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SYSTEMS APPROACH TO PLANNING INTERPLANT WATER MANAGEMENT IN INDUSTRY

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SYNOPSIS

The fundamental requirement which any interplant water management system is expected to meet is that water of the volume, quality and pressure required for the water using processes should be available reliably and efficiently at specific points and times. The two basic / flow-through and recirculation / models of supply can be connected to each other parallel, or in series. The alternative systems composed of the basic models are examined by the flow-rate-, quality- and pressure equations. The same equations form the mathematical models for formulating the computer programmes of the systems.

The balance equations for the two basic models are derived.

RESUMÉ

Planification systématique de l'aménagement en eaux des usines industrielles

L'exigence fondamentale envers le systéme d'aménagement en eaux d'une usine industrielle est d'assurer en lieu et en temps bien determinés la quantité, qualité et pression par une solution optimale et fiable pour les besoins des processus nécessitant l'eau.

La solution possible consiste d'employer l'un des deux modéles de base de l'utilisation d'eau / traversant ou recirculatif / et pour chacun, utiliser l'un des deus méthodes de raccordement / parallèle ou successif /.

Les différentes variations de systéme établies à partir des modèles de base peuvent être examinées à l'aide des équations quantitatives, qualitatives et d'équilibre de pression. Ces équations peuvent servir également comme base pour aux programmes d'ordinateur des variations. L'étude fournit une analyse des équations d'équilibre pour les deux modèles de base de l'utilisation d'eau.

RESUMEN

Planificación de la gestión de agua en plantas industriales de acuerdo con el modo de ver de la teoria de sistemas

El requisito basico, a lo que debe responder la suministro de agua de una planta industrial es que la agua pedida para los procesos industriales debe ser garantizar en cuantidad, en cualidad y con la presión deseada, en punto y tiempo definido, con seguridad de servicio y con la solución óptima.

La solución es possible con ayudo de dos modelos basicos / con agua pasada y con agua recirculada / y cada uno con dos tipos de conexiones / paralela y en suceción /. Los tipos diferentes de las sistemas formados de los modelos basicos pueden ser investigados con ayudo de ecuaciones de equilibrio referentes a la cualidad, cuantidad y presión de la agua. Estas ecuaciones dan la base del modelo matemático necesario para la programación computadora.

El estudio tace conocer las ecuaciones de equilibrio para los dos modelos basicos de suministro de agua.

Viewed on the average, the water resources of Hungary would be sufficient to meet the present and anticipated future demands, were it not for the fact that over 90 % of these supplies are available along the three major streams, namely the Danube, Tisza and Dráva rivers. This is the reason why the supplies are short in several regions.

The water demands of advanced agricultural production, accelerating rates of industrial development and rising living standards of the population have exhausted the local supplies in several regions already. Moreover, unless the current techniques of using water are improved, the supplies needed for the development of industry, or any other sector of economy will be impossible to procure at reasonable cost in the majority of the regions.

Of the total withdrawal from natural supplies by all sectors of economy, the share of industry is almost 60 % /3 thousand million m^3/year/ and round three-quarters of the pollutants detrimental to water are discharged by industrial plants to the recipient streams and lakes. A development programme has therefore been developed to achieve the balance of demands and supplies over long perspectives. The two main objectives of the programme are as follows:

a/ Controlling the runoff of surface waters to augment the supplies /storage/ and the distribution thereof by regional networks /long-distance pipelines/.

b/ Controlling the demands /reduction of the demands, or at least slowing down considerably their growth rate/.

Economic opportunities for effectively controlling withdrawals from supplies and discharges of harmful pollutants exist primarily in the sector of economy using the largest volumes of water, namely industry. In the overwhelming majority of industrial plants no more than 3 to 5 % of the total technological water demand must, or can economically be met from freshwater resources. /On the average for the entire industrial sector this proportion is estimated at rd. 8 - 10 %./ The present freshwater consumption of industry in Hungary is, however, 43 to 45 % on the average and 28 to 30 % if the power industry is neglected.

Evidently, the rate of reuse at industrial plants is a question of economics alone, as long as fresh water can be procured at reasonable costs. Beyond this limit reuse becomes an emergency measure, i.e., the plant must be kept operating with the fresh water supply that can be made available, insofar as this solution remains at all within the margin of profitability.

Another possibility consists of reducing the overall water demand of the individual operations /or eliminating the demand entirely/ by modifying the technology of production.

Even greater attention must be devoted to water pollution caused by industry. The losses resulting therefrom are in the majority of cases heavier than those due to wasteful consumption. This is why the controls imposed upon discharges of industrial wastes to the recipients present a much more severe constraint than the former, the potential solutions requiring often considerable engineering efforts and high costs /treatment of wastewaters, modification of production technologies, etc./.

Rational designs for interplant water management systems in industry will be examined subsequently.

1. Designing rational water management systems for industrial plants

The fundamental requirement which any interplant water management system is expected to satisfy is that water of the volume, quality and pressure required for the water using processes of the plant should be available reliably at specific points and times. It should ensure, moreover, the safe removal of the effluents produced. At the same time, the system should be efficient from the engineering and economic aspects alike.

The first step of designing consists of checking the water demands specified by the technologist for their quantity and quality, further of estimating the pollutant emission by each of the individual water using operations and equipment performing these, taking into account all potential conditions of operation.

In the next step the supplies available in the surroundings of the proposed plant site should be explored, identifying their geographical position, quantity, quality and water level elevation. The potential recipients should also be explored for their position, actual level of pollution and the amount of pollutants that may be discharged into them without violating the relevant quality criteria.

Once reliable figures have been established on the demands and effluent parameters pertaining to different operating conditions of the plant, further with accurate information available on environmental criteria and particulars, work can be started on designing the interplant water management system.

The alternative supplies to the individual consumption points within the plant are determined by examining the flow-, quality- and pressure balances for the two basic water management models adopted for industrial plants, viz.

- the open /flow-through/ system and
- the closed /recirculation/ system.

Both basic water management models can be connected to each other

- parallel, or
- in series.

The symbols used in the figures are explained as follows:

Q_F freshwater demand $/m^3/h/$
Q_P compensation water demand $/m^3/h/$
Q_T total technological water demand $/m^3/h/$
Q_H total flow used $/m^3/h/$
Q_R flow recirculated $/m^3/h/$
Q'_{Hh} reuse from interplant effluent $/m^3/h/$
Q''_{Hh} reuse from external effluent $/m^3/h/$
Q_L effluent from the recycling circle $/m^3/h/$
Q_{Sz} plant effluent /wastewater discharge/ $/m^3/h/$
Q_{Vp} evaporation from the system $/m^3/h/$
Q_V total loss from the system $/m^3/h/$
Sz_n pollutants entering and leaving the system /kg/h/
Sz_{ki} permissible water pollutant discharge from the plant /kg/h/
K_n symbol of water- and wastewater treatment facilities
c_n pollutant concentration /mg/l/
p_n water pressure /Pa, metre water column, El. above sea level/

1.1 Balance analysis of open /flow-through/ water management model /ref.Fig.1/

The magnitude, quality and pressure of the water demand needed for the production technology:

Q_T, c_T, p_T

The magnitude and quality of the supplies available in the area:

Q, c, p

where $Q \geq Q_T$, $c = c_F$, $p = p_T$

The amount of pollutants $/Sz_1/$ to be removed at the fresh water treatment plant K_1 is thus

if $c_F > c_T$

$$Sz_1 = Q_F\ /c_F - c_T/$$

$$Q_F \cong Q_T$$

The amount of pollutant which the recipient is capable of assimilating

$$Sz_{ki} = Q_{sz}\, c_{sz}$$

The amount of pollutant which must be removed by treatment

$$Sz_2 \cong Q_T c_T + Sz_T - Q_{sz}\, c_{sz} = Q_H\, /c_H - c_{sz}/$$

The water losses caused by using the water

$$\Sigma Q_V = Q_F - Q_{sz} = Q_{V_1} + Q_{V_T} + Q_{V_2}$$

The balance analysis for two, or more open water management systems connected in series is performed in a similar manner following logically the same approach.

1.2 Balance analysis of a closed /recirculation/ water management model /ref.Fig.2/

The parameters of the water demand needed for the production technology are

Q_T, c_T, p_T

The magnitude, quality and pressure of the freshwater supplies available in the area:

Q, c, p

where $Q < Q_T$, $Q \geq Q_F$, $c = c_F$, $p = p_F$

The amount of pollutants which the recipient is capable of assimilating

$$Sz_{ki} = Q_{sz}\, c_{sz}$$

The kind of treatment $/K_1/$, the flow of compensation water $/Q_p/$, the kind of effluent /wastewater/ treatment $/K_2, K_3, K_4/$ and the effluent release $/Q_L/$ in the case of recirculation can be determined by examining the balance conditions.

Consider thus the flow- and water quality balance conditions of the system.

The flow balance in the recirculation loop is

$$Q_p = \Sigma Q_{V_R} + Q_L$$

The water wuality balance /by polluting component/ is

$$Q_p c_p + Sz_T = /\Sigma Q_{V_R} - Q_{V_p}/ \; c_R + Q_L \; c_R + Sz_2$$

Once the basic criterion Sz_T is established, the water losses are determined, further the water- and wastewater treatment technologies are decided upon, the values of Q_V, Sz_n and c are known. The two unknowns Q_p and Q_L can be found from the two balance equations.

If $Q_p + Q_{V_1} = Q_F$ and $Q_F > Q$,

then it is necessary to reduce Q_p, which can be achieved by improving the quality of compensation water, thus the level of water treatment must be raised and this will decrease Q_L at the same time.

If $Q_L c_L > Q_{Sz} \; c_{Sz}$

then additional wastewater treatment $/K_3/$ must be introduced, or Q_L, Q_P and c_p must be reduced. A third alternative is to reduce Sz_T /changing the technology of water use/.

1.3 General model of interplant water management system

By the different combinations of the following parameters, any particular water management system model can be derived from the general system illustrated in Fig.3.

With $Q_R = 0$ and $Q_{Hh} = 0$ -- open system
With $Q_R = 0$ and $Q'_{Hh1} = A \; m^3/h$ -- series-connected system
With $Q_R = A \; m^3/h$ and $Q'_{Hh1} = 0$ -- recirculation system
With $Q_R = A \; m^3/h$ and $Q'_{Hh1} = B \; m^3/h$ -- series-connected recirculation system.

The operation of the interplant water management system can be represented visually by indicating the elements and subsystems, as well as the technological-functional relations thereof. The pattern of the system thus produced is the ikonographic model thereof. By describing the interrelations between the elements of the resulting model /Fig.3/, further the effects of various outputs and inputs with the help of exact, or approximate mathematical expressions, i.e., by describing the operation of the system in analytical terms, the methematical model of the system is obtained.

/The balance equations of pressure conditions can also be written with the help of the corresponding familiar relationships./

The approach outlined in the foregoing is suited to the examination of interrelations between the elements of interplant water management models and to select the model applicable in particular cases.

The water management system in most industrial plants, particularly in the large ones, is composed of several of the aforementioned basic water management models in different parallel, or series arrangements, which are in simple, or multiple functional connection with each other.

2. Optimization of interplant water management systems

Owing to the wide engineering varieties of the elements and subsystems composing the water management system, as well as to the wide range of requirements imposed on the production technological system of the consumer, to the broad spectrum of different supplies and water quality criteria of the regional system, a number of potential alternatives are conceivable for the interplant water management system of an industrial plant. Of these the most efficient can be selected by setting a definite objective. E.g. the water demand of a production technology must be met in a reliable manner and at the lowest possible cost

- with the lowest freshwater demand, or
- with the lowest power consumption, or
- with the lowest pollutant discharge, etc.

The target function to be optimized is in symbolic form:

$K_V + K_a + K_{Tt}$ --> minimum

under the constraints

$Q_{Tmin} \leq Q_T \leq Q_{Tmax}$

$Q_F \leq Q_K$

$Q_{Sz} c_{Sz} \leq Sz_{e1}$

$I_{Sz} \leq Sz_{e2}$

Notations:

Sz_{e1} = the amount of pollutants that can be discharged to the recipient with the waste water Q_{Sz}

Sz_{e2} = the amount of pollutants that can be disposed of in the environment with the sludge I_{Sz}

K_V = the total cost associated with the freshwater and the effluent

K_{Cs} = the total cost associated with the waste water and the sludge

K_{Tt} = the additional cost of modifying the production technology for improved water management.

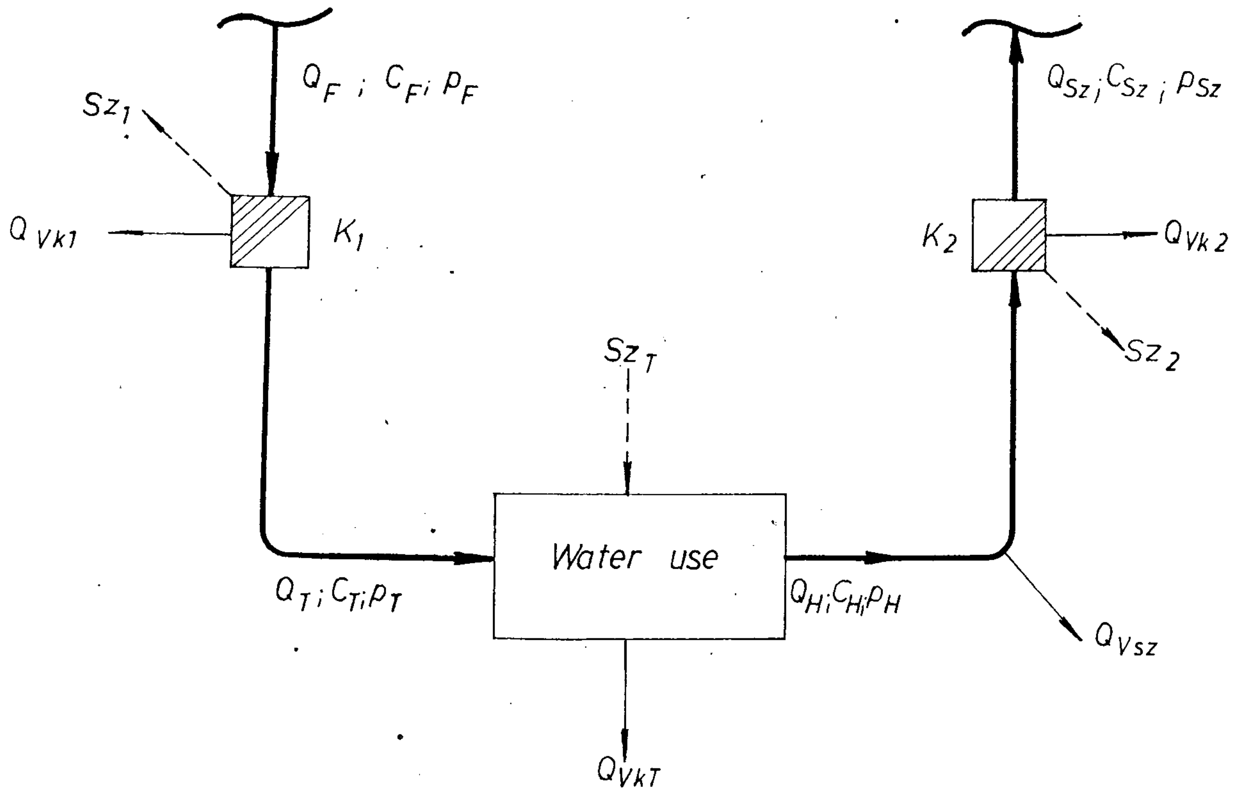
A graphical plot of the symbolic cost function of the system is shown in Fig.4.

The Symbols used in Fig.4. are explained as follows:

a_1, a_2 = Construction costs of water supply-sewerage for the same plant at different sites

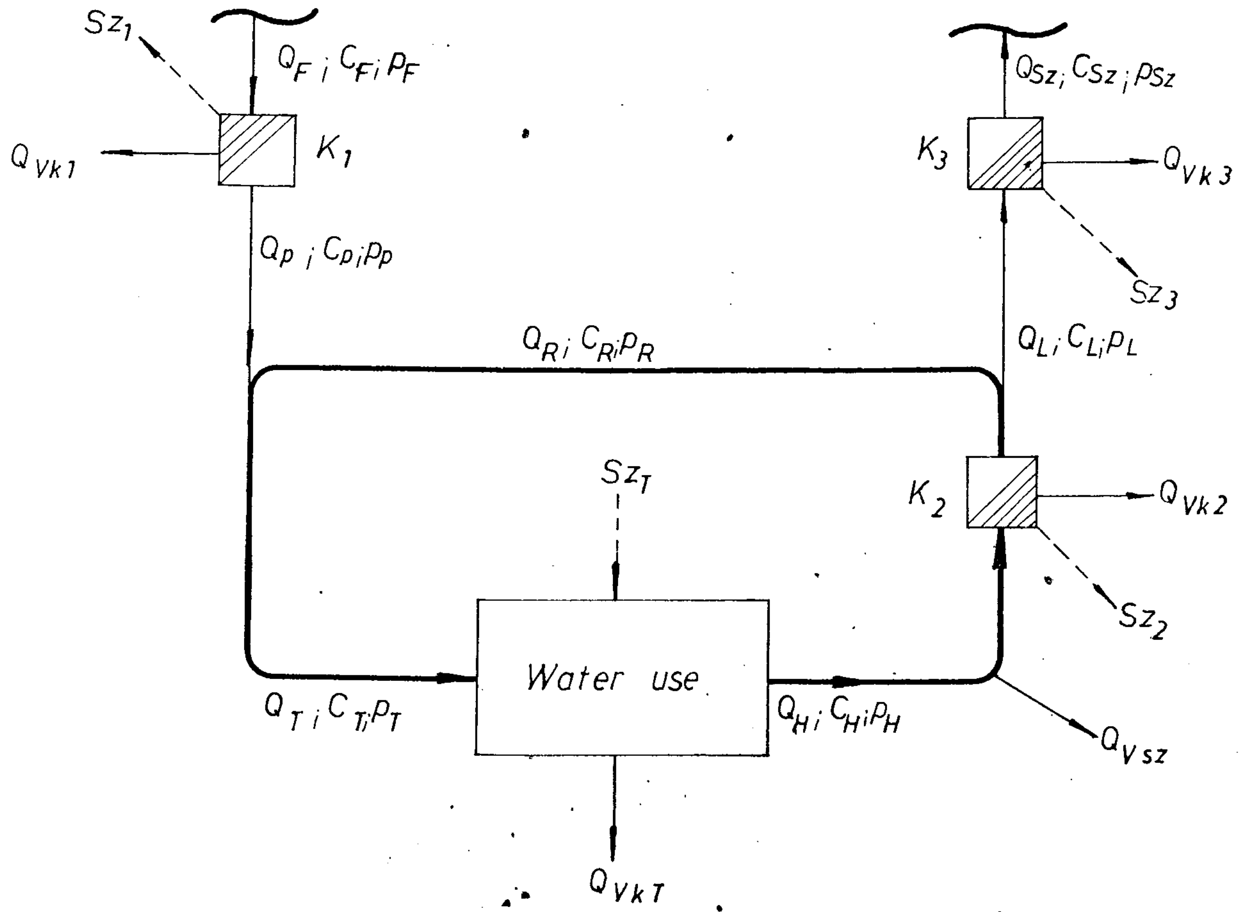
b = additional costs of modifying the production technology and equipment for improved water management, as well as for water reuses.

Rational and more careful management of water supplies has become a problem of growing economic importance in Hungary. Several industrial regions face already serious water shortages and pollution increases rapidly in the main sources of supply, viz. in the surface waters. Since industries play a decisive role in water management, effective controls on water demands and water pollution in this field present a key problem. The systems approach outlined in the foregoing to water management planning for industrial plants would offer the possibility of effective control at least in the case of new plants, or such contemplated for expansion, or reconstruction, modernization.



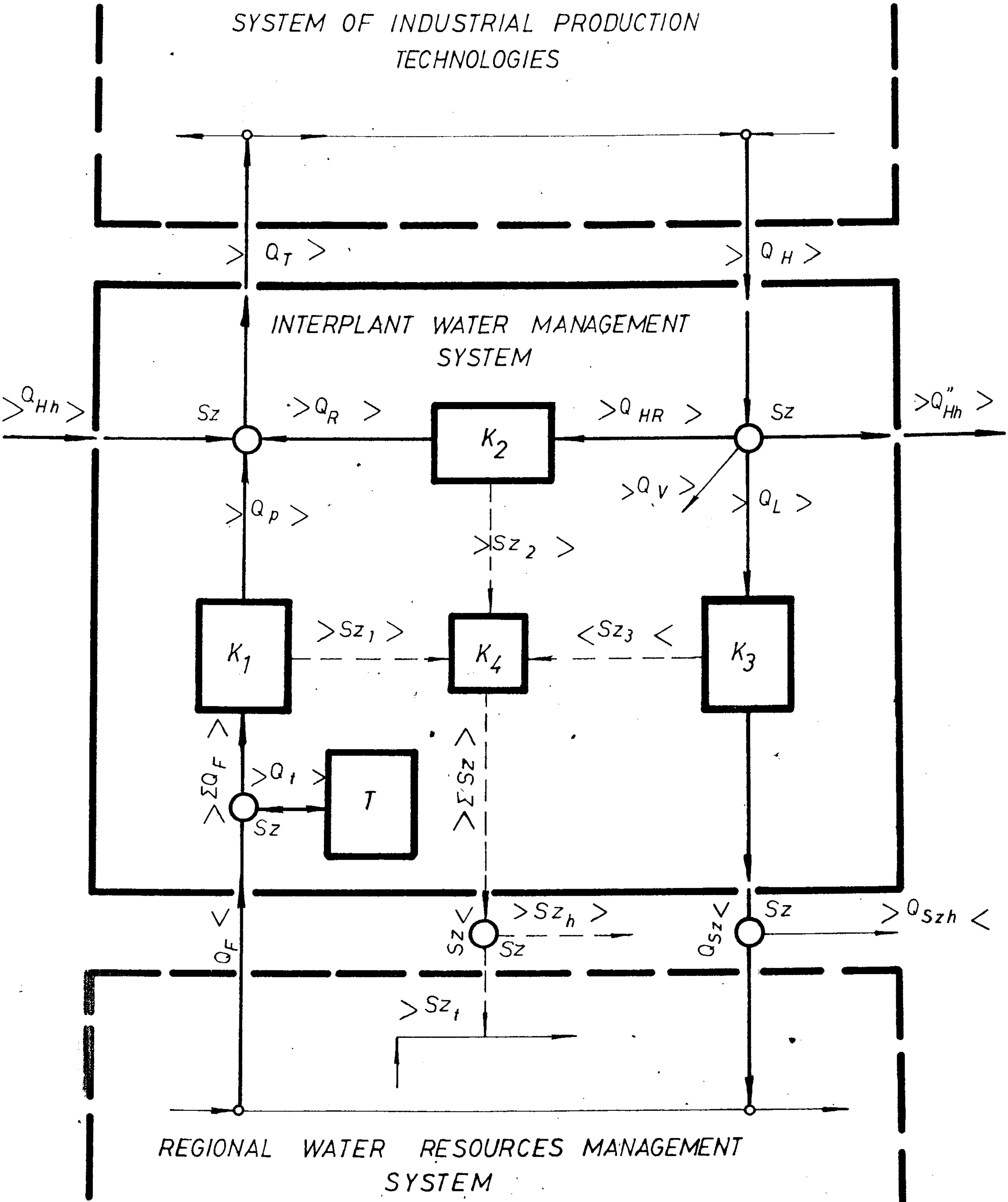
Open water management system

fig. 1.



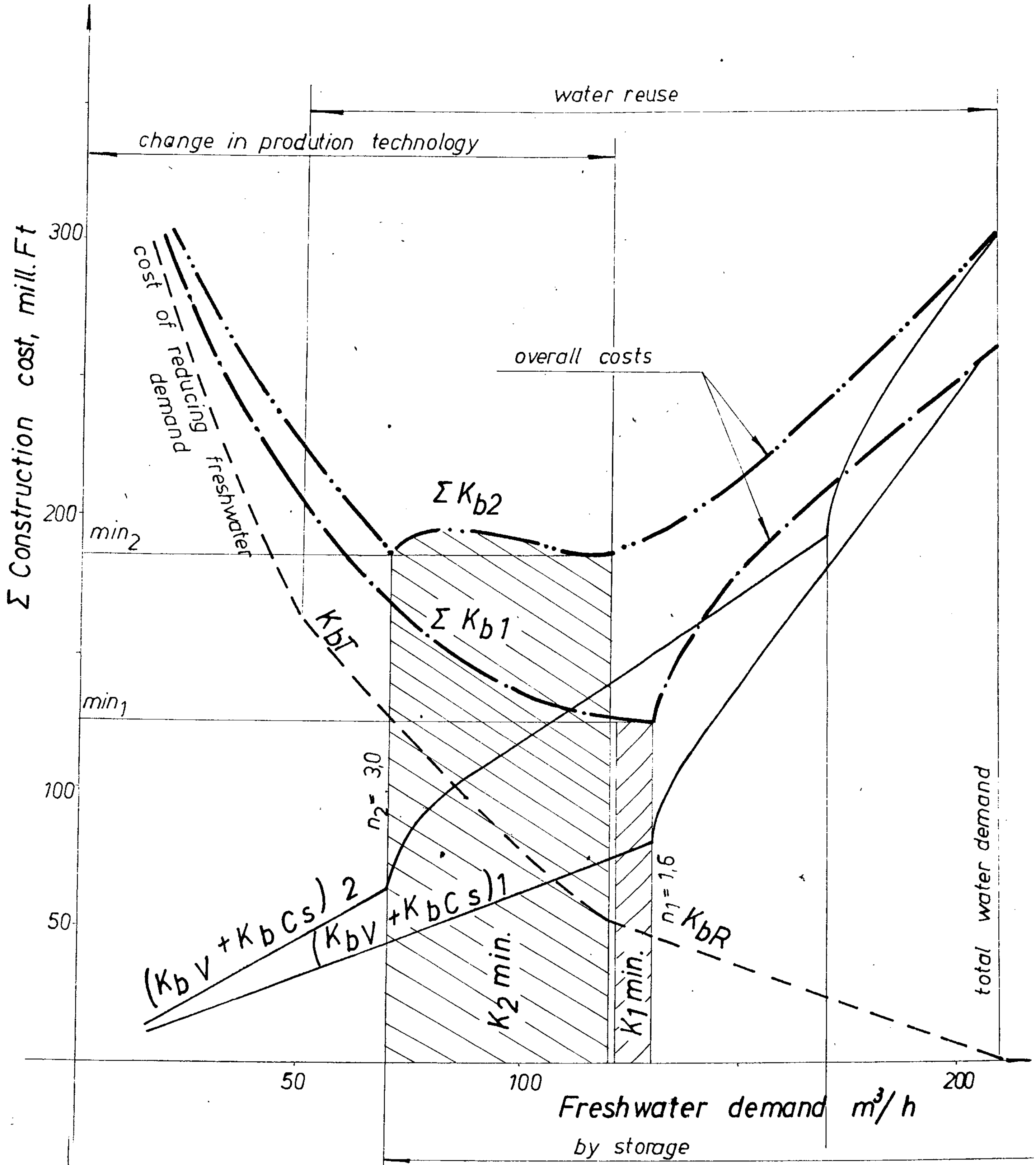
Closed water management system

fig. 2.



General model of interplant water management system

fig.3.



subscripts 1 and 2 = alternative plant sites

Cost function of interplant water management system

Fig. 4.