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MULTICRITERIA PLANNING OF WATER RESOURCES-DEMAND EQUILIBRIUM IN INDUSTRIAL AREAS

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SYNPOSIS

The comprehensive planning of water resources-demand equilibrium in industiral areas is a comlicated problem. The paper provides a multicriteria planning methodology for accomplishment of equilibrium by a comprehensive development of the most reasonable multipurpose water management system. The approach is based on the general process control model for regulation of equilibrium, which involves three basic regulation element and five regulation factors. The alternative systems are evaluated by a multicriteria goal function which involves ten economic, social, water management, environmental, natural resource criteria. The selection of alternatives can be solved by one of the multicriteria ranking methods. The application of the methodology is shown in a realistic example.

Etudes à la méthode de plusieurs critères de l'équilibre resources - besoins en eau aux établissements industriels

L'étude complexe de l'équilibre ressources - besoins en eau est une tâche composée. Le mémoire présente un procédé d'études à plusieurs critères pour la mise en pratique de l'équilibre par le développement général du système d'économie hydraulique le plus rationnel a buts multiples.

L'approche se repose sur le modèle de direction de cours général de la régulation d'équilibre, qui comprend trois éléments de régulation de fond et cinq facteurs de réglage.

Les systèmes alternatifs sont évalués par une fonction de but à plusieurs critères, qui renferme dix critères exprimant des ressources économique, sociale, d'économie hydraulique, d'environnement et naturelle.

Le choix des alternatives peut se faire par une méthode de classement quelconque à plusieurs critères.

L'application du procédé est illustrée par un exemple réel.

La planificación de policriterio del equilibrio, entre la demanda y los recursos hidráulicos, respecto las regiones industriales

La planificación complexo del equilibrio, entre la demanda y los recursos hidráulicos es una tarea compleja. En el estudio se presenta un método de planificación de policriterio, para realizar el equilibrio, con el desarollo complejo de un sistema de recursos hidráulicos, con varios objetos y de modo que es el más razonable. La base de la aproximación es el modelo general de la orientación del proceso de la regulación del equilibrio, que contiene tres elementos básicos de regulación y cinco factores de ragulación. Los sistemas alternativas son evaluados por una función de policriterio, que contiene dies criterios, respecto los recursos de: económicos, sociales, hidráulicos, ambientales y natural. Se puede realizar la selección de las alternavivas con la ayuda de alguno método de graduación de policriterio. Un ejemplo práctico muestra la aplicación del método.

INTRODUCTION

The purpose of this paper is to provide a multicriteria planning methodology for accomplishment of equilibrium between natural water resources and demands for water in industrial areas with water shortages , by a comprehensive development of the most reasonable multipurpose water management system /WMS/.

A multicriteria model for basin-wide regulation of general water resources demand equilibrium in river basins has been developed by DÁVID /198o a./. It is based on the process control theory of the long-term river basin development and it considers the river basin as a hierarchical system. Among others, the optimum water resources system planning has been investigated in de NEUFVILLE and MARKS /1974/, who have analyzed the problem from a stochastic viewpoint. Multiobjective planning of runoff regulation under uncertain water demands has been studied in DÁVID and DUCKSTEIN /1976/ and in DÁVID, DUCKSTEIN and KRZYSZTOFOWICZ /1977/. GREENBERG and HORDON /1976/ investigated the deterministic equilibrium between resources,demand and capacity for a domestic water supply problem. Further aspects of such equilibrium in river basin planning have been reported by the UNITED NATIONS /1976/. MOSS and DAWDY /1977/ have investigated the economic optimization of under stochastic supply and demand. The basin-wide aspects of planning system have been reported by KUZIN /1979/. The trade-off between increase of water availability by runoff regulation and by water quality control has been examined in DÁVID /1978/.

As a further step, the present paper describes a multicriteria study on comprehensive planning of industrial WMS in river basins with water supply shortages. It can be used for the development of both new and existing industrial areas. The WMS is considered as a bridge between natural water resources and the water demands.

The paper is constructed as follows. First the characterization of equilibrium and the goals of its regulation are presented, then the multicriteria model for ranking of alternatives is described. Finally a simplifled example reporting an experiment on application of the model illustrates how the most reasonable WMS for [illegible] on equilibrium can be selected.

REGULATION OF RESOURCE-DEMAND EQUILIBRIUM

The concept and system of regulation is described in details in DÁVID /198o b/. Refering this presentation, the regulation of water resource-demand equilibrium in industrial areas can be considered as follows

$$\underline{\underline{A}}\ /t/ + \max.\ \underline{\underline{CM}}\ /\Delta t/ = \underline{\underline{A}}\ /t+\Delta t/ \qquad /1/$$

where - $\underline{\underline{A}}/i/$ - indicator matrix to describe the existing resource-demand situation in time t and it is assumed that $\underline{\underline{A}}/t/ \neq \underline{\underline{A}}o$, where $\underline{\underline{A}}o$ is the indicator matrix for the equilibrium in industrial area. Therefore $\underline{\underline{A}}/t/$ describes here an unbalanced situation, which needs planning and development;

- max. $\underline{\underline{CM}}$ /Δ t/ – the <u>control matrix</u> to describe the most reasonable system of control systems needed to achieve a new equilibrium, during time Δt;

- $\underline{\underline{A}}$/t+$\Delta$ t/ – indicator matrix of the planned resource-demand situation in the t+Δt for which $\underline{\underline{A}}$ /t+Δt/ = $\underline{\underline{A}}$o, therefore it indicates an equilibrium.

The state variables form two groups, namely the <u>basic regulation elements</u> /natural water supply /resources/ – S; water demand – D; system capacity of WMS – SC/ and the <u>regulation factors</u> /space – s; time unit – t; quantity or volume – v; quality – q; energy content – e/.

The <u>indicator matrix</u> /$\underline{\underline{A}}$/ can be composed by these variables, where the basic elements form the rows, while the regulation factors form the column of the matrix, as follows

$$\underline{\underline{A}}/t/ = \begin{bmatrix} Ss, & St, & Sv, & Sq, & Se \\ SCs, & SCt, & SCv, & SCq, & SCe \\ Ds, & Dt, & Dv, & Dq, & De \end{bmatrix} \qquad /2/$$

This 3x5 matrix describes the resource-demand situation in a general form Each of the 15 elements of the matrix can be specified by one or more positive figures, not less than 0. For example the Sv, SCv, and Dv elements indicate the quantitative character of S, SC, and D,respectively as random variables. Each of the elements, for example, can be specified by two, three or more components of the basic elements. The system of D for all of v, q and e factors can be specified by the freshwater demand /DFW/, the water consumption /DCU/, the total water use /DTU/, the reuse /DRU/, the waste water produced /WWP/, the treated waste water /TWW/ and by the need for waste water disposal /WWD/, considering the connections among these elements and their random characters /DÁVID and DUCKSTEIN, 1976/. The St, SCt, Dt elements indicate the time unit of the process control elements /e.g. year, month, ten-days, day, hour, second etc./. The Sq, SCq and Dq indicate the qualitative character of S, SC and D respectively, also as random variables. Summarizing, the indicator matrix can be developed to a multi-dimensional matrix by the specification of general elements according to the planning circumstances and it can provide a basis for the planning of equilibrium.

The $\underline{\underline{A}}$/t/ matrix describes an <u>equilibrium situation</u> only if the following <u>system of constraints</u> is completely realized:/$\underline{\underline{A}}$/t/ = $\underline{\underline{A}}$o/:

1.	$Ss = SCs = Ds$	3.	$Sv \geq SCv \geq Dv$	6.	$Uv \leq IUv$	/3/
2.	$St = SCt = Dt$	4.	$Sq \geq SCq \geq Dq$	7.	$Uq \leq IUq$	
		5.	$Se \geq SCe \geq De$	8.	$UE \leq IUe$	

Constraints 1. and 2. prescribe that the evaluation and the process control should

be made for the same territory and for the same time unit by all basic regulation elements. Constraints 3. denotes the quantitative, Constraint 4. the qualitative equilibrium of the basic elements, respectively. For example Constraint 4. prescribes that the quality of the available water resources and/or the quality of the water delivered by the treatment capacity of the WMS should be better or equal with the water quality needed by the water demand. Considering the random character of S, SC and D, the Constraints 3., 4. and 5. can be performed only with certain uncertainty. Therefore Constraints 6., 7. and 8. denote that the uncertaintes of equilibrium according to the quantity, quality and energy aspects /Uv, Uq, Ue/ should be less than the acceptable limit uncertainties /LUv, LUq, LUe/, respectively.

The two other matrices in Eq /1/ are formed in the same structure as $\underline{\underline{A}}$/t/. They are also 3x5 matrices. To achieve the equilibrium, a set of alternative industrial WMS-s each of which indicated by a control matrix, should be planned. In case of planning of a new industrial area, the first element of Eq/1/ can not be considered. The alternative systems should meet the following goals:

- a/ the constraint system of equilibrium /Eq 3/ should be accomplished;
- b/ the utilization of natural, economic, social resources needed for the development, should be kept to a minimum;
- c/ a harmonized connection between the industrial water management system and its natural and regional environment should be provided;
- d/ the selected WMS should be flexible enough to meet a broad spectrum of future requirements, most of which cannot be foreseen at time of planning.

The selection of the most reasonable WMS /$\underline{\underline{CM}}/t/_y \longrightarrow$ max, where y=1,2, ... denotes the specific WMS/ can be performed by a multicriteria analysis, according to the large number of variables, purposes and constraints involved in this planning problem.

MULTICRITERIA RANKING OF ALTERNATIVE SYSTEMS

Let us assume that the specified variables, state transition functions and constraints are known for each alternative WMS on the basis of the specification of the control model /Eq.1/. These systems involve the different combination of the three basic control actions, namely the run-off regulation, the water demand regulation and the increase of the delivering system capacity. The next task is the formulation of the criteria as goal functions to evaluate alternative systems. The following ten criteria have been selected to measure how well a given system performs with respect to meeting the listed goals.

1. Total annual monetary expenditures /total costs - TC/ which involve both the

investment and operation costs /C/ of the three basic control actions to perform the equilibrium from quantity, quality and energy aspects altogether:

$$TC = C \left[Sv,\ Sq,\ Se,\ SCv,\ SCq,\ SCe,\ Dv,\ Dq,\ De \right] \qquad /4/$$

2. Total annual monetary /economic/ losses /L/ which are expected in consequence of the random character of D and S the deterministic character of SC, and of the uncertainties of the planned equilibrium:

$$TL = L \left[Sv < SCv < Dv;\ Sq < SCq < Dq;\ Se < SCe < De;\ Uv;\ Uq;\ Ue \right] \qquad /5/$$

3. Probability of fresh water shortage /PS/ which evaluate the social, non-monetary impacts of quantitative uncertaintes involved in the planned equilibrium, considering water resources availability:

$$PS = P \left[Sv,\ SCv,\ Dv\ /DFW/,\ Uv \right] \qquad /6/$$

This criterion involves the evaluation of Constraints 3. and 6. in Eq /3/.

4. Extent of the reuse of water resources in the industrial WMS which evaluates the water demand regulation from water resources management aspect:

$$RF = \frac{\text{average amount of reused water /DRU/}}{\text{average amount of waste water produced /WWP/}}\ 100 \qquad /7/$$

5. Extent of water consumption in the industrial WMS which evaluates the water demand regulation from technological aspect:

$$WC = \frac{\text{average amount of consumed water /DCU/}}{\text{average amount of fresh water demand /DFW/}}\ 100 \qquad /8/$$

6. The fulfilment of water quality requirements /WQ/ to evaluate the environmental and social, non-monetary qualitative impacts of the planned equilibrium by the WMS including the impacts of waste water treatment and disposal. It integrates the evaluation of Constraints 4. and 7. It can be expressed by both measurable and subjective, non-measurable forms, as follows

$$WQ = f\ /Sq,\ SCq,\ Dq/ \qquad /9/$$

or WQ may take on the ratings of very good, good, fair, bad, very bad

7. The fulfilment of energy requirements /ER/ to evaluate the energetical, non-monetary impacts of the planned equilibrium. It integrates the evaluation of Constraints 5. and 8. It can be expressed, for example, by the energy factor which indicates the ratio of produced /Ep/ to consumed /Ec/ energy by the system and by considering the acceptable limit energy uncertainties /LUe/;

$$ER = f\ /Se,\ SCe,\ De/ \approx ff \left(\frac{Ep}{Ec};\ LUe \right) \qquad /10/$$

8. Cooperation possibility /CP/ which measures the capability of WMS to develop harmonized cooperation with its natural /river basin/ and socio-economic /regional

development/ environment, by ratings of very good, good, fair, bad, very bad. It includes the evaluation of waste disposal too.

9. The <u>utilization</u> of <u>land</u> resources /LU/ needed to develop the WMS, which evaluates the social and environmental values of land use. This criterion is expressed by the area occupied, as one of the main natural resources involved.

10. <u>Flexibility</u> /FL/ of each alternative to changes in inputs and errors in planning and development elements to insufficient information, to development possibility, to sensitivity of the system to various uncertainties and to effects of resource-demand systems outside of the planning area /e.g. upstream influences/. It is a subjective criterion with five possible ratings very good, good, fair, poor and very poor.

The purpose of the ranking process is to find the alternative which minimizes TC, TL, PS, WC, LU and maximizes RF, WQ, ER, CP, FL. To solve this multiobjective planning problem, an <u>array of alternatives versus criterion</u> should be prepared. With this information in hand, ranking of the alternatives can be undertaking using, for example, one of the following methods: ELECTRE, as in DÁVID and DUCKSTEIN /1976/, concordance analysis, as in NIJKAMP /1976/ or multiattribute utility theory as in KEENEY et al. /1976/. Here the ELECTRE approach is presented under the form of an application example.

<u>EXAMPLE FOR PLANNING OF MULTIPURPOSE INDUSTRIAL WATER MANAGEMENT SYSTEM</u>

For illustration of application of the present methodology, the results of a feasibility study are presented. Based on the long-term development alternatives for the Tisza river basin in Hungary /DÁVID and DUCKSTEIN, 1976/, four alternative industrial WMS-s have been developed to meet the requirements of an large, complex industrial area in the middle-part of the Tisza basin with shortages of natural water supply. Based on the technical and economic characteristics of the alternative systems, the system versus criteria array /Table 1./ has been generated. It presents the main characteristics of the WMS-s.

System I. is mainly oriented to surface run-off regulation including inter-basin water transfer to the area. System II. is also oriented to surface run-off regulation but by the storage of own water resources of the area. System III. is oriented to the conjunctive use and development of surface and sub-surface water resources and a high-level water demand regulation. Problems of waste water disposal occure. System IV. involves mainly the use of sub-surface water with high level demand regulation and difficulties of waste water treatment and disposal.

Based on the informations in Table 1, the comparison of alternative systems was done by the method ELECTRE, elimination and /et/ choice translating reality /BENAYOUN et al., 1972/. Considering the applied description of this nethod in DÁVID and DUCKSTEIN /1976/, here only the used inputs and the outputs are presented. The weighting data for computing concord and discord indices are shown in Table 2.

Table 1. System versus criteria array

Number	Criteria	Units	Alternative system /y/			
			I.	II.	III.	IV.
1.	Total annual costs /TC/	10^6 Ft/yr	130	104	84	70
2.	Total annual expected losses /TL/	10^6 Ft/yr	26	32	80	90
3.	Probability of fresh water shortage /PS/	%	3	10	15	12
4.	Extent of reuse /RF/	%	0,3	0,4	0,7	0,9
5.	Extent of water consumption /WC/	%	0,2	0,3	0,4	0,4
6.	Water quality requirements /WQ/	-	good	very good	fair	bad
7.	Energy factor /ER/	%	0,4	0,3	0,05	0,01
8.	Cooperation possibility /CP/	-	very good	good	bad	very bad
9.	Land use /LU/	hectar	800	550	40	60
10.	Flexibility /FL/	-	good	very good	very bad	fair

The results of ELECTRE analysis state that for the range of $0{,}5 \leq p \leq 0{,}65$ and $0{,}45 \geq q \geq 0{,}15$ comparison levels, System II. represents a reasonable compromise among costs, expected losses, shortage, water quality and other criteria. Therefore this WMS is suggested for further study.

Table 2. Input data for computing concord and discord indices

Number	Criteria	Criterion weight /for concord index/	Maximum scale interval /for discord index/
1.	TC	3	12
2.	TL	2	12
3.	PS	2	15
4	RF	3	8
5	WC	1	8
6	WQ	3	12
7	ER	1	1o
8	CP	2	1o
9	LU	1	6
1o	FL	2	1o

CONCLUSIONS

The following main conclusions may be drawn:

1. It is a basic requirement for planning of water resource-demand equilibrium that the quantity, quality and energy components of equilibrium and the water supply and waste water disposal activities can not be reparated. They form an integreted system.

2. The multicriteria methodology leads to a trade off among the regulation of natural water supply and water demand and the increase of system capacity. For the comparison of alternative WMS-s a system of ten criteria is proposed.

REFERENCES

Benayoun,R.O.,Larichev,J., de Montgolfier and Tergny,J., /1972/ Linear programming with multiple objective functions, the method of constraints. Automation and Remote Control, January.

Dávid,László /1978/ System development of water resources and quality control. Proceedings, Baden Symposium on modelling the water quality of the hydrological cycle. IAHS-AISH Publ. No.125.

Dávid, László /198o a/: Multicriteria model for regulation of resources-demand equilibrium in river basins. Presented to the Second International Conference on State of-the-art of Ecological Modelling. International Society for Ecological Modelling.

Dávid, László /198o b/: Multiattribute analysis of decision problems in regional water management. Hungarian experiences Presented to the Workshop on Criteria, Conflicts, Uncertainty and Institutions in Regional Water Management, IIASA, Laxenburg.

Dávid,L. and L.Duckstein /1976/ Multi-criterion ranking of alternative long-range water resource systems, Water Resources Bulletin, Vol.12. No.3. August, 731-754.

Dávid,L.-Duckstein,L.-Krzysztofowicz,R. /1977/ Multiobjective planning of runoff regulation under uncertain water demands. Proceedings, International Conference on Applied Numerical Modelling, University of Southampton, South-Southampton, England.

Greenberg,R.M. and Hordon,R.M. /1976/. A test of alternatives for meeting public potable water requirements, Water Resources Bulletin, Vol.12. No.4. August.

Keeney,R.L., Wood,E.F., Dávid,L. and Csontos,K. /1977/ Evaluating Tisza River Basin Development Plans Using Multiattribute Utility Theory, CP-76-3,IIASA, Laxenburg, Austria.

Kuzin,A.K. /1979/ Razvitie szisztemü planirovanie vodoohranii /Development of water conservation planning system - in Russian/ Vodnüe Reszorszü, No.5, Moscow.

Moss,M.E. and Dawdy,R.D. /1977/ Optimization problems with stochastic supply and demand curves, Session on Decision - Making Under Risk and Uncertainty in Water Reseurces, TIMS/ORSA Joint Spring Meeting, San Francisco.

deNeufville,R. and Marks,D. /1974/ Systems Planning and design: Case Studies in Modeling, Optimization and Evaluation, Prentice-Hall, New York.

Nijkamp,P. /1976/ Multiobjective programming models: new ways in regional decision making. Research Memorandum, No.43. Dept. of Economics, Free University,Amsterdam.

United Nations /1976/ River basin development policies and planning, Proceedings, UN Interregional Seminar on river basin and interbasin development, Natural Resources/Water series No.6, New York - Budapest.