# SOLAR SALTWORKS' WETLAND FUNCTION

NICHOLAS A. KOROVESSIS[1], THEMISTOKLES D. LEKKAS[2]

[1]Hellenic Saltworks S.A., Asklipiou 1 str., 10679 Athens, Greece

[2]Dept. of Environmental Studies, University of the Aegean, 81100 Mytilini, Greece

**e-mail: nkor@hol.gr**

## ABSTRACT

Salt is the world's best-known mineral. Apart from its significance for the creation of life on the planet it is the chemical substance most related to human civilization history.

Man produces salt by solar evaporation since the dawn of human civilization. Nevertheless, recognition of the unique coastal ecosystems that developed in parallel with the Solar Saltworks production process evolution is often lacking. The basic steps of that process, which as it is shown, has actually transformed Solar Saltworks into saline coastal ecosystems are identified and analyzed.

Coastal saline wetlands are compared with Solar Saltworks ecosystem. We emphasize on the case of "Aliki" lake, a natural saline coastal wetland located in Lemnos, a North Aegean Island in Greece. It is shown that if a Solar Saltworks is constructed in the area of "Aliki" lake, an upgraded and more stable ecosystem will be created, where both the population and the encountered bird species will be increased significantly!

The environmental uniqueness of Solar Saltworks, particularly current operations, is based on the fact that they are steady state, constructed coastal ecosystems, where regular and hyper saline environments coexist and establish high significant shelters for wildlife.

**Keywords:** Solar salt, solar saltworks, production process, biological process, salinas, wetlands, Lemnos, Aliki Lake.

## *INTRODUCTION*

It is common knowledge that life began in the oceans, where the first monocellular organisms were created. Even the creatures that after a long evolutionary process left their marine environment are continued being dependent on salt. Nowadays, we know that sodium chloride is the basic extra-cellular electrolyte of the human body and that the salinity levels of the environment where human foetuses develop are similar to those of the sea!

Salt has remained a necessary element for the survival and proliferation of the herbivorous animals, which take the necessary quantity of salt by licking the salty soil and also for carnivorous ones, which ensure the necessary intake of salt from the blood of their prey (Young 1977).

Salt, the common name for the compound of sodium ($Na^+$) and chloride ($Cl^-$), is the first substance after water to have attracted humans' attention in their evolution from wilderness to civilisation. Salt along with water, cereals (bread) and the meat of domestic animals constituted the staple basis of human society in its infancy. The time when humans began engaging in farming activities and became settlers coincides with **their search for salt**, which is provided by nature in abundance. (Baas-Becking 1931).

Initially, salt was used to cater for the needs of human diet and later its significant food preserving property was discovered. This particular property made salt one of the most important commodities for centuries, comparable to the importance of oil in our times.

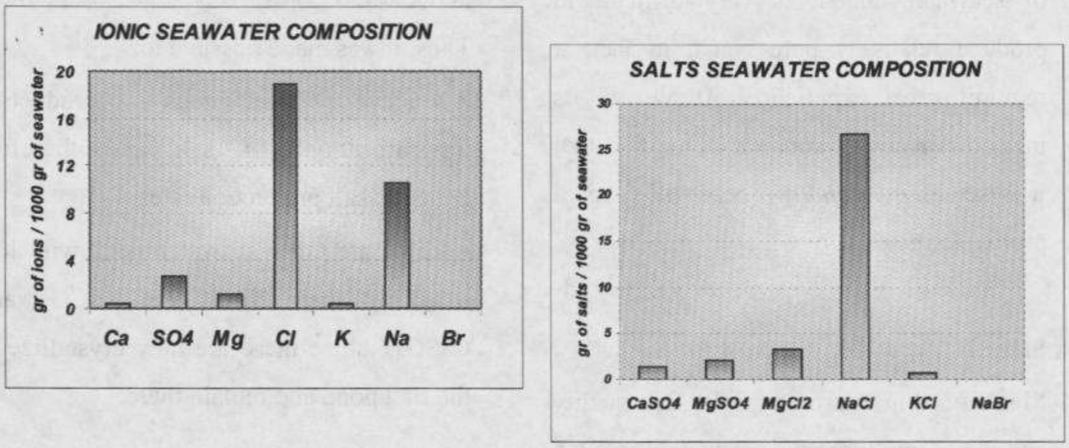
Although the industrial revolution resulted in a gradual decline of the use of salt as food preservative, people's needs did not follow the same trend. The extensive use of sodium chloride as raw material in the chemical industry have increased salt consumption worldwide, with annual figures reaching 200 million tonnes nowadays. One third of this is produced in Solar Saltworks. About 20% of the international salt production is destined for human consumption, whereas 55% is used in the chemical industry and 15% for de-icing roads in winter.

It is worth to mention that the root of salt derives from the Latin word ***sal***, which derives from the Greek words □λς (sea) and □λας (salt). The initial letter ***s*** in the Latin word derives from the early Greek whereby the words for salt and sea started with an *s* too. Later, in ancient Greek, this ***s*** was dropped and was replaced by the breathing ‘. (Korovessis & Lekkas, 2000).

## *SOLAR SALTWORKS PRODUCTION PROCESS*

### a. Salt recovery from seawater

Solar Salt (NaCl) is recovered from seawater by solar evaporation. Production of salt from seawater involves the selective recovery of pure NaCl, free of other soluble or non-soluble salts or other substances. Solar evaporation of an appropriate quantity of seawater leads to the fractional crystallization of all salts contained; a process based on their varying solubility. Initially the less soluble salts of $CaCO_3$ and $CaSO_4$ are crystallizing and separate from the brine, then NaCl and finally Magnesium salts.




(a) (b)

**Figure 1. Indicative ionic (a) and salts (b) sea water composition (Bassegio, 1974)**

Solar saltworkers use the empirical Baume scale (°Be) to measure the brine concentration. According to that scale the seawater salinity is approx. 3.5 °Be, the crystallization of $CaCO_3$ begins at 4.6 °Be and that of $CaSO_4$ at 13.2 °Be. NaCl crystallizes at 25.7 °Be and the more soluble Mg salts at 30 °Be.

**b. Solar Saltworks production process evolution**

It has been already mentioned that when humans start searching for salt they must have found it specific places where it is produced by nature in abundance. Such places are coastal concavities, lagoons or lakes where seawater is trapped, evaporated in the sun and deposited its salt content.

**Stage I**

It can be reasonably deduced that, after a long period of observation and knowledge-building, humans eventually copied nature and began producing salt by evaporating sea water in single ponds such as coastal concavities, lagoons etc. We identify that as the ***first stage (STAGE I) of solar salt production process*** hereby described (Figure 2). Man should have made his first step in salt production process when the quantity of naturally produced salt was not enough to satisfy his needs. Producing salt in single ponds actually allowed humans to produce it in quantities meeting their personal and social needs, moving away from nature's production rates.

Although with this method one can produce high quality salt on the surface of the brine, it has certain disadvantages since the salt that precipitates contains all the ingredients of seawater and it is very difficult to produce relatively pure NaCl, in fact, it requires great experience. Above all, its main disadvantage consists in the fact that it is actually a ***batch process*** with limited production rates.

**Stage II**

Man's need in improving Solar Salt quality and increasing more the production rate led him to the second step in its production process. That step must have been made by the division of the single evaporation pond into two (Figure 2, STAGE II). The first pond, usually called nurse pond (or evaporation pond), was used for the production of saturated (with respect to NaCl) brine, which was fed into the second pond, usually called crystallizer (or pan).

Thus, it was made possible to:

- Achieve continuous production (crystallization) of salt and therefore unbound salt production rate.
- Eliminate those seawater salts, with less solubility than NaCl (i.e. $CaCO_3$ and $CaSO_4$), since these are now crystallize in the first pond and remain there.

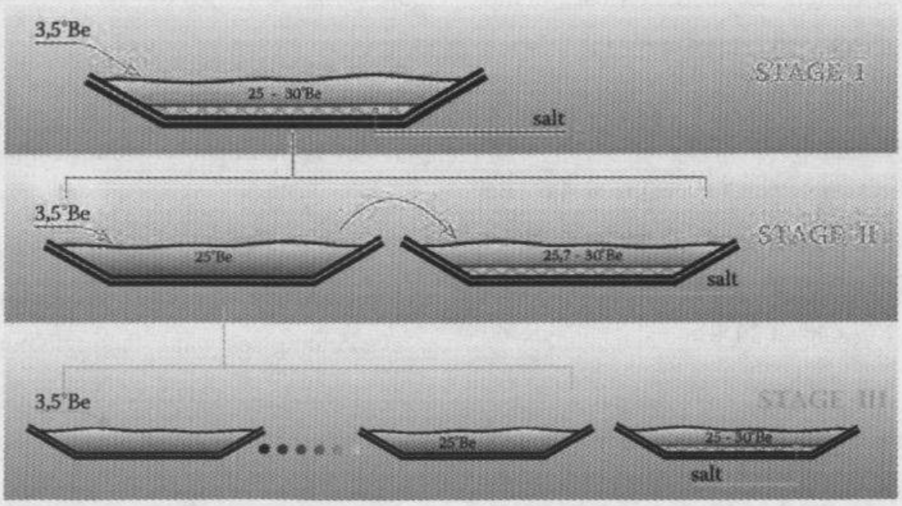



**Figure 2. Main stages in Solar Saltworks production process evolution.**

**Stage III**

The third step was made to improve even more salt quality and production rate and actually lead us to the operating design scheme of current Solar Saltworks. That step concerned the division of the nurse pond into several interconnected ponds. Solar Saltworks have now become a system of interconnecting ponds where the seawater enters the first pond and, as it flows through the next ponds and evaporates in the sun, its concentration increases. Thus, by the time it reaches the last pond, which has now become the nursing pond, it has a concentration of 25.7 °Be, corresponding to the saturated (in terms of NaCl) brine that is used to feed the crystallizers.

With this process one can achieve optimum Solar Salt quality and production rates because we are able to:

- Control better both the brine's concentration and quantity which is fed through the pond system, thus resulting in optimized and steady conditions in every pond and especially in the crystallizers where salt crystallizes and
- Increase further the salt production rate because the average brine concentration in the pond system decreases drastically compared with STAGE II – it is known that the evaporation rate increases as the brine salinity decreases.

These three stages constitute man's basic steps towards improving Solar Salt Producing Technology. Unfortunately, there are no data or information available confirming the time when the aforementioned production methods were first used, although it is certain that it has not been a uniform process throughout the world. The fact that all stages described above are still alive even nowadays is impressive. In Greece, for instance, the Saltworks on the Island of Kythera still produce salt in concave rocks by the sea.

**c. Important remarks**

**It is important at this point to observe that, moving from STAGE I to STAGE III, we have actually transformed a <u>transient process</u> to a <u>steady state one</u>.**

In the single pond case (STAGE I) the salinity gradient changes with respect to time, whereas in the multiple pond case (STAGE III) every pond has constant salinity; it changes only with respect to area (from the first pond to crystallizers). That means that whatever takes place in STAGE I through a certain period of time in terms of physical and biological processes, in STAGE III it occurs at any moment of that period. In other words every pond of STAGE III is a live phase (a picture) of STAGE I and, most important, they are steady in time because every pond has more or less fixed salinity. **Obviously the multiple pond system constitutes a more manageable, stable and integrated system than the single pond case.**

**d. Current Solar Saltworks production process**

The ***operation principle*** of current Solar Saltworks is basically the one described as STAGE III (fig. 2,3). That is actually the process that current Solar Saltworks use to recover salt from seawater, although there have been improvements and variations, allowing for the production of some hundred to some million tonnes of salt, depending on the size and the microclimate of the area in use. The only differences that have occurred, since the method was first applied, concern its optimisation as well as the means by which brine is transferred and salt is harvested, resulting from subsequent technological progress.

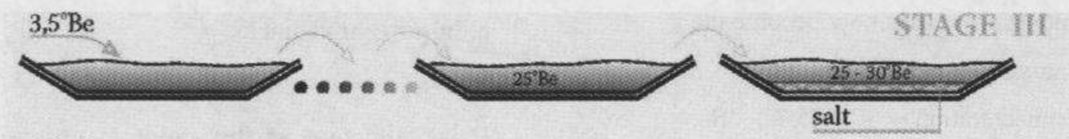



**Figure 3. Current Solar Saltworks production process scheme**

Modern Solar Saltworks are specially designed according to their area characteristics and the prevailing weather conditions. They consist of a system of shallow ponds (15-60 cm deep), connected mainly in series. Those ponds are divided into two basic groups. The first group, usually called ***evaporation ponds***, is used to concentrate seawater up to saturation salinity with respect to NaCl (25.7 °Be). Their bottom is totally natural without any intervention and has the appropriate clay composition to ensure very low water permeability. A salinity (salt concentration) vector is created throughout the pond system with a simultaneous and continuous reduction of the seawater volume that initially entered the first pond. Almost 90% of the water content of seawater has to evaporate in order to reach saturation point and salt crystallization salinity. As a result **the total area of the first group of ponds, that is the evaporation pond's area, in every solar saltworks, covers almost 90% of their total production area.** The evaporation ponds' brine salinity covers the whole range from 3.8 °Be (almost seawater) to 25.7 °Be, corresponding to the last pond which continuously feeds the crystallizers with the required saturated brine (nurse pond).

The second group, called ***crystallizers or pans***, consists of the ponds where salt crystallizes via further evaporation of the brine up to 28-29 °Be. These ponds are specially designed and have their bottom levelled and concentrated, aiming to facilitate and optimise mechanical salt harvesting. Crystallizers take up the remaining **10%** of the production area. That constitutes the ***physical process*** of solar salt production.

Surprisingly enough, despite rising salinity, life in the ponds does not stop. Seawater organisms gradually disappear as they move from the initial pond to the hostile environment of the others. However, other organisms develop in their place and, as there is no competition, they proliferate. Such large populations are able to survive in areas with different salinity levels (that is, in different ponds) because of their varying sensitivity to the ion composition of the medium they inhabit (Davis, 1974). Thus, in parallel with the physical process, a chain of organisms is developed in the evaporating ponds system both in planktonic and benthic communities, similar to those of naturally saline or hyper saline coastal ecosystems, constituting the ***biological process*** of Solar Salt production process. That process depends directly on the following parameters (Davis, 1980, McArthur, 1980):

- The quality of feeding seawater,
- The prevailing conditions in the ponds, such as, brine temperature, depth, turbidity and salinity,
- The control of the physicochemical process during salt production and
- The overall design of the Saltworks.

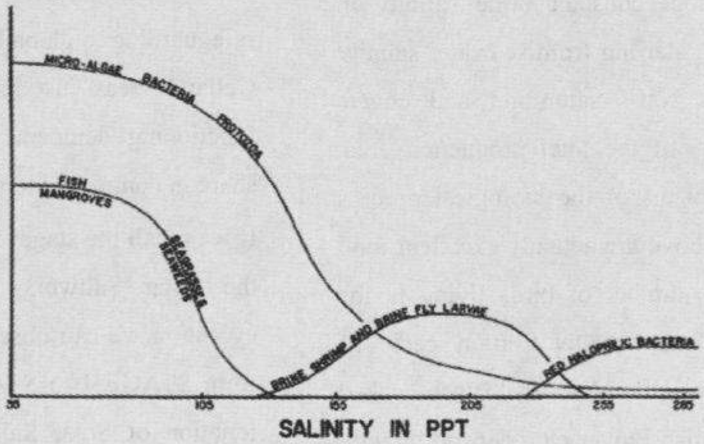



**Figure 4. Rough estimate of principal organisms in Solar Saltworks (Davis, 1993)**

The biological process interacts with the physicochemical process and it is in admirable harmony with the production process (Davis, 1980):

- It produces the appropriate quantity of organic matter, which is a source of energy for the various organisms, and reduces the permeability of the bottom of the ponds, thus minimising brine losses, particularly at low concentrations,
- It colours red the concentrated brines in the crystallizers thus, eliminating solar radiation reflection from the white salt bed.
- Finally it creates and maintains the appropriate conditions especially in the crystallizers for high quality salt production.

The ***optimal operation of Solar Saltworks is impossible without maintaining at their pond system a healthy and stable ecosystem*** (Davis, 1993). Comparing modern with traditional Solar Saltworks, whose operation is fragmentary with negligent brine flow control, we end up with the surprising paradox that ***modern Solar Saltworks are better and more stable ecosystems than the traditional ones!***

**e. Wetland function**

The biological process that develops in the evaporation pond system of Solar Saltworks actually transforms them into integrated coastal ecosystems. That interconnected ponds system has an increasing but constant brine salinity in every pond, starting from seawater salinity up to that NaCl saturation and covers almost 90% of the total production area. Basic organisms of the biological process described above are actually excellent food for a large number of birds living in the Saltworks for this matter. Certain species of birds, especially Avocet, Black-necked Grebe, Kentish Plover etc., depend directly on Saltworks productivity since their diet is exclusively based on Artemia salina. Artemia is also part of the diet of the beautiful flamingos and it colours orange their feathers. More than 100 species of birds have been observed in every Solar Saltworks in Greece (188 in Kitros Saltworks in 1990). Many of them are protected by Greek, European or International conventions.

Solar Saltworks in parallel with their main objective that is to produce salt, they additionally function as wetlands and contribute to the conservation of the environment, which is highly valued in our times. They offer their share in safeguarding globally the remaining wetland areas just as citizens in a well functioning democracy should offer their share in common interest.

If we recall the stages we have identified in the Solar Saltworks production process evolution we can observe that as we move from STAGE I to STAGE III the wetland function of Solar Saltworks emerges and becomes more and more stable (Figure 5).

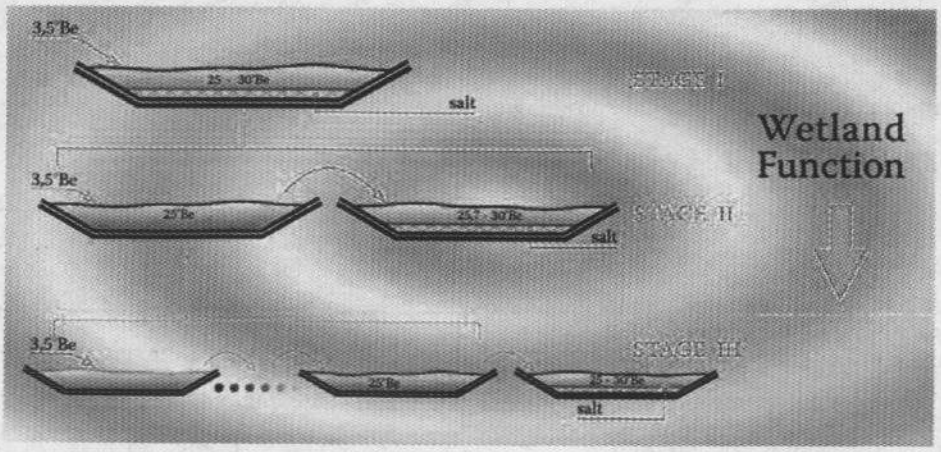


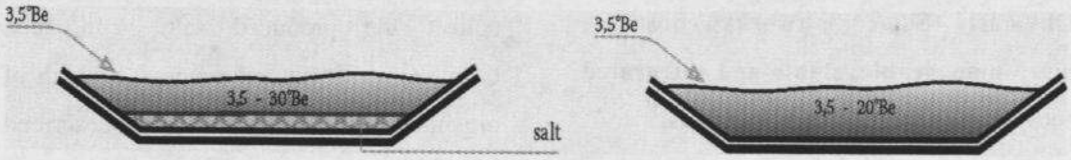

**Figure 5. Solar Saltworks wetland function**

This is true because the biological process that develops in Stage I, is a transient one, thus changing in time and unstable. We have shown that as we move from STAGE I to STAGE III, that process becomes steady state and multipond system with increasing brine salinity starting from that of seawater up to over saturated brines, thus resulting in an integrated and steady ecosystem.

Solar Saltworks are also unique in terms of their architecture. As they optimize their production process they develop a better ecosystem which ensures optimum product quality and production rate!

***COASTAL WETLANDS vs. Current SOLAR SALTWORKS***

**Natural coastal wetlands** are single pond, transient processes and their operating scheme is similar to the first stage of the Solar Saltworks production process evolution (fig. 2, STAGE I). They are fed with seawater only by the action of sea tidal waves and their salinity increases due to the prevailing higher evaporation rates than the open sea. We can distinguish two general cases of shallow natural coastal wetlands. Those with special hydro-geological conditions where seawater is trapped and establish a salinity gradient that reaches salt crystallization point (fig. 6 case a) and those with freely entering seawater where the salinity gradient never reaches salt crystallization point (fig. 6 case b). Case (a) wetlands produce naturally salt similar to STAGE I Solar Saltworks and may undergo a dry period without any wetland function.




Case a. Trapped seawater    Case b. Freely entering seawater

**Figure 6. Coastal Wetlands operating scheme**

**Solar Saltworks'** pond system is continuously fed with seawater during the production period. The seawater inflow rate is controlled either by wooden gates, if we take advantage of the sea tidal waves, or by using axial flow pumps. They operate through the whole year without any dry period. Even in the case of seasonal Saltworks the evaporation ponds never dry out, if during the seized period care is being taken from salt workers to feed every pond with the proper amount of brine in order to retain the ecosystem in function. The difference with the operating period however relies in the fact that there is no brine circulation and that brine salinity never reaches saturation point.

**Important remarks**

Natural coastal Wetlands and Solar Saltworks develop similar biological processes. Their differences derive from the fact that they have different operation scheme that as it has been shown it is in favour of Solar Saltworks. Wetlands are single pond transient processes whereas Solar Saltworks are multipond steady state ones. Similarly with our remarks on Solar Saltworks production process evolution, all phases of coastal wetlands (STAGE I) through a whole year are present at any moment in Solar Saltworks (STAGE III) and spread to their production area. In other words every pond of Solar Saltworks is a picture of coastal wetlands in terms of physical and biological processes. Additionally Solar Saltworks salinity gradient covers the whole range from seawater up to over saturated brines. **Obviously Solar Saltworks constitute more manageable, stable and integrated ecosystems than Coastal Wetlands!**

Important differences that are also in favour of Solar Saltworks are also the following:

- In solar Saltworks dikes, birds can find more area for nesting
- Small birds find more area with shallow waters where they can feed, comparing with the case of one big lake
- Salt is produced only in the 10% of the total production area whereas in natural saline wetlands covers the whole area
- Saltworks are free of any chemical substances (fertilisers, etc), which the inflow rainwater conveys into the Coastal Wetlands from the surrounding area.

***LEMNOS Solar Saltworks PROJECT***

"Aliki" is a natural coastal lake with 6,300,000 $m^2$ area, located in the Island of Lemnos in Northern Aegean Sea of Greece. Its operation scheme is similar to those of figure 6 case (a) wetlands. The seawater is allowed to flow freely into the area and then under the prevailing hydro-geological conditions it is trapped into the lake. With the influence of the local microclimate, which is highly conducive to evaporation, the trapped quantity of seawater constantly condenses until salt is finally produced without any human intervention. The crystallization of salt usually starts in June and finishes by the end of July every year. In early August the lake usually "dries up" of brine and the whole phenomenon repeats itself the following winter. During the dry period people can walk in the lake and collect the produced salt. In fact, throughout this natural process, a chain of organisms similar to the one described above develops and dies every year, constituting the biological system of the lake.

HELLENIC SALTWORKS S.A. was planning to construct a new Solar Saltworks in 'Aliki' Lake with a preliminary design shown in fig. 7. The new investment was going to cover the country's needs in salt and offer jobs to local people taking into account that the unemployment in the Island is high. According to our study the construction of a Solar Saltwork in the area of "Aliki" lake will create a steady state pond system (fig. 7) with salinity gradient starting from almost seawater up to oversaturated brine that will never undergoes a dry period.

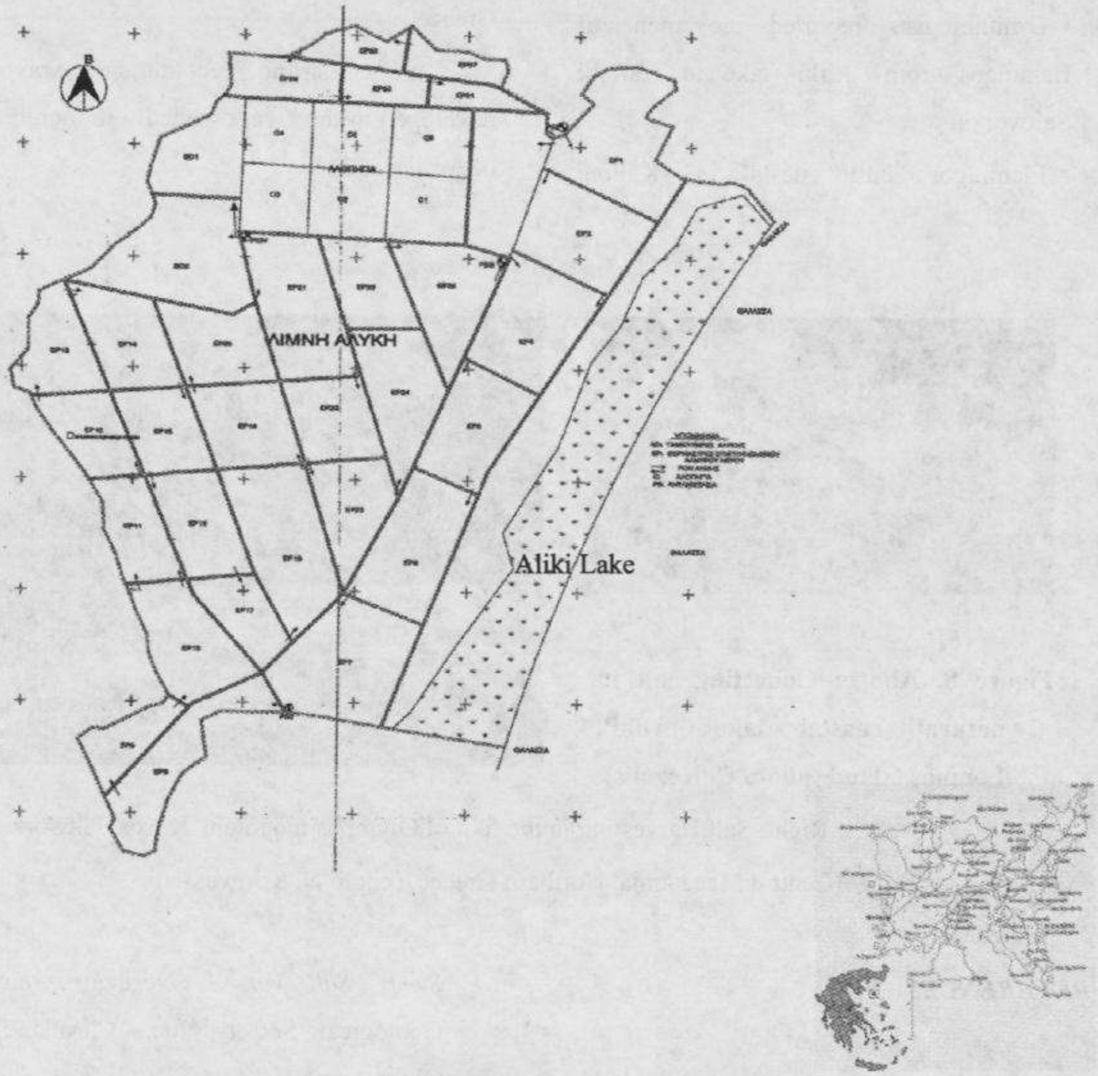



**Figure 7. Design of Solar Saltworks in "Aliki" lake, Lemnos Island, Greece.**

That system obviously will increase significantly the number and the population of the encountered bird species in the lake and the duration of their stay, finally resulted to an upgraded and more stable ecosystem! As we have already shown salt harvesting in the case of Solar Saltworks takes place only in the 10% of their area using one harvesting machine whereas in the case 'Aliki' a lot of people are walking and collecting the salt in the whole area of the lake. Last but not the least; the new investment is going to develop a strong ecotourism wave into the Island.

We can also argue from the case of Kalloni Saltworks located in the nearby Island of Lesvos where just a few years after its process optimization and production area redesign:

▪ There was a remarkable increase in bird species and population

▪ Ornithologists reported movement of flamingos from 'Aliki' lake to Kalloni Saltworks

▪ Flamingos built nests in Kalloni Saltworks for three consecutive years, trying to reproduce for the first time in Greece

▪ A very strong ecotourism wave developed in the area, especially in months of April and May

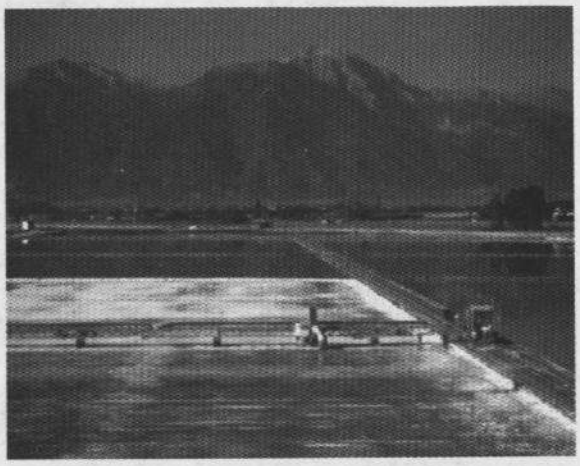


**Figure 8. Above: Collecting salt in natural coastal lake 'Aliki', Lemnos Island (photo C. Kazolis).**

Right: Salt Harvesting in the foot of Olympus mountain, Kitros Saltworks (Central Macedonia, Northern Greece, (photo N. Korovessis)

***REFERENCES***


Baas-Becking L.G.M. 1931. Historical Notes on Salt and Salt-Manufacture. Scientific Monthly, pp 434-446

Young G. 1977. Salt, the Essence of Life. National Geographic, pp 381-401.

Bassegio G. 1974. The composition of seawater and its concentrates. Proc. 4th int. Symp. Salt Vol. 2, pp. 351-358. Northern Ohio Geological Society, Inc., Cleveland, Ohio.

McArthur J.N. 1980. An approach to process and quality control relevant to solar salt field operations in northwest of Western Australia. *Proc. 5th int. Symp. Salt Vol. 1.* Northern Ohio Geological Society, Inc., Cleveland, Ohio.

Korovessis N.A. and Lekkas T.D. 2000. Solar Saltworks Production Process Evolution – Wetland Function." *Post conference Symposium Proceedings in 6th Conference on Environmental Science and Technology*. Pythagorion, Samos, 1st September 1999, GlobalNEST, Athens. pp 11-30

Davis J.S. 1974. Importance of microorganisms in solar salt production. *Proc. 4th int. Symp. Salt* Vol. 2, pp. 369-372. Northern Ohio Geological Society, Inc., Cleveland, Ohio.

Davis J.S. 1980. Biological management of solar saltworks. *Proc. 5th int. Symp. Salt* Vol. 1, pp. 265-268. Northern Ohio Geological Society, Inc., Cleveland, Ohio.

Davis J.S. 1993. Biological management for problem solving and biological concepts for a new generation solar saltworks. *Proc. 7th int. Symp. Salt* Vol. 1, pp. 611-616. Elsevier Science Publishers B.V., Amsterdam.