially in Korea where is composed of high density and complex land use. The water purification coefficient (K) accounts for the difference between the total generated pollution load and the discharged pollution load by the outgoing drainage network in a specified watershed.

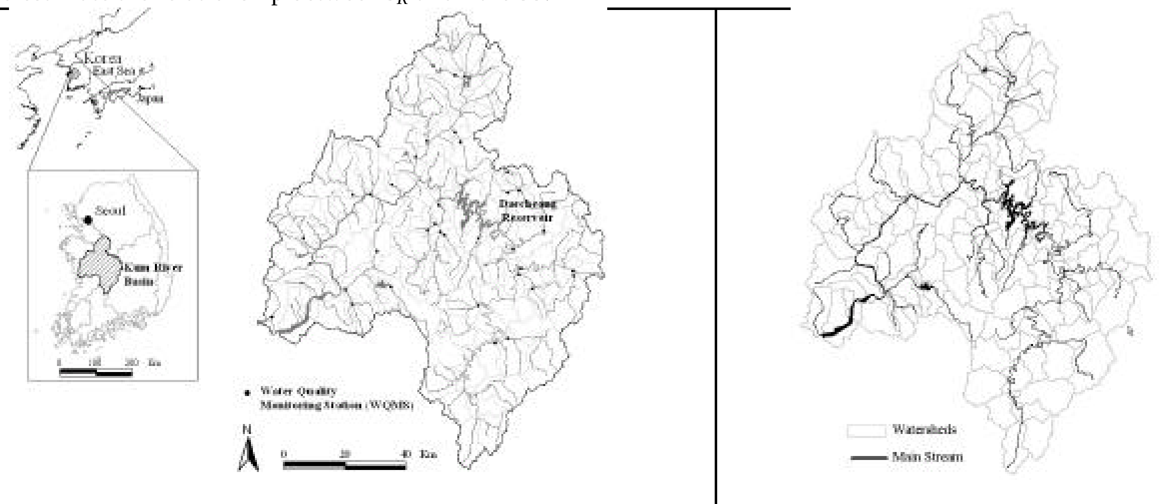
This simple rate coefficient, however, can't be used for estimation of pollution load delivered (PLD) at watershed where has no WQMS. In addition to, it is impossible that the K consider the changes of carrying capacity caused by change of land use. Thus, K calculated by simple rate method (SRM), is hard to use for planning of land use and/or control of pollution load to achieve the standard water quality. To surmount these problems, there is a lot of studies have carried out using complex mathematical methodology (CMM) for pollution runoff. Ha *et al*. (1998) had used kinematic wave to reveal the runoff mechanism of pollutant in urban area. In that study, so many variables, such as rainfall intensity/duration, particle size of pollutant etc. was considered. Even though the enormous effort, those study have limitations on application to watershed management practices, especially in very wide area, because it is so complex and requires a great deal of information.

In the previous study (Ha and Bae, 2001), the assimilative capacity, K was estimated using single geomorphological factor, which is Horton's watershed form ratio, S_f. The assimilative coefficient, K was divided into two factors, namely, a watershed self-purification coefficient (k) and a watershed form ratio (S_f). The watershed form ratio, S_f is the equivalent density of stream of a watershed and had considered to index of accessibility of pollution load to water body. Even though the S_f had shown a clear reciprocal relationship with the watershed self-purification coefficient (k), in agricultural area, there is a limitation that the k, estimated by using a S_f only, can't consider the change of land surface characteristics and/or land use of watershed.

This study is focused on the repletion of limitations of SRM and CMM. The geo-characteristic index (GCI) was suggested to consider the changes of geomorphological properties such as land coverage, slope, and soil type using GIS and remote sensing techniques. The main object of this study is to develop the GCI and to explore the relationship between GCI and PLD. The S_R, as a simple GCI, was developed using by Horton's watershed form ratio, S_f and flow accumulation ratio of pollution load (F_r).

METHODS
Study area

Kum River basin located in the central part of South Korea and include the Dacheong reservoir, of which the total storage capacity is 1,490million tons and the water supply source for about three million people. The area of Kum River basin is about 9,910km^2 and the annual precipitation is about 1,400mm/year but more than half of it concentrates on rainfall season from July to September. The delivery time of storm peak in Kum River is comparatively short to response against shortterm rainfall events and it takes less than 2 days. The watersheds, in this study, are divided into 121 and the WQMS which is used to estimate the relationship between S_R and k are 35.



KUM River basin and WQMS | watersheds

Figure 1 Study area

GOVERNING EQUATIONS

The process to derive the Horton's watershed form ratio, S_f, flow accumulation ratio of pollution load, F_r, and simplified GCI, S_R is illustrated in Figure 2. The governing equation to calculate the PLD is as follows:

$$P_M = P_{Tre} + \{P_{Non} * Exp(-k * S_R)\} \quad (1)$$

$$S_R = S_f * F_r \quad (2)$$

$$S_f = D^2/A \quad (3)$$

$$F_r = FAV_W / FAV_N \quad (4)$$

where P_M, P_{Tre} and P_{Non} are the pollution load monitored at WQMS, the discharged pollution load with/without treated, respectively. D and A are the summation of drainage networks and the area of watershed, and FAV_W and FAV_N are the weighted flow accumulation value and the non-weighted flow accumulation value at watershed outlet, respectively. And k is the self-purification coefficient on the specified watershed. The length of drainage networks, D, is depend upon threshold value of flow accumulation (TAV). There is no standard on TAV, so that 500, 1000, 2000, 3000, 5000 and 10000 of TAV were estimated.

RESULTS AND DISCUSSION

Weighted geo-delivery impact factor

Pollution runoff is greatly depends upon the geomorphological conditions. The weighted geo-delivery impact factor based on literature review (Corbett *et al*., 1997; Wanielista *et al*., 1997; Katerina and Christopher, 1999; Daniel *et al*., 2002) was built as follow Table 1. Residential and road category are impervious area so that there is no impact with slope. Water body doesn't lead to the pollution load, but the delivery ratio in water body is practically 1.

Table 1 Weighting factor with land coverage and slope

Land Coverage	Slope (%)				
	0~0.25	2.5~5	5~7.5	7.5~10	10~
Forest	0.075	0.115	0.155	0.195	0.235
Cultivate	0.150	0.188	0.225	0.263	0.300
Water body	1.000	1.000	1.000	1.000	1.000
Residential	0.950	0.950	0.950	0.950	0.950
Road	0.950	0.950	0.950	0.950	0.950

Table 2 RMSE of drainage network with TAV (Km)

	TAV					
	500	1000	2000	3000	5000	10000
Upstream	11.25	6.98	10.26	13.00	16.87	20.71
Downstream	11.48	8.76	12.60	15.22	17.99	21.40
Total	11.40	8.10	11.73	14.39	17.57	21.14

Table 3 Results of GCI and self purification coefficient, *k*

WQMS	BOD (mg/L)	Flow Rate (m^3/sec)	P_M (Kg/day)	Area (Km^2)	Stream Length (Km)	Geo-characteristic index (GCI)					Pollution load discharged		Self purification coefficient, k
						S_f	FAV_N	FAV_W	F_r	S_R	P_{Tre}	P_{Non}	
S1	1.3	20.87	2344.39	1058.1	383.7	34.78	1,162,938	264,525	0.23	7.91	0.00	4167.66	0.073
S2	0.9	7.78	605.16	394.8	148.8	14.02	428,528	98,143	0.23	3.21	0.20	935.37	0.136
S3	1.9	4.42	726.22	220.4	69.9	5.54	308,624	65,589	0.21	1.18	1.18	966.70	0.244
S4	1.0	1.17	101.01	59.4	23.5	2.33	56,526	12,292	0.22	0.51	0.00	200.03	1.349
S5	1.8	2.92	464.33	143.5	55.2	5.31	162,024	35,321	0.22	1.16	68.14	464.33	0.137
S6	0.8	3.64	251.28	184.8	68.8	6.41	205,390	47,747	0.23	1.49	0.00	300.73	0.121
S7	1.1	0.91	86.48	46.2	14.5	1.13	25,343	4,979	0.20	0.22	0.00	151.36	2.520
S8	1.2	13.11	1358.83	666.1	212.8	16.99	651,264	131,916	0.20	3.44	0.04	2372.68	0.162
S9	0.8	0.51	35.04	25.8	8.4	0.68	20,448	3,993	0.20	0.13	0.01	172.34	11.994
S10	1.0	0.43	37.00	21.1	6.3	0.47	21,280	3,846	0.18	0.08	0.00	91.50	10.752
S11	1.0	2.81	242.37	140.6	43.9	3.43	146,747	31,220	0.21	0.73	0.04	791.51	1.621
S12	1.0	8.49	733.64	425.4	137.4	11.09	521,829	105,920	0.20	2.25	29.22	2437.20	0.551
S13	1.0	11.02	951.84	553.5	185.8	15.60	647,945	132,504	0.20	3.19	29.22	2778.59	0.346
S14	1.8	3.60	560.39	178.0	40.8	2.34	162,101	33,227	0.20	0.48	29.38	757.04	0.741
S15	4.4	5.07	1927.48	251.9	77.7	6.00	249,289	60,512	0.24	1.46	108.82	2931.81	0.328
S16	3.2	6.20	1714.19	309.3	101.1	8.25	316,899	87,764	0.28	2.29	108.82	3818.67	0.379
S17	3.7	1.76	562.24	89.4	35.2	3.47	99,808	37,576	0.38	1.30	0.00	782.02	0.253
S18	3.6	6.22	1945.66	298.6	119.1	11.88	332,412	111,115	0.33	3.97	0.60	5988.12	0.283
S19	6.7	20.31	11755.57	649.0	241.2	22.41	707,667	225,097	0.32	7.13	8397.12	11670.64	0.175
S20	3.5	5.80	1753.34	293.3	91.7	7.17	457,313	98,014	0.21	1.54	21.61	3666.86	0.488
S21	1.1	1.69	160.22	85.7	30.4	2.70	94,489	23,823	0.25	0.68	0.00	216.37	0.441
S22	8.1	0.76	528.82	115.5	44.2	4.24	145,112	36,951	0.25	1.08	0.00	687.51	0.243
S23	1.1	2.62	248.99	114.0	42.8	4.01	143,868	35,719	0.25	1.00	0.01	505.99	0.713
S24	2.3	3.40	674.82	172.4	59.8	5.18	177,002	50,993	0.29	1.49	15.18	2734.80	0.953
S25	2.3	3.92	779.76	199.2	71.9	6.49	207,746	68,465	0.33	2.14	87.91	3622.52	0.774
S26	1.4	7.22	898.52	366.1	138.9	13.17	395,760	96,119	0.24	3.20	17.71	6243.05	0.612
S27	2.1	3.05	553.09	136.2	41.5	3.16	131,126	29,142	0.22	0.70	221.66	1409.14	2.063
S28	1.7	0.97	142.93	49.5	16.4	1.36	73,239	15,444	0.21	0.29	0.00	388.29	3.487
S29	1.6	3.18	440.16	161.8	58.8	5.35	182,053	43,048	0.24	1.26	0.38	667.61	0.330
S30	1.4	5.56	672.67	282.6	110.1	10.73	309,573	70,560	0.23	2.44	0.00	1400.20	0.300
S31	2.0	3.97	686.64	200.8	72.3	6.50	270,731	68,704	0.25	1.65	0.00	1678.99	0.542
S32	2.4	3.23	669.41	164.1	60.3	5.55	181,387	50,517	0.28	1.55	0.00	1644.27	0.582
S33	1.1	3.85	365.90	195.7	64.9	5.37	244,801	57,753	0.24	1.27	0.00	699.88	0.511
S34	2.3	1.70	337.72	86.4	34.8	3.50	133,996	28,607	0.21	0.75	0.00	513.77	0.561
S35	1.4	1.67	201.78	84.8	28.7	2.44	111,815	27,760	0.25	0.60	0.00	622.77	1.863

Figure 3 shows the weighted impact factor of pollution runoff. Dae-jun and Cheong-ju are the major city in Kum River basin, where are mainly impervious area. The length of drainage network, D, in Equation (3) is depend on the TAV. The cell, which is great than TAV, will be drainage network (Olivier and Frederic, 2001). Table 2 shows the root mean square error (RMSE) with TAV in upstream, downstream and total of Kum River basin. The drainage network of Korea Water Resource Corporation (KOWACO) as a real drainage network was used to calculate the error although there is some inconsistence with a real drainage network. As shown in Table 2, drainage network with TAV=1000 is most approximated to KOWACO drainage network.

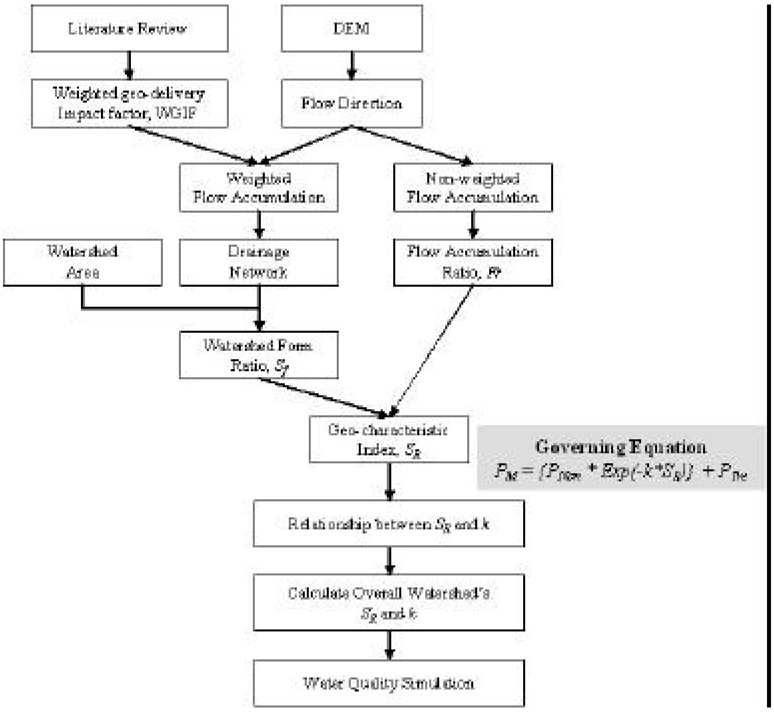
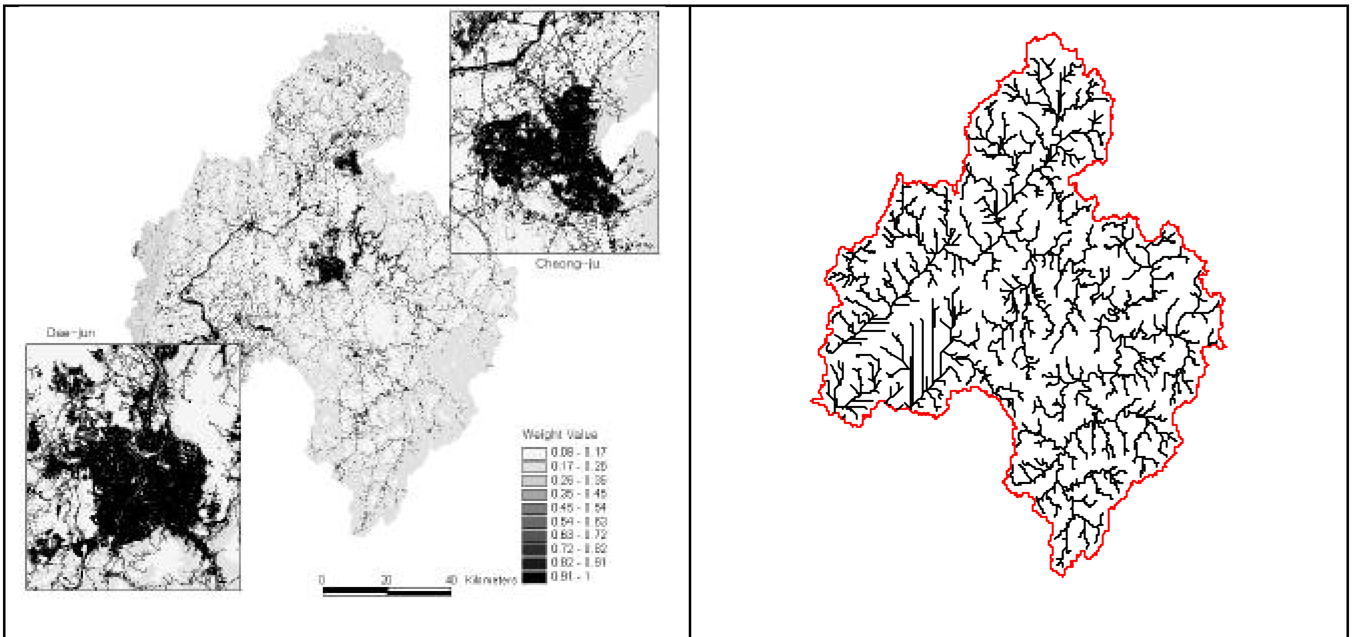


Figure 2 Process of this study



pollution load runoff	stream network derived by DEM with TAV=1000

Figure 3

RELATIONSHIP BETWEEN GCI AND SELF PURIFICATION COEFFICIENT

The results of GCI and self purification coefficient on WQMS elaborated in Table 3. BOD (mg/L) and flow rate (m^3/sec) are average value in December, 1998 because the water quality standard is based on Q_{275}. k, self purification coefficient, was calculated by Equation (1) and the relationship between S_R and k illustrated in Figure 4. As shown in Figure 4, downstream has not clear relationship between S_R and k than upstream. The regression curves of upstream, F1 and F2, are similar but that of downstream, F3, F4 and F5, are definitely different. It is cause by mixed land use in downstream. Impervious urban area has k less than k in pervious cultivate or forest area. Table 4 shows the regressive equation between S_R and k, and the WQMS which is belongs to each regression curve. The watersheds belonged to F5 have a lot of portion of urban area but there is no wastewater treatment plant. The watersheds belonged to F3 are mostly urbanized area, such as Daejun, Cheongju in Figure 3(a), but there is well municipal wastewater treatment plant.

Table 4 Regressive relationship between S_R and k

Regression curve*	Regressive equation	WQMS belonged to regression curve	R^2
F1	$k = 1.0379 * S_R^{-1.0950}$	S1, S9~S13	0.9775
F2	$k = 0.3591 * S_R^{-1.1193}$	S2~S8, S14	0.8036
F3	$k = 0.6840 * S_R^{-0.6971}$	S16, S18~S20, S23, S30~S33	0.9362
F4	$k = 1.3866 * S_R^{-0.7408}$	S24~S28, S35	0.9855
F5	$k = 0.3560 * S_R^{-0.7592}$	S15, S17, S21, S21, S29, S34	0.5447

* The regression curve in Figure 4.

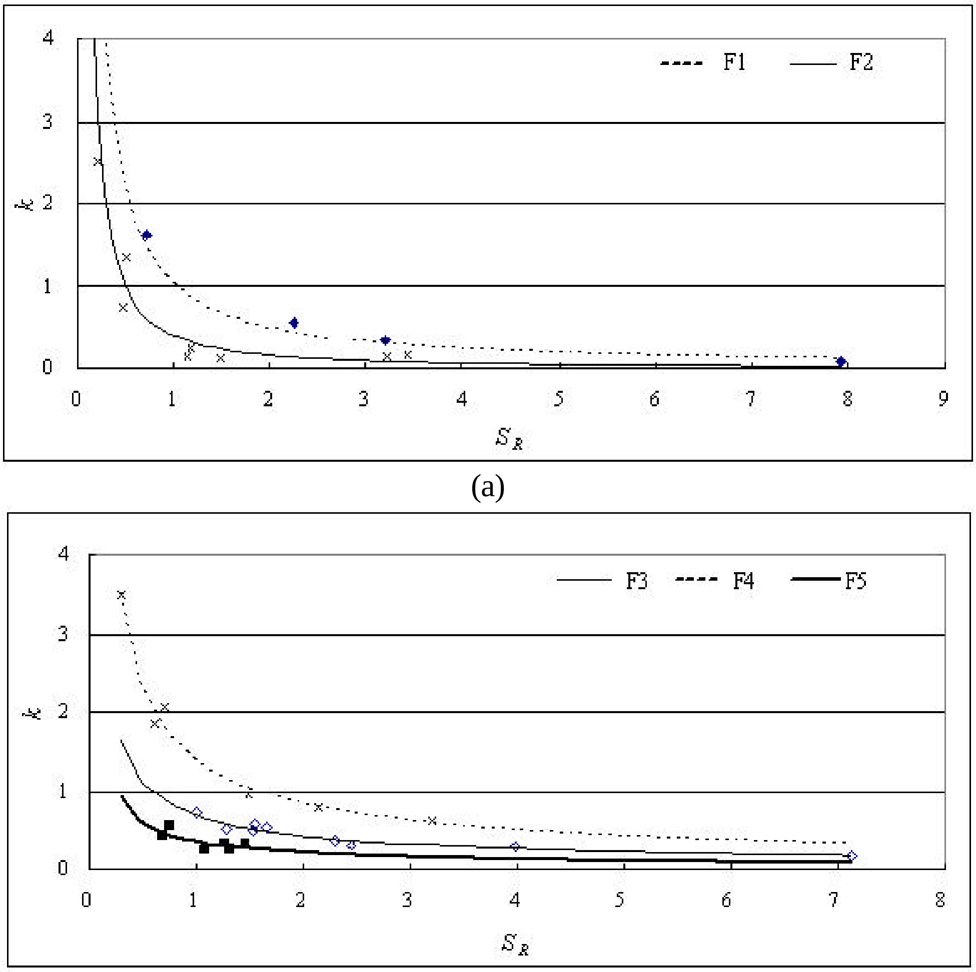


Figure 4 Relationship between S_R *and* k*: upstream (a), downstream (b)*

Figure 5 illustrates the results of water quality simulation using QUAL2E model in Kum River upstream with TAV (1000, 2000 and 5000), and there is no attractive difference on BOD simulation. It reveals that the TAV is not a significant factor to estimate the pollution load discharged from watersheds using S_R. In other word, it means that the effort to determine how much TAV should be used is not necessary. Therefore, the methodology suggested in this study can sweeps an error caused by TAV.

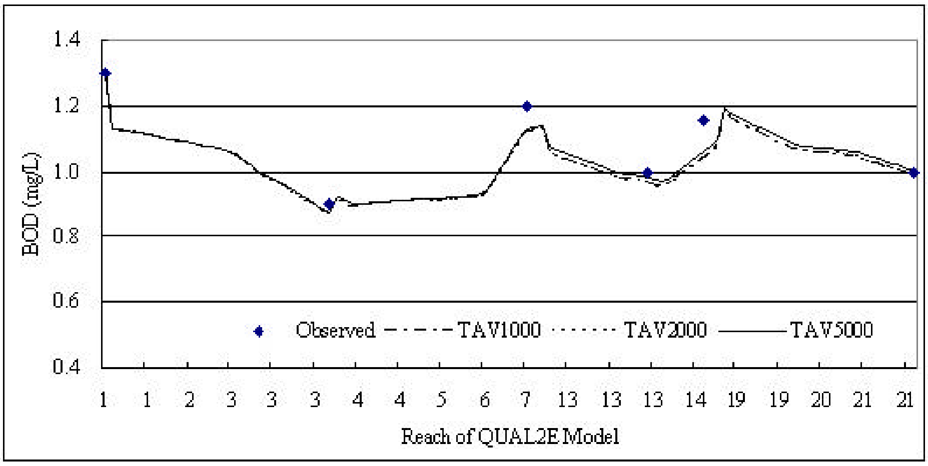


Figure 5 Results of stream water quality simulation with TAV

CONCLUSIONS

This study was undertaken to calculate the pollution load discharged at watersheds, which have no observed data, using geo-morphological properties and to improve GCI, S_f in the previous study. The S_R, as a new GCI, was suggested to consider the change of land coverage and is composed of S_f and weighted flow accumulation ratio, F_r. To figure out the S_R, hydrology tools of GIS and remote sensing techniques were used. The influence of TAV on water quality simulation was also analyzed.

As a result of this study, it was proved that there is clear reciprocal relationship between watershed-based self-purification coefficient, k and S_R. Even though, the drainage network with TAV=1000 is most consistence to real stream topology, the results of water quality simulation with TAV didn't show pretty difference. It reveals that the TAV is not a significant factor for estimation of pollution load discharged from watersheds using S_R. In other word, it means that the effort to determine how much TAV should be used is not necessary. Therefore, the methodology suggested in this study can sweeps the error caused by TAV.

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