DEVELOPMENT OF DECISION-MAKING SUPPORT SYSTEM FOR USE OF MULTIPLE WATER RESOURCES

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Abstract

The city of Fukuoka meets its water demand through a complicated system of water supply, which is formed by storing water at 5 locations. Water managers, with the focus on how the daily demand of water is pumped from the reservoirs to the purification stations, thereby are attempting to develop an expert system from existing rules, and their personal experiences and knowledge in these matters. The system is termed "a supporting expert system for estimating the water quantity extracted". The study, with the objective of developing this system, is still at a preliminary state. However, in this article it is described how the actual data can be incorporated in simulations, and thereby to verify the efficiency of the system. It is shown that the results obtained through the expert system are almost equal to the quantity of water actually extracted from the supply reservoirs.

keywords

water resource management, water extraction process, expert system, frame structure, production rules

1. Introduction

Development of new water supply systems is no longer a simple task in Japan, due to the lack of suitable reservoir sites, and various restraints necessitated by environmental preservation concerns. When the limited water resources as components of the hydrological cycle are considered, it is said that in the future, integrated management of a network of several reservoirs is more favorable than utilizing them separately. In the respect of the afire-mentioned integrated management, the following are regarded necessary: data base management in machine accessible form, inflow conditions at the reservoirs, flow predictions of river streams, predicted demand of water, and standard coding system for daily applications at sites. However, the research in the field projects of water resources engineering, so far was not been able to reach a satisfactory prechill applicable system. Therefore, for a rational management process, while seeking solutions to individual problems encountered in the process, a parallel focus should be made on developing a system which integrates the technical knowhow and on-site experiences. For this purpose, Fukuoka city was been selected as study area, with the intention of developing a water resource management system. As the first step of the study, a model that supplies information on estimating the water quantity that has to be extracted from each reservoir has been developed [1][2][3][4][5]. In this article, with the focus on the quantity of water extracted daily for purification purposes, it is attempted to construct an expert system for supporting the estimation of this volume. In other words, this system therefore is aimed at providing guidelines to the respective water resource managers in estimating water quantities that should be extracted from various resources.

The water supply for Fukuoka is mainly secured by four suburban rivers, multiple dams, and the long-distance water transferred from Chikugo river. However, except for Chikugo river, the rivers are secondary streams, and the capacities of the dams may not be sufficient either. Therefore, the present condition reveals that there is no flexibility for capacity expansion in any catchment area of these resources. Additionally, the future demand of water in the city is expected to rise continuously, and the water supply necessary to meet this demand may be forecasted. However, given the constraints in geography and environmental problems, there is hardly any room left for new constructions of large-scale water reservoirs.

In the present article, the focus is on the development of an expert system for estimating the quantity of water extracted, from the water supply sources. Simulations using the this expert system have been conducted and the results show that there exists a close resemblance between the actual and computed values of the water quantity extracted. It is further revealed that there is a high feasibility for a rule and experience based expert system to be applied to real-world situations within this framework.

2. Prevailing conditions on the estimation of extracted water quantity

In order to satisfy consumer demand in the entire city area, water managers estimate the volume demanded at each reservoir or dam considering the rules applied to extraction and the on-site conditions. If the expected demand cannot be satisfied, then either water is supplied from another water purification station, or a change of the distribution zone is made. This type of work is usually handled by the water management center of the city's water bureau, and the work procedure is as follows: First, in order to determine the daily demand at 9 a.m., managers at each dams and reservoir check the existing flow conditions at rivers and inflow conditions at catchment areas due to heavy rains if any. Also they collect simultaneous information from each purification station concerning the conditions there, and determine the volume of water distributed. Then, considering which day of the week it is, the weather condition, and other special characteristics of the day, they decide on both the expected demand at each purification station as well as the volume to be supplied to these stations from each reservoir. In this case, if a certain station is found unable to meet the demand at its distribution zone, as mentioned before, either the zone is changed or water is supplied by another suitable station instead. All these steps are regarded a complicated work schedule necessary for

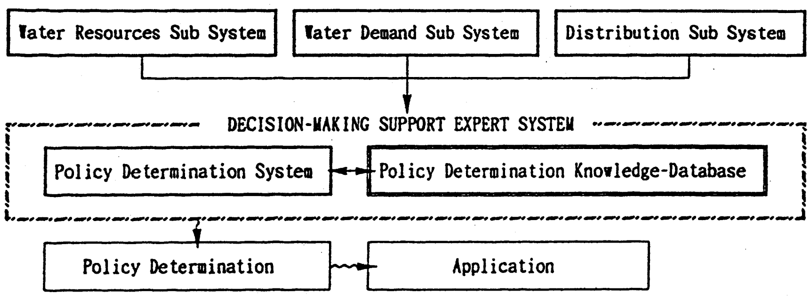

Figure 1 Outline of the water resource management system

accomplishing knowledge and experience for estimating the volume of water to be supplied to the purification stations.

3. Acquisition of rules, knowledge and experience

The expert system that is developed in this study is represented by a broken line frame in Figure 1. The system consists of two sub-systems, policy estimation system, and policy estimation knowledge database [2].

In compilation of knowledge and know-how, the basic rules have been re-organized. The rules are available in manuals but yet to be revealed, pertaining to extraction of water from resources and application in purification stations, according to whether the resource is either a reservoir or a dam. Additionally, we have conducted a number of questionnaire surveys and interviews on-site personnel, and obtained records on knowledge and experiences for extraction and application aspects. These are certainly based on real-world situations, but yet may be regarded as unrevealed.

4. Development of the expert system

As shown in Figure 2, water resources in Fukuoka city include 4 river reservoirs (R_1–R_4), six dams (D_1–D_6), long-distance transfer from Chikugo river (R_5), and 5 purification and distribution stations (P_1–P_5). Since Chikugo river is a primary stream,

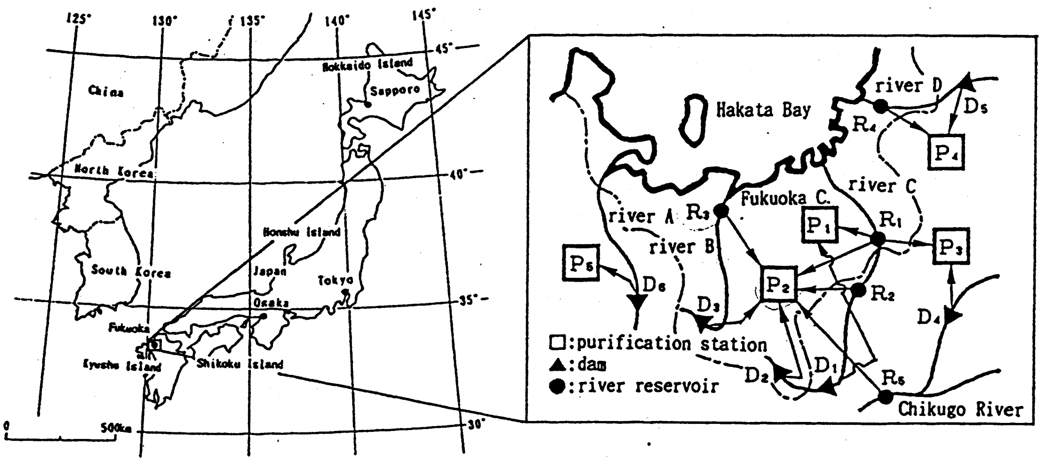

Figure 2 Location of Fukuoka City and water purification facilities

An example of the expression of Class (purification station)

frame name : purification station P1	
slot = maximum water volume prified	slot value = 174000 m^3
slot = minimum water volume prified	slot value = 40000 m^3
slot = aimed demand at station	slot value = user input
slot = sum of volumes anthorised at each resouce	slot value=demon procedure
slot = sum of possible volumes extracted from each resouce	slot value=demon procedure
slot = total of volumes extracted from each resouce	slot value=demon procedure

An example of the expression of Instance (water resouce)

frame name : river reservoir R1		
upper frame : purification station P1		
slot = volume used	facit name = 1/JAN - 31/JAN facit name = 1/FEB - 28/FEB : facit name = 1/DEC - 31/DEC	facit value = 58000 m^3 facit value = 50000 m^3 : facit value = 18000 m^3
slot = possible extracted volume	slot value = demon procedure	
slot = extracted volume	slot value = demon procedure	

Figure 3 An example of expression through a frame

its flow is comparatively stable and since the water demand in Fukuoka city is rather constant, we refrain from considering the conduit (R_5) in our system here. It is clear from the figure that in certain cases, many purification stations extract water from a single resource. However, especially in Meotoishi purification station (P_2), the extraction network is complicated, including the transfer from Chikugo, 4 river reservoirs, and 2 dams. Earlier, the stations were not inter connected, but the past experiences and lessons of severe draughts have now made possible a mutual accommodation of these stations,os that a fair distribution service to every zone of the city is achieved. As a way of expressing its fundamental knowledge, the expert system adopts a frame structure for each station and supply sources, while it uses production rules for extraction and application rules [6]. Let us consider an example of a station frame as indicated in Figure 3. Here this frame is named a class, and is made up of the following slots: maximum and minimum water volumes of the facility, predicted demand volume of the station, total water volume authorized at related resources, total possible volume extracted from related resources, total volume extracted from related resources. Again, the water resource frame is termed "instance", and constitutes the following slots: frame name (according to its river reservoir), upper frame definition of the related station, seasonally variable consumption, possible extraction volume, extracted volume. Next, we express the basic rules concerning extraction and application, and the experiences of the managers in terms of "IF~ THEN~" type production rules. Further, we make two sets of rules, in which the already revealed extraction-application related rules are defined as "basic rules", while those related with knowledge and experience but not made clear so far, are defined as "experience rules". Again, various numerical computational processes that are required in inference procedure are made to be taken care of by the demon procedure.

The outline of the system is illustrated in Figure 4. First, the 5 basic pieces of user information necessary to be input are date, flow condition at each river, usable water ratio at each dam, expected inflow at each dam, and predicted demand at the distribution zone of each station. With these data as a base, the system seeks access to desired frame or slot described above, while referring to the extraction/application rules as well as knowledge/experience rules.

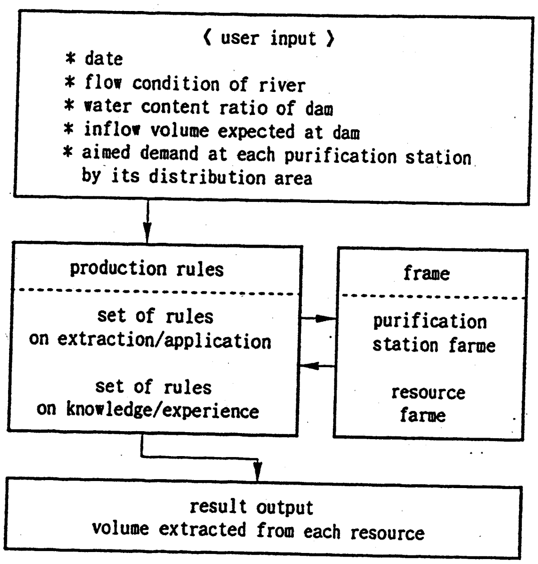

Figure 4 Development of the system in estimating the extraction water volume

The concrete procedure of the system is shown in Figure 5. When the system is started up, 1) a date is required to be input. When this is complete, it checks the authority rules that are subject to complex changes over the year and displays 2) authorized volume of water at each resource. Once this volume is confirmed, the user 3) inputs the flow condition at each river reservoir obtained through a phone call. Thereafter, once the rules on river flow conditions are checked, a tentative volume of

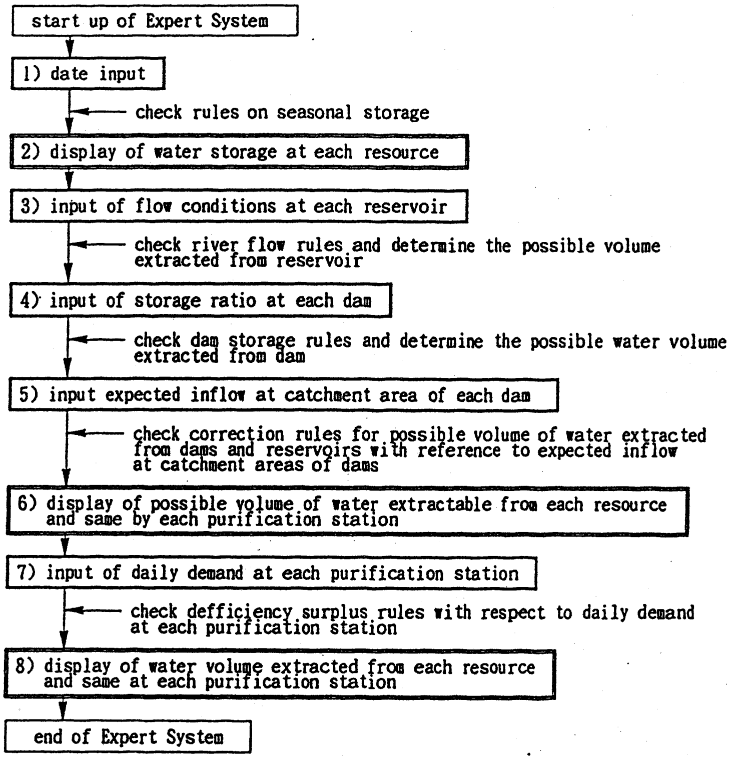

Figure 5 System procedure flow

water possible to be extracted from each supply source is determined. Likewise, when the user 4) inputs the available water ratio of each dam (on calling the dam site), rules related to the available water ratio of the dam are checked and a tentative volume that is possible for extraction at each dam is determined. Again, for 5) an input of expected inflow at each dam, correction rules on tentative volume possible for extraction at each reservoir and dam are checked and 6) corrected volume possible for extraction at each supply source and purification station is displayed. Here, 7) if the expected demand at each distribution zone of each purification station is input, deficient volume procedure rules on expected demand at each station are checked and finally 8) water volume extracted at each resource by each station is displayed. If the actual total of possible volumes extracted is greater than 6), then the excess amount is supplied to the zones where their expected demand is not satisfied. On the other hand, if the total of possible volumes to be extracted by each station is less than 7), then it is either necessary to make a reduction of its distribution zone or supplying the deficiency from another station.

However, the presently the system is unable to carry out adjustments from other stations since it is still at a developing stage as far as distribution zones are concerned. Therefore, in the case of surplus, 3), 4), 5), are considered and the volume extracted from the supply sources is decreased, but in the case of deficiencies, then an output message of "deficiency in meeting the expected demand" is displayed. At present, the possible volume to be extracted of 6) is considered an output result of the expert system, while the expected demand of 7) is computed using the actual values.

The computer hardware requirements for this system are an NEC PC 9801 with a 80 MB hard disk memory, a high resolution display, and a laser printer, while the software needs would be the expert shell "DAISOGEN" developed by AI SOFTWARE COMPANY.

5. Application and results

Simulations on extraction of water at 5 purification stations have been conducted for the year 1990 using the actual data. Also the accuracy of the system over the whole year has been verified by making comparisons between actual values and the results obtained from the simulations. Similar to the storage ratios, the simulations were conducted at 10-day periods, and the mean values of each 10-day period have been used in the computations.

Actual and computed values of the monthly variation of the water quantity extracted at each purification station P_1 through P_5 is compared in Figures 6 to 10. Although to some extent errors can be observed for certain months in stations P_1 to P_3, where the

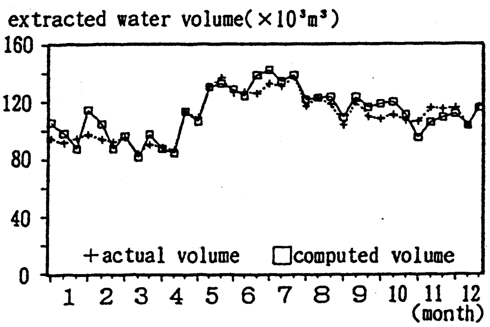

Figure 6 Water volume extracted in purification station P_1

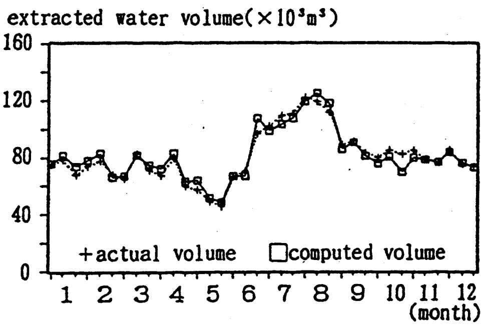

Figure 7 Water volume extracted in purification station p_2

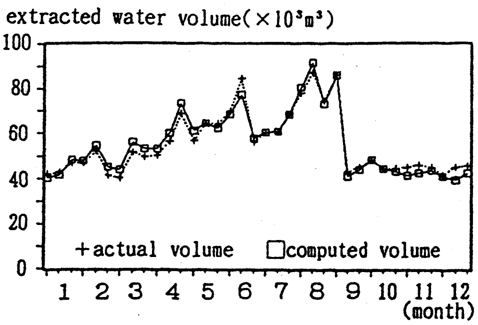

Figure 8 Water volume extracted in purification station P_3

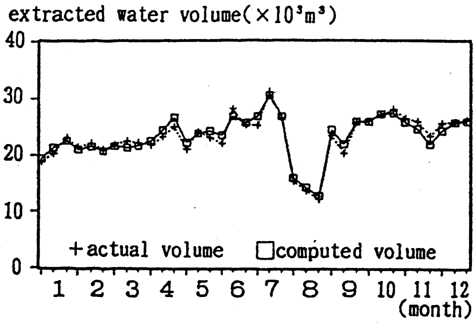

Figure 9 Water volume extracted in purification station p_4

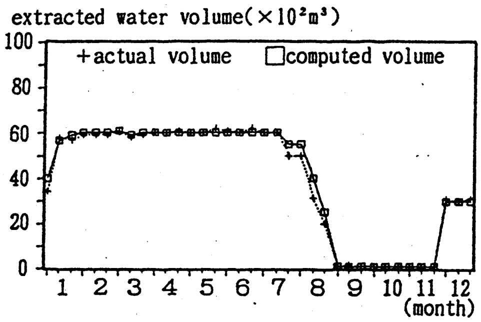

Figure 10 Water volume extracted in purification station P_5

distribution volumes are comparatively large (Figures 6-8), the stations of lower distribution volumes indicate almost no errors (Figures 9-10). In general, it is clear that the computed values through simulations are almost equal to the actual values of 10-day means. Therefore it may be expected that the system with behave quite well in providing guidelines to water managers in estimating the volumes to be extracted from supply sources and relevant applications.

6. Concluding comments

The prime objective of this study is to develop an integrated water management system covering the entire process, from the extraction level to the distribution level, with mutual consideration of the prevailing conditions at resources as well as related facilities.

As a step towards this system, the present article describes the construction of an expert system focussing on water extraction practice for managers in estimating the volume of extraction from each reservoir or dam. The system aims at lessening the burden on managers, avoiding problems in policy execution, providing diversification and continuation of knowledge and field experiences, with parallel objectives of establishing technical standards and providing new employee-education.

For this purpose, so called basic rules, which are not yet clear, have been collected from manuals concerning the extraction of water from supply sources and practices from purification stations. Also field interviews have been conducted to compile knowledge and experiences of managers. This information has subsequently been converted into production rules. Both these types of rules are thus separately defined as rule sets in the system, which primarily adopts a frame structure for representing the basic data on characteristics of river reservoirs, dams, and purification stations.

In testing the applicability of the expert system, simulations have been conducted on changes of water volumes extracted at stations, where the data collected are the 10-day means covering a period of a year. From the results it is observed that the computed values are almost equal to the actual ones, thus confirming the realization of a concept that links rules and experiences concerning water extraction and practice in estimation of the volume of water to be extracted from supply resources. Present stage of the system is only limited to purification station as its unit.

However, with respect to future developments in this study, we may expect that the water managers would construct a system, adding and re-organizing field experiences, while attaching necessary rules as well. Thereby our objective is to achieve fullness in supporting capabilities of the expert system in the simulations of future aspects of extraction and application in related planning processes when there occur changes in the conditions of the resources.

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