Software for a Saltworks' Yearly Production Cycle

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ABSTRACT

In solar saltworks, the annual production cycle is closely linked with weather conditions. In temperate climates, these conditions determine, in a more or less clear-cut way, two different periods, as follows:

- *An active period, when salt is being produced and harvested on the crystallizers*
- *A passive period, during which optimum conservation conditions must be maintained for the bitterns of various concentrations that remain after the end of the active period.*

Between these two periods, there are shorter, transient phases of activity when substantial movements of bitterns take place between the basins that make up the saltworks. All these elements of the annual operations cycle have been programmed for ELECTRONIC DATA PROCESSING. These programmes calculate, day by day and according to weather forecasts, the evolution of the various production parameters for each natural pond as well as for the whole complex.

The programmes include the following:

- *A SATUR (production of saturated brines) programme with an auxiliary DATREC (harvesting dates) programme covering the so-called active period and permanently providing operational schedules and production forecasts*
- *A HIVER (winter) programme which determines parameters evolution during the passive period*
- *An ETALE (conservation of bitterns) programme to cover the intermediate phases that separate the active from the passive period.*

Such programmes allow for permanent production management and also provide all types of forecasting possibilities based on advanced weather reports.

INTRODUCTION

The prevailing climate in the south of France does not allow salt to be produced throughout the whole year, as is often the case in different countries. The yearly cycle may be broken up into two periods:

1. *The rest period* (Wintering), characterised by unfavourable meteorological conditions (rainfall exceeding evaporation on brine). It extends from the beginning of October to the end of February.
2. *The production period*, from March to the end of September, when the evaporation is considerably in excess of rainfall. This excess is the key to production of sea salt.

A saltworks' layout may be roughly divided into two parts which relate to two different sorts of production:

The condensers, whose role is to supply the crystallizers with saturated brine according to their requirements

The crystallizers in which saturated brine precipitates under the form of crystallized salt.

In order to take the fullest advantage of the production period on the crystallizers it is necessary for saturated brine to be available for the whole period. Consequently, it is not sufficient to produce brine but also to ensure there is no need to wait for seawater to reach saturation, by, as far as possible, maintaining the concentrated solution from the previous cycle. In addition, during the production period, heavy rainfall which will upset the cycle may occur. It will be necessary to take rapid decisions to optimize the overall operations.

In order to satisfy these aims we have drawn up a series of computer programs, each of which relates to a phase of the yearly cycle. These use the computer language Fortran, and a conversational procedure has been adopted to allow decisions to be evaluated and taken on the basis of actual or forecast states, thanks to a dialogue with the computer. The data used in the various modules of these programs is mainly made up of the following parameters (Diagram I):

Daily average or forecast meteorological data (evaporation, rainfall)

Descriptive file of the different salt pans on the works (surface, depths)

Level of concentration and volumes at the beginning of *each basic period.* (This may be represented by a day or a series of consecutive days)

Functions for the evolution of the brine on the basis of the data for evaporation, rainfall and seepage.

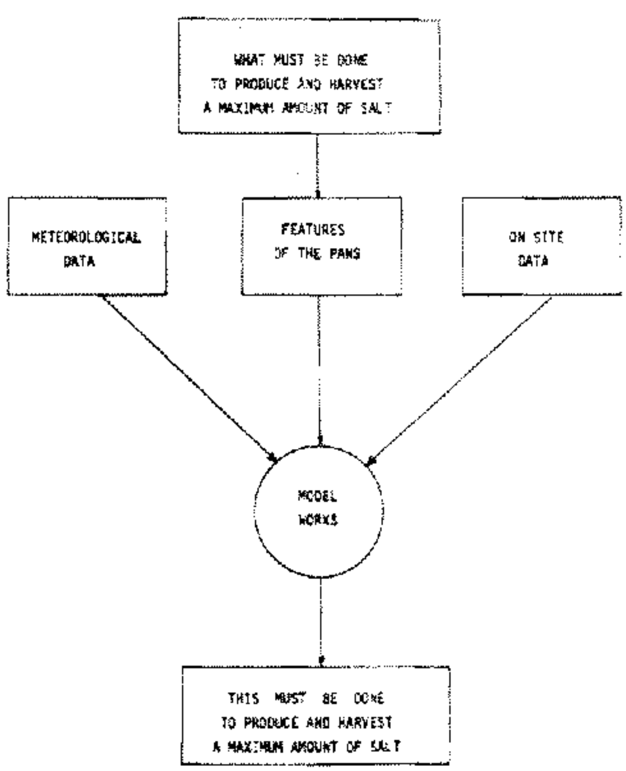
These functions, which were first worked out by Lambert (1923), have been added to and improved over the many years of production since then. The use of calculators has allowed them to be developed and commonly adopted. They now represent a coherent set that covers the whole process of transformation of seawater into salt.

It is clear that an extensive data bank is essential. Depending on the site, we are able to use daily meteorological data for forty to ninety year periods. If data is only available for a shorter period it is nevertheless possible to obtain average data together with the frequency range thanks to highly developed statistical methods.

We shall consider, in order, the three main programs which each covers a phase of the yearly cycle. These three main programs are known as: SATUR, DATREC and HIVER. SATUR and DATREC cover the production period and HIVER is only used for the rest period: winter.

When used together they allow on the spot decisions to be taken, short and medium term forecasts to be made, and the saltworks' production capacity to be studied.

DIAGRAM I



SATUR PROGRAM

(See Diagram II)

AT THE BEGINNING OF THE PRODUCTION PERIOD

Aim of the Program

Starting from the state at the end of winter, to obtain the time table for brine production which ensures optimum use of the crystallizers.

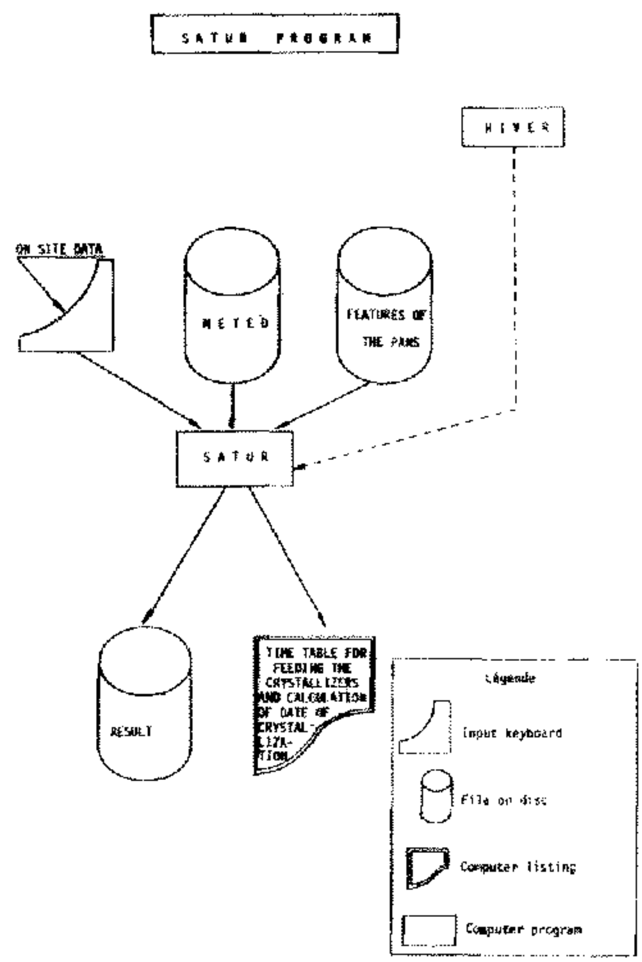
Principle

By comparing and adjusting the volumes, to choose the earliest date at which the crystallizers may start production (average data for salt making), provided that further feeding is ensured.

Method Adopted

Available volumes. On the basis of an initial state which is particular to each pan (volume, level of concentration), and in the case of a given meteorological series (average or

DIAGRAM II



specific) to calculate at which date the level of saturation is reached, and the volume of saturated brine thus obtained. By adding these data, it is possible to establish a time-table.

This result is reached by using formulae which take into account actual evaporation, impluvium (the rainfall catchment area), and seepage as well as the thickness of water flowing.

Requirements. We take into account, in terms of saturated brine:

- The initial volumes needed to fill the crystallisers
- Compensation for losses by seepage and evaporation
- Any additional volume for protection
- Removal of brine which contains too high a concentration of secondary salts

on successive days starting with the beginning of the production period.

At each date the sum of needs for the whole of the production period is compared to the schedule of available volumes. These allow the earliest possible definitions of the date for starting production per group of crystallizers as well as the calculation of the mean date for the total of the crystallizers.

DURING PRODUCTION

Feeding Period

The program may be used at any time while the crystallizers are being fed by replacing the average figures for climatological data with the actual figures. The time-table for starting production is thus up-dated.

After Heavy Rainfall

Such rainfall is quite infrequent but of a stormy character that may lead to heavy downpours. These are usually unequally spread over the surface of a saltworks when this covers a large area (for instance, more than 2.000 hectares). Thanks to the program, and by adopting as large an amount as possible of local data (rain gauge), it will be possible to find out within a very short time the new state of each pan. The data thus obtained regarding concentration will be more precise than that given by spot readings because of the time necessary for the rainfall and brine to mix and become homogeneous.

It may be necessary to redistribute the brine solution in order to maintain a logical sequence within the evaporative circuits; such a redistribution may be selected by simulation on an additional program which ensures that the consequent delays are minimized. The time-table for feeding the crystallizers will also be modified by the program, which will simulate the actual case and will show the surface of crystallizers with which it will be possible to maintain production with the new available brine volumes and concentrations.

PRACTICAL EXAMPLES

The Beginning of the Production Period

We shall consider the results of the charts in the order in which the computer prints out, on request, giving the results of the calculations.

The first printout gave the state of the pans: at the end of winter, with average weather conditions starting from March 31 and for a deadline by which the brine must have been redistributed; the volume of saturated brine for each pan, together with the date at which it becomes available. Calculations are based on average flow depth or one which is specific to each pan. For example, this chart shows that distribution from a particular pan should be started on March 31 when the initial volume is at a maximum of 356,575 and the initial concentration is at a maximum of 143.2 G/L.

The second printout gave the timetable for feeding the crystallizers. The information contained is:

- a detailed schedule for the feeding or compensating losses of thickness on the surfaces in question
- forecast average date for salt production
- forecast date on which bitterns (brines that contain more than 45 g per liter of Mg) may be drawn from the crystallizers. These brines may be used for the production of by-products, bromine, Mg and K salts.

The printout shows that salt production should begin on the 3rd of May and that the first draw off of bitterns should be on the 3rd of July.

Graph I, printed out by the computer, represents the accumulated comparison of the volumes of brine available (p) and those that are required (*).

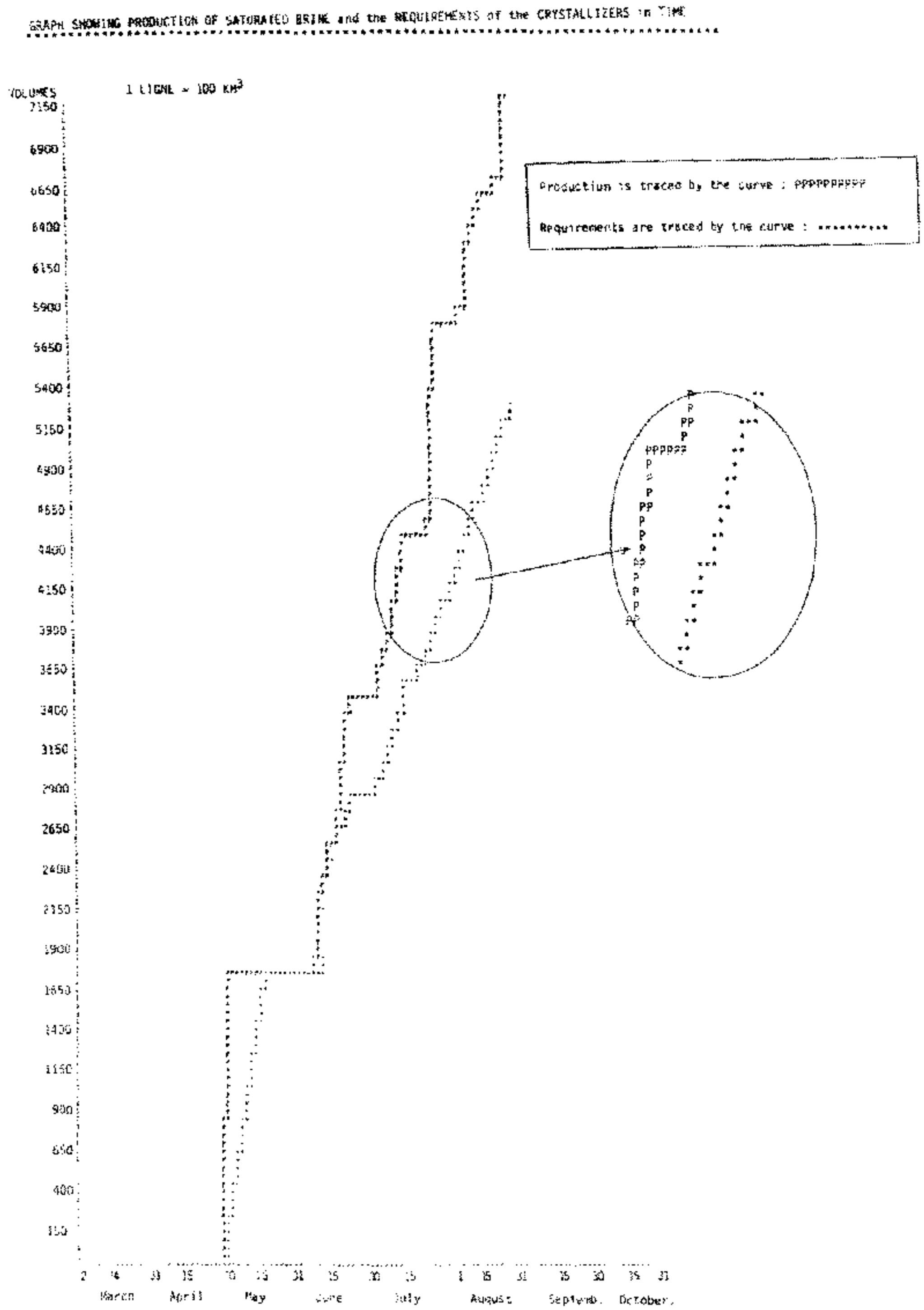
During the Production Period

Production periods may occasionally be subject to abnormal climatic conditions. Such was the case in 1977 in the south of France. Thanks to the SATUR program it was possible to rapidly take several important decisions relating to production of the Giraud saltworks.

State of the brines at the beginning of April. It was possible to cover 770 hectares of crystallizers at the beginning of May, adopting the 15th of May as the average date on which salt crystallization could begin.

State on the 15th of June. One hundred ninety-five mm of rain fell between the 1st of April and the 15th of June, whereas the normal average is 94 mm. This was compounded by a 54 mm short fall in evaporation during the same period. Production of the first saturated brine did not start until the 22nd of June, and it was possible to produce salt on only 725 hectares with a minimum thickness of 120 mm (Graph II). The printout for the 15th of June indicated the first salt would be produced on the 4th of July and that the first draw off of bitterns containing 45 g of Mg per liter would be on the 29th of September.

GRAPH 1



Later developments. Heavy rainfall continued throughout July reaching five to six times the average level. The program then indicated that assuming a thickness of 120 mm on the crystallizers there would be eleven days in August during which the link between requirements and the available saturated brine would not be ensured. Both the quality and quantity of the harvest were seriously threatened by this state of affairs.

The structure of the saltworks allowed two hypotheses to be considered, each involving planned reduction of the surface of the crystallizers:

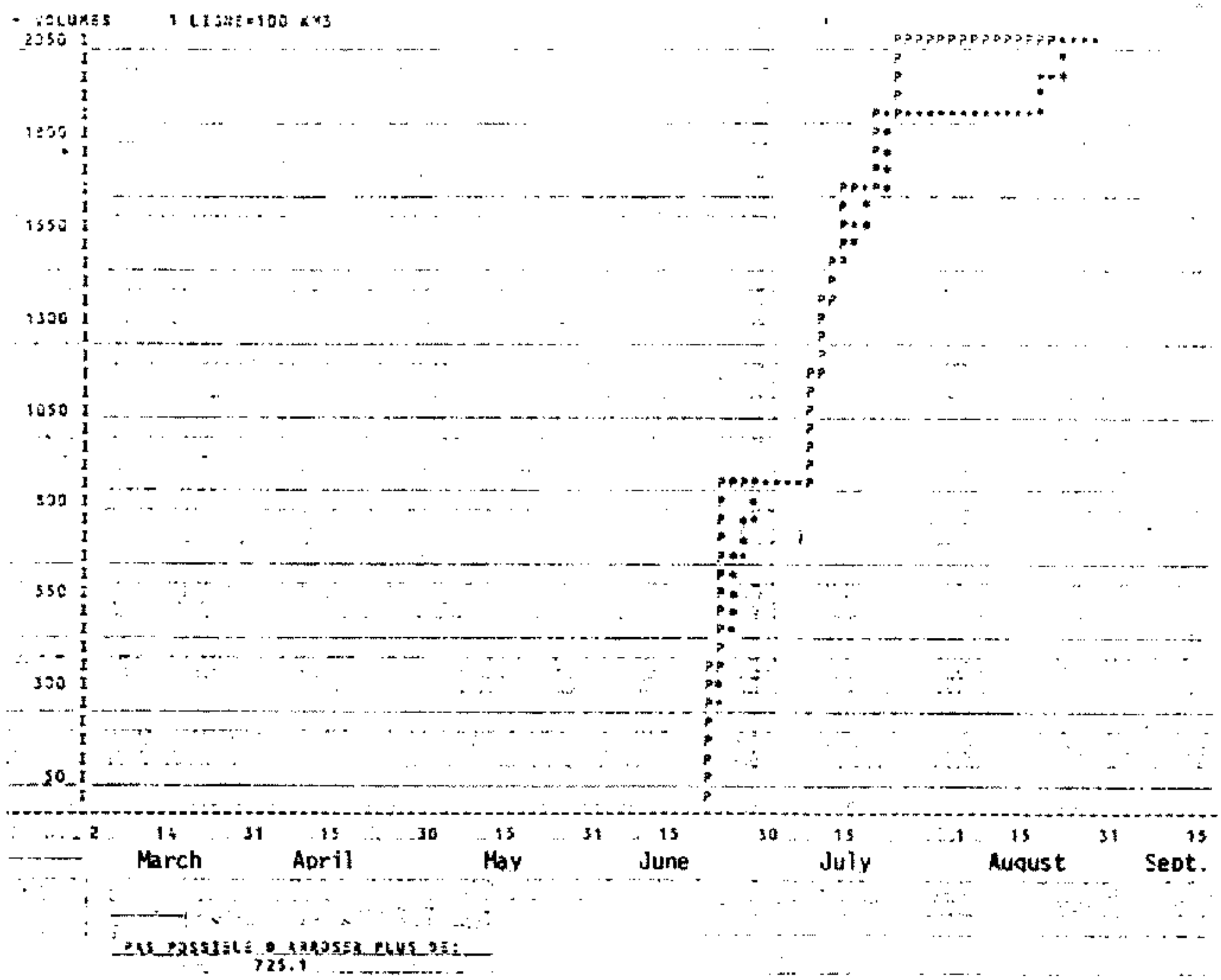
- reduction of 105 hectares leaving 620 hectares in production
- or reduction of 78 hectares leaving 647 hectares in production.

GRAPH 2

GRAPH SHOWING PRODUCTION OF SATURATED BRINE AND THE REQUIREMENTS OF THE CRYSTALLIZERS

PRODUCTION IS TRACED BY THE CURVE PPPPPPPP

REQUIREMENTS ARE TRACED BY THE CURVE *******



(Impossible to feed more than 725,1 hectares)

The surfaces thus removed from production would be used as condensers.

The program showed that the first hypothesis involved no risk for the harvest and that the second would lead to a drop in thickness from 120 to 100 mm. This second solution was chosen, as the element of risk was quite small. The printout for 31 July 1977 shows that this maximum production area was 639 hectares compared to 647 hectares actually used. These decisions were taken on the dates given. Later on, we were able, by introducing actual climatological data into the program, to confirm that the surfaces used in production corresponded, within 1%, to the quantities of available brines.

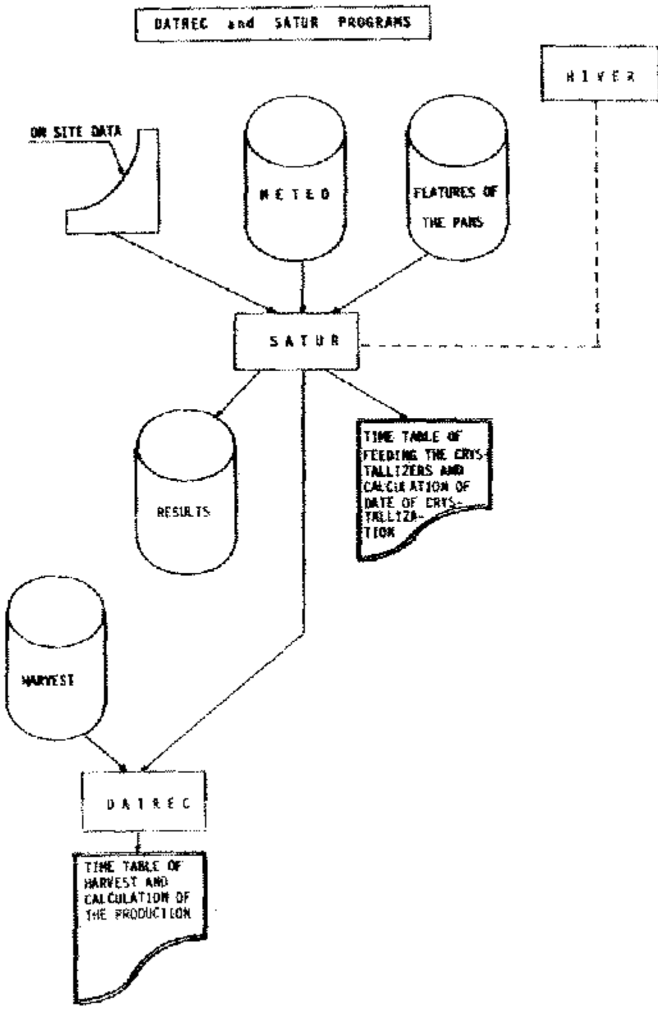
DATREC PROGRAM

(See Diagram III)

Aim of the Program

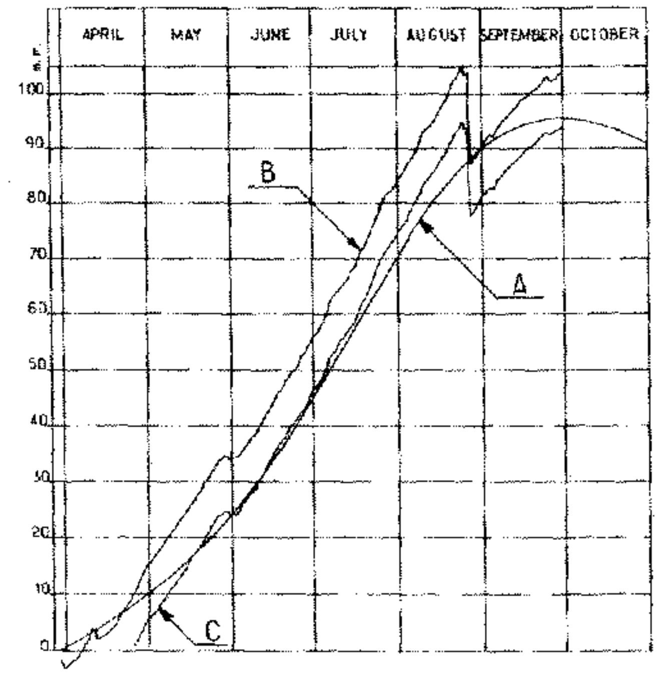
In saltworks which are not under permanent production, a period is set aside for salt harvesting in order to op-

DIAGRAM III



GRAPH 3

ACCUMULATED THICKNESS OF SALT



timize the annual tonnage harvested. In our case this period is toward the end of the production period and the beginning of the winter period. If we set out on a time chart the accumulated thickness of salt on the crystallizers after the average date for salt making, the curve will pass through quite a flat maximum point toward the end of September.

Graph 3 provides an example of the calendar graph employed, which presents several curves:

- average thickness of crystallized salt with point of crystallization on the first of April, on which the average date of crystallization begins. (curve A)
  This curve presents quite a flat maximum extending to the end of September and it is obvious that the furthest date for harvesting must cover this maximum period in order to take full advantage of it.
- annual thickness calculated on the assumption that crystallization begins on the 1st of April. This curve reflects climate conditions for this particular year, which may vary to a greater or lesser extent from average climatic conditions (curve B).
- curve showing thickness for the year whose starting point is the date on which crystallization has actually started, depending on other conditions than climatic ones. This is obtained by horizontal transposition of the preceding curve (curve C).

Harvesting needs time, and it would be preferable for this, to be contained within the period which corresponds to the curve's maximum; however, such a choice would entail the use of equipment on a large scale in order to harvest up to 100,000 tons per day over a surface of about 100 hectares. Economic calculations have shown that it was better to accept a slight reduction in the tonnage harvested and to adopt equipment at a size of about a quarter of that mentioned above, thus extending the harvest period. Therefore, it is necessary that the date on which harvesting starts be established exactly, taking into account the average weather conditions, the means available for harvesting and any other constraints such as

- not beginning before such a date
- finishing at the latest on . . .

Such is the aim of the DATREC PROGRAM.

Principle

The aim is to calculate by simulation the tonnage harvested on the basis of selected dates for the harvest beginning, starting from the earliest date possible (e.g. on the 15th August). Obviously for each sequence, the calculation takes into account the meteorological conditions affecting it—average or specific forecast figures. The rate of harvesting—daily surface or tonnage—is taken into account through the output of the machines and the thickness to be harvested. By comparing the sequences, it is possible to choose that plan which gives the optimum tonnage or otherwise to find out the average tonnage lost if we deviate from the optimum date.

Method Adopted

If we assume that the average date for salt production is to be the 31st of October, the program works out, on a daily basis, the thickness of salt deposited on the crystallizers and the total thickness; these are provided by an experimental formula which is particular to each saltworks and which takes into account evaporation, rainfall and specific features of the works:

Salin de Giraud

$$e = 0.103\ E - 0.198\ P$$

in which:

- e = thickness of salt in millimeters
- E = Evaporation over fresh water in millimeters during the production period
- P = Rainfall in millimeters for the same period.

Then it carries out as many simulations as there are days in which it is possible to start harvesting, each of these simulations provides a tonnage harvested depending on the date adopted. In practice the first date adopted for the calculation is the 15th of August.

Example

In the 1981 harvesting schedule for the Salin de Giraud, the printout indicates the optimum date for starting the harvest was the 30th of August, that the harvest should end on the 1st of October, that the total tonnage available for sale was 877,137.1 tons and that the surface harvested per day would be 23.32 HA.

Optimization of the Harvest

If as in the example, we are not subject to any specific date for finishing the harvest, it is possible to obtain an optimization of the harvest period, which follows the available average meteorological data. In retrospect, if we know the actual climatological data and the average date on which salt making may begin, it is possible to work out the optimum period for the year in question. The results of this simulation for 1969 to 1975 indicate that the harvest would begin between the 15th August and the 24th September, and end between 20th September and 31st October.

The calculation has been worked out for years between 1889 and 1980. We thus work out the date for the start of harvest which, if adopted would have allowed the production for this whole period to be greatest. This date is the 12th September. If we had always started on this date, we would have lost 37,000 tons per year in comparison with the maximum tonnages which it would have been possible to harvest if we have known the optimum date each year. Graph 4, drawn by the computer, shows the tonnage that

GRAPH 4

SUM of LOSSES for HARVESTING STARTING on DIFFERENT DATES

was thus lost by systematically beginning on dates between the 15th of August and 30th of September. If we were to begin on the 30th of August each year we would lose 51,000 tons, but if we were to begin on the 25th of September, there would be a loss of 82,000 tons in comparison with the harvest started on the optimal date each year. In a certain sense, we could say that such losses forecast the cost of inaccurate meteorological data.

Salt-making tradition generally required harvesting to be over by the September equinox, on which date heavy storms often occur. Simulation using DATREC showed that on average it was better not to follow the tradition but to delay considerably the beginning of the harvest. Nevertheless this overall improvement is not without an increase in the risk of being "ruined," as is shown in the following chart for production in August, September and October of average, minimum and maximum thickness of crystallized salt.

Thickness of salt deposit mm	August	September	October
Minimum	5	−16	−54
Average	17.7	5	−12
Maximum	28	17	14

It is understandable that the systematic adoption of the 12th of September as a date for starting a harvest, which will then end in October, will in certain years lead to considerable losses in the portion harvested in October. Adopting such a practice will consequently require a large buffer stock to be maintained. If the reliability of medium range weather forecast (2 or 3 months) were to improve it, it is obvious that we would be able to work out the ideal period for harvest each year, and thus gain on average, the 37,000 tons per year mentioned above.

HIVER PROGRAM

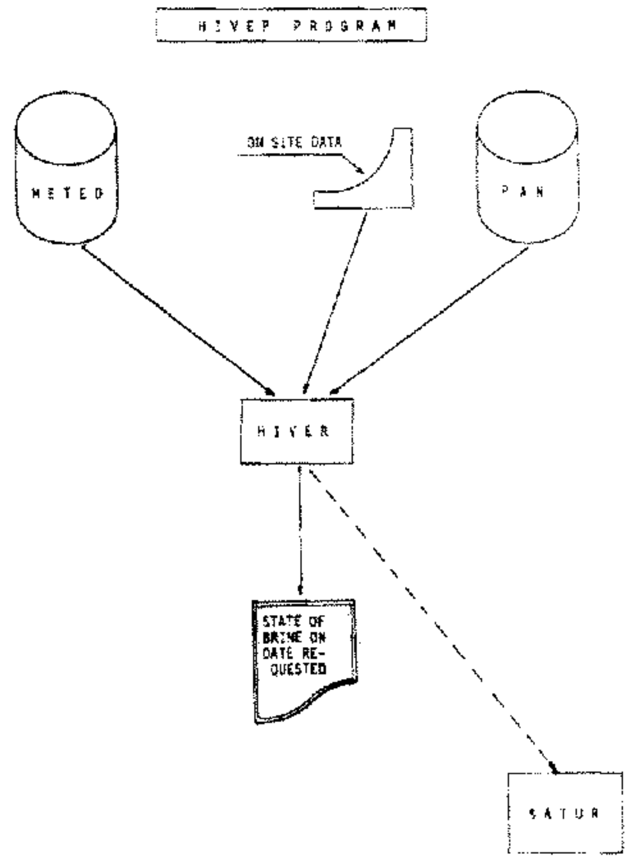
(See Diagram IV)

Aims

At the end of the production period, the brines from the condensers are stored on the different pans awaiting the next year. Residual brines from the crystallizers may be added to them. These include unused brines and brines from washing the floor of the crystallizers, depending on their respective levels of concentration. Because of the variability in rainfall that may occur during winter, it may be necessary to reorganize the distribution of brines and even to pump out to sea those brines that have become too diluted.

The HIVER program has been written to manage such a situation and to indicate the necessary operation. Because of the relative slowness with which the rain and the brine mix, it allows us, by the use of simple calculations, to find out more quickly the result of the evolution of each

DIAGRAM IV



pan and to decide immediately which operations are necessary.

This program also satisfies other aims such as

- The need to calculate volumes of the storage pans, their depth and the height of the surrounding dikes or embankment
- The need to select storage methods which ensure the best possible protection of the concentration of the

CHART I

	Figures	Volumes m3	Tonnage T	Potential Te m3
From 04/10 to 3/11	Theoretical	20 753 900	2 654 365	70 637 200
	Actual	21 579 000	2 645 640	69 616 000
From 20/10 to 1/12	Theoretical	22 416 100	2 611 290	67 193 100
	Actual	24 376 000	2 731 770	69 421 000
From 05/10 to 29/12	Theoretical	22 070 500	2 524 290	64 325 959
	Actual	25 452 000	2 582 000	61 552 000
From 26/10 to 28/01	Theoretical	22 736 900	2 554 990	64 753 400
	Actual	26 384 000	2 666 650	65 557 000
From 06/10 to 23/02	Theoretical	23 566 600	2 545 416	65 542 900
	Actual	25 009 000	2 636 100	65 652 000

CHART II

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---> EVOL. WITHOUT SALT                                    - 23 -

NUM = 69    NAME = JEUX DU COQUILLER

                    SURF.  =     39.35
                    VOL.   =     31190.
                    CONC.  =     77.39
                    G.T.   =     6253
                    TE.    =     134637
                    VOL.SALT  =     0.
                    DEPTH SALT =    0.00

---> EVOL. WITHOUT SALT

NUM = 70    NAME = COULOIR DES CUVETTES

                    SURF.  =     20.00
                    VOL.   =     56315.
                    CONC.  =     139.57
                    G.T.   =     7316
                    TE.    =     213592
                    VOL. SALT  =     0.
                    DEPTH SALT =    0.00

---> EVOL.WITHOUT SALT

NUM = 71    NAME = CUVETTES

                    SURF.  =     61.00
                    VOL.   =     437937.
                    CONC.  =     196.79
                    G.T.   =     50279
                    TE.    =     2360316
                    VOL.SALT  =     0.
                    DEPTH SALT =    0.00

---> EVOL. WITH SALT

NUM = 73    NAME = ETANS FARAMAN 6

                    SURF.  =     50.00
                    VOL.   =     212780.
                    CONC.  =     277.33
                    G.T.   =     106568
                    TE.    =     3134530
                    VOL. SALT =     28810.
                    DEPTH SALT =    57.62

---> EVOL WITH SALT

NUM = 74    NAME = ETANG FARAMAN 2

                    SURF.  =     43.00
                    VOL.   =     236167.
                    CONC.  =     273.30
                    G.T.   =     111037
                    TE.    =     3356379
                    VOL. SALT  =     27840.
                    DEPTH SALT =    64.74
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brines. For the evaluation of these concentrations we use the term of potential which is the result of multiplying the volume of each particular brine by the increase in concentration achieved in comparison to its concentration at the intake. It is easy to prove that this figure is more or less equivalent to the volume of water which it has been necessary to evaporate to reach these concentrations. This parameter—Te—evaporated tons, will be used to represent the potential of the brines.

Principles and Method of Calculation

On the basis of an initial state—the beginning of winter—and by the adoption of basic formulae which integrate evaporation, rainfall and seepage, we obtain the end state at any moment during winter. For the period in question, the program calculates the final state of the pan (or group of pans), taking into account the above factors and the area/volume ratio of this pan. The pans are divided into two main groups, those which have salt deposits and those which have no salt deposits.

During their evolution, some pans change from the first to the second group. Some of them may also dry out through evaporation. The salt which is thus deposited would be taken into account by the program once it has been transformed into brine by rainfall. Some pans dry out through seepage. In these cases the brine and the salt are subtracted from the calculation. Finally, if the level of concentration of a pan becomes lower than that of the sea as a result of rainfall, the volume in question is subtracted from the calculation (pumped out into the sea).

Example

This recently written program has been used at the Salin de Giraud since the winter of 1980/1981. Chart VI sets out the state for different periods of this winter between the 6th of October 1980 and the 29th of February 1981. Extracts from print-outs show the kind of data obtained. An example is given by Chart VII. It provides, for each pan, the physical state of the brine contained, with or without a deposit of solid salt. In addition, any volumes which may be pumped back into the sea are indicated.

The close correspondence between theoretical figures and the actual figures for the 21st of February 1981 is noted. In particular, the variation between the volumes stored is made up of brines at a level of concentration of 26.2 g/l. As we pointed out earlier, the program systematically eliminated those brines that are useless. The actual pumping operation has yet to be carried out.

Link Up Between HIVER and SATUR Programs

The HIVER program was retrospectively applied to the winter of 1979, starting on the 1st of January. The state obtained for the beginning of April was adopted by the SATUR program and the calculation continued—with real meteorological data—up to the harvest of 1979. The actual harvest was 1,150,000 tons. The programs' forecast 1,177,000 tons. The gap is about 2%.

CONCLUSION

The confirmation provided by the low variation between the results given by the programs and actual results allows them to be adopted for managing the production of the saltworks under the best possible conditions, taking into account all the parameters involved, the most important of which, climatology, is known for its unpredictable nature. Such a model may be used in other fields subject to similar unforeseeable factors. For example, this program may be employed for the management of water resources for irrigation or hydroelectric purposes, calculation of the number of harvesters in agriculture, sewage settling ponds, etc.

Each year, an additional production cycle contributes to further information, which allows us to perfect the programs and thus aims at greater economic efficiency in our management for which optimization of harvest is clearly the fundamental factor.