

**SIMGES Simulation Model of Water Resource  
Management including Conjunctive Use.**

**Version 3.02**

**User Manual**

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# SIMGES MODEL V 3.00 USER MANUAL

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## 1. INTRODUCTION

**SIMGES** is a general management simulation model for basins or complex water resources systems that contain surface and underground elements for regulation and storage, intake, transport, consumption/use and artificial recharge.

The model admits any configuration and is limited only by hardware capacity, so that it can be used for any type of water resource scheme.

Simulation is performed on a monthly scale and reproduces water flow through the system with the degree of detail selected by the user. Surface subsystem flows are calculated simply by continuity or balance. For underground subsystems or aquifers, flow can be simulated by single or multicellular models, as required, or also by distributed linear flow models. The system computes evaporation and infiltration losses from reservoirs and riverbeds and the interaction between surface and ground waters.

Water resource management is carried out with operating rules that tend to maintain similar water levels in reservoirs, based on the initial reservoir zoning curves entered by the user. Minimum ecological flows and different user priorities can be defined.

Surface system simulation and management are run simultaneously using a conservative flow network optimisation algorithm, which controls system flow while minimising deficits and maximising adaptation to reservoir target volume curves and hydroelectric production.

Results include monthly or annual evolution of the variables, average simulation period variables and reliability. This means the model can be used to determine:

- The reliability obtained from different hypothetical infrastructures, demand patterns and basin operating rules.
- The most suitable operating rules for the required guarantee levels.
- The advantages and disadvantages of changing water use priorities.
- Reservoir, channel and pumping capacities for given demand and guarantee levels.

## 2. ELEMENTS CONSIDERED

The definition of pattern elements, which can be combined as required by the user, means the model can be adapted to any type of scheme. These elements include:

- **Surface reservoirs:** including interbasin flow. These are defined by their physical and management parameters (maximum volumes, target volumes and storage priority over other reservoirs).
- **Intermediate inflows:** these are inflows that cannot or should not be considered as direct reservoir inflows.
- **Channels:** including river reaches, canals, etc. Defined by their physical parameters (including maximum capacity) and possible minimum inflows (normally ecological). There are 5 types:
  - **Type 1:** As defined above.
  - **Type 2:** Include loss by infiltration.
  - **Type 3:** Consider hydraulic connection between a river and an underlying aquifer, including aquifer-river and vice-versa, depending on the state of the aquifer.
  - **Type 4:** Defined as in Type 1, with instantaneous maximum flow as a function of the difference between the elevations of the start and finish of the channel. If it begins or ends in a reservoir, the height difference is considered in determining the monthly maximum.
  - **Type 5:** Hydraulic connections between nodes and reservoirs. Circulating flow is a function of the different elevations of entrance and exit. Water can flow in both directions and variations in reservoir levels throughout the month are considered.
- **Consumptive demands:** Consist of elements that use water, part of which is consumed and therefore lost to the system. This type includes irrigation zones and industrial and urban demands. They are defined by their demand curves, consumption parameters, intakes and any connection to a return element. Individual demands can be supplied from different sources.
- **Return elements:** Definitions of points at which water returns to the system from consumptive demands.
- **Non-consumptive demands:** These are elements that use water but do not consume it, e.g. hydroelectric demands. They are defined by their physical and production data and by target monthly flow.

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- **Artificial recharge:** These are elements used to recharge aquifers with excess water from other sources and are defined by their physical characteristics.
  - **Additional extraction facilities:** These elements collect water from aquifers for incorporation into surface systems for use in a zone other than the pumping zone.
  - **Aquifers:** Defined by their physical parameters and certain operating parameters. Extraction ceases when the limits are reached. Types of aquifer include:
    - Tank aquifer
    - Single-cell aquifer
    - Spring aquifer
    - Multicellular aquifer
    - Aquifer hydraulically connected to a river with distributed modelling by the Eigenvalue method
    - Homogeneous rectangular aquifer connected on one of its sides to a fully penetrating river
    - Homogeneous rectangular aquifer connected on two contiguous sides to fully penetrating rivers
    - Aquifer with three different outlet levels: this is a simplified model that makes it possible to consider connections with two different surface water levels and variable annual evapotranspiration.
    - Aquifer modelled by Eigenvalues with no geometrical limits or hydrodynamic parameters

### 3. USER SCHEME

To use the model, the user must first create a scheme of the basin or system using the pattern elements described above. For this, he must define a series of nodes in the surface hydraulic system located at the following points:

- Reservoirs
- Points where two or more channels merge
- Points where a channel branches or receives an inflow
- Demand intake and return points
- Possible intermediate inflow points or additional pumping points
- Points where channel characteristics change

The next step is to define and classify according to type the connections (channels) between nodes.

Intermediate inflows into nodes or reservoirs are then located (if not already associated with the reservoir).

Demands with their intake and return nodes (elements) are then defined, specifying the aquifers from which they can be supplied and those which can receive returns by seepage.

Artificial recharge point of origin nodes and additional pumping nodes are then identified.

Restriction criteria for emergency situations are identified. These may be associated with demand intakes or Type 1 channels.

The definition of the hydraulic scheme is completed by providing the model with the connections between nodes, besides the individual data pertaining to each element.



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## 4. BRIEF DESCRIPTION OF INTERNAL OPERATION OF MODEL

As has already been mentioned, the simulation and management of the surface subsystem are run simultaneously by means of a conservative flow network optimisation algorithm.

The user scheme as described in the previous section is a flow network, but is not conservative since it is not a closed system and there are storage nodes (corresponding to reservoirs). The first task of the model after reading the data is therefore to modify the scheme to a conservative network. This means firstly establishing some “closing” nodes and then extending pattern elements into a subscheme of arcs and nodes to ensure the correct simulation of hydraulic behaviour and element management. This will give the model a much more complex and conservative “internal flow network” than that designed by the user.

The simulation model is now active. For each monthly period, aquifers and flow network are solved with the corresponding inflows, demands and management parameters, aquifers are simulated, iteration is performed between these last two steps (due to non-linearities and river-aquifer interactions) and values are stored for annual writing and statistics. Finally, after completing the simulation period, the relevant statistics are generated and guarantees are calculated

## 5. DEFINITIONS OF THE DIFFERENT ELEMENTS

This section describes the different elements included in the basin scheme, the physical data required for their definition, the role of the element in the scheme and the management parameters required for simulation.

### 5.1. Nodes

Even though nodes are not strictly speaking elements, it is important to realise their role in simulation. Due to one or more circumstances, a node is a significant point in the scheme at which:

- different flows or channels join together or separate
- a reservoir is located
- an inflow, return or additional extraction is incorporated
- an artificial recharge outflow or a demand intake occurs
- river or channel characteristics change.

The user must number the different nodes for identification. This can be done randomly or at the discretion of the user.

The only requisite is that one node from which flows leave the system (i.e. those not incorporated in the system) should be assigned the number 0.

It should be remembered that **neither demand elements nor aquifers constitute nodes** and alarm indicators are not directly represented in the scheme. .

### 5.2. Connections

When the nodes have been defined in this way, the next stage is to define the inter-node connections, using the nodes to physically locate the connections.

Connections, or channels, always flow in a unique direction. This means that water flows from **“initial node”** to **“final node”**. The circulation of water inside the system is defined by these nodes and their corresponding numbers.

Type 1 channels are assigned a **maximum monthly flow** and also a **minimum monthly flow**, which can vary from month to month.

When simulating management the model will never violate maximum flow, so that special care must be taken in setting maximum flows for natural channels (river reaches), since if they

are too low they may be physically impossible to comply with, **causing a serious error in the model simulation.**

On the other hand, minimum flows are not taken as physical but rather as management limits, and the model will do its best to observe them within the established priorities, so that if minimums have to be ignored the execution of the model will not be affected.

Five channel types are recognised with the following definitions and operations:

- **Simple channel:** corresponds to the previous description, and is perfectly defined with the inputs mentioned. It may also be known as **channel type 1** or **river reach type 1 (TR1)**. For reasons of internal program operation **there should not be more than one TR1 with the same initial and final nodes or with interchanged initial and final nodes.** TR1 channels can be assigned an arbitrary flow cost or user cost which allows water assignation to be varied arbitrarily. To define this user cost, see Section 6.1.2, which deals with the contribution of the target function to TR1 channels. They can also be defined as **unit or by-pass cost** to divert the flow to another channel when two channels of equal cost are available. Type 1 channels may have an Alarm Indicator incorporated (described below), whose function is to reduce maximum capacity during months in which the volume stored in certain system reservoir groups is low. The Alarm Indicator can be optionally assigned to either maximum monthly flow or to annual flow, if this is limited.
- **Channel with infiltration:** these lose water through seepage. Water loss,  $P$ , is considered as a function of flow,  $Q$ , at the start of the reach and is expressed as follows:

$$P=a+b Q^c \quad (5.1)$$

**a, b** and **c** being parameters required by the model and supplied by the user.

To assign infiltration to an aquifer, unitary external stresses must be defined for this aquifer (basic stresses are defined in Section 5.9) and that corresponding to the recharge caused by channel infiltration identified.

These channels may also be called **type 2 channels** or **type 2 river reaches (TR2)**.

- **Channel hydraulically connected to aquifer:** This type passes through an aquifer with a hydraulic connection between both, so that water may seep from the channel to the aquifer or from the aquifer to the channel, according to the piezometric levels in the aquifer. It will therefore be necessary to define which aquifer is connected to the channel and which aquifer control response (**control parameters**) quantifies the flow between both (see Section 5.9).

These channels are also known as **river reach type 3 (TR3)**.

- **Channel hydraulically limited by the height difference between its extremes:** Its definition is basically that of a simple channel (TR1) but with the constraint that maximum instantaneous flow is a function of the height difference between the initial and final nodes. This type of channel can simulate situations such as that of a channel starting from a reservoir at a certain elevation in such a way that the maximum flow is limited by the elevation of the water surface. Apart from the usual inputs for simple channels (TR1), the user will have to define the curve relating maximum instantaneous flow with height difference. This difference can vary from month to month if there is a reservoir at either end. In such a case, maximum flow is obtained by integration, assuming that height difference varies linearly during the month.

These channels are also known as **type 4 channels** (TR4).

- **Hydraulic connections between nodes and/or reservoirs:** In this type of channel, instantaneous flow is determined only by the height difference between the extremes, which cannot be regulated. Water can flow in both directions. This type may connect two reservoirs. Besides initial and final nodes, the user must define the curve relating instantaneous flows with elevation difference. Monthly flow is determined by integration, assuming that elevation difference varies linearly throughout the month.

These channels are also known as **type 5 channels** (TR5).

### 5.3. Inflows

Inflows include all the water added to the system. An entrance point is defined which must be a system node. A distinction is made between intermediate inflows and reservoir inflows. The former are incorporated in non-reservoir nodes and the latter in reservoir nodes. However, intermediate inflows can be incorporated into reservoirs.

The user must enter monthly inflow values in a special inflow file, with a column for every inflow considered in the scheme. The column number corresponding to a given inflow will therefore be among the data required by the model. This number is requested even for reservoir data in the case of reservoir inflows.

### 5.4. Water imports

Like the intermediate inflows, these are inflows into the system, the difference being that imports can be altered by the user in each simulation and are therefore included in the general model data file.

### 5.5. Reservoirs

Surface reservoirs correspond to points in the scheme at which there is water storage capacity and are basic management elements. Simulation is performed simply by mass balance, so that the end-of-month volume  $V_f$ , can be expressed as:

$$V_f = V_i + A_e + A_a - P_f - E - S_c - S_v \quad (5.2)$$

where:

$V_i$	is the start-of-month volume
$A_e$	is the reservoir hydrological inflow
$A_a$	are inflows from upstream of the reservoir
$P_f$	are seepage losses
$E$	are losses due to evaporation
$S_c$	are controlled releases, i.e. those that do not exceed reservoir drainage capacity, including intakes inside the reservoir
$S_v$	are uncontrolled releases due to excess capacity that cannot be dealt with by controlled drainage.

To apply Eq. 5.2 in the first month, initial reservoir volume must be defined at the start of the simulation.

Seepage losses can be expressed as:

$$P = a + bV^c \quad (5.3)$$

Where  $P$  and  $V$  are losses and instantaneous volume, and  $a$ ,  $b$  and  $c$  are parameters supplied by the user and required by the model. The linear integration of Eq. 5.3 for a period of one month gives us the following equation:

$$P_f = a + \frac{b}{(c+1)(V_f - V_i)} (V_f^{c+1} - V_i^{c+1}) \quad (5.4)$$

with units of  $P$  in Eq. 5.3 of  $\text{Hm}^3/\text{month}$  and  $V$ ,  $V_f$  and  $V_i$  in  $\text{Hm}^3$ .

To calculate evaporation losses, we apply:

$$E = \frac{S_f + S_i}{2} e \cdot 10^{-5} \quad (5.5)$$

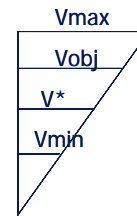
where  $S_f$  and  $S_i$  are the reservoir surface areas (Hectares) of the final and initial volumes, respectively, and  $e$  is evaporation figure in mm.

For uncontrolled releases to occur, the stored water must exceed maximum volume,  $V_{max}$ , defined for each month, and exceed the capacity of controlled discharge. This maximum volume can be varied each month so as to be able to define the safety margins for possible floodwater levels.

If uncontrolled releases cannot be used, they can be defined as supply nodes at the end of the system. It should also be noted that the model needs a value for maximum release flow ( $S_c$ ), and if the demands that have to be met from the reservoir exceed this value the model will not be able to supply total demand from this reservoir, even if there are usable reserves.

The management of the basin reservoirs is done in such a way that they are all kept as far as possible within the same capacity zone, considered as the user's definition of monthly target volume,  $V_{obj}$ , and monthly minimum volume,  $V_{min}$ , the zones being automatically defined as follows.

- Upper zone: between  $V_{max}$  and  $V_{obj}$
- Intermediate zone: between  $V_{obj}$  and  $V^* = 1/2(V_{obj} + V_{min})$
- Lower zone: between  $V^*$  and  $V_{min}$
- reserve zone: between  $V_{min}$  and empty.



A **storage priority number in reservoir**,  $N_p$ , is also defined for each reservoir.

In this way, the model will not use water from the intermediate zone of a reservoir until all the water has been used from the upper zones of all the other reservoirs. If two reservoirs are in the same zone, the model will first take water from the reservoir with the highest storage priority number.

When a reservoir is in the reserve zone, for the following months no water can be taken from it (For exceptions see Section 6.2).

The scheme described is of proven efficacy (Hisch et al., 1977; Loucks and Sigvaldason, 1979) and is flexible enough for the user to be able to assess different surface management strategies and joint groundwater strategies by varying  $V_{obj}$  and  $V_{min}$ .

## 5.6. Consumptive demands

These include irrigation and industrial and urban zones that use water in such a way that part of it is consumed and is therefore not returned to the system, constituting a loss.

To define the consumptive demands, the **monthly demand** values for the area must be indicated, corresponding to the water that, if available, would be applied to this use.

To satisfy this monthly demand, one or more surface system **intakes** must be defined. The concept of intakes corresponds to different water sources but can also be used to distinguish between priorities of water from the same point or even to supplies from different subzones within the zone considered. This flexibility is obtained by defining an annual capacity value for each intake, besides the intake node, so that if this value is reached, this intake is not used again until the next hydrological year. Monthly peak values, different for each month if desired, and priority numbers for each intake must also be defined with a relationship to the priority numbers of the rest of the demand zones. To simulate the subsequent evolution of the water used, two coefficients must be defined for each intake: a return coefficient,  $\alpha$ , and a consumption coefficient,  $\beta$ . The water returned to the system in the form of surface water is thus:

$$R = \alpha \times S_{sup} \quad (5.6)$$

Where  $S_{sup}$  is the intake's surface supply. To properly measure this return, the number of the **return element** at which the  $R$  volumes are incorporated must be defined

The water consumed, and so lost to the system, is given by:

$$X = \beta \times S_{sup} \quad (5.7)$$

The rest is considered as deep infiltration and is given by:

$$I = (1 - \alpha - \beta) \times S_{sup} \quad (5.8)$$

which goes to increase the recharge of the underlying aquifer. So that this can be accurately measured, the user must supply the model with the data of the **number of the underlying aquifer** and **basic stress** corresponding to the recharge caused by infiltration in the zone.

Should the surface supply be insufficient, the rest of the demand can be supplied by pumping water from an aquifer, which does not necessarily have to be the same aquifer recharged by the infiltration in the zone. It is therefore necessary to supply the **number of the aquifer in the zone from which water can be pumped**, as well as the **number of the basic stress** that corresponds to this pumping. The decision to pump also depends on the state of the aquifer, for which the user defines a given control parameter value after which pumping ceases. The control parameters are defined in the section dealing with aquifers.

Surface supply by a given intake may also be limited by other physical and/or management conditions:

- In the case of intakes connected to reservoirs, the elevation of the connection is considered as part of the data, so that water can only be taken from this intake when the water level in the reservoir is above the level of the intake. If it is above this level at the start of the month and below at the end, the volume that can be supplied is calculated by

integration and deducting the remaining reservoir discharges and losses. In fact, the situation of trying to satisfy multiple objectives from a given reservoir can be solved by iterations carried out in each simulated month.

- Each intake of each of the consumptive demands can be associated with a system alarm indicator. These indicators, described below, involve the reduction of the intake's monthly (or annual) maximum when the volume of water stored in a certain group of reservoirs falls below a certain threshold as defined by the user. This is a way of restricting consumption when water supplies are lower than normal.

## 5.7. Return elements

The definition of this element is purely functional since it would have been possible to simply define a node number incorporating surface returns from the different intakes. However, to reduce running time and memory requirements it was decided to define the return elements and that each one could be used by one or more intakes from the same or different zones.

To define the return elements, it is only necessary to supply the model with the number of the node at which the related inflows enter the system. Various return elements connected to the same node or reservoir can be defined.

## 5.8. Hydropower plants

These are practically the only demands that use but do not consume considerable quantities of water.

The intake and return nodes must be defined, also **maximum flow** (maximum power for power stations below a dam) and **target monthly flow** (variable from month to month) and a **priority number**

The model will always try to satisfy target flow without infringing on the priorities of other demands (with lower priority numbers).

Energy production is calculated by using the gross head and a global efficiency coefficient. If the power station is at the base of a dam, gross head is calculated previously using the reservoir elevation-volume curves. Monthly energy generation is given as:

$$E = H_m \cdot \mu \cdot V_T \quad (5.9)$$

where  $H_m$  is average total fall. In the case of a station at the base of a dam:



$$H_m = \frac{H(V_{i-1}) + H(V_i)}{2} - H_c \quad (5.10)$$

where:

$H(V_i)$	is the elevation of the reservoir for a volume $V_i(m)$
$\mu$	is the global efficiency coefficient ( $Gw.h/Hm^3*m$ ) calculated as the non-dimensional global efficiency coefficient multiplied by 0.0027222
$V_T$	total volume of water used ( $Hm^3$ )
$H_C$	height deducted for the calculation of hydroelectric production ( $m$ )

Minimum flow passing through turbines use can also be defined for a hydropower plant. Since the model works on monthly time steps, it is better to give this a null value, since it is more than likely that one of the regulation elements of the month will allow this volume to be concentrated into a time that will give the real minimum flow of the plant.

A minimum reservoir water level for power generation can also be defined for a station at the base of a dam to operate. In the case of mean water level in the reservoir in a given month being lower than this minimum, power production is halted.

Like the consumptive demand intakes, a hydropower station can have an associated system alarm indicator. These indicators, described below, reduce the monthly target flow to the power plant when the water volume in a given group of reservoirs goes below certain thresholds defined by the user. This is a way of restricting outflows for electricity production when water supplies are lower than normal.

## 5.9. Aquifers

Aquifers form part of the elements of a system which are connected to the other elements by the actions that they initiate. Most of these actions have already been described: infiltration from reservoirs and river reaches, river-aquifer connections, deep irrigation zone infiltration and pumping. Others will be described later, such as artificial recharge and additional extraction.

At this point, two concepts should be clarified which will be used extensively throughout this manual for model data inputs: these are basic stresses and control parameters.

A **basic stress** means an action or series of actions involving the aquifer that may vary in intensity in the course of simulation. For example, pumping water from a well is a basic stress and the monthly flow of water is the intensity. Extracting water from different wells in the same zone is also a basic stress, as long as the distribution between the wells of the total water pumped is considered to be permanent, the intensity of the stress being the total water extracted from the wells in a month. Modeling of lumped aquifers can admit only one basic stress, which is (positive or negative) recharge, since their location does not matter. On the other hand, the modeling of distributed aquifers does permit various basic stresses.

**Control parameter** means any aquifer response that provides information, e.g. the level of a cell, total volume, the river-aquifer relationship. Control parameters are used as criteria to define the rules of operation of aquifer management. Pumping may be stopped when a given control parameter reaches a threshold value.

The model admits several conceptual types of aquifer, which are described below.

### 5.9.1. *Tank aquifer*

This aquifer is not hydraulically connected to the surface system and the only information of interest is its water content or volume. The data to be entered are initial volume and the aquifer's natural recharge. The model used is:

$$V_n = V_{n-1} + R_n + R_{LL} \quad (5.11)$$

Volume at the end of the month,  $V_n$ , is the sum of the initial volume  $V_{n-1}$ , monthly recharge,  $R_n$ , and natural recharge,  $R_{LL}$ , which is included in the form of 12 average monthly recharge figures.

This aquifer model only permits one basic action, which is net recharge (basic action nº 1) and one control parameter, the stored volume (control parameter nº 1).

### 5.9.2. *Single-cell aquifer*

This aquifer is hydraulically connected to the surface system, with a drainage coefficient of  $\alpha$ . As demonstrated by Andreu (1983), the resulting equations are:

$$V_n = V_{n-1}e^{-\alpha} + \frac{R_n}{\alpha}(1 - e^{-\alpha}) \quad (5.12)$$

$$Q_n = \alpha V_n = Q_{n-1}e^{-\alpha} + R_n(1 - e^{-\alpha}) \quad (5.13)$$

The first equation gives the volume at the end of month  $V_n$ , or final volume at the end of the preceding (or initial) month,  $V_{n-1}$ , drainage coefficient,  $\alpha$ , and the recharge in month  $R_n$ .

The second equation gives the relative river-aquifer flow  $Q_n$  according to the flow in the preceding month and other factors explained above.

The data that will have to be supplied are therefore the values of  $\alpha$  and  $V_o$  (initial volume).

If we assume  $V_o=0$  and the values of  $R_n$  are only those of the net recharges from irrigation, we are working by superposition, so that the values of  $Q_n$  are the changes to natural river flow, as this is the way in which SIMGES operates.

This aquifer model only admits one basic action, which is net recharge (basic action n° 1) and supplies two control parameters. The n° 1 control parameter is volume and control parameter n° 2 is the flow into or out of the river. If this is positive, it goes from aquifer to river, and if negative, from river to aquifer.

### 5.9.3. Spring aquifer

This is the name for an aquifer whose relationship with the surface system is such that the surface system receives the drainage from the aquifer, normally in the form of a spring.

To simulate this type of aquifer an aggregate model is used which must be supplied with the drainage coefficient value  $\alpha$ , the historic natural flows from the spring,  $Q_a$ , and the aquifer initial volume  $V_{n-1}$  (see Sahuquillo, 1983).

Total monthly spring volume is given by:

$$V_n = (V_{n-1} - V_{DET})e^{-\alpha\Delta t} + \frac{RL_n}{\alpha}(1 - e^{-\alpha\Delta t}) \quad (5.14)$$

where  $RL_n$  is the recharge value (or extraction value if negative) far from the spring and  $V_{DET}$  is the outflow that could not be extracted in the preceding month.

Total monthly alteration of natural river flow is given by:

$$Q_n = V_{n-1} - V_{DET} - V_n + RL_n + RC_n \quad (5.15)$$

as a consequence of integrating the instantaneous flow formulas from time  $t_{n-1}$  to  $t_n$  (1 month) and  $RC_n$  is the recharge near the spring.

Total monthly volume drained from the spring would be:

$$Q_m = Q_a + Q_n \quad (5.16)$$

If  $Q_m$  is negative the values are modified accordingly:

$$V_n = V_n + Q_m \quad (5.17)$$

$$Q_m = 0. \quad (5.18)$$

$$Q_n = -Q_a \quad (5.19)$$

$Q_n$  thus being the effect on river flow.

It should be noted that we are working by superposition of the impaired regime, and therefore the flow series used in the surface model will be the natural ones, which will be modified during the simulation by the value of  $Q_n$ .

Two basic actions are thus used, n° 1 is the recharge far from the spring and n° 2 is recharge near the spring. As in the case of the unicellular aquifer, there are two control parameters.

#### 5.9.4. Multicellular aquifer

This is an aquifer whose relationship with the surface system depends on a law represented by different discharge coefficients identified as cells.

To simulate these aquifers, a global multicell model is used (A.Sahuquillo, 1983) which must be provided with the drainage coefficient value  $\alpha_i$  in each cell, the coefficient of distribution of each basic action on each of the cells  $b_{ij}$ , and the initial aquifer volume  $V_i^{k-1}$  in each cell.

The month-end volume of each cell is given by:

$$V_i^k = V_i^{k-1} e^{-\alpha_i \Delta t} + \sum_j \frac{b_{i,j} R_j^k}{\alpha_i} (1 - e^{-\alpha_i \Delta t}) \quad (5.20)$$

where  $R_j^k$  is the basic stress  $j$  (recharge if positive or extraction if negative).

For the flows we have:

$$Q_i^n = Q_i^{n-1} e^{-\alpha_i \Delta t} + \sum_j b_{i,j} R_j^n (1 - e^{-\alpha_i \Delta t}) \quad (5.21)$$

The impaired spring flow at month-end is given by:

$$Q^n = \sum_i \alpha_i V_i^n \quad (5.22)$$

The monthly impaired spring volume for each cell is given by:

$$A_i^n = V_i^{n-1} - V_i^n + \sum_j b_{ij} R_j^n \quad (5.23)$$

The total impaired spring volume is the sum of the impaired volumes of all the cells.

$$A^n = \sum_i A_i^n \quad (5.24)$$

Should this value be negative, the corresponding volume will be extracted from the river flow (through the type 3 channel connected to the aquifer). If the river does not have sufficient flow to make this withdrawal, so-called “impossible extractions” are generated, which will be discounted in the following month from the volume stored in the cell with the most dynamic relationship with the river, i.e. the one with the lowest  $\alpha_i$  value. For this cell, the preceding month-end volume is modified in the following way:

$$V_{CR}^{n-1} = V_{CR}^{n-1} + DI \quad (5.25)$$

CR being the index of the cell with the lowest  $\alpha_i$  value and DI is the value of the impossible withdrawal calculated for month  $n-1$  (DI is negative). Obviously, Eq. 5.25 is applied before Eq. 5.20.

This model can be applied to three similar aquifer situations but with different physical conditions. These are, firstly, an aquifer connected to a river modeled by superposition of the impaired regime; the second is the spring aquifer also modeled in the same way; and the third is a spring aquifer completely modeled with historic rainfall data.

#### 1. Aquifer connected to a river modeled by superposition of the impaired regime

In this case the aquifer can extract water from the river with the available flow being the only limit.

Modeling requires a type 3 channel connected to the aquifer model downstream of surface system inflow in the impaired regime including aquifer discharge to the system.

#### 2. Spring aquifer modeled by superposition of the impaired regime

Unlike the previous case, this type of aquifer cannot extract water from the river, however, the natural inflow from this source is included in the series of inflows downstream of the spring. It is therefore necessary to limit the simulated extraction to the spring's maximum flow.

As in the preceding case, the model includes a type 3 channel connected to the aquifer model downstream of the natural inflows including that of the aquifer itself. The channel's maximum flow must be limited to the value of the water supplied by the spring, thus limiting surface water extraction to the maximum value of water supplied from the spring. Also, to permit the passage of total river flow, a type 1 channel will be included with a by-pass cost so that it only takes flows that exceed the outflow from the spring.

### 3. Fully modeled spring aquifer with rainfall recharge data

In this case the natural river-aquifer discharge is not included in the series of surface inflows downstream of the spring.

Modeling will include first a stretch of river with infiltration separated from the surface system that receives the monthly rain recharge time series values. Secondly, a type 3 channel must be included connected to the aquifer with null surface inflows.

#### **5.9.5. *Aquifer connected to a river modeled by the Eigenvalue method***

This includes aquifers for which a distributed parameters model is considered necessary and thus also the exact location of the actions that affect the aquifer as well as the aquifer's response to such actions.

The Eigenvalue method was chosen since it has been shown (Andreu and Sahuquillo, 1987) to be more efficient for supposedly linear systems in which few responses are studied (control parameters) and on which few actions take place which could be described as linear combinations of predetermined unitary actions (basic actions).

Users should first become familiar with the method (Andreu and Sahuquillo, 1987). The steps are as follows:

- a) Definition of the hydrodynamic characteristics of the aquifer (transmissivities, storage coefficient) as well as its geometry and the initial and operational conditions.
- b) The creation of a finite differences or finite elements grid adapted to the shape of the aquifer and obtaining a system of differential equations whose unknowns are the elevations of the nodes or discretization blocks.
- c) Obtaining the corresponding Eigenvalues and Eigenvectors. This can be carried out by any package of mathematical subroutines.
- d) Definition of basic actions. Each basic action is a vector with a non-null value in the element corresponding to the cell on which it acts and 0 in the rest. The sum of the components is unity.
- e) Definition of control parameters (e.g. level in a cell, average levels, zone volume, flow through a river-aquifer boundary segment, etc)
- f) Deciding how many  $n_a$  Eigenvalues to include. Reducing the number of Eigenvalues (truncation) also reduces computation time (Andreu and Sahuquillo, 1986).

- g) Obtaining the matrices  $[A^R]$ ,  $[L]$ ,  $[B]$ . The  $[A^R]$  matrix is known as the "reduced A matrix" (Andreu and Sahuquillo, 1987) and has a row for each control parameter. It will therefore be  $n_p \times n_a$  where  $n_p$  is the number of control parameters. The  $[L]$  matrix is the diagonal matrix that contains the Eigenvalues, so that only the  $n_a$  elements of the principal diagonal are other than zero.  $[B]$  is the state modification matrix, so that the vectorial equations used in the **SIMGES** model are the following:

$$\{c_n\} = [A^R] \{l_n\} \quad (5.26)$$

$$\{l_n\} = [e^{-\alpha \Delta t}] \{L_{n-1}\} + [B] \{B\} \quad (5.27)$$

where  $\{B\}$  is a vector containing the intensities of the basic actions for the month under study, and therefore has  $n_e$  elements (one for each basic action defined).  $\{l\}$  is the aquifer state vector (see Andreu and Sahuquillo, 1987), which contains  $n_a$  elements. The  $[B]$  matrix therefore has  $n_a \times n_e$  elements, with a column for every basic action.

The data needed for the model are:

- The  $[L]$  matrix (diagonal) or Eigenvalues
- The  $\{l\}$  vector for the initial state,  $\{l_0\}$ ,
- The rows of the  $[A^R]$  matrix (a row for each control parameter), and
- The columns of the  $[B]$  matrix (a column for each basic stress).

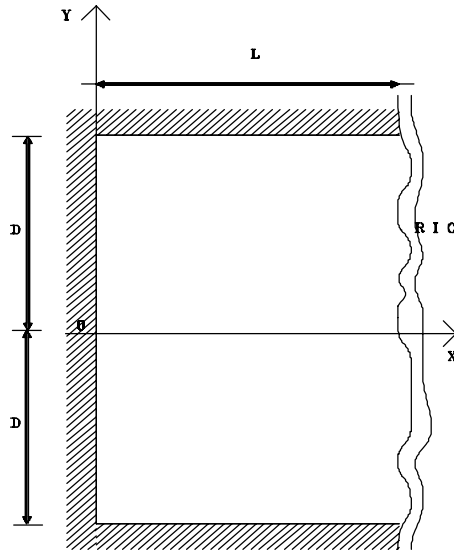
#### ***5.9.6. Homogeneous rectangular aquifer connected on one side with a totally penetrating river***

This model permits the simulation of homogeneous rectangular geometry aquifers connected to river reaches.

In many cases, this approach involves an over-simplification of the real situation but also allows the deferred effects of the river-aquifer interaction to be studied in greater detail than the single-cell model.

The model is based on the analytic solution of the case shown in the figure below and allows different locations to be chosen for actions involving the aquifer.

The solution to the problem was provided by Sahuquillo (1981) and was applied to the joint use of surface and ground waters by Marco and Andreu (1983).



The following data should be available:

- a) Hydrodynamic parameters: transmissivity  $T_X$  in the direction of the X axis, transmissivity  $T_Y$  in the direction of the Y axis and storage coefficient S.
- b) Geometry: the lengths of  $D$  and  $L$  as shown in the above figure.
- c) Initial aquifer levels: 15 quantities must be obtained to form an approximation of the initial state (initial state vector) of the aquifer to be supplied to the model as data input. The following cases can be considered:
  - c.1) Proceeding by superposition of the impaired regime of the aquifer:  
In this case the 15 quantities are all zero.
  - c.2) Considering an elevation distribution in the aquifer given by the function  $H(x,y)$ .

The following quantities must be calculated:

$$l_0^n = \frac{S}{LD} \int_{x=0}^{x=L} H(x,y) \cos\left(\frac{(1+2n)\pi}{2L} x\right) dx dy \quad (n = 0, \dots, 14) \quad (5.28)$$

which, considered in the order given by  $n$ , form the initial state vector and must be entered as data input.

- d) Basic stresses: Two types of basic stress are considered:



d.1) A set of individual stresses, each of which is defined by its location  $(x_k, y_k)$  and weight  $p_k$ . The sum of the weights for a set of individual stresses must have a value of one and all must be positive.

d.2) An action distributed throughout a rectangle whose sides are parallel to the coordinate axes.

This is defined by the coordinates of the centre of the rectangle  $(XG_k, YG_k)$  and the lengths of its sides ( $LX_k$  for the side parallel to the X axis and  $LY_k$  for the side parallel to the Y axis).

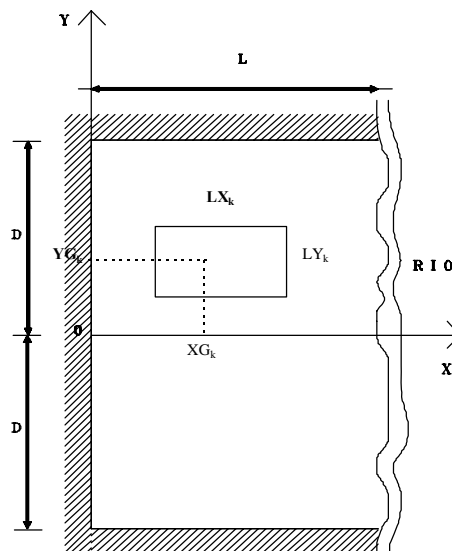
e) Control parameters: the simplicity of this analytical model approach leads us to consider the two following:

e.1) Volume stored in the aquifer.

e.2) River-aquifer relationship along the  $x=L$  side.

Since the **SIMGES** model works by superposition, the above parameters in fact refer to variations on the system's natural state. Thus, if the historical situation involves drainage into the river, this is included in system inflows and would be altered by outflows (variations of the natural regime).

All the necessary calculations are carried out by the simulation model.



Aquifer simulation is performed in a similar way to the Eigenvalues method described in Section 5.9.5. The state vector is re-calculated in each simulated time interval according to the expression:

$$\{l_{t+\Delta t}\} = [E] \{l_t\} + [\psi] \{B\} \quad (5.29)$$

with

$$[\psi] = [\alpha]^T [I-E] [\psi^*] \{B\} \quad (5.30)$$

and control parameters are obtained in the form of vectors by:

$$\{c_{t+\Delta t}\} = [A^R] \{l_{t+\Delta t}\} \quad (5.31)$$

where:

- $\{l_t\}$  is the state vector at time  $t$
- $[\alpha]$  is the 15x15 matrix whose diagonal contains the Eigenvalues of the problem  $\alpha_n$ .
- $[E]$  is the matrix whose diagonal contains the elements  $e^{-\alpha_n \Delta t}$
- $[\psi]$  is the state modification matrix which converts the intensities of basic actions to modifications of the state vector. Each of its columns corresponds to a basic action.
- $\{B\}$  is the basic stress intensities vector.
- $[A^R]$  is the reduced "A" matrix connecting the state vector with the control parameters vector. Each row corresponds to a control parameter.

The  $\{B\}$  vector is obtained in each simulated time step and includes extractions and recharges.

The  $[\psi^*]$  matrix is obtained by the model in the early stages of simulation. Each column, corresponding to a basic action  $k$ , is composed of a set of individual actions and has the elements:

$$\psi_{n,k}^* = \frac{1}{\sqrt{LDS}} \sum_{r=1}^{no.acces} p_r \cos\left(\frac{(1+2n)\pi}{2L} x_r\right) \quad (5.32)$$

taking these elements in the given order for  $n$  in the initial state vector of the expression (5.35).

The column corresponding to a basic stress  $k$  distributed in a rectangle is given by 5.33.

$$\psi_{n,k}^* = \frac{4\sqrt{L}}{\pi(1+2n)\sqrt{DS} L X_k} \cos\left(\frac{(1+2n)\pi}{2L} X G_k\right) \sin\left(\frac{(1+2n)\pi}{4L} L X_k\right) \quad (5.33)$$

Since only two control parameters are considered, matrix  $[A^R]$  in this case has two rows. The first corresponds to the aquifer stored volume control parameter,

$$A_{1,n}^R = \frac{4\sqrt{LDS}(-1)^n}{(1+2n)\pi} \quad (5.34)$$

and the second refers to outflows from the side  $x=L$ ,

$$A_{2,n}^R = \frac{4\sqrt{LDS}(-1)^n}{(1+2n)\pi} \alpha_n \quad (5.35)$$

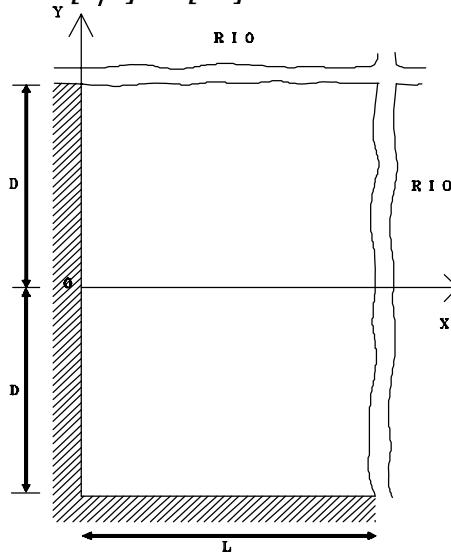
The Eigenvalues are obtained by

$$\alpha_n = \frac{\pi^2}{4S} \left[ T_x \frac{(1+2n)^2}{L^2} \right] \quad (5.36)$$

#### 5.9.7. Rectangular aquifer connected on two contiguous sides with a fully penetrating river

This model is similar to that described in Section 5.9.6 but with the modifications corresponding to the presence of a fully penetrating river at  $y=D$ . The figure below shows the positions of the coordinate axes.

The analytical solution to this case was given by Ramos et al. (1983). Here, it is adapted to obtain the elements of the matrices  $[\psi^*]$  and  $[A^R]$  described in Section 5.9.6.



The data required are the same as in the case described in Section 5.9.6. However, in this case the initial state vector is obtained by:

$$l_0^{n,m} = \sqrt{\frac{2S}{LD}} \int_{x=0}^{x=L} \int_{y=-D}^{y=D} H(x,y) \cos\left(\frac{(1+2n)\pi}{2L}x\right) \cos\left(\frac{(1+2m)\pi}{4D}(D+y)\right) dx dy \quad (5.37)$$

The components must be given in the order corresponding to the following (n,m) pairs: (0,0), (0,1), (1,0), (0,2), (1,1), (2,0), (0,3), (1,2), (2,1), (3,0), (0,4), (1,3), (2,2), (3,1), (4,0), (0,5), (1,4), (2,3), (3,2), (4,1), (5,0), (0,6), (1,5), (2,4), (3,3), (4,2), (5,1), and (6,0).

The four control parameters considered in this case are the following:

1. Volume stored in aquifer
2. Total outflows to river by sides  $x=L$  and  $y=D$
3. Outflows to river by side  $x=L$
4. Outflows to river by side  $y=D$

Aquifer simulation is performed in a way similar to the case described in Section 5.8.5 but the calculation of the elements in matrices  $[\psi^*]$  and  $[A^R]$  is different. Each column in  $[\psi^*]$  corresponds to a basic stress  $k$  composed of a set of basic stresses whose elements are given by 5.44.

$$\psi_{n,m,k}^* = \sqrt{\frac{2}{LDS}} \sum_{r=1}^{no.accs} p_r \cos\left(\frac{(1+2n)\pi}{2L}x_r\right) \cos\left(\frac{(1+2m)\pi}{4D}(y_r + D)\right) \quad (5.38)$$

The columns corresponding to a basic stress  $k$  distributed in a rectangle:

$$\begin{aligned} \psi_{n,m,k}^* = \frac{32\sqrt{2LD}}{\pi^2(1+2n)(1+2m)LX_kLY_k\sqrt{S}} \cos\left(\frac{(1+2n)\pi}{2L}XG_k\right) \sin\left(\frac{(1+2n)\pi}{4L}LX_k\right) \\ \cos\left(\frac{(1+2m)\pi}{4D}(D+YG_k)\right) \sin\left(\frac{(1+2m)\pi}{8D}LY_k\right) \end{aligned} \quad (5.39)$$

In expressions 5.38 and 5.39, the order of  $n$  and  $m$  is as specified in 5.37.

The  $[A^R]$  matrix in this case has four rows referring to the control parameters given above:

1. The first corresponds to aquifer stored volume:

$$A_{1,n,m}^R = \frac{8(-1)^{n+m} \sqrt{2LDS}}{\pi^2 (1+2n)(1+2m)} \quad (5.40)$$

2. The second to total outflows from sides  $x=L$  and  $y=D$ ,

$$A_{2,n,m}^R = \frac{8(-1)^{n+m} \sqrt{2LDS}}{\pi^2 (1+2n)(1+2m)} \alpha_{n,m} \quad (5.41)$$

3. The third to outflows from side  $x=L$

$$A_{3,n,m}^R = 2T_x \sqrt{\frac{2}{LDS}} \frac{D(1+2n)}{L(1+2m)} (-1)^{n+m} \quad (5.42)$$

4. The fourth to outflows from side  $y=D$ ,

$$A_{4,n,m}^R = \frac{1}{2} T_y \sqrt{\frac{2}{LDS}} \frac{L(1+2m)}{D(1+2n)} (-1)^{n+m} \quad (5.43)$$

In fact, Eq. (5.49) can be obtained from (5.47) and (5.48) since total outflows are the sum of those corresponding to both sides  $x=L$  and  $y=D$  at a constant level.

Eigenvalues are obtained from the expression:

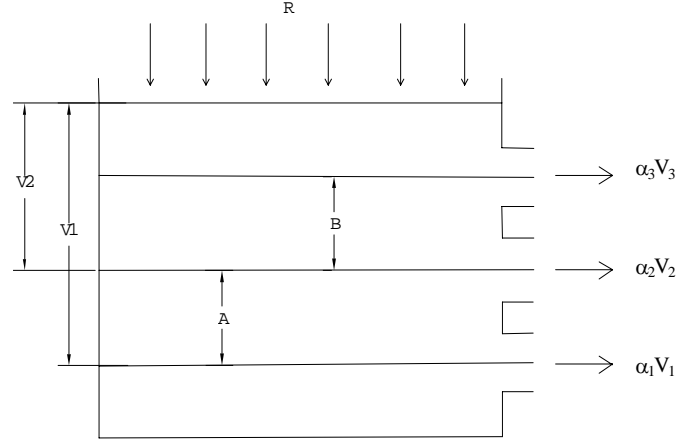
$$\alpha_{n,m} = \frac{\pi^2}{4S} \left( T_x \frac{(1+2n)^2}{L^2} \right) \quad (5.44)$$

The pairs of values  $(n,m)$  are always taken in the order defined for Eq. (5.37).

It should be pointed out that two type 3 channels are associated with each side of the aquifer or one with both sides of the aquifer.

### 5.9.8. Three-level aquifer

This three-level aquifer model is designed to simulate the case in which an aquifer, e.g. the aquifers at the mid and low lowlands of the river Segura, can lose water through evaporation, intermediate drainage from drainage channels and the hydraulic connection with a river. The resulting equations are explained as follows:



$$dv = R dt - \alpha_3 V_3 dt - \alpha_2 V_2 dt - \alpha_1 V_1 dt \quad (5.45)$$

$$\frac{dV_1}{dt} = R - (\alpha_1 + \alpha_2 + \alpha_3) V_1 + \alpha_3 (A + B) + \alpha_2 A \quad (5.46)$$

whose solution is:

$$V_1(t) = V_1(o) e^{-(\alpha_1 + \alpha_2 + \alpha_3)t} + \frac{R + \alpha_3 (A + B) + \alpha_2 A}{\alpha_1 + \alpha_2 + \alpha_3} (1 - e^{-(\alpha_1 + \alpha_2 + \alpha_3)t}) \quad (5.47)$$

If  $V_1 > A+B$  (hereinafter designated for the sake of clarity as  $V_k$ , eliminating the subindex 1)

$$V_{k+1} = V_k e^{-(\alpha_1 + \alpha_2 + \alpha_3)\Delta t} + \frac{R_k / \Delta t + \alpha_3 (A + B) + \alpha_2 A}{\alpha_1 + \alpha_2 + \alpha_3} (1 - e^{-(\alpha_1 + \alpha_2 + \alpha_3)\Delta t}) \quad (5.48)$$

$$\Delta V_k = V_k^* - V_k \quad (5.49)$$

$$V_{k+1}^* = V_k^* e^{-(\alpha_1 + \alpha_2 + \alpha_3)\Delta t} + \frac{R_k / \Delta t + \alpha_3 (A + B) + \alpha_2 A}{\alpha_1 + \alpha_2 + \alpha_3} (1 - e^{-(\alpha_1 + \alpha_2 + \alpha_3)\Delta t}) - B_k \quad (5.50)$$

$$\Delta V_{k+1} = \Delta V_k e^{-(\alpha_1 + \alpha_2 + \alpha_3)\Delta t} - B_k \quad (5.51)$$

If  $V_I < A+B$  y  $V_I > A$

$$V_{k+I}^* = V_k^* e^{(\alpha_1 + \alpha_2) \Delta t} + \frac{R_k / \Delta t + \alpha_2 A}{\alpha_1 + \alpha_2} (1 - e^{-(\alpha_1 + \alpha_2) \Delta t}) - B_k \quad (5.52)$$

$$\Delta V_{k+I} = V_k^* e^{-(\alpha_1 + \alpha_2) \Delta t} - V_k e^{-(\alpha_1 + \alpha_2 + \alpha_3) \Delta t} + \frac{R_k / \Delta t + \alpha_2 A}{\alpha_1 + \alpha_2} \cdot \quad (5.53)$$

$$(1 - e^{-(\alpha_1 + \alpha_2) \Delta t}) - \frac{R_k + \alpha_3(A + B) + \alpha_2 A}{\alpha_1 + \alpha_2 + \alpha_3} (1 - e^{-(\alpha_1 + \alpha_2 + \alpha_3) \Delta t}) - B_k \quad (5.54)$$

If  $\alpha_1 + \alpha_2 + \alpha_3$  is sufficiently small:

$$\Delta V_{k+I} = (\Delta V_k e^{(\alpha_3 \Delta t)} + \alpha_3 \Delta t V_k) e^{-(\alpha_1 + \alpha_2 + \alpha_3) \Delta t} - \alpha_3 (A + B) \Delta t - B_k \quad (5.55)$$

If  $V_I < A$

$$V_{k+I}^* = V_k^* e^{(-\alpha_1 \Delta t)} + R_k - B_k \quad (5.56)$$

$$\Delta V_{k+I} = (V_k^* e^{(\alpha_2 + \alpha_3) \Delta t} - V_k) e^{-(\alpha_1 + \alpha_2 + \alpha_3) \Delta t} - (\alpha_2 A + \alpha_3 (A + B)) \Delta t - B_k \quad (5.57)$$

$$\Delta V_{k+I} = (\Delta V_k e^{(\alpha_2 + \alpha_3) \Delta t} - V_k (1 - e^{(\alpha_2 + \alpha_3) \Delta t})) e^{-(\alpha_1 + \alpha_2 + \alpha_3) \Delta t} - (\alpha_2 A + \alpha_3 (A + B)) \Delta t - B_k \quad (5.58)$$

As in the case of unicellular aquifers with only one outlet, when a non-linearity exists, to calculate the volume  $V_{k+I}$  in the next time step, the non-influenced volume  $V_k$ , or the volume drained from the aquifer during this time, must be known. It can also be calculated by using the recharge  $R_k$  for the time step. However, this figure is not usually available for longer periods.

The data necessary for simulation are:

- The values of the drainage coefficients  $\alpha_1$ , corresponding to the river-aquifer connection and  $\alpha_2$ , corresponding to intermediate drainage from drainage channels.
- The monthly drainage coefficient values,  $\alpha_3$ , by potential evapotranspiration.
- Volumes between the river-aquifer connection level and intermediate drainage, A, between this last and the level at the end of evaporation, A, between this last and the level at the end of evaporation, B, and total initial volume  $V_1$ .
- Historical recharge values.

From these data and the net recharge values (basic stress n° 1), excluding natural flow, the model supplies the values of the relationship with the river,  $Q_1$  (control parameter n° 1), outflows by drainage channels,  $Q_2$  (control parameter n° 2), actual evaporation,  $Q_3$  (control parameter n° 3), and month-end volume  $V_1$  (control parameter n° 4).

It should be noted that in this case we are not working by superposition, so that the values are total values. Caution should therefore be exercised if there are inflows downstream of the connection with the aquifer, as in this case they should be previously corrected by deducting the historical river-aquifer relationship.

#### ***5.9.9. Summary of basic stresses for different types of aquifer***



Tank	1	1. Net Recharge
Single cell	1	1. Net Recharge
Spring	2	1. Recharge far from the spring 2. Recharge near the spring
Modeling by Eigenvalues	NAES	NAES actions are defined by the user.
Rectangular homogeneous connected on one side	NAES + 1	<b>Type of Aquifer</b>
Rectangular homogeneous connected on two contiguous sides	NAES + 3	<ul style="list-style-type: none"> <li>- The user defines NAES actions</li> <li>- The following three actions correspond to compensation for impossible extractions: <ul style="list-style-type: none"> <li>. NAES+1 for connection by x=L</li> <li>. NAES+2 for connection by y=D</li> <li>. NAES+3 for the case of connection by only one type 3 channel but on two sides x=L and y=D</li> </ul> </li> </ul>
Three levels	1	1. Net Recharge
Multicellular Aquifer	NAES	1. Uniform recharge 2 a NAES. Actions defined by user

### 5.9.10. Summary of control parameters for different types of aquifer

Aquifer Type	Number of Parameters	Description
Tank	1	1. Stored volume
Single cell	2	1. Stored volume 2. Aquifer outflows
Spring	2	1. Stored volume 2. Spring outflows
Eigenvalue modeling method	NPC	NPC parameters defined by user
Rectangular homogeneous connected on one side	2	1. Stored volume 2. Aquifer outflows from side $x=L$
Rectangular homogeneous connected on two contiguous sides	4	1. Stored volume 2. Aquifer outflows from side $x=L$ 3. Aquifer outflows from side $y=D$ 4. Total outflows from sides $x=L$ and $y=D$
Three levels	4	1. Relationship with river 2. Outflows through irrigation channels 3. Effective evaporation 4. Month-end volumes
Multicellular aquifer	NANT+3	1. Stored volume 2. Spring outflows at month end ( $\text{hm}^3/\text{month}$ ) 3. Total monthly spring outflows ( $\text{hm}^3/\text{month}$ ) 4. Volume in cell 1 n+3. Volume in cell n

## 5.10. Artificial recharges and additional pumping

These are simply elements defined to connect possible controlled flows from the surface system to groundwater (in the case of artificial recharges) and/or vice versa (additional extraction).

In both cases they must be defined by supplying the node number of the location in the scheme of the outflow or inflow and the maximum recharge flow.

During management simulation, the model will initiate artificial recharge when there is excess water available in the surface system upstream of the recharge intake.

Additional extraction consists of water extracted from an aquifer and pumped into the surface system for use downstream. The model will resort to additional extraction when surface supplies are insufficient for zones with a priority number equal to that designated when the additional pumping was defined and when the deficit exceeds a certain percentage of the demand.

## 5.11. Alarm indicators

These are management criteria or operating rules whose purpose is to reduce water consumption when the system reserves, or part of the reserves, fall below the limits specified by the user. Each indicator is defined by the system state variables and a function by which the operating rule is deduced.

The system state indicator may consist of an evaluation of the reserve volume in one or several reservoirs or in the calculation of the total volume of natural resources supplied by a part of the basin in recent months.

Each alarm indicator is associated with a group of reservoirs (or inflows) and a volume-restriction coefficient table. Some reservoirs may be connected to different indicators and different indicators may be defined as associated to the same group of reservoirs.

The volume-restriction coefficient table can be different each month. Another option is to base it on the calculation of the reserve volume at the start of the month or to establish a minimum threshold volume which the program will try to stay above.

To calculate the start-of-the-month volume, the program totals the volumes stored in the reservoirs and by means of the table provided obtains the restriction coefficient corresponding to the indicator for the month under study. It should be emphasized that these indicators are based

on the reserves at the start of the month and do not take into account any inflows in the course of the month or the situation of the reservoir at the end of the month. The table below gives an example of interpolating a curve of this type.

Definition of alarm-restriction indicator as a continuous curve evaluated at the start of the month.	Reservoirs:      Reservoir 1 Reservoir 2				
	Volume-restriction curve				
	Volume	20	25	80	130
	Restriction	0.7	0.5	0.5	0.2
Examples	Volume of reservoir at start of month			Restriction	Supply
	Reservoir 1	Reservoir 2	Total		
Situation 1	10	4	14*	79%	21%
Situation 2	15	11	26	50%	50%
Situation 3	50	40	90	44%	56%
Situation 4	70	70	140**	14%	86%

\*For volume values below the first number interpolate with: volume = 0; restriction = 1.0

\*\* For volume values above the last number extrapolate from the 2 final data, if there is only one, use this and the value (volume=0; restriction=1)

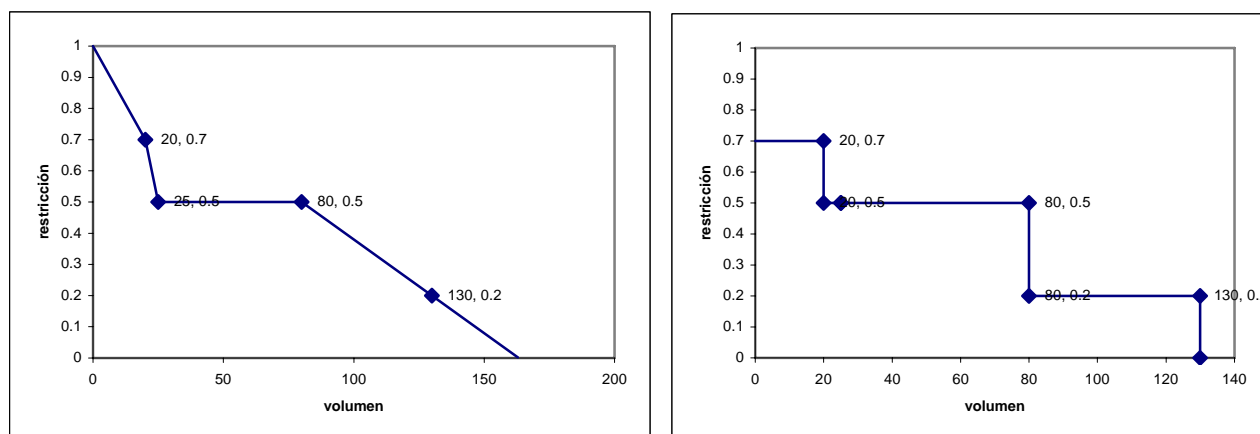
In the case of defining the operating rule as threshold, the program does not interpolate between the different values of the curve, but each volume value is taken as the minimum threshold below which the level must not be allowed to drop. Therefore, the control of the alarm indicator is achieved in the iterative process on the final reference volume instead of being calculated on the initial volume. In this case, the table of values defined above would have the following restrictions:

Definition of alarm-restriction indicator as a minimum threshold.	Reservoirs:      Reservoir 1 Reservoir 2				
	Volume-restriction curve				
	Volume	20	25	80	130
	Restriction	0.7	0.5	0.5	0.2
Examples	Calculated final monthly volume			Restriction	Supply
	Reservoir 1	Reservoir 2	Total		
Situation 1	10	4	14	70%	30%
Situation 2	15	11	26	50%	50%
Situation 3	50	40	90	50%	50%
Situation 4	70	70	140	0%	100%

\* It should be noted that, unlike the previous case, these volumes are based on monthly management statistics and therefore depend on the restriction applied. For volume results near to the threshold, the calculated restriction coefficient may take a value between the threshold and the previous coefficient.

Also, by means of an iterative process the program will attempt not to descend below the threshold of the supply defined in the same step, so that if the difference between the volume available and the immediate threshold volume is small a supply will be calculated that is not under the threshold level.

It should be noted that in each case even if the curve values are the same the curve is defined differently. In the first case the curve is continuous and in the second it is stepped (see figure below).



The first curve represents operating rules n's 1 and 3 and the second n's 4 and 5. When calculating reservoir volumes, 1 and 2 are based on start-of-month reserve values while 4 and 5 try not to go below them during the month.

Alarm indicators can be applied to monthly maximum demand flows, monthly maximum type 1 channel flows, monthly minimum type 1 channel flows, or target monthly non-consumptive demand flows. They can also be applied to maximum annual demand of the intakes or type 1 channels. When applied to annual demand, the model calculates the water volume supplied in the preceding months of the hydrological year and if this figure is lower than the new annual demand it maintains supplies until the reduced annual demand is complete.

The user must use his own discretion in choosing this type of indicator according to the nature of the problem being dealt with.

## 6. WATER RESOURCES SYSTEM MANAGEMENT

To solve the system management problem, the program constructs a conservative flow network which it solves by optimization. The optimization problem is described in Sections 6.1 and 6.2.

The program also carries out an iterative process on the optimization algorithm to solve non-linear flows such as reservoir evaporation, and operating rules such as alarm indicators and the sharing of the deficit between “isopriority groups” (Section 6.3).

### 6.1. Target Function

Strictly speaking, when solving flow network optimization, the model uses the following target function for each month:

Minimize:

$$T_E + T_{R1} + T_{R2} + T_{R3} + T_{R4} + T_{R5} + T_{DC} + T_{DN} + T_{RA} + T_{BA} \quad (6.1)$$

where:

$T_E$  is a term for reservoirs

$T_{R1}$  is a term for type 1 river reaches

$T_{R2}$  is a term for type 2 river reaches

$T_{R3}$  is a term for type 3 river reaches

$T_{R4}$  is a term for type 4 river reaches

$T_{R5}$  is a term for type 5 river reaches

$T_{DC}$  is a term for consumptive demands

$T_{DN}$  is a term for non-consumptive demands

$T_{RA}$  is a term referring to artificial recharges

$T_{BA}$  is a term referring to additional extraction

The terms are subject to mass conservation constraints (continuity) and to the physical transport limits imposed by channels and the capacities of reservoirs and other elements.

The following section deals with the mathematical expression of the terms and an explanation of how the target function obtained contrives to supply the demand while at the same time fully meeting the requirements of reservoir management strategies.

### 6.1.1. Contribution to the target function from the reservoir elements

Given the configuration of the internal network created for a reservoir element, its contribution to the target function is:

$$T_E = \sum_{i=1}^{nemb} \left( \left( \sum_{j=1}^4 V_{ij} CE_{ij} \right) + P_i CV \right) \quad (6.2)$$

where:

**nemb** is the number of reservoirs  
 **$V_i$**  is the month-end volume in each zone  **$j$** ,  **$j=1,2,3$**  and  **$4$**  of reservoir  **$i$** . Zone 1 is the reserve, 2 is the lower zone, 3 the intermediate and 4 the upper zone  
 **$P_i$**  is (uncontrolled) releases from reservoir  **$i$**   
 **$CE_{ij}$**  is the fictitious cost associated with the volume stored in zone  **$j$** , and is given by:

$$CE_{ij} = k_j + NP_i \quad (6.3)$$

where :

**$k_j$**  are pre-established values (by default, they are:  **$k_1=-1700$** ;  **$k_2=-1100$** ;  **$k_3=-1000$** ;  **$k_4=-700$** ) and  
 **$NP_i$**  is the priority number assigned to the reservoir, and  
 **$CV$**  is the fictitious cost associated with overflow (default  **$CV=2000$** )

### 6.1.2. Contribution to the target function from Type 1 channels

Given the configuration for a type 1 river reach in the internal network, we have:

$$T_{RI} = \sum_{i=1}^{ntr1} (D_i CD_i + Q_i CQ_i) \quad (6.4)$$

where:

**ntr1** is the number of type 1 river reaches  
 **$Q_i$**  is the flow in river reach  **$i$** . If a minimum flow has been defined in the river reach, the value of  **$Q_i$**  will be the maximum between actual flow and the defined minimum flow. A fictitious cost in a river reach is therefore not added to the cost associated with the minimum flow deficit.  
 **$D_i$**  is the deficit with respect to the declared minimum flow:

$$D_i = \begin{cases} Q_i^{min} - Q_i & \text{si } Q_i^{min} > Q_i \\ 0 & \text{si } Q_i^{min} \leq Q_i \end{cases} \quad (6.5)$$

$CD_i$  is the fictitious cost associated with minimum flow deficit and is given by:

$$CD_i = KD - NP_i \quad (6.6)$$

where:

$KD$  is a constant value (default  $KD = 2000$ ) and  
 $NP_i$  is the priority number assigned to minimum flow in river reach  $i$ .  
 $CQ_i$  is the fictitious cost associated with flow in reach  $i$ ,  $CQ_i=0$  by default. If it is declared in another way it can have the value  $CQ_i=1$  or can be defined by the user.

### 6.1.3. Contribution to the target function from Type 2 channels

For type 2 river reaches we have:

$$T_{R2} = \sum_{i=1}^{ntr2} (D_i CD_i + DF_i CF_i + 1) \quad (6.7)$$

where:

$ntr2$  is the number of type 2 reaches  
 $D_i$  and  $CD_i$  have the same meaning as in type 1 channels and are given by Eqs. (6.5) and (6.6) respectively.  
 $DF_i$  is the possible infiltration deficit, given by:

$$DF_i = \begin{cases} FILC - QENT & \text{si } FILC > QENT \\ 0 & \text{si } FILC \leq QENT \end{cases} \quad (6.8)$$

where:

$FILC$  is the infiltration obtained from Eq. 5.3  
 $QENT$  is the initial flow into the reach.  
 $CF_i$  is the cost associated with  $DF_i$  (default  $CF_i=2100$ )



The second term of the expression in brackets in Eq. (6.7) is merely functional in order to avoid non-feasible solutions in the algorithm. In the final iteration of the month under study it is eliminated since  $DF_i=0$ . Therefore, the actual inflow from type 2 reaches is:

$$T_{R2} = \sum_{i=1}^{ntr2} (D_i CD_i + 1) \quad (6.9)$$

#### 6.1.4. Contribution to the target function from Type 3 channels

Similarly, given the scheme generated in the internal network, the strict formula is:

$$T_{R3} = \sum_{i=1}^{ntr3} (D_i CD_i + DF_i CF_i + 1) \quad (6.10)$$

where :

$ntr3$  is the number of type 3 reaches, but their contribution in the last iteration is:

$$T_{R3} = \sum_{i=1}^{ntr3} (D_i CD_i + 1) \quad (6.11)$$

since  $DF_i$  is eliminated.  $DF_i$  is in this case the difference between the possible extraction  $DET$ , calculated by the simulation of the aquifer connected to the river and the flow at the entrance to the reach, in case this is not enough for:

$$DF_i = \begin{cases} DET - QENT & \text{si } DET > QENT \\ 0 & \text{si } DET \leq QENT \end{cases} \quad (6.12)$$

where:

$CF_i$  has the assigned value  $CF_i=2100$ .

#### 6.1.5.- Contribution to the target function from Type 4 channels

Given the configuration for type 4 channels in the internal network, their contribution is the same as for type 1 channels:

$$T_{R4} = \sum_{i=1}^{ntr4} (D_i CD_i + Q_i CQ_i) \quad (6.13)$$

where:

***ntr4*** is the number of type 4 channels  
***Q<sub>i</sub>*** is flow *i* through the type 4 channel  
***D<sub>i</sub>*** is the deficit of the monthly minimum flow:

$$D_i = \begin{cases} Q_i^{min} - Q_i & \text{si } Q_i^{min} > Q_i \\ 0 & \text{si } Q_i^{min} \leq Q_i \end{cases} \quad (6.14)$$

***CD<sub>i</sub>*** is the fictitious cost associated with the minimum flow deficit and is given by:

$$CD_i = KD - NP_i \quad (6.15)$$

where:

***KD*** is a constant value (default ***KD*** = 2000) and  
***NP<sub>i</sub>*** is the priority number assigned to minimum flow in type 4 channel *i*.  
***CQ<sub>i</sub>*** is the fictitious cost associated with flow passing through channel *i*.  
***CQ<sub>i</sub>***=0 by default. If it is declared in another way it can have the value ***CQ<sub>i</sub>***=1 or can be defined by the user.

#### 6.1.6.- Contribution to the target function from Type 5 channels

For type 5 channels we have:

$$T_{R5} = \sum_{i=1}^{ntr5} DF_i CF5_i \quad (6.16)$$

where:

***ntr5*** is the number of type 5 channels  
***DF<sub>i</sub>*** is the possible deficit of minimum channel flow given by:

$$DF_i = |Q_{INT} - Q_{ENT}| \quad (6.17)$$

where:

***QINT*** is the flow that must pass through the channel, obtained by adding instantaneous flows for the month under study as a function of the height difference between the beginning and the end of the channel.

***QENT*** is the flow at the start of the channel

***CF5<sub>i</sub>*** is the cost associated with ***DF<sub>i</sub>*** (default ***CF<sub>i</sub>***=1800)

In this type of channel flow can be in either direction and is determined by the total of instantaneous monthly flows. When ***QINT*** has been obtained the direction of flow is determined. ***QENT*** is therefore always in the same direction as ***QINT***.

The inflow from this type of channel to the target function reaches zero as monthly iterations are repeated. Its purpose is simply to satisfy a physical condition of the system.

#### 6.1.7. Contribution to the target function from consumptive demands

Given the configuration of the internal network generated by consumptive demand elements, the strict formula is:

$$T_{DC} = \sum_{i=1}^{ndc} \left( D_i CK + \sum_{t=1}^{nto} (S_{it} (CT_{it} + 1) - DS_{it} CT_{it}) \right) \quad (6.18)$$

where:

***ndc*** is the number of consumptive demands

***D<sub>i</sub>*** is the deficit of total demand of zone ***i*** for the month under study

***CK*** is a constant fictitious cost associated with the deficits of the demand zones (***CK***=750 by default)

***nto<sub>i</sub>*** is the number of intakes of demand ***i***

***S<sub>it</sub>*** is gross supply to intake ***t*** of demand ***i***.

***DS<sub>it</sub>*** is the deficit of minimum gross supply calculated by the model

So that net supply to the intake is:

$$SN_{it} = S_{it} - DS_{it} \quad (6.19)$$

The terms ***S<sub>it</sub>*** and ***DS<sub>it</sub>*** have a different value in the iterations, but in the last one we have ***DS<sub>it</sub>***=0 and ***SN<sub>it</sub>***=***S<sub>it</sub>***, so that the definitive formula for the inflow to the target function is:

$$T_{DC} = \sum_{i=1}^{ndc} \left( D_i CK + \sum_{t=1}^{nto} SN_{it} CT_{it} \right) \quad (6.20)$$

where:

$$CT'_{it} = CT_{it} + 1 \quad (6.21)$$

and:

$$CT_{it} = -CTC + (NP_{it} - 1) CDC \quad (6.22)$$

when:

**CTC** is a constant value, like **CDC** (**CTC=750**, **CDC=5**, by default)  
**NP<sub>it</sub>** is the priority number of intake *t* of demand *i*.

#### 6.1.8.- Contribution to the target function from non-consumptive demands

This is given by:

$$T_{DN} = \sum_{i=1}^{ndnc} (DO_i CN_i + SO_i CS) \quad (6.23)$$

where:

**ndnc** is the number of non-consumptive demands  
**DO<sub>i</sub>** is the deficit of target flow **QO<sub>i</sub>**  
**SO<sub>i</sub>** is the surplus of target flow given by Eq. (6.24).

$$QO_i - Q_i = \begin{cases} SO_i & \text{si } Q_i > QO_i \\ DO_i & \text{si } Q_i < QO_i \end{cases} \quad (6.24)$$

It should be noted that **SO<sub>i</sub>** and **DO<sub>i</sub>** cannot both be different from 0 at the same time.

**CN<sub>i</sub>** is the fictitious cost associated with the deficit given by:

$$CN_i = CKN - (NP_i - 1) \times CDN \quad (6.25)$$

where:

**NP<sub>i</sub>** is the priority number assigned to non-consumptive demand  
**CKN** and **CDN** are constant values (**CKN=1500**, **CDN=5**)

**CS** is the fictitious cost associated with the surplus (**CS= -5**)

### 6.1.9. Contribution to the target function from recharge elements

This is given by:

$$T_{RA} = \sum_{i=1}^{nra} (QR_i CR) \quad (6.26)$$

where:

***nra*** is the number of artificial recharges  
***QR<sub>i</sub>*** is the flow recharged by installation *i*  
***CR*** is a fictitious cost associated with artificial recharge (***CR***=-5.)

### 6.1.10. Contribution to the target function from additional extraction

This is given by:

$$T_{BA} = \sum_{i=1}^{nba} (QB_i CB_i) \quad (6.27)$$

where:

***nba*** is the number of additional extractions  
***QB<sub>i</sub>*** is the flow extracted by installation *i*  
***CB<sub>i</sub>*** is the fictitious cost associated with installation *i*.

and is given by:

$$CB_i = CTC + CK - (NP_i - 0,5) \times CDC \quad (6.28)$$

where:

***CTC***, ***CK*** and ***CDC*** have the same values as in consumptive demands and  
***NP<sub>i</sub>*** is the priority number of the isopriority group we wish to supply (e.g. if ***NP<sub>i</sub>*** is 4, ***BAD*** will supply groups 1 to 4).

## 6.2. Explanation of the system management as a consequence of the target function

Since the target function is a minimization-type function, and since the contributions to it are the costs corresponding to the variables explained by Eqs. 6.2 to 6.8, the algorithm will try to increase the value of the variables with the lowest cost.

Therefore, from a review of Eqs. 6.2, 6.4, 6.9, 6.11, 6.13, 6.16, 6.20, 6.23, 6.26 and 6.27 and of the costs included in them the following conclusions can be drawn:

- From an analysis of Eqs. 6.18 and 6.19 to 6.22 it can be concluded that a unit of water that is not supplied to demand  $i$  through intake  $t$  involves an increase in the target function whose value is:

$$F = CK - CT'_{it} = CK + CTC - NP_{it} \cdot CDC + CDC - 1 \quad (6.29)$$

which, given the default values of  $CK$ ,  $CTC$  and  $CDC$  of 750, 750 and 5, respectively, imply that

$$F = 1504 - 5 NP_{it} \quad (6.30)$$

which means that a deficit unit in a zone with priority  $NP_{it}=1$  increases the target function by 1499 cost units, and a unit with priority of 2 increases it by 1494 and so on. It can thus be seen that the model will first try to satisfy the demands with the lowest priority number.

- From Eqs. 6.4 to 6.12 it can be concluded that a unit of water that does not pass through a minimum flow channel until the minimum is reached implies an increase in the target function of:

$$F = CD_i = KD - NP_i \quad (6.31)$$

so that a deficit unit in the minimum flow in a channel with priority 1 implies an increase in the target function of 1999 units, with priority 2 of 1998, and so on.

- Comparing the values given by Eqs. 6.30 and 6.31 it can be seen that with the default values of the cost parameters, ecological demands will be given preference over consumptive demands. If  $KD=CK+CTC+CDC$ , then the minimum flow and consumptive demand priorities will coincide with priority nº 1. If the minimum flows are given priority numbers in sets of fives ( $CDC$ s) their priorities will be equal to demands with priorities 2, 3, etc. It should also be noted that with these parameter default values, water from the reserve zone of the reservoir will be used to supply minimum flows in channels.

- From Eqs. 6.23 and 6.25 it can be concluded that a unit of water not supplied to a non-consumptive demand, until the target flow is reached, implies an increase in the target function of

$$F = CN_i = CKN + CDN - CDN \cdot NP_i \quad (6.32)$$

which, with the above defect values mean that:

$$F = 1505 - 5 \cdot NP_i \quad (6.33)$$

with the same comments being applicable as those for Eq. 6.30.

- Therefore, with the default values, non-consumptive and consumptive demands have practically the same priority.
- From Eq. 6.26 it can be seen that a unit of water for artificial recharge increases the value of the target function by:

$$F = CR \quad (6.34)$$

which, with the default value of  $CR$  is

$$F = -5. \quad (6.35)$$

- From Eqs. 6.27 and 6.28 it can be seen that a unit of water taken out by additional extraction increases the value of the target function by:

$$F = CB_i = CTC + CK - (NP_i - 0,5) \cdot CDC \quad (6.36)$$

which, with the default values of  $CTC$  and  $CDC$  is:

$$F = 1500 - 5 (NP_i - 0,5) \quad (6.37)$$

so that an additional extraction in which  $NP_i = 1$  would give  $F = 1497,5$

- From Eqs. 6.2 and 6.3 it can be deduced that a unit of water stored in reservoir zone  $j$  involves an increase in the target function given by Eq 6.3, which, since  $k_j$  are negative by default, in fact mean a decrease in the target function. As  $NP_i$  increases, the value of  $F$  also increases, so that the algorithm will tend store water in the  $j$  zone of a reservoir with lower  $NP_i$  than in one with higher  $NP_i$ . However, since  $|k_{j+1}| \ll |k_j|$ , the algorithm will tend to store in the  $j$  zone of reservoir  $i$  before the  $j+1$  zone of reservoir  $k$ , even if  $NP_i < NP_k$ . The result will therefore be to keep both reservoirs at the same level and to take water first from the one with the highest  $NP_i$ .

- With the default values  $k_j$  ( $k_1=-1700$ ,  $k_2=-1100$ ,  $k_3=-1000$ ,  $k_4=-700$ ) we see that water can be taken from any zone to satisfy demands, except from the reserve zone, which will remain untouched, since it is at level **1700** while demands were at level **1500**.
- The cost associated with uncontrolled releases is simply to avoid the algorithm sending water through this part of the network before the reservoir is full. If there were several reaches with ecological flow situated in series downstream, then we could have the situation of extracting water from the reservoir by spillage, which would not correspond to the physical reality of the system. Any such situations must be detected by the user.

### 6.3. Isopriority groups

The same priority number can be given to different intakes for different consumptive use, in which case the intakes will form an “isopriority group”. In the case of a water shortage, the model will then share out the available supply among the intakes in the group in proportion to the (peak) demand value of each one. This will occur whenever possible, although it may not always be so, for example in the case of a zone far upstream which does not receive intermediate flows.

### 6.4. Iterative process

Besides the above-described target function, the program needs to solve certain non-linear conditions, such as: evaporation in reservoirs, seepage, aquifer simulation and its relationship with a river, returns, type 4 and 5 channels and “alarm-restriction” type operating rules. In order to solve these non-linear problems, SIMGES enters the solution of a target function in an iterative process, which at each step modifies the limits in the arcs corresponding to the target function to adapt it to the new conditions. The iterative process continues until there is little difference between successive solutions, or until a certain maximum is reached.

The conditions given by the alarm-restriction elements could greatly affect the results of the system management described in the preceding sections, since they can completely change the water allocations. For example, they may alter the priority system established by the isopriority groups by arbitrarily reducing the supply to a demand or demands regardless of their priority number. The use of the alarm-restriction elements is explained in Section 5.11.



## 7. PREPARATION OF DATA FILES

Before using the model, the user must prepare six data files as follows:

- 1 - Reading and writing data file
- 2 - Physical and management file
- 3 - Fictitious cost file
- 4 - Inflow file
- 5 - Evaporation file (optional)
- 6 - Graph data file (optional)

As we shall see later, the second of these files is the most important and complex. The first, third and sixth are quite simple. The data for Nos. 4 and 5, dealing with evaporation and inflows, must be obtained from previous studies.

It is important to specify the number of decimals used in calculations. By default, the model works to three decimal places; maximum is four decimal places.

A description of the content of the data files is given below.

### 7.1. Reading and writing data file

This has been given the name of **DATOS.DAT** and the model looks for it under this name in the directory from which it is executed.

It contains the names of other data files besides those used for the results output files.

It contains the following registers (lines) (in free format with alphanumerics between brackets):

- 1st register:        - Will contain the number of the **SIMGES** version being used, preceded by the letter “V” and a blank space (V 1.30, etc). This information allows simulations to be carried out with previous versions of data files that are described in previous editions of this manual, and which may therefore not contain certain data described here. The description of data files included in this manual is “V 2.20”).
- 2nd register:        - Name of the file containing the data that define the topology, physical characteristics and system management rules.

- 
- |                |  |
|----------------|--|
| 3rd register:  | - Name of the file containing data on inflows to be used in the current simulation. .  |
| 4th register:  | - Name of the file containing the actual evaporation series to be used in the current simulation. If these data are not used for any system reservoir, this file will not be opened by the program and its non-existence will therefore not cause any errors in the execution of the model. As this line is always read by the model, it must contain a file name between brackets (a row of blank characters can be entered if this file is not to be used).  |
| 5th register:  | - Name of the file containing the fictitious costs of the internal network.  |
| 6th register:  | - Name of file provided for data echo output (In Section 8.1 it is identified as writing file "nombre1.ext").  |
| 7th register:  | - Name of device or file provided for annual outputs (must be different from the preceding file). If annual outputs are defined for groups of years (as explained in Section 7.2, 3 <sup>rd</sup> register) multiple annual output files are generated, whose extension corresponds to the three final digits of the number of the first year of each group of years. Thus, in this case, the extension is not maintained and the user must ensure that possible combinations of the name with the different extensions generated do not coincide with any other file names (in Section 8 it is identified as "nombre2.ext" writing file). |
| 8th register:  | - Name of device or file provided for a resume (must be different from the two preceding files). If the output of the target function is required (see below) the average of the results is written in the second part of this file. (In Section 8.1 it is identified as "nombre3.ext" writing file).  |
| 9th register:  | (If the results writing indicator for graphs in the system's physical definition file is greater than 0, otherwise this register is excluded.)<br>- Name of file containing graph specifications.  |
| 10th register: | (9th register if results output for graphs has not been indicated. Only necessary if the system definition file indicates that an output of balances is required, otherwise this register is excluded.)<br>- Name of file provided for writing results for further processing: obtaining balances, making summaries, etc.  |
| 11th register: | (May be 9th or 10th, according to whether or not graph output and post-processing registers have been included.)   |

- Name of file for annual outputs of partial results of the target function (must be different from all previous file names). If output is defined for groups of years, as specified below, the extension is substituted in the same way as in the annual results output file. Special care must be taken not to repeat the name given to the 7<sup>th</sup> register.

In all cases, care must be taken not to repeat file or device names, including **DATOS.DAT**, as otherwise the running of the model may be aborted, data may be deleted or incomplete and/or incorrect results may be produced. Names may have a maximum length of 255 characters. In the case of annual results output files and target functions the 255 characters may be extended by an additional 3 characters (if this has not occurred in **DATOS.DAT** and output has been defined in groups of years).

If files are in the unit and path assumed by default in the system, it will not be necessary to indicate "path" in the name.

## 7.2. Basic data file

This file is composed of a series of cards in the following order:

- card with general data of the problem
- reservoir cards (one for each reservoir declared)
- type 1 channel cards (one for each type 1 channel declared)
- type 2 channel cards (one for each type 2 channel declared)
- type 3 channel cards (one for each type 3 channel declared)
- type 4 channel cards (one for each type 4 channel declared)
- type 5 channel cards (one for each type 5 channel declared)
- consumptive use cards (one for each declared consumptive use)
- return cards (one for each return declared)
- power plant cards (one for each power plant declared)
- artificial recharge cards (one for each artificial recharge declared)
- intermediate inflow cards (one for each intermediate inflow declared)
- aquifer cards (one for each aquifer declared)
- additional pumping cards (one for each additional pumping declared)
- alarm indicator cards (one for each alarm indicator declared)
- water importation cards (optional)

**The data are in free format on all cards, so that alphanumerics must be placed between inverted commas (e.g. "TITLE") and each register is a line of the file. The data of each register are separated by blank spaces, commas or tabulations and a point is used to define decimals.**

A description of the organisation of each file is given below.

As has already been indicated, the number of cards pertaining to an element included in this file must coincide with the number of elements of this type declared in the general data file. There is a limit to the number of elements of each type that can be included, which in principle for the 2.00 version model is as follows:

Nodes (excluding final node 0) .....	300
Reservoirs .....	100
Type 1 channels .....	300
Type 2 channels .....	20
Type 3 channels .....	20
Type 4 channels .....	2
Type 5 channels .....	2
Intermediate inflows .....	50
Consumptive demands.....	200
Hydropower plants .....	30
Inst. artificial recharge.....	110
Aquifers .....	20
Additional pumping events.....	10
Return flows.....	200
Isopriority groups .....	20
Eigenvalues (in an aquifer) .....	30
Basic stresses (in an aquifer) including distributed stresses and groups of occasional stresses .....	8
Maximum no. of occasional stresses in the definition of a basic stress in a type 5 or 6 aquifer .....	5
Control parameters (in an aquifer) .....	10
Alarm indicators .....	10
Inflow file columns .....	150
Evaporation file columns .....	100
Consumptive demand intakes .....	5
Elements of each type in output for graphs.....	300
Nº of inputs in type 4 and 5 channel tables and alarm indicators.....	10
Nº of inputs of imported water .....	5

These limits are considered to be sufficiently wide to enable the simulation of any system. If required, an executable file can be supplied with limits different to those cited above. If limits are expanded, executable file sizes are larger.

The physical data file begins with the **GENERAL DATA** file of the problem. It is composed of 5 registers which contain:

## 1st Register (1 item):

- Title nº 1 (up to 80 characters).

## 2nd Register (2 items):

- Number of simulation years.
- Number of initial year (e.g. 1940).

## 3rd Register (5 items):

- Data echo indicator (Yes=1, No=0). 2 can also be specified instead of 0 or 1, which means that after the reading of data and the writing of the data echo the program execution stops. This feature can be used to review data without running the program.
- Short list indicator (resumee only) (Yes=1, No=0, 100+n). If 2 is used it will give an extended list with all the results of all the simulated months with a final resumee. If 1 is used, only the final summary will be provided.  
If an extensive output is required in groups with the same number of years in different files, this indicator will have the value '100+n', n being the number of years in each group. The names of these files are generated from those declared in **DATOS.DAT**, changing the extension: the three last digits of the first year in each group are selected. For example, the hydrological year group 1940-41 to 1944-45 (5 years) would have the extension '.940'; the following group 1945-46 to 1949-50 would have the extension '.945'.
- Graph files output indicator (No=0). If a number other than 0 is selected this will be assumed to be the maximum number of years for which information is required for graphs.
- Balance file output indicator (Yes=1, No=0).
- Target function output indicator (Yes=1, No=0, 100+n). If it is required to divide the detailed output of the target function into groups of 'n' years, '100+n' is selected, following the same criteria of file names as with annual results output.

## 4th Register (1 item):

- Title nº 2 (up to 80 characters)  
Both title no 1 (1st Register) and title no 2 will appear in the list sheets.

## 5th Register (17 items):

- 1) Maximum number used to number user scheme nodes (Final Node not included)
- 2) Number of **reservoirs**
- 3) Number of **type 1 channels**
- 4) Number of **type 2 channels**
- 5) Number of **type 3 channels**
- 6) Number of **type 4 channels**
- 7) Number of **type 5 channels**
- 8) Number of **intermediate inflows**
- 9) Number of **consumptive demands**

- 10) Numbers of **hydropower plants**
- 11) Number of **artificial recharges**
- 12) Number of **aquifers**
- 13) Number of **additional extractions**
- 14) Number of **return elements**
- 15) Number of **isopriority groups**
- 16) Number of **alarm indicators**
- 17) Number of **water importation elements**

### 7.2.1. **RESERVOIR** cards

These are composed of 13 registers with the following contents:

1st Register (1 item):

- Name (up to 15 characters)

2nd Register (4 items):

- Number of corresponding node
- Number of spillover node (0 may indicate end of the system)
- Inflow data column (if there are no inflows, 0 is selected)
- Evaporation data column (if evaporation is not considered, 0 is selected, in which case the averages given below are used)

3rd Register (1 item):

- Priority number

4th Register (5 items): (the last statistic refers to the type of aquifer with infiltration)

- Coefficient of infiltration formula "**A**" (see Section 5.5)
- Coefficient of infiltration formula "**B**"
- Coefficient of infiltration formula "**C**"
- Number of aquifer with infiltration (if 0, infiltration is presumed to be lost outside the system, although it is subtracted from stored volume).
- Number of basic infiltration action

5th Register (1 item):

- Initial volume of reservoir ( $\text{Hm}^3$ )

6th Register (1 item):

- Maximum flow of controlled releases, including intakes ( $\text{Hm}^3/\text{month}$ )

7th Register (12 items):

- 12 values for maximum volume ( $\text{Hm}^3$ )

8th Register (12 items):

- 12 objective volume values ( $\text{Hm}^3$ )

9th Register (12 items):

- 12 minimum volume values ( $\text{Hm}^3$ )

Registers 10-12 compose the Elevation-Surface-Volume table of the reservoir:

10th Register (10 items):

- 10 elevation values (m)

11th Register (10 statistics):

- 10 surface values (Ha)

12th Register (10 items):

- 10 volume values ( $\text{Hm}^3$ )

13th Register (12 items):

- 12 monthly evaporation values (mm). These will be used by the model when the evaporation column number is 0.

### 7.2.2. TYPE 1 CHANNEL cards

These are composed of four registers, containing:

1st Register (4 items):

- Name (up to 15 characters)
  - Maximum annual volume ( $\text{Hm}^3$ ). 0 is selected if there is no annual limit. This channel is eliminated by giving it a value of 0.001.
  - The restriction indicator to be used.
  - Value 0, 1, 2 or 3 (0 = monthly max. flow, 1 = annual max. flow, 2 = both max. flows and 3 = minimum monthly flow).

2nd Register (5 items):

- Initial node
- Final node (0 indicates system output)
- Minimum flow priority number in this reach
- River reach cost indicator (0=No cost, 1=unit cost or bypass, 2=cost chosen by user)
- River reach flow cost (only used when River Reach Cost Indicator is 2)

3rd Register (13 items):

- 12 minimum flow values ( $\text{Hm}^3/\text{month}$ )

- Acceptable  $Q_{min}$  failure level. This defines, as a percentage of  $Q_{min}$ , the acceptable  $Q_{min}$  deficit before a failure. If this flow is 0, due to rounding off problems, a failure may be declared when it does not in fact exist. It is recommended to use 1 as the minimum value.

4th Register (12 items):

- 12 max. flow values ( $\text{Hm}^3/\text{month}$ )

### 7.2.3. TYPE 2 CHANNEL cards

These are composed of 5 registers, containing:

1st Register (1 item):

- Name (up to 15 characters)

2nd Register (3 items):

- Initial node
- Final node
- Priority of minimum flow

3<sup>er</sup> Register (13 items):

- 12 minimum flow values ( $\text{Hm}^3/\text{month}$ )
- Acceptable  $Q_{min}$  failure level. This defines, as a percentage of  $Q_{min}$ , the acceptable  $Q_{min}$  deficit before a failure. If this flow is 0, due to rounding off problems, a failure may be declared when it does not in fact exist. It is recommended to use 1 as the minimum value.

4th Register (12 items):

- 12 max. flow values ( $\text{Hm}^3/\text{month}$ )

5th Register (5 items): (the second statistic depends on the type of aquifer with infiltration)

- Number of aquifer receiving infiltration (0 if it leaves the system)
- Number of basic action (0 if the preceding statistic is 0)
  - Coefficient of infiltration law "A"
  - Coefficient of infiltration law "B"
  - Coefficient of infiltration law "C"

### 7.2.4. TYPE 3 CHANNEL cards

These are composed of 5 registers, containing:



1st Register (1 item):

- Name (up to 15 characters)

2nd Register (3 items):

- Initial node
- Final node
- Priority of min. flow

3rd Register (13 statistics):

- 12 min. flow values ( $\text{Hm}^3/\text{month}$ )
- Acceptable  $Q_{\min}$  failure level. This defines, as a percentage of  $Q_{\min}$ , the acceptable  $Q_{\min}$  deficit before a failure. If this flow is 0, due to rounding off problems, a failure may be declared when it does not in fact exist. It is recommended to use 1 as the minimum value.

4th Register (12 items):

- 12 max. flow values ( $\text{Hm}^3/\text{month}$ )

5th Register (4 statistics): (The last two items depend on the aquifer with which the channel is connected.)

- Number of aquifer to which it is connected
- Number of the control parameter corresponding to the relationship
- Number of basic action to compensate for impossible withdrawals from the river (valid for type 1, 5 and 6 aquifers; for other aquifers the basic action is predetermined).
- Coefficient between 0 and 1 to allocate the result of the connection of the aquifer among various type 3 reaches. The sum of the connections of a control parameter must be equal to 1.

#### 7.2.5. TYPE 4 CHANNEL cards

These consist of 7 registers, containing:

1st Register (2 items):

- Name (up to 15 characters)
- Annual max. flow ( $\text{Hm}^3$ ), (0 for unlimited max. flow).

2nd Register (5 items):

- Initial node
- Final node
- Priority of min. flow in this reach
- River stretch cost indicator (0=No cost, 1=unit cost or bypass, 2=cost fixed by user)

- River reach flow cost (only active if the preceding item is 2)

3rd Register (13 items):

- 12 min. flow values ( $\text{Hm}^3/\text{month}$ )
- Acceptable  $Q_{\min}$  failure level. This defines, as a percentage of  $Q_{\min}$ , the acceptable  $Q_{\min}$  deficit before a failure. If this flow is 0, due to rounding off problems, a failure may be declared when it does not in fact exist. It is recommended to use 1 as the minimum value.

4th Register (12 items):

- 12 max. flow values ( $\text{Hm}^3/\text{month}$ )

5th Register (2 items):

- Elevation at the start of the channel (m). If the entry node corresponds to a reservoir, this item has no effect on the calculation.
- Elevation at the end of the channel (m). If the end node corresponds to a reservoir, this item has no effect on the calculation.

The 3 registers below make up the height-instantaneous flow table:

6th Register (1 item):

- Number of values (n') for elevation-flow relationship ( $2 \leq n' \leq 10$ ).

7th Register (n' items):

- Height values (m) for elevation-flow curve.

8th Register (n' items):

- Instantaneous flow values ( $\text{Hm}^3/\text{month}$ ) for the elevation-flow curve.

#### **7.2.6. TYPE 5 CHANNEL cards**

These consist of 6 registers, containing:

1st Register (1 item):

- Name (up to 5 characters)

2nd Register (2 items):

- Initial node
- Final node

3rd Register (2 items):

- Elevation at the start of the channel (m). If the entry node corresponds to a reservoir, this item has no effect on the calculation.
- Elevation at the end of the channel (m). If the end node corresponds to a reservoir, this item has no effect on the calculation.

The next 3 registers make up the elevation-flow table:

4th Register (1 item):

- Number of values ( $n'$ ) for elevation-flow relationship ( $2 \leq n' \leq 10$ ).

5th Register ( $n''$  items):

- $n''$  elevation increase values (m)

6th Register ( $n''$  items):

- $n''$  instantaneous flow values corresponding to elevation differences ( $\text{Hm}^3/\text{month}$ )

### 7.2.7. CONSUMPTIVE DEMAND cards

These consist of 11 or more registers, according to the number of intakes, and contain:

1st Register (1 item):

- Name (up to 15 characters)

2nd Register (12 items):

- 12 total monthly demand values ( $\text{Hm}^3$ )

3rd Register (7 statistics): (the 2nd, 3rd and 5th items depend on aquifer type)

- Number of aquifer recharged
- Number of basic recharge stress
- Number of aquifer from which water is extracted
- Number of basic extraction stress
- Number of control parameter for extraction authorisation test (if 0, extraction is always authorised).
- Threshold value of preceding control parameter below which extraction is not authorised.
- Max. extraction flow ( $\text{Hm}^3/\text{month}$ )

4th Register (6 items). Corresponding to percentage of demands used to calculate guarantees. These are, in order:

- Coefficient **A**, for the monthly guarantee
- Coefficients **B** and **C**, for Hydrological Plan type guarantees
- Coefficient **D,E** and **F** for "Utah DWR " type guarantees (F.Estrada, 1991), as established by the IPH (2008) for agricultural demands.

- Coefficients **G** and **H** for the calculation of guarantee criteria as established by the IPH (2008) for urban demands (in theory, 8% and 10%). See Section 8.1 "name 3.ext" file for the meaning of these coefficients. If coefficients A, B and C are assigned a value of 0, failures may be declared when they do not in fact exist. This is due to rounding out and it is recommended to give them a minimum value of 1.

5th Register (1 item):

- Number of different intakes (max. 5)

For each intake: 6 registers, containing:

\* 1st Register (1 item):

- Name (up to 15 characters)

\* 2nd Register (2 items):

- Intake node
- Intake elevation. This figure affects the calculation when the intake node belongs to a reservoir.

\* 3rd Register (3 items):

- Annual Volume ( $\text{Hm}^3$ )
- Return coefficient (between 0 and 1)
- Consumption coefficient (between 0 and 1)

\* 4th Register (3 items):

- Priority number
- Restriction alarm indicator number. If 0, no alarm indicator is connected to the intake.
- 1 or 0 (1 for annual flow and 0 for monthly flow)

\* 5th Register (1 item):

- Number of return element used

\* 6th Register (12 items):

- 12 monthly peak values ( $\text{Hm}^3/\text{month}$ )

### 7.2.8. **RETURNS** cards

These consist of 2 registers, containing:

1st Register (1 item):

- Name (up to 15 characters)

2nd Register (1 item):

- Node at which they return. This cannot be the final node.

### 7.2.9. HYDROPOWER PLANT cards

These consist of 4 registers, containing:

1st Register (1 item):

- Name (up to 15 characters)

2nd Register (6 statistics):

- Intake node
- Return node
- Minimum usable flow ( $\text{Hm}^3/\text{month}$ ). If there are no abnormal conditions, this value is normally 0, as otherwise it is assumed that flow to the turbines is constant during the month.
- Max. flow ( $\text{Hm}^3/\text{month}$ )
- Priority number
- Number of alarm-restriction indicator used to reduce the values of monthly target flow (if 0, no alarm indicator is applied).

3rd Register (12 items):

- 12 target flow values ( $\text{Hm}^3/\text{month}$ )

4th Register (3 items):

- Node number of reservoir below which the station is situated (0 if run-of-the-river)
- Gross head (m). For stations below a dam, the value entered is the elevation difference with the reservoir surface height to obtain gross head.
- Global electrical energy production coefficient ( $\text{Gwh}/(\text{Hm}^3.\text{m})$ )

5th Register (Not used if the first statistic of the 4th register is 0, i.e. if the station is run-of-the-river type (1 item):

- Minimum height of reservoir surface for power generation. No power is produced if monthly average elevation of reservoir surface is lower than the value entered.

### 7.2.10. ARTIFICIAL RECHARGE cards

These consist of 2 registers, containing:

1st Register (1 item):

- Name (up to 15 characters)

2nd Register (4 items):

- Intake node
- Number of aquifer
- Number of basic stress
- Max. recharge flow ( $\text{Hm}^3/\text{month}$ )

#### 7.2.11. INTERMEDIATE INFLOW cards

These consist of 2 registers, containing:

1st Register (1 item)

- Name (up to 15 characters)

2nd Register (2 items):

- Node at which they enter
- Column of corresponding inflow data (in Inflows file)

#### 7.2.12. AQUIFER cards

The first two registers are the following:

1st Register (1 item):

- Name (up to 15 characters)

2nd Register (1 item):

- Indicator of aquifer type

If the aquifer type indicator is over 100 (e.g. 101) this means that the readings of aquifer data are taken from another file and the aquifer type is (TYPE-100). For example, if the indicator is 101 the type of aquifer is equal to 1. The second line will contain the aquifer data file name. The 1<sup>st</sup> and 2<sup>nd</sup> registers of the general data file are repeated in this file and continue in the 3rd register with the structure described below.

If the type of aquifer is equal to 1, (**GENERAL EIGENVALUE MODEL**) the units are *m* and *days*, and the rest of the card includes firstly four more registers, containing:

3rd Register (3 items):

- Number of Eigenvalues
- Number of basic stresses
- Number of control parameters

4th Register (2 items):

- Number of control parameter for pumping test (If 0, no test is carried out)
- Threshold of control parameter at which pumping may not be performed.

5th Register ( $n_a$  items):

- Eigenvalues (as indicated by the first item of the third register)

6th Register ( $n_a$  items):

- Initial state vector (with a component for each Eigenvalue)

For each basic stress, 2 registers are included:

1st basic action register (1 item):

- Name of basic stress (up to 15 characters)

2° basic stress register ( $n_a$  items):

- Corresponding column of the matrix for conversion of basic action intensities to state vectors.

For each control parameter 2 registers are included:

1st control parameter register (1 item):

- Name of control parameter (up to 15 characters)

2nd Register ( $n_a$  items):

- Corresponding row of the matrix for conversion of state vectors to control parameter vectors.

If the aquifer type is equal to 2 (**SINGLE-CELL MODEL**) the rest of the card includes 2 registers:

3rd Register (2 items):

- Number of control parameter for extraction test (must be 1 (Volume) or 2 (Flow). (If 0, no test is carried out)
- Control parameter threshold below which extraction is not carried out (in  $\text{Hm}^3$  if the preceding value is =1, and in  $\text{Hm}^3/\text{month}$  if =2).

4th Register (2 items):

- Value of  $a$  (in  $\text{month}^{-1}$ )
- Value of initial volume ( $\text{Hm}^3$ ) (0 if working by superposition)

If aquifer type is equal to 3 (**SPRING MODEL**) the rest of the card includes 3 registers:

3rd Register (2 items):

- Number of control parameter for extraction test (must be 1 (Volume) or 2 (Flow). (If 0, no test is carried out)
- Control parameter threshold below which extraction is not carried out (in  $\text{Hm}^3$  if the preceding value is =1, and in  $\text{Hm}^3/\text{month}$  if =2).

4th Register (2 items):

- Value of  $\alpha$  (month<sup>-1</sup>)
- Value of initial volume (Hm<sup>3</sup>) (0 if working by superposition)

5th Register (12 items):

- 12 measured flow values (Hm<sup>3</sup>/month)

If aquifer type is equal to 4 (**TANK MODEL**) the rest of the card includes 3 registers:

3rd Register (2 items):

- Number of control parameter for extraction test (must be equal to 1). (If 0, no test is carried out.)
- Control parameter threshold below which extraction is not carried out (Hm<sup>3</sup>)

4th Register (1 item):

- Initial Volume (Hm<sup>3</sup>)

5th Register (12 items):

- 12 rain recharge values (Hm<sup>3</sup>/month)

If aquifer type is equal to 5 (**RECTANGULAR-HOMOGENEOUS WITH A RIVER**) the rest of the card contains the following registers:

3rd Register (1 item):

- Number of basic stresses

4th Register (2 items):

- Number of control parameter for extraction test (0=always permitted, 1=volume, 2=discharge into river)
- Threshold of control parameter below which extraction is not permitted (units depend on the preceding statistic but are always m<sup>3</sup> and days).

5th Register (5 items):

- Transmissivity  $T_X$  in the direction of the  $X$  axis (m<sup>2</sup>/day)
- Transmissivity  $T_Y$  in the direction of the  $Y$  axis (m<sup>2</sup>/day)
- Coefficient of storage  $S$
- Length  $L$  (m)
- Length  $D$  (m)

6th Register (15 items):

- Components of the initial state vector as defined in 5.9.5 (all null if superposition is assumed)



Two registers for each basic action. The first includes:

1st Register (2 items):

- Name (up to 15 characters).
- Type (1=group of individual actions; 2=distributed in a rectangle)

If type 1, the 2nd register includes:

2nd Register:

- Number of grouped individual actions
- and a set of three numbers for each number in the preceding item, consisting of:
- $X_k$  coordinate of the action (m)
  - $Y_k$  coordinate of the action (m)
  - Weight of the action  $P_k$  (the sum of the weights will be 1 and all will be positive)

If type 2, the next register has:

2nd Register (4 items):

- $XG_k$  coordinate of the centre of the rectangle (m)
- $YG_k$  coordinate of the centre of the rectangle (m)
- Length  $LX_k$  of the side parallel to the  $X$  axis (m)
- Length  $LY_k$  of the side parallel to the  $Y$  axis (m)

If the aquifer type is equal to 6 (**RECTANGULAR-HOMOGENEOUS WITH TWO RIVERS**) the rest of the card contains exactly the same data as type 5, but there are differences in the following registers:

4th Register (2 items):

- Number of the extraction test control parameter (0=always allowed, 1=volume, 2=discharge into river, 3=outflows by  $X=L$ , 4=outflows by  $Y=D$ )

6th Register (15 items):

- Initial state vector components will be defined as in Section 5.9.6.

If aquifer is type 7 (**MULTI-CELL SPRING AQUIFER**) the rest of the card consists of:

3rd Register (2 items)

- N° of cells in the model
- N° of exterior stresses on the aquifer

4th Register (2 items)

- Control parameters for extraction test
- Threshold value

5th Register (one item for each cell)

- Values of  $\alpha$ (month<sup>-1</sup>)

6th Register (1 item for each cell)

- Initial cell volume (Hm<sup>3</sup>)

7th Register

- Name of the basic stress for uniform recharge

8th Register (1 item for each cell )

- Coefficient of distribution of uniform recharge (0 to 1)

Registers 7 and 8 are repeated once for each declared exterior action, apart from uniform recharge.

If aquifer is type 11 (**THREE-LEVEL AQUIFER**) the remainder of the card content is as follows:

3rd Register (2 items)

- Number of the extraction test parameter control (0=always allowed, 1=flow with river, 2=flow with irrigation channel, 3=Evaporation, 4=volume)
- Threshold value

4th Register (14 items)

- Value of  $\alpha$  river (in month<sup>-1</sup>)
- Value of  $\alpha$  irrigation channel (in month<sup>-1</sup>)
- 12 Values of  $\alpha$  Evaporation (in month<sup>-1</sup>)

5th Register (3 items)

- Value of volume between river and irrigation channel (Hm<sup>3</sup>)
- Value of volume between irrigation channels and evaporation (Hm<sup>3</sup>)
- Value of initial volume (Hm<sup>3</sup>)

6th Register (10 items)

- 12 historical recharge values (Hm<sup>3</sup>/month)

### 7.2.13. **ADDITIONAL PUMPING** cards

These consist of 2 registers, containing:

1st Register (1 item):

- Name (up to 15 characters)

2nd Register (8 items): (2nd and 3rd items depend on type of aquifer)

- Number of aquifer from which water is pumped

- Number of basic stress
- Number of extraction authorisation test (0 = always allowed)
- Threshold value of preceding control parameter below which pumping is not authorised
- Max. extraction volume (Hm<sup>3</sup>/month)
- Node at which it enters system
- Number of isopriority group that initiates extraction
- Max. supply level for extraction to take place

For example, if 4 and 0.8 are declared for the two preceding items this means that when surface supply is over 80% of demand in the isopriority group 4 additional extraction will not take place but will be performed if the supply drops below 80% of the demand.

#### 7.2.14. **ALARM-RESTRICTION INDICATOR cards**

These consist of 5 registers, containing:

1st Register (1 item):

- Name of indicator

2nd Register (6 items):

- Option of type of rule (1 to 5)
- Option of type of decision (1 or 2)
- Number of elements (reservoir or inflow) included in indicator(ne)
- Number of months in the year in which operating rule is calculated (only used if value of 2nd item is 3. This value will normally be 1.
- Value 1 (reservoirs) or 2 (inflows)
- Number of months during which inflows have accumulated

3<sup>er</sup> Register (ne items):

- Identification number of each reservoir under study

The following three lines are repeated once for each month required to define the operating rule. In options of rules type 1 and 4, they are repeated only once; options 2 and 5 always 12 times; and for option 3 as often as the value of item 4 in the 2<sup>nd</sup> register.

4th Register (2 items):

- Number of month in which the next operating rule is calculated (1 = October).
- Number of valid data in the next curve (nd).

5th Register (10 items):

- 10 values for reference volume (only the first nd values will be valid).

---

6th Register (10 items):

- 10 coefficient values to be applied from 0 to 1 (only the first nd values will be valid).

#### **7.2.15. WATER IMPORT cards**

These consist of 2 registers for each water import element, and contain:

1st Register (1 item):

- Number of node at which imported water enters the system.

2nd Register (1 item for each month of the simulation period):

- Imported volume ( $\text{hm}^3$ ) in each month of the simulation.

### 7.3. Graph data file

If the graph indicator of the physical data file is equal to 1 (3<sup>rd</sup> line, 3<sup>rd</sup> item) it will be necessary to provide a file whose name must be specified in the file data file (7<sup>th</sup> line). This file determines the results that will be written in the monthly results files separated by types of elements. These results files are described in Section 8.2.

The contents of the specifications for graphs will have the following format:

The first three registers pertain to reservoirs:

- 1st Register:** No reading/data, free for comments.
- 2nd Register:** Number of reservoirs for which data are required (max. 300)
- 3rd Register:** Numbers of the reservoirs for which data are required. This is left blank if the value of the preceding register is 0.

The next 3 registers are for type 1 channels:

- 4th Register** No data
- 5th Register** Number of river reaches for which data is required (max. 300).
- 6<sup>o</sup> Register:** Numbers of the type 1 river reaches for which data is required.

The next 3 registers are for type 2 channels:

- 7th Register:** No data
- 8th Register:** Number of type 2 river reaches for which data is required (max. 300).
- 9th Register:** Numbers of the type 2 river reaches for which data is required.

The next registers are for type 3 channels:

- 10th Register:** No data
- 11th Register:** Number of type 3 river reaches for which data is required (max. 300).
- 12th Register:** Numbers of the type 3 river reaches for which data is required.

The next registers are for type 4 channels:

- 10th Register:** No data
- 11th Register:** Number of type 4 channels for which data is required (max. 300).
- 12th Register:** Numbers of the type 4 channels for which data is required.

The next registers are for type 5 channels:

- 10th Register:** No data
- 11th Register:** Number of type 5 channels for which data is required (max. 300).
- 12th Register:** Numbers of the type 5 channels for which data is required.

The next 3 registers are for consumptive demands.

- 13th Register:** No data

- 14th Register:** Number of demands for which data is required (max. 300).  
**15th Register:** Numbers of the demands for which data is required.

The next 3 registers are for non-consumptive demands.

- 16th Register:** No data  
**18th Register:** Number of demands for which data is required (max. 300).  
**19th Register:** Numbers of the demands for which data is required.

The next 3 registers are for additional extraction .

- 20th Register:** No data  
**21st Register:** Number of additional extractions for which data is required (max. 300).  
**22nd Register:** Numbers of the events.

The next 3 registers are for artificial recharges. :

- 23rd Register:** No data  
**24th Register:** Number of artificial recharges for which data is required (max. 300).  
**25th Register:** Numbers of the recharges.

The next 3 registers are for control parameters:

- 26th Register:** No data  
**27th Register:** Number of control parameters to be represented (max. 300).  
**28th Register:** Two numbers for each control parameter in the 27th Register. Each pair formed by: number of aquifer and number of control parameter.

The next 3 registers are for net recharges of aquifers.

- 29th Register:** No data  
**30th Register:** Number of aquifers for which net recharge data is required (max. number is determined by the sum of this number and that given in the 33<sup>rd</sup> Register, which cannot exceed 300).  
**31st Register:** Numbers of the aquifers.

The 3 final registers are for water extracted from aquifers:

- 32nd Register:** No data  
**33rd Register:** Number of aquifers for which extraction data is required (same conditions apply as in the 30th register).  
**34th Register:** Numbers of aquifers.

Data from all the system alarm indicators are always considered to be required.

## 7.4. Inflow data file

This consists of the following registers:

1st Register (1 item):

- Name of type of data in file. This will always be "INFLOWS" (including inverted commas).

2nd Register (1 item):

- Title (up to 20 characters)

3rd Register (1 item):

- Title (up to 20 characters )

4th Register (1 item):

- Number of inflow columns (a).

5th Register (2+a items):

- Text "**YEAR**"
- Text "**MONTH**"
- Names (between inverted commas) of the (a) inflows.

6th and following Registers (2+a items):

- Number of year (4 digits).
- Number of month (1: January to 12: December).
- (a) data separated by blank spaces containing inflows ( $\text{Hm}^3/\text{month}$ ) corresponding to month and year of the register and the inflow element of the column indicated in the 5<sup>th</sup> Register.

Inflow data registers must be consecutive and contain the simulation period defined in the physical data file, as otherwise the program will give incorrect readings in this file.

## 7.5. Evaporation data file

The structure of this file will be identical to the inflow data file, except in the case of the first register, which will contain "EVAPORATION". The contents will be of specific evaporation series.

## 7.6. Fictitious costs data file

This file must only be modified when the user is fully conversant with the operation of the model and system priorities have to be changed. The behaviour of the target function described

in Section 6.1 will therefore have to be studied in detail and the information contained in Sections 6.2 and 6.3 will have to be kept in mind.

The following file is supplied with the model and includes the definition of all the information in the form of the terms used in Section 6.1.

### File list:

```
* RESERVOIR COSTS
  KD      K4      K3      K2      K1      CV
2000.   -700.   -1000.  -1100.  -1700.  2000.
* TYPE 1 CHANNEL COSTS
  KD
2000.
* TYPE 2 CHANNEL COSTS
  CFi      KD
2100.   2000.
* TYPE 3 CHANNEL COSTS
  CFi      KD
2100.   2000.
* TYPE 5 CHANNEL COSTS
  CF5i
1800.
* CONSUMPTIVE USE DEMANDS
  CTC      CK      CDC
750.   750.   5.
* HYDROELECTRIC STATIONS
  CKN      -CS      CDN
1500.   -5.   5.
* ARTIFICIAL RECHARGE
  CR
-5.
```

Additional information can be included in this file that alters the operation and/or output of the model. There are various possibilities, some of which can be used simultaneously. Each one includes one or more additional lines, as follows:

- Consideration of the hydrological year in the southern hemisphere:  
**JL AG S O N D JAN F M A MY JN**  
 An extra line must be included with the name **HEMISUR** in capitals starting in the first column.
- Result files options: There are two other possibilities besides the model's default system:
  - Both are specified with a first line which includes the word **CODCOL** in capitals beginning in the first column.
  - In the next line, there are two options:
    - 0: Output is limited to 132 columns with printing codes pertaining to FORTRAN ('0','1',' ' and '+') programming language formats. Results are given to fewer decimal places than with the default method
    - 1: Similar to the above option but without FORTRAN printing codes.



- Conversion to whole numbers for optimisation. The number of decimal places is specified for the calculation. By default, the model works to 3 decimal places but this figure can be modified to 2 or 4
- A first line is included with the word **CODCONV** in capital letters beginning in the first column.
- For the next line, there are three options:
  - 2: 2 decimal places
  - 3: 3 decimal places
  - 4: 4 decimal places

The number of decimal places only needs to be increased when working with values close to the minimum precision number.

- Configuration to exit program without waiting for the user's confirmation: A line is included with the code **CODFIN** and a second line with the value 1. This usually becomes necessary in a process involving multiple simulations.

There are other options designed to analyse any model internal network problems or to modify convergence criteria, number of iterations, etc. These are not described here since they require the user to be perfectly familiar with the internal working of the model. However, if operational problems were to become apparent that involved the intervention of the creators of the model, users can request the inclusion of additional options to study internal network flows or to modify convergence criteria.

## 7.7. Modification basic data file

This file is not essential for running the model. However, it can be useful when it is necessary to define model data without actually including them in the physical data file. This occurs mainly when working with the SIMWIN graphic interface and the user has to include information which this system does not accept.

It is included in the model directory under the name "Simges.avz". Special care must be taken when filling in these data in order to avoid design errors in the simulation schemes. The file must also be deleted from the work directory as a precautionary measure when the data are no longer needed, since otherwise one could possibly be working with false data. Data can only be entered as described below.

This file is structured by the identifying labels given to the data that will activate the corresponding readings. Only the data related to the labels that appear in this file will be required.

### *Alarm-restriction indicator data*

Line 1: text

[ALARM-RESTRICTION]

Line 2: (1 item)

Number of restrictions modified

Then follows a data group (2+24=26 lines) for every restriction modified in the preceding item.

Line 1: (1 item)

Number of the position occupied by the alarm-restriction indicator in the physical data file.

Line 2: (12 items)

Number of alarm-restriction data ( $n_i$ ) to be read for each month (1st month - October, 4th month - January, etc.)

Then follow 12 pairs of lines, one pair for each month, beginning with October (total of 24 lines).

Line 1: ( $(n_i)$  items)

Volume data in  $\text{hm}^3$  for the definition of restrictions (in order of size from smallest to largest).

Line 2: ( $(n_i)$  items)

Restriction coefficient data (between 0 and 1) for each of the preceding volumes.

### ***Variable demand data file***

This file can be used to input a series of variable demand data for an entire historical period. Variable demands are defined and identified for the whole period and these values are then entered in a second file with a format similar to those described in the inflows and evaporation sections. It should be remembered that these files only accept variable data for “demand” elements, while the “supply” elements will continue with the data entered in the physical data file. This means that in the variable demand data file the data on supply capacity must be defined with a monthly value higher than the defined maximum monthly demand, as otherwise artificial supply deficits could be generated.

The file contents are as follows:

Register 1: Label

- Text: [VARIABLE DEMAND]

Register 2 (1 item):

- Number of variable demands (ndv).

Register 3. (1 item):

- Name of the file with series of demand data

Register 4 (ndv items)

- Each item contains the position number of each demand in the physical data file.

Register 5 (ndv items)

- Each item contains the number of the column in the demand data file of the demand corresponding to the position indicated in Register 4.

### ***Demand data file***

The structure of this file is identical to that of the inflow data file, except in the case of the first register, which must contain “DEMANDS”. The contents consist of the monthly demand series which will be used for simulation instead of the fixed demands defined in the physical data file.

## 8. RESULTS

**SIMGES** provides results in the form of ASCII files, which are described below. The model creates a file with the name '**SIMGES.ERR**' and which is located in the work directory. This directory records the dates and times of the start and finish of the simulations carried out. Also located in '**SIMGES.ERR**' are any possible model error warnings, which will be described later.

### 8.1. Basic Results files

Three files are produced which can be printed or included in a report:

- "label1.ext"      where *label1.ext* is the name of the file declared in the **reading and writing data file** corresponding to **echo data**, (e.g. ECODAT.SAL). This file is only created if 1 or 2 is the value of the echo data option in the physical data file. The file contains a repeat of the data entered as physical and management data, presented in order. There are a large number of columns, which, as described in Section 7.6, can be reduced to 132.
- "label2.ext"      where *label2.ext* is the name of the file declared in the **reading and writing data file** corresponding to **annual output** (e.g. SALANU.SAL). this file contains the size of the network generated, the iterations carried out in each month of each year of the simulation period. If 0 is the option chosen for the "summarised list" item in the physical data file, it also gives the values of all the relevant variables for each month of the simulated hydrological years. Thus, for each month we have:
- Firstly, the values of **intermediate inflows** with their annual total.
  - Intermediate inflows for all **reservoirs**, inflow from the preceding section of the system, end-of-month volume and elevation of the water surface, controlled and uncontrolled releases, evaporation and infiltration (monthly values and annual total).
  - For all **type 1 river reaches** it draws up a table with circulating flow (outflow) and the annual total.
  - For **type 2 river reaches**, as well as outflow it also gives monthly seepage volumes and annual total.
  - For **type 3 river reaches**, besides outflow it also gives the values of the river-aquifer relationship (losses if positive and gains if negative).

- For **type 4 channels** it gives circulating flows, annual total and maximum monthly flows under the conditions existing in the system.
  - For **type 5 channels** it gives monthly circulating flows and the annual total.
  - For **consumptive demands** it repeats the value of the volume supplied, gives surface supply, groundwater supply and deficit. Surface supply is divided by intakes.
  - For **return elements** it gives monthly and annual totals.
  - For **hydropower plants** it repeats the value of the target flow and gives the values of the flow used to generate power, gross head and power production.
  - For **additional extractions** it draws up a table with monthly extracted water volumes and annual total.
  - For **artificial recharges**, monthly results and annual totals are given.
  - For **aquifers** monthly net recharge values are obtained (minus extracted water values), monthly extracted water values and monthly values of the control parameters.
  - For system **alarm indicators** it gives the monthly values of the volume in each group of reservoirs and their corresponding restriction coefficients.
- "label3.ext" where *label3.ext* is the name declared in the reading and writing data file for the file that will contain the **simulated horizon summary** (e.g. SUMMARY.SAL). This file must always be included and contains the mean values of the values mentioned in the preceding item, as well as:
- **For reservoirs:** the number of times they were filled and emptied, in absolute numbers and percentages.
  - **For channels** (except type 5): number of minimum flow failures (a failure is a month in which minimum flow is not reached, according to the failure level defined for each channel) and monthly guarantee, calculated as:
 
$$G = \left( 1 - \frac{Failures}{Months} \right) \bullet 100 \quad (8.1)$$

Where the number of failures is the sum of the number of months with failure, a failure being when the deficit of the minimum flow exceeds the acceptable  $Q_{min}$  failure level.

- **For consumptive demands** various guarantee results are given: the number of months with a failure (as in the case of channels, a failure being a month with a deficit higher than A% of monthly demand, A being the value declared in the demand guarantee line), the monthly guarantee calculated as in Section 8.1 the volumetric guarantee calculated as:

$$G_v = \frac{\text{supplied\_volume}}{\text{demanded\_volume}} \cdot 100 \quad (8.2)$$

maximum deficit in one month and maximum deficit in two consecutive months.

Number of failures is also given according to an annual criterion (Hydrological Plans), as well as the corresponding guarantee, which counts as failures a year in which one of the following circumstances occurs:

- . The deficit exceeds **B**% of monthly demand in any month.
- . Yearly deficit exceeds **C**% of annual demand.

A guarantee is also determined according to a criterion similar to the "Utah DWR" (F.Estrada, 1991), which considers a failure to be one of the three following conditions:

- . Yearly deficit exceeds **D**% of annual demand.
- . The deficit in two consecutive years exceeds **E**% of annual demand.
- . The deficit in ten consecutive years exceeds **F**% of annual demand.

Values of 50, 75 and 100 for D, E and F will meet the IPH 2008 reliability criteria for agricultural demands.

It also gives the value of the yearly deficit in each of the three preceding criteria as a percentage of annual demand.

The criterion fixed by the IPH 2008 for urban demands is SATISFIED if the deficit does not exceed 8% of demand in one month nor 10% of annual demand in 10 years. In the program these thresholds are optional and are included in the demands file.

It also provides the number of failures according to each criterion.

To analyse a demand that has been entered with different values for each year, the guarantee criteria are computed in the same way for periods of less than 1 year, bearing in mind the real value of the demand for each month and year. For periods longer than 1 year, the reference value will be the mean demand for the entire period.

## 8.2. Results files arranged for spreadsheets

The ASCII files produced by **SIMGES** and described below can be imported for spreadsheets (Lotus 123, Excel, Quatro Pro). They have the PRN extension and the alphanumerics are put between inverted commas. They are created as long as they have been requested in the graphics data file and the corresponding indicator in the physical data file is greater than 0.

There are 13 different types of files, corresponding to the different types of elements, to aquifer recharge and extraction results and to alarm indicators. They are described below. In the descriptions below 'N' is the number of years in which results have been provided for graphs. The last file described contains all the simulation results regardless of the graphic options selected.

**RESERVOIRS.PRN:** Contains **reservoir results** and are structured as follows: .

1st Register (1 item):

- number of simulation years, "label of simulation".

In the following registers each contains as many items as the number of reservoirs specified for graphs output (max. 300).

2nd Register (max. 300 items):

- Column headings. Contains the names of the reservoirs in the respective columns.

3rd to 14th Registers (max. 300 items):

- In each row, the minimum volume values corresponding to the reservoirs of the respective columns for months 1 (Register 3) to 12 (Register 14).

15th to 26th Registers (max. 300 items):

- In each row, the maximum volume values corresponding to the reservoirs of the respective columns for months 1 (Register 15) to 12 (Register 26).

27th to 38th Registers (max. 300 items):

- In each row, the target volume values corresponding to the reservoirs of the respective columns for months 1 (Register 27) to 12 (Register 38).

39th Register (max. 300 items):

- Initial volume values for the respective reservoirs.

40th to 39+(Nx12)th Registers (max. 300 items):

- Final reservoir volumes for all simulation months, from 1 (Register 40) to Nx12 (Register 39+(Nx12)th).

40+(Nx12)th to 51+(Nx12)th Registers (max. 300 items):

- Mean value for the simulation period of the final volumes for each month in the year from October (Register 40+(Nx12)th) to September (Register 51+(Nx12)th).

**EVAPO.PRN:** Contains the **reservoir evaporation results** and is structured as follows:

1st and 2nd Registers.

- Similar to those in EMBALSE.PRN.

3rd to 2+(Nx12)th Registers (max. 300 items):

- Monthly evaporation values in the reservoir corresponding to each column.

**EMBFILT.PRN:** Contains **reservoir infiltration results** and is structured as follows:

1st Register.

- Similar to that in EMBALSE.PRN.

2nd Register (1 item).

- Title of the problem.

3rd to 5th Registers.

- Free.

6th Register.

- Names of the reservoirs in the order in which the data will appear.

7th to 6+(Nx12)th Registers. (max. 300 items):

- Infiltration inflow from each reservoir for each simulated month.

**CONDUC1.PRN:** Contains the **type 1 channel results** selected to appear in this file and is structured as follows:

1st and 2nd Registers (1 item):

- Similar to those in EMBALSE.PRN.

3rd to 14th Registers (max. 300 items):

- In each row, monthly minimum flow values declared for months 1 (Register 3) to 12 (Register 14).

15th to 26th Register (max. 300 items):



- In each row, monthly maximum flow values declared for months 1 (Register 15) to 12 (Register 26).

27th to 26+(Nx12)th Registers (max. 300 items):

- Circulating flows in each simulation month from 1 (Register 27) to Nx12 (Register 26+(Nx12)th).

27+(Nx12)th to 38+(Nx12)th Registers:

- Monthly mean flow values for each month of the year from October (Register 40+(Nx12)th) to September (Register 51+(Nx12)th).

**CONDUCT2.PRN:** Similar to CONDUCT1.PRN, but for **type 2 channels**.

**COND2FIL.PRN:** Contains the **type 2 channel infiltration results** selected to appear in this file. Its structure is similar to EMBFIL.PRN.

**CONDUCT3.PRN:** Similar to CONDUCT1.PRN, but for **type 3 channels**.

**COND3FIL.PRN:** Contains the **type 3 channel infiltration results** selected to appear in this file. Its structure is similar to EMBFIL.PRN.

**CONDUCT4.PRN:** Contains results of the selected **type 4 channels** and the maximum volumes they could have supplied.

1st and 2nd Registers:

- Similar to those in EMBALSE.PRN.

3rd to 14th Registers:

- Contain the declared monthly minimum flows.

15th to 26th Registers:

- Contain the declared monthly maximum flows.

27th to 26+(Nx24)th Registers:

- These are pairs of registers that contain the circulating flows in each simulated month and the maximums they could have supplied in accordance with the elevations of their start and finish points.

27+(Nx24)th to 50+(Nx24)th Registers:

- These are pairs of registers that contain mean monthly flow values and the mean possible maximums.

---

**CONDUCT5.PRN:** Contain the results of the selected **type 5 channels**.

1st and 2nd Registers:

- Similar to those in EMBALSE.PRN.

3rd to 2+(Nx12)th Registers:

- Contain the circulating flows for each month of the simulation.

3+(Nx12)th to 14+(Nx12)th Registers:

- Contain mean monthly flow values.

**DEMANDAS.PRN:** Contains the results of the **consumptive use demands** that have been selected to appear in this file and has the following structure:

1st and 2nd Registers:

- Similar to those in EMBALSE.PRN.

3rd to 14th Registers:

- Contain the monthly demand values of the corresponding zone.

15th to 26th Registers:

- Contain the monthly maximum values corresponding to the zone intake 1.

27th to 38th Registers:

- Contain the monthly maximum values corresponding to the zone intake 2 (if this does not exist results will be 0).

39th to 50th Registers:

- Contain the monthly maximum values corresponding to the zone intake 3 (if this does not exist results will be 0).

51st to 62nd Registers:

- Contain the monthly maximum values corresponding to the zone intake 4 (if this does not exist results will be 0).

63rd to 74th Registers:

- Contain the monthly maximum values corresponding to the zone intake 5 (if this does not exist results will be 0).

75th to 74+(Nx12)th Registers:

- Contain the values of the monthly deficits recorded throughout the simulation.

75+(Nx12)th to 86+(Nx12)th Register:

- Contain the values of the mean monthly deficits recorded at the simulation horizon.

87+(Nx12) to 98+(Nx12), from 99+(Nx12) to 110+(Nx12), from 111+(Nx12) to 122+(Nx12), from 123+(Nx12) to 134+(Nx12) and from 135+(Nx12) to 146+(Nx12) Registers

- Contain mean supplies through intakes 1, 2, 3, 4 and 5 respectively of the demand zone.

147+(Nx12)th to 158+(Nx12)th Registers

- Contain the mean monthly values of pumping carried out in the demand zone.

**SUMINIST.PRN:** Contains the results of supplies to the **consumptive demands** selected to appear in this file and has the following structure:

1st and 2nd Registers:

- These are similar to those in EMBALSE.PRN.

3rd to 2+(Nx12)th Registers:

- Contain the values of the monthly supplies recorded throughout the simulation.

**CENTRALS.PRN:** Contains the results of supplies to the **non-consumptive demands** selected to appear in this file and has the following structure:

1st and 2nd Registers:

- These are similar to those in EMBALSE.PRN.

3rd Register:

- Contains the declared maximum flow value.

4th to 15th Registers:

- Contain the declared monthly target flow values.

16th to 15+(Nx12)th Registers:

- Contain the flow values used by hydropower plants during the simulation period.

16+(Nx12)th to 27+(Nx12)th Registers:

- Contain mean monthly flow values of the water used by hydropower plants (12 values).

**CENTPROD.PRN:** Contains the **non-consumptive demand hydroelectric production results** selected to appear in this file. The structure is similar to EMBFILT.PRN.

**RECARTF.PRN:** Contains the **artificial recharge** results selected to appear in this file and has the following structure:

1st and 2nd Registers:

- These are similar to those in EMBALSE.PRN.

3rd Register:

- Contains the declared maximum recharge capacities.

4th to 3+(Nx12)th Registers:

- Contain the values of monthly recharges carried out during the simulation.

4+(Nx12)th to 15+(Nx12)th Registers:

- Contain mean monthly recharge values.

**BOMBAD.PRN:** Similar to RECARTF.PRN, but with **additional extractions** instead of artificial recharges and **extraction** instead of recharge.

**PCACU.PRN:** Contains the values of the results (**control parameters**) obtained from aquifers for which this information has been requested and has the following structure:

1st and 2nd Registers:

- These are similar to those in EMBALSE.PRN.

3rd Register:

- Contains the names of the control parameters in the corresponding column.

4th to 3+(Nx12)th Registers:

- Contain the monthly values of the control parameters registered throughout the simulation.

4+(Nx12)th to 15+(Nx12)th Registers:

- Contain the mean monthly values of the control parameters.

**RNBOMBAC.PRN:** Contains the values of **net recharges and water extracted from aquifers** that have been requested and has the following structure:

1st Register(1 item):

- Number of years in simulation, “title of the problem”. Each of the following registers contains an item for the extractions and recharges specified in the graph output file.

2nd Register (max. 300 items):

- Column headings. Contains the names of the aquifers corresponding to the extractions of the respective column and also the names of the aquifers corresponding to the recharge of the respective column.

3rd Register:

- Contains the terms “Extraction and/or Recharge” according to type of result.

4th to 3+(Nx12)th Registers:

- Contain all the simulation values.

4+(Nx12)th to 15+(Nx12)th Registers:

- Contain the monthly mean values.

**ALARMAS.PRN:** Contains the values of the **reservoir volumes and restriction coefficients obtained for all alarm indicators** in the order in which they have been defined in the data file. Its structure is as follows:

1st and 2nd Registers:

- These are similar to those in EMBALSE.PRN.

3rd to 2+(Nx12)th Registers:

- Contain pairs of volume values – restriction coefficients for all indicators.

3+(Nx12)th to 14+(Nx12)th Registers:

- Contain pairs of mean values of volume and restriction coefficients.

**TABLA.TXT:** Contains **all simulation results** in table format for easy transfer to spreadsheets and is structured as follows:

Each row contains all monthly simulation results in the following order:

- The 2nd and 3rd items are year and month of simulation.

The 4<sup>th</sup> and succeeding items include simulation results ordered as described below. A "TABLA.DIR" file is also written with the names of the items that appear here in the same order. Each row contains the type of element, the name of the element and the type of item for each data series in the table.

---

(inflow data)

- intermediate inflows

(reservoir data)

- intermediate inflows defined in reservoirs
- inflows to modelled reservoirs
- final reservoir volumes
- final reservoir elevation
- controlled releases
- spills
- evaporation in reservoirs
- infiltration in reservoirs

(channel data )

- flow in type 1 river reaches
- flow at end of type 2 river reaches
- seepage in type 2 river reaches
- flow at end of type 3 river reaches
- seepage or inflows in type 3 river reaches
- flow in type 4 river reaches
- maximum flow in type 4 river reaches
- flow in type 5 river reaches

(demand data)

- consumptive demand values
- surface supply to consumptive demands
- underground supply to consumptive demands
- supply deficit to consumptive demands
- supply to consumptive demands by intake (ordered by demand and number of intakes for each demand).

(returns data)

- flow in return elements

(hydroelectric station data)

- target flow
- flow to turbines
- elevation of turbines
- hydroelectric production

(additional pumping data)

- volume of water extracted

(artificial recharge data)

- recharged flow

(aquifer data)

- net recharge in aquifers
- total extraction in aquifers
- aquifer control parameters (ordered by aquifer)

(operating rules data)

- reference volumes in alarm restriction elements
- restriction values in alarm restriction elements

The order of each type of elements is the same as that read by the program in the physical data file, coinciding with the user numeration order in AQUATOOLDMA.

Also, the column containing the first item of each set of values is indicated in the graph results file in xml format, described in the next section, (to examine this, it should be renamed with the extension “.xml” and opened with Internet Explorer) in the set of <NOMBRES> located before each set of names under the <ICol1Tabla> label.

### 8.3. File containing results labelled for graphs

A data structure labelled in XML style was designed to be read by specially-designed libraries and by any program that uses SIMGES results as inputs. This file is also used by the GRAFDMA graph file in the AQUATOOLDMA interface. Its default name is "salanupp.tmp".

#### Data labels

Data are grouped by opening and closing labels as indicated in XML but not in such great detail. Labels occupy a single line so as to be easily read and interpreted by sequential reading programs such as Fortran (the symbols '<' y '>' are added to the beginning and end of the labels in the table, respectively).

Labels	Description	1	2	3
DATGEN MODEL	"SIMGES", "SIMRISK", "OPTIGES" according to what program they are generated in	x	x	x
	Number of elements of each type (in general one item per label, except derived elements such as intakes that have the ordered numbers of intakes of each demand.	x	x	x
TITRE	Title 1 of scheme	x	x	x
TITULO	Title 2 of scheme	x	x	x
NANY	Number of simulation years	x	x	x
NANI	Initial simulation year	x	x	x
MSINI1	Initial simulation month (1:January)			x
NSERI	Number of simulated series			x
NMSCAM	Total number of simulated months			x
NNOD	nodes	x	x	x
NEMB	reservoirs	x	x	x
NTR1	Type 1 river reaches	x	x	x
NTR2	Type 2 river reaches	x		x
NTR3	Type 3 river reaches	x		x
NTR4	Type 4 river reaches	x		x
NTR5	Type 5 river reaches	x		x
NAPINT	Intermediate inflows	x	x	x
NDC	Consumptive demands	x	x	x
NUMTO	Number of ordered intakes for each demand	x		x
NDN	Non-consumptive demands	x		x
NRAR	Artificial recharges	x		x
NACU	aquifers	x		x
NPCS	Number of control parameter in each aquifer	x		x
NAES	Number of basic stresses in each aquifer	x		x
NBAD	Additional extractions	x		x
NRET	returns	x	x	x
NISOP	Isopriority groups	x		x
NINRE	Restriction indicators	x		x
NAMES	Labels of the names of all elements. Format: (i3,1x,a30)	x		x



Labels		Description	1	2	3
ICollTabla		Indicates position of first item of each type of element in the results file in the form of a single table. Situated at the same level as the names just before each names label.			
NOMDC		Name of consumptive use demand 1	x	x	x
NOMTC		Name of intake J of consumptive demand 1	x		x
NOMAPI		Name of intermediate inflow 1	x	x	x
NOMEMB		Name of reservoir 1	x	x	x
NOMTR1		Name of river reach type 1 1	x	x	x
NOMTR2		Name of river reach type 2 1	x		x
NOMTR3		Name of river reach type 3 1	x		x
NOMTR4		Name of river reach type 4 1	x		x
NOMTR5		Name of river reach type 5 1	x		x
NOMRET		Name of return flow 1	x	x	x
NOMDN		Name of non-consumptive demand 1	x		x
NOMBAD		Name of additional extraction 1	x		x
NOMRAR		Name of artificial recharge 1	x		x
NOMACU		Name of aquifer 1	x		x
NOMAE		Name of basic stress K of aquifer 1	x		x
NOMPC		Name of control parameter J of aquifer 1	x		x
NOMINR		Name of alarm indicator 1	x		x
RED		Definition of simulation graph	x	x	x
TR1	rio 1	One line for each element. For dependent elements (i.e. intakes: TDC) the lines are in the same order as demands.	x	x	x
TR2	rio 2	In each line 3 items refer to an element:	x	x	x
TR3	rio 3	1st number of arc	x	x	x
TR4	rio 4	2nd number of element of origin	x	x	x
TR5	rio 5	3rd number of destination element	x	x	x
APINT	aportac.	For elements that have no node of origin or destination node the value is -1.	x	x	x
TDC	tomas	The numeration of elements is that pertaining to the type of element to which it belongs and is determined by the type of arc.	x		x
DNC	centrales		x		x
RAR	recargas		x		x
RET	retornos				
BAD	bombeos		x		x
EMB		One item for each reservoir. Each item is the number of the node assigned to the reservoir. Items are in the same order as the reservoir numeration.	x	x	x
IANY		Number of the year which data refer to. Repeated for each simulated year.	x	x	x
DEMANDAS			x		x
SSUPC		surface supply to demands	x		x
DEFC		supply deficit to demands	x		x
SSUBC		groundwater supply to demands	x		x
TOMAS			x		x
SSUPTC		surface supply by intakes ordered by demand numeration	x		x
APINT		intermediate inflows	x	x	x
EMBALSES			x		x
APEMB		intermediate inflows to reservoirs	x		x
ENTEB		inflows to reservoirs by river reaches	x		x
VFIN		final volume	x	x	x
CFIN		end-of-month elevation	x		x

Labels	Description	1	2	3
SUELTE	controlled releases	X		X
VERTE	uncontrolled releases	X		X
EVAPE	evaporation	X	X	X
FILTE	infiltration	X		X
QT1	type 1 river flow	X	X	X
RIOT2		X		X
QT2	type 2 river flow	X		X
PERTR2	infiltration	X		X
RIOT3		X		X
QT3	type 3 river flow	X		X
RT3	connection to aquifer	X		X
RIOT4		X		X
QXT4	maximum flow	X		X
QT4	type 4 river flow	X		X
QT5	type 5 river flow	X		X
RETOR	surface return	X	X	X
CENTRALES		X		X
QOBN	target flow	X		X
QTUR	flow to turbines	X		X
HTUR	elevation	X		X
PROD	production	X		X
BOMBAD	additional extraction	X		X
QREC	artificial recharge	X		X
ACUIFEROS		X		X
RECNET	net aquifer recharge	X		X
BACU	total aquifer pumping	X		X
PARAMCONT		X		X
PCONT	control parameters	X		X
ALARMREST		X		X
VEBIR	volume in alarm indicators	X		X
CRIR	restriction coefficient applied	X		X
RESUMEN		X		X
GARANTIAS		X		X
DEMANDA	Includes number of the demand and contains the following guarantee calculations (repeated for each consumptive demand).	X		X
XFALL	Number of failures	X		X
GAR	Monthly guarantee.	X		X
GARV	Volumetric guarantee.	X		X
XDFMX	Maximum one-month deficit.	X		X
XDFMX2	Maximum two-month deficit.	X		X
XFALPH	Number of failures according to Hydrological Plans.	X		X
GARPH	Guarantee according to Hydrological Plans.	X		X
XFAV1	Max. failure in one year. As % of annual demand.	X		X
XFAV2	Max. failure in two years. As % of annual demand.	X		X
XFAV10	Max. failure in ten years. As % of annual demand.	X		X

(1) simges      (2) optiges      (3) simrisk

### Example

The following table shows the results file of a scheme with one reservoir, one demand, one type 1 channel and a one-year simulation.

```
<?xml version="1.0" encoding="ISO-8859-1" ?>
<SIMGES>
<DATGEN>
<TITRE>
" ejemplo"
</TITRE>
<TITULO>
" demo"
</TITULO>
<NANY>
1
</NANY>
<NANI>
1980
</NANI>
<NNOD>
1
</NNOD>
<NEMB>
1
</NEMB>
<NTR1>
1
</NTR1>
<NAPINT>
1
</NAPINT>
<NDC>
1
</NDC>
<NUMTO>
1
</NUMTO>
<NISOP>
1
</NISOP>
</DATGEN>
<NOMBRES>
<ICollTabla> 4</ICollTabla>
<NOMAPI>
1 " Aportación nº 1"
</NOMAPI>
<ICollTabla> 5</ICollTabla>
<NOMEMB>
1 " Embalse 1"
</NOMEMB>
<ICollTabla> 13</ICollTabla>
<NOMTR1>
1 " Conducción 1"
</NOMTR1>
<ICollTabla> 14</ICollTabla>
<NOMDC>
1 " Demanda nº 1"
</NOMDC>
<NOMTC>
1 " Toma nº 1"
</NOMTC>
</NOMBRES>
<RED>
<APINT>
1 -1 2
</APINT>
<TR1>
1 2 0
</TR1>
<TDC>
1 2 1
</TDC>
</RED>
<IANY>

1980-1981
<APINT>
1 1.1500 1.3800 6.5500 2.2100 9.0300 13.4300 24.7200 18.4400 3.8100 1.1200 0.4400 0.4400
</APINT>
<EMBALSES>
<APEMB>
1 1.1500 1.3800 6.5500 2.2100 9.0300 13.4300 24.7200 18.4400 3.8100 1.1200 0.4400 0.4400
</APEMB>
<ENTEB>
```

```

1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
</ENTEB>
<VFIN>
1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
</VFIN>
<CFIN>
1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
</CFIN>
<SUELTE>
1 1.1500 1.3800 6.5500 2.2100 9.0300 13.4300 24.7200 18.4400 3.8100 1.1200 0.4400 0.4400
</SUELTE>
<VERTE>
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</VERTE>
<EVAPE>
1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
</EVAPE>
<FILTE>
1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
</FILTE>
<EMBALSES>
<QT1>
1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
</QT1>
<DEMANDAS>
<DEMC>
1 30.0000 30.0000 30.0000 30.0000 30.0000 30.0000 30.0000 30.0000 30.0000 30.0000 30.0000 30.0000
</DEMC>
<SSUPC>
1 1.1500 1.3800 6.5500 2.2100 9.0300 13.4300 24.7200 18.4400 3.8100 1.1200 0.4400 0.4400
</SSUPC>
<SSUBC>
1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
</SSUBC>
<DEFC>
1 28.8500 28.6200 23.4500 27.7900 20.9700 16.5700 5.2800 11.5600 26.1900 28.8800 29.5600 29.5600
</DEFC>
<TOMAS>
<SSUPTC>
1 1.1500 1.3800 6.5500 2.2100 9.0300 13.4300 24.7200 18.4400 3.8100 1.1200 0.4400 0.4400
</SSUPTC>
</TOMAS>
</DEMANDAS>
</IANY>
<RESUMEN>
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<GAR> 0.000 </GAR>
<GARV> 22.978 </GARV>
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<XDFMX2> 59.120 </XDFMX2>
<XFALPH> 1.000 </XFALPH>
<GARPH> 0.000 </GARPH>
<XFAV1> 77.022 </XFAV1>
<XFAV2> 0.000 </XFAV2>
<XFAV10> 77.022 </XFAV10>
</DEMANDA>
</GARANTIAS>
</RESUMEN>
</SIMGES>

```

## 8.4. Balance calculation file

To facilitate the calculation of balances by basin zones the model can produce a file in ASCII format which stores all the information from the final summary file but without text or labels. The data in this file, together with the contents of the physical data and management file ( e.g. "DATFIS.DAT") can be used to obtain the balances of the basin zones. All the written results are 4-byte floating-point numbers separated by a semi-colon (so that they can be opened with the values divided into cells from a spreadsheet). The structure of the file, whose name is indicated in the reading and writing data file ('DATOS.DAT') is as follows:

An identifying label is written before each type of result.

The order number and name of the element are written before the results of each element.

In addition, the following values are written for each element:

- One **register** (line) for each **intermediate inflow**, each containing 12 mean monthly values and mean annual value.
- Seven **registers** for each **reservoir**, containing:
  - 1st Register: 12 monthly intermediate inflow values and mean annual value.
  - 2nd Register: 12 upstream mean monthly inflow values and mean annual value.
  - 3rd Register: 12 mean monthly final volume values.
  - 4th Register: 12 mean monthly controlled release values and mean annual value.
  - 5th Register: 12 mean monthly spill values and mean annual value.
  - 6th Register: 12 mean monthly evaporation values and mean annual value.
  - 7th Register: 12 mean monthly infiltration values and mean annual value.
  - 8th Register: Number of months in which final volume is null and number of months in which max. value is reached.
- One **register** for each of the **type 1 river reaches**, each containing 12 mean monthly circulating flow values, their mean annual values and the number of months in which minimum flow has been violated.
- Two **registers** for each of the **type 2 river reaches**, containing:
  - 1st Register: 12 mean monthly outflow values, their mean annual value and the number of months in which minimum flow has not been reached.
  - 2nd Register: 12 mean monthly seepage values and mean annual value.
- Two **registers** for each of the **type 3 river reaches**, containing:
  - 1st Register: 12 mean monthly outflow values, their mean annual value and the number of months in which minimum flow has not been reached.
  - 2nd Register: 12 mean monthly river-aquifer relationship values and mean annual value.

- 
- Two **registers** for each of the **type 4 river reaches**, containing:
    - 1st Register: 12 mean monthly outflow values, their mean annual value and the number of months in which minimum flow has not been reached.
    - 2nd Register: 12 mean possible maximum flow values for each month and mean annual total.
  - One **register** for each **type 5 channel**, containing: 12 mean monthly outflow values and their mean annual value.
  - For each **consumptive demand** there are 4 initial registers plus one register per intake. The 4 initial registers contain:
    - 1st Register: 12 monthly demand values and total annual value.
    - 2nd Register: 12 mean monthly surface supply values and mean annual value.
    - 3rd Register: 12 mean monthly groundwater supply values and mean annual value
    - 4th Register: 12 mean monthly deficit values and mean annual value.

Then follow 5 registers for **intakes**, each of which contains 12 mean monthly supply values of the supply provided by each intake and mean annual value. If there are fewer than 5 intakes, the lines are completed with values of 0.

    - Next register: (3 items) Number of months in which demand has not been met (number of failures), max. deficit in a month and max. deficit in two consecutive months ( $Hm^3$ ).
    - Next register: Number of failures according to the criteria of Hydrological Plans.
    - Final register: (4 items) Number of failures according to the UTA-DWR type criterion (if greater than 0, it is no longer complied with). Max. deficit as % for 1, 2 and 10 years.
  - One **register** for each **return element** containing 12 mean monthly return values and mean annual value.
  - Three **registers** for each **non-consumptive demand**, containing:

- 
- 1st Register: 12 monthly target flow values and total annual value.
- 2nd Register: 12 mean monthly values of supply to turbines and mean annual value.
- 3rd Register: 12 mean monthly energy production values and mean annual value.
- One **register** for each **additional extraction** containing 12 mean monthly pumping values and mean annual value.
  - One **register** for each **artificial recharge** containing 12 mean monthly values and mean annual value.
  - For each **aquifer** there are 2 initial registers plus one register for each control parameter. The 2 initial registers contain:

1st Register: 12 mean monthly values of net aquifer recharge and mean annual value.

2nd Register: 12 mean monthly total aquifer extraction values and mean annual value.

3rd to 12th Registers: Ten registers corresponding to each control parameter contain 12 mean monthly control parameter values and mean annual value. If the model has fewer than 10 control parameters, it is completed with 0 registers.
  - Two registers for each **alarm indicator**, containing:

1st Register: 12 mean values of mean stored volumes.

2nd Register: 12 mean values of restriction coefficients.

## 9. ERROR MESSAGES

Simulation may be interrupted if the program detects errors, in which case the message 'TERMINACIÓN EN ERROR' will appear on the screen and the error will be written in the 'SIMGES.ERR' work directory file. The following error messages may cause the program to stop.

- **NON CONNECTED NETWORK – n errors.**

This is due to an error in the user scheme. The number n may give an idea of the number of errors involved. It will be necessary to check that all the necessary requisites have been complied with in defining the user scheme, especially in defining the initial and final channel nodes. Initial nodes must have a preceding element such as another channel, inflow, etc. Final nodes must either have a following element or be the final system node (999).

- **INSUFFICIENT DIMENSIONS OF INTERNAL NETWORK**

In theory, this error cannot occur if all the restrictions included in the manual have been complied with. Check that all the restrictions in Section 7.2 have been fulfilled.

- **PROBLEMS WITH UPPER AND LOWER LIMITS IN SCHEME**

In this case there is no feasible solution when solving monthly optimisation as the error is in the upper and lower limits of the internal network.

The model will give the year, month and iteration in which the error occurred.

It is generally due to the incorrect definition of maximum and minimum flows in channels or to incorrect zoning of a reservoir.

- **MAXIMUM PERMITTED NUMBER OF ELEMENTS HAS BEEN EXCEEDED**

If the maximum number of elements is exceeded, check that the restrictions specified in Section 7.2 are complied with.

- **ERROR: MAX. (type of element) HAS BEEN EXCEEDED**

The model has detected more elements than those permitted for the type in question in Section 7.2.

- **READING ERROR IN PHYSICAL DATA FILE: LINE ???**

The program stops when it detects an error in the physical data and management file. The number of the line containing the error is indicated.

The error is due to an incorrect file either from omission of data, incorrect data type, reaching the end of the file, etc

The solution is to check the file following the instructions given in Section 7.2, beginning with the lines close to that indicated by the model.

- **ERROR: RETURN ??1 OF DEMAND ??2 INCORRECT**

The model has detected an incorrect return number, which could be either negative or higher than the declared number of returns.



- 
- READING ERROR IN AQUIFER FILE N° ??  
Error has been detected in aquifer data. The existence and location of the file must be checked. If these are correct, check contents.
  - GRAPH DIMENSIONS HAVE BEEN EXCEEDED  
Graphic dimensions have been exceeded due to incorrect data in the graph specifications file. Graph information has been entered in excess of the permitted maximum (see restrictions in Section 7.3). file
  - INCORRECT HEADING OF INFLOWS FILE  
On reading the inflows file, incorrect heading structure has been detected.
  - INCORRECT HEADING OF EVAPORATION FILE  
On reading the evaporation file, incorrect heading structure has been detected.
  - INFLOW READING ERROR IN LINE ???  
Reading error has occurred in the inflows line specified. The file must be checked.
  - EVAPORATION SERIES READING ERROR IN LINE ???  
Reading error has occurred in the evaporation line specified. The file must be checked.
  - ERROR: END OF INFLOWS FILE  
End of the inflows file has been reached sooner than expected. The error may be in the file itself or in the initial year and number of years given in the physical data file.
  - ERROR: END OF EVAPORATION SERIES FILE  
End of the evaporation file has been reached sooner than expected. The error may be in the file itself or in the initial year and number of years given in the physical data file.
  - ERROR: INFLOWS: N° OF COLUMNS ??? EXCEEDS MAX. \$\$\$  
Number of columns in the inflows file exceeds the maximum permitted by the model.
  - EVAPORATION ERROR: N° OF COLUMNS ??? EXCEEDS MAX. \$\$\$  
Number of columns in the evaporation file exceeds the maximum permitted by the model.
  - READING ERROR IN FICTITIOUS COSTS FILE  
An error has occurred in the reading of the fictitious costs file. The file must be checked.
  - NO FEASIBLE SOLUTION IN SCHEME

In this case, no feasible solution can be found to solve monthly optimisation. The cause is probably due to an error in the user scheme, e.g. maximum channel limits that do not allow flood flow to be drained away.

The model then lists the year, month and iteration in which the error occurred.

- ERROR ON WRITING IN ECHO FILE OR RESULTS FILE. CHECK THAT NO OTHER APPLICATION HAS OPENED THE FILE.

The problem happens when the model is initiated and the user is writing in the data echo file when it has been opened by another application or by the interface. May also occur if any of these files are blocked by the “reading only” property, as happens when a copy is made directly from a CD.

- Other errors:

The running of the program may be interrupted and an error message may appear on the screen due to reasons such as:

- . uncontrolled releases
- . error in opening files
- . error in reading files
- . lack of space for writing results
- . insufficient memory to run the program

In general, these will be due to improper configuration of the hardware used or to defects in the construction of the data files.

If all these possibilities can be excluded after a thorough check, the user should then get in touch with the authors of the program.

## 10. INSTALLATION OF THE MODEL

The program can be executed by the Microsoft Windows 98, NT or 2000 operating systems. (Other versions are available for running on MSDOS or UNIX).

The installation requires a hard disk capacity of 30 Mb. Since large scale files may be stored on the hard disk (over 100 Mb) during simulations, if space is limited special care must be taken with the results options.

To install the program, simply copy it into the chosen hard disk directory. Operations are then similar to any other program in the Windows environment.

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