Identification of Critical Source Areas on Water Quality in a Rural Watershed

하천수질자료를 이용한 농촌하천유역 오염원의 규명

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Abstract

농촌유역하천에서 수집된 수질측정자료를 이용하여 주요 오염원을 규명하였다. 분석에 이용된 수질항목은 BOD, COD, EC, pH, TN, TP, NO_3-N, NH_4-N, PO_4-P 등으로서 하천 본류내 구간별로 쌍대비교를 통해서 항목별 차이에 대한 유의성 검정을 하였다. 유의성 검정에 이용된 방법은 쌍대비교를 위한 비모수검정법인 Wilcoxon 순위검정법을 이용하였다. 검정결과, 유기성 오염물질의 지표로 이용되는 BOD와 COD가 상승하는 구간은 주로 생활하수가 유입되는 구간으로 나타났다. 인구밀도가 매우 높으나 생활하수가 처리장으로 배제되는 지역의 하천구간에서는 이들 농도변화는 없었다. 유역 내 축산농가가 밀집되어 있는 지역의 하천구간에서도 농도의 변화 또한 존재하지 않았다. 본 연구에서 조사된 유역에서와 같이 축산분뇨를 퇴비화 및 농지환원하는 경우에는 하천수질에 거의 영향을 미치지 않는다는 것을 알 수 있었다. 따라서 농촌지역의 하천 수질을 개선하기 위해서는 생활하수에 대한 처리가 선행되어야 한다.

I. Introduction

Environmental monitoring is one of the elemental components in environmental quality management. The monitoring for a period of time provides valuable information, such as changes in environmental quality, in planning management programs. Even after a management program is initiated, monitoring should be continued to assess its effectiveness. These hold true for water quality monitoring.

At the initial stage of planning water quality management programs, major pollution sources and the critical source areas in which the need to be identified based on the analysis of water quality data. Identification of the critical source areas requires extensive monitoring efforts with many sampling points for a long period. However, water quality is usually monitored at a limited number of sampling points, considering monitoring objectives.

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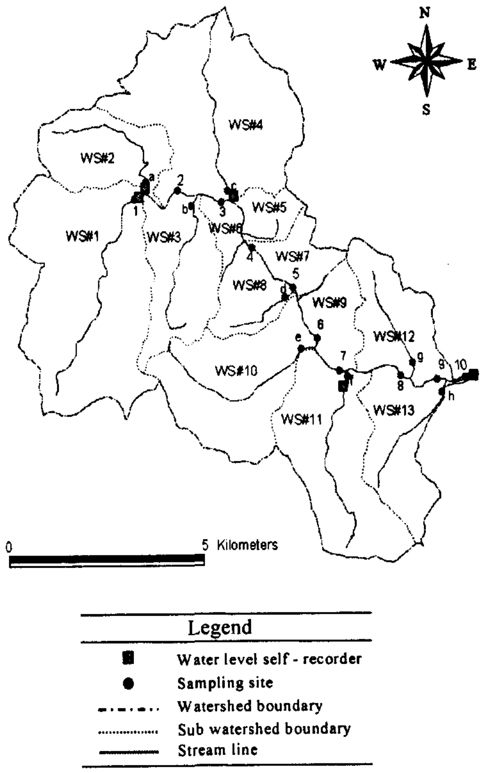
When water quality is monitored only at the outlet of a watershed, it is difficult to identify major sources and pollution processes.

Therefore, monitoring network should be prepared in order to meet the main objectives of the monitoring. When the network has been constructed appropriately considering watershed characteristics such as topography and profiles of pollution sources, critical source area and pollution processes could be possibly understood without much difficulties. It seems more reasonable to have more sampling points in understanding water quality with respect to watershed characteristics, even though number of sampling is quite limited in a certain flow condition(Grayson, et al., 1997).

Critical source areas could be identified using simulation models. Some models such as AGNPS (Young, et al., 1989) provide spatial information of critical source areas with respect to a certain water quality component. Since most of models need to be calibrated, however, water quality data should be provided for the calibration. Therefore, it is reasonable to analyze water quality data for identifying critical source areas when the data is available.



The objectives of this paper are to 1) examine the changes in water quality along the main channel of the watershed, 2) identify critical source areas for different water quality parameters. Identification of critical source areas could provide elemental information in planning appropriate management plans for the particular water quality parameters.

II. Description of watershed and water quality monitoring network

In 1996, a stream water quality monitoring program, as a part of a research regarding water quality management, had been initiated for a rural watershed located in Kyonggi province for five years(Figure 1). The drainage area of the watershed is 78.7 km^2 and its outlet is located at Jumi bridge, located in Ichon-city. The main tributary is about 17 km long with 8 tributary junctions. Most of farm lands are located near the tributaries and animal farms are scattered in the watershed area. Water samples were taken at 10 sites along the main tributary. Additional samples were also taken at the outlet of 8 sub-watersheds.

Forested area is 64% of the entire watershed, and farm land is 26%. The rest of the watershed areas include roads, residential area, and so forth. The entire population is over 10,000 and population densities of sub-watershed range from 0.45 to 16.0 persons/ha(Table 1).

Table 2 shows the number of livestock and dominant types of animal waste treatment methods. The number of livestock raised in the watershed was surveyed twice, in 1996 and 1998. Total numbers of both cattle and pigs were increased for the entire watershed in 1998 compared to those in 1996. Sub-watershed WS#4 and WS#12 showed relatively larger number of livestock compared to the rest ones.

Water samples were taken on a monthly basis at the sampling points from 1996 until August, 2000. Major water quality parameters such as EC, pH, BOD, COD, TN, TP and SS were analyzed. The samples were analyzed at the department of Environmental Science, Yonsei University. Both EC and pH were measured using portable metersat the sampling sites. BOD was measured through 5-day incubation, and COD was analyzed by $K_2Cr_2O_7$ reagent. Nitrate nitrogen was analyzed with ion chromatography and ammonium ion was determined by a phenate method. Total Kjeldahl nitrogen was analyzed by peroxide digestion method. PO_4-P was determined by ascorbic acid method and TP was by persulfate digestion method.

Ⅲ. Analysis of water quality monitoring results

1. Statistical method for data analysis

The classic test for equality of means between two groups of normally distributed observations is the Student's t-test. Nonparametric methods are used when data are not normally distributed. Water quality data is the case. Mann-Whitney test is the nonparametric alternative to the t-test(Ward et al., 1990). For the paired observations, Wilcoxson signed rank test is used, which makes use of the sign and the magnitude of the rank of the differences between pairs of measurements. It is an alternative to the paired t test. In this study, the signed rank test was employed to compare the means for each set of two adjacent sampling sites.

Table 1 Landuse and population in sub-watersheds

Watershed	Area (ha)	Population	Population -density (p/ha)	Landuse (ha)				Landuse (%)			
				Paddy	Upland	Forest	Other	Paddy	Upland	Forest	Other
WS#1	1522.99	2,117	1.39	178.57	145.54	1052.03	146.9	11.7	9.6	69.1	9.6
WS#2	507.82	315	0.62	58.02	49.45	389.37	11.0	11.4	9.7	76.7	2.2
WS#3	576.7	261	0.45	80.07	63.58	394.88	38.2	13.9	11.0	68.5	6.6
WS#4	1401.37	1,701	1.21	224.47	156.09	927.41	93.4	16.0	11.1	66.2	6.7
WS#5	155.26	529	3.41	40.96	23.16	68.79	22.4	26.4	14.9	44.3	14.4
WS#6	103.02	1,648	16.0	19.08	23.97	43.3	16.7	18.5	23.3	42.0	16.2
WS#7	216.4	126	0.58	63.11	15.76	110.04	27.5	29.2	7.3	50.9	12.7
WS#8	278.56	962	3.45	64.16	32.87	131.5	50.0	23.0	11.8	47.2	18.0
WS#9	269.63	190	0.70	64.43	17.58	148.16	39.5	23.9	6.5	54.9	14.6
WS#10	873.4	747	0.86	75.7	103.15	585.73	108.8	8.7	11.8	67.1	12.5
WS#11	972.18	840	0.86	184.8	77.39	641.15	68.8	19.0	8.0	65.9	7.1
WS#12	476.73	601	1.26	104.17	46.67	242.23	83.7	21.9	9.8	50.8	17.5
WS#13	519.96	426	0.82	118.93	51.28	289.09	60.7	22.9	9.9	55.6	11.7
Total	7874.02	10,463		1276.47	806.49	5023.68	767.4	16.2	10.2	63.8	9.7

- WS#6 - sewage collection and treatment

Table 2 Number of livestock and dominant types of animal waste treatment for each sub-watershed

Sub-watershed	Dominant treatment type (solid/liquid)	Cattle			Hog			Chicken		
		'96	'98	(%)*	'96	'98	(%)*	'96	'98	(%)*
WS#1	LA/LA	38	40	105.3	0	1,000	-	8,000	35,000	437.5
WS#2	-	40	0	-	1,550	0	-	35,000	0	-
WS#3	LA/NT	75	0	-	570	700	122.8	10,000	0	-
WS#4	LA/TT	579	715	123.5	3,167	3,879	122.5	0	0	-
WS#5	LA/LA	0	30	-	976	1,400	143.4	0	0	-
WS#6	-	6	0	-	0	0	-	0	0	-
WS#7	LA/LA	145	178	122.7	821	0	-	30,000	45,000	
WS#8	LA/LA	164	70	42.6	0	0	-	0	0	-
WS#9	-	20	0	-	55	0	-	0	0	-
WS#10	LA/LA	457	754	164.9	871	300	34.4	109,000	0	-
WS#11	LA/TT	461	612	132.7	0	0	-	30,000	0	-
WS#12	LA/TT	415	870	209.6	2,589	6,514	251.6	20,000	0	-
WS#13	LA/TT	293	846	288.6	280	1,578	563.5	115,000	47,700	41.4
Total		2693	4,115		10,879	15,371		357,000	127,700	

* : percent increase compared to value of '96
Types of treatment : LA-land application, NT-no treatment, TT-treatment

2. Stream water quality

When only descriptive statistics were used in analyzing the monitoring results, it seems difficult to confirm the differences among the reaches. Figure 2 and Table 3 show the descriptive statistics and Box-Whisker plots for some parameters. It is hard to identify the differences between adjacent sampling sites based on mean or median values.

Average values of water quality parameters are plotted along the stream(Figure 3). Even though there seems to exist some distinct changes in the average values in the graphs, the results of signed rank test indicate that only a few number of reaches have differences. In spite of fluctuation of mean pH along the tributary, increases in the average pH exist only at the reaches S1-S2 and S9-S10 at the 95% significance level. The result of signed rank test for EC indicates that the mean values at S3 increases while those at S7 and S10 decrease. There are no differences for most of reaches except for the reach S4-S5. Meanwhile, pH, EC, and SS shows slightly increasing trends towards downstream.

The mean value of BOD increases at the reach of S4-S5, but decreases at S6-S7. Unlike the above three parameters, BOD does not show any trends along the stream. In the reach, S4-S5, there is an increase in the mean COD with the significance.

There is no significant difference in the mean values of NH_4-N concentrations in any reaches. Meanwhile, there exist significant differences in the mean nitrate nitrogen for three reaches. As the sum of NO_3-N, NH_4-N, and total Kjeldahl nitrogen, TN concentrations were decreased in the subsequent reaches, S1-S2 and S2-S3. With some fluctuations, PO_4-P differences are existed at S2, S3, and S7. Most of reaches do not show sig-

Table 3 Descriptive statistics of the major water quality parameters

Sampling sites	BOD		TN		TP	
	Mean	Median	Mean	Median	Mean	Median
S1	3.05	2.70	3.404	2.270	0.132	0.081
S2	2.78	2.40	2.844	2.040	0.104	0.065
S3	3.10	3.02	2.818	2.080	0.107	0.073
S4	2.90	2.60	3.470	2.471	0.123	0.079
S5	3.93	3.30	3.177	2.300	0.102	0.070
S6	3.43	3.30	3.175	2.015	0.119	0.060
S7	2.95	2.90	3.063	2.280	0.099	0.060
S8	3.57	3.05	3.011	2.100	0.120	0.062
S9	3.20	3.04	3.259	2.356	0.122	0.066
S10	3.12	2.92	2.899	2.031	0.132	0.064

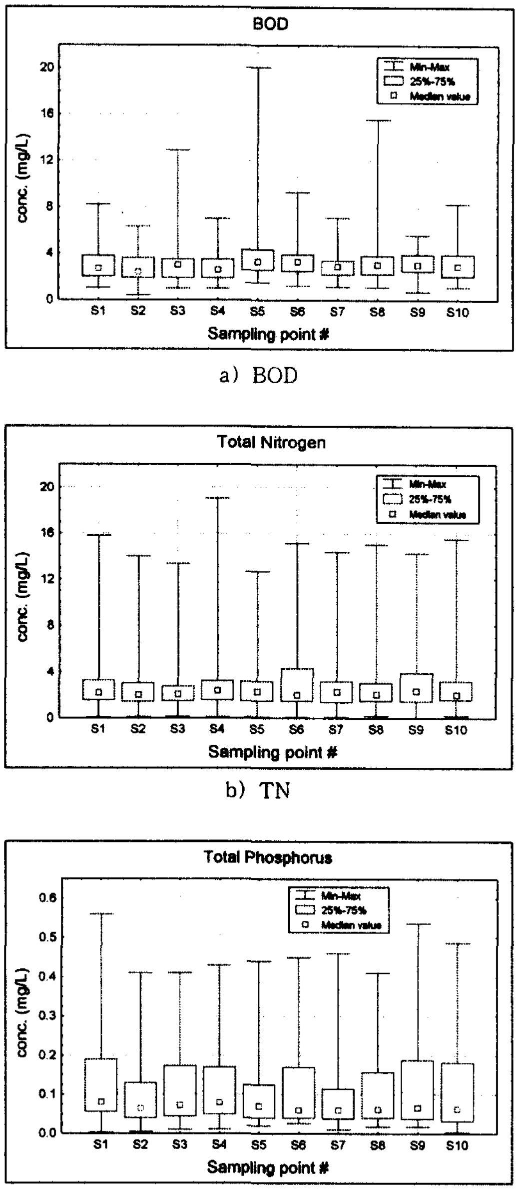
Table 4 Signed-rank test results for the mean value of water quality parameters along the reaches

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
pH		↑								↑
EC			↑				↓			↓
SS					↑					
BOD					↑		↓			
COD					↑					
NO_3-N		↓	↑		↓					
NH_4-N										
TN		↓	↓							
PO_4-P		↓	↑				↓			
TP		↓								

↓ : decrease in the reach at 95% significance level
↑ : increase in the reach at 95% significance level

nificant differences in TP except for the reach S1-S2.

As summarized in Table 4, major nutrient parameters are decreased in the reach S1-S2, while oxygen demanding parameters such as BOD and COD increases at the sampling site S5. Three ion related parameters including EC, NO_3-N, and PO_4-P increase at S3. As in the reach S1-S2, there exists some improvements in EC and BOD in the reach of S6-S7.



a) BOD

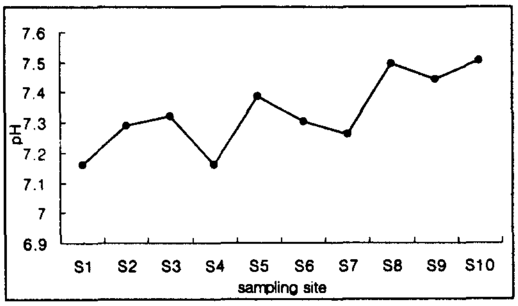
b) TN

c) TP

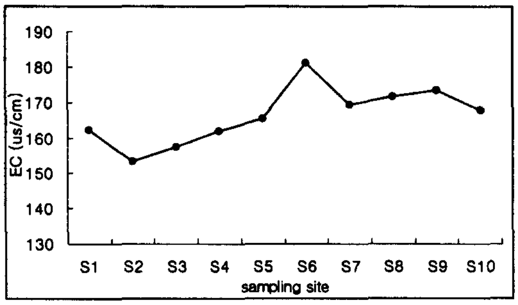
Fig. 2 Box-Whisker plots of BOD, TN, and TP for the sampling sites

Ⅳ. Identification of critical source areas

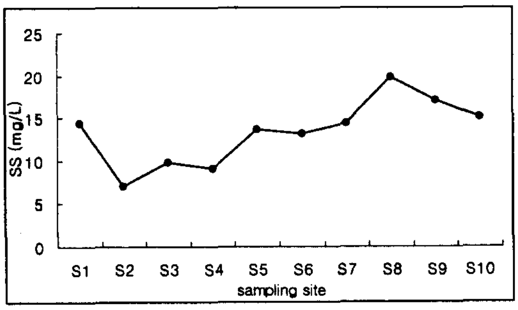
Based on the analyses of water quality parameters, two reaches of S2-S3 and S6-S7 could be



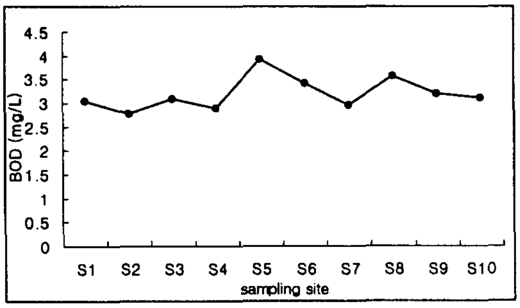
a) pH



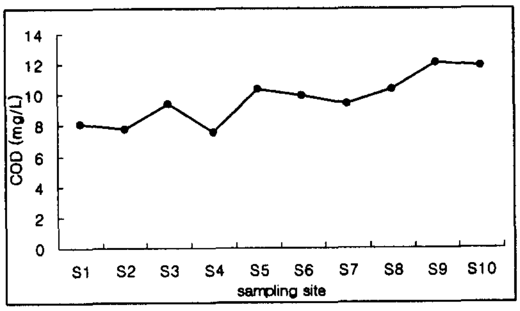
b) EC



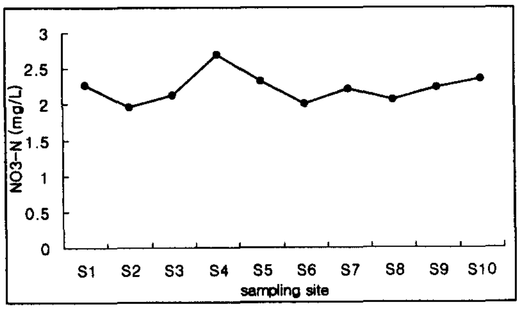
c) SS



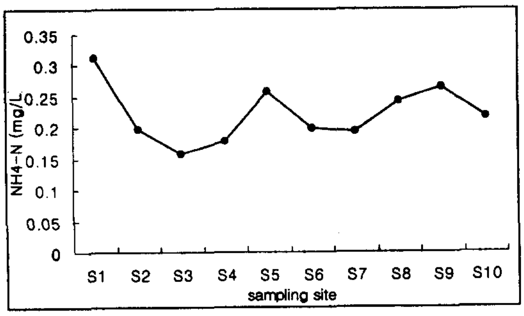
d) BOD



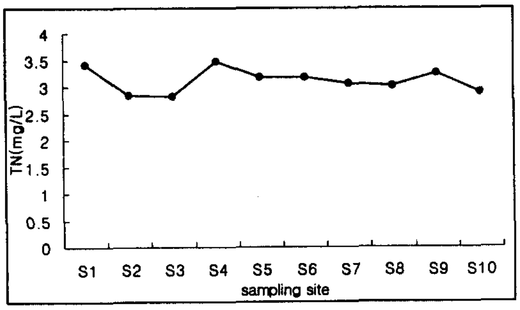
e) COD



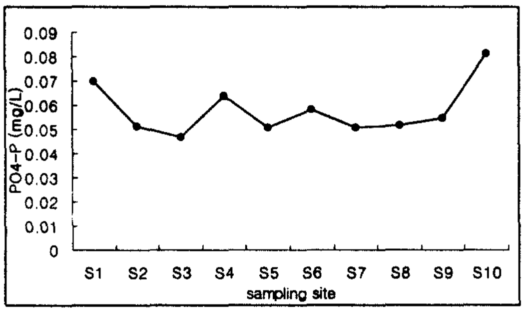
f) NO_3-N



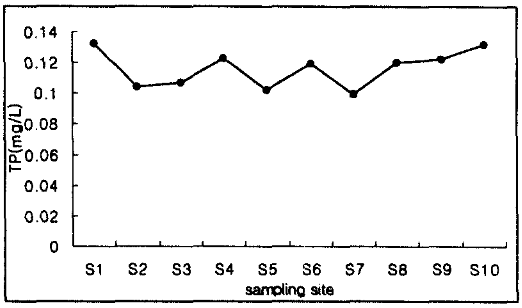
g) NH_4-N



h) TN



i) PO_4-P



j) TP

Fig. 3 Changes in the average water quality parameters along the stream

identified as the paths influenced by critical source areas. Considering that major water quality parameters are improved along the reach S1-S2, sub-watershed for S1 might be also taken into the critical source area. The reach S6-S7 also shows improvements in some parameters, indicating that no substantial contribution of pollution is made. Therefore, drainage basins or adjacent areas of these reaches may be considered as relatively 'sound' or less polluting areas.

Sub-watershed, WS#3 is the critical source area for the reach S2-S3. As described above, dissolved solids measured by EC, NO_3-N, and PO_4-P are increased. EC is influenced by geology or rock type of drainge basin, which is considered as a natural contribution(Grayson, et al., 1997). When EC increased, it is presumed that sources of pollutants includes effluents from treatment plants, urban runoff, and agricultural runoff. Evaporation also contribute the increase of EC, particularly in lakes. However, the population of WS#3 is 261 and population density is 0.45 persons/ha, respectively, which is the smaller than that of any other sub-watersheds. In addition, the number of livestock is relatively smaller than other areas. Landuse is similar to other sub-watersheds. These watershed characteristics indicates that there is no particular sources of the EC and nutrient components. In fact, the mean value of EC at the outlet of WS#3 is 152.8 ㎲/cm, which is lower than that of S3. Therefore, further field investigation would be required for identifying the sources.

Increases in SS, BOD, and COD indicate that pollutants related to human activities are contributed from source areas of the reach S4-S5. The source area includes most part of two watersheds, WS#7 and WS#8. Sub-watershed WS#8 has a relatively higher population density without sewerage. Meanwhile, the population density of WS#7 is low and the size of livestock is negligible. Therefore, appropriate control measures such as sewerage works should be taken for the residential area in WS#8

Another possible critical source area is WS#1. Except for pH, most of water quality parameters including nutrients decrease along this reach. Pollution sources are also not less than other regions. Population of 2,117 without sewerage discharges household wastewater into the stream. Importance of sewerage may be explained by no differences in all the water quality parameters in reach S3-S4, where municipal wastewater is collected and transported to treatment plants. Table 1 shows that drainage basins of the reach S3-S4, WS#5 and WS#6 are highly urbanized and WS#6 has the highest population density.

EC and BOD concentrations at S7 are lower than those at S6 with the significance. Drainage basins for this reach includes WS#10 and WS#11, both of which have lower population densities. This also suggests that household sewage substantially influence the steam water quality under the current watershed condition.

There are no differences in most of water quality parameters in reaches S9-S10, for which drainage basins have the largest number of livestock. EC at S10 is rather decreased compared to that of S9. It clearly suggests that animal farms or size of livestock may not be the major pollution source under the current condition of animal waste treatment practices in streams of this rural watershed.

V. Summary and conclusions

Water quality monitoring is one of the crucial components in planning and managing water quality. Based on the analysis of stream water quality monitoring results, critical source areas were identified and discussed with respect to the source area characteristics such as population density, livestock, etc. In spite of apparent differences in water quality parameters, signed-rank test confirmed that differences between adjacent sampling sites existed only in a limited number of reaches.

Three sub-watersheds, WS#1, WS#3, and WS#8 were presumed to be critical source areas. In case of WS#3 which has no notable pollution sources, it is not easy to identify the major sources and hard to explain the reason for the increases in EC. It would need further field investigations for clear identification. Meanwhile, the increases in SS, BOD, and COD were easily explained by domestic sewage since both WS#1 and WS#8 have higher population density than other sub-watersheds. Importance of sewerage may be explained by no differences in all the water quality parameters in reach S3-S4, where municipal wastewater is collected and transported to treatment plants. Even though drainage basins of the reach S3-S4, WS#5 and WS#6 are highly urbanized and WS#6 has the highest population density, the water quality parameters were not different between S3 and S4.

There are no differences in most of water quality parameters in reaches S9-S10, for which drainage basins have the largest number livestock. EC at S10 is rather decreased compared to that of S9. It suggests that animal farms or size of livestock may not be the major pollution source in rural watersheds under the present conditions.

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