論文の内容の要旨

論文題目　Characterization and Modeling of Wet Weather Pollution Dynamics in Combined Sewer considering In-Sewer Deposits and Dry Weather Flow
（管路内堆積物及び晴天時下水を考慮した
雨天時合流式下水道汚濁流出プロセスの特性評価とモデル化）

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（本文）Lately, various problems originated from combined sewer overflows (CSOs) during wet weather events have been becoming social issues. CSOs occur by wet weather events in the main, when wet weather flows (WWFs) exceed the capacity of a combined sewer system (CSS) or a wastewater treatment plant. When CSOs occur, contaminated stormwater flows into receiving waters directly without any appropriate treatment in general, and it has the high potential to affect adversely those aquatic environments. Urban catchments are particularly problematic due to their landuse property with high rate of runoff containing a great deal of surface pollutant deposits accumulated in antecedent dry weather period (ADWP).

Usually WWFs of CSS mainly consist of surface pollutants, domestic wastewater and in-sewer deposits. Moreover, the generation and transport of pollutants in CSS during wet weather events are very complex because of various media, space and time scales. Therefore, in order to understand the behavior of CSOs, it is one of the best approaches to observe the runoff behavior of these constituents separately. In particular, the drainage characteristics of dry weather flow (DWF), the behavior of particulate pollutants in CSS and in-sewer deposits should be investigated thoroughly.

The concentrations and loads of pollutants in WWFs depend on several factors such as rainfall conditions, washoff of surface pollutants, runoff of in-sewer deposits and diurnal fluctuation patterns of DWF. It is considered that, whilst the surface pollutants and in-sewer deposits, whose total loads change due to ADWP, affect the first flush stage mainly, discharge loads originating from DWF influence the whole of WWF duration with different time-series variation patterns for every pollutant.

Numbers of researches on the behavior and risks of pathogenic microorganisms in CSOs including bacteria and viruses as well as the impact by overall pollutants and nutrients have been reported. A large number of research results have pointed out that in-sewer deposits in CSS are closely related with the behavior of pathogenic microorganisms. Pathogenic microorganisms with considerable concentrations are transported in the adhering form to solid materials, deposited and concentrated in the sediment of CSS in dry weather, and during wet weather events such sediment is flowed out rapidly. In addition, it has been also reported that there is fair possibility of repopulation within the deposits in CSS especially in the case of bacterial indicators and coliphages.

In order to assess the impacts of CSOs, to protect the public health and to enhance the environmental quality of receiving waters, it is crucial to investigate the runoff characteristics of WWFs and to develop a detailed model for the simulation of the runoff dynamics of each pollutant and microorganism in WWFs. Therefore, the specific objectives of this study were (1) to monitor the diurnal fluctuation patterns of each pollutant in DWF of CSS and to evaluate their characteristics, (2) to validate the drainage properties of microorganisms in DWF, (3) to grasp the behavior of particulate materials in CSS and the relationship between particulate materials and microorganisms, (4) to investigate the washoff behavior of in-sewer deposits and to elucidate the role of in-sewer deposits for the runoff of pollutants and microorganisms in WWFs, (5) to develop a model for the simulation of the runoff dynamics of WWFs based on the measured data of the study area.

To study the diurnal fluctuation patterns of each pollutant and microorganism in DWF, 24 hour monitoring was conducted two times at a combined sewer catchment in dry weather. Multivariate analyses including correlation analysis, cluster analysis and factor analysis were carried out using the 24 hour time-series monitoring data. Moreover, artificial field flushing experiments which could separate the washoff of in-sewer deposits from surface effluents in WWFs were carried out in order to investigate the washoff behavior of in-sewer deposits in CSS. The time-series washoff characteristics of each pollutant, bacterial indicator and enteric virus were investigated. To grasp the details of the washoff behavior of each pollutant and microorganism, time-series analysis on the runoff concentration and load curves was conducted, and all kinds of indices on the first foul flush were utilized. Furthermore, in order to simulate the dynamics of pollutants and microorganisms in WWFs, a sewer runoff model was developed based on on-site monitoring data. The models were especially aimed to describe the runoff behavior of in-sewer deposits and the diurnal fluctuation of DWF in CSS. Lastly, the runoff behavior of each pollutant and microorganism was simulated for various rainfall conditions using the model developed in the study. The behavior and contributions of each constituent such as surface pollutants, in-sewer deposits and DWF were simulated respectively.

The results of 24 hour monitoring of the time-series concentration and load variations of DWF at a small subcatchment in CSS were discussed in Chapter 4. The ranges of diurnal load variations of each water quality parameter reached ten to several tens times within a day. It also became obvious that the 24 hour concentration and load fluctuation characteristics of each parameter differ from each other. The patterns of concentrations and loads of SS, VSS and COD showed their peaks at late night and in the morning; and TN, DTN and NH_3-N in the early afternoon and in the morning. Bacterial indicators were discharged rather uniformly from daytime to midnight representing the highest peaks in the morning, after continuous decrease till early morning. On the other hand, coliphages and enteric viruses revealed far intense variations of concentration and load.

In Chapter 5, multivariate analysis was performed using the 24 hour load variation data in order to characterize the diurnal fluctuations of each pollutant and microorganism in DWF. All of the water quality parameters were divided into three groups according to their origins and existence forms: The nitrogen parameters (TN, DTN and NH_3-N), conductivity, phosphate and bacterial indicators belonged to group 1, which was mainly considered to originate from the toilet wastewater (urine, feces); washing wastewater-related materials such as LAS and fluorescent agents (DSBP, DAS1) belonged to group 2; and organic solid materials such as SS, COD and turbidity categorized into group 3. Therefore, in order to monitor the behavior of WWFs appropriately, it should be taken care enough that the discharge patterns of each water quality parameter, for instance bacterial indicators, may differ from those of overall water quality parameters greatly.

The washoff characteristics of in-sewer deposits in CSS were investigated in Chapter 6. The washoff patterns of each parameter resulting from in-sewer deposits by an artificial field flushing were to be categorized into typical 3 groups; strong first foul flush group including SS, VSS and COD. This group was estimated to be caused mainly by the erosion of upper deposit layer containing organic solids abundantly; partial first foul flush group including bacterial indicators. This group was considered to be influenced by a few factors, i.e. the earlier first foul flush-like washoff, the latter “delayed” washoff by additional erosion of the residual deposits and the inflow of DWF; and no first foul flush group including enteric viruses and DOC. The order of these groups signifies the strength of the first foul flush and the runoff priority as well. In view of practical management of CSOs, much portion of SS, VSS and COD runoff loads can be controlled by relatively small interception of WWFs. However, this countermeasure appropriate for strong first foul flush group would not work well for bacterial indicators and enteric viruses. If our concerns are laid on the management of pathogenic microorganisms, new strategy should be explored.

In Chapter 7, a sewer runoff model composing a distributed runoff model was developed. The values of key parameters, i.e. potency factors of each pollutant in DWF, attached ratios of microorganisms to suspended substances, particle size distribution, representative size and specific gravity of particles, were experimentally determined. Instead of present simulation using one set of representative size and specific gravity, it was confirmed that the simulation considering two particle groups with different representative sizes and specific gravities was reasonable. Furthermore, while discussing the expected problems by direct input of 24 hour profiles surveyed at a specific point, new methodology which estimates the source profiles using the data measured downstream was established. To understand the transformation characteristics of flow rate and each water quality parameter in the transport process in CSS, runoff factors composed by time delay factor, removal efficiency factor and flattening factor were proposed and applied to estimate the source profiles. As a result, the simulated profiles using the estimated source profiles represented good agreement with the measured profiles. In particular, the accordance of 24 hour SS profile was greatly improved.

In Chapter 8, the runoff dynamics of each pollutant and microorganism were simulated for various rainfall conditions using a distributed runoff model, InfoWorks CS ver. 7.5. The origins of each constituent in WWFs were classified into surface deposits, coarse and fine particles in DWF and dissolved substance in DWF, and simulated individually. The runoff dynamics of each water quality parameter in WWFs were different from each other according to their main origins. SS, COD and TOC represented strong first foul flush resulting from the erosion of coarse particles in in-sewer deposits. TN and bacterial indicators showed partial first foul flush. Coliphages revealed no first foul flush. From the viewpoint of runoff load, the earlier first foul flush originating from in-sewer deposits and the latter prominent inflow of surface pollutants were to be divided distinctively; the latter was observed in SS, TOC and TN. The loads of bacterial indicators and coliphages from surface deposits were negligible. After the first flush stage, the runoff concentrations and loads of WWFs were directly governed by the time-series variation of DWF. Hence, in order to manage CSO-related measures, it would be significant to consider the time-series variation patterns of DWF as well as the first (foul) flush behavior of each water quality parameter.

Therefore, it could be concluded that this study provides new information and the simulation tool for better understanding of the runoff dynamics of each pollutant and pathogenic microorganism in WWFs considering in-sewer deposits and DWF, which will be truly useful to apprehend the runoff behavior of CSOs and to explore the measures for CSO issues.