THE CHEONGGYE-CHEON RESTORATION PROJECT AND HYDROLOGICAL CYCLE ANALYSIS

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Abstract: This paper introduces the Cheonggye-cheon restoration project. The restoration project aims to revive the 600-year-old city of Seoul by recovering the historical heritage, guaranteeing safety from the deteriorated covering structures, creating the environment-friendly space, and revitalizing the neglected city centers. In order to understand the current hydrological cycle of the Chenggye-cheon watershed, the annual water balance of the region was calculated using the observed data including precipitation, runoff, water supply and sewage, and the changes in the groundwater level. The 2001~2002 data were used to calibrate the WEP, and the 2003~2004 data were used to verify the WEP. The calibration and validation results for the flood hydrograph show a reasonable value (at Majanggyo station, the R2 for the calibration period was 0.9, and that for the validation period was 0.7). According to the annual water balance of the Cheonggye-cheon watershed for 2004, the amount of surface runoff, infiltration, and evapotranspiration was 1,097mm, 216mm and 382mm, respectively, for an annual precipitation of 1,499mm. The application results from WEP, a distributed hydrological model, provide more detailed information of the watershed, and the model will be useful for improving the hydrological cycle in urban watershed.

Keywords: Cheonggye-cheon restoration, hydrological cycle, WEP, distributed hydrologic model

1. INTRODUCTION

The Seoul Metropolitan Government decided to restore the Cheonggye-cheon (CHEON-gay-cheon) Stream, which flows through downtown Seoul. The city government began the restoration work on July 1, 2003, with the goal of completing the project by September 2005. The stream had been covered and used for roadway and elevated expressway from 1971. After the restoration project is completed, the stream will be 30~80 m wide and 30~40 cm deep. In order to achieve this, 98,000 m^3 of water will be supplied daily from the Jayang Intake Facility, which collects water from the Han River through the pipes used solely for this purpose, and 22,000 m^3 of groundwater will also be supplied from the subway stations. A total of 120,000 m^3 of water will flow daily into the Cheonggye-cheon main stream (Lee, 2004, Seoul Metropolitan Government, 2003)

In Korea, nature-friendly river improvements in urban areas are increasing. Recently, even the covered streams which were used for roadway, parking lots or residential buildings are being restored or planned. Just as the ecosystem-restoration is important, the hydro- restoration for sustainable water cycle is also essential in the river restoration because ecosystem can not be maintained without water. In the case of the Cheonggye-cheon restoration, this area is severely urbanized (76% of the area is developed into residential and commercial regions), so the hydrological cycle was severely distorted, and the water supply from the watershed was very restricted. Therefore, water supply to the restored stream should come from the Han River.

This research will analyze the hydrological cycle of the Cheonggye-cheon watershed using the results of monitoring and modeling, and present the methods of improving a distorted hydrological cycle. The hydrological analysis, based on monitoring and distributed model can provide the current hydrologic condition and suggest the possible measures for improving the water cycle in the urban watershed.

2. OVERVIEW OF THE CHEONGGYE-CHEON RESTORATION PROJECT

2.1. Background

The Cheonggye-cheon was a stream transversing the heart of Seoul from east to west. Its waters originated from Mts. Bukaksan and Inwangsan. From the beginning of the Joseon Dynasty the stream banks overflowed every time there was a flood. In dry seasons, however, the stream was usually extremely polluted because of the lack of running water. In the reign of the 21^{th} King Yeongjo in 1760, two hundred thousand (200,000) people were recruited to widen the stream and built the stone embankments, and the waterways were straightened to the present conditions. And after that every king throughout the Joseon Dynasty had always been concerned with dredging and flooding.

From 1937 to 1942, the Cheonggye-cheon was covered up from Gwangwhamun to Gwanggyo Bridge for the first time. The stream was covered for roadway from 1958 to 1978. The construction of Samil Elevated Expressway and Cheonggye Elevated Expressway began in 1967 and was completed in 1976.

Restoring the Cheonggye-cheon means a rediscovery of the long lost natural feature of Seoul. It also has a historic meaning as a link to the 600 years of Seoul's urban history. The deteriorated covering structures do not guarantee safety because repairs alone cannot ensure the safety of Seoulites who are threatened by 30 to 40 years old cement and corroded reinforced steel and structural faults. Seoul needs to become a human-oriented, environment-friendly city. The restoration of Chenggye-cheon will renew the image of the city of Seoul by restoring urban ecology, transforming the city into a human oriented environment-friendly city. Finally, a balanced regional development will be achieved by revitalizing the neglected city centers (Seoul Metropolitan Government, 2004).

2.2. Before the restoration project

Cheonggye covered road is 50~80 m wide and about 6 km long. Cheonggye Elevated Expressway extending from Namsan Tunnel No. 1 to Majangdong is a 16 m wide, 5.8 km long, 4 lanes two-way expressway and presently restricted to passenger vehicles because of its structural weakness. Daily total traffic load reaches about 170,000 vehicles over Cheonggye-cheon Road and Cheonggye Elevated Expressway.

Under the 12~80 m wide and 5.5 km long structures which are covering Cheonggye-cheon from Gwanggyo Bridge to Sindap Steel Bridge, the 2~5 m wide and 11 km long Intercept Sewer has been installed, and a total of 32 facilities including waterworks, electricity, telecommunication and gas pipes have been buried beneath.

According to the investigation of KSCE (Korean Society of Civil Engineering) conducted from Jan. 1991 to Oct. 1992, the piers and foundations and pre-stressed concrete (PSC) beams werer found to be relatively safe, but 20% of high strength beams were corroded or damaged. The top plates were found to be below standards requiring replacement of the reinforcement. Therefore, a general ban of all but passenger vehicles has been imposed from May 1997 onwards. In addition, from August 2000 to May 2001, safety evaluation results called for general repair works from Chegonggye-4 Ga to Majangdong.

2.3. Process of restoration

The restoration project consists of dismantling the elevated expressway, removing the structures covering the stream, constructing a total of 21 bridges across the stream including the historical bridges of Gwanggyo and Supyogyo, and building two-lane roadways on each side of the stream. The total cost of the project was estimated at ₩330 billion ($100 million).

This project divides the 5.8 km length into three sectors and it is conducted simultaneously (Figure. 1). The construction work proceeds in five steps; 1) setting up temporary structures for safety in transportation and construction works dismantling of decks, crossbeams and the covering, 3) dismantling of piers, 4) construction of intercepted sewers and a road for temporary use, and dismantling of the coverings in the commercial area, and 5) landscaping for the recovered area including the stream (Figure. 2, Figure. 3).

Much attention has been given to the problem of supplying water to the restored stream, the goal being a stream depth of at least 30 cm. To ensure acceptable water quality and prevention of pollutants inflow, an alternative source is necessary. The water, 98,000 m^3 for each day, will come from the Han River. Each day the stream will also receive 22,000 m^3 of groundwater collected by the subway stations.

To prevent the loss through ground seepage and maintain a flow depth of 30~40 cm with a seepage loss of 3 percent, the streambed was treated with the Bentonite screen and cutoff walls at each side of the bank.

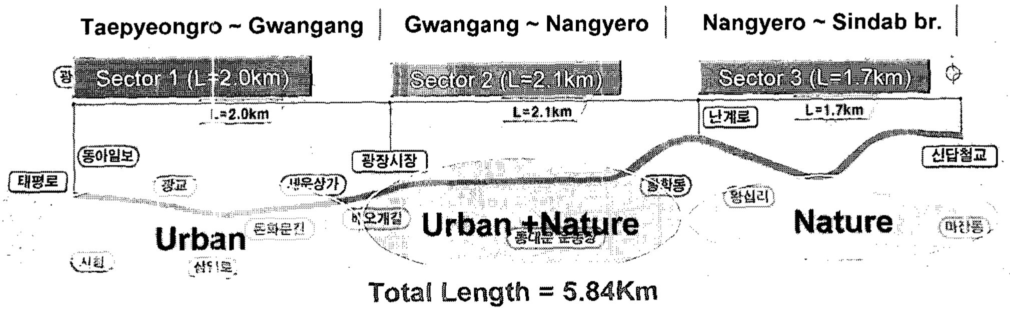


Figure 1. Division of the construction sector for the Cheonggye-cheon restoration project

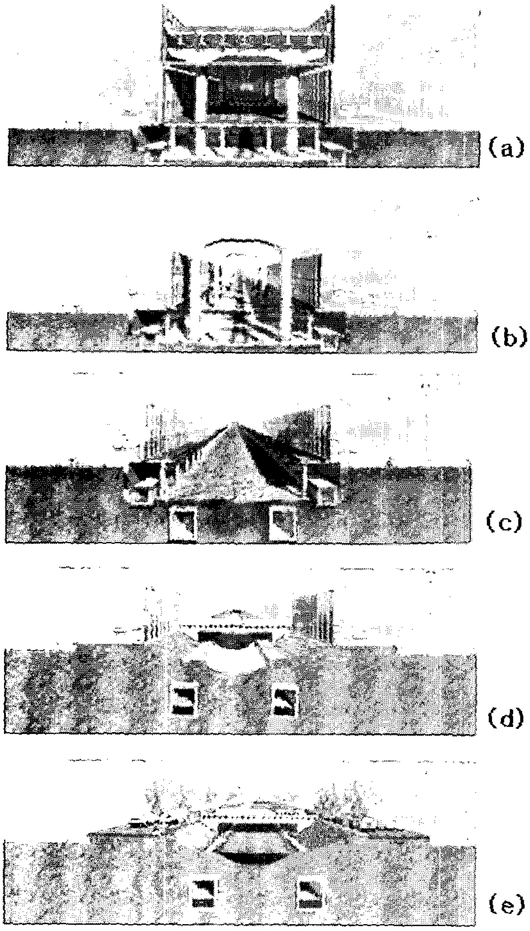
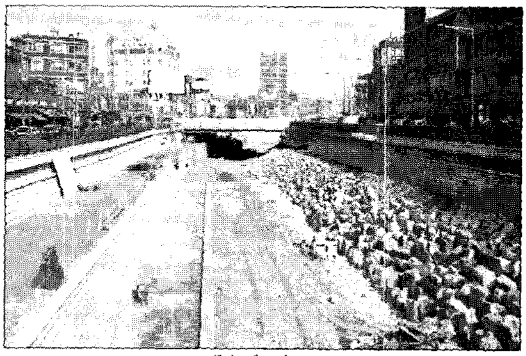


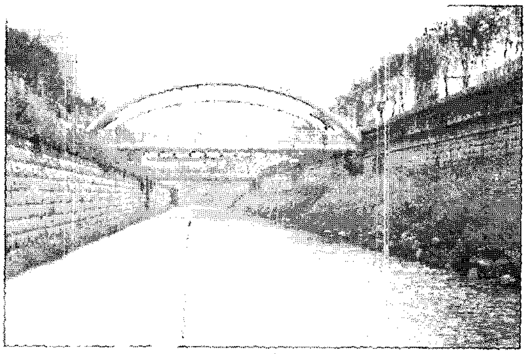
Figure 2. Methods and process of the Cheonggye-cheon restoration project.

(a) Setting up facilities for transportation, safe and construction
(b) Dismantling of decks, crossbeams and the covering
(c) Dismantling of piers
(d) Construction of intercept sewers and a road for temporary use and dismantling of the coverings in the commercial area
(e) Landscaping for the recovered area including the river

(a) before



(b) during



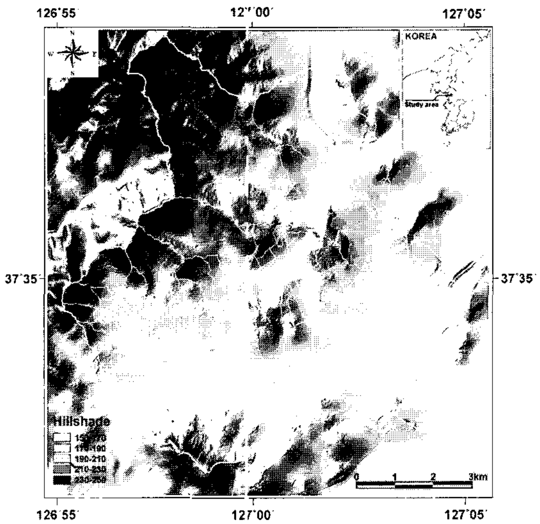
(c) after

Figure 3. The Cheonggye Express Way and the restored Cheonggye-cheon

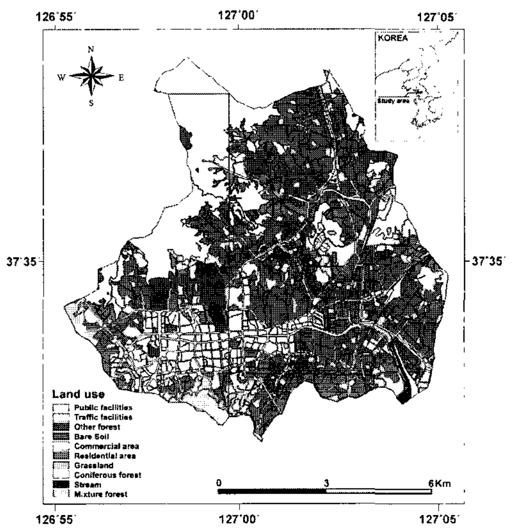
3. ANALYSIS OF GYDROLOGICAL CYCLE

3.1. Characteristics of the Cheonggye-cheon watershed

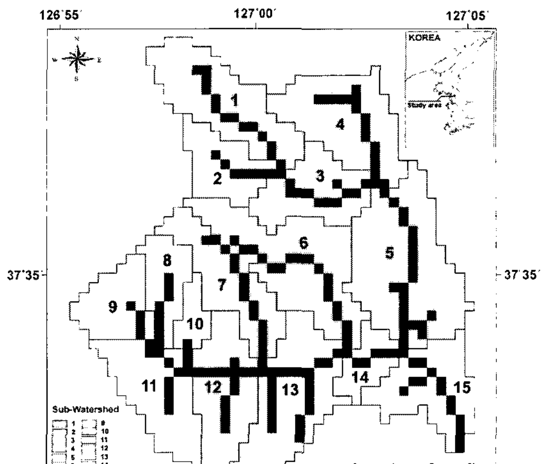
The Cheonggye-cheon stream is the second tributary of the Han River. The Cheonggye-cheon watershed is 50.96 km^2 in area and 13.75 km in length, and it is located in the downtown of Seoul City. Over 1.4 million people reside in this area, and many people pass by the area every day. The average elevation and slope of the Cheonggye-cheon watershed are 70.1m and 0.07, respectively. Figure 4 shows the topographic characteristics of the region, including DEM (digital elevation model) data. The dominant soil types of the Cheonggye-cheon watershed are silty loam (25.3%), silty clay loam (33.0%) and clay loam



(a) Topography



(b) Land Use



(c) Sub-watershed

Figure 4. Topographic characteristics, land use and sub-watershed delineation of the Cheonggye-cheon watershed

(35.9%). The land is used for various purposes: forested areas (23.2%: coniferous trees 17.7%; mixed trees 2.7%; and other forested areas 2.8%), urban areas (75.9%: residential areas 42.6%; commercial areas 9.4%; traffic facilities 12.3% and public facilities 11.6%). The average temperature throughout the year is 12.8 C, and the annual precipitation of recent 10 years is 1,455 mm, but the rainfall during the rainy season from June to August is 960 mm (66%).

3.2. Water balance calculation

There are many models which can simulate the hydrological cycle in a watershed, but they have limitations in considering the natural and artificial water cycles in the urban area. In this study, the WEP (Water and Energy transfer Process model) was selected and applied to analyze the existing hydrological cycle, and the countermeasures were sought for a sustainable water cycle in an urban area.

Jointly developed by Doctor Jia, the Public Works Research Institute in Japan, and the Japan Science and Technology Agency, WEP is a physically-based and spatially-distributed model for quantifying the hydrological cycle of an urban watershed with complex land uses. After a basic version of the model was developed, it was modified for additional functions such as the calculation of groundwater flow, ground-surface flow interaction, and the effects of flooding facilities, flood retention reservoirs, and agricultural land (Public Works Research Institute in Japan, 2002).

The WEP can predict a streamflow precisely without the past streamflow data and validation, as it directly interprets the physical features of various hydrological cycle processes. It can also simulate spatial and temporal distributions of infiltration, evapotranspiration, surface runoff into rivers, groundwater runoff, groundwater flow, etc., on a watershed scale. In addition, it reflects the heterogeneity of land use within the mesh using a mosaic method, and it identifies the artificial water flow caused by human activities in terms of time and space (Jia et al., 2001).

Figure 4(c) shows the fifteen sub-watersheds and the locations of channels. The Cheonggyecheon watershed was divided into grids of 200m size (54x54) and divided again into fifteen sub-watersheds by inputting the accumulated data into the GIS program after which the ground surface elevation, slope, flow direction, etc., of those grids were determined. Data such as the types of surface soils, network of river channels, land use, etc., were obtained from the GIS data. Hourly precipitations and weather data measured at the Seoul Weather Station were used for the evapotranspiration using the Penman-Monteith equation. And the aquifer data including thickness and hydraulic conductivity were cited from the preliminary investigation report of the Cheonggye-chon restoration project, and the boring data from National Groundwater Information Management and Service center (Kim, 2005a; Kim et al., 2005b; Noh, 2005).

3.3. Simulation results

In order to mitigate the effects of initial conditions such as the initial moisture level of the surface soil and the initial groundwater level, we simulated the 1998~2000 period and used the conditions at 24:00 on December 31, 2000 as the initial conditions. The simulation period was a four-year period from January 1, 2001 to December 31, 2004. The 2001~2002 data were used to calibrate the WEP, and the 2003~2004 data were used to verify the WEP. The calibration and validation results for the flood hydrograph show a reasonable value (at Majanggyo station, the R^2 for the calibration period was 0.9, and that

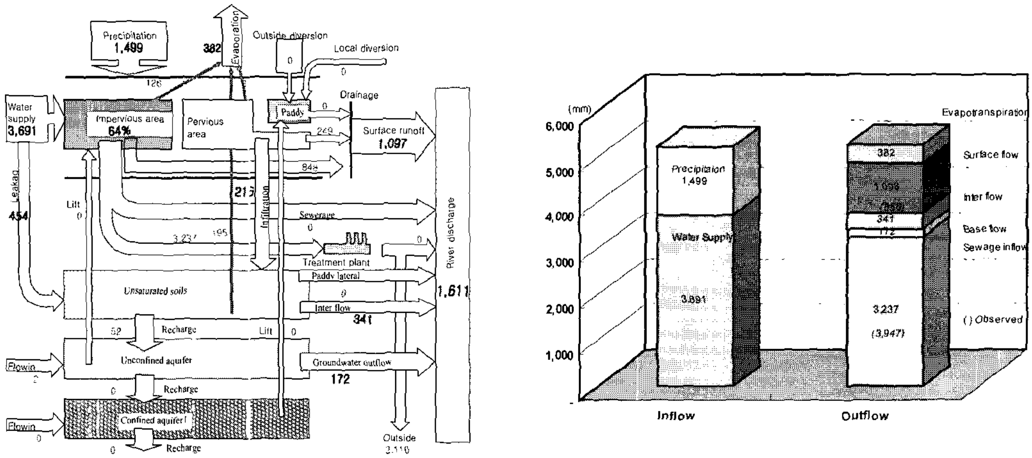


Figure 5. Annual water balance in the Cheonggye-cheon watershed (2004).

for the validation period was 0.7)

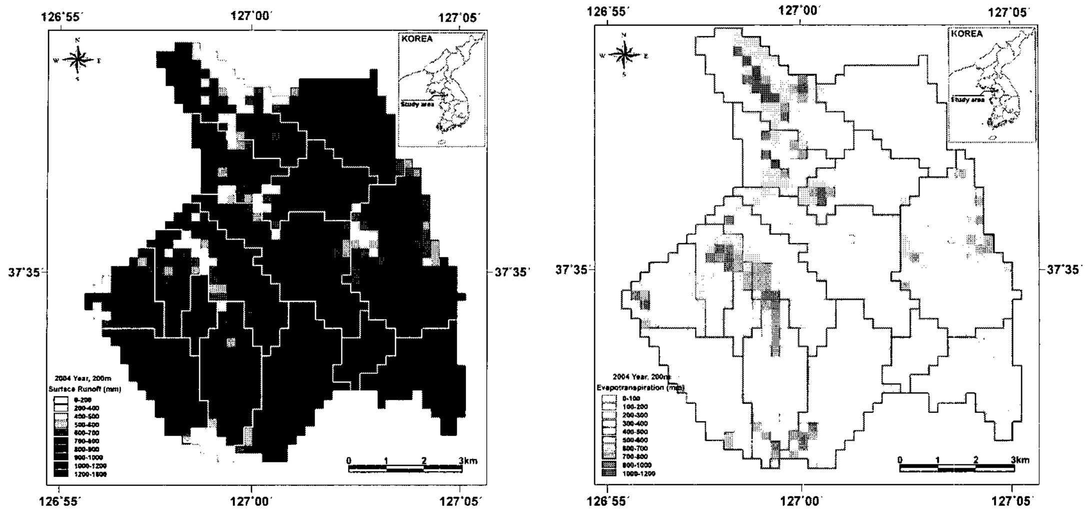
Figure 5 shows the WEP simulation results for the annual water balance of the Cheonggye-cheon watershed for 2004. According to the results, the amount of surface runoff, infiltration, and evapotranspiration was 1,097mm, 216mm and 382mm, respectively, for an annual precipitation of 1,499mm. The runoff to stream was 1,611mm (the proportion of direct runoff, intermediate runoff and groundwater runoff was 68%, 21% and 111%, respectively). The river discharge (1,611 mm) is larger than the annual precipitation (1,499 mm) because it is originated by the leakage from the municipal water supply. The average leakage rate of Seoul is about 12 %. The water leaked from the water supply pipe infiltrates and saturates the soil and is percolated to the groundwater. In the model, the leaked water flows out through the interflow and the base flow. The observed surface flow at the Majanggyo gauging station is 856mm, which is less than the simulated surface flow of 1,098 mm, because the low water level is not measured, and most low flows are connected to the combined sewage network. Thus, the simulated sewage inflow (3,237 mm) is smaller than the observed value (3,947mm) at the sewage plant.

Figure 6 shows the cumulative and surface runoff by grid square for 2004. There is more surface runoff in grid squares containing the urban areas than in those grid squares with lower impermeability rates because of the relatively abundant forests and green zones.

4. CONCLUSION

When the Cheonggye-cheon restoration project is successfully completed, the capital will turn into a city friendly to both the environment and people. The project is also expected to set a new paradigm for urban management in the 21^{st} century and contribute to renewing the image of Seoul. Once the historical site is restored, Seoul will regain its 600-year history as the capital city of Korea by turning itself into a city where the modern era is wonderfully amalgamated with tradition.

In order to analyze the hydrological cycle of the Cheonggye-cheon Watershed, we reviewed the current hydrological monitoring system, analyzed hydrometeorological data, and measured



(a) Surface Flow (b) Evapotranspiration

Figure 6. Annual spatial distribution of surface flow and evapotranspiration (2004).

the region's streamflow on a regular basis to gather information on the flow into the upper watershed in the dry season. The annual water balance in the region was calculated using observed data such as precipitation, runoff, water supply and sewage, changes in groundwater storage. WEP, a distributed hydrological model, was also used. The results from the grid based distributed model provided more detailed information of the watershed. The spatial distributions of evapotranspiration and runoff can be analyzed from the model and utilized for the normalization plan of the urban water cycle.

The 2001~2002 data were used to calibrate the WEP, and the 2003~2004 data were used to verify the WEP. The calibration and validation results for the flood hydrograph show a reasonable value (at Majanggyo station, the R^2 for the calibration period was 0.9, and that for the validation period was 0.7). According to the annual water balance of the Cheonggye-cheon watershed for 2004, the amount of surface runoff, infiltration, and evapotranspiration was 1,097mm, 216mm and 382mm, respectively, for an annual precipitation of 1,499mm.

The application results from WEP, a distributed hydrological model, provide more detailed information of the watershed, and the model will be useful for improving the hydrological cycle in urban watershed.

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REFERENCES

Jia, Y., Ni, G., Kawahara, Y. and Suetsugi, T., (2001). Development of WEP model and its application to an urban watershed. *Hydro-*

logical processes, 15., pp. 2175-2194.

Kim, H. J., (2005a). *Monitoring and Hydrological Cycle Analysis of the Cheonggyecheon Restoration Project.* SWRRC(2-6-2), Korea Ministry of Science and Technology (in Korean).

Kim, H. J. et al., (2005b). "Monitoring and Analysis of Hydrological Cycle of the Cheonggyecheon Watershed in Seoul, Korea", *Proc. Int. Conf. Simulation and Modeling 2005*, Bangkok, Thailand, pp. 410-417.

Lee, T. S., 2004, Buried Treasure, *Civil engineering 74 (1)*, pp. 32-41.

Noh, S.J., Kim, H.J. and Jang, C.H., 2005, Application of WEP model to the Cheonggyecheon watershed, *J. of Korea Water Resources Association*, KWRA, Vol. 38, no. 8, pp. 645-653.

PWRI, (2002). *WEP Model Manual*, Public Works Research Institute (in Japan).

Seoul Metropolitan Government, (2003). *Cheonggyecheon Restoration Project.* <http://www.metro.seoul.kr/kor2000/chungaehome/en/seoul/main.htm> [accessed March 1, 2005]

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