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An Expert System for Reservoir Discharge Quality Control

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Abstract. A methodology combining simulation, dynamic programming and expert system is presented for determining optimal operational polices for selective withdrawal structure in reservoirs to meet down stream water temperature targets. While the thermal simulation model concentrates on simulating the thermal stratification cycle of a reservoir, the object-space-dynamic programing optimizer calculates modified target temperatures that take into account anticipation of future critical temperature conditions. The expert system (WAT), on the other hand, evaluates the thermal structure of the reservoir, the modified desired temperature target, and the total flow to be released downstream. Accordingly, WAT determines the combination of selective withdrawal ports to be operated and the flows to be released from those ports taking into consideration number of experience-based operational preferences. An advantage of WAT is being a stand alone model that can be interfaced to the optimization module without the need for restructuring of either models. Application to a hypothetical example shows the potential for improved system performance using the expert system approach that utilizes experience and comon sense in reservoir water quality operation.

Introduction

For the purpose of managing water properly, reservoirs are constructed in river systems. The construction of these reservoirs in the river system may cause considerable changes in the natural characteristics of the water both upstream and downstream. Changes include thermal, physical, biological and chemical features. In order to meet the downstream water quality and quantity requirements, there should be a suitable release policy that takes such requirements into account. There are various water quality parameters considered usually when evaluating the released water for the different purpose of uses. One parameter commonly used is water temperature.

Water temperature (WT) is important for downstream fishery, irrigation, and pollution control. Each of these purposes requires certain range of WT. In reservoirs, WT varies vertically with water depth, and this variation dominates horizontal variation for most reservoirs [1]. The vertical thermal variation can be represented by discretizing reservoirs into horizontal layers, or stratas. This process is called stratification. A typical summer vertical WT profile during stratification is shown in Fig. 1 including the characteristics of the different strata.

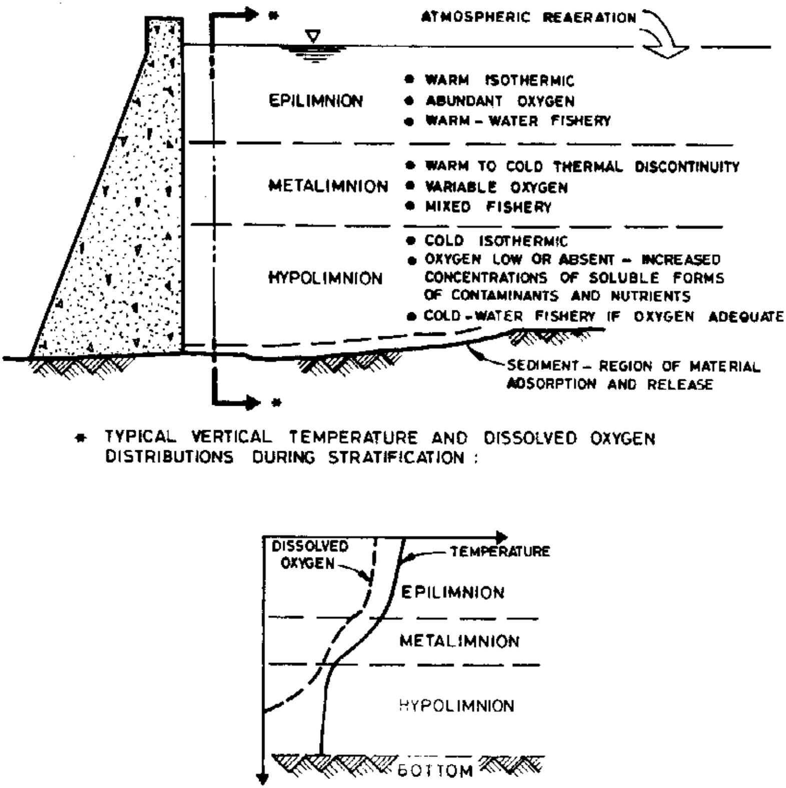


Fig. 1. Cross section of a thermally stratified reservoir indicating location and characteristics of the Epilimnion, Metalimnion and Hypolimnion and typical summer temperature-dissolved oxygen distributions [2].

U.S. Army Engineer Waterways Experiment Station has developed one-dimensional reservoir thermal simulation model called WESTEX [3]. WT profile for the entire reservoir is estimated through the estimate of the profile for each stratum using mass and heat conservation for each layer individually. Besides WESTEX model, there are other thermal simulation models such as those developed by Eilker [4] and Markofsky and Hareman [5].

If reservoirs are operated to satisfy present requirements without considering future needs, there may be a large deviation between the possible released WT and targeted WT. Due to the sequential nature of the reservoir operation problem, dynamic programming is a good technique that can be used to minimize such deviations. Farber [6] combined a thermal simulation model with a dynamic programming for water quality management of reservoir selective withdrawals. As extension of the conventional dynamic programming, Tauxe *et al.* [7], have developed multiobjective dynamic programming to consider multiple noncommensurate objectives. Fontane *et al.* [1], formulated objective-space dynamic programming to develop the optimal operation of each decision period to control reservoir discharge quality. Their objective was to minimize the sum of the squared deviations of released WT from the targeted WT. An example of a reservoir in north-western Pennsylvania was also presented. In general the output of the dynamic programming is usually the optimal distribution of WT released over the stratification cycle.

Released WT is usually governed through the use of outlet works, such as gates, of reservoirs. So, it is important to optimally simulate the selective withdrawal structures. As example, WESTEX model has a subroutine called DECIDE for the purpose of determining the combination of selective withdrawal gates. Hydraulic constraints on gates operations and operational preferences are characteristics included in the DECIDE subroutine.

The study presented herein is an extension of the previous reservoir quality management studies where expert system is used to simulate the selective withdrawal policies. Expert systems are models which attempt to make use of subjective information and experience that cannot be expressed in mathematical terms. If those systems are linked with optimization tools, they will increase the ability of reservoir operators to handle the anticipated problems. Application of expert systems in reservoir management have been addressed in several previous studies.

Akoundi and Karamouze [8] have developed a prototype expert system named CAPI to train novice water managers. This model explained the theory and operation of reservoirs including the dynamic interactions of available reservoir capacity, water levels, inflows, demands, and losses. A dynamic reservoir simulation methodology called SLIN was presented by Antunes *et al.* [9], which incorporated subjective knowledge through expert system production values. A knowledge-based expert system which utilizes real time hydrometerological inputs, manipulates them by heuristics, and produces real time reservoir operational guidelines was developed by Floris [10]. Savic and Simonovic [11] described an expert system called REZES which helps selecting optimization tools put by reservoir planners and operators. An expert system for evaluating storage and water quality information has been developed by Clarkson and Hartigan [12] to guide in reservoir operating decisions for the city of Newport News, Virginia, U.S. Bahatty *et al.* [13], has constructed a hybrid expert system/optimization procedure called RESEXP for the purpose of the operation of the multipurpose Tarbela Reservoir on the Indus River, Pakistan. A more complicated expert system for real time operation of a multipurpose multi-unit reservoir system was outlined by Fischer and Schultz [14]. An expert system called DELAQUA which combines Artificial Intelligence and simulation methods was developed by Rechnagel *et al.* [15] to support decision making in water quality control of lakes and reservoirs.

The main objective of this study, which is an extension of a previous research by Taher *et al.* [16], is to develop an expert system (WAT) that includes different experience-based rules concerning the operation of reservoir withdrawal structures to meet downstream water quantity and quality requirements. Thermal simulation model and dynamic programming are required tools to optimally find out the released WT while the expert model wisely selects the best combination of gates to be opened to satisfy the predetermined water temperature and discharge required downstream. A hypothetical example is also presented.

Combined Simulation, Objective-Space Dynamic Programming and Expert System

The problem of determining optimal selective withdrawal structure operations that minimizes the deviation of release water temperature from target release temperature was solved by Fontane *et al.* [1] using a combined simulation and Objective-Space Dynamic Programming Approach (OSDP). OSDP was selected because of the sequential decision nature of the problem, the ability of DP in general to handle system nonlinearities, and the great power of OSDP in reducing the original multidimensional problem to a one dimensional dynamic programming problem.

Thermal simulation model

Any thermal simulation model can be used to simulate the thermal stratification cycle in a reservoir (vertical temperature profile) based on the hydrologic and meteorologic data of the region. A one dimensional representation of the thermal structure of the reservoir can be developed by conceptually discretizing the reservoir into horizontal layers and computing the temperature in each layer for each time period using heat and mass conservation equations.

The heat transfer equation for any layer in its general form is a function of inflow and outflow temperatures, internal mixing, vertical advection, and air-water interaction at the water surface:

$$\frac{\partial T}{\partial T}=\frac{T_iQ_i}{A\Delta Z}-\frac{T_oQ_o}{A\Delta Z}+\frac{1}{A}\frac{\partial}{\partial Z}KA\frac{\partial T}{\partial Z}-\frac{1}{A}\frac{\partial(Q_oT)}{\partial Z}+\frac{1}{\rho C_pA}\frac{\partial H}{\partial Z} \tag{1}$$

where

T	temperature of layer, °F;
t	time, days;
T_i	inflow temperature, °F;
Q_i	flow rate into layer, ft^3/d;
A	horizontal cross sectional area, ft^2;
ΔZ	layer thickness, ft;
T_o	outflow temperature;
Q_o	outflow rate, ft^3/d;
Z	elevation, ft;
K	vertical diffusion coefficient, ft^2/d;
Q_i	net vertical flow into or out of layer, ft^3/d;
ρ	density of water; lb/ft^3;
C_p	specific heat of water, Btu/lb/°F;
$\partial H/\partial Z$	external heat source, Btu/ft/dy.

Loftis [3] developed a one dimensional thermal simulation model, WESTEX, based on solving the above set of simultaneous equations by sequentially evaluating the effect of each component of the equation. This model was later used by Fontane [1] in his combined simulation - OSDP approach.

Objective-space dynamic programming

The role of this model is to determine a modified target temperature that incorporates anticipation of future climatic conditions. Formulation of the OSDP problem [1] can be briefly summarized as follows:

$$S=\mathrm{Min}\sum_{i=1}^{L}\Delta D_i=\mathrm{Min}D_L \tag{2}$$

The return function for any stage is

$$F_i\,(D_i)=\underset{D_{i-1}}{\mathrm{Min}}\;[\;\Delta D_i+P\,(T_{rel_i},\overline{\overline{T}}_{trgt_i})+F_{i-1}\,(D_{i-1})\;] \tag{3}$$

where

$$\Delta D_i=D_i-D_{i-1} \tag{4}$$

D_i represents the accumulated squared deviation between actual target temp T_{trgt} and an OSDP modified target temp $\overline{T}_{trgt}$,

$$\overline{T}_{trgt_i} = T_{trgt_i} + ((D_i)^{1/2} \tag{5}$$

With $\overline{T}_{trgt_i}$ specified by OSDP, T_{rel_i} is obtained from a "port selector" subroutine (i.e. DECIDE subroutine) using initial discrete temperature profile x^*_{i-1} (D_{i-1}) stored for stage i-1 (i could be any time interval).

If the subroutine could not regulate the ports to achieve a release temperature T_{rel} as close as possible to the modified target $\overline{T}_{trgt}$, then a penalty term P $(T_{rel}, \overline{T}_{trgt})$ is added to the stage return function to penalize any discrepancy.

As soon as T_{rel} is determined, a thermal simulation model, (i.e. WESTEX module) recalculates the temperature profile x^*_i (D_i) at the end of period as a function of D_i. Recursive solution of Eq. (3) will eventually yield the minimal value of D_L in Eq. (2).

It is important to note that the optima found in Eq. (3) are unique for each discrete D_i. In other word, the resultant port operation policies are also unique. Violation of this means there could be several possible end-of-period temperature profiles for the same release temperature target [1].

Knowledge-Based Expert System

Presented herein is a stand alone prototype knowledge-based expert system WAT developed to demonstrate the use of knowledge, common sense and experience in addition to hydraulic, environmental and institutional factors as bases in selective withdrawal structure operation. This expert system also provides an opportunity to link the experience of reservoir operators with the powerful optimization and simulation techniques described earlier.

Based on the characteristics of the withdrawal structure, thermal structure of the reservoir, the desired temperature target, total flow to be released and water level in the reservoir, the WAT model determines the most appropriate combination of selective withdrawal ports to be operated and the flows to be released from those ports in order to meet the downstream modified target temperature as close as possible. WAT consists of three subsystems: 1) user friendly input interface; 2) knowledge base and 3) output interface.

(I) The input subsystem

The input subsystem allows the user to key enter data, read data from file, edit existing data and save results. The input data required by WAT can be grouped into five categories:

1. Temperature-depth profile for each stage (x_i), i could be as short as one day. This profile can be obtained from any thermal simulation model such as WESTEX.

2. **Withdrawal structure characteristics:** The physical and hydraulic characteristics of the structures such as number of ports in use, port location along dam face, port capacity and limitation on minimum and maximum port opening.

3. **Characteristics of the reservoir:** Storage capacity, dam height, and water level in the reservoir are also required. Water level in the reservoir is a function of time. This appears from the fact that the rate of change of reservoir storage over short time equals the difference between inflow and outflow rates which fluctuate over the operational horizon.

4. **Downstream target temperature and discharge:** These parameters can be obtained by different approaches. An effective and recommended methodology is the OSDP. Based on the OSDP formulation of the problem shown earlier, a modified target temperature T_{trgt_i} will be given by OSDP. Along with T_{trgt_i}, desired downstream discharge should also be provided.

5. **Preferences on heuristic rules to be executed:** An experienced user has the choice to select among the heuristic rules the one that he prefers to execute, and to assign a weight to each rule according to his preference. A weight of zero means that the corresponding rule will not be executed. On the other hand, assigning a value for the rule other than zero determines its priority of execution with respect to the others. Automatic weight assignment is also available for novice users.

(II) The knowledge base

The knowledge base subsystem consists of two components; algorithmic modules and heuristic rules.

1) Algorithmic module

a) Calculation of temperature at the center of each gate

This can be achieved by a linear interpolation of temperature-depth curve. Given the geometry and elevation of each gate, the corresponding released temperature can be calculated as follows.

$$T = [\,(T_{i+1} - T_i\,) * (Y - Y_i) / (Y_{i+1} - Y_i)\,] + T_i$$
$$\text{such that } Y_i < Y < Y_{i+1}$$

where

T_i temperature at point i on Temp-depth profile.
Y_i depth at point i.
T_{i+1} temperature at point i+1.
Y_{i+1} depth at point i+1.
T temperature at the center of the gate in concern.
Y depth of gate in concern.

b) Calculation of all possible gate combinations

This combination of gates is used to release the required downstream discharge and temperature. Each combination represents a solution that includes number of gates in operation, gates Identification Numbers (ID), and their corresponding discharges.

For any number of gates, the general equations are:

$$T_R = \sum_{j=1}^{N} (T_j * Q_j) / QR \tag{6}$$

$$Q_R = \sum_{j=1}^{N} Q_j \tag{7}$$

$$Q_j \leq Q_{\max j} \tag{8}$$

where

- N number of used gates.
- T_j water temperature at center of gate j.
- Q_j discharge from gate j.
- T_R required downstream temperature.
- Q_R required downstream discharge.

This equation yields an infinite number of solutions for N $\geq$ 2. Therefore a discretization technique will be used to reduce the number of possible combinations.

c) Discretization technique

Since discharge is a continuous function; it is impossible to study each possible discharge value. Therefore the the discharge function is discretized as follows:

$$\Delta Q_j = Q_{\max j} / m \tag{9}$$

$$Q_j = k\ (\Delta Q_j) \tag{10}$$

where

m = selected discharge interval.
k = 0,1,2,3, ..., m

2) Heuristic module

To reduce the number of possible combinations, nine heuristic rules were considered based on the experience of a group of experts in reservoir operation.

The rules are:

Rule 1: Use minimum number of gates.
Reason: To minimize the operational cost.

Rule 2: Use more of the upper gates.
Reason: This is due to the fact that in summer the quality of water at the bottom of the reservoir is low. This water is normally low in dissolved oxygen (DO). So, releasing water from upper gates provides better DO content. Moreover, using upper gates helps getting rid of any suspended materials.

Rule 3: Use more of the lower gates.
Reason: Release water from bottom gates to flush cold water (lower quality) which tends not to blend. In addition, releasing water from lower gates is necessary for flushing out accumulated sediments.

Rule 4: Use adjacent gates.
Reason: To minimize turbulence losses. Such a rule is helpful when a discharge from a thin layer of the reservoir is required.

Rule 5: Use non adjacent gates.
Reason: Releasing water from adjacent gate might create some structural damage especially for gates releasing large discharge.

Rule 6: Use one gate.
Reason: To minimize the operational effort.

Rule 7: Use combination of two gates.
Reason: To decrease operational effort if compared to rule 8, and to prevent rusting of gates due to long term unuse.

Rule 8: Use combination of three gates
Reason: To prevent rusting of gates due to long term unuse.

Rule 9: Minimum discharge equal to 10% of Q_{max}.
Reason: To prevent gate vibration, the minimum discharge that can be passed from any gate should not be less than 10% of the gate capacity.

Tracing Optimal Solution Using Heuristic Rules

As mentioned earlier, there is a number of candidate gate combinations that satisfy the downstream requirements produced by the algorithmic models. Each of these solutions is evaluated with respect to each heuristic rule and then the best one is chosen. Theoretically, the optimal solution should satisfy all the rules. But realistically, it is impossible to find a solution that perfectly meets all the user's preferences. Therefore, a weighted scoring algorithm was developed to sort candidate solutions as follows:

Each rule in assigned a weight W_i (a number from 0 to 100). And each mathematical solution (j) has a score S_{ij} with respect to each rule (i) (a number from 1 to 10). Then, the total score S_{tj} for using solution (j) equals to:

$$S_{tj} = \sum_{i=1}^{N} W_i S_{ij}$$

where N is the total number of rules. Accordingly, the optimal solution is the one that has the highest total score. In this procedures, weights are assigned either directly by an experienced user or can be determined with the assistance of a weight-knowledge base while scores are calculated or assigned values in the score-knowlege-base.

Weight assignment

A weight represents the importance of its corresponding rule with respect to the other rules. A novice user will be asked several questions in which his response determines the weight to be given for each rule. A typical rule in this knowledge base is:

IF: Operational cost is not critical
AND: little floating debris show on the water surface.
AND: sediment level is low.
AND: no turbulance is allowed.
AND: no gate has been used for long time (rusting possibilities).
AND: low discharge does not affect gates.
THEN: Rule 4 must be given high priority; $w_4 = 100$
Rule 1, 2 are given low priority; $w_1 = w_2 = 10$
Rule 3,5,6,7,8,9 are not considered $w_3 = w_5 = w_6 = w_7 = w_8 = w_9 = 0$.

To clarify, a hypothetical example shows the evaluation of two solutions using two different sets of weights with only three rules considered.

The solutions suggest releasing a required discharge Q_R and temperature as follows:

Gate number	Solution 1 (% of Q_R)	Solution 2 (% of Q_R)
Gate 1 (upper)	50	80
Gate 2	50	0
Gate 3	0	20
Gate 4 (lowest)	0	0

According to Rule 1 both solutions have the same score that equals to 7. This is because both candidates suggest using two gates. Rule 2, on the other hand, prefers solution 2 since more discharge is given by the upper gate. Finally, analysis of Rule 4 strongly supports the solution where adjacent gates are operated.

Table 1 shows that the optimal solution is the first one with a total score of 1152. If these weights have been altered to meet different user's preferences then the optimal solution becomes the second one as shown in Table 2.

Table 1. Evaluation of two alternative solutions based on three rules; solution 1 is optimal

i	W_i	Score S_{ij}	
Rule	**Weight**	**Solution 1**	**Solution 2**
1	10	7	7
2	10	8.2	8.8
4	100	10	5.5
Total score = S_{ij}		1152	708

Table 2. Evaluation of two alternative solutions based on three rules; Solution 2 is optimal

1	W_i	Score S_{ij}	
Rule	**Weight**	**Solution 1**	**Solution 2**
1	10	7	7
2	100	8.2	8.8
4	10	10	5.5
Total score = S_{ij}		990	1005

Score calculation

A score represents the importance of each solution with respect to a particulate rule. Thus, a mathematical expression is developed for each rule to calculate the score to be given to a solution as follows.

Rule 1: Minimum number of gates

WAT will give a score of ten for solutions suggesting the use of only one gate. Otherwise, the score will be:

$$S_{1j} = -3N_j + 13$$

where N_j is the number of open gates in solution j (maximum of 4). The equation shows that a minimum score of one will be obtained if all the "N" gates are in use.

Rule 2: Use the gates near to the surface

The expression used is:

$$S2_j = -(3M_j / Q) + 13$$

where

Q = total target discharge

$$M_j = \sum_{i=1}^{N} i * Q_{ij}$$

i = gate number

Q_{ij} = discharge in gate i for the solution j.

N = number of open gates (Max. of 4).

M_j is a weighted sum of discharges through all gates. When Mj equals to Q, it means that all the target discharge was given by the upper gate. The score in this case is 10.

Rule 3: Use the gates near to the bottom of the reservoir

The expression used is:

$$S3_j = (3M_j / Q) - 2$$

With the same definitions as in rule 2.

When M_j equals to 4Q then it means that all the quantity is given by the gate at the bottom; and the score is ten. This rule is the opposite of the previous rule.

Rule 4: Use adjacent gates

The score is calculated as follows

$$S_{4j} = - 4.5 D_j + 10$$

where D_j is the number of closed gates between any two open gates. For example, if the solution suggests opening the gates 1,2 and 3 then $D_j = 0$.

Another alternative could be openning gates 1 and 4 only resulting in $D_j = 2$. Since WAT is limited to four gates, then D_j can have the values of only 0, 1 and 2, and their scores will be 10, 5.5 and 1 respectively.

Rule 5: Use non adjacent gates

The expression is:

$$S5_j = - 4.5D_j + 1$$

Rule 6: Use only one gate

Only two possible scores can be assigned:

$$S_{6j} = 10 \text{ if } N_j = 1$$
$$S_{6j} = 1 \text{ otherwise.}$$

Execution of this rule forces the program to use only one gate if possible.

Rule 7: Use two gates

Only two scores are possible:

$$S7_j = 10 \text{ if } N_j = 2$$
$$S7_j = 1 \text{ otherwise.}$$

Firing this rule forces the program to use two gates if possible.

Rule 8: Use three gates

Possible scores are:

$$S8_j = 10 \text{ if } N_j = 3$$
$$S8_j = 1 \text{ otherwise.}$$

With this rule the user forces the program to use three gates if possible.

Rule 9: A gate will be opened only if its discharge is more than 10% of its capacity

$S_{9j} = 10$ if all gates are opened more than 10% of their capacities.

$S_{9j} = 1$ otherwise.

If a gate is slightly opened, a structural damage might occur due to gate vibrations.

(3) Output interface

The output interface displays the results in a graphical mode. The output screen shows the following:

1. Actual temperature-depth profile considered in the calculation.
2. Cross sectional view of the reservoir: It shows water surface in the reservoir at dam, location of gates on dam body, and dam height measured from the bed level.
3. Front view of the dam: It shows gates ID numbers, temperature at the center of the gates, and discharge released from each one. It also shows how wide each gate is opened to release its contribution of discharge needed. i.e. if it is fully open, partially open or closed.
4. Required downstream discharge and temperature.

Figure 2 shows the different components of WAT, while Fig. 3 shows the output interface window.

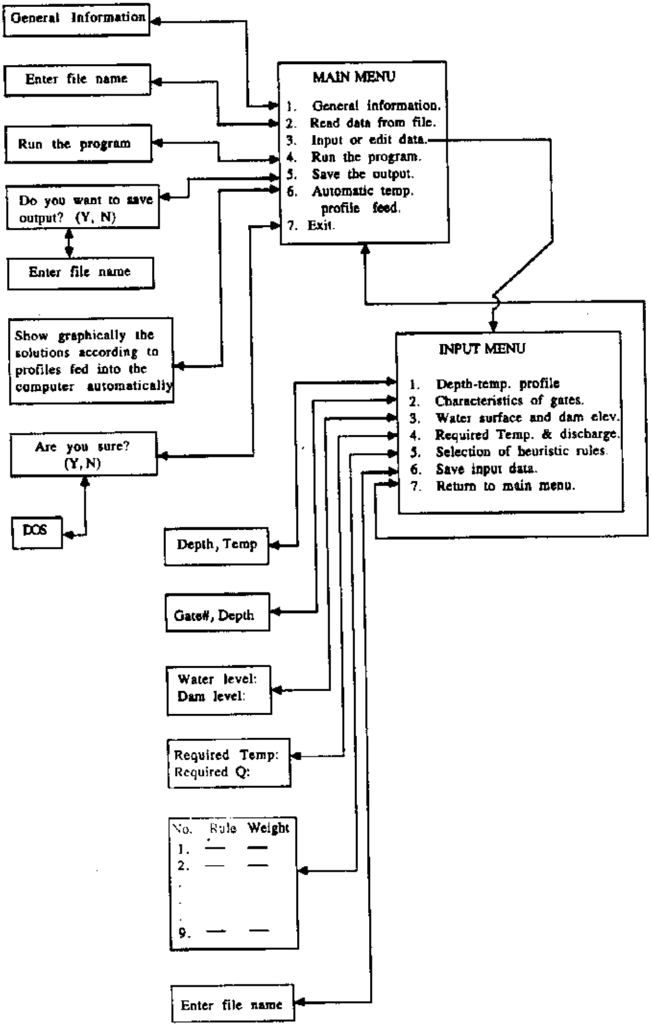
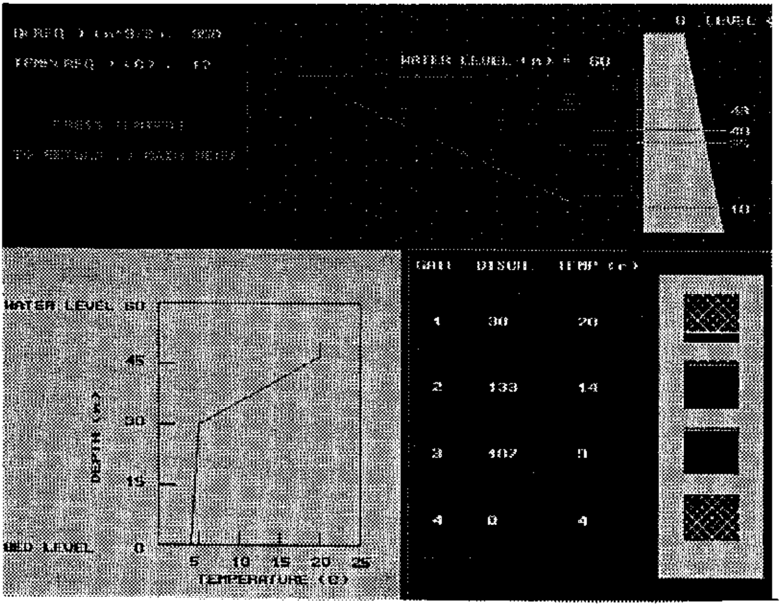


Fig.2 The Different Components of WAT.



WATER LEVEL (m) = 60

GATE	DISCH.	TEMP (c)
1	30	20
2	133	14
3	107	9
4	0	4

Fig. 3. The output interface showing results in tabular and graphical forms.

Conclusion

An approach combining simulation, object-space dynamic programming and expert system for controlling the quality of water released from a reservoir was presented. Given the water temperature profile in the reservoir (obtained from a thermal simulation model) and the optimal released water temperatures (derived from an object space dynamic programming technique), WAT provides the reservoir operators with policies for managing the reservoir gates opening. Hydraulic, institutional, and operational preferences were considered in WAT through different heuristic rules and algorithmic modules. Nine heuristic rules based on the experience of hydraulic systems specialists were discussed.

Although WAT requires knowing the water temperature profile and the optimal distribution of target released water temperature over time (stages), which should be obtained from outside models, its design makes it capable of working as a stand alone decision support system. It can be used separately to demonstrate the use of experience and common sense in reservoir water quality operation. The model is not limited to the heuristic rules presented here, but it can be easily extended to include more rules according to the expertise available and the nature of the problem.

The operational strategy achieved by WAT is optimal and unique only with respect to the rules considered in the analysis. This is true because of the subjectivity incorporated in building the knowledge base.

Application of WAT to a hypothetical example revealed the ease of use through the interesting, interactive and brief graphical capabilities used in presenting the results. Users with minimum knowledge of computer, which is the case with most reservoir operators in the developing countries, should find WAT an useful analytical tool in the decision-making process for reservoir operation.

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نظام خبرة للتحكم في نوعية المياه المتصرفة من الخزانات

سعود بن عبد القادر طاهر و عبد المحسن بن عبد الرحمن آل الشيخ
قسم الهندسة المدنية ، كلية الهندسة ، جامعة الملك سعود ، ص.ب ٨٠٠ ،
الرياض ١١٤٢١ ، المملكة العربية السعودية

(استلم في ١٧/١٠/١٩٩٥م ؛ وقبل للنشر في ١٩/٦/١٩٩٦م)

ملخص البحث . تقدّم هذه الورقة طريقة تجمع التمثيل، البرمجة الديناميكيّة ونظام الخبرة من أجل إيجاد سياسة تشغيليّة مثلى للمنشآت المستعملة لتصريف المياه من الخزّانات بهدف تلبية الحاجة إلى أن تكون المياه خلفها ذات درجات حرارة مناسبة. ويركّز النموذج الحراري على تمثيل الدورة الحراريّة خلال طبقات ماء الخزان كما تحسب البرمجة الديناميكيّة درجات الحرارة المطلوبة للمياه آخذةً بعين الاعتبار الحالات الحرجة المستقبليّة لدرجات حرارة الماء . ومن ناحية أخرى ، فإنّ نموذج الخبرة المقدّم في هذه الورقة يقوّم البنية الحراريّة للخزان ودرجات الحرارة المرغوبة وكميّات الماء المراد صرفها . وطبقاً لذلك فإنّ نموذج الخبرة المقدّم يعيّن مجموعة الفتحات المطلوب تشغيلها لتصريف الماء مع مراعاة عدّة قواعد تشغيليّة مبنيّةٌ على الخبرة . ومن مزايا هذا النموذج إنّه نموذج قائم بذاته يمكنه الاتّصال مع نموذج البرمجة المتحركة دون الحاجة إلى إعادة تشكيل أحد النموذجين . ولقد أظهر تطبيق هذا النموذج على مثال افتراضي قدرته على تحسين كفاءة النظام المدروس باستخدام نموذج الخبرة الذي يعتمد على الخبرة والمنطقيّة في تشغيل خزّانات المياه .