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# A Development of Safety Management System for Water Lines Using GIS

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## Abstract

Due to the fast industrial growth and unplanned urban underground development in Korea, systematic management for water lines could not be accomplished. Unsystematic water line management has resulted in difficulty in finding the exact location and the age of the lines, which has the potential of leading to a disastrous situation. The objective of this study is a development of safety management system for water lines using GIS. This system is constructed to easily estimate water line deterioration by the geographic output system on it, search for damaged objectives near the surrounding area in a situation of destruction, and offer the emergency information by which one can quickly take action. Also, it is constructed to prevent accidents from occurring during work by presenting underground utilities and states of work.
*Keywords : GIS, safety management system, water lines, underground utilities*

## 1. Introduction

GIS is a system that has the ability of integrating, managing and analyzing the voluminous graphic and text data, which is an adequate system to manage the complex networks of the underground utilities of urban areas. Therefore, underground utility management systems using GIS have been developed and widely used by the local governments in Korea (Jang and Kim, 1993; The City of Cheonan, 2000). The purpose of this study is focused on the development of deterioration estimation and management system for water lines using GIS.

This system consists largely of two parts; deterioration estimation and efficient management of water lines. The deterioration estimation system evaluates safety according to the water line deterioration and the management system offers general information required for water line management. The deterioration estimation model selected in this study is the Numerical Weighting System developed by KOWACO (Korean Water Resources Corporation), which estimates quantitatively pipeline deterioration using factors such as the year laid, material, diameter, etc. Deterioration index tables were generated for the realization of the model in this system. The database (DB) for system application was designed by analyzing the task of the water supply control center and the deterioration estimation model. Then, a proto-type deterioration estimation and management system was developed on the basis of the studied model and the designed database. The deterioration estimation system, characteristic output system, tracing system of damaged facilities, emergency information output system, and construction management system was developed by using ARC/INFO from the ESRI Company as its main tool.

## 2. Deterioration Estimation Model for Water Lines

Generally, destruction of water lines occurs through complex causes. In Japan, it is said that water line destruction is due largely to pipeline deterioration and traffic load increase. In the U.S. and Europe, soil movement is emphasized as a reason. In this study, the Numerical Weighting System developed by KOWACO to adjust to the Korean environment has been used as the pipeline deterioration estimation model (Korea Water Resources Corporation,

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1995).

In this method, pipes are classified into eight types according to diameter and material. These pipes were as follows:

(1) diameter of 700 mm and over (steel pipe), (2) diameter of 700 mm and over (cast iron pipe, ductile cast iron pipe), (3) diameter of 700 mm and over (concrete pipe), (4) diameter from 150 to 600 mm (steel pipe), (5) diameter from 150 to 600 mm (cast iron pipe, ductile cast iron pipe), (6) diameter from 150 to 600 mm (PVC, PE, concrete pipe), (7) diameter of 150 mm and below (copper pipe, stainless steel pipe), and (8) diameter of 150 mm and below (PVC, PE pipe)

Also, the estimation factors are classified into 19 types such as maximum water pressure (kg/cm$^2$, on-the-spot survey), site type (on-the-spot survey), road type (on-the-spot survey), pipe type (on-the-spot survey), year laid (data analysis), accident frequency (on-the-spot survey), anhydride rate (%, data analysis), soil resistance rate (W cm, laboratory analysis), pH (laboratory analysis), redox potential (mV, laboratory analysis), sulphuric acid ions or chlorine ions (mg/kg, laboratory analysis), C value (on-the-spot survey), basement (on-the-spot survey), fulfillment (soil type, laboratory analysis), diameter (mm, on-the-spot survey), cathodic protection (on-the-spot survey), joints (joint method, on-the-spot survey), divergency (on-the-spot survey), and junctions (on-the-spot survey).

In this method, the total score of deterioration by each estimation factor is a rating of 100 as a maximum for the best-conditioned pipe, and a score of 12-23 as a minimum for the worst-conditioned. A pipe with a score under 60 has become antiquated considerably and should be changed, 60 to below 70 is also antiquated, but it needs to be monitored rather than immediately repaired, 70 to below 80 is in a comparatively good state, and 80 and over ranked as excellent. This method simply quantifies water line deterioration and it makes it easy to design pipeline repair reasonably and economically, by estimating deterioration in terms of various factors. However, data survey of various estimation factors should precede for real application.

## 3. Database Design

Most databases used in this system are owned by the City of ChangWon (Hanjin Information System & Telecommunication Co., 1995). Some data were collected by the researcher. The database was designed to run each function effectively and it indexes to make the best use of GIS. It is important to study the database format of the GIS tool to be

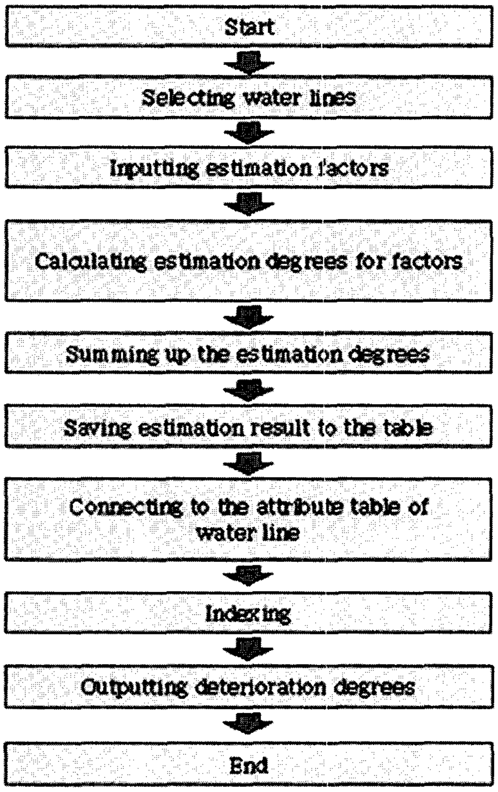


Fig. 1. Flow chart of deterioration estimation.

Table 1. Layer Used in This Study.

| | | |
|---|---|---|
| Neat line layer | 1:1,000 | Polygon |
| Building layer | Detached house, Row-house, Apartment, School, Kindergarten, Educational facility, Fire station, Medical institution, Media facilities, Gas station | Polygon |
| Real width road layer | Driveway, Shoulder, Sidewalk, Median strip, Bikeway, Bridge, Tunnel | Polygon |
| Road facility layer | High level road, Underpass, Footbridge | Polygon |
| Street center line layer | Street, Bridge, Tunnel, Overpass, Ramp | Line |
| Cadastral line layer | Cadastral line, Administrative boundary | Polygon |
| Water line layer | Transmission pipe, Drain pipe, Water supply pipe, Industrial water lines | Line |
| Water line facility layer | Sluice valve, Other valves, Storage tank, Water meter, Flow meter, Fire hydrant, Water supply tower | Point |

used in the study, because the optimum database design is different according to it. For this study, ARC/INFO was selected and all DB sets were designed according to ARC/INFO specifications (Environmental System Research Institute, Inc., 1994). Fig. 1 is a process of deterioration estimation and database design follows these processes.

Various layers, such as topographic (building, road, road facility), road network (street center line, intersection), land use, and water line were used. Table 1 shows the layers used in this study.

Feature attribute tables, relational tables, and lookup tables on layers were also designed. The relational table was drawn up using INFO Module of ARC/INFO to preserve continuously data which resulted from pipeline deterioration estimation. Table 2 shows relational tables for deterioration estimation.

The lookup table can represent color or symbol of graphic output effectively. The lookup tables designed for this study were such as classification tables of pipe type, pipe diameter, year laid, accident frequency, etc. of water lines. Table 3 shows the lookup tables for classification of pipe diameter and underground utilities.

## 4. Deterioration Estimation and Management System

This system is divided into largely six sub-systems and each sub-system consists of two~seven modules. Each module was formed with items which should be applied to works directly by the water line manager in the field. Table 4 shows functions of each module of this system.

### 4.1. Deterioration Estimation System

The deterioration estimation system which is for evaluating water line deterioration consists of a numerical weight input system, a deterioration output system, and a accident frequency output system. The numerical weight input system can input estimation scores of various estimation factors about specific pipes. It was designed for all types of input and the screens were different from each other, because there were one~four numerical differences for estimation factors according to pipe type and pipe diameter.

Table 2A. Relational Table Design for Deterioration Estimation : Estemation Factor Code Table

| No. | Item name | Item | Type (Width) | Key | Null | Remark |
|---|---|---|---|---|---|---|
| 1 | Dia-Metr | Pipe diameter and pipe type classification | B(4) | P | N | |
| 2 | Factor | Estimation factor classification code | C(4) | | N | |
| 3 | Level-No | Factor range number | N(2) | | N | |
| 4 | Level-Name | Factor range | N(2) | | N | |
| 5 | Level-Point | Factor numerical weight | N(2) | | N | |

Table 2B. Relational Tables Design for Deterioration estimation : Estimation Result Classification Table

| No. | Item name | Item | Type (Width) | Key | Null | Remark |
|---|---|---|---|---|---|---|
| 1 | Factor-code | Estimation factor classification code | C(2) | P | N | |
| 2 | Item-name | Estimation factor name | C(30) | | N | |
| 3 | LS-check | Steel pipe of 700 mm and over | C(1) | | N | Y or N |
| 4 | LD-check | Cast iron and ductile cast iron pipe of 700 mm and over | C(1) | | N | Y or N |
| 5 | LC-check | Concrete pipe of 700 mm and over | C(1) | | N | Y or N |
| 6 | MS-check | Steel pipe between 150 mm and 600 mm | C(1) | | N | Y or N |
| 7 | MD-check | Cast iron and ductile cast iron pipe between 150 mm and 600 mm | C(1) | | N | Y or N |
| 8 | MC-check | PVC, PE, and concrete pipe between 150 mm to 600 mm | C(1) | | N | Y or N |
| 9 | SS-check | Copper and stainless steel pipe of 150 mm and below | C(1) | | N | Y or N |
| 10 | SP-check | PVC and PE pipe of 150 mm and below | C(1) | | N | Y or N |
| 11 | Method | Survey method | VC2(150) | | | |
| 12 | Remark | Remark | C(15) | | | |

Table 2C. Relational Tables Design for Deterioration estimation : Estimation Result Saving Table

| No. | Item name | Item | Type (Width) | Key | Null | Remark |
|---|---|---|---|---|---|---|
| 1 | ID | Code for attribute link | B(4) | P | N | |
| 2 | YEAR | Estimated date | C(4) | | N | |
| 3 | A0 | Maximum water pressure | N(2) | | N | |
| 4 | B0 | Site type | N(2) | | N | |
| 5 | C0 | Road type | N(2) | | N | |
| 6 | D0 | Pipe type | N(2) | | N | |
| 7 | E0 | Year laid | N(2) | | N | |
| 8 | F0 | Accident frequency | N(2) | | N | |
| 9 | G0 | Anhydride rate | N(2) | | N | |
| 10 | H1 | Soil resistance rate | N(2) | | N | |
| 11 | H2 | pH | N(2) | | N | |
| 12 | H3 | Redox potential | N(2) | | N | |
| 13 | H4 | Sulphuric acid ions or chlorine ions | N(2) | | N | |
| 14 | I0 | C value | N(2) | | N | |
| 15 | J0 | Basement | N(2) | | N | |
| 16 | K0 | Fulfillment | N(2) | | N | |
| 17 | L0 | Diameter | N(2) | | N | |
| 18 | M0 | Cathodic protection | N(2) | | N | |
| 19 | N0 | Joints | N(2) | | N | |
| 20 | O0 | Divergency | N(2) | | N | |
| 21 | P0 | Junctions | N(2) | | N | |
| 22 | TOTAL | Total score | N(3) | | N | |

Table 3A. Lookup Tables Design: Classification Table of Pipe Diameter

| No. | Item name | Item | Type (Width) | Key | Null | Remark |
|---|---|---|---|---|---|---|
| 1 | KNKYNG | Pipe diameter classification code | C(8) | P | N | |
| 2 | SYMBOL | Symbol type | I(3) | | N | |

Table 3B. Lookup Tables Design: Classification Table of Underground Utility

| No. | Item name | Item | Type (Width) | Key | Null | Remark |
|---|---|---|---|---|---|---|
| 1 | ALL | Underground utility classification code | C(40) | P | N | |
| 2 | SYMBOL | Symbol type | I(3) | | N | |

The estimation factor code table and estimation factor classification table were designed and drawn up. When the user clicks a specific pipe on screen, the input screen corresponding to that pipe appears automatically. These two tables are linked with an attributes table of water line coverage, therefore each pipe comes to be linked with the input screen of eight types classified in the deterioration estimation model.

The deterioration output system was constructed to link each pipeline with an estimation result storage table and to know the deterioration at a glance through the index. If the values of each factor are assigned into each pipeline, the output with deterioration degrees would be shown in different colors corresponding to each estimated values. Fig. 2 shows output of deterioration degrees.

The accident frequency output system has an ability to

Table 4. Function of Deterioration Estimation and Management System

| Item | Function | Remark |
|---|---|---|
| Deterioration Estimation | Output of water line deterioration degree by deterioration model-Numerical Weight System | |
| – Numerical weight input | Data input function for deterioration estimation | |
| – Deterioration output | Deterioration output function with index | |
| – Accident frequency output | Accident frequency output function with index | |
| Characteristics Output | Classification and output by characteristics of pipe | |
| – Pipe diameter | Pipe diameter output function with index | |
| – Pipe type | Pipe type output function with index | |
| – Year laid | Output function of year-laid with index | |
| Searching Damaged Facilities | Output of facilities which have the possibility of damage when water line is broken | |
| – Valves which should be closed | Tracing function of valves which should be closed when water line is broken | |
| – Buildings which have possibility of blockage of water supply | Tracing function of buildings which have the possibility of blockage of water supply when water line is broken | |
| – Valves which should be closed and buildings which have the possibility of blockage of water supply | Tracing function of valves which should be closed and tracing function of buildings which have the possibility of blockage of water supply when water line is broken | |
| Emergency Information Output | Output of information for trouble shooting when water line is broken | |
| – Water supply control center | Information output function of water supply control center which should be called when water line is broken | |
| – Prevention Center | Information output function of administrative organizations such as city hall, district office, police department, etc. which should be called when water line is broken | |
| – Controlled road | Information output function of roads which should be controlled when water line is broken | |
| Construction Management | Management of construction which has an effect on underground utilities | |
| – Underground utilities status | Prevention function of underground facilities from damage due to ground excavation | |
| – Construction status | Output function of construction which is in progress status | |
| Screen control | Control of graphic screen | |
| – Zoom in | Zoom in selected zone | |
| – Zoom out | Zoom out selected zone | |
| – Undo | Undoing screen | |
| – Erase | Erasing screen | |
| – Pan | Panning to selected zone | |
| – Partial extension | Extension of selected site by box | |
| – Full extension | Loading whole area | |
| Others | Running command except menu by users typing | |
| Quit | Quit system | |

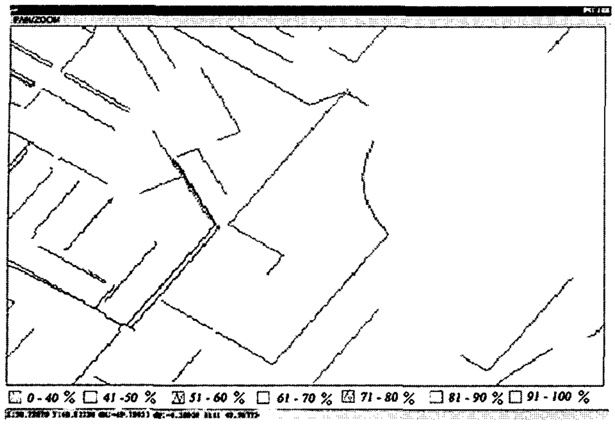


Fig. 2. Output of deterioration degrees.

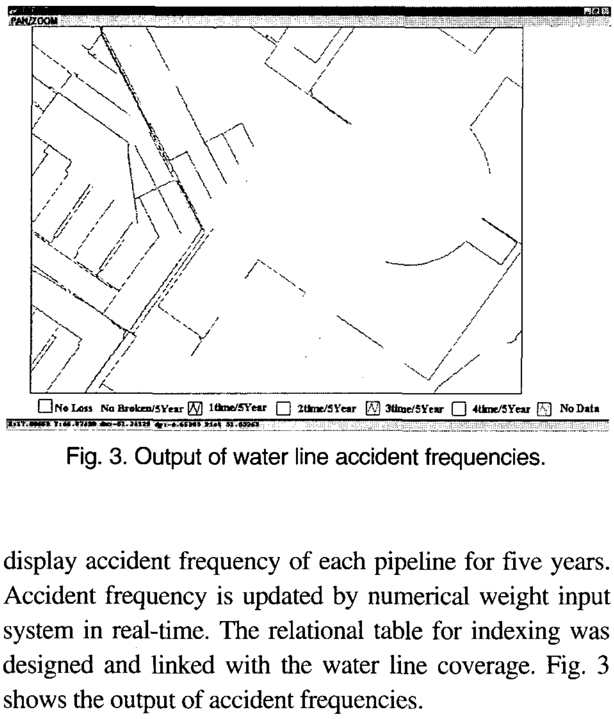


Fig. 3. Output of water line accident frequencies.

display accident frequency of each pipeline for five years. Accident frequency is updated by numerical weight input system in real-time. The relational table for indexing was designed and linked with the water line coverage. Fig. 3 shows the output of accident frequencies.

### 4.2. Output System of Characteristics

The output system of characteristics has functions to provide information for pipelines by their types, diameters, years laid, etc. The output system of water line types shows each pipeline type in index and shows all the water lines attributes. This system can output their own number for each water line, and connect the number with its corresponding water line attributes. The relational table was designed and linked with the water line coverage. The output system of pipe diameters and years laid classifies and supplies the output data for pipes by diameters and years laid. The lookup table of these systems was designed and linked with the water line coverage. Fig. 4 is output of water line diameters.

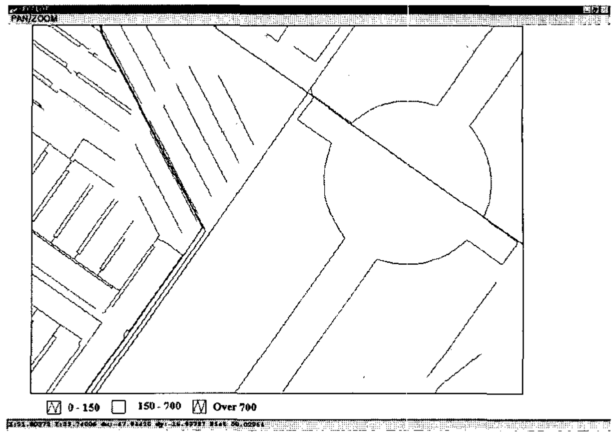


Fig. 4. Output of water line diameters.

### 4.3. Damaged Facilities Trace System

A searching system for damaged facilities traces valves which should be closed when water lines are destroyed. Also, it searches blocked water line sections, damaged buildings, etc. and shows attributes of the damaged elements.

An output system of valves which should be closed has the function of searching for water line valves which should be closed. It displays surrounding building names at the same time to represent well locations of valves. For this system, after valve branches are cut within a certain radius, it uses the network function of ARC/INFO.

The trace system of buildings which have the possibility of blockage of water supply has the ability of tracing buildings which have the possibility of blockage of water supply with its attributes in a water line accident. It provides the number of buildings, their addresses, and phone numbers using attribute values which could be used to inform owners easily. For this system, a water lines layer was created. And buildings which are overlapping with the water lines layer within an area of blockage of water supply are traced and displayed. Fig. 5 is an output of valves which should be closed and buildings which have the possibility of blockage of water supply.

### 4.4. Emergency Information Output System

The emergency information output system offers useful information such as a water supply control center, a prevention center, and the controlled road for recovery in case of accidents to water lines. The output system of the water supply control center and prevention center can inquire about information for organizations which should be contacted in order to recover promptly from damage to water lines. Attribute information for each system can be updated easily because it is constructed in a text file independent of

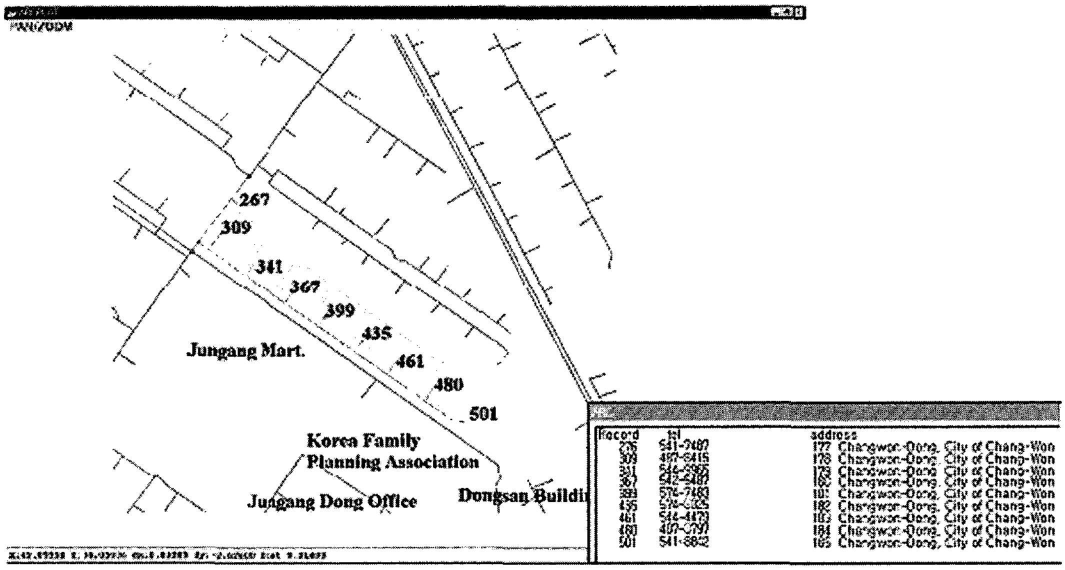


Fig. 5. Valves which should be closed and buildings which have the possibility of blockage of water supply.

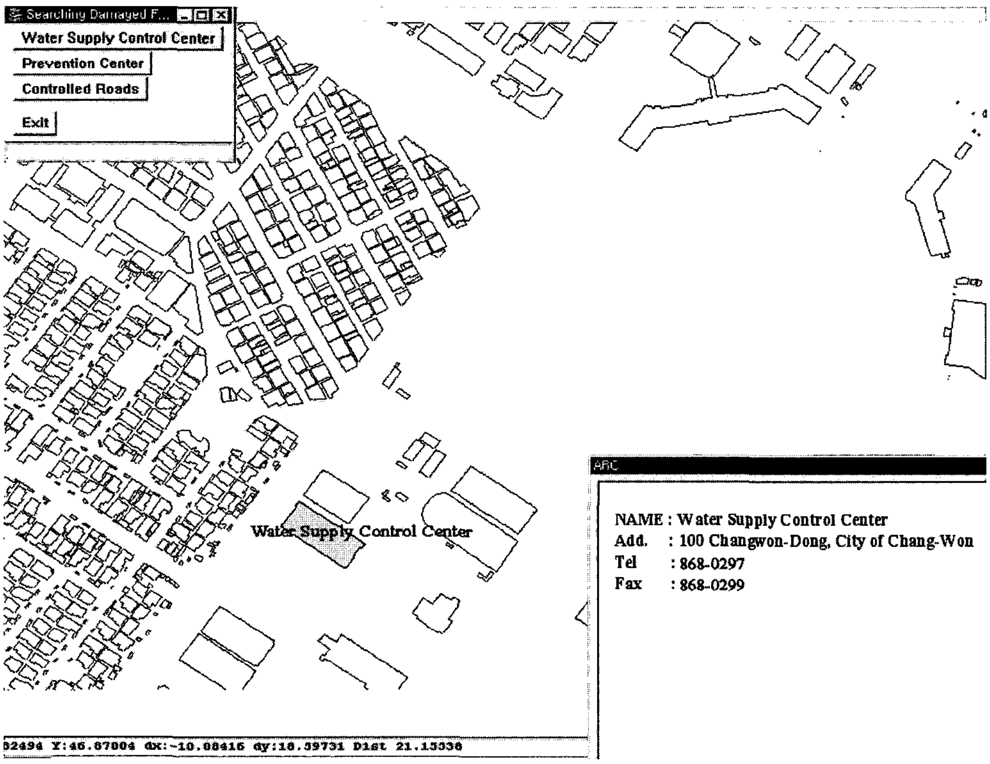


Fig. 6. Output of water supply control center.

attribute tables of the building layer. Fig. 6 shows an output of water supply control center.

Also, the output system informs the controlled roads in the event of water outflow due to water lines damage.

### 4.5. Construction Management System

The construction management system consists of an underground utilities status output system and a construction status output system. For this system, a special relational table was designed separately. The underground facilities output system prevents accidents from occurring during construction works.

With the construction status output system, it is possible to find out the locations and kind of construction work. It

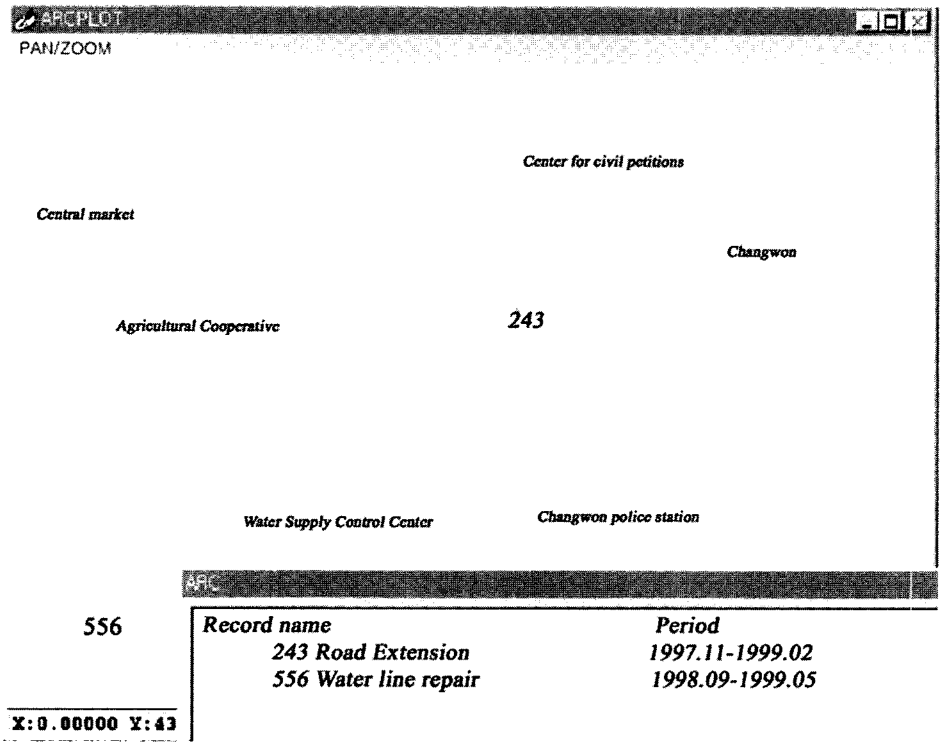


Fig. 7. Output of construction status.

allows the water supply control center to monitor and manage water lines accidents during construction work. Construction information is built in the attribute tables of roads, considering that most water liness are located under roads. Fig. 7 is an output of construction status.

### 4.6. Screen Control System

The screen control system allows the user to access several functions such as zoom in, zoom out, undoing, deleting, panning, partial extension, and full extension.

## 5. Conclusions

The proto-type safety management system for water lines using GIS was developed to be used easily by nonprofessionals. This system estimates water line deterioration considering various factors such as the year laid, material, blockage frequency of water supply, etc. Therefore, this system allows for rational and economical choices rather than estimating the deterioration and deciding for repair of water lines due to one certain factor. And it can easily catch water line deterioration distribution through the index.

This system is able to search automatically for valves which should be closed and buildings which have the possibility of blockage of water supply when water line accidents occur. It also outputs information for related organizations. This makes it possible to take rapid emergency steps. And this system is able to output graphic and attribute data of water line characteristics at the same time.

As this system offers data on the status of underground utilities, it prevents accidents from occurring during construction works. Also by inspecting the construction status, the safety of water lines under work projects could be assured.

This system was designed to be used immediately by water line management sites. By using this system, it will help manage water lines effectively and with less manpower. If safety estimation sensors can be installed on the underground utilities, a real-time monitoring system can be developed following this study.

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