Study of diffuse source pollution management for land use and drainage system planning

K. Yamada*, T. Funaki**, S. Honda** and M. Sugihara**

*Professor of the Department of Environmental Systems Engineering, Ritsumeikan University,
1-1-1 Noji-Higashi, Kusatsu City, Shiga Pref. 525-8577, Japan
**Graduate Student at the Department of Environmental Systems Engineering, Ritsumeikan University,
1-1-1 Noji-Higashi, Kusatsu City, Shiga Pref. 525-8577, Japan

Abstract
This study aims to clarify the mass balance of pollutants during both dry periods and storm events and to discuss the effects of some strategies such as pollutant removal, land use planning and new drainage systems by simulation. Three subjects are discussed in this paper. First, the amount of pollutants entering Lake Biwa from an urban area have been roughly estimated by using data collected by the local government. Second, many additional samples were collected from road surfaces, house roofs and parking lots to consider the role of land use in pollutant runoff. Third, some ongoing BMP projects in an urban area are introduced. As a result, some ideas on how to solve the problem of diffuse pollution in urban areas have been obtained.

Keywords
Diffuse source pollution; drainage system; roof and property drainage; storm event; urban BMP

Introduction
The control of diffuse source pollution is becoming an important part of watershed management in urban areas. There is a lack of research results about the phenomenon, modeling and strategies to control diffuse source pollution from its origin to the receiving water. Most of the pollutants deposited on impervious surfaces in urban areas are washed off during storm events. This study aims to clarify the mass balance of these pollutants during both dry periods and storm events and to discuss the effects of some strategies, such as pollutant removal, land use planning and new drainage systems, by simulation after a rough estimation of the amount of pollutants entering Lake Biwa from urban areas. In addition, some ongoing projects of urban BMP are introduced.

A mass balance model for pollutants deposited on an impervious surface in urban areas and the effect of some strategies to reduce pollutants has already been presented at the last conference. In that research, many samples were collected from road surfaces, house roofs and parking lots in order to examine the role of land use in pollutant runoff. Indices analyzed are as follows: total solids, grain size, organic matter in ignition loss, COD, TN, TP and heavy metals. Each model has been developed for accumulation during dry weather and for washout during storm events by using these data. Calibration for parameter determination and verification was carried out. The results were as follows:

1. Enough data to roughly estimate mass balance was collected by field investigation at every stage.
2. Some models to represent the dynamics of pollutants deposited on surface were developed and each parameter was determined by the data.
3. A rough estimation of mass balance was realized.
4. Pollutant in the range of 20–50% is removed by sweeping once a week.

Here, a more detailed survey is presented to clarify the mass balance for policies.
Diffuse source pollution problem in Lake Biwa

Lake Biwa is the most important lake for drinking water in Japan. About 14 million people, most living out of the watershed, use this water. Most of the intake points are located in the downstream section of the Yodo River that receives water from Lake Biwa. The trend and the target of water quality in Lake Biwa are shown in Figure 1. Many strategies including sewerage expansion have been employed. Yet, while the water quality in most of the rivers has improved, the water quality in the lake has not yet improved. Ambient TP concentrations have been slightly lowered, but TN is maintaining the same level. Furthermore, COD is gradually getting worse. The short-term targets for in-lake concentrations of the various parameters have been eased through time. As a result, the target is becoming farther from the ambient standard.

There are several proposed reasons why the quality has not yet been improved, but none are accepted as conclusive. In this research, some hypotheses were checked. First, land use in the watershed was analyzed. As shown in Figure 2, more than half of the land is covered with forest, but 10–36% of land is covered with “Land” including housing, roads and golf courses. Moreover “Land” area is increasing gradually. Second, the change of population with sewerage service was checked. As shown in Figure 3, the unsewered rate decreased from 80% to 54%, while during the past decade the population increased about 20%. Nowadays the sewered rate is more than 50%. However there are some problems in semi-sewered facilities because of insufficient pollutant removal.

The pollutant load entering the lake from inland was estimated for 1995 and forecasted for 2010. The land use is classified by five items, such as urban, industrial, agriculture, land and natural. The estimation and forecast were calculated by supposing frame-like population and products, unit pollutant load at the origin and removal rate at treatment plants. The results, which do not include direct deposition to the lake, are shown in Figure 4. Because of the expansion of the sewerage system and other policies, the pollutant load from urban and industrial area as a point source is decreasing. However, the pollutant load from the other land uses is increasing. In particular, the load from “land” will become a large part of the total load and will be almost equal to the pollutant from agriculture. Some new policies for pollution from “land” are needed. There is some serious problem concerned with the above estimation. The amount of unit pollutant load for non-point sources has been determined with very few data observed from the origin sources. To clarify the mechanism of non-point

![Figure 1: Trend of water quantity in Lake Biwa: (a) 75% of COD; (b) TN; (c) average of COD; and (d) TP](https://iwaponline.com/wst/article-pdf/44/7/203/430649/203.pdf)
source load generation and to determine the amount of pollutant, a detail survey is necessary.

**Mass balance on land use**

In addition to the last paper, some supplement field surveys were carried out by the authors in the same areas. The pollutants provided from the air are each composed of fallout during dry weather period and rainwater. Figure 5 shows the relationship between the amount of fallout and dry weather period according to three typical rainfall series.

The amount of deposition depends on land use. Figure 6 shows the existing deposition on impervious land. They are distributed with wide range, and the deposition on trunk roads (highways) and roads in the industrial area are significantly large. The two equations, (1 and 2), for the mass balance on the road were proposed at the last conference. Equation (1) shows some activities during a storm event. The mass balance on road was simulated annually and the results are shown in Figure 7. In this figure, the origin of fallout and human activity are compared and the amount of accumulated load during dry days is compared with the amount of load moving out of the road.

Dry weather period:

\[
\frac{S}{Su} = 1 - \exp(-KtT)
\]

where \(Su\) is the ultimate pollutant load (mg/m\(^2\)), \(Kt\) is the coefficient of accumulating rate (day), \(T\) is the elapsed time (days).

**Figure 2** Land use of watershed (1995)

**Figure 3** Diffusion of sewer system (in population base)

**Figure 4** Pollutant load entering Lake Biwa
Storm event:

\[
\frac{L}{S} = 1 - \exp\left(-KrR \right)
\]

where \( L \) is the runoff pollutant load (g/m\(^2\)), \( Kr \) is the coefficient of runoff rate (d/mm), and \( R \) is the precipitation (mm/event).

Finally, the effect of road sweeping was quantified in the pollutant load base. In general, sweeping is carried out by hand in residential areas and by sweeping cars on trunk roads and highways. The effect is shown in Figure 8. If the road sweeping is carried out once a week on highways and every three days in residential areas, 50–60% of load in total solid, 10–20% of load in TN and 30–35% of load in TP are removed.

BMP projects for diffuse pollution in urban area

Most diffuse pollution problems in urban areas are caused by storm events. The magnitude of each diffuse pollution source depends on land use as shown above. In particular, runoff water from highly developed residential areas and highways is highly polluted. In order to deal with this problem, three projects are on-going in Kusatsu City. There are now 13 experimental fields and facilities in the Experimental Center for River Water Quality Preservation, which were constructed by the government and managed by a water resources agency located in Kusatsu City. Two projects are now on-going under the cooperation of Ritsumeikan University. A study on reed growth under conditions of changing water level and wave action is being carried out in the Lakeshore Experimental Field. The results of a two year study have been already reported. Another project, a study on removal of COD substances discharged from road surfaces, is being carried out in the Special Field for Soil Infiltration on a pilot scale. New experiments for some additional pollutant indices are planned for next year. In addition, a project on the removal of pollutants discharged from highly developed urban areas because of storm events is now being planning and designed. This project is also carried out with the cooperation of Ritsumeikan University.
Several facilities to remove pollutants, such as a screen, grit chamber, sedimentation tank, retention tank, contact oxidation, aquatic plants, oxidation pond, filter and plants and naturalized channel are being employed and installed. This is a full-scale project for a 120 ha area and the first trial for non-point pollutant removal from an urban area in Japan.

Figure 7 Mass balance on road for: (a) TR; (b) TN; and (c) TP
Concerning water conservation in Lake Biwa, three subjects were discussed and summarized as follows:

1. It has been clarified that “land” is one of the key words for diffuse pollution in urban areas in the future.
2. A mass balance model presented at the last conference has been enhanced.
3. Three on-going projects on diffuse pollution were introduced.

**References**


**Figure 8** Effect of road sweeping

**Conclusion**

Concerning water conservation in Lake Biwa, three subjects were discussed and summarized as follows:

1. It has been clarified that “land” is one of the key words for diffuse pollution in urban areas in the future.
2. A mass balance model presented at the last conference has been enhanced.
3. Three on-going projects on diffuse pollution were introduced.