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Web Based Environmental Management System using Predictive Spatial Information Models

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예측적 공간정보 모형을 이용한 Web 기반의 환경관리시스템의 개발 및 적용

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Abstract

This study is aimed at the development of comprehensive environmental management system, which can be operated on the basis of world wide web, as a topic of G7 project. Even though there should be lots of works remaining to achieve this goal, preliminary products can be summarized as follows : 1) integrated environmental information management system, 2) web based control engine, 3) surface water environment management system, 4) subsurface water environment management system, 5) sewer and waterworks management system. The core methodology of the engine is the generalized multidimensional finite element matrices to depict the terms in the analysis of various partial differential equations. Spatial information management system (ArcView) and Visual Basic were extensively employed to construct GUI oriented web based engine. The developed systems were composed of very intense computer codes due to the necessity of combinatory management of environmental problems. The web based engine could be served as a decision tool for the integrated management of environmental projects in Korea.

Key Words : comprehensive environmental control, web based engine, FEM, SIMS

요 약 문

본 연구는 G7 과제의 일환으로서, Internet상에서 운영될 수 있는 광역적 환경 관리

시스템의 개발에 목표를 두었다. 이러한 목적을 달성하기 위해서는 아직 더 많은 연구가 수행되어야 하지만, 예비적인 개발 성과를 다음과 같이 요약할 수 있다 : 1) 통합적 환경 정보 관리 시스템, 2) web 기반의 제어 엔진, 3) 지표수환경 관리 시스템, 4) 지하수환경 관리 시스템, 5) 하수도 및 시설 관리 시스템. 본 엔진의 핵심 방법론은 다양한 편미분 방정식의 해석에 있어서 각 미분항을 서술하는 범용적 다차원 유한요소 행렬이다. GUI 지향적인 web 기반의 시스템을 구축하기 위해 공간 정보 관리 시스템(ArcView) 및 Visual Basic이 폭넓게 사용되었다. 개발된 시스템들은 환경 문제의 복합적인 관리의 필요성으로 인해 매우 집약적인 프로그램으로 구성되었다. web 기반의 엔진은 환경관련 사업의 통합적인 관리를 위한 정책 결정 도구로 제공될 수 있을 것이다.

주제어 : 종합적 환경 제어, web 기반 엔진, 유한요소법, 공간정보관리시스템

I. Introduction

There are many environmental studies going on in the field of air, water, waste management system by several research groups in Korea. All these systems depend heavily upon the combinatory practices of computational models, spatial information management system, tele-monitoring system (including remote sensing), and automatic realtime control techniques.[3,4,6,10,11,12] Because of the recent abnormal meteorological and hydrological change in Korea, the necessity of combinatory management has increased quite much, so that the above mentioned three sectors should be managed in integrated fashion.[11] This fact is pretty much important in managing landfill site, incinerator, acid rain, and storm water problems. Environmental Ministry in Korea would like to have some system operating on the basis of distributed computer network for a wide application in overall Korean region. This study has been initiated in aiming at very intense computer system for this governmental goal. This means that all the relevant environmental facilities and problems should be analyzed and operated using graphical tools in a comprehensive computer system. Using the concept of digital map, remote sensed pictures, and animation techniques, relevant data can be analyzed in a user friendly system. Even though there should be lots of works remaining to accomplish this project, preliminary products are prepared in the following sections.

II. Distributed Information Management System

In Korea, there are many management offices located in vast area due to the widely spread characteristics of pollution source and watershed.[10] So, it is very imperative to share centralized information management system using computer network. In 1998, the authors started to develop similar system to provide easy access using Internet.[11] This system will be offered based on the users needs. The system will be improved using centralized database management system in near future. Some of the already developed system,

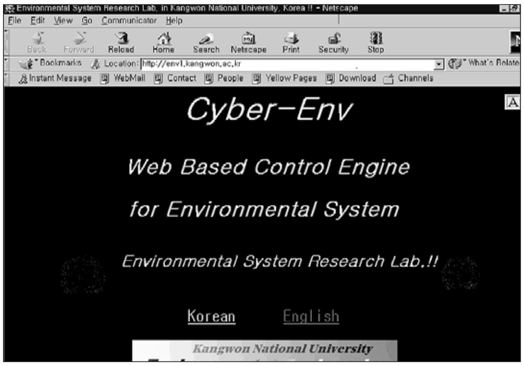

Fig. 1. Web based control engine of environmental system

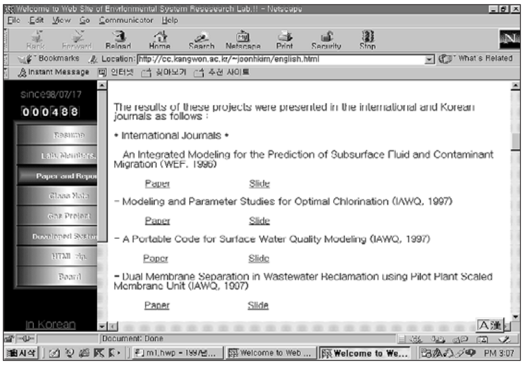

Fig. 2. Details of developed control engine (models, papers, projects, research groups)

published reports and papers are provided in this system (Fig.1-2).

III. Surface Water Environment Management System

1. Multidimensional Hydraulic Model

Multidimensional hydraulic model is now under construction for the simulation of surface water flow in lakes and estuaries based upon following works. Two-dimensional tidal flow model was developed using harmonic finite element method. Triangular or bilinear element can be used together to depict complicate geomorphology. Pre- and post-processing modules were prepared to enable overall modeling process. The model was verified and compared with analytical solution, and used in many projects, such as sea dike construction, the environmental impact assessment of cooling water discharged from power plant, and the dredging of sediment in an estuary lake (Fig.3-4).[3, 8]

2. Multidimensional Surface Water Quality Management System

An integrated system was developed to analyze present and future environmental quality status of surface water using ArcView and MFEMWASP (Multidimensional Finite

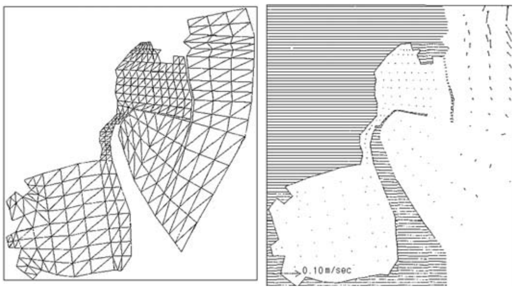

Fig. 3. Tidal flow modeling of Lake Chungcho located adjacent east sea

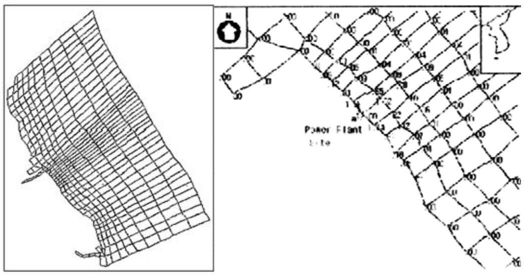

Fig. 4. Prediction of thermal impact of cooling water from power plant

Element Model using WASP Kinetics).[10] All the input data and computational results can be analyzed and graphically displayed on the basis of ArcView. MFEMWASP and ArcView were integrated using the script of Avenue. Modeling menus were inserted in the GUI of ArcView. For the application examples of this system, the water quality of Lake Paldang and Youngwol was simulated. The developed system can be applied to the water quality management of drinking water resources to set up the regulatory acts and project plan of governmental policy (Fig.5-6).

IV. Subsurface Environment Management System

1. Integrated Groundwater Management System

This study was performed to develop an information processing system for the sound conservation of groundwater resources.[11] The system contains the geographic information system (ArcView), the analytical solution, and the numerical model of groundwater flow (MODFLOW) and contamination (MOC3D). The analytical solution was compared with the measured data in several mineral water companies to verify the validity of the analytical solution. Correlation between the pumping rate and the drawdown in observation wells was ascertained based upon regression analysis. The measured drawdown was in accordance with the analytical solution. Finally, analytical solution, numerical model of groundwater flow and GIS were integrated for the construction of an integrated management system of pure groundwater resources. The impact of pumping over the overall catchment basin was modeled using the developed system for the decision of management criteria(Fig.7-8).

2. Multicomponent Multiphase System for Soil and Groundwater Contamination

An integrated model is presented to describe

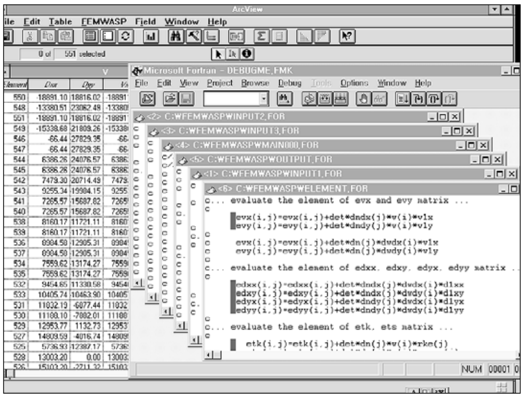

Fig. 5. Integration of ArcView and MFEMWASP using Avenue

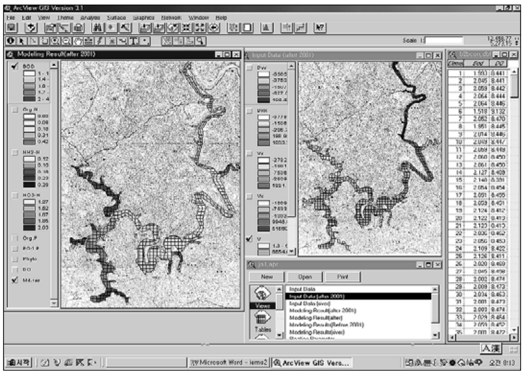

Fig. 6. Prediction of eutrophication of Lake Youngwol using MFEMWASP

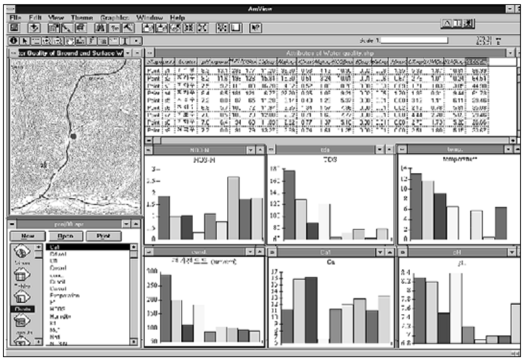

Fig. 7. Feature and attribute data of surface and subsurface environment

subsurface flow and mass transport, using a composite multiphase approach(Fig. 9).[4,5] Compact and systematic notations of relevant variables and equations are introduced to simulate the complex migration and transformation processes in the variable spatial dimensions. The resulting nonlinear system is solved by a multidimensional finite element code. To avoid the numerical oscillations of the nonlinear problems in the case of convection dominant transport, the techniques of upstream weighting, mass lumping, and elementary-wise parameter evaluation are applied. Traditional governing equations for groundwater flow and pollutant migration

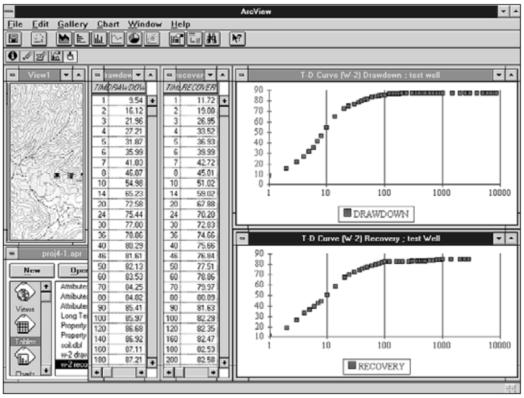

Fig. 8. Variation of groundwater depth resulted from pumping

was obtained from the integrated transport equation by parameter substitution of saturation, mass fraction, and fluid conductivity. To demonstrate the robustness of this approach, several hypothetical problems, from traditional groundwater flow to composite multiphase flow, are simulated through parameter substitution. The cases presented are unsaturated flow through an embankment, one-, two-, three-dimensional multiphase flow, and three-dimensional composite multiphase TCE migration(Fig.10).[6] Parameter dependency and sensitivity of the model are analyzed with respect to the

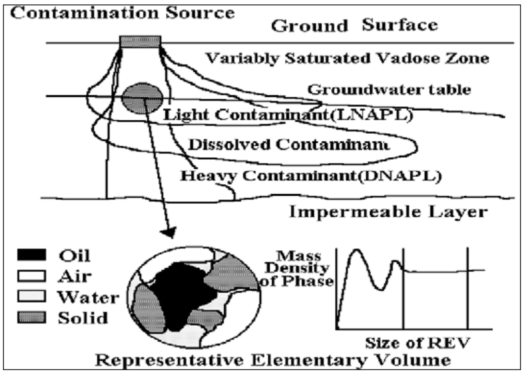

Fig. 9. System of composite multiphase flow

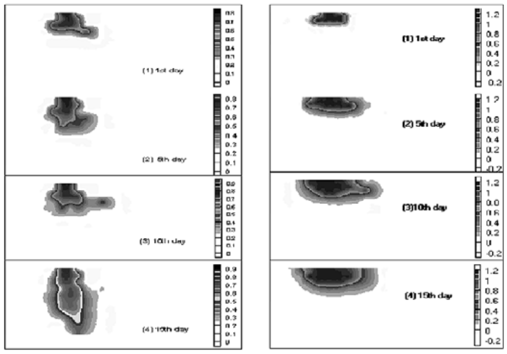

Fig. 10. Simulation of TCE migration

boundary conditions, the fluid conductivity, and the magnitude of contaminant source.

The model is highly structured to facilitate the inclusion of the additional constitutive and reaction equations. Extensive theoretical parameter studies are implemented with respect to transport (capillary pressure, dispersion), mass transfer (dissolution, volatilization, and sorption) in a composite multiphase system.

3. Multidimensional Gas Flow Model

The composite multiphase transport theory was employed to analyze the gas migration problems in soil. Relevant mathematical algorithm and parameters were studied with respect to the derivation of governing and constitutive equations. A portable code (MFEMGAS : Multidimensional Finite Element Model for Gas Flow in Soil) was developed based upon recent state art of numerical analysis.[12] Multidimensional coding was prepared depending on the data availability and parameter requirements. The highly structured module could include the future development of the various aspects such as experimental findings. The model was verified against the experimental results. Multidimensional simulations were implemented with respect to the computation of gas flow and concentration. ArcView and MFEM-GAS were integrated for a comprehensive management system of gas facilities and efficient predictive tool(Fig. 11-12).

4. UST(Underground Storage Tank) Management System

The facility status of underground storage tank and level of soil contamination was examined to establish its management criteria. A database code was developed to analyze the correlation between specific characteristics of UST and level of soil contamination(Fig. 13). For suitable management of UST, leakage monitoring and inspection of UST was suggested. The inspection period was established based upon the leakage rate. The cause of leakage was studied, and the most

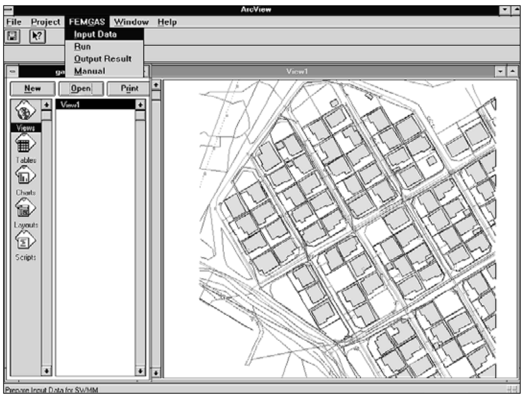

Fig. 11. Depiction of gas facilities using ArcView

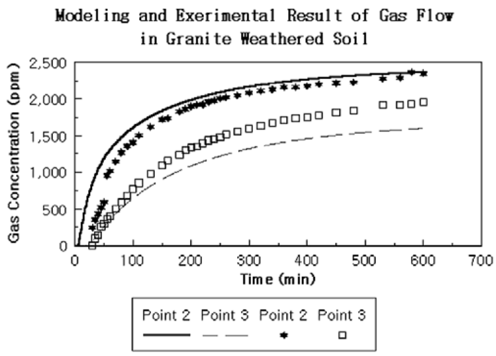

Fig. 12. Modeling and experimental results of underground gas flow

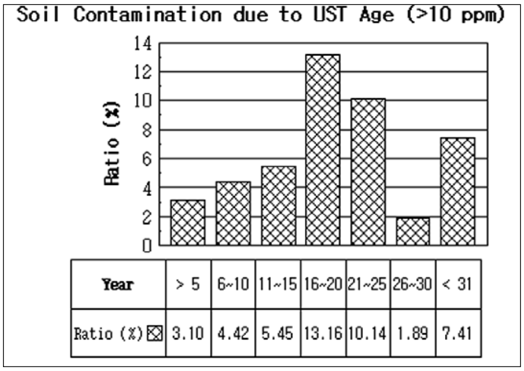

Fig. 13. Relation between soil contamination and UST status

dominant factor seemed to be the corrosion. The management criteria such as, construction method, inspection period, and corrosion protection system was recommend for optimal protection of UST(Fig. 14).[9] Considering the present management status of UST in Korea, inspection and management criteria of UST should be accomplished for the contamination protection of leakage, and proper regulation act should be introduced for each specific site.

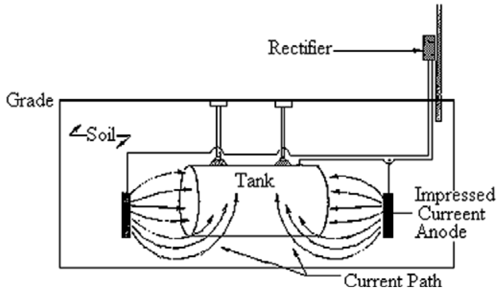

Fig. 14. One of the management system of UST[9]

V. Sewer and Waterworks Management System

1. Sewer Management System

SWMM, MODFLOW and ArcView were combined to produce a comprehensive management system for sewer facilities with respect to Inflow/Infiltration, exfiltration and CSO (Combined Sewer Overflow) management (Fig. 15-16).[11,13] MFEMGW (Multidimensional Finite Element Model for Groundwater Flow) was developed to analyze exfiltration problems, and compared with conventional groundwater flow model, MODFLOW.

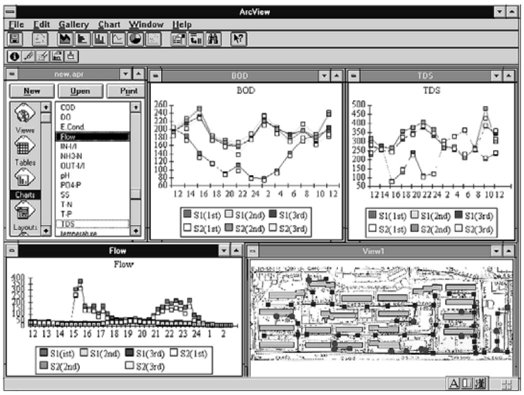

Fig. 15. Facility and operation data of sewer system on the basis of ArcView

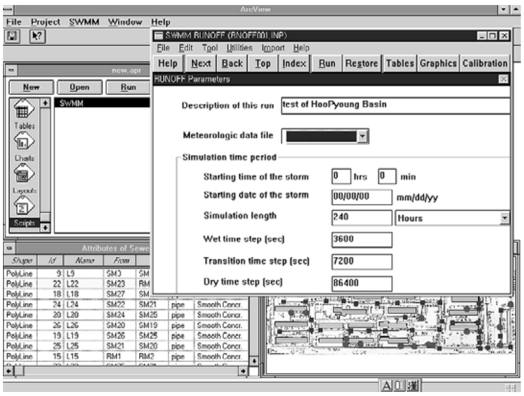

Fig. 16. Integration of ArcView and SWMM

2. Predictive Control of Sewer System

The realtime control has been applied in many cities for optimal operation and maintenance of the combined sewer system.[14] The main targets are to reduce combined sewer overflow by maximizing storage in sewer system, and to minimize inflow/infiltration and exfiltration.[15] Relevant computer programs automatically determine the settings for in-line regulator gates and pump speeds in order to maximize the use of in-line storage during storm events. Distributed computer network allows the control decisions to be implemented without operator intervention. The new “Predictive” control program has been replaced the old heuristic control algorithm.[14] The effort to develop an improved control algorithm began as a result of a study showing that extra capacity in the sewer system could be utilized by improving the software, and as part of an overall hardware and software upgrade for off-site pump and regulator stations. GIS and sewer flow models have improved the knowledge for locating the point and quantity of I/I and exfiltration. And new system parameters were employed to define the scale of I/I and exfiltration based upon the measured field data. Finite element code was developed to analyze the unsteady infiltration due to sewer exfiltration.

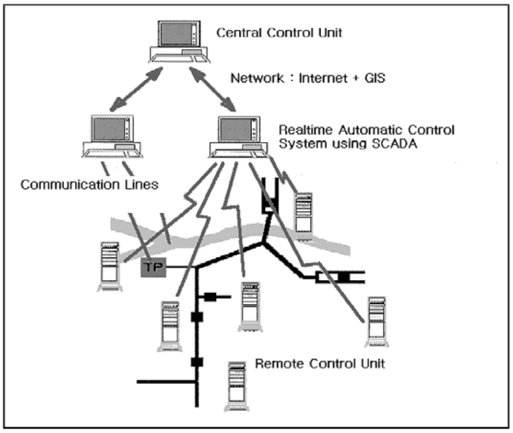

Fig. 17. Overall diagram of sewer control system[15]

3. Optimal Operational Model of WWTPs

The WWTPs (wastewater treatment plants) need to meet the regional requirements with the use of reasonable amounts of energy, chemicals, equipment, and operator hours. To maximize the benefit in the condition of restricted human sources, the automatic control and expert system has been widely applied in many WWTPs.[2] The typical hardware system is consisted with, central computer room, local area network, and water treatment operation room. In using the expert system, the plant operator can access the extensive data of expert knowledge, and databases of past operation. The operation parameters in each process can be summarized as follows:

- Between equalization and aeration Basins:

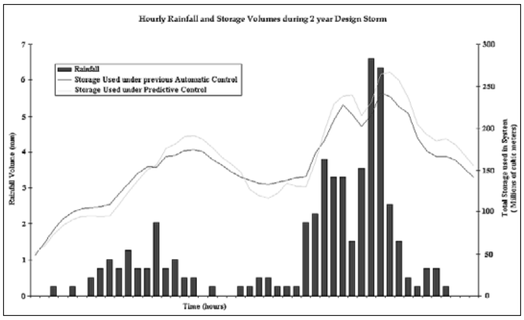

Fig. 18. Hourly rainfall and storage volume by predictive and automatic control[14]

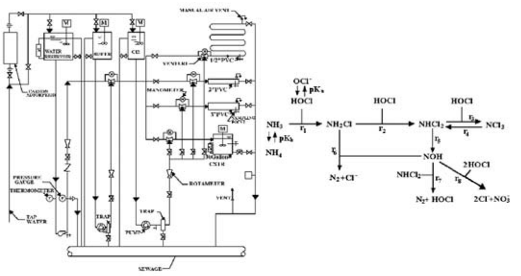

Fig. 19. Experimental unit and 8 reactions of chlorination process

pH, TOC, NH4, flowrate, temperature, TSS.

- At aeration basin: DO, pH, MLSS, temperature, sludge age, maximum nitrification rate, F/M, airflow rate, discharge pressure, suction pressure.
- Between aeration basins and clarifiers : returned activated sludge flow, wasted activated sludge flow, returned activated suspended solid.
- At clarifiers: sludge blanket depth

The automatic control involves the use of logic control of motors, gates, and valves in response to sensors, and data logging, alarms, report generations, and optimal operation of the WWTPs in the case of heavy rainfall event.

4. Optimal Chlorination Model for Waterworks System

Because of the deteriorated drinking water sources, many problems have been arisen from the secondary toxic species produced during the chlorination process in the treatment plant, which is critical to human body.[1] A mathematical model comprised with eight simultaneous quasi-linear partial differential equations was suggested to provide optimal chlorination strategy.[7] Upstream weighted finite element method was employed to construct two-dimensional numerical code. The code was verified against measured concentrations in three types of reactors. Boundary conditions and reaction rate were calibrated for the seventeen cases of experimental results to regenerate the measured values. Eight reaction rate coefficients were estimated from the modeling result. The reaction rate coefficients were expressed in terms of pH and temperature. Automatic algorithm was invented to estimate the reaction rate coefficients minimizing the sum of squares of the numerical errors.

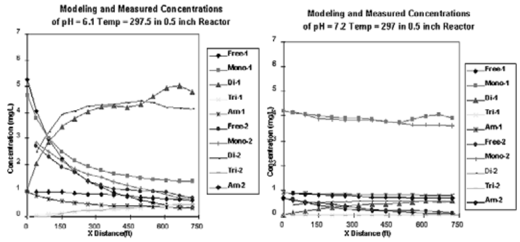

Fig. 20. Comparison of Modelling and experimental results

VI. Conclusions and Future Works

Several environmental management tools in the field of surface water, subsurface water, and soil were developed. All the relevant computational models could have been developed using the new concept of general finite element matrices for the evaluation of spatial derivative in the governing equations. For our final goal of research, next studies will be implemented through the period of 2000, and 2001 in G7 project.

- Integrated sewer management system
- Integrated waste management system
- Integrated air pollution management system

All the above systems will be combined with the results of other research groups. Around the year of 2003, Environmental Ministry in Korea could have truly integrated system of environmental management.

Acknowledgement

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