INTEGRAETED RIVER BASIN ENVIRONMENT ASSESSMENT AND PLANNING THROUGH HYBRID SIMULATION PROCESSES

KOJIRI Toshiharu* and TERAMURA Toshihisa**

* Water Resources Research Center, DPRI, Kyoto University, Gokasho, Uji, Kyoto, Japan, 611-0011

** Penta-Ocean Co., Ltd., 2-2-8 Kouraku, Bunkyo-ku, Tokyo, Japan, 112-8576

1 INTRODUCTION

Due to the recent social and economical development, multi-viewpoint or multi-criteria on river basin has been requested. Especially, the life environment in addition to the life convenience has become one of the important issues from engineering aspects. Nowadays Japanese government proposed the new river basin plan called "sound water circulation" including water quantity, quality and ecosystem in the basin scale.

On the other hand, the distributed runoff models have been developed by many researchers using GIS (Geographical Information System) and land data such as digital elevation map, land use map, population map and so on. Consequently the basin-wide situations on water quantity and quality can be easily grasped from not only long but also short-term viewpoints. In this paper, we will propose the integrated river basin management procedures combining runoff simulation and improvement technologies.

Firstly the concept of river basin management is proposed and the objective functions are formulated considering the common events such as flood, drought, river scenery, water amenity and so on. Secondly introducing the distributed runoff model, the river basin situation is evaluated through the fuzzy set concept. Finally the improvement technologies to perform the sustainable water resources management are proposed through the genetic algorithm.

2 RELATED FACTORS FOR THE INTEGRATED RIVER BASIN MANAGEMENT

The river basin management can be formulated "(1) considering whole river basin environment in long and short-term, (2) evaluating the objective functions and the related situations and (3) improving the spatial and temporal factors to conserve the enjoyable and sustainable life. Originally, the river basin has different characteristics and circumstances according to location, land use, culture and history. The evaluated factors are extracted from various viewpoints of time, space, purpose and regional significance. The present necessary factors concerning the river basin environment are assumed to be the following nine ones; namely i) high flow, ii) low flow, iii) dispersion of discharge, iv) water quality, v) riverside style, vi) urbanization, vii) river scenery, viii) recreation I (population), ix) recreation II (accessibility to the river). Each factor can be formulated as follows;

i) Flood control: High water is evaluated with the following criteria;

$$FL(i) = Qt\max(i) / Qtflst(i) \tag{1}$$

where, *Qtmax(i)* is the maximum discharge at point i and *Qtflst(i)* is the design discharge.

ii) Low flow regulation: Low flow is also evaluated against the drought risk as follows;

$$DR(i) = Qtdrst(i) / Qt \min(i) \quad (2)$$

where, *Qtmin(t)* is the minimum discharge at point i and *Qtdrst(i)* is the necessary water demand.

iii) Dispersion: Dispersion of discharge sequence has a great impact on channel bed erosion, habitat environment and water use as follows;

$$ST(i) = (Qt \max(i) - Qt \min(i)) / (Qtflst(i) - Qtdrst(i)) . \quad (3)$$

iv) Water quality: For water use and environmental conservancy, the water quality in the river is regulated under the limited criteria as follows;

$$PO(i,n) = Ql \max(i,n) / Qlst(i,n) \quad (4)$$

where, *Ql(i,n)* is the maximum concentration value of water pollutant n at point i and *Qlst(i,n)* is the standard criteria on pollutant n.

v) Riverside style: Historically, in the urban area, the embankment has been structured with concrete or composed type for flood control. The riverside in the mountain region has invested its own characteristics for visitors to enjoy natural life and scenery. Those functions are formulated as follows;

$$RSS(i) = fRSS(LS(j), WA(j)) \quad (5)$$

where, *fRSS()* is the function of embankment structure, *LS(j)* is the embankment structure and *WA(j)* is the acceptability of water amenity around embankment j. Normally it is represented with construction material and type with regional attributes.

vi) Urbanization: The distribution of land use affects not only the infiltration rate of runoff process but also the emission rate of waste water from sewerage system as one of environmental factors. This factor will have an impact on landscape or water amenity evaluated as follows;

$$UG(i) = LUurban(i) / LUtotal(i) \quad (6)$$

where, *LUurban(i)* is the total urbanized area in mesh i and *LUtotal(i)* is the total area of mesh i.

vii) River scenery: The river scenery is evaluated at its location according to the utilization situation consisting of many components such as outdoor activities or aesthetic functions as follows;

$$ILS(i) = fILS(LM, ED, PT, DST) \quad (7)$$

where, *fILS()* is the evaluation function of river scenery, and *LM, ED, PT, and DST* are the aesthetic indices on landmark, edge, path, and district, respectively.

viii) Population: The population distribution along the river has also great impacts on water utilization; namely drinking water, release capacity of waste water, relaxation space and outdoor activity area. The importance is evaluated as follows;

$$POP(i) = fPOP(\sum population(i,u)) \quad (8)$$

where, *fPOP()* is the evaluation function of population, *population (i,u)* is the population number inside of walkable range u at mesh i.

ix) Accessibility: The access situation such as road and parking lot networks is the significant factor for visitor to approach to the river. It is represented as the joint function of population and distance as follows;

$$AC(i) = fAC(RD(i), \sum population(i,u)) \tag{9}$$

where, *fAC()* is the evaluation function of accessibility and, *RD(i)* is the road distance and conditions to the amenity points. All of factors are expressed with different functions and should be transferred into the non-dimensional range between numerical values of 0 to 1 for their uniformity.

3 OPTIMIZED MANAGEMENT PROCEDURES OF RIVER BASIN

Before taking optimization, the river basin is partitioned into three categories such as i) mountain, ii) suburb, and iii) urban zones according to the location and utilization attributes from roughly geographical viewpoint. Each zone must be evaluated with its specific occupation of land use and population. The mountain can be covered with trees and aqua area to enjoy the natural life, the suburb needs comfortable space in both of river and urban district to stay in the outer city and the urban permits the artificial style of concrete embankment for business purpose and life protection. Assuming that the river basin consists of square meshes as components of the distributed runoff model, the attribute of considered mesh is represented its result as the maximum value among all indices as follows;

$$area(i) = \max(area_{mnt}(i), area_{sub}(i), area_{urb}(i)) \tag{10}$$

subject to

$$area_{mnt}(i) = f_{mnt}(areamount(i), areaurban(i), areapop(i)) \tag{11}$$

$$area_{sub}(i) = f_{sub}(areamount(i), areaurban(i), areapop(i)) \tag{12}$$

$$area_{urb}(i) = f_{urb}(areamount(i), areaurban(i), areapop(i)) \tag{13}$$

where, *areamount(i)*, *areaurban(i)*, and *areapop(i)* are zone information on land use rate on mountain, urban and population at mesh i. This index takes an efficient roll for the specified objective of water amenity to recognize the regional characteristics because each zone has different environmental criteria based on the geographical and cultural conditions.

Consequently, the optimization for the whole river basin can be taken for minimization/maximization approach on the designated objective, minimization on the occurrence frequency of the worst situation, maximization on the preferable situation or minimization/maximization on integration among objective values. In the case of min-max one, the integrated objective function with the integrated value *ZFc* is formulated as follows;

$$Opt(for\ desigbated\ objective) = \min(ZFc) \rightarrow \max\ . \tag{14}$$

For the river basin management, the environment circumstances should be modified against the evaluated value under the requested constrains such as construction cost, operation cost and so on. For instance, the optimization problems on water resources management and planning have been formulated with the traditional linear programming. Improvement on optimization should be carried out to minimize/maximize the evaluation value for designated objectives. Though the linear programming or non-linear programming must be applicable after formulating the complex water circulation processes, the iteration method, that is, the genetic algorithm (GA) is introduced to increase the optimization capability from viewpoints of non-linearity and multi-objective. So, the calculation procedure is called as hybrid-methodologies because the spatial and temporal situation in the whole river basin is evaluated through the distributed runoff model and then the genetic algorithm is handled to obtain the optimal management solution. Herein, the modified genetic algorithm is proposed with conditional operation for management purpose such as construction location and scale of designed equipments as shown in Fig.1.

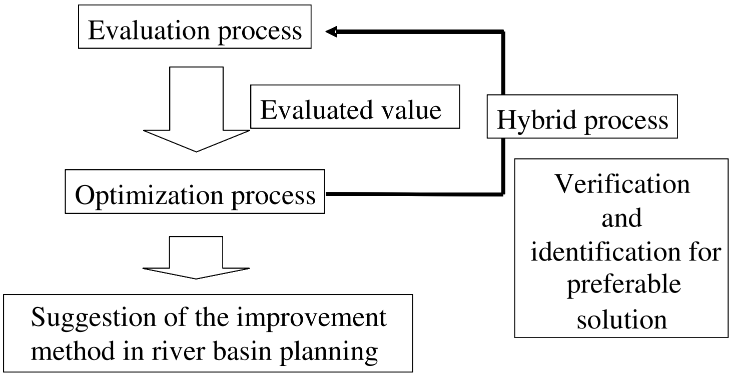


Figure 1 Optimization procedures for integrated river basin management

Basically, GA consists of three stages in the genetic process [Kitano, 1993]; namely (i) generation of initial combination of genes as chromosomes, (ii) calculation of performance of genes against environment circumstances and (iii) calculation of genetic algorithm of multiplication, crossing-over and mutation. Multiplication is carried out to procreate necessary chromosomes at next generation to compensate the removed ones with selection from current generation. Crossing-over is also carried out to procreate the new chromosomes with extracted genes at random. Mutation means the changing characteristics of gene with assumed rate. In this paper, the elite preservation approach is applied to change the combination of gene with the highest performance from the combination of the lowest one.

4 FORMULATION OF EVALUATION PROCESS THROUGH THE FUZZY SET

Typical four main goals of water resources such as water utilization, flood control, water amenity and river scenery are discussed in the previous chapter, individually. On water utilization, drought situation (low flow) and water quality (ex. BOD) are treated as significant factors. As it is very hard to evaluate the actual condition with simple numerical value, the fuzzy set is introduced to handle their uncertainty. The following IF-THEN form is defined to represent the antecedents and the consequent condition of water utilization as inference rule k [Sugeno, 1988];

$$IF\,(low\ flow\ level\ is\ m\ and\ water\ quality\ level\ is\ n),\ THEN\ (water\ utilization\ level\ is\ k) \qquad (15)$$

Table 1 is the assumed combination of antecedents and consequent. By using the actual observed data which is obtained from GIS or monitoring record, the fuzzy grades are calculated with fuzzy membership functions as shown in Fig. 2 and 3. Defining that $FG(k)$ is the fuzzy grade on fuzzy rule k, $FG_{DR}(k)$, $FG_{PO}(k)$ and $FG_{EU}(k)$ are the fuzzy membership functions of low flow, water quality and consequent, respectively. The fidelity, that is, the fuzzy grade of consequent is calculated though the fuzzy multiplication as follows;

$$FG_{WU}(k) = \min\{FG_{DR}(k), FG_{PO}(k)\} \qquad (16)$$

Then the fuzzy membership function of consequent is modefied though the fuzzy α cut method as follows;

$$Fh_{Zk} = FG_{EU}(k) \wedge FG_{WU}(k) \qquad (17)$$

The evaluated value ZFc for optimization is calculated through the fuzzy composition and gravity method as follows;

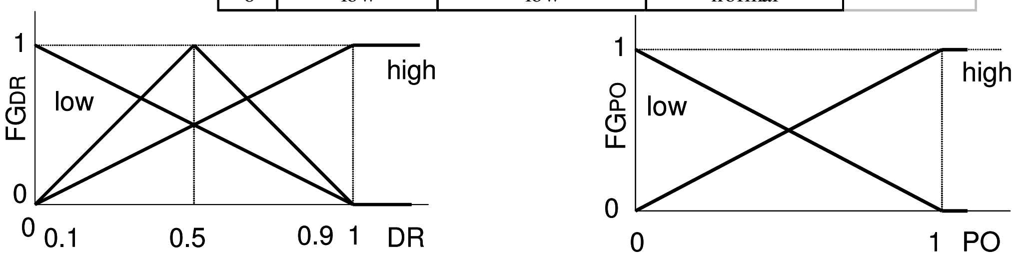
$$ZFc = \frac{\int z \cdot Fh_z \, dz}{\int Fh_z \, dz} \tag{18}$$

$$Fh_z = Fh_{z1} \vee Fh_{z2} \tag{19}$$

On the rest of related objective such as flood control, water amenity and river scenery are evaluated and decided its satisfactory level with same approaches. For instance, the combination of inference rules and membership functions on the flood control involving high water and dispersion as shown in Table 2 and Figure 4, where the construction conditions are defined with mitigation level against flood risk. The water amenity is taken through low discharge level, water quality and riverside style and the additional factor of importance was presented with accessibility. The river scenery is expressed with riverside style and urbanization. The riverside style was classified into five patterns. The first one is made of natural materials with relatively steep slope in mountain side and slow slope in the estuary area. The second one is covered by simple concrete and the third is done by concrete with decorated fashion. The forth is the compound shape of channel section covered by concrete and vegetation and the last is the sheet pile bulkhead to prevent flood inundation in the urbanized narrow space.

Table 1 Fuzzy scope on water utilization

Rule	DR(low flow)	PO (Water quality)	Water Utilization
1	high	high	bad
2	medium	high	bad
3	low	high	bad
4	high	low	good
5	medium	low	good
6	low	low	normal



(a) Drought situation (b) Water quality

Figure 2 Fuzzy membership functions of antecedent on water utilization

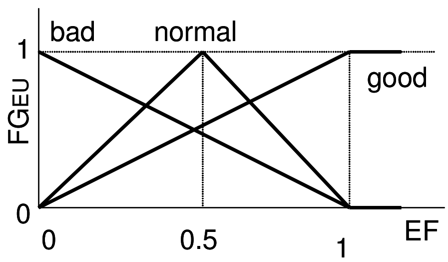
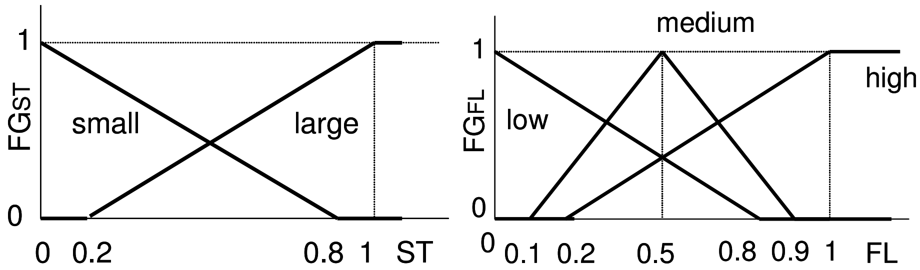


Figure 3 Fuzzy membership function of consequent on water utilization

Table 2 Fuzzy scopes on water amenity

Rule	FL(high flow)	ST(dispersion)	EF(flood control)
1	high	big	construction (improvement)
2	medium	big	construction (improvement)
3	low	big	no construction
4	high	small	construction (improvement)
5	medium	small	no construction
6	low	small	no construction



(a) Drought situation (b) Water quality
Figure 4 Fuzzy membership functions of antecedent on flood control

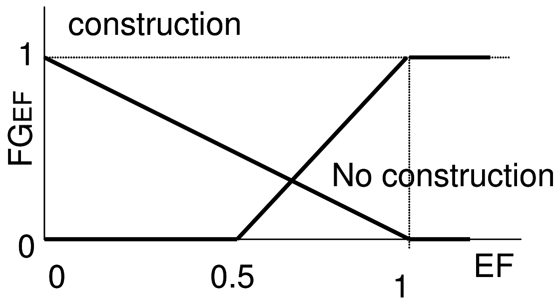


Figure 5 Fuzzy membership functions of consequent on flood control

The river scenery can be described with landmark, edge, path and district. The landmark is equal to scenic object matching hinterland view in the mountain or urbanized area. Otherwise the curious landmark spoils the whole scenery. The preferable landmark obtains the high mark through the fuzzy set. Not only aesthetic but also cultural meaning should be marked. Edge is the remarkable line to discriminate one section from the other and represented as cliff, waterside and mountain foot. Path has same meaning as Edge consisting of artificial structure of road and railway. Well-designed bridge in both of traditional and modern style obtains high mark. District is one of the urbanized blocks including residences, business offices and other markets because the river brings the regional activity, communication and contentment space for citizens. The river scenery factor is calculated by summing up all of estimated marks.

Accessibility shows the efficiency of considered point for neighboring users to enjoy the nearest river point. As the citizens can come to the riverside on foot or car, the population in walkable area of 2 km and movable area of 10 km following municipal roads as shown in Fig.6 is transferred into feasible level through the fuzzy set.

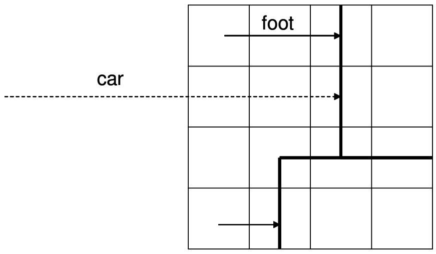


Figure 6 Illustration of accessibility

The flow discharge is calculated through the distributed runoff model using GIS, DEM and land use data provided by the public organizations. For water quantity, the heat balance method is introduced to calculate the evaporation and snowmelt at each mesh and at each day. On the runoff process, the runoff model (Hydro-BEAM) is applied with the kinematic wave method for surface and the linear storage method for ground water of first to forth layer [Kojiri et al., 2002]. The continuous and momentum equations on surface and sub-surface flow are formulated as follows;

-Kinematic wave method-

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r(x,t) \qquad (20) \qquad\qquad q = \alpha h^{m} \qquad (21)$$

-Linear storage method-

$$dS_A / dt = f_{in} + QF_A + QH_{Ain} - QH_{Aout} - QV_{Aout} - EVA \qquad \text{(first layer)} \qquad (22)$$

$$dS_{\cdot} / dt = QH_{\cdot in} + QV_{\cdot in} - QH_{\cdot out} - QH_{\cdot out} \qquad \text{(B, C, and D layer)} \qquad (23)$$

where, h is discharge height, q is discharge volume per unit width, and $r(x,t)$ is effective rainfall at location x and time t. α and m are parameters, respectively. $S.$ is storage volume at considered mesh, f_{in} is infiltration discharge at surface, QF_A is runoff discharge from upstream surface, $QH._{in}$ is horizontal inflow from upstream mesh, $QH._{out}$ is horizontal outflow to downstream mesh. $QV._{in}$ is vertical infiltration discharge at considered mesh, $QV._{out}$ is vertical outflow and EVA is evaporation converted through the heat balance equation. The flow rooting in the river channel is calculated with same methodology. The general momentum formula from the first to forth layer is dominated with the linear storage concept as follows;

$$QO = S / \kappa \quad where \quad ds / dt = QI - QO \qquad (24)$$

where, κ is transmissivity, QI and QO are total amount of input and output discharge at considered mesh. The water quality can be analyzed by combining those equations, the necessary diffusion equation and the emission rate from sources area.

5 APPLICATION OF PROPOSED METHODOLOGIES INTO THE REAL BASIN

The Shonai River which is located at middle part of Japan was applied to verify the proposed methodologies. The upper and middle river basin was applied in this paper and divided into 504 meshes consisting of 1 km and 1 km squares. The applied standard values such as design flood, water quality and so on were assumed considering the statistical and governmental data. The riverside style was categorized through the field survey and not considered on sheet pile bulkhead. The urbanized level was decided with the land use database (KS-202-1). Edge, Path, District on river scenery were classified through the map and field survey, too. The landmark did not exist in this considered river basin. The population is estimated on basis of census database.

On the present environmental situation, water utilization was shown in Fig. 7. Tajimi located at downstream area was evaluated with high mark because the enough water with bad quality discharged into the main channel in the downstream point. Fig. 8 shows the flood index with high risk areas in the upper and downstream area. Totally, as the present river basin is well-managed according to population distribution, the whole area keeps the same risk level.

For water amenity, Fig. 9 shows the present situation at mesh considering categorized indices of mountain, suburb and urban. The preferable points are spread in the whole basin because the utility and satisfactory marks are judged with regional characteristics. Fig. 10 shows the accessibility of mesh to the nearest point to be approached in the river. We consider the mobility of foot or car to evaluate the convenience in meshes along the wider regional roads. Moreover, considering the river scenery, the water amenity is re-evaluated with same distribution of the human emotion.

To obtain the converged solution through GA, the following initial conditions were set in advance. Initial population of chromosome is set as fifty generated at random. On selection, ten chromosomes with lower fitness were reduced among fifty one. On crossing-over, ten chromosomes were reproduced with crossing-over method that ten chromosomes among left forty ones were arbitrarily chosen and the assigned genes were crossed over to keep same population number. Mutation was assumed to be happened with the occurrence probability of 0.1 after events of selection and crossing-over. The designated gene was chosen with uniform random number and its situation was reversed from 0 to 1 or vise versa.

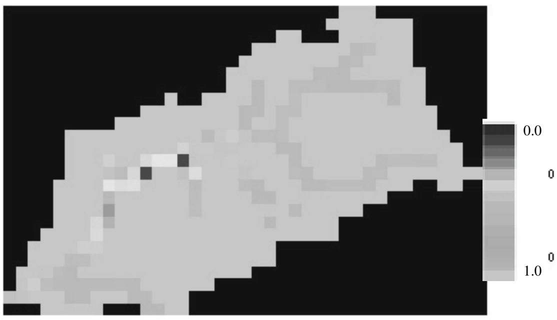


Figure 7 Present situations on water utilization

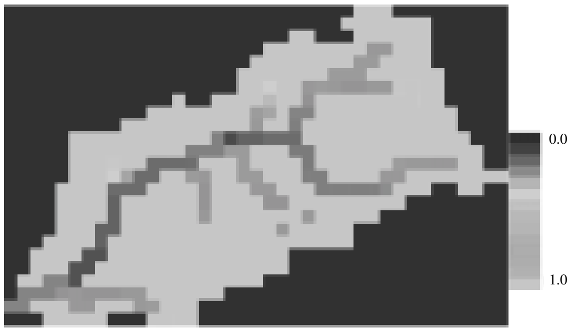


Figure 8 Present situation on flood control

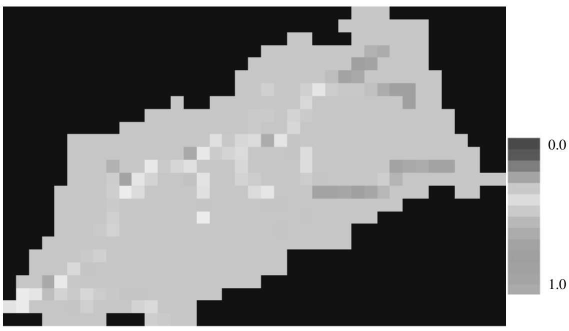


Figure 9 Present situations on water amenity

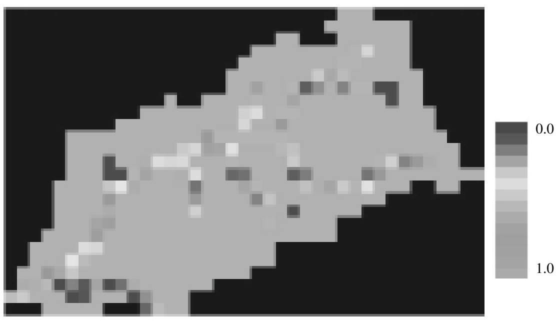
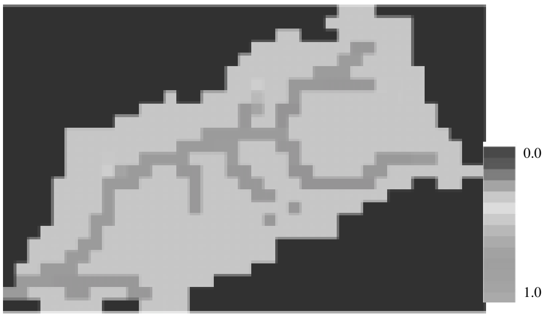


Figure 10 Present situation on accessibility

The two treatment plants for water quality and three construction locations of embankment for flood control were chosen. Fig. 11 shows the optimized result on water utilization. The construction efficiency of water treatment plant was not strongly appealed because the evaluation was judged with drought risk. In the downstream area from the plant, the evaluation value was improved for water quality. The iteration was converged at the chromosome type of (00110100011001101111001) with performance level of 0.803 after fifty calculations. Fig. 12 shows the optimized result on flood control and the high efficiency of embankment construction at the risky area for flood inundation.



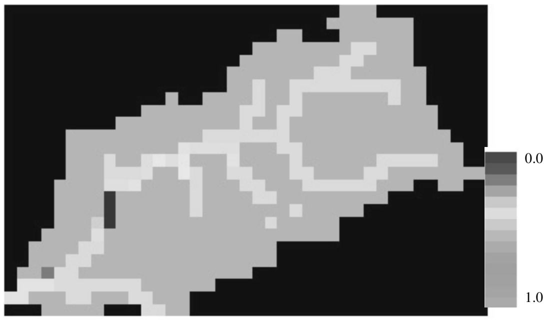


Figure 11 Optimized result on water utilization Figure 12 Optimized result on flood control

6 CONCLUSIONS

In this paper, the basic concept of integrated river basin management for whole river basin was discussed and by using the distributed runoff model and GIS data, the river basin was evaluated from multi-viewpoint of water quantity, quality, river scenery and water amenity. The output of optimization yields the sound water circulation system. To sum up, the following results were obtained.

i) The necessary and significant factors were formulated through normalization techniques including water quantity, quality and river scenery and water amenity.
ii) The allowable objective functions were also formulated through the fuzzy set among extracted factors.
iii) The modification procedures for river basin situation were taken with the conditional genetic algorithm.
iv) The proposed methodologies were applied into the real river basin to verify their applicability and performance.

References

Kitano, H.: Genetic Algorithm, Sangyo-Tosho Publishing Company, 1993, 44-60
Kojiri, T., A. Tokai and Y. Kinai: Assessment of River Basin Environment through Simulation with Water Quality and Quantity, The Annuals of the Disaster Prevention Research Institute, Kyoto University, 1998, 119-134
Sugeno, M.: Fuzzy Inference, Nikkankogyo, Newspaper Co., Ltd., 1988, 67-90

Tuchiya, M.: Comprehensive water amenity plan on urban rivers, Shinzansya Publishing Company, 1999, 21-38