Modeling and analysis of water resources system problems by using the causal feedback loop diagram of system dynamics

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Abstract: -To the work of modeling and analysis of water resources system problems, it is hard to realize completely the structure and behavior of a system just from a system diagram, flowchart, or the outcomes of a software simulation. With a causal feedback loop diagram of system dynamics, the casual interactive relationships among model variables and parameters can be revealed to elucidate the nature of impact dynamics and feedback, portraying information feedback in a system. Therefore, in this paper, the causal feedback loop diagram of system dynamics was briefly described and the feedback characteristics within a system was identified by using the technique of causal feedback loop diagram through two case studies of a general reservoir operation problem and a water resources system capacity-expansion planning. According to scenario results and analysis, a causal feedback loop diagram of system dynamics is one approach that can help decision maker to better grasp the structure and characteristics of a system.

Key-Words: - Causal feedback loop diagram; System dynamics; System analysis; Water resources system; Reservoir operation; Flowchart; Modeling.

1 Introduction

The most important consideration in the planning and operation of a water resources system is to satisfy consumer demands. The water resources system planning can be done more efficient if one can check the reliability of a water resources system in advance. In general, reliability is defined as the probability that a system performs its mission within specified limits for a given period of time in a specified environment [1]. Besides reservoirs, the most important hydraulic facilities in a water resources supply system, can have a significant impact on regional water conservation. The conventional system analysis approaches for reservoir operation problems have been applied to simulate, optimize, or choose a compromise alternative solution based on trade-offs between conflicting objectives [2, 3, 4, 5, 6, 7, 8, 9].

In the past, the system diagram and flowchart always serve as the blueprints of a model development for system analysis. However, neither of these two diagrams is enough to provide all the information required for program development, because the system diagram presents the structure of system components and the flowchart describes the computation procedures in the model. Besides, the casual interactive relationships among model variables and parameters are not revealed from these two diagrams such that it is difficult for a programmer to grasp immediately all the contents and relationships merely by viewing both diagrams.

Furthermore, a feedback refers to the situation of X affecting Y, and Y in turn affecting X, perhaps through a chain of causes and effects. If dynamic behavior arises from feedback within the system, it is likely that problems might worsen over time. This is similar to how reservoir levels vary, which can be represented as a problematic trend over time. Finding an effective mode of operation usually requires understanding the system feedback structure. Nevertheless, the characteristic of feedback to reservoir operation problem can't be showed within the system diagram and flowchart.

System dynamics and its models were originally developed at the Massachusetts Institute of Technology in the 1950s and published in the article 'Industrial Dynamics: A Major Breakthrough for Decision Makers' by Jay W. Forrester in 1958. He analyzed relationships and processes in industry [10]. After that, during the late 1950s and early 1960s, Forrester and his graduate students team had changed the format of system dynamics from hand-simulation to computer-modelling [11].

A causal feedback loop diagram of system dynamics provides an understanding of the nature of impact dynamics and feedback. A causal feedback loop portrays information feedback in a system [12], while system dynamics models are used to depict and analyze dynamic systems [10]. Causal refers to a cause-and-effect relationship. The presentation of such a relationship consists of variables, abbreviations and arrows. The arrows link variables as shown in Fig.1, wherein the cause-and-effect relationships can be clearly indicated by adding "+" or "-". A " + " on an arrow connecting two variables indicates a positive correlation, which means as the variable at the tail of the arrow increases, the variable at the head of the arrow also increases. A " - " indicates a negative correlation; as the variable at the tail of the arrow increases, the variable at the head of the arrow decreases.

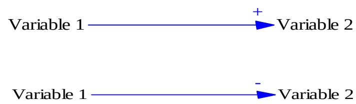


Fig.1. Causal relationship between variables.

The word feedback loop refers to a closed chain of cause-and-effect and a change in one variable among the loop feeds back to reinforce or slow down the initial change. There are two types of feedback loops. One is called positive, shown in Fig. 2 [13], indicated by a " ⊕ " sign, if it contains an even number of negative causal links. The other is called negative, shown in Fig.3, indicated by a " ⊖ " sign, if it contains an odd number of negative causal links. Positive causal feedback loops generate growth, amplify deviations, and reinforce change. This behavior in mathematics is called "dispersion", shown in Fig.4, Negative causal feedback loops seek balance, equilibrium, and stasis. Also, negative causal feedback loops act to bring the state of the system closer to a goal or desired state. This behavior in mathematics is called "convergence", shown in Fig.5 [14]. From above, using the technique of causal feedback loop diagram in reservoir operation problem is easy to present the characteristic of feedback within a system.

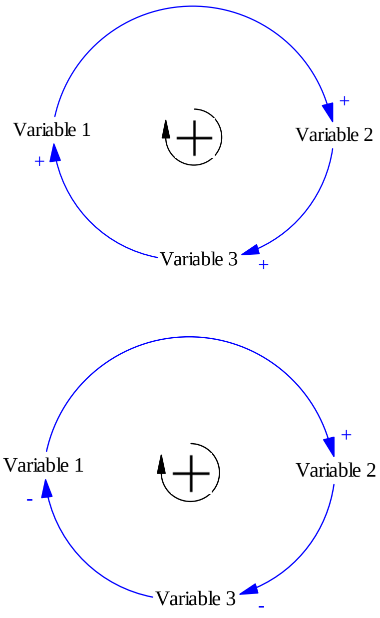


Fig.2. Positive causal feedback loops.

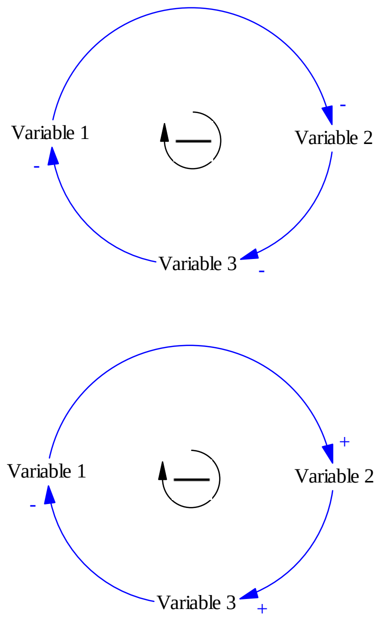


Fig.3. Negative causal feedback loops.

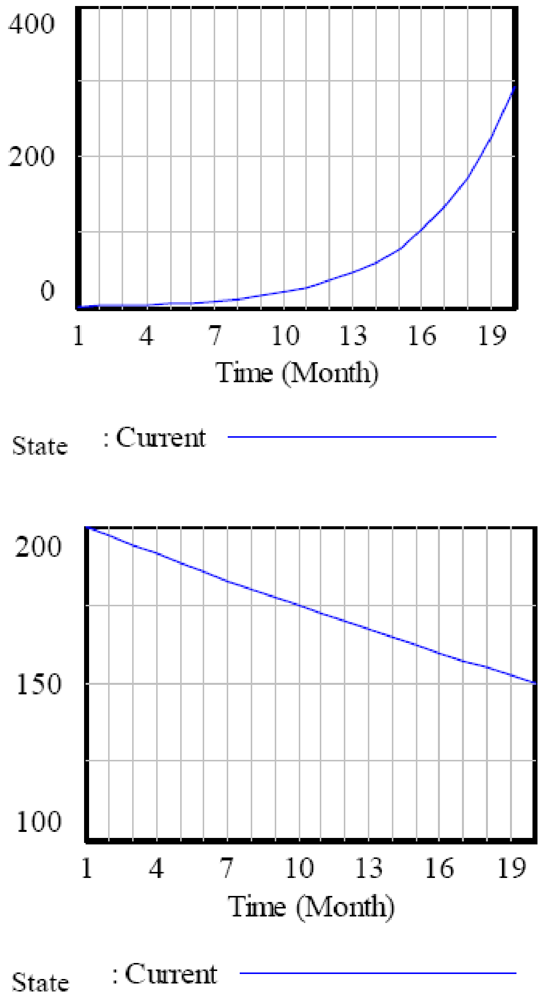
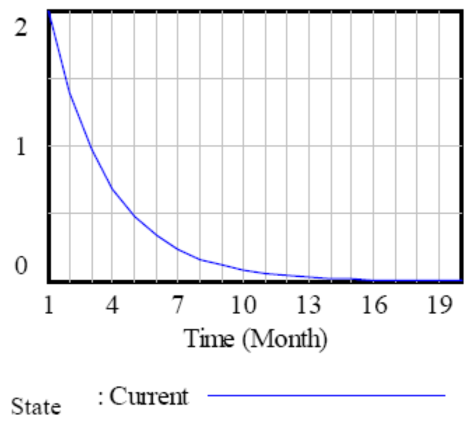


Fig.4. Behavior of positive causal feedback loops.



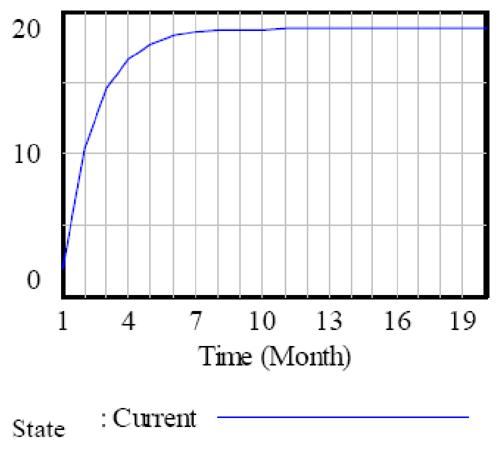


Fig.5. Behavior of negative causal feedback loops.

Although system dynamics was proposed more than forty years ago, only a few researches had applied it in the field of water resources [15, 16, 17]. Furthermore, these studies do not discuss the feedback characteristics of causal feedback loops within a system. Therefore, this paper aims to address the above mentioned issues through the following cases.

2 Case studies

Water resources systems are far more complex than anything analysts have been, or perhaps ever will be, able to model and solve. The reason is not simply any computational limit on the number of model variables, constraints, subroutines or executable statements in those subroutines. Rather it is because we do not understand sufficiently the multiple interdependent physical, biochemical, ecological, social, legal and political (human) processes that govern the behavior of water resources systems [20].

Infrastructure (hydraulic structures) decisions and their costs usually are more lengthy through meetings and administrative coordination such that the decisions are often made too late to carry. However, in the stage of initial planning, the transition patterns or trends of related factors and the interactions among them are the primal interests for decision makers. For those conditions, System Dynamics serves better than traditional simulation or optimization approaches do.

The System Dynamics theory is jointly related to system thinking: causes and effects are not linear in time and space, but multiple feedback loops interact as variables of a complex system. As a graphical qualitative representation of the relationships between interrelated factors affecting a system and its problems, the causal loop representation requires defining all variables and mutual relationships in a system. To obtain a quantitative outcome and analyze the system behavior, a computer-compliant "System Dynamics model" is necessary to translate the influence diagram into enabling calculations of a number of simultaneous feedbacks [3]. The details of the causal feedback loop diagram applied to a reservoir operation problem and a water resources system capacity-expansion planning are explained in the following two case studies.

2.1 Case study one: reservoir operation problem

Shown in the left side of Fig.6, the system diagram of a hypothetical water system is basically comprised of a reservoir (*S*, represented by an inverse-triangle), an inflow into the reservoir (*I*, represented by an arrow) and a water supply from the reservoir (*O*, represented by an arrow.) Within a time period, five operational steps to compute the water supply of the reservoir are formulated in the flowchart, the right side of Fig.6. Meanwhile, those computation steps also illustrate how the variables in Fig.6, change their values during the system operation.

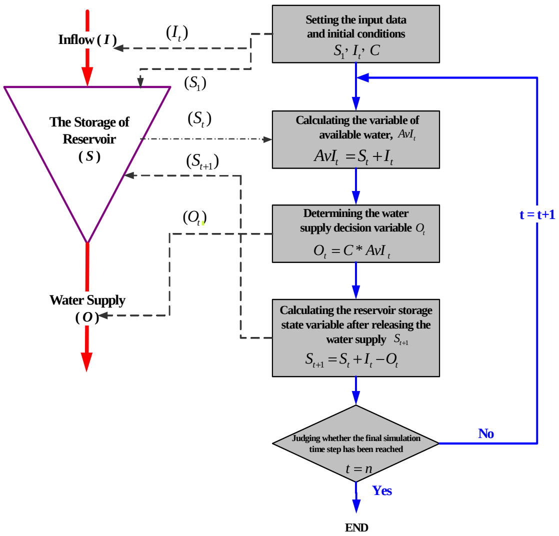


Fig.6. Visual connective arrow between system diagram and flowchart drawing.

Step1.Setting the input data and initial conditions.

Conventionally, setting input data and initial conditions is always the first step in the flowchart. In this case, the inflow of the reservoir at every time period (*It*), initial reservoir storage volume at time t = 1(*S1*) and the coefficient of water supply (*C*) are given as input data. Then an unknown decision variable, the state variable and the related variable can be estimated.

Step2.Calculating the variable of available water.

The available water at time *t* is the sum of reservoir storage and inflow at time *t*.

$$AVI_t = I_t + S_t \qquad t = 1 \ldots n \qquad (1)$$

Where, *AVIt* is the available water of system at time *t*; *St* denotes the storage of the reservoir at time *t*; *It* represents the inflow of reservoir at time *t*; and n is the number of simulated periods.

Step3.Determining the water supply decision variable.

The determination of the water supply from the reservoir (*Ot*) is assumed to be a linear function, denoted by equation (2), consisting of the available water supply and the coefficient of water supply. If the value of the coefficient is 0.5, it means that only half the volume of available water can be released to meet demand at time *t*; the rest must be stored in the reservoir.

$$O_t = C \times AVI_t \qquad t = 1 \ldots n \qquad (2)$$

Step4.Calculating the reservoir storage state variable after releasing the water supply.

Equation (3) is the transition function of reservoir storage during time interval [*t*, *t+1*]. This implies that reservoir storage at time *t+1* (S_{t+1}) depends on the storage at time *t* (S_t), the inflow of reservoir at time *t* (*It*), and the water supply of reservoir at time *t* (O_t).

$$S_{t+1} = S_t + I_t - O_t \qquad t = 1 \ldots n \qquad (3)$$

Step5.Judging whether the final simulation time period has been reached.

The simulation stops when t = n, otherwise it returns to step2 and continues the procedures for the next time period.

From Fig.6, the system diagram displays the relation among the components, the structure, in a water supply system, while the flowchart demonstrates the operating/computing procedures of the system. The values of three variables (*I*, *S*, *O*) at every time period in the system diagram must always be defined by the flowchart. However, the interaction between the system diagram and flowchart is not presented within neither of these two diagrams, and those hidden information are usually essential for implementing a program.

For this reason, this study tries to draw several visual connective arrows between the system diagram and flowchart to illustrate their underlying hidden relationships. To set the input data and initial conditions in the first rectangular box of flowchart, two values required for the system diagram, *It* and *S1*, are provided. Thence, two visual connective arrows from the first rectangle into the inflow (*I*) and storage of reservoir (*S*) of the system diagram were added to show the relationship. To calculate the available water (*AVIt*) in the second rectangle of flowchart based on the formula $\mathrm{AVI}_t = I_t + S_t$, the inflow data *It* at every time step is given directly from the first rectangle of the flowchart. However, only the initial storage volume of reservoir at time t = 1 (*S1*) is from the first rectangle, the storage in every subsequent time step, i.e., S_t, t > 1, has to be specified from the system diagram such that a visual connective arrow displays how S_t is moved from the system diagram into the flowchart. In the other hand, the water supply decision variable (O_t) in the third rectangle of the flowchart is calculated based on the results from previous rectangles, therefore, a visual connective arrow from the this box into the water supply (*O*) of the system diagram is utilized to reveal the relationship. To obtain the reservoir storage state variable after releasing the water supply, the value of S_{t+1} is found through the equation in the fourth rectangular box of the flowchart. Consequently, another visual connective arrow from this fourth box is linked into the storage of reservoir (*S*) of the system diagram. In conclusion, the design of the five visual connective arrows clearly displays the relationships between the system diagram and the flowchart in Fig.6.

Next, reference to above variables of *I*, *S*, *O*, *AVI* and *C*, the causal feedback loop herein is a negative causal feedback loop, as shown in Fig.7. The loop shows how the storage of the reservoir, the available water for supply, and the actual volume of water supplied all change and affect one another in each simulated time step. When the storage of the reservoir at time *t* increases, the available water at time *t* also increases. This will cause the water supply at time *t* to rise, while the available water at time *t* increases. As the water supply increases, the storage of the reservoir at time *t+1* will decrease. The negative sign in the center of this loop means that the storage of the reservoir will gradually approach steady levels over time, a behavior which in mathematics its called convergence. Furthermore in Fig.7, the inflow and the coefficient of water supply are not internal variables of this loop, thus they are called external variables. They will strongly affect the time spent on and scale of convergence. When the inflow at time *t* increases, the available water at time *t* and the storage of the reservoir at time *t+1* also increases. As the coefficient of water supply increases, the water supply will increase.

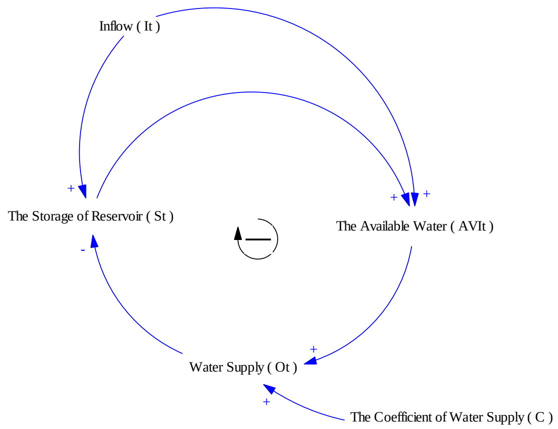


Fig.7. Causal feedback loop in case study one.

In reality, the determination of the water supply is strongly related to water demand, which should be met to the fullest extent possible. Based on this premise, case study one uses a variable of water demand (*Dt*) instead of the coefficient of water supply (*C*). A modified causal feedback loop is also shown in Fig.8, wherein the volume of available water (*AVIt*) is compared to water demand (*Dt*). If the volume of available water is greater than the volume of water demand $(\mathrm{AVI}_t > D_t)$, this indicates that the reservoir not only has enough water to meet water demand, but also that the rest can be stored in the reservoir. In this situation, the causal relationship between the available water and the water supply is inactive because the volume of water supply is always equal to the volume of water demand whatever the variation of available water

$(O_t = D_t)$. Therefore, the causal feedback loop in Fig.8 should be modified as shown in Fig.9. There is no negative causal feedback loop in Fig.9 due to an inactive link between the available water and the water supply, preventing convergence. Otherwise $(AVI_t \leq D_t)$, the maximum water supply of a reservoir is equal to the volume of available water $(O_t = AVI_t)$ such that the causal relationship between the available water and the water supply is active. Therefore, a negative causal feedback loop exists and convergence takes place. From the above, the determination of the water supply from the reservoir (*Ot*) must obey a if-then-else rule as denoted by equation (4),

$$\text{If } AVI_t > D_t \text{ Then } O_t = D_t$$
$$\text{Else } O_t = AVI_t \quad t = 1 \dots n \qquad (4)$$

Where *AVIt* is the available water of system at time *t*; *Dt* denotes the water demand at time *t*; *Ot* is the water supply of a reservoir at time *t*; and n is the number of simulated periods.

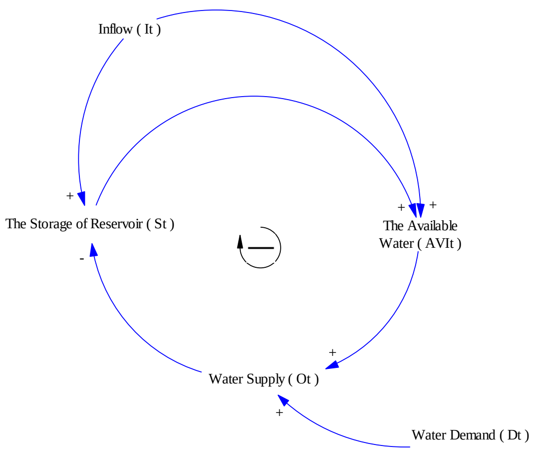


Fig.8. Causal feedback loop considering the water demand (*Dt*) in case study one

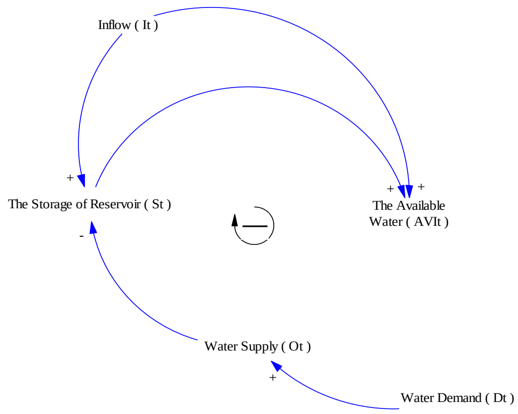
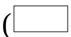
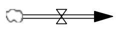
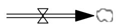


Fig.9. Causal feedback loop under $AVI_t > D_t$ in case study one

Next, the tool of simulation model design in system dynamics contains objects for implementing the design of a causal feedback loop, comprising stocks, flows, converters and connectors (Chang et al., 2011). Stocks () represent 'how things are,' with accumulations serving as resources. Flows, which represent 'how things are going', are used to represent components whose values are measured as rates. The symbol  represents an inflow and  an outflow. It is easy to present the topology relation among the components in a water supply system by stocks and flows. Converters convey inputs into outputs and they can represent information or material quantities. Connectors ( ) link stocks to converters and flow regulators, or converters to other converters, and they do not take on numerical values; they are transmitting them. The model can be designed as presented in Fig.10 with stocks, flows, converters and connectors in reference to the causal feedback loop in Fig.8. The simulation model can then be developed and implemented using systems dynamics software according to the above model design.

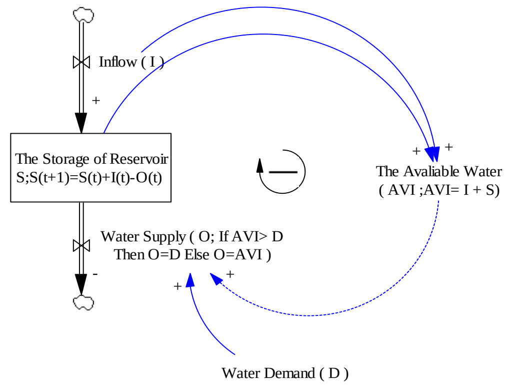


Fig.10. Simulation model design in case study one.

There are two kinds of scenario simulations conducted in this case. The first one is the change of inflow under *Dt* = 120 m^3 and *S1* = 500 m^3, while the second one is the change of water demand under *It* = 100 m^3 and *S1* = 500 m^3. In the first scenario, reservoir storage levels shown in Fig.11 will stabilize over time when the volume of inflow is less than the volume of water demand $(I_t \le D_t)$. Given $I_t \le D_t$, the water deficit between *It* and *Dt* must be compensated for by using reservoir storage (S_t), which inevitably decreases over time whether the initial storage (*S1*) is large or small. Therefore, the condition of $AVI_t \le D_t$ (*AVIt* consists of *It* and *St*) may occur at any one time step during the model simulation. This will result in the volume of water supply in the reservoir equaling the volume of available water $(O_t = AVI_t)$ from equation (4). Thus, the causal relationship between the available water and the water supply is active. Then a negative causal feedback loop, displayed in Fig.8, exists and also systematically converges. On the other hand, reservoir storage levels shown in Fig. 11 will grow constantly over time when the volume of inflow is larger than the volume of water demand $(I_t > D_t)$. Given $I_t > D_t$, the volume of available water (*AVIt* consists of *It* and *St*) is always greater than the volume of water demand $(AVI_t > D_t)$. According to equation (4), the volume of water supply is always equal to the volume of water demand $(O_t = D_t)$. Next, the condition of $O_t = D_t$ creates an inactive causal relationship between the available water and the water supply as presented in Fig.9. Thus, a negative causal feedback loop does not exist such that convergence will not occur. Instead, the surplus water between *It* and *Dt* is stored in the reservoir which explains why reservoir storage levels will grow constantly over time.

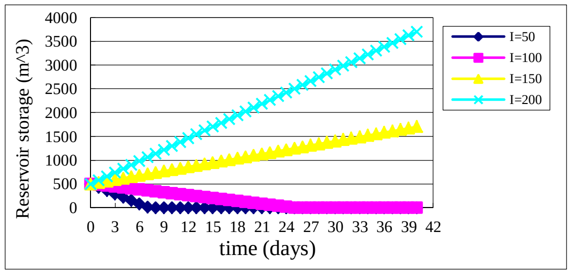


Fig.11. Results of first scenario in case study one (*Dt* = 120 m^3).

Simulation results in the second scenario are presented in Fig.12, indicating that reservoir storage levels will stabilize over time when the volume of inflow is less than the volume of water demand $(I_t \le D_t)$. Fig.12 also indicates that reservoir storage levels will grow constantly over time when the volume of inflow is larger than the volume of water demand $(I_t > D_t)$. This explanation for this is the same as in the first scenario.

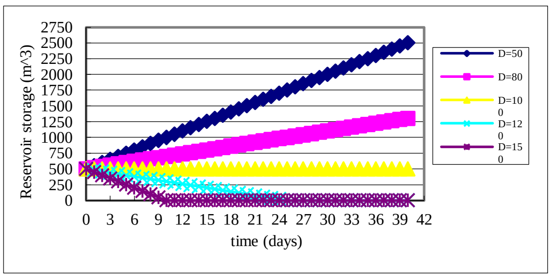


Fig.12. Results of second scenario in case study one (*It* = 100 m^3).

2.2 Case study two: water resources system capacity-expansion planning

Except the reservoir operating problem, the causal feedback loop is also well applied in the issue of water resources system capacity-expansion planning. The illustration in Taiwan is described as follows.

The Shortage index (SI) developed by the U.S. Army Corps of Engineers is commonly used in Taiwan. The water shortage index is defined as

$$SI = \frac{100}{N}\sum_{i=1}^{N}\left[\frac{Sh_i}{T_i}\right]^2 \qquad (5)$$

Where N = number of periods; Sh_i = shortage volume during the period i ; Ti = target demand during the period i and $\sum$ is the summation of the indicated values for all periods. Ten days is usually taken as the period of reservoir operation for planning purposes in Taiwan.

The value of one of shortage index is acceptable to the Water Resources Agency in Taiwan. If the value is the bigger than one for water system considering the increased water demand of high economic growth indicates that water shortage is serious. So how to formulate suitable strategies to maintain a steady water supply for the target public water demand is the major concern. Furthermore, if all suggested strategies are implemented simultaneously, the water shortage problem can be modified significantly. However, the financial impact of strategies will have to be assessed for increasing implementation feasibility. Consequently, another concern in this issue is budget constraint. The total cost, comprising construction and operating costs for all proposed strategies, is confined by budget constraints and the facility capacity needs to be reduced where the total cost is larger than budget constraints.

Figure.13 shows a causal feedback loop for water resources system capacity-expansion planning. The capacity-expansion planning problem is to expand the capacity of an existing water resources system to fulfill increased water demand. Figure.13 contains two negative feedback loops. Negative causal feedback loops seek balance, equilibrium, and stasis. Also, negative causal feedback loops act to bring the state of the system closer to a goal or desired state. Loop 1, describing system operation phase of the problem, consists of total water supply, water shortage and water supply from the planning facility. Loop 2, describing the facility expansion phase of the problem, consists of total water supply, water shortage, accumulated water shortage, shortage pressure, capacity of planning facility (for example : Artificial Lake), water supply from planning facility and total water supply. Loop 1 indicates the total water supply comes from the existing system and planning facility, and the water shortage is the discrepancy between total water supply and water demand. An increase of water shortage induces the increment of water supply from planning facility and existing system, thereby reducing the water shortage. Loop 1 describes the effort to reduce water shortage in the operation phase. Loop 1 is a negative feedback loop, meaning water shortage in time will approach a small value for a given facility capacity. However, because of the hydrological cycling of dry and wet seasons, water shortage is unavoidable. The shortage index as previously defined represents the average condition of water shortage in a given time period. On the other hand, it implies the risk of a water shortage occurring. The higher the index value, the higher the risk of water shortage. In Loop 2, the water shortage accumulated for each time step and the accumulated water shortage defines a water shortage index. If the shortage index value for a given period is larger than a specific level, it implies water shortage risk is not acceptable for operations and action is triggered to increase planning facility capacity. The increment of system capacity reduces the risk of a water shortage through modifying the system structure. Loop 2 is also negative feedback loop, meaning the system as a whole will approach the given water shortage risk level in the long run. In summary, the causal feedback loop shown in Figure.13 considers both the system operation and facility planning phases for a capacity-expansion problem in water resources system planning.

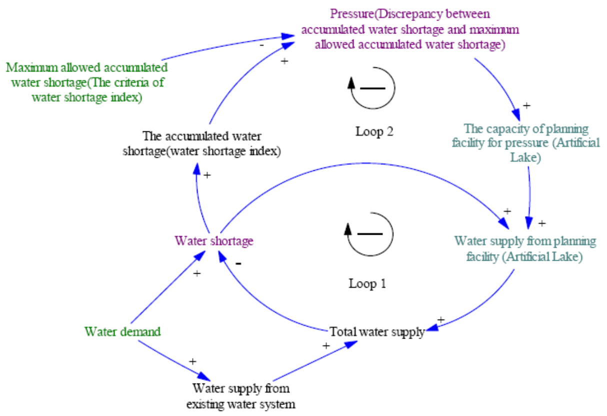


Fig.13.The causal feedback loop for water resources system capacity-expansion planning

Figure.14 shows a potential extension of Figure.13 by adding the consideration of budget constraints. This is also a design of Loop 3. Loop 3 demonstrates that increasing water supply and facility capacity will increase the operation cost and construction cost respectively, thus increasing total cost. The total cost is confined by budget constraints and the facility capacity needs to be reduced if the total cost is larger than budget constraints.

For example, if the value of SI in the fifth year is bigger than 1 (i.e., the value of shortage index acceptable to the Water Resources Agency in Taiwan), the capacity of new facilities or existing facilities is set as a maximum value after the fifth year. The value of the shortage index and total cost in every scenario can be obtained after model simulation is completed. Because total cost is confined by budget constraints, any scenario with the total cost larger than budget constraint would never be considered as a feasible solution.

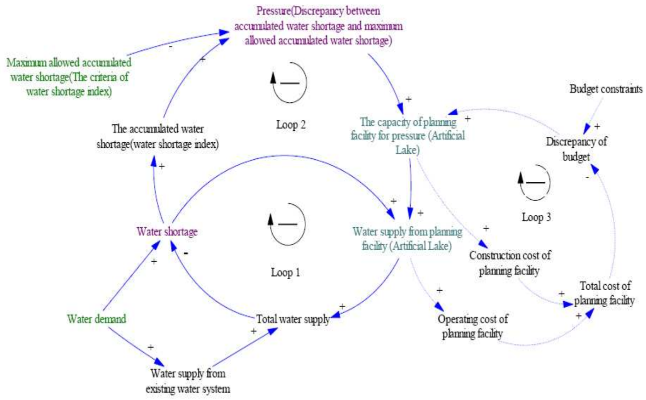


Fig.14.Causal feedback loop for water resources system capacity-expansion planning considering budget constraints

Figure.15 displays the system dynamics model (also called the stock-flow diagram) in this study. The rectangles are the stocks that graphically representing the volume of water in dams, reservoirs, water purification treatment plants, artificial lakes, and water reclamation centers of water resources system. The connectors with valves are the flows of water in or out of a given stock. The other variables are converters that denote the rules or conditions controlling the stocks and flows.

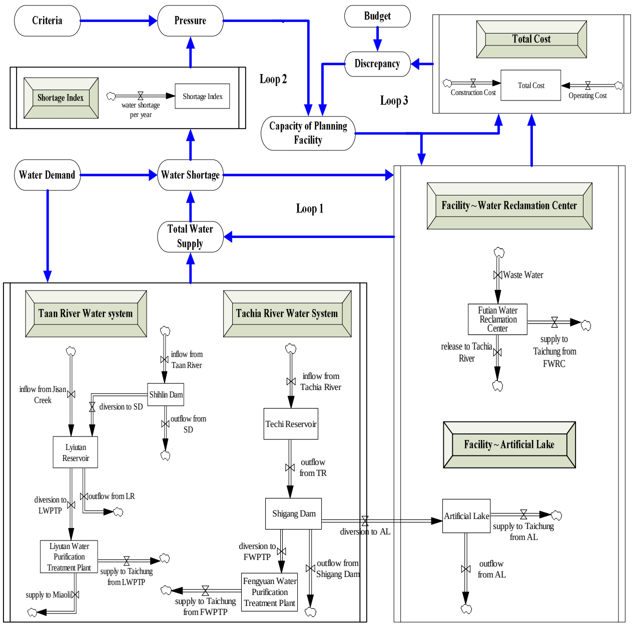


Fig.15. System dynamics model

3 Conclusions

Identified as a methodology and mathematical modeling technique for conceptual pattern of complex issues and problems [11, 19], system dynamics is applied to solve two water resources system problems systematically and effectively in this research through the causal feedback loop diagrams. It produced the following findings: (1) In case study one, according to scenario results, our proposed design of causal feedback loop has the ability to show the causal relationships among variables in the system and analyzes effectively the feedback of system to reservoir operation problems. (2) In case study two, the causal feedback loop diagram shows the causal relationship among variables in the system and effectively analyzes a problem related to water resources system capacity-expansion planning.

In conclusion, it is hard to realize completely the structure and behavior of a system just from a system diagram, flowchart, or the outcomes of a software simulation. A causal feedback loop diagram of system dynamics is one approach that can help decision maker to better grasp the structure and characteristics of a system. It uses a perspective based on information feedback and mutual or recursive causality to elucidate the dynamics of concerned system. Therefore, this study demonstrates two simple cases that adopt the causal feedback loop diagram of system dynamics to design and analyze reservoir operation problems more easily understood by general water resources engineers. It is also believed that the study can serve as a useful reference to general water resources engineers who would like to apply the causal feedback loop of system dynamics in their works.

In the future study, we will try to propose a systematic approach to transfer the system diagram and flowchart into a single stock-flow diagram which can clearly present the problem structure and help to establish a simulation model. On the other hand, Taiwan has experienced the driest year in 2015. Therefore, our future research direction will also focus on the modeling and analysis of drought problems by using the causal feedback loop diagram of system dynamics to illustrate the appropriate platform of water right negotiation among stakeholders.

References:

[1] Camelia Gavrila, Andreea Vartires, Ion Gruia, and Florinela Ardelean, *Reliability Analysis of Water Distribution Systems*, Environment, 2013, pp.198-203.

[2] Chang, L. C., and Chang, F. J., *Multi-Objective Evolutionary Algorithm for Operating Parallel Reservoir System*, Journal of Hydrology, 2009, pp.12-20.

[3] Chang LC, Yang CC, *Optimizing the rule curves for multi-reservoir operations using a*

genetic algorithm and HEC-5, Journal of Hydroscience and Hydraulic Engineering JSCE, 2002, pp.59-75.

[4] Mitchell VG, McCarthy DT, Deletic A, Fletcher TD, *Urban stormwater harvesting - sensitivity of a storage behaviour model*, Environmental Modelling & Software, 2008, pp. 782-793.

[5] Oliveira R, Loucks DP, *Operating rules for multi-reservoir systems*, Water Resource Research, 1997, pp. 839-852.

[6] Reddy MJ, Kumar DN, *Multi-objective particle swarm optimization for generating optimal trade-offs in reservoir operation*, Hydrological Processes, 2007, pp.2897-2909.

[7] Soncini-Sessa R, Castelletti A, Weber E, *A DSS for planning and managing water reservoir systems*, Environmental Modelling & Software, 2003, pp.395-404.

[8] Wang, C. Y. and Wang, J. B., *Analysis and Evaluation of Taiwan Water Shortage Factors*, Asian Social Science, 2010, pp.44-67.

[9] Yang CC, Chang LC, Yeh CH, Chen CS, *Multi-objective planning of surface water resources by multi-objective genetic algorithm with constrained differential dynamic programming*, Journal of Water Resources Planning and Management ASCE, 2007, pp.499-508.

[10] Dipartimento di Ingegneria meccanica, energetica, gestionale e dei trasporti, *System Dynamics Model for Simulation the most effective elimination of accidental and operational injuries at the Public Transport and prospect of using IT innovations (SBA)* , Recent Advances in Economics, Management and Marketing, 2014, pp.106-111

[11] Putsadee Pornphol, Suphamit Chittayasothorn, *A Conceptual Schema of the System Dynamics Casual Loop Diagram*, Recent Advances in Knowledge Engineering and Systems Science, 2013, pp.86-91

[12] Forrester JW, Industrial dynamics, Productivity , 1961.

[13] Yang, C. C., and Yeh, C.H., *Application of Systems Dynamics in the Environment Risk Management of Project Management for External Stakeholders*, Systemic Practice and Action Research, 2014, pp.211-225.

[14] Sterman J, *Business dynamics: systems thinking and modeling for a complex world*, McGraw-Hill, 2000.

[15] Xu, Z. X., Takeuchi, K., Ishidaira, H., and Zhang, X. W., *Sustainability Analysis for Yellow River Water Resources Using the System Dynamics Approach*, Water Resour. Mgmt., 2002, 239-261.

[16] Stave, K. A., *A System Dynamics Model to Facilitate Public Understanding of Water Management Options in Las Vegas*, J. Environ. Mgmt., 2003, 303-313.

[17] Sehlke, G., and Jacobson, J., *System Dynamics Modeling of Trans-Boundary Systems: the Bear River Basin Model*, Ground Water, 2005, 722–730.

[18] Albertode Marco, Carlo Rafele, *Simulating Regional Logistics: the North-Western Italy Case-Study*, 6th WSEAS International Conference on System Science and Simulation in Engineering, Venice, Italy, November 21-23, 2007, pp.274-279

[19] Stanislav Tripes, Veronika Zelena, Jan Voracek, Pavel Kral, *Knowledge Modeling of National Sport Policy*, Mathematics and Computers in Contemporary Science, 2013, pp. 54-59.

[20] Daniel P. Loucks and Eelco van Beek, *Water Resources Systems Planning and Management*, UNESCO, 2005.