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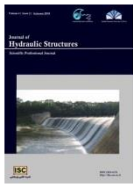

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A Conceptual Framework of a Surrogate-based Quality-Quantity Decision Support System (Q2DSS) for Water Resources Systems

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Abstract

The water crisis in different countries of the world has made the earth undergo tremendous changes compared to the past years. Therefore, it is very necessary to have intelligent systems that can help managers make correct and optimal decisions in various possible conditions. In recent years, the biggest challenge faced by water resource managers in the Karun Basin in Iran has been the decline in the quality of surface waters in the downstream areas of the basin. In this research, a surrogate-based model has been developed for predicting and controlling the quantity and quality of water in different parts of the basin. As a decision support system, this model can evaluate the quantity of water at different points in the basin and also predict its quality in various probable conditions. This model will also be used to extract optimal operating policies with the aim of satisfying quality constraints in different conditions. The model can help decision makers in the optimal management of the system and also greatly reduce the losses caused by quality issues in possible future situations.

Keywords: Quality Management, Surrogate, Water Resources, Intelligent computational modelling.

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1. Introduction

Water resources are quantitatively and qualitatively limited in Iran's plateau [1]. This has necessitated the principled and optimal utilization of the existing water resources [2]. However, most of the water basins in Iran, known as water resource systems, lack long-term management schedule or optimal operating rules, and are mainly based on individual experiences of operators or managed through very simple relationships without prospecting [3]. With the development of optimization methods and the introduction of intelligent computing methods in recent years, the

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optimal operation of the reservoir systems has entered a new phase [4]. Investigation of the research studies conducted in this field shows that the operation of multi-reservoir water resources systems is known as a complex issue in planning and decision making [5]. Since finding suitable operating policies for such issues is very difficult due to the dimensional complexity of the problem, they are often referred to as large-scale problems [6-10]. A coordinated and effective management of such systems should be able to provide and implement a policy that controls the storage volumes and reservoir releases to result in maximal benefits or tolerance of minimum cost for the whole system [11]. To achieve such goals, managers and system administrators usually prefer to use predefined rule curves that make decisions based on the existing system conditions [5]. Such operating curves are usually derived from the integration of simulation models and efficient optimization algorithms. Meanwhile, applying effective surrogate modelling can reduce the computational cost of water resources simulation and optimization models [12]. The surrogate modelling has recently become more popular in the field of analyzing water distribution networks [13-17].

Due to the complex nature of multi-reservoir systems, and the technical difficulty in identifying the optimal management policies for water resources systems at a basin scale, most simulation and optimization models applied to optimize these systems are developed by considering multiple assumptions and simplifications [18]. Despite of the large number of developed optimization algorithms, all the existing computational algorithms do not have the same ability to solve various problems [5, 19]. Therefore, finding powerful computational algorithms or computational solutions that reduce the simplifications in system modeling is still one of the most important issues in the area of water resources operating problems. Surrogate models can be assumed as appropriate facilities to achieve less complicated models in the field of basin-river management.

The water crisis in different countries of the world has made the earth undergo tremendous changes compared to the past years [20]. Conventional operating policies that have been developed and considered as optimized strategies for many years now should be redefined based on recent resources constraints [10]. In addition, extracting optimal policies for utilizing resources systems is not efficient regardless of the quality of water at a basin. This issue is becoming increasingly important due to the increased pollution caused by industrial development and agricultural land development [2]. Considering the actual amounts of water received in different consumption nodes and taking into account the amount of water loss are other issues requiring a closer examination [21]. The loss of resources is exacerbated by the pollutions in broad basins and high elemental complexity such as Great Karun Basin. In order to solve this problem, the amount of water loss in distribution and transmission systems, the delay time to distribute and transfer, the time and space distribution of inter-basin surface flows, etc. should be considered in the modeling.

In order to determine the optimal water resources allocation in the Jiaojiang River basin a Coupled Water Quantity-Quality model was presented by Peng et al., [22]. Their proposed model includes coupled hydrodynamic water quality and basin scale hydrologic models which are designed to work interactively. Zhang et al. [23], introduced an integrated water quantity-quality method for achieving a more efficient water allocation pattern compared to the conventional methods. In their proposed approach, the increasing of water demands is considered besides of enhancing water pollutions. Many different studies have been conducted recently in a same manner [24-29]. It should be noted that, the applied approaches within the aforementioned studies are applicable in small basins. In the case of large-scale watersheds with complicated water resources systems, such models are not efficient due to the increased computational cost. And using some simplifications is mandatory to setup efficient models.

The decision makers of basin-scale water resources systems need to have an accurate projection of the variation of quality and quantity of water resources as well as trend of water demands. Hence, applying Decision Support Systems (DSS) is essential for water system management. The conventional generic models such as WEAP and Modsim are able to quantitatively model the water resources system. However, coupling these models with quality modeling is a big challenge. In order to reduce the required run time, a quantity-quality DSS was presented by Azmi and Heidarzadeh [30]. The proposed DSS was designed based on the system dynamic approach and a one-dimensional water quality model was implemented for the reservoir quality modelling. In recent decades, some researches have been conducted in similar cases [29, 31-39]. All of them contain some modification that affect the modelling results. Moreover, many of developed quality-quantity models are so time consuming and hence are not applicable in real-word applications.

In this study, a Surrogate-based Quality-Quantity Decision Support System (Q2DSS) is proposed for Great Karun River basin as one of the most complicated water resources systems in Iran. Implementing surrogate models reduces the running time of the final model and makes the decision-making process more applicable in real situations. In this paper, the proposed approach for developing an appropriate DSS is introduced conceptually. Each sub model within the proposed approach should be presented in a separate paper broadly. The coupling manner of different computational models and the developing of interacted surrogate models is presented here.

2. Proposed Approach

An integrated model for determining the optimal allocation of resources between different centers/users with short-term (one-day or multi-day) steps can be a major step towards the deployment of an optimal and applied management system for water resources systems [40]. Considering and modelling the time lag between supply sources and consumption centers and modeling the amount of water loss allocated to consumption centers can be considered as the main strength of such a model. The extraction of optimal operating rules of the system in the long term (monthly) periods is inevitable due to the variables of the system status and quantity and quality parameters. Regarding the specific governing conditions on the Great Karun River basin, the main model that determines the general policy of system utilization includes a timely model for determining the priorities and optimal allocations for short periods (with a daily scale) according to the system status and effective parameters for decision making in each time step. Figure 1 shows the conceptual flowchart of the proposed model.

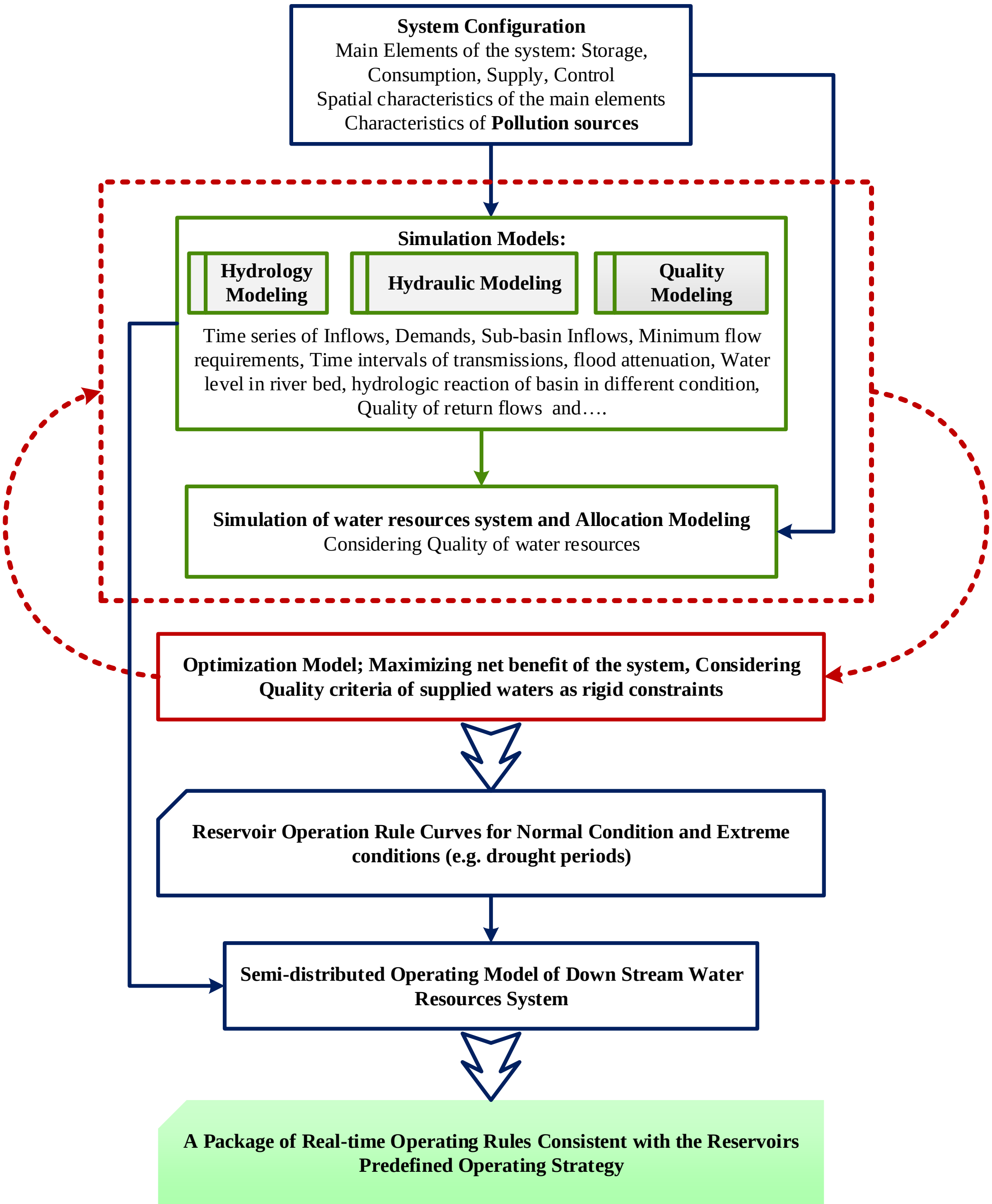

Figure 1. Schematic of the proposed model for extracting the water resources system operating strategies

Various meteorological, hydrological, hydraulic and hydro dynamical models can be aggregated within the proposed water resources model to determine the optimal operation rule package. The most important issues of the applied models are compatibility of the applied models and reducing the required running time of the integrated model. The output of this model is a set of operating rules, each of which is developed to manage one of the key points in the system and is defined in the context of a more general operating policy at the basin level. Such a model has been developed to apply optimal utilization policies, resulting in reduced water losses and the maximum use of water resources. Advantages of using such a model are as follows:

1- Determining the optimal water allocation under different conditions in order to reduce water losses in long-term intervals and to increase water quality in downstream areas.
2- Determining the amount of high-quality water to be allocated under different probable conditions.
3- Determining the package of optimal operating instructions for key control points at the basin level.
4- Determining the optimal sequence of distribution of water, or, in other words, determining the optimal allocation priorities in different hydrological conditions.
5- Determining the optimal operating policy in different conditions to increase the amount of available water with standard quality.

In order to obtain an applicable operating policy according to the requirements of Great Karun multi-reservoir system, a model will be developed that is able to determine the reservoirs' releases and allocation strategy in the short-term (on a daily basis) step. In addition, utilization instructions for key points of the system are extracted as an integrated management package. It should be noted that the assignment model should be designed in a way to have the flexibility to adapt to different conditions in different time periods. Accordingly, a variety of computational tools, computer models, and intelligent methods (e.g. [21, 41-45]) will be used in this study to formulate the allocation model. Furthermore, the allocation model is trained in the range of the results of a long-term optimal operating model. This helps short-term decisions taken by the allocation model pass an optimal route in the long run.

3. Computational Methodology

In the first step, a complete schematic of the current status of basin under study should be identified. Based on the schematic and the data of the key points, it is possible to configure the watershed area, which is a prerequisite for modeling. This configuration will form the basis of the modeling performed in this design. Since the ultimate goal is to achieve optimal operating policies, simulation-optimization models are used in both long-term and short-term steps. Therefore, the more accurate and realistic configuration, results in more accurate hydraulic and water resources simulations [46]. In the simulation model, the prioritization of the water demand allocation as well as the preferences of the utilization from different sources should be well defined. Such a model can be created using generic simulation models of water resource systems (e.g. WEAP, MODSIM) or by coding and developing an exclusive simulation model.

What is important in specifying the actual flow quality is determining the location and capacity of agricultural land and industrial centers [47]. Therefore, in the proposed modeling, system requirements are considered as semi-distributed. At this stage, the goal is to provide the required amount of water in long term periods. At each long-term period, the provided amount of water is distributed in different short-term intervals using the allocation model in next stages. After simulating a multi-year (or multi-ten-year) long-term course with a monthly step, the values of system performance criteria such as reliability, vulnerability, and resiliency are measurable for each of the demand sites. In this way, the impact of adopting different system operating rules on the performance of the long term can be calculated. Figure 2 shows the conceptual diagram of simulation-optimization models.

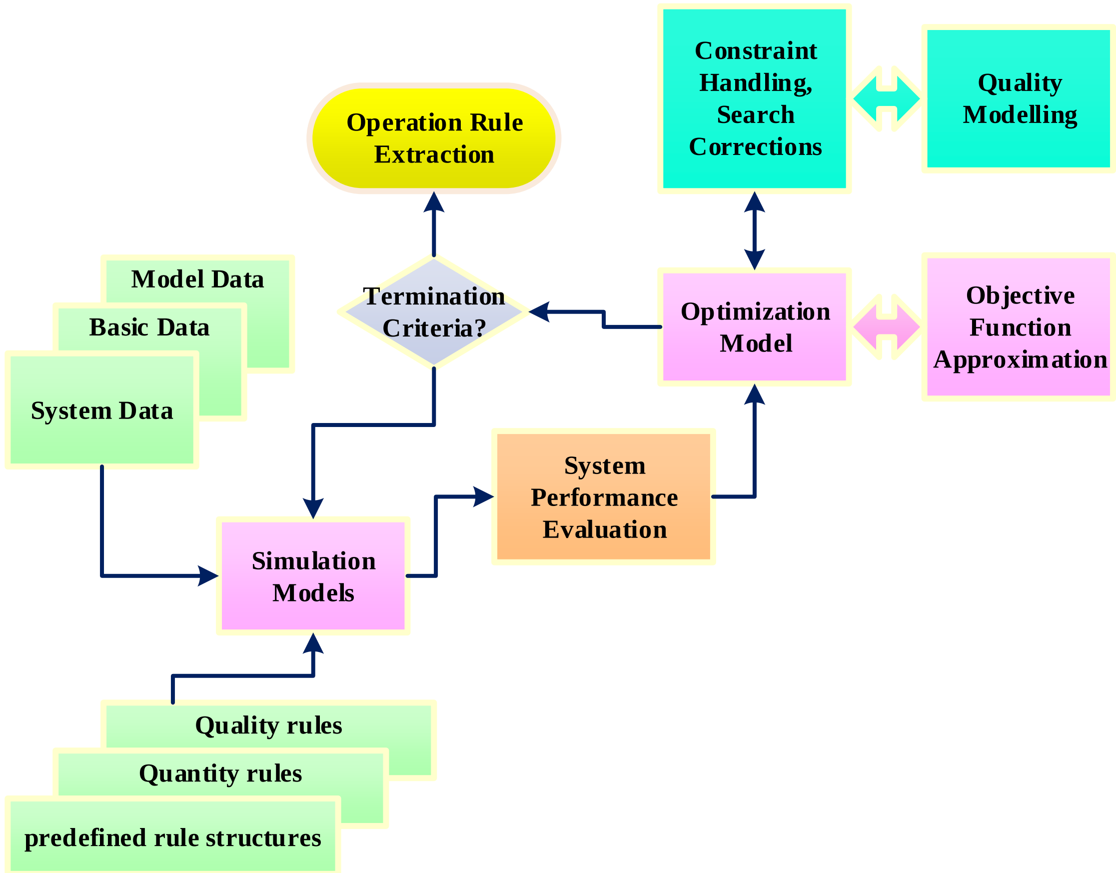

Figure 2. Water Resources Optimization-Simulation Schematic model

In order to extract the principle of optimal operation based on the chosen policy, it is necessary to create an optimization model and then solve it. What is considered in this model is to achieve the maximum benefits of the system by taking the constraints of water quality into account. Such an optimization model can be considered as follows:

$$Max\ NB = \sum Ben_{i,j,t} - \sum Cost_{i,j,t}$$

$$\begin{aligned} &Subject\ to: \\ &\quad All\ Configurational\ Constraints \\ &\quad All\ Quality\ Constraints \\ &\quad\quad All\ Operational\ Constraints \end{aligned} \tag{1}$$

One of the most effective methods for optimizing water resource systems, which has been repeatedly applied in recent decades, is the use of simulation-optimization models [48]. This approach provides the ability to take into account the system's details to the desired extent for the modeler, while at the same time benefits from results with a good accuracy with acceptable computational costs. To expand such a model, it is necessary to first create a simulation-optimization model using a proper stochastic search algorithm and the system simulation model described earlier.

The hydraulic-hydrodynamic flow model will have a special application in these studies. What is important in this plan is to estimate the increase in the amount of flow of pollutants from sources to consumption areas, which is obtained based on the development of proper hydraulic-hydrodynamic models according to the available information. These values are applied in modeling the distribution and allocation of water at the basin level [49]. To this end, the load of pollutants in return flows of agricultural and industrial demand nodes must be calculated. Another variable that is calculated in this model is the amount of water loss the transmission links, which has a great impact on the water quality within different branches.

In the water allocation sub-model, the Great Karun River Basin is simulated with more details than the original model [11]. In this modeling, the downstream demands of the multi-reservoir system are modeled completely distributed throughout the basin. Time discretization in this model is conducted on a daily basis. The main objective in this sub-model is to find daily release values of reserves and allocation priorities for different demand sites by taking into account the monthly amounts obtained from previous calculations. The delay time of the released flows and the branch losses calculated in the hydraulic model determines how much flow and at what time in each management scenario will flow to key distribution points. Accordingly, it is necessary that the management of the key points is optimized in a coordinated manner with the allocation plan, in order to obtain the best allocation strategy with the least amount of water loss at the basin level. In fact, this sub-model provides system managers with a real-time scheduled program that is obtained based on the conditions set by the optimizer model and the optimal system operating rule. In order to obtain a real-time operating program, we need to define and solve an allocation optimization model at the basin level. This optimization model is defined for determining the prioritization of the allocation time as a mixed integer nonlinear (or linear) programming (MINLP) model [50]. Solving such a planning model involves the use of multi-stage techniques or the use of simulation-optimization models. Hydraulic route loss and unauthorized water withdrawal are calibrated using hydrological models, and hydrometric station information. In this modeling, the amount of water loss during the transfer is estimated using simple equations. Flow quality is estimated using the simulation model of flow quality parameters in the key points of the basin and the non-violation of the quality limits is considered as a constraint in allocation modeling.

In the event that the scheduled water allocation and release values from the main reservoirs of the specified quality are known, it is possible to develop simple models to estimate and simulate flow quality indicators based on the flow rate at any key point of the system through the consideration of the quality of the return water with specific a quality level. This requires accurate statistics and information regarding the quantitative flow indicators at the basin area, as well as an accurate estimate of the impact of agricultural and industrial areas on the value of these indicators. Figure 3 illustrates the computational flowchart of the proposed model in this study.

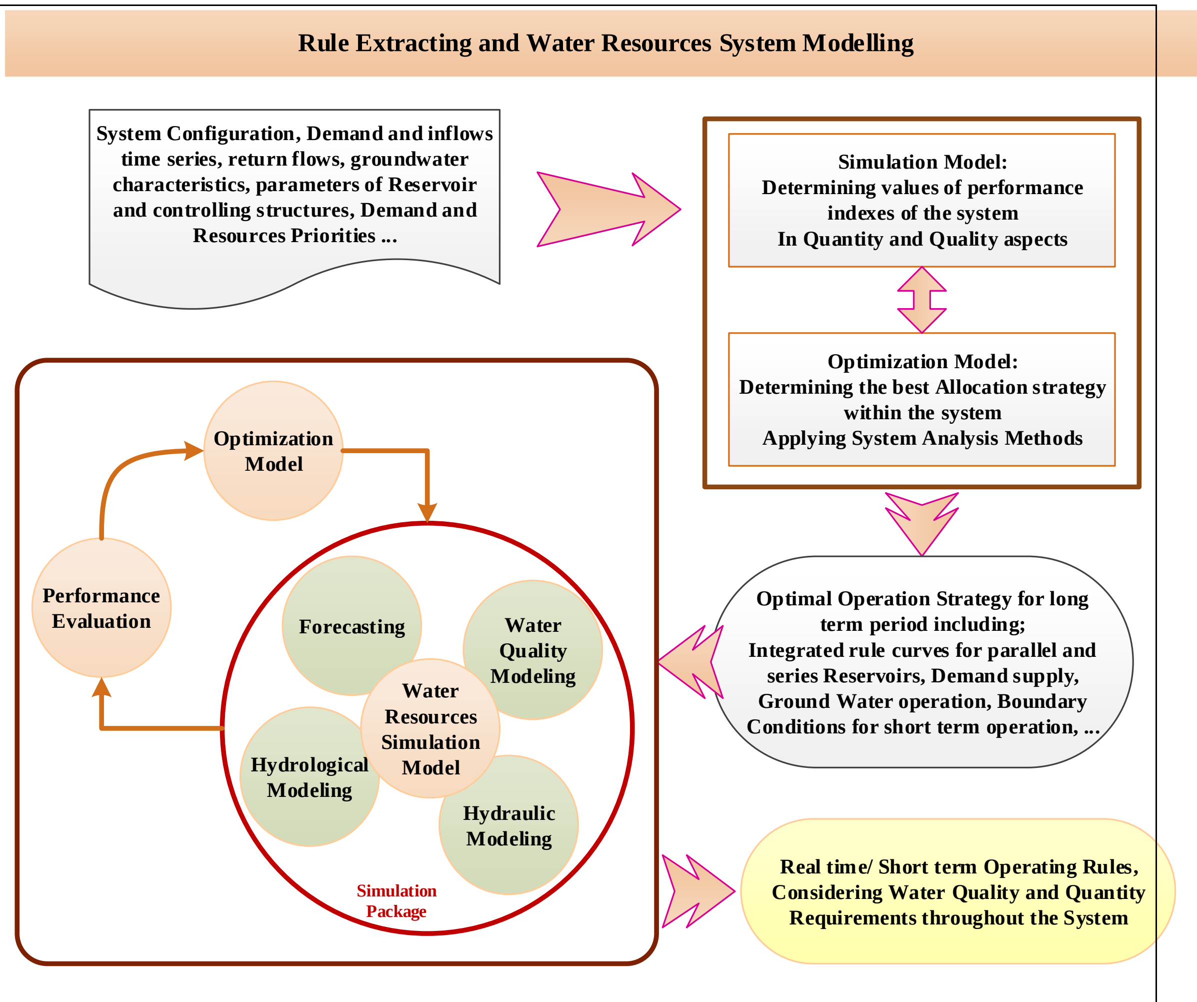

Figure 3. Computational flowchart of proposed approach

The package of allocation policy is in fact a set of operating rules, each designed for one of the flow control points at the basin level. These rules of operation are meaningful and optimal for each upstream policy, and each one may not be applied individually. To define such rules, smart management-computational models such as artificial neural networks and intelligent search algorithms (e.g. Melody search algorithm [41]) are adopted [51-54]. In this case, of course, such rules require the creation of an appropriate structure as well as accurate instruction in order to realize the ultimate goal. Figure 4 illustrates the training diagram and the use of intelligent alternative models in the proposed approach.

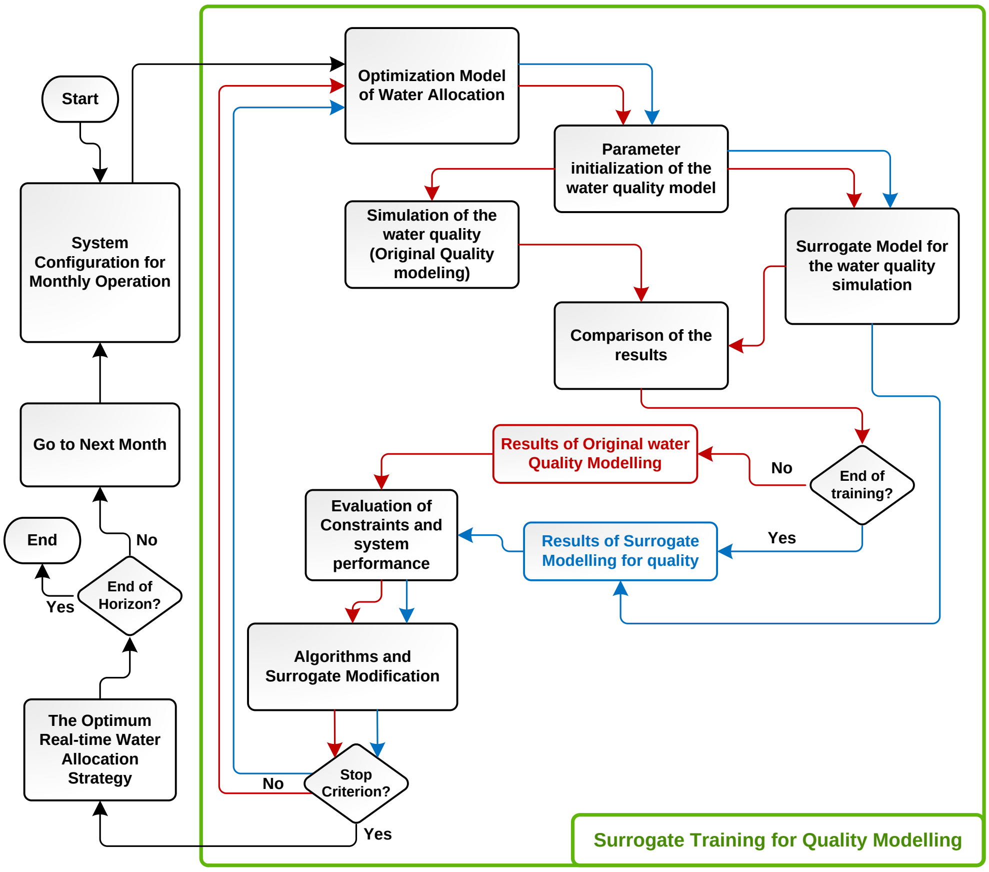

Figure 4. Flowchart of water quality surrogate model training

These operating strategies in fact provide the operating instructions for the integrated and coordinated management of the system in different parts of the basin, and can be used as a decision support tool to facilitate decision making in different probable conditions.

4. Conclusions

A computational framework was introduced in this study for the development of a quantity-quality decision support system of Great Karun River Basin. In addition to monitoring the quantity-quality conditions of the basin in different conditions, the proposed model is also used to obtain the applied operating policy of the system, and is able to determine the reservoirs' releases to perform optimal allocation to the demand sites in the short term (in daily scale). It should be noted that according to the proposed approach, the allocation model is designed to have the flexibility to adapt to different conditions in different time periods. Accordingly, intelligent computing tools were used to develop the allocation model in the present study. In addition, the allocation model is trained in the range of results of a long-term optimal operation model. This helps short-term decisions taken by the allocation model pass an optimal route in the long run. With the appropriate time and cost, the suggested models of this research can be transformed into generic models that can be used for other basins. It should be noted that the production of generic programs at this level requires a very high level of costs for modeling and programming, and also the use of expert knowledge and experience.

Considering the problems of operation in Great Karun Basin, it is vital to develop a comprehensive decision support model, which is a combination of water resources simulation models, optimization models and water quality models. The implementation of the framework presented in this study can be a major step towards solving the management problems of the water resources system of Great Karun River basin and increasing quality indicators of the flow at the basin level.

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