ECONOMIC EVALUATION OF A PILOT STUDY FOR THE RECLAMATION OF THE ALLUVIAL AQUIFER OF LA LLAGOSTA BASIN

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ABSTRACT

La Llagosta basin constitutes the most important Quaternary hydrological unit of the middle basin of the Besós river. The presence of very dense urban and industrial developments in this basin has caused the pollution of its waters. The polluting mechanisms are, in decreasing order of importance, the uncontrolled filling-in of gravel pits with waste materials, and the dumping of waste waters into the river. The central zone of La Llagosta basin is also the zone most affected by uncontrolled filling with hazardous waste materials. The reclamation methods discussed herein are part of a pilot plan which is applicable to the rest of the aquifer. There are three feasible alternatives for the correction or elimination for these wastes: extraction and removal of the waste materials, isolation of dumping sites and on site neutralization of the wastes. The cost of extraction and relocation is estimated to be 14.5×10^6 \$. This plan supposes the extraction of $3.4 \times 10^6 m^3$ of residual material, and the removal from the site of $0.7 \times 10^6 m^3$ of solid wastes. The cost of on site physico-chemical treatment is estimated to be 1.5×10^6 \$. The cost of sealing off and confinement is estimated to be 1.8×10^6 \$. Concurrent treatment of the polluted water is also considered; this operation would cost 140,000 \$ for $0.5 \times 10^6 m^3$ of water (0.28 \$/m^3).

1 HYDROGEOLOGICAL SETTING

La Llagosta basin is delimited by the straits of Montcada and the confluences of the major tributaries of the Besós River, excepting the Ripoll River (fig. 1).

A number of urbanized areas are located in the basin; their approximate combined population is 70,000 (1985). The area also contains a high concentration of factories (chemical, metallurgical, plastics, tanning, textiles, and other industries).

The alluvial aquifer rest on the impermeable Miocene formation. It is composed of alluvial gravels and sands, and the colluvial silts associated with them; these form the middle and lower terraces of the Besós River.

The alluvial aquifer is, in general, unconfined. Locally, however, it behaves as semiconfined owing to the presence of surface layers of clays

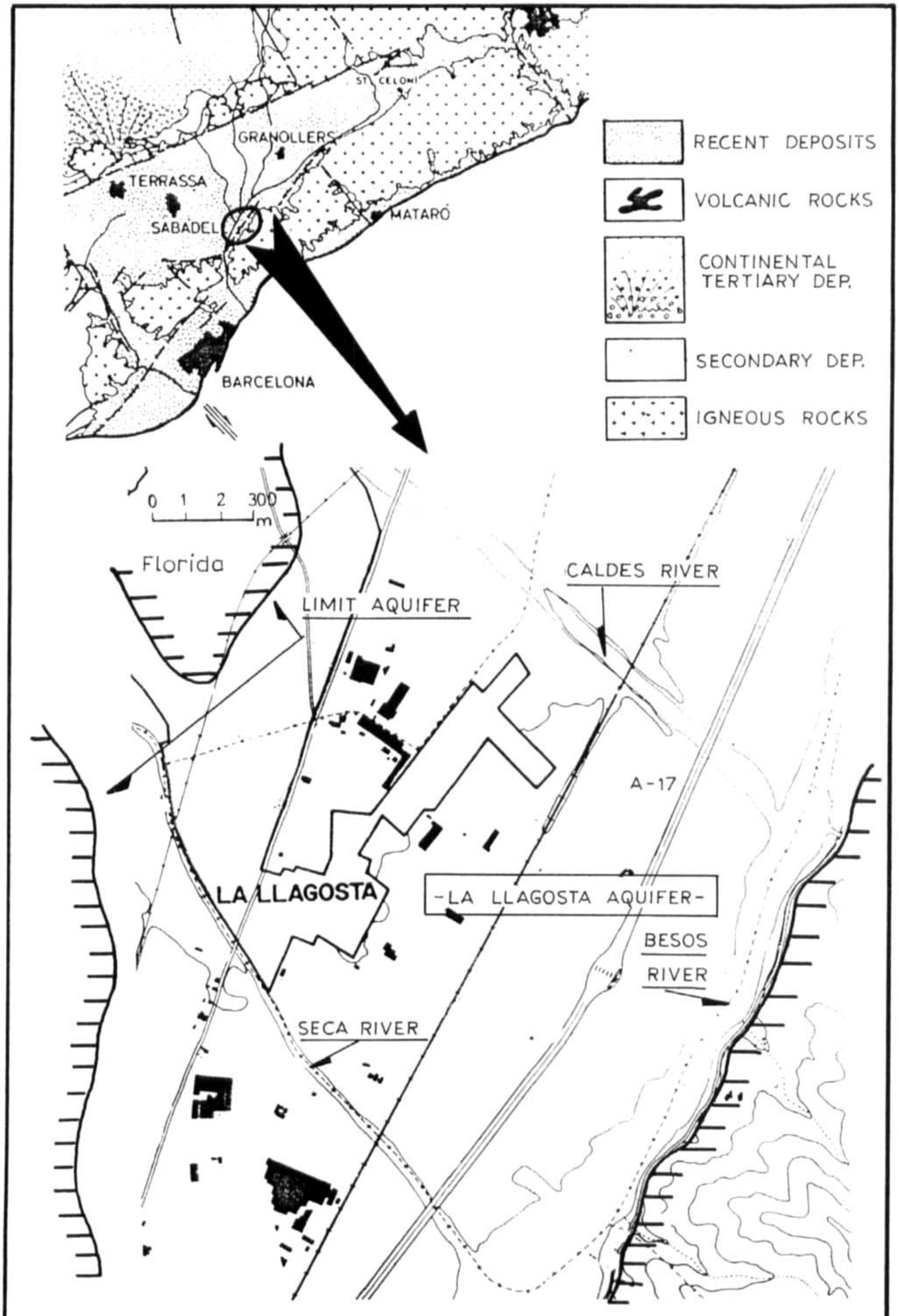


FIG. 1.- SITUATION MAP OF LA LLAGOSTA BASIN.

and silts. Transmissivity values range from 100 to 1400 m^2/day. The average thickness of the aquifer is 12 m. Its surface extends over 12 km^2, and the water usable reservoir volume of the aquifer is 15 x $10^6 m^3$.

The extraction of ground water from the alluvial aquifer was estimated to be 8.3 x $10^6 m^3$ during 1984, and 11.5 x $10^6 m^3$ in 1970. This consumption of ground water accounts for 50% of the water used in the area; the remaining 50% is transferred from the Ter River, in Northern Catalonia.

2. POLLUTION OF GROUND WATER AND SPECIFIC SOURCES OF POLLUTANTS

The ground water of the basin is currently (1987) polluted with specific heavy metals (Fe, Zn, Cr, As, Hg) in areas adjacent to buried waste. This is particulary true at the confluence of the Caldes river with the Besós river, as well as at the confluence of the Besós with the Tenes river. The presence of organic micro-pollutants in the central area of the basin endangers public water-supply wells.

The sources of ground water pollution are, in order of descending importance:

(a) gravel pits which have been filled with solid wastes (municipal and industrial wastes).
(b) municipal landfill.
(c) waste water dumped into the rivers.
(d) agricultural activity (irrigation return flows containing agricultural fertilizers).
(e) leakage from septic tanks and poorly maintained sewage networks.

The filling-in of former gravel pits had been very frequent in the areas adjacent to the Besós river and near the points of confluence with the Caldes river. Landfills are the source of heavy metals (Al, Fe, Zn, Mn), organic materials, sulfates, and high salinity in the water. Note that 20% of the aquifer has been disturbed by this landfill activity (Corominas 1982).

Uncontrolled dumping of industrial wastes has an impact similar to the filling-in of gravel pits; identical waste materials have frequently been deposited in several types of sites (river side, near the factories).

The dumping of waste waters containing heavy metals into the rivers is very common. It constitutes the primary source of surface water pollution. The role in ground water pollution is unclear, due to the retention of pollutants by the muds of the river bed and the nonsaturated zone of the aquifer.

Agricultural activity in the area is responsible for the appearance of nitrates and increased chloride, sulfate and bicarbonate.

Septic tanks and badly maintained sewage systems are the origin of high levels of nitrates in the waters of some urban areas.

All of these sources and mechanisms of pollution are conditioned by the morphology of the aquifers. Alluvial deposits throughout the basin fill paleochannels excavated in the Miocene formation. Ground water generally circulates independently along the different palaeochannels of each basin. As these waters do not mix with each other, dumping or polluting activities in on site may affect only one palaeochannel, while the rest is spared. This phenomenon produces clear geochemical distinctions within the groundwaters, permitting to locate and to predict the movement of pollutants in function of the geometry of the aquifer.

3 METHODS FOR CLEANING UP UNCONTROLLED DUMPING SITES

Uncontrolled dumping sites located in gravel pits or at land surface are the main cause of the degradation of the aquifer. The technical procedures used in the clean-up of these sites can be grouped into three categories: emptying out of the dumping sites, physical elimination of the wastes, and on site processing.

Two of the above mentioned methods are generally used in the clean-up of hazardous waste sites:

(a) extraction and removal to a controlled dumping site.

(b) on site decontamination.

The excavation of buried waste materials is justified only by the degree of urgency of a decontamination project, or by the possibility of eliminating waste materials in another location with an acceptable cost (OCDE 1983). In practice, the excavation and removal of waste materials is implemented if these wastes are on the surface or, if buried, when they are easy to locate and remove (ANRED 1983).

Systems for the physical elimination or decontamination of waste materials, i.e. incineration or reclamation, are usually not feasible, this is due to either the high cost of the system (incineration) or the negligible value of the residue, or the technical difficulties inherent in the reclamation of the residues.

On site processing procedures are most common in the cleaning up of uncontrolled dumping sites. Immobilization, one of the outstanding processing procedures, is usually carried out in one of two ways (Dawson et al.

1985):

(a) hazardous wastes, in mobile or isolated forms, are embedded in an insoluble matrix.

(b) pollutants are isolated from those waters which could mobilize them.

Physical or chemical stabilization of pollutants can be brought about using a number of substances, such as silicates, organic polymers or quicklime.

Impermeable barriers are designed to completely isolate uncontrolled dumping sites from infiltration waters.

4 APPLICABLE METHODS AND ECONOMIC COST

Most ground water pollution in the central part of La Llagosta basin originates from deposits of the various waste materials used to fill gravel pits or dispersed in uncontrolled dumping sites near industrial locations (fig. 2).

The nature of the waste materials in one area (the confluence of the Besós river with the Caldes river) is known. Extrapolating this information to the entire area of the basin, we obtain the following estimate of the average composition of waste materials:

- industrial wastes, including heavy metals (Fe, Zn, Cu, Cr, As).
- urban wastes.
- inert wastes and soils.

Our calculations of the volume of waste in this zone are based on mapped sites of landfill and uncontrolled dumping, and on a number of drillings which have penetrated the waste materials. The calculated volume is $3.4 \times 10^6 m^3$.

The pilot experiment forsees the implementation of three procedures to clean up the waste materials deposited in the Donadeu well area (fig. 2). This area is completely controlable. The following three procedures will be considered:

(1) Extraction and removal to a controlled dumping site.

(2) Complete sealing off of waste deposits.

(3) Treatment in situ, to make deposits of industrial wastes inert.

4.1 Extraction and removal to a controlled site

Waste deposits generally consist of a layer or urban and industrial waste mixed with debris, in gravel pits. Industrial and urban layer wastes is topped with a 2 to 4 m layer of clays and inert materials. Industrial

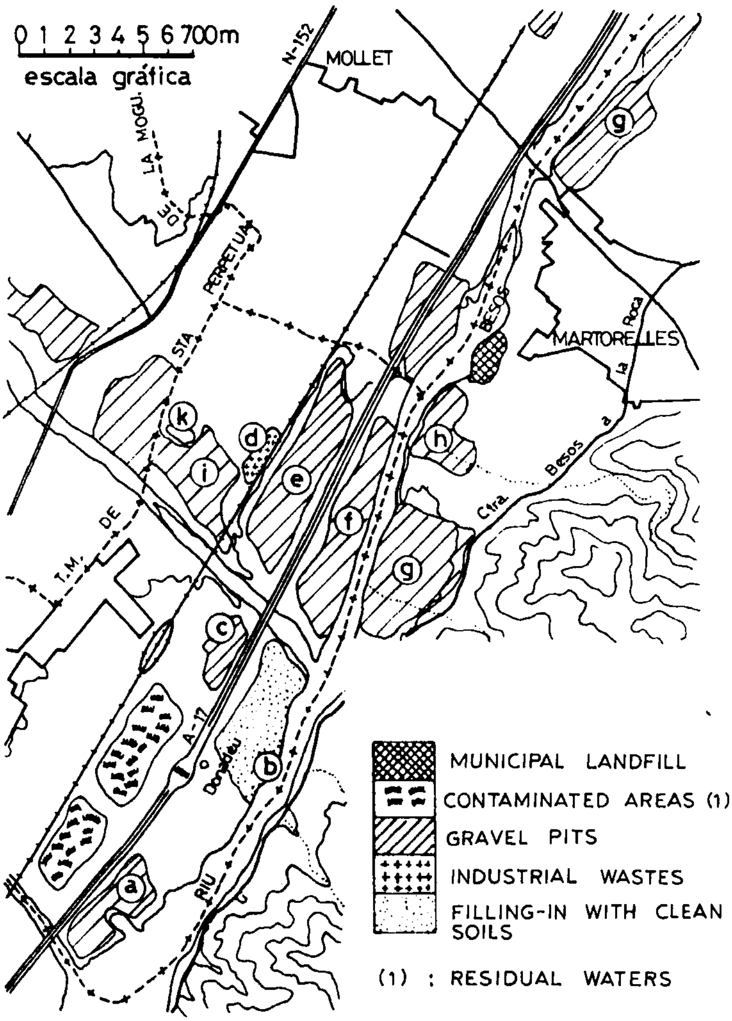


FIG. 2.- WASTE DISPOSAL SITES.

and urban waste is estimated at 0.7 x $10^6 m^3$ of the total volume (3.4 x $10^6 m^3$) of waste material and landfill to be removed from the site.

The combined extraction and removal operations are broken down as follows:

TABLE 1 Costs for extraction and removal operations to a dumping site.

Operation:	Volume (in $10^6 m^3$)	total cost in $10^6$$
Extraction	3'4	5'2
Removal to a controlled site	0'7	1'2
Controlled dumping	0'7	6'3
Filling in and compacting	0'7	1'5
Clossing of the site with a grass cover	0'6	0'2
T o t a l	6'1	14'4

The total cost of extraction of waste materials and their removal to a dumping site within a 20 km radius would be 14.4 x $10^6$$. Consequently, this method is feasible only in the case of potentially hazardous waste materials; it is not economically feasible for all of the waste materials under consideration here. It should be noted that only the cost of transport is reduced in removal to a controlled dumping site if the volume of hazardous solid wastes decreases. The cost of all other items in the operation is constant (see fig. 3). The unitary cost of this procedure is 2'4 $\$/m^3$.

4.2 <u>Complete sealing-off of waste deposits</u>

This measure involves the complete isolation of solid wastes by impermeable lateral barriers and an impermeable top layer. The creation of an impermeable layer below the waste deposits is not planned, because the waste deposits are generally located above the phreatic level. This measure accepts the risk of leaching the solid wastes during years of exceptionaly high water table levels.

The combined operations and the cost of each one are broken down as follows:

TABLE 2
Costs for impermeabilitation.

OPERATION:	volume of excavation and surface isolation (m^3)	total cost in 10^6\$
excavation of lateral barrier	12,300	0,35
impermeable cover (1 m clay)	240,000	1,2

Placing of an impermeable surface layer is suitable for a good isolation of waste deposit sites, with the exception of e, f, g, h, and i (fig. 2). A surface layer of inert soils is already in place at these sites.

These measures would also have some effect on the aquifer infiltration, because the surface clay layer placed is important. The unitary cost of isolation is 6'14 $/$m^3$.

The construction of a piezometer at each waste site has also been considered. These piezometers would monitor the effectiveness of the impermeable barriers. The cost breakdown for a 10 year observation period is as follows:

TABLE 3
Costs for observation piezometers.

ITEM	amount	total cost in $
Piezometers to 25 m depth	7	16,100
Piezometers conservation	21	9,555
Periodical analysis of ground water	840	259,560
Monitoring operation	120	10,920

The unitary cost of monitoring piezometers is 42,305 $/piezometer. This monitoring network should provide information of effective isolation of a hazardous waste disposal sites with a periodical analysis of ground water near the disposal sites.

The overall cost of this corrective measure is 1.8×10^6 $ (see fig. 3).

4.3 Treatment of industrial wastes

In this section we will only considerer an intervention over industrial wastes located in the center of the basin (deposits d, k; fig. 2). Chemical analysis of the lower aquifer indicates that these sites may contain wastes of industrial processes, because there is a certain degree of heavy metal contamination in the ground water of adjacent areas.

The cleaning up measures recommended for theses sites includes inertization of waste materials and neutralization with quicklime. The surface of these deposits would be isolated with a layer of clay. The various operations which this clean-up procedure requires, along with their corresponding costs, are broken down as follows:

TABLE 4
Costs for treatment of industrial wastes.

OPERATION	amount	unit cost ($)	total cost in 10^6 $
Extraction	68,000 m^3	3,0	0,20
Mixing	68,000 m^3	9,0	0,61
Quicklime	2,600 tons	96,3	0,25
Filling-in and compacting	70,600 m^3	4,5	0,31
Sealing with clay	17,000 m^3	5,0	0,08
Monitoring piezometers	2	42,305	0'08
T o t a l			1'53

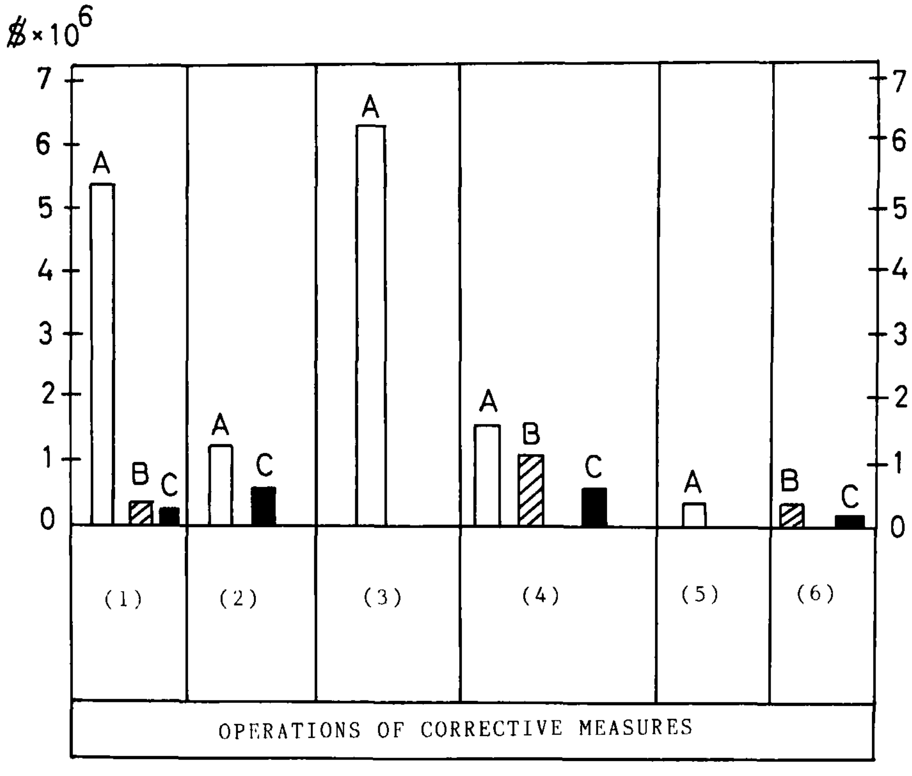
The cost of monitoring piezometers is calculated for a period of ten years. This monitoring activity must, however, be extended indefinitely in view of the permanent nature of the pollutants and their potential for mobilization after a possible failure of the neutralization matrix or surface sealing layer. It is not possible to predict self-elimination for these industrial wastes, unlike urban waste materials.

The total cost of these measures is 1.53 x 10^6 $. This gives us an approximate cost per metric ton of waste of 15 $. This would eliminate the major sources of pollution, although the remaining untreated waste materials would continue to generate pollutants.

5 CONCLUSIONS

La Llagosta basin contains a large number of uncontrolled dumping sites with urban and industrial wastes. These are usually located in former gravel pits, and are the major source of ground water pollution.

Reclamation of the alluvial aquifer of La Llagosta basin supposes a cleaning up of the existing uncontrolled dumping sites. A pilot study of the central area of the basin has been developed. This pilot study would reclain 4 hm^3 of water per year. The total volume of waste materials is estimated to be 3.4 hm^3, 0.7 hm^3 of this amount can be considered actual solid wastes, the rest being landfill and inert materials. The cost of the corrective measures considered in this study are shown in the table 5. These figures assume capital amortization of 10% over 30 years:



Considered measures:
(A) Extraction and removal to a controlled dump.
(B) Complete sealing of wastes disposal sites.
(C) Treatment of industrial wastes.

Operations:
(1) Extraction.
(2) Removal or treatment.
(3) Deposition in a controlled disposal site.
(4) Filling-in and compacting.
(5) Cover with grass.
(6) Monitoring network.

FIG.3.-Costs for considered measures and operations.

TABLE 5

Costs for the corrective measures considered.

Procedure	Investment 10^6 \$	Anual amortization 10^6 \$	Water cost increment \$/m^3
(A) Extraction and removal	14,40	1,54	0,38
(B) Sealing-off	1,85	0,19	0,04
(C) Neutralization of industrial wastes	1,57	0,16	0,04

Monitoring costs for procedure B and C are not calculated after the tenth year.

Measure A is the most efficient of the three, although its high cost and the problem of finding a suitably large dumping site make this measure less advisable. Measure B does not guarantee the absolute stabilization of hazardous wastes, nor the permanence of impermeable barriers. Measure C only addresses pure industrial waste, and also cannot provide a guaranteed inmobilization of pollutants over the long term.

This pilot study for reclamation of the aquifer also includes the treatment of 0.5 x $10^3 m^3$ of the most polluted waters. The cost is based on the cost for the treatment of water polluted with similar substances in Mercier (Lanctôt, 1985). This measure would cost an additional 140.000 \$. These figures give an approximate idea of the real cost of cleaning up the central area of La Llagosta basin, and they are an economic assesment of enviromental impact of uncontrolled industrial activity.

The cost of corrective measures have been evaluated in function of the knowledge of the structure of landfill site i (fig. 2); this is one of the few filled areas with data drillings. Some further information has been obtained from analysis of recent landfill sites, as well. In order to fully validate this data, an exhaustive program of characterization of waste deposits is called for.

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