TS
628.3 California Univ., Berkeley.
O86a Treatment and Reclamation of Tunis Sewage.
William J. Oswald. Apr. 1972.
83 p. appendices.
Prepared for USAID/Tunisia.
1. Sewage disposal - TS. 2. Waste disposal - TS.
3. Waste water - TS. 4. Sewage lagoons - TS. I.
Ponding System for Tunis Sewage Lisposal. II. Title.
III. Oswald, William J.

PN-ABI-977
73111

UNITED STATES OF AMERICA

AID Mission to Tunisia

c/o American Embassy

Tunis, Tunisia

TREATMENT AND RECLAMATION OF TUNIS SEWAGE

by

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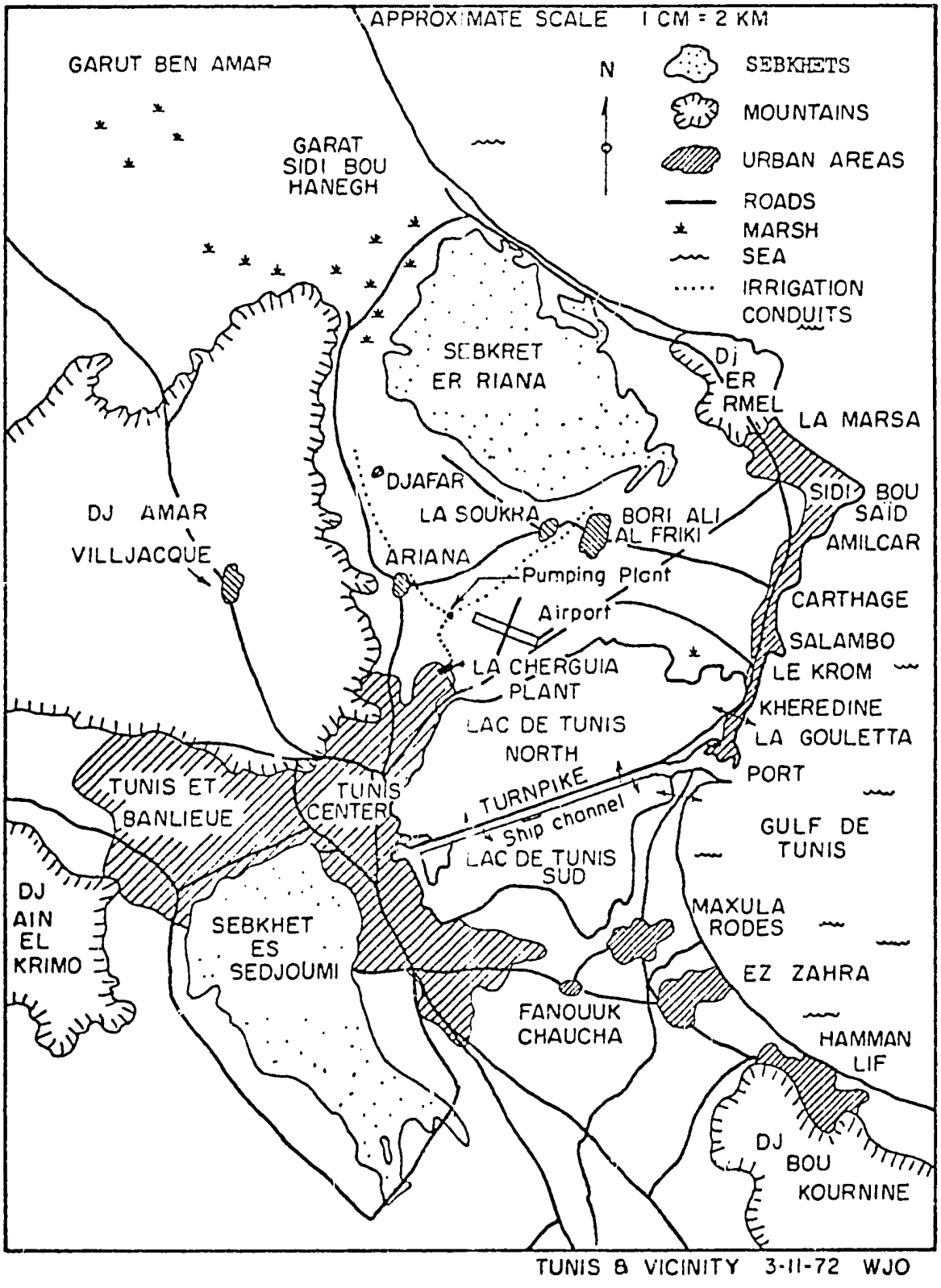
April 27, 1972



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ACKNOWLEDGEMENTS

Without the generosity and support of many persons, the preparation of this report would not have been possible. Accordingly, acknowledgement is extended to the following persons.

Through discussions and written communications, much of the data and background information was provided by, and my thanks are due to, Mr. Robert Samama, Directeur, Direction de l'Hydraulique et de l'Amenagement Rural (HAR), Ministere de l'Agriculture, La Kasaba; Mr. Ameur Horchani, Ingenieur Principal, Chef de la Division Barrage, Direction HAR; Mr. Youssef Bochaala, Ingenieur Principal, Service Assainissement Urbain, Ministry of Agriculture, Tunis; and Mr. Tunzi, Engineer, HAR, Tunis.

My oral communications were rendered not only complete and informative but also pleasurable by the constant attendance and excellent interpretive work provided by Mr. Anwar BachBaouab, Administrative Advisor to USAID, Tunis. My thanks are due Mr. BachBaouab and also to Mrs. Elizabeth Boughammi, Secretary to the Engineer Advisor of USAID for preparing the first draft of portions of the manuscript.

Thanks are also due to Mr. Gordon Pierson, Economist for AID, Mr. Wally Bowles, Chief Engineer for USAID, North Africa, Mr. William S. Rizk, Industry Officer, USAID, Tunis, Dr. William P. Davis, Director, and Dr. Hedi Baccar, Assistant Director, Mediterranean Marine Sorting Center, The Smithsonian Institution, Kherreddine. Their generosity in providing background information, questions, interest and hospitality are greatly appreciated.

I am deeply indebted to Mr. A. W. Plummer, Agricultural Engineer Advisor and Water Resource Specialist, USAID, Tunis, who provided not only the impetus for this study but also many of the ideas and much of the data. Mr. Plummer was constantly with me while I was in Tunis, and his charming wife is also due special thanks for her hospitality at La Marsa.

I am also deeply appreciative of the active interest and strong support provided for these efforts by Mr. Sumner Gerard, Director of the United States Aid Mission to Tunisia.

My thanks are due also to Mr. Charles B. Thompson, Civil Engineer, Africa Bu., USAID, Washington, D. C., for the many patient hours he spent searching for me by phone before and after arranging the contractual and consultative details of this study and for his hospitality and interest during my debriefing visit to Washington, D. C. My thanks are also extended to Ms. Gilda Varatti, Desk Officer, and Mr. Sam Lubin, Chief Engineer for Africa for attending my debriefing and for their questions.

Acknowledgement and special appreciation are extended to Mr. Henry Gee, Civil Engineer, University of Hawaii, for preparing the Figures and to Miss Roseanne Dana, Graduate Student in mathematics, University of California, for preparing the French translation of this study.

SUMMARY

Lake Tunis and the environment in the vicinity of the Lake are being severely damaged by putrefactive substances and excessive fertility resulting from the discharge of both treated and untreated sewage into the Lake. Tangible losses resulting from this undesirable practice are currently estimated to be as much as one-half million Dinars per year.

The sewage treatment plant currently employed at La Cherguia is functioning poorly due to overloading and other factors. Even if it were functioning well, it would continue to discharge seriously detrimental amounts of nutrients to the Lake. Thus, repair or enlargement of the activated sludge aspect of the La Cherguia plant is unlikely to provide a permanent solution or even a substantial temporary solution to the environmental problem.

Lake Tunis has a low assimilation capacity for waste or nutrients because it is shallow, has poor circulation, and because of its high surface area to volume ratio cannot support methane fermentation. Accordingly, unless all waste discharges--treated or not--are removed from Lake Tunis, it will fill up with carbonaceous materials and disappear within the next century.

The current waste collection system of Tunis permits intrusion of salty groundwater and seawater into the system, impairing the waste water quality to such an extent that it is difficult, if not impossible, to subject the waste to any biological waste purification process on a

sustained basis. Repair of the collection system to prevent volume changes and saltwater intrusion is thus vital to any permanent solution of the water quality and reclamation problems.

The current practice of utilizing unchlorinated activated sludge effluents for irrigation of crops is hazardous to health even though only orchard crops are irrigated. Raw activated sludge effluents are highly infectious and must be chlorinated or stored for several months before being used safely on such crops. Their use on root crops is questionable under any conditions. Future systems should therefore provide for chlorination and/or adequate disinfection through long-term ponding with positive safeguards against short circuiting.

Reduction-reclamation or facultative ponds are ideal for application in Tunis because of the sunny climate and readily available flat land. If reduction-reclamation ponds are used, they should cover a minimum area of 236 hectares in order to treat an assumed flow of 100,000 m^3 per day. The cost of such a reduction-reclamation ponding system will be about 2.2 million Dinars and will treat water for about 10.5 milliemes per m^3.

Facultative ponds are also ideal for Tunis but will require more area. If used, at least 320 hectares of facultative ponds will be required to process 100,000 m^3 per day. The capital cost will be about 1.75 million Dinars and the unit cost to treat waste will be about 7.5 milliemes per m^3.

Conveyance of waste to and from the ponds, if located in the

Er-Riana Sebkhet, will add about eight milliemes per m^3 to the handling of the waste, but complete disposal will be provided.

The possibility of disposing of Tunis' primary treated waste into the sea was explored and estimated to be more economical than activated sludge or trickling filter treatment unless some value were ascribed to the water reclaimed in the biological processes.

Analysis of up-to-date cost data from the United States for activated sludge, trickling filters, primary treatment, pumping plants and ponds, modified for application in Tunis, indicates that activated sludge is the most expensive alternative for waste disposal available, being about 2.25 times as expensive as the least costly alternative, facultative ponds.

An analysis of the effectiveness of the various alternative waste disposal methods and systems indicates that either facultative ponding or reduction-reclamation ponding would be more effective for Tunis than mechanical systems in that both are fail-safe and flexible and can be constructed more quickly with local materials. Properly designed ponds will also yield more hygienic and uniform effluents than mechanical systems.

Because of the economic losses and odor nuisance due to current discharge of sewage in Lake Tunis and because several years will be required for a permanent solution, interim emergency measures should be taken now to oxidize the sewage completely using floating aerators or to remove the sewage completely from Lake Tunis by conveying it to a temporary ponding system in Sebkhet Er-Riana.

Only one collection point and a limited number of disposal points were explored in this study. Additional studies should be conducted to determine whether or not more economical and effective collection and storage systems may exist for Tunis.

Before permanent ponding can be carried out in the Sebkhets, they should be studied to determine their soil, geological and hydrological characteristics. Studies should include in situ permeability and leaching tests and in situ pilot plant impoundment studies. Methods of interchanging freshwater for salty water in the Sebkhets should be evaluated.

It is concluded that unless unforeseen factors result from recommended studies, properly designed raw facultative ponds followed by storage and irrigation will be the most effective and economical method of waste disposal for Tunis within the foreseeable future. The Sebkhets should be carefully studied as major ponding sites. If they can be used, the cost of treating and reclaiming Tunis sewage should be less than 20 milliemes per m^3.

CONCLUSION

If ponding can be utilized in Tunis--and there is little reason to believe that it cannot--it will be the most economical, effective and reliable method of waste treatment and water reclamation available. The cost will be less than one-half as much as the cost of any mechanical system capable of producing an effluent of suitable and equivalent quality and less than half as much as total waste disposal at sea.

RECOMMENDATIONS

Discharge of any waste water into the Lake de Tunis should be terminated as soon as possible, even if a "crash program" is required to do so.

To permit the application of ponds to treat the wastes of Tunis and provide an opportunity for their assured success, studies should be undertaken in or near Tunis to evaluate the following:

1. Hydrologic properties of the Sebkhets, Er-Riana and Es-Sedjoumi.
2. Soil characteristics of the Sebkhets including structural characteristics for levees and slope stability, soil porosity and permeability, salt content, ion exchange properties, subsidence and drainage properties. Such studies should be conducted in situ with waste water insofar as is possible.
3. Durability of local quarry rock as a rip rap material.
4. Impoundability of Tunis sewage from the standpoint of methane fermentation, algal growth, sulfate reduction, pH, disinfection, BOD and nutrient removal and environmental impact. This latter study could perhaps be done at the small community of Hammam Lif, south-east of Tunis.

A full-scale ponding system at Hammam Lif would serve as a study demonstration and training unit to permit Tunisian water quality and

agricultural engineers and other personnel to become familiar with and confident in this natural and scientific method of waste treatment and disposal.

If an experimental ponding system were constructed at Hammam Lif, it should incorporate the most up-to-date pond design information and be built and studied under a carefully prepared plan.

INTRODUCTION

Because of its location on the Mediterranean sea near the northern extremity of the Continent of Africa, the Port City of Tunis is a vital outlet for the rich agricultural and mineral productivity of the Country of Tunisia. Also, because of a combination of superb climate, natural beauty, historical interest, modern airport and living facilities, incomparable wine and cuisine, and a progressive and hospitable citizenry, Tunis is rapidly becoming a major center of international tourism. A simplified map of the greater Tunis area is shown in Figure 1 (Frontispiece).

Critical to the progressive technologic and economic development of Tunis is a parallel development of programs for optimal management of its natural resources and for environmental control. Modern approaches to resource and environmental management involve the inclusion of all factors in the environment, including air, water, land, energy and human resources. However, our major concern in this study is the special area of water resources, with emphasis on waste water management and reclamation. As will be evident, a detailed study of waste water problems significantly involves all other resources as well.

The Hydraulic and Rural Development Department (HAR) of the Tunisian Ministry of Agriculture, has within the past 10 years, sponsored a number of important studies of water supply and waste collection treatment and disposal (1,2,3,4). To summarize the general findings of these studies, the crucial needs were found to be water resource development and reclamation in the area for irrigation uses and for water pollution control in Lake Tunis. Pollution

control is essential to protect the beaches and fishery in the Lake of Tunis and along the Bay of Tunis and to avoid the severe air pollution and odor nuisance problems which occur in Lake Tunis each spring, summer and fall. In this report we shall examine the crucial waste management needs of Tunis in some detail and in the light of advanced concepts of water quality and environmental control technology.

Idealistically, it should be possible to quickly accomplish water and air pollution control while at the same time correcting deficiencies in the waste water collection treatment and disposal system in a dependable, economical and nuisance-free manner. In practice, however, the ideal is difficult to attain. For most waste management systems, five years is required from conception of a need until planning, design, construction, start-up and operational completion can be attained. During that five years, most populations will have increased by 15 percent or more while any existing mechanical waste treatment systems will have deteriorated by 25 percent or more. Thus, an adjustment of 40 percent is necessary in the usual conception-to-function lag of five years--an adjustment of eight percent per year. With such facts in mind, it is not difficult to imagine how a society may fall behind in its waste collection treatment and disposal system, but population increase and obsolescence are not the only problems.

In addition many waste management systems suffer from the engineering selection of inappropriate or unworkable components or from overall designs which cannot provide the type or degree of treatment needed regardless of

size. It is a tragic fact that because of inappropriate selection of components, misdesign, and poor operation coupled with obsolescence and population increase most of the world's waste management systems are failing to meet their design goals and are falling steadily behind. To reverse this trend a great deal of future attention must be devoted to the selection of collection, treatment and disposal systems which will bear scrutiny in the light of such criteria as technical feasibility, enhancement of health hygiene and the environment, functional feasibility, compatibility with existing and planned future systems for water supply and use and for land use, flexibility and reliability, construction feasibility, construction cost, operational feasibility, operational cost, cost effectiveness and decision-to-application time. These criteria are not listed in any special order of importance for indeed each must be satisfactorily fulfilled if a waste management system is to sustain its function in the delicate environmental management complexes of the future.

The problems of waste management in Tunis are similar to those in the rest of the world. The population is growing rapidly. As indicated in a 1970 Italconsult report (5), the 1970 population of 770,000 persons for greater Tunis was expected to double to 1,540,000 by 1995, while the central City was expected to grow from 530,000 to 1,052,600. Such population increases together with an expected increase in per capita use will probably increase the current waste flow of 60,000 cubic meters (m^3) per day to as much as 180,000 m^3 per day by 1995. Also, in common with much of the world, the current waste water management systems of Tunis are overloaded, and

as a result the environment of Tunis is being degraded at an unacceptable rate. A review of the current collection, treatment and disposal system for Tunis may indicate the gravity of the situation.

CURRENT COLLECTION SYSTEMS IN TUNIS

The authors of previous reports have gone into substantial detail with regard to the inadequacy of the current collection system for sewage in central Tunis. The Montplaiser pumping station is below capacity; sewer slopes are too flat so that during dry periods sewage flows too slowly through the lines. Solids settle and putrefy in the lines. This leads to emission of hydrogen sulfide (H_2S) odors in the streets and probably to accelerated deterioration of the sewers due to microbial sulfuric acid formation. Infiltration of brackish groundwater through broken sewers or loose joints and intrusion of seawater through unprotected storm overflows add greatly to the volume of sewage and change its chemical composition adversely for both treatment and disposal. Some areas have no sewers, and some of the outlying suburbs discharge raw sewage directly into Lake Tunis, the Sebkhets, or the sea. Thus, Tunis is confronted with a need to upgrade its sewage collection system to a point where it is complete, dependable and nuisance-free and hence no longer a limiting factor in environmental quality or in the development or function of subsequent treatment or disposal systems.

CURRENT WASTE TREATMENT IN TUNIS

The only waste treatment system of substantial size in Tunis is the combined primary treatment and activated sludge system known as La Cherguia.

The location of the La Cherguia plant together with other major surface features in Tunis are shown in Figure 1.

According to HAR (6), about one-half of the 60,000 m^3 per day of sewage currently collected from Tunis passes completely through the La Cherguia plant. Half, or 30,000 m^3 per day, is settled and then is discharged directly to the Lake of Tunis. The balance, or 30,000 m^3 per day, which is passed through the activated sludge plant, is available for use in irrigation in the vicinity of La Soukra (Refer to Fig. 1). But most of it is not applied and therefore is also discharged into the edge of the Lake of Tunis.

An inspection of La Cherguia plant indicates that in common with many of the world's treatment plants it has serious deficiencies and is in serious trouble. The digesters which are apparently sized for high-rate digestion are limited in volume by accumulated sand and grease, and their heating system is currently not operational. The plant is equipped to use sludge gas to drive gas engines which in turn drive generators to generate electricity. Unfortunately, this expensive feature of the system is not now used for lack of adequate gas and because the generator engines have broken down. With loss of waste heat from the engines, designed to be used for digestion heating, the digesters do not produce sufficient gas for power. Instead of operating on internally produced power, the plant compressor-aerators and equipment are operated on purchased electricity, thus negating the substantial capital investment in sludge gas utilization. The grease and sludge removal systems of the primary plant do not function

well and grease accumulates extensively and must be disposed by hand, although suitable disposal sites are not available close by. The aeration and sludge return elements of the activated sludge plant are functioning well. However, the final sludge settling tanks are discharging large amounts of bulky sludge with the final effluent. This degrades the quality of the final effluent to a point where it contributes an additional heavy sludge load to Lake Tunis.

The existence of bulky sludge actually reflects the fact that the digesters are not functioning well and that supernatant discharged from the digesters is excessively rich in organics. It appears that the digesters are producing much more acid and odor and much less methane than they should and that heating should be applied to decrease the required fermentation time and to increase the permissible loading. However, the gas scrubbers and direct sludge heaters are also not functional and hence heat cannot be applied. Without heating it seems unlikely that the digesters can produce enough gas to heat themselves; hence, the problem is circular and probably is not correctable without a major overhaul of the system.

While it does seem likely that the Cherguia plant could be overhauled and made to function as it was designed, or modified to function reasonably well, particularly in the summer time, it is capable of processing less than half of the sewage delivered to the system. Its biological functional operation is also probably interrupted by excessive amounts of seawater which enters the collection system during heavy rains. Consequently, winter operation of this or any similar activated sludge or other intensive

bio-mechanical treatment plant would depend on a rigidly controlled bypass of salty water and a program of operation and maintenance which will add greatly to the overall cost of treatment. Intensive operation of the system will also place unusual stresses on mechanical equipment which is difficult to repair or replace.

It is apparent from inspection of this system that even though provision were made for cleaning the digesters and for grease incineration and special grit removal and even though the digesters were brought back into operation considerable additional work must be done on the plant to make it fully operational. Moreover, combustion of sludge gas for power generation may be more expensive in the long run than the direct purchase of power because unit costs of power are extremely high for small generation systems in spite of the fuel being free.

CURRENT DISPOSAL SYSTEM IN TUNIS

As noted previously, currently most of the sewage from La Cherguia and from portions of the collection system are dispersed into Lake Tunis and during the growing season (according to the Italconsult report) as much as 530,000 m^3 per month following activated sludge treatment is utilized for irrigation primarily of citrus crops.

First, considering the irrigation aspect, the direct use of either untreated or rapidly treated sewage for irrigation of crops to be used for food may have serious hygienic objections. Even use for citrus orchard irrigation is hazardous because the fruit may be dropped to the ground and become soiled with sewage residues and because the workers cannot be

prevented from soiling their hands in handling containers, ladders and other tools which are in contact with the soil. Moreover, it is impossible to be certain that irrigation water, once delivered, will not be used either to irrigate all kinds of crops including those eaten fresh and raw or be used for other purposes such as washing in the fields.

The disposal of raw or freshly treated sewage by irrigation is frought with potential problems, but the currently used alternative of discharging excess waste water directly into the Lake of Tunis has created problems with immediate environmental, economic and aesthetic impact as well as long-term potential problems.

Although Lake Tunis is connected to the Bay of Tunis and to the Mediterranean sea, there is very little tidal flushing. A causeway created by dredging the ship channel (c.f. Fig. 1) divides the north section of the Lake (where most sewage is discharged from La Cherguia) from the south section of the Lake. Openings through the turnpike, the ship channel levee and the peninsula at La Gouletta and north of Maxula Rades do not provide sufficient area to permit tidal flushing to carry the wastes to sea or indeed even to provide sufficient oxygen to prevent putrefaction of the wastes.

Schemes to improve tidal flushing of the Lake by dredging around its edges to increase water depth and circulation, although expected to improve the Lake, probably would not correct the basic problem of excess organic loading and fertilization. This is in part because the La Cherguia discharge

is in a portion of the Lake remote from the source of tidewater (c.f. Fig. 1), because the growth of emergent vegetation in the Lake water is so intense that it restricts circulation; fish traps in the channel openings also restrict flow, and the tidal prism in the Lake is not sufficient to permit rapid displacement in the face of the above obstructions.

Because it is such a shallow body of water (about 1 meter average depth), Lake Tunis is highly eutrophic and is in the process of rapidly filling up with carbonaceous material and becoming another Sebkhet. If Tunis continues to put its waste water, treated or not, into Lake Tunis, it may be safely predicted that the Lake will cease to exist within another 100 years. This is because the added fertility, particularly nitrogen, is causing a rapid fixation of insoluble carbon from the sewage, the air and from seawater. Also, because of decreased circulation and decreased tidal flushing due to floating organic growth, there is no mechanism for loss of insoluble material from the system. Based on photosynthetic principles, one may estimate that carbonaceous deposition in the Lake is occurring at a rate approaching 1 cm per year. There is also evidence of deposition of sulfur, silicate, calcium, magnesium and phosphate as well as carbon, adding to the rate of filling in.

The vile odors from Lake Tunis are probably caused mainly by a bacterial process of sulfate reduction to H_2S in the presence of excess organic matter and the absence of dissolved oxygen. Excess organic matter originates from sewage and from organic growth in the system. Odors other

than H_2S also come from putrefying sewage as it is converted by bacteria to malodorous, volatile acids and related products.

A natural body receiving organic matter in excess of its oxidation capacity must undergo methane fermentation to dissipate carbon and to avoid foul odors. Methane is an odorless gas and is 75 percent carbon, and, when methane fermentation is in vigorous progress, BOD and carbon are rapidly removed from the body of water without objectionable odor. The environmental requirements ideal for methane fermentation are not present in Lake Tunis because the environment changes quickly from aerobic to anaerobic with time and the sensitive methane microbes cannot tolerate such changes and therefore cannot become established. The methane bacteria are also inhibited by temperature below 15°C. Thus, during the winter, waste introduced to the Lake simply settles and stores up on the bottom. As the water warms in spring and summer, putrefaction of the winter's accumulated sludge increases, organic acids are released which are quickly oxidized by bacteria depleting the overlying water of oxygen. Any fish present die due to lack of oxygen. Sulfate is also reduced by bacteria in the absence of oxygen and H_2S is released. This H_2S provides a substrate for the photosynthetic sulfur bacteria and the Lake becomes red and unsightly as well as odorous.

The violent odor which is said to pervade the atmosphere of Tunis during the summer months must greatly decrease the number of tourists who would come and remain in an otherwise delightful environment. Aside from health factors, aesthetics, and intangibles such as the destructive

corrosion of materials and surfaces due to H_2S, the direct and immediate losses to Tunis of tourist trade must therefore be very substantial--perhaps as much as 250,000 Dinars each year. It has been estimated that fish losses due to death in the anoxic Lake of Tunis in 1971 amounted to about 80 tons, having a retail value of over 40,000 Dinars(7).

Also, according to data collected by Italconsult, of the 23,000 m^3 per year of waste water currently produced around the Lake, only about 3,000,000 m^3 per year are actually reclaimed by irrigation. The balance, or about 20,000,000 m^3 per year, goes into the Lake and is lost. If this waste water is worth 5 milliemes per cubic meter, the annual loss is 100,000 Dinars. Thus, tangible losses of as much as 0.4 million Dinars per year may result from the current waste disposal system in Tunis. Intangible losses may be ten times as great.

Instead of using Lake Tunis as a depository for waste, it should be protected as a treasured area of beauty and open space, with its natural productivity maintained and enhanced by proper scientific management and scenic development.

From the foregoing description of the current problems with waste water disposal in Tunis, it is apparent that there is a need for comprehensive long-range planning in the development of a future waste water management system for Tunis. However, before considering the alternatives in a comprehensive long-range plan for collection, treatment and disposal of the waste water of Tunis, it is essential to consider some additional general aspects of waste management.

GENERAL COMMENTS REGARDING COLLECTION

While it is not within the scope of this report to extensively discuss collection of sewage, something of a general nature should be said regarding adequate collection systems since they substantially influence subsequent treatment and disposal. Adequate collection systems should draw from a carefully analyzed collection area and convey wastes only such distances as can be justified on the basis of economics and ultimate disposal requirements. The systems should convey only those kinds of waste water which can be handled in subsequent treatment or disposal systems. Conveyance to the point of treatment or ultimate disposal should be as rapid and economical as possible. The collection of abrasive, corrosive, encrustive, volatile, explosive, tarry, toxic or excessively strong wastes should be avoided since they will interfer with most treatment processes and ultimately destroy the collection system, the treatment plant or parts of the receiving body. Such wastes should be dealt with either on the property of the producer or be handled essentially as solid wastes; that is, concentrated and trucked or conveyed to special disposal sites where they will not constitute an environmental hazard.

The minimum velocity of flow in any collection system should be 60 cm per second with the sewer flowing full, and pumping plants should be employed as frequently as necessary to provide such velocities. In areas where steep slopes are required, full flow velocities should not exceed 300 cm per second to prevent sewer erosion. The collection system should be designed, constructed and operated to prevent intrusion of ground

or surface water since these may overtax the conveyance capacity and disturb or disrupt the treatment and disposal process. Sewers which flow by gravity should be adequately vented by providing manholes at each change in grade and direction and at a maximum spacing of 180 meters. Force mains should be designed with full flow velocities between 60 and 300 cm per second. Pumping systems of the flush clean or non-clog variety should be used in collection systems so that fine screening may be unnecessary, particularly in intermediate stations.

GENERAL COMMENTS REGARDING TREATMENT

Five stages of waste water treatment are recognized in the United States today, and the degree of treatment to some extent is dependent upon the disposal to be used.

Primary Treatment

As is well known, the first stage of treatment involves metering and removal of all floatable and settleable materials. In mechanical systems, the removed materials consisting of grit, sludge and grease must be disposed separately from the waste water. This may be accomplished by burial of the grit and by either separate sludge digestion or incineration of the grease and sludge. Separate sludge digestion is sometimes difficult to maintain under varying conditions of loading and climate, and there has been a recent trend in the United States toward incineration of grease and sludge. In fact, combined dissolved air flotation of both grease and sludge and incineration of the floated material are becoming widely used. A more costly and dependable mechanical process is thus replacing the less

expensive and less dependable sludge digestion process. Following incineration a greyish sandy residue remains which may be used for fill whereas following digestion the residual sludge may not be sufficiently stable to be disposable on land. The effluent from primary treatment is low in suspended solids but normally retains more than 75 percent of its original organic content.

Secondary Treatment

Secondary treatment involves removal of dissolved organic matter remaining in sewage following primary treatment and, properly, disinfection of the sewage by chlorination. Secondary treatment involves the growth of an enriched bacterial culture at the expense of the soluble organics in the waste followed by removal of the bacterial cells and their inert residues for fermentation or burning together with the primary sludge. The supernatant liquid from a secondary treatment plant should be virtually free of suspended matter and low in dissolved organic matter. The effluent is, however, usually rich in nitrates, phosphates, ammonium and carbonates and consequently is a ready source of nutrients for plant growth.

Three techniques of secondary treatment are well known--activated sludge treatment and trickling filtration or biofiltration and oxidation ponds.

Activated Sludge Treatment. The activated sludge process was discovered in the early part of the 20th Century to be a biological process which effectively oxidizes and removes the soluble organic matter in sewage. It is a rapid process requiring large amounts of air or oxygen and sustained

aeration during periods on the order of four to six hours. The process requires grit and grease removal prior to aeration and is also greatly benefitted by primary sedimentation prior to the aeration process. However, the key to the process is sedimentation and return of the bacterial solids which grow in the aeration tank. These solids innoculate and in the presence of oxygen rapidly adsorb and oxidize the incoming sewage. As surplus sludge develops, it must be wasted to sustain growth; otherwise, the sludge tends to age and become bulky and difficult to settle. In any system bulky sludge which enters the effluent will degrade the degree of treatment attained. Excess sludge must be disposed by anaerobic fermentation, by extended separate aeration or by burning. Activated sludge is a particularly useful process in localities where land costs are high and where land is not available for other forms of treatment. Because it is sufficiently rapid to be complete before the normal residual heat of sewage is depleted, it is the only oxidation process that can be made to work well during the winter in countries where freezing conditions persist during much of the time. It is, however, an expensive process to construct and operate and is unnecessary or in fact undesirable where the climate is mild and open land is available for ponds.

Trickling Filtration. The second conventional method of secondary waste treatment, trickling filtration, also requires primary treatment and grease removal as a pretreatment and involves passing the primary effluent over a bed of stones or other medium through which the sewage can absorb oxygen and microbes growing on the medium surfaces can adsorb and oxidize

the organic matter from the waste. Insoluble material and bacterial cells which accumulate on the rocks ultimately slough off and are removed in a secondary settling system. Recycle maintains the load application and sloughing during periods of low flow. Sloughed material is disposed of with the primary sludge. Trickling filtration cannot be used where intense freezing occurs and is most applicable in areas of moderately cold climate where land is moderately expensive and a process somewhat less efficient and less complex than activated sludge is sufficient. Trickling filtration, like activated sludge, is expensive to build and complex to operate and is unnecessary where the climate is mild and land is available for ponds.

Oxidation Ponds. The third method of conventional secondary treatment, oxidation ponds, will be discussed in a later section.

Tertiary Treatment

Tertiary treatment involves the removal of plant nutrients from waste water usually following secondary treatment. The nutrients most commonly removed are phosphate, ammonium, and nitrate. Carbonates and iron are also removed in certain cases.

Mechanical Systems. Phosphate is removed by precipitation with lime or aluminum hydroxide; ammonium may be removed by raising the pH, converting the ammonium ion to ammonia and stripping the waste in an air column. As noted previously, ammonium may also be removed through growth of algae in ponds.

Nitrate may be removed either by an anaerobic microbial process known

as denitrification or by growth of algae. Carbonates and iron may be removed by growing and removing algae or by chemical precipitation at a high pH. Complete tertiary treatment by chemical and mechanical processes is extremely expensive, costing more than twice as much as primary and secondary treatment combined.

Activated sludge, trickling filter and anaerobic digester effluents are particularly rich in plant nutrients and provide beneficial fertility when applied immediately in irrigation of crops. On the other hand, such effluents are invariably a problem when they are discharged to lakes, streams, estuaries or storage reservoirs in warm climates. Effluents from modern pond systems contain fewer unoxidized nutrients and hence are less of a problem when storage is practiced.

Ponding. While ponding has been practiced in connection with fish culture for hundreds of years, little scientific work had been done on ponds as sewage treatment devices until the last two decades. Since 1950, intense research programs at the University of California and the University of Texas together with work by U.S. Federal and state agencies has led to an increasing realization of the potential importance of ponds as complete treatment and storage systems. In addition to lower unit costs, than trickling filters or activated sludge systems, ponds provide multiple benefits not shared by other process, as, for example, they provide opportunities for both treatment and storage of waste water in the same system. When properly designed and operated, they provide opportunities for reclamation of water and nutrients, enhance the propagation of fish

and wildlife, provide open space, and contribute to the beautification of an area. In this sense pond systems are the most modern and advanced form of waste disposal available. In the period since 1961, ponds designed especially to enhance methane fermentation and foster algal growth have developed from small experimental systems of 10^6 liters in volume to a functional system in Modesto, California, which has an algal growth pond of 10^9 liters in volume. The algal pond surrounds a set of more conventional facultative ponds. The total area involved is 340 hectares and the total volume 5,000,000 m^3. During the canning season, the ponds treat a sewage flow of 110,000 m^3 per day and remove more than 50,000 kilograms of BOD per day. An aerial photograph of the entire Modesto ponding system is presented in Figure 2.

Generally speaking, ponds which are designed to depend on photosynthesis for their oxygen are applicable anywhere that the visible solar energy input exceeds 100 gm calories per cm^2 per day more than 90 percent of the time throughout the year and freezing conditions do not persist. These conditions are of course easily met in Tunis.

Quaternary and Quinternary Treatment

To complete the discussion of the five stages of waste treatment, it should be noted that quaternary treatment is under intensive study in the United States today. This treatment is designed to remove refractory substances (i.e. substances which do not oxidize easily) and toxic substances. The most common forms of quaternary treatment are chemical precipitation, activated carbon column extraction, and ion exchange. A degree of quaternary

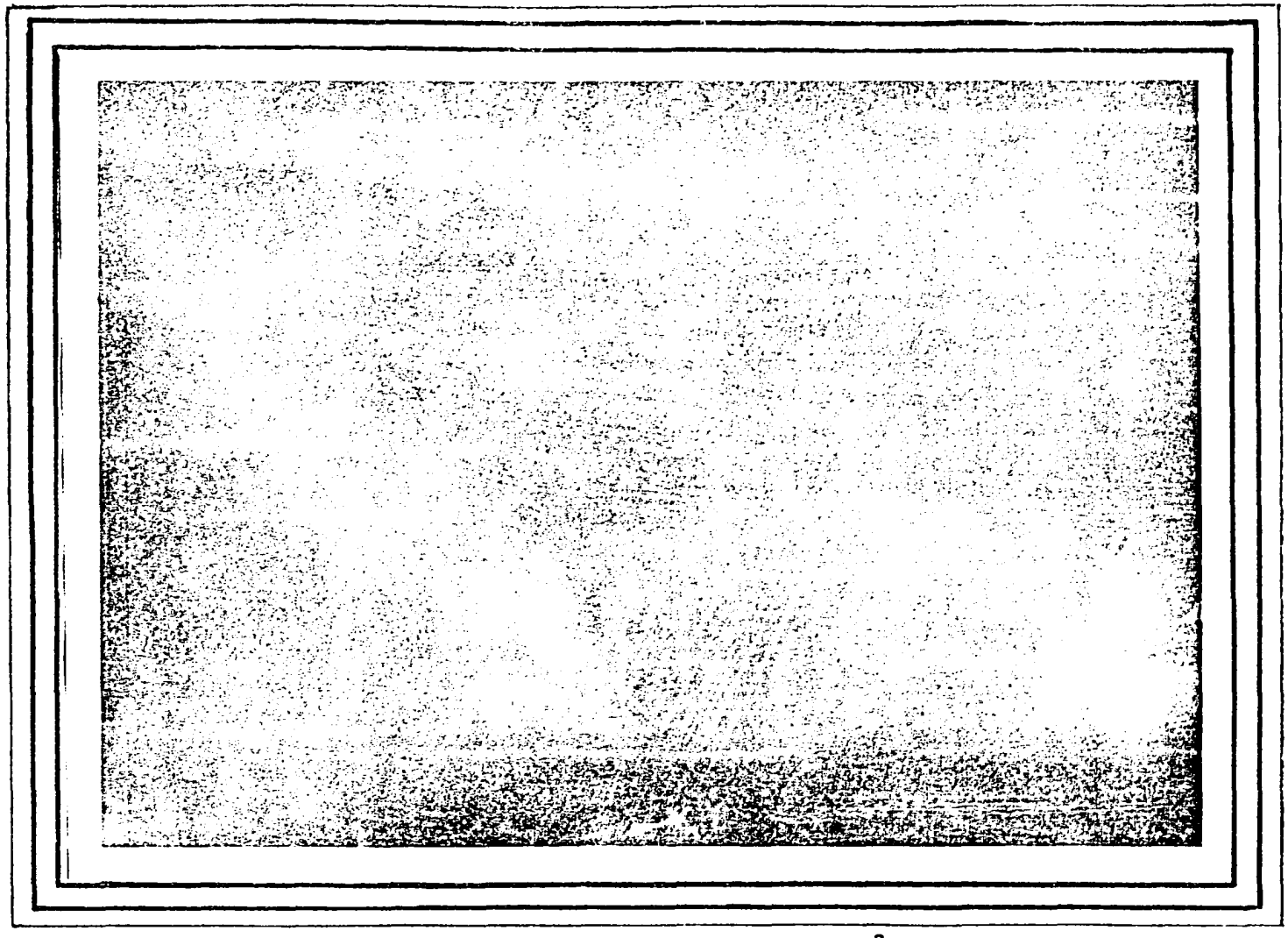


FIGURE 2. Modesto, California, USA. 340 Hectare, 5,000,000 m^3 High Rate and Facultative Ponds. Flow: 110,000 $meters^3$ per day. BOD Removal: 50,000 kilograms per day. Courtesy of Jenks and Adamson Consulting Engineers, Palo Alto, California.

treatment is also provided in algal ponds since algae have strong ion exchange properties.

The term quinternary treatment is reserved for controlled processes of desalinization or distillation of waste water.

In closing this general discussion of waste treatment, it should be noted that the existence of five stages of waste treatment stems from the fact that the stages must be accomplished in proper sequence, particularly when mechanical systems are used. Thus, primary treatment must precede secondary treatment, secondary treatment must precede tertiary treatment, and so on. Without the preceding treatment, the ensuing process becomes fouled and will not function for a sustained period. Thus, to treat waste to the second, third or fourth degree mechanically is extremely expensive.

On the other hand, a high degree of complete waste treatment can be attained in a properly designed ponding system at little more cost than required for primary treatment by mechanical systems.

GENERAL COMMENTS REGARDING DISPOSAL

The type of treatment system which should be used is to a substantial extent determined by the disposal system. The practical choices for ultimate disposal of sewage are relatively few; namely, water disposal, land disposal, recycle, or various combinations of these three. Water disposal may be into lakes, flowing streams, estuaries or the sea; land disposal may be into dry water courses, open grass or forest lands, by use in irrigation of crops or into ponds. In any case land disposal ultimately involves evaporation, evapotranspiration, or percolation of waste water into

the soil. Recycle may take the form of treatment and reuse within a single process but more often may involve use in a series of processes until the water quality is degraded to an extent that it must be discarded or submitted to higher degrees of treatment. The reuse of domestic waste water for domestic purposes is usually unnecessary and should only be considered when no other source is available.

Freshwater Disposal

Disposal of waste water into lakes, flowing streams and estuaries provides some opportunities for waste water reclamation if the bodies of water are fresh and flow slowly through areas where irrigation or industrial water is needed. Unfortunately, the practice of discharging primary or even secondary waste water into fresh or brackish water bodies has created far more problems than it has solved. Problems of hygiene and health, oxygen deprivation from fish and aquatic life due to warm and oxygen demanding wastes, intoxication or death of fish and aquatic life due to complex chemicals or toxic metals often in wastes and the uncontrolled proliferation of unwanted bacteria, algae or higher plants due to discharge of nutrients, almost always occur. Thus discharge of raw waste and primary and secondary effluents to natural waters should be avoided if at all possible.

Seawater Disposal

Discharge of raw sewage to the sea involves sight and odor nuisances due to floatable objects and grease, problems of hygiene and health along beaches and has also raised questions of oxygen deprivation or toxicity to

fish and the sensitive larval forms of many free floating organisms and most bottom organisms in the sea. Excessive fertilization of the sea also may occur with subsequent overgrowth of floating plants, diatoms and other planktonic organisms and interference with the light penetration needed for growth of seaweeds and corals dependent on bottom attachment. This in turn may disrupt the breeding cycle of many organisms dependent on seaweed and coral for food and protection from predators. As a consequence of these factors, disposal of sewage into the sea may ultimately decrease the diversity and productivity of the sea in a much larger area than the immediate vicinity of the outfall.

Most biologists familiar with the problems cited would agree that a dilution of 1 part of sewage with more than 10,000 parts of seawater may be necessary before effects of the type described could not be detected. But regardless of theoretical dilution, floatable solids and grease will collect on the sea surface and find their way to shore and consequently must be removed before waste water is properly disposed at sea. Also, regardless of theoretical dilution, much of the waste settleable material will find its way to the sea bottom in the outfall vicinity and will disrupt sealife patterns in that area. However, the provision of treatment to remove settleable as well as floatable solids and dispose of them separately will effectively prevent any but sensitive bacterial detection of sewage in seawater if the dilution exceeds 10,000 to 1. Certain, continuous dilution of waste with 10,000 parts of seawater requires a long outfall and diffusion system which is, however, very

costly. Thus, it may often be more economical to treat sewage extensively to modify its quality to a point where it may be discharged without extensive dilution. With such a high degree of treatment, it then may become attractive as a water resource and too expensive to discharge.

Land Disposal

Although most waste treatment processes have been devised with the idealistic objectivesof modifying water quality, preventing toxicity, and removing nutrients which may be harmful in receiving waters, most processes unfortunately fall far short of the ideal because they either become overloaded or are improperly designed or operated. There are few things more futile and costly on a sustained basis than a waste disposal plant which does not perform its design function. This is no less true for land systems than for other disposal systems.

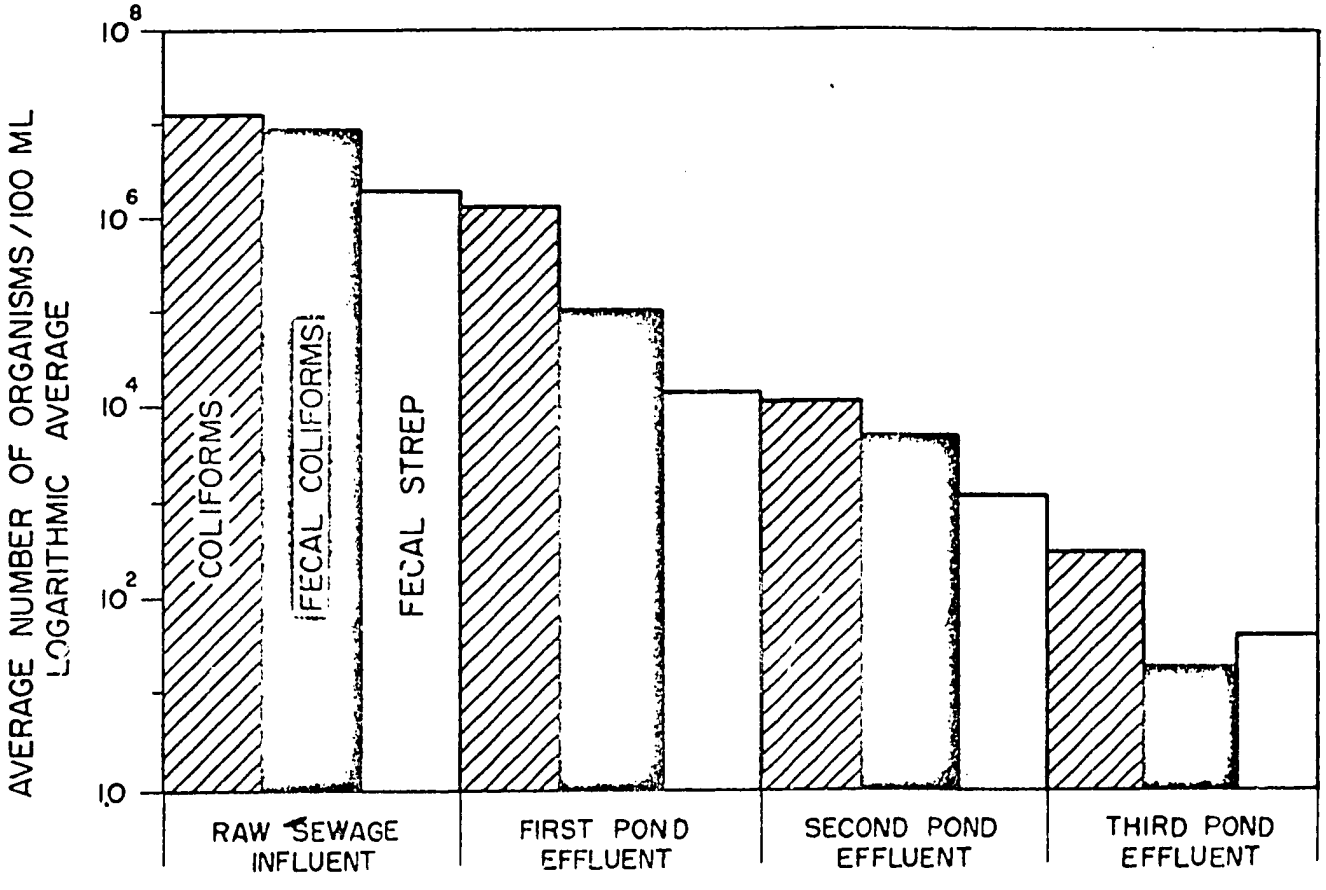
Reclamation and disposal of sewage onto the land poses potential problems of disease transmission through foods grown on the land and eaten raw. The use of sewage effluents for direct irrigation of food crops, while beneficial in terms of water and nutrients, is actually potentially dangerous and potentially enormously expensive when it is practiced because it inexorably degrades the public health. While immunization or treatment of typhoid fever and cholera and several other sewage transmitted bacterial diseases is possible, many of the helminth (worm), amoeboid, and virus infections, such as hepatitis and probably those of the long-term degenerative diseases, are also transmitted by sewage, and once contracted there is little defense against these at

this time. The shorter the time that elapses between production of a waste water and its reuse, the higher the probability that it will convey such diseases.

Because activated sludge is a fast process, it has a high probability of disease conveyance. This probability of transmitting infections can be greatly decreased by use of chlorine, but dosage must be adequate and unfortunately chlorinators frequently fail to work properly, or the chlorine supply may be interrupted. Systems which depend entirely on chlorine for disinfection are consequently hazardous in that they are not at all safe from failure.

If waste water is to be reclaimed for irrigation of food crops, either long-term storage in ponds with provision to prevent short circuiting of new waste into the water ready for reuse or filtration through two or three meters of clean, porous sand or soil are the most fail-safe methods available to decrease the probability of conveyance of infectious agents to food by way of irrigation water. If both processes can be used, an even greater factor of safety is attained.

To illustrate disinfection in ponds, the effect of a series of three ponds on the numbers of coliform bacteria, fecal coliforms and fecal streptococci found in series pond effluents is shown in Figure 3. It is evident from Figure 3 that, unless short circuiting were to occur, with three or more ponds in series the bacterial quality of the pond system effluent would be equivalent to that of good raw water from most sources. Four or five ponds in series would be even more effective.



After Ringsage and Micone

FIGURE 3. The Influence of Series Ponds on Decrease in Average Number of Sewage Bacteria

Indeed, ponds which are properly designed may provide not only disinfection but primary and secondary treatment equal or superior to that of mechanical systems. For example, shown in Table I is typical data obtained from samples taken from a series of three sewage ponds at Esparto, California. The ponds had a cumulative detention period of about 120 days. As is evident from the data, removals of BOD, COD and suspended solids exceeded 90 percent in each case. Excellent removal of nutrients such as ammonium and phosphorus was also attained indicating that those ponds also accomplished tertiary treatment along with disinfection and storage.

Any plan to dispose of treated waste water solely by means of irrigation immediately poses a problem of long-term storage. In arid regions. the need for irrigation water reaches its peak in late summer whereas the production of waste water remains about constant or increases during the rainy season. There is, however, little need for irrigation water during the rainy season, and at that time the soil will not accept large amounts of water. Spraying sewage on forest and grass lands as an alternative to storage is objectionable because the water is wasted and the rapid runoff from sprayed areas which occurs during rains carries disease organisms, organic matter and nutrients into water courses and reservoirs. The runoff poses problems of lesser magnitude but similar to those resulting from direct discharge of sewage. Thus, any adequate reclamation system should include complete storage as a basic essential of the system. The fact that ponds provide both treatment and storage is thus

TABLE I

ESPARTO PONDS APRIL 1965 CHEMICAL AND BIOLOGICAL DATA (AFTER KEPPLE)

Test Description	Raw Sewage (mg/l)	Pond #1 (mg/l)	Pond #2 (mg/l)	Pond #3 (mg/l)
$B.O.D._5$ (20°C)[a]	203[b]	14[e]	7[e]	3[e]
C.O.D. (Dichromate)[f]	452[b,c]	287[c]	265[c]	70[c]
Suspended C.O.D.	231[b,c]	207[c]	195[c]	9[c]
Total Solids	903	685	606	514
Total Volatile Solids	291[b]	279	229	197
Suspended Solids[d]	166	90	70	6
Volatile Suspended Solids[d]	93[b]	75	45	3
Total Nitrogen	35[b]	20	12	2
Organic Nitrogen	10[b]	12	7.5	1.7
Ammonia Nitrogen	25[b]	8	4.5	0.3
Nitrate Nitrogen	No test	No test	No test	0.5-0.3
Orthophosphates	68	"	"	9
Alkalinity	455[c]	405[c]	340[c]	340[c]
Coliform Bacteria (Milipore Filter) org./ml.				7-35 (15 ave)

[a]B.O.D.* samples from ponds were centrifuged at 500g for 10 minutes to remove algae prior to incubation (*BOD denotes Biochemical Oxygen Demand)

[b]Samples of raw sewage were 2 hour mid afternoon composites. A factor of 80% has been applied to those values indicated so that they more nearly represent a 24 hour average

[c]Only one test made

[d]Suspended solids were determined by 10 minute centrifugation at 500 g. It is expected that values are low for raw sewage.

[e]The algae were centrifuged prior to dilution and incubation.

[f]C.O.D. (Chemical Oxygen Demand)

an additional significant reason for using ponds in any reclamation scheme.

INTEGRATED PLANNING FOR TREATMENT AND RECLAMATION

With the preceding facts concerning collection, treatment and disposal in mind, further consideration may be given to an improved comprehensive waste management plan for the Tunis area. In developing the plan, it will be presumed that the major objective is to develop a maximum quantity of water suitable for irrigation of all types of crops. This requires not only adequate waste collection and treatment but also adequate storage of treated water throughout the year, particularly in the winter. Treated water should be stored in such a way that it is hygienic, does not become an odor nuisance or evaporate excessively and yet is readily available for use in irrigation.

A centralized authority is essential to develop and implement such a comprehensive plan for water management. This authority should include thinking members from all agencies concerned with water. It should plan to take maximum advantage of the available natural resources and to minimize wasteful redundancies. It should plan to use only systems which are reliable and fail-safe.

The planning stage itself involves a consideration of the apparently feasible alternatives for collection, treatment and disposal and the integration of these alternatives into several integrated, overall waste management schemes or systems.

Outlines of the apparently available collection, treatment and disposal

alternatives are shown in Tables II, III, and IV.

The first integrated scheme in which these alternatives are used is the current plan for waste management which has grown out of several previous plans to improve Lake Tunis by various international engineering firms. The plan is shown schematically in Figure 4 and is referred to herein as the HAR plan. This is similar to the Bonifica Plan of 1969 and, with respect to collection, involves construction of a new main collection sewer on higher ground to avoid the saltwater intrusion that now occurs. It also involves improvement or repair of the La Cherguia plant, a 100 percent enlargement of La Cherguia plant and construction of a sewage effluent irrigation and evacuation canal from a receiving station northwest of the La Cherguia plant and a conveyance channel around the south and west end side of S. Ariana to the sea at Raouad. Treated sewage would be pumped from La Cherguia to the receiving station near the divide west of Ariana.

The 1969 Bonifica Plan (see Figure 5) would add a storage reservoir of 7,000,000 m^3 located near the small village of Djafar and another of 5,000,000 m^3 located near the west edge of Sebkhet Er Riana. Also, in the Bonifica Plan, the marshes of Gavot Ben Amar and Garat Sidi Bau Hanegh would be provided with under-drainage for reclamation and control of salt accumulation using waste water for leaching. Treated waste water would also be conveyed northwestward and eastward, as it is now, to provide irrigation for the agricultural area. Excess waste water and drainage would go into the sea.

TABLE II

ALTERNATIVE COLLECTION SYSTEMS FOR TUNIS SEWAGE

1. Centralized Plan - Collect all sewage from the greater Tunis area as far south as Hammam Lif, as far north as B. Fathallah and Gamart, as far west as Sidi Bou Said and La Gouletta, and as far east as Lalla Manoubia and convey it by way of trunk sewers and pumping plants to La Cherguia for treatment.

2. Decentralized Plan

   A. Collect sewage from low-lying areas near Lake de Tunis and convey to La Cherguia.

   B. Collect sewage from high elevation areas around Sebkhet Es-Sedjoumi and convey by gravity to a treatment plant at southwest end of Sebkhet Es-Sedjoumi.

   C. Collect sewage from intermediate elevation areas of central Tunis and from Maxula Rades eastward by gravity to a collection basin at the southeast tip of Lake de Tunis from whence it would be pumped to the treatment plant at the southwest end of Sebkhet Es-Sedjoumi.

   D. Collect sewage from the Hammam Lif and S. Germain (Ez Zahra) areas for local treatment.

   E. Collect sewage from the Gamart, La Marsa, Carthage, La Gouletta strip for pumping and gravity flow to a treatment plant at the southwest end of Sebkhet Ariana or to the La Cherguia plant.

3. Partially Decentralized Plan

   A. Collect sewage from the greater Tunis area, from Maxula Rades eastward and from the Gamart, La Marsa, Carthage and La Gouletta strip and convey to La Cherguia for treatment or diversion.

   B. Collect sewage from the Hammam Lif and S. Germain area for local treatment.

TABLE III

ALTERNATIVES FOR TREATMENT OF TUNIS SEWAGE

1. Repair and continue to utilize the current La Cherguia activated sludge plant for 30,000 m^3 per day. Increase the size of the current La Cherguia activated sludge plant by 30,000 m^3 per day to a total of 60,000 m^3 by 1977. Increase the size of the 1977 La Cherguia activated sludge plant by 40,000 m^3 per day by 1990 for a total of 100,000 m^3 per day. Install chlorination facilities for total plant effluent.

2. Repair and continue to use the current La Cherguia activated sludge plant. Install a 60,000 m^3 per day trickling filtration system. Install chlorination facilities for total plant effluent.

3. Install a modern stabilization ponding system or systems in appropriate locations as required for treatment and storage to provide irrigation water.

TABLE IV

ALTERNATIVE DISPOSAL SYSTEMS FOR TUNIS SEWAGE

1. Current Practice - Use of effluent for irrigation and surplus discharged to Lake de Tunis.

2. Conveyance of all waste or treated water to irrigation or storage with surplus going into the sea northwest of Sebkhet Ariana.

3. Conveyance of all waste water or treated water to irrigation with surplus or rejected water going into the Sebkhets.

4. Storage of all waste water for irrigation with only irrigation return water discharged into the sea.

5. Disposal of all waste water at sea.

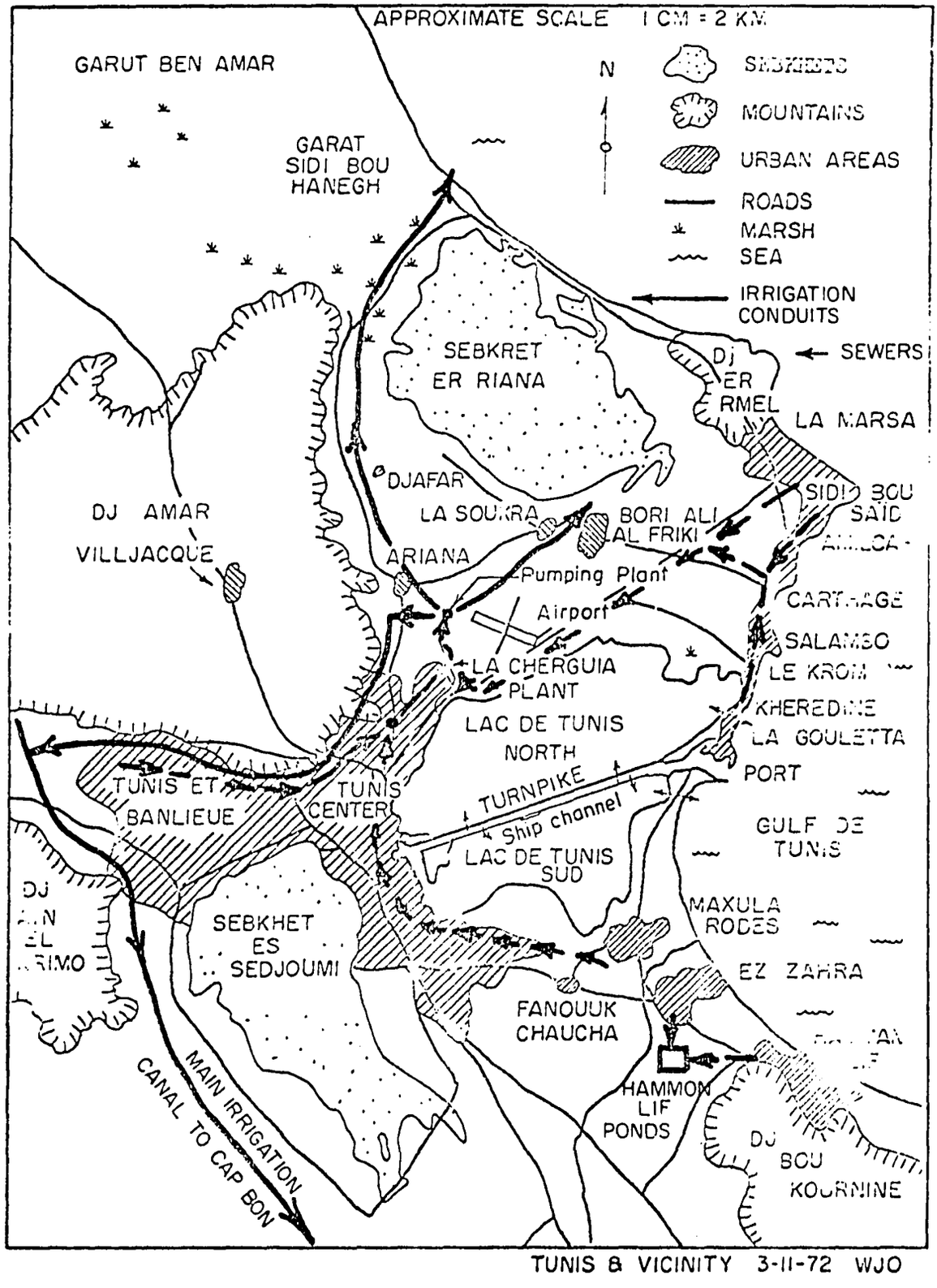


FIGURE 4. Showing Present Plan (HAR) for Sewerage and Water Reclamation at Tunis.

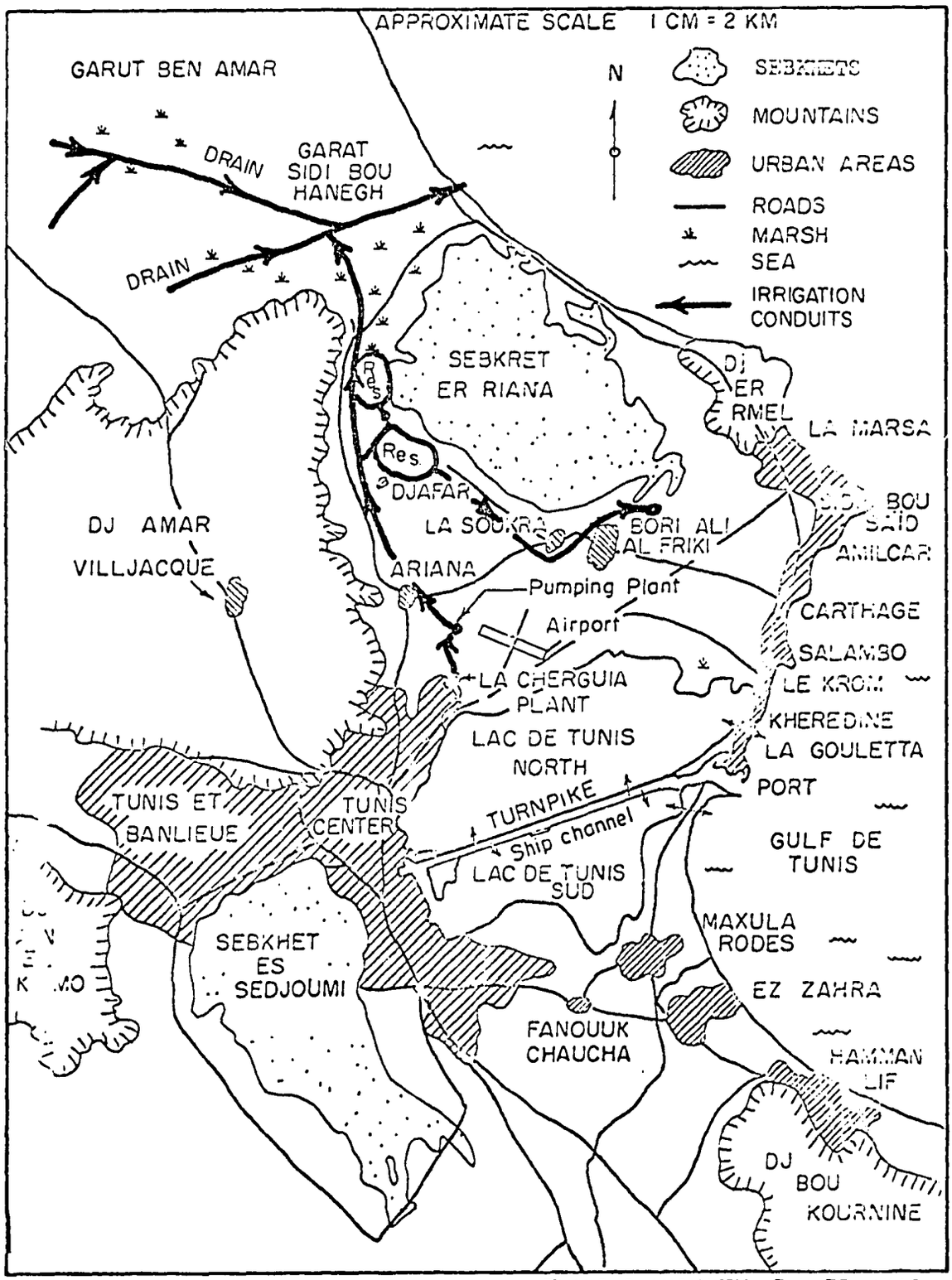


FIGURE 5. Bonifica Plan for Water Reclamation, Tunis, 1969. Drain would reclaim marshes; excess sewage and drainage water to the sea. Sewage collection system similar to that shown in FIGURE 4.

The major shortcoming of these plans is that they unecessarily utilize the complex, expensive and often unreliable activated sludge method of waste treatment prior to pumping the water and do not provide for adequate disinfection of the water. In the current or Bonifica plan, no consideration is given to utilization of the two seasonally dry lakes (Sebkhets) which constitute an enormously valuable resource in terms of potential waste treatment, disposal and storage area which could provide opportunities for other possible uses of reclaimed sewage for fish culture and for reclaiming the Sebkhets. Tunis' fortuitous combination of flat, close-in, no-cost land, excellent climate, and a need for irrigation water close to a large city is unique in the world. The fact that it is so unique is perhaps the reason that the great potential of pond treatment has, to now, been overlooked by the various engineering firms which have examined the problem.

Because of the fact that the current HAR plan does not include the use of ponds for treatment, a second alternative system is proposed which essentially duplicates the HAR plan with the exception that ponds would be used for treatment. La Cherguia would be the central point for collection and pumping all waste water, and the Sebkhet Er Riana would be the location of the main treatment pond system. The water, depending on its content of salt, would be treated in west ponds for salty water or east ponds for good water. Treated water suitable for irrigation would be pumped to the Djafar reservoir for use in irrigation. In this plan, conveyance of raw sewage from La Cherguia to the Er Riana ponds would be

by closed conduit or force main. Although the sewage could be conveyed from the divide northwestward by open conduit, this would not be hygienic because it would permit the possible unknowing use of fresh raw, untreated sewage by persons having access to the canal. It would also probably create a solid waste and odor nuisance problem as well. The third alternative is thus to utilize the HAR-Bonifica plan except to convey sewage from La Cherguia to Sebkhet Er Riana by force or gravity main and to use ponds for treatment. This plan is shown schematically in Figure 6.

A third alternative plan, shown in Figure 7, would involve collection of all waste at the La Cherguia plant and pumping it to a combined treatment pond and storage system near Djafar between the town of Ariana and the Sebkhet Ariana. The effluent from this storage system could be used either directly for irrigation, pumped to higher storage for later irrigation, or permitted to go by gravity into Sebkhet Ariana where it could be used for a land reclamation scheme or fish ponds.

A fourth alternative, emphasizing decentralization, gravity collection of sewage and maximizing the volume of high storage, is shown schematically in Figure 8. This plan has evidently not been considered previously but seems to have a large number of desirable characteristics.

The plan involves division of the collection system of Tunis into several major districts, at least four of which would be: The Es-Sedjoumi District; The Lac de Tunis District; The Ariana and Coastal District; and the South East District. Waste water from these districts would be collected mainly by gravity and treated by advanced ponding within the

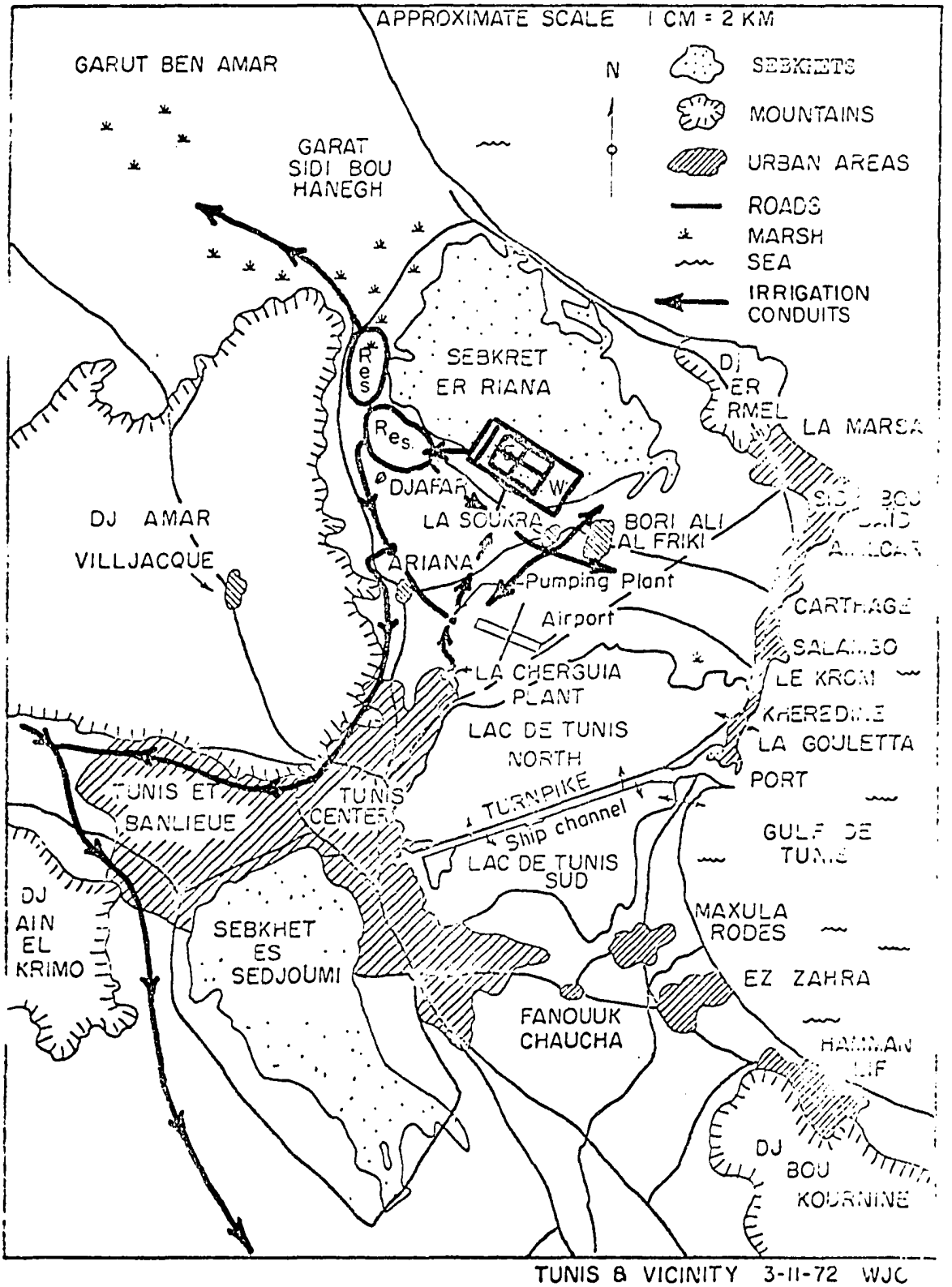


FIGURE 6. HAR-Bonifica Plan with La Cherguia Used As Collection Point. Waste Conveyed to Er Riana Ponds by Force Conduit for Treatment. Waste Collection System Similar to FIGURE 4.

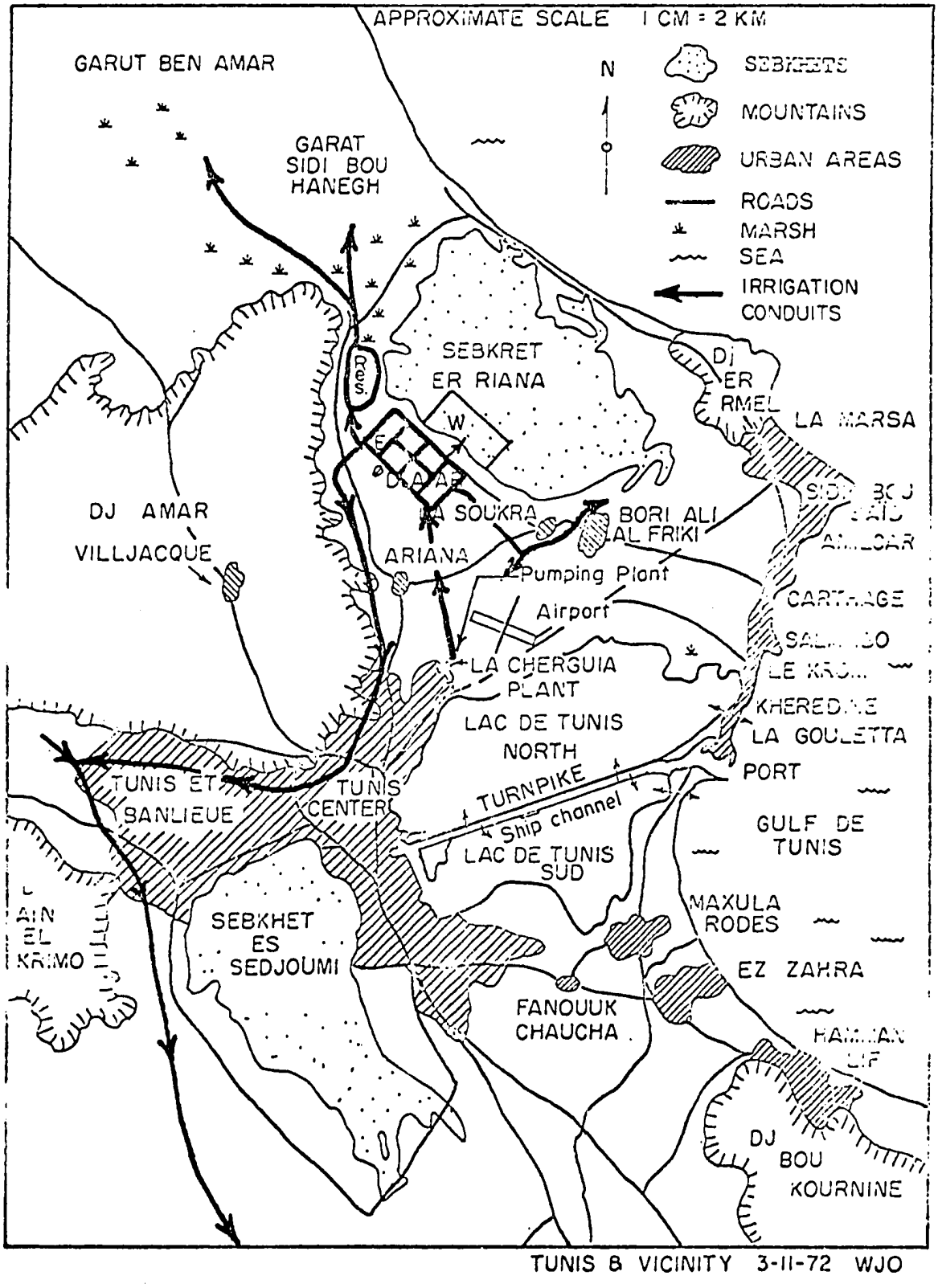


FIGURE 7. Force Conduit From La Cherguia Pumping Plant With Combined Treatment and Storage Near Djafar. Reject water to west pond in Er Riana.

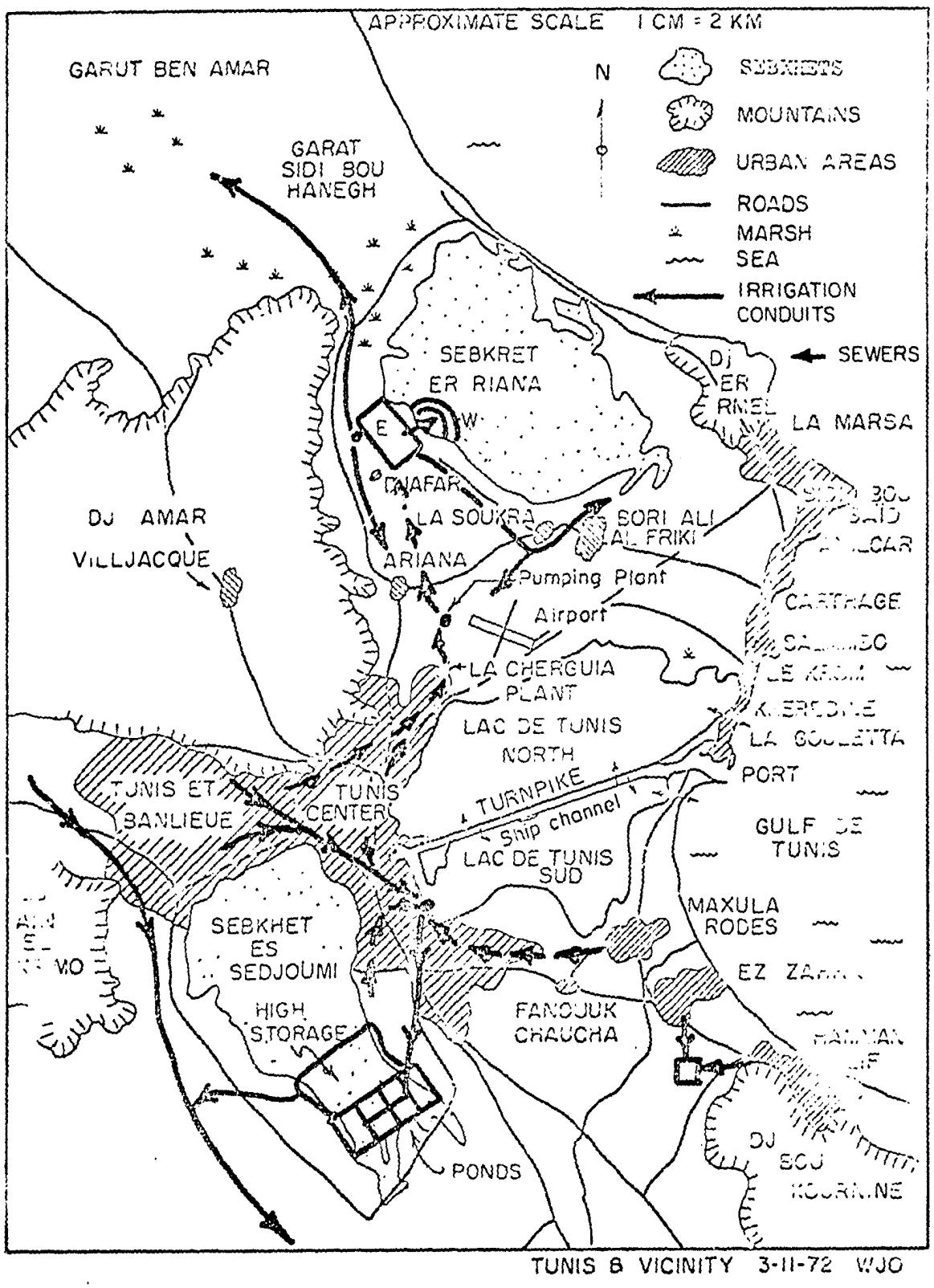


FIGURE 8. Decentralized Plan for Collection, Treatment and Disposal of Tunis Sewage.

district except the Lac de Tunis District which would be drained to a major pumping plant in the vicinity of the west port where it would be boosted into an interceptor running along the east shore of Es-Sedjoumi and together with drainage from Es-Sedjoumi District would enter a combined ponding storage system for treatment and reclamation. Wastes currently flowing into the La Cherguia plant and from the coastal area would be conveyed from La Cherguia to Sebkhet Ariana where, depending on its quality, it would be either discharged into a special holding pond in the bed of Ariana or treated and pumped to storage for irrigation. Wastes from the South East District would be ponded separately near Hammam Lif. Thus, at least three separate ponding systems would be established utilizing land which is now mainly wasted. The ponds would be located approximately as indicated in Figure 8. In this plan all useful waste water could be conserved, and thus any need to discharge waste water into the sea would be eliminated. The great value of using the Sebkhet Es-Sedjoumi for storage is the fact that the elevation of its bed is about 10 meters, and hence water could be provided by gravity for irrigation over a wide area of the well-drained soil to the south and east.

A final alternative which should be considered by any coastal community is a deep water outfall. Although it is our objective in this report to consider ways of conserving water, because a value of only about 5 milliemes per m^3 is currently ascribed to the waste water, its complete discard should at least be considered as an alternative to treatment. It is estimated that to provide an assured dilution of 10,000 to 1 and thus

to attain proper dilution the waste water should be injected into the Gulf of Tunis at least eight kilometers from the coast and at a depth no less than 50 meters. This scheme would require collection of all sewage at one point, such as La Cherguia, complete primary treatment and absolutely fail-safe removal of floatable materials, grease and settleable solids, followed by chlorination to prevent putrefaction in transit and contamination of the beaches. The waste water would then be pumped to a high point near La Marsa from whence it would flow either by gravity into the sea or require forced injection, depending upon results of a pumping cost versus pipe cost optimization study. A schematic diagram of the ocean outfall alternative is shown in Figure 9.

CRITERIA FOR EVALUATION OF ALTERNATIVE PLANS

As indicated in the introduction, many criteria must be met if the collection, treatment and disposal elements of a comprehensive system for waste management are to be declared feasible. These criteria center around effectiveness and cost. Within the effectiveness area, one has technical and functional feasibility, human impact including sanitation and environmental impact including compatibility with natural resources, water and land use and the biota* of the area.

Within the cost area are construction and operation costs and decision to application time. No detailed evaluation of the effectiveness and cost of the several alternative collection systems will be made. Similarly, no detailed evaluation will be made of the several potential disposal systems. However, an analysis will be made of several specific

*Biological organisms.

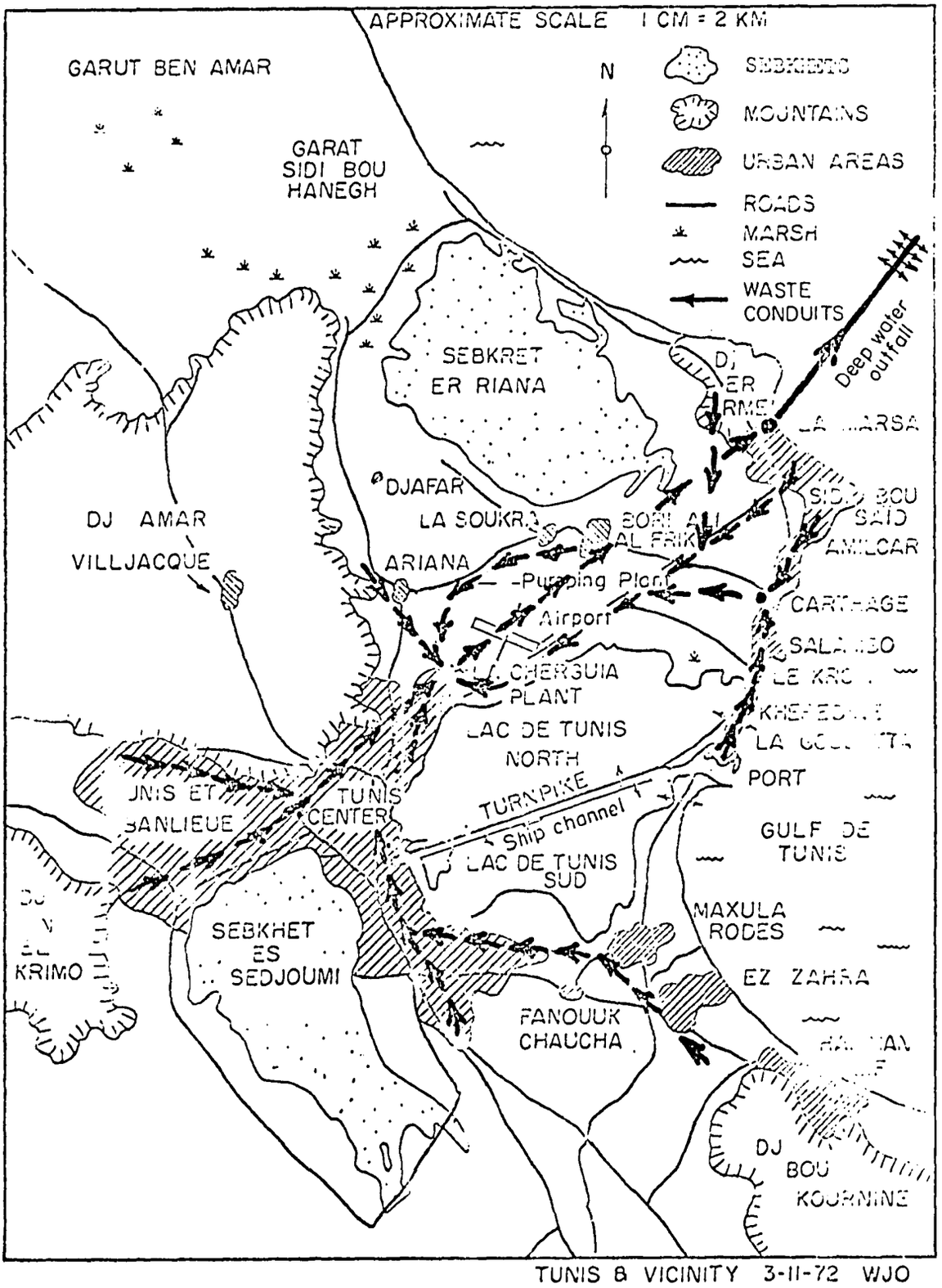


FIGURE 9. Centralized Collection of Tunis Sewage with Deep Sea Outfall.

combined treatment and disposal systems which appear to be technically feasible. The analysis will be in sufficient detail to permit conclusions to be drawn. Before these alternatives are presented and discussed, it is necessary to discuss the criteria in some detail.

While it is beyond the scope of this report to dwell in great detail on the several criteria of effectiveness and cost, something must be said about each to substantiate a basis for evaluation. In the interest of efficiency, the discussion, although somewhat general, will specifically deal with the proposed alternative treatment systems for Tunis, that is, mechanical systems and ponding systems.

Effectiveness of Treatment Systems

Technical Feasibility. Both mechanical systems and ponds are technically feasible since they are used over most of the world.

Functional Feasibility. Functionally, mechanical systems are much more delicately balanced than ponding systems and hence vulnerable to sudden changes and upsets.

Because of their large volume, ponding systems have a built-in redundancy that protects their functional characteristics from change whereas mechanical systems can afford little redundancy because of land and cost restrictions. Each component of a mechanical system is dependent on each other component for its function; hence, failure of one part can cause failure of the whole system.

Human Impact. With regard to human impact, there are several areas of concern including health, hygiene and aesthetics.

Health: We have previously discussed the fact that ponds provide a buffer against the transmission of disease that cannot be duplicated by mechanical systems even when chemical disinfection is employed. Thus, in a comparison of alternatives, chlorination must be employed to give a mechanical effluent equivalent to that of ponds.

Hygiene: Arguments similar to those for pathogens apply to substances of hygienic significance such as refractory compounds, toxicants and carcinogens. There is a much higher probability that these will be transmitted to humans by mechanical plant effluents than by pond effluents. Moreover, chlorination does not assure the elimination of toxicants and may actually create toxic compounds by interacting with certain substances in wastes.

Aesthetics: Properly designed and operated ponds are aesthetically pleasing in that they provide large areas of open space, sparkling water, wildlife enhancement and have no objectionable odor. Most individuals find aesthetic pleasure in the machinery, paint, polished brass and efficient sound of mechanical plants, but, unless the plant is working perfectly, the odor is sometimes less reminiscent of a drinking water treatment plant or power generation station than it is of an abattoir. Ponds, of course, do not project into the skyline but have a profile which is essentially unnoticeable from a short distance. The digesters or incineration towers of mechanical plants are very noticeable and in a few documented cases have actually been struck by flying aircraft.

Environmental Impact. The environmental impact of either type of

system is somewhat dependent on its function. Ponds make best use of renewable natural resources in that they may be constructed of local materials, on wasteland, and use sunlight as their primary source of energy. Mechanical plants may use waste materials as a source of energy, but the cost of the required energy recovery systems is frequently greater than the value of energy recovered. Since they are normally constructed of concrete and steel, mechanical plants have a high, non-renewable resource demand. To function, mechanical systems are dependent on moving machinery which is highly vulnerable to the corrosive substances in wastes and, therefore, require continuous skilled maintenance and part replacement to assure sustained function.

The maintenance requirements of mechanical plants are such that a great many skilled mechanical technicians are required to obtain sustained operations whereas in a ponding system operations are minimized because sustained function is built into the system. The skills of maintenance personnel required for ponds are similar to those required by irrigation and agricultural specialists.

Water Recovery: With regard to water recovery systems, mechanical plants deliver to the effluent essentially all of the influent water at about the same level of solids and nutrients but at a lower BOD, but as noted previously the water may contain pathogens, toxicants and carcinogens*. The amount of water discharged from ponds is diminished in volume by evaporation and percolation. The dissolved solids content of pond water is increased in proportion to the evaporation which occurs during residence in

*Substances capable of producing cancerous growths in living organisms.

the pond. Percolation from the pond does not change water quality but infiltration into the pond can change quality. Infiltration is normally prevented by maintaining the surface of the pond water above the pressure crest of the groundwater. Pond effluents are normally lower in pathogens, toxicants and carcinogens than mechanical plant effluents.

Land Use: If reservoirs are required for storage of irrigation water, the reservoir may be used for pond treatment or conversely ponds may be used to store substantial quantities of water. Ideal irrigation storage should be high with respect to the land to be irrigated whereas gravity fed ponds are normally located on low land. Detailed studies of land values and pumping costs must be made to reach any rational combination of high and low storage in ponds. For mechanical systems pumped direct application or pumped storage is normally required. Land use for storage should be included in the land use assignments for mechanical plants.

Biota: Ponds provide a habitat for fish and bird life and may eventually be used for the production of animal feeds. The effluents from mechanical plants when stored often become a base for blue-green algae growth. Such algae are sometimes malodorous and toxic to wildlife. Secondary effluents discharged into shallow saltwater bodies cause proliferation of seaweed.

Flexibility: Mechanical treatment systems are generally quite inflexible so that operational skill, while essential, can do little to improve the built-in performance of the system. On the other hand misoperation, neglect or the loss of some critical part can convert a

functional mechanical system into a mere wide place in the outfall sewer. Some flexibility is available in well-designed ponding systems, particularly with respect to series versus parallel operation and the use of shorter detention periods in summer and longer detention periods in winter. Generally speaking, however, pond systems which have built-in function are not highly flexible. They are, however, unlikely to break down.

Reliability: The reliability of mechanical plants is generally quite low. This is because they have little buffer capacity and hence cannot maintain performance when there is a breakdown of some element of the system or a sudden increase in volume or waste strength or an influx of toxicants. Often, if some component of the system fails, wastes must be bypassed until function is restored. The resultant is a breach in the reliability of the system. Ponds which are properly designed to prevent short circuiting of wastes will, because of their buffer capacity, provide an effluent of remarkable consistency in quality and volume. Thus, ponds are much more reliable than mechanical systems.

The preceding effectiveness factors are difficult to evaluate precisely, but on the other hand alternative systems cannot be compared unless some quantitative scale is used. Accordingly, in this study, an arbitrary effectiveness scale will be used for each effectiveness factor, the values ranging from one for low effectiveness to ten for high effectiveness. Obviously, such a rating system is highly subjective and would to some extent vary with each person's views and knowledge of the systems in question.

Cost Effectiveness. The cost criteria require much less subjectivity. Construction cost records are available for the systems in question, and cost indices are also available to compensate for the rapid changes that occur in costs with respect to time. Comparative cost indices for various geographical areas are also available. Fixed costs are, of course, a function of capital costs, the rate of interest and the debt repayment time. They are also a function of the life expectancy of the system because some systems are so short-lived that they must be replaced or overhauled before they are paid for. To compensate realistically for this contingency, shorter capital recovery times should be assumed for mechanical systems than for ponding systems.

Operations and Maintenance: Operation and maintenance cost data are available from U.S. sources but cannot be applied directly to Tunis because of substantial differences in the cost of labor, materials and energy. Therefore, operation and maintenance costs are estimated on the basis of such data as is available for Tunis.

Decision to Application Time: This factor is of significance because it involves the fact that costs continuously change while a system is under design and construction. A complex mechanical system may be in the design stage for two or three years whereas a ponding system may be designed within one or two years. A complex mechanical system also requires a great deal more routine detailed engineering whereas a ponding system may require substantial amounts of innovation, soils work, geology and engineering judgement. A mechanical system requires the ordering and delivery of large,

complex parts whereas a ponding system requires mainly local materials. For these reasons, engineering and contingency factors which are used for mechanical systems should be much larger than those used for ponds. However, in the interest of simplicity, equal engineering and contingency factors have been used for both types of systems in the cost comparisons of this report.

Cost-Effectiveness: This is a parameter by which the effectiveness of expenditures can be compared. In this study the cost of the system will be divided into the effectiveness number. Thus, the highest number will be associated with the most feasible project.

COSTS OF TREATMENT SYSTEMS

Cost Indices

The prediction of construction costs in Tunis based on U.S. cost indices is at best an uncertain procedure. Substantial differences in the costs of labor, energy and materials probably tend to cause divergences, but there is little that can be done in a study of short duration to evaluate such divergences. Accordingly, this analysis is based on the assumption that costs in Tunis are somewhat comparable to those in the United States.

The pertinent cost indices for sewage treatment plants and sewers are published in the U.S.A. by the Environmental Protection Agency (8), and those for the earthwork are published by the U.S. Bureau of Reclamation (9). These are shown in Figure 10. Projected cost indices for mid-1972 are for sewers, 1.88 (1957-58 costs = 1.00); for sewage treatment plants,

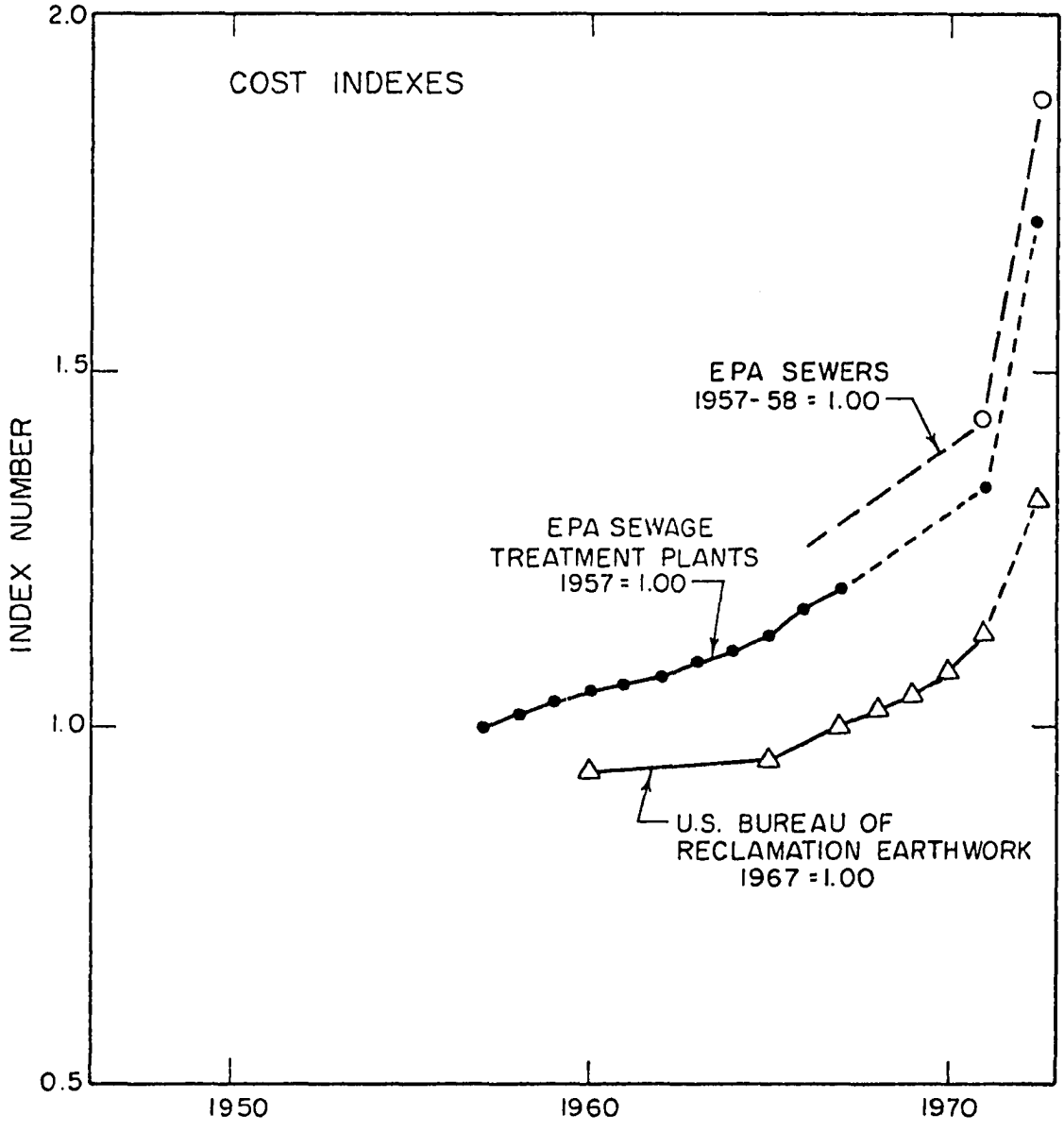


FIGURE 10. COST INDEXES FOR SEWERS, SEWAGE TREATMENT PLANTS, AND EARTHWORK, U.S.A., 1957-1972

1.71 (1957-58 cost = 100); and for earthwork, 1.31 (1967 cost = 1.00).

In using these indices, data on costs was adjusted by multiplying by the ratio of the pertinent cost index for the year of the data divided into the cost index for mid-1972.

Cost Curves

Cost curves for primary treatment, activated sludge treatment, trickling filter treatment and chlorination published by Robert Smith (10) from the United States Environmental Protection Agency were applied. Efforts to obtain Smith's most recent data in time for use in this report were unsuccessful.* Hence, his data of 1967 wa. applied by dividing the 1967 index of 1.19 into the 1972 index of 1.71 to obtain an index ratio of 1.44.

Comparative Indices U.S. and Construction Abroad

According to the American Society of Civil Engineers (11), construction costs in Tripoli are about 1.1 times higher than those in the United States (no data is presented for Tunis).

On the assumption that Tunis costs may be similar to those of Tripoli, a U.S. to Tunis index of 1.1 was applied to the adjusted 1972 U.S. values.

Application of Indices. The treatment cost curves of Smith, adjusted to 1972, increased by a factor of 1.1 and converted to the metric system and to Dinars are presented in Figures 11, 12, 13 and 14, for primary

*Smith's most up-to-date information was received on April 15 and appears to be comparable to the data applied in this report.

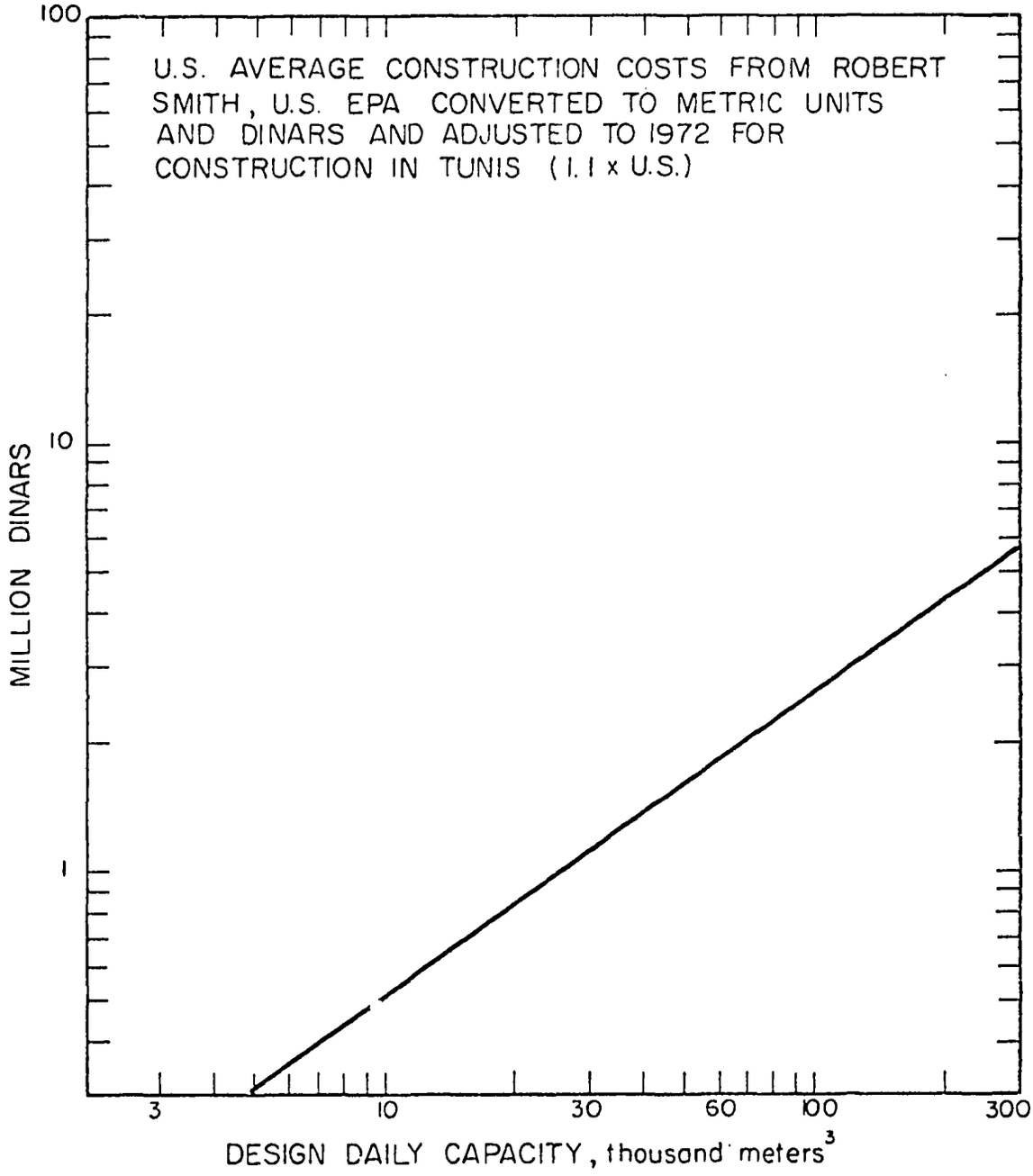


FIGURE 11. ESTIMATED COSTS FOR PRIMARY TREATMENT SYSTEMS TUNIS, 1972

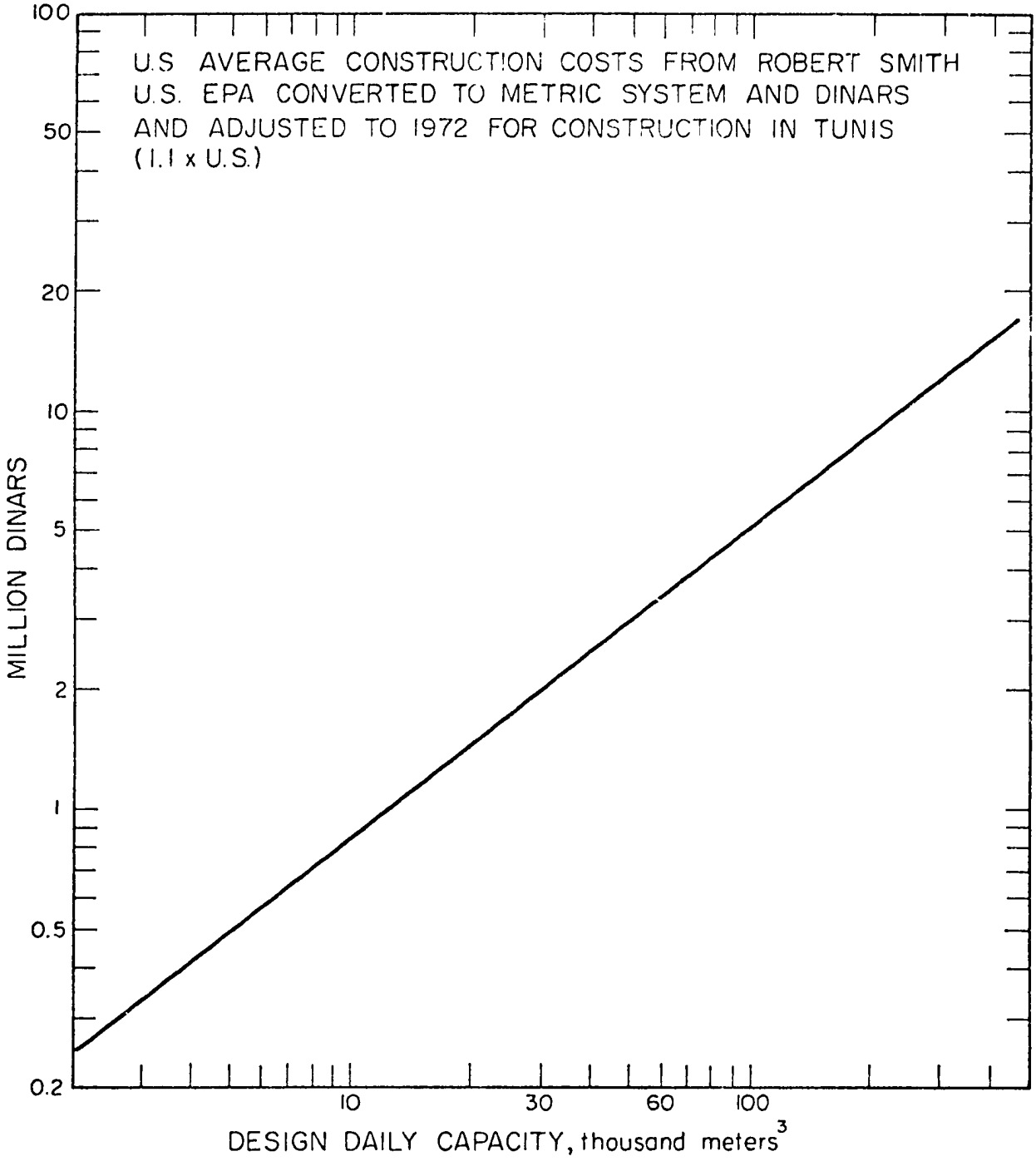


FIGURE 12. ESTIMATED COSTS FOR ACTIVATED SLUDGE TREATMENT SYSTEMS, TUNIS, 1972

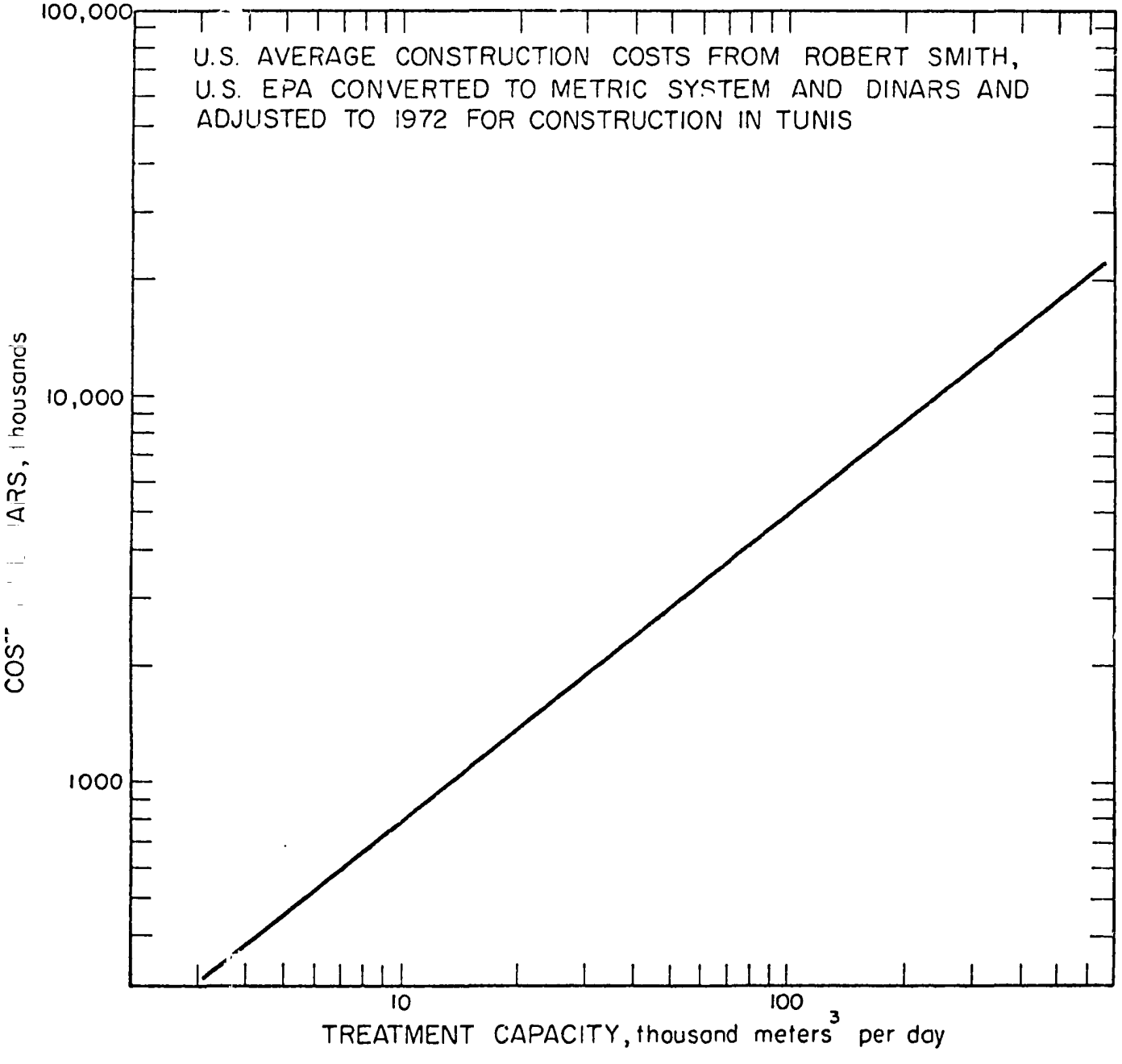


FIGURE 13. ESTIMATED COSTS FOR TRICKLING FILTER SYSTEMS TUNIS, 1972

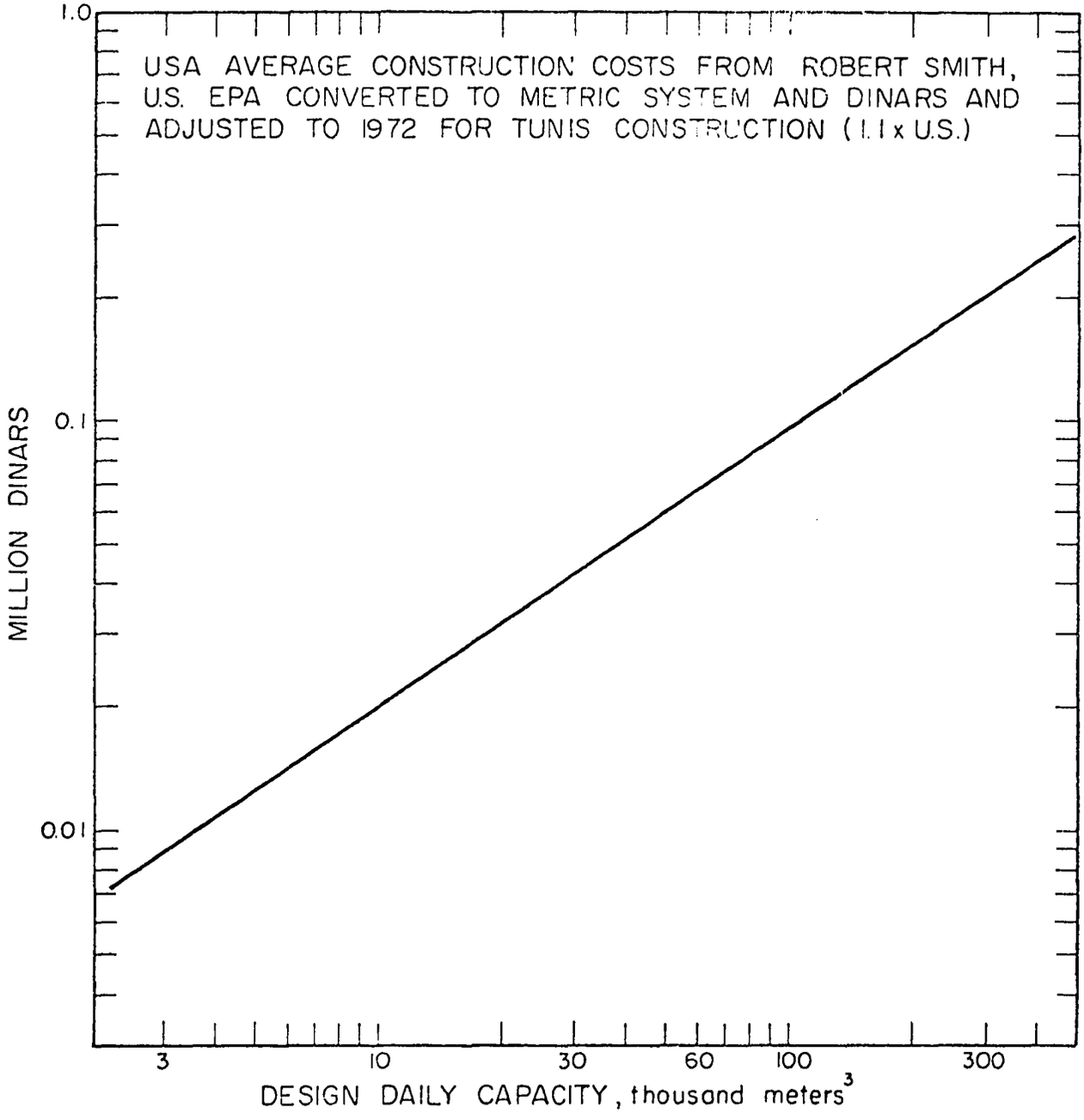


FIGURE 14. ESTIMATED COSTS FOR CHLORINATION FACILITIES, TUNIS 1972

treatment, activated sludge, trickling filtration and chlorination respectively. Smith's cost data for debt retirement, operations and maintenance are not used because of differences in assumed interest and debt retirement as well as the cost of labor, materials and energy.

Pond Costs. The cost curves shown in Figure 15 for ponds are not EPA curves but are based on costs of systems with which the author is familiar and for which cost data was readily available. Costs are adjusted from the year of construction to 1972 by using the ratio of the 1972 index of 1.71 to the index of the year of construction. The data on ponds which stems mainly from California with an ASCE index of 1.09 may well be directly applicable to Tunis. Nevertheless, all pond cost data was multiplied by the U.S. to Tunis conversion factor of 1.10 as was the case for other types of treatment systems.

Conveyance Costs.

Pipelines: The cost of waste water conveyance systems was evaluated on the basis of data on pipe costs for Tunis and the U.S.A. as presented in Figure 16. No data were available for large pipe in place in Tunis; consequently, the ratio of cost installed to factory cost for smaller pipes in Tunis was determined and extrapolated to larger pipe from which the large pipe installed value was estimated. Assuming that the available pipe data applied to early 1971, the data was increased by the EPA pipe index factor of 1.88/1.50 or about 1.25. The available data indicates that small pipe costs in place in Tunis are about 60 percent less than in the United States.

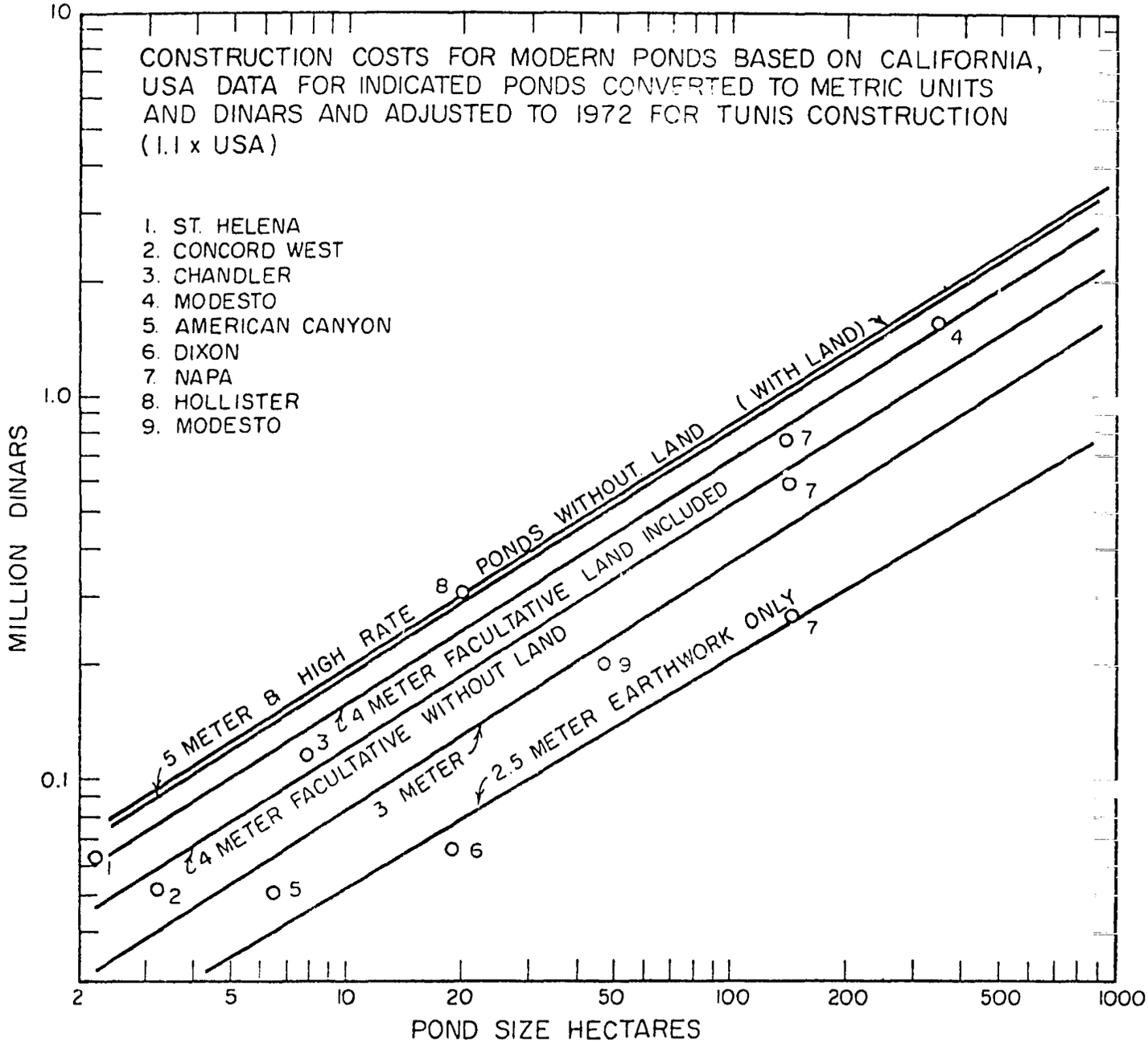


FIGURE 15. ESTIMATED COSTS FOR PONDS, TUNIS 1972 (INCLUDES USA COSTS FOR SPECIFIC PONDS ADJUSTED TO 1972)

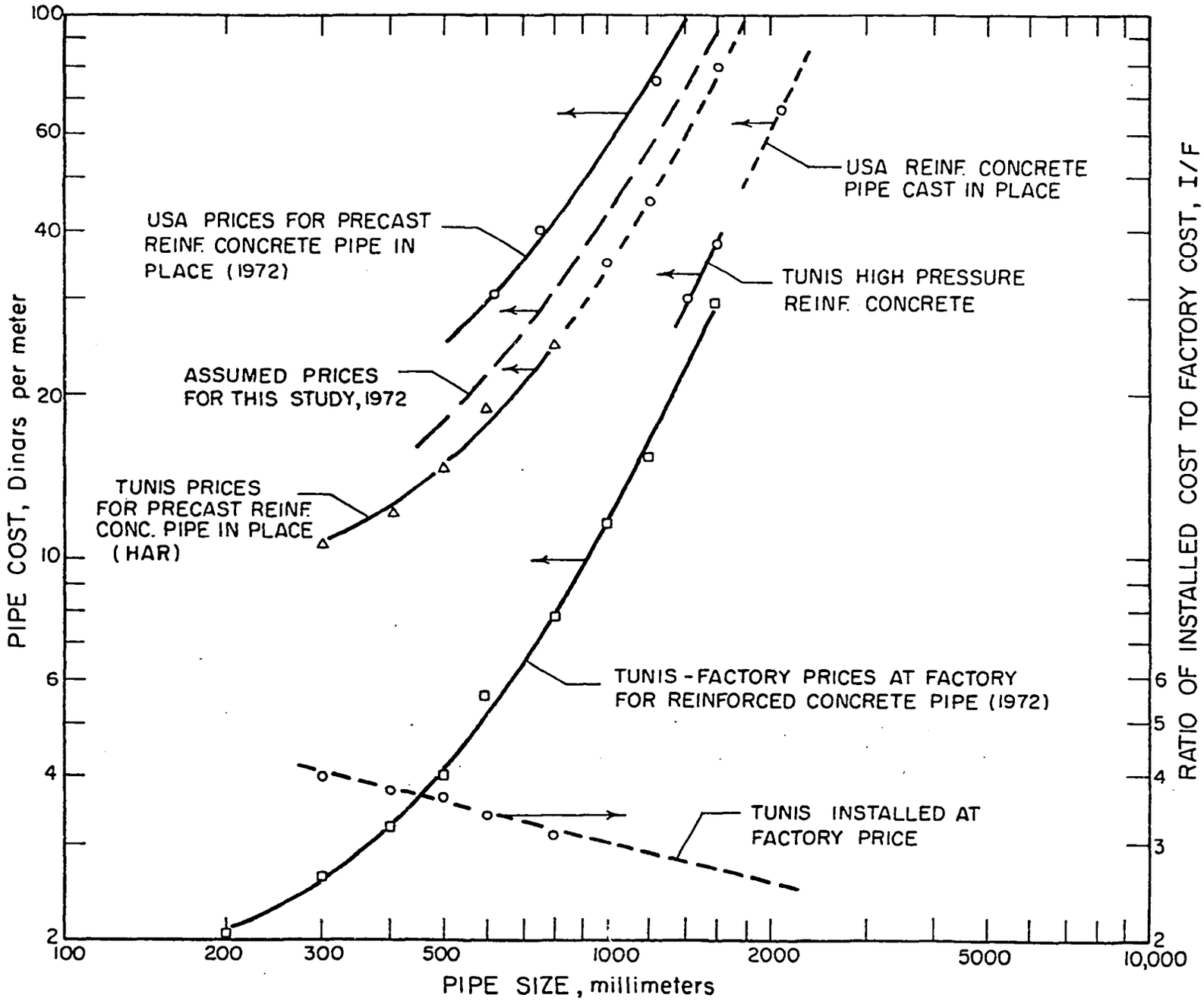


FIGURE 16. Conduit Cost Data.

Pumps. Recent (1970) data for the cost of small line-pumping stations was available from Tunis (6). Cost data from the 65 MGD Napa, California (1967), pumping station was converted by using the cost index of Figure 10, converting to metric units and Dinars and multiplying by 1.1. These data were then plotted to give the cost curve for pumping station costs shown in Figure 17. These costs for pumping stations are applied only to line systems with lifts on the order of 10 meters or less.

Other Cost Factors. None of the cost curves used are assumed to include an engineering and contingency factor. Thus, in computing annual costs and unit costs for the various systems, a contingency factor of 20 percent was in each case added to the capital costs involved.

None of the cost curves used are assumed to include land or easement costs. However, inasmuch as the potential ponding sites in Tunis are public lands and inasmuch as land costs for pumping sites and easements are normally small, they are presumed to be included in the 20 percent contingency factor applied to the capital cost in each case.

A uniform interest rate of seven percent applied to all capital expenditures is assumed in all cost calculations. There being considerable differences in the life of mechanical equipment as compared with earth structures and pipes, it has been assumed in this study that mechanical equipment will require replacement each 15 years and earth structures and pipes each 25 years. Thus, a factor of 15 percent per annum is applied for mechanical systems and a factor of 11 percent per year is applied for earth structures and pipes.

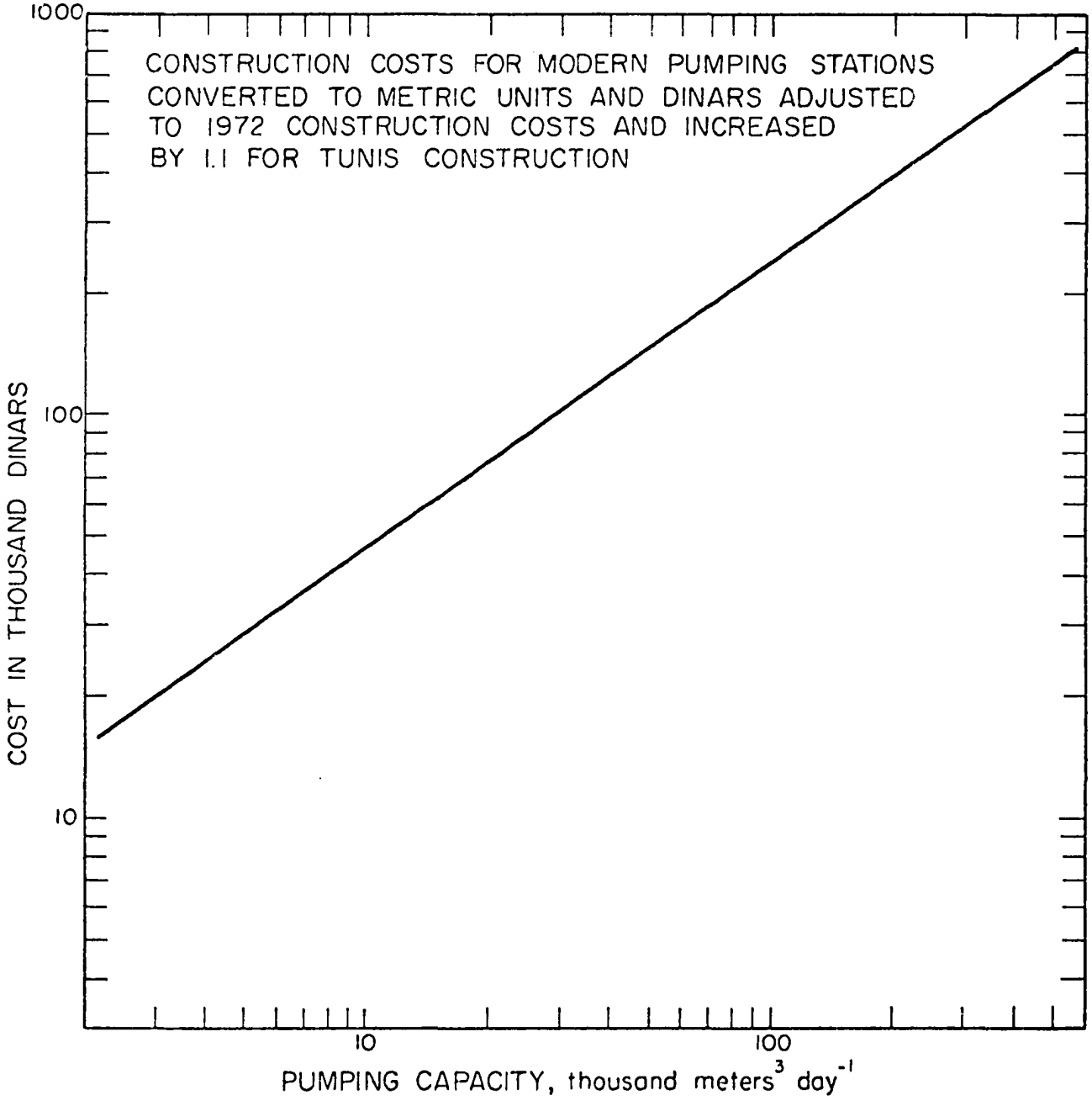


FIGURE 17. ESTIMATED COSTS FOR PUMPING STATIONS, TUNIS, 1972

A uniform cost for electrical power of 10 milliemes per kilowatt hour was presumed and a cost for personnel of 150 Dinars per month was assumed. Chlorine is assumed to cost 25 milliemes per kg.

Plant Design Considerations

The costs of mechanical plants in this study could be evaluated on the basis of assumed flow volumes. Ponds on the other hand are best evaluated on the basis of area, the required area for the same flow being somewhat different for each locality. Thus, it was essential to design ponds for Tunis in order to evaluate cost. There are two varieties of ponding systems which would work well in Tunis to be considered, reduction-reclamation ponds and facultative ponds. The former include mechanically mixed photosynthetic facilities, termed "high-rate ponds", as a part of the system whereas the latter have no special mixing facilities. The design and cost evaluations for each type of pond applied specifically to a 100,000 m^3 system in Tunis are presented in Appendix 1. Some of the essential data entering into these designs are discussed in the following section.

Population and Flows. The basis for waste treatment plant design is normally flow volume and BOD. Italconsult in 1970 reported a flow of 50,000 m^3 per day for La Cherguia when the population served was 350,000. The indicated per capita flow was 155 liters per day.

Population data for Tunis as reported by HAR is shown in Figure 18. According to the data, approximately half of the population currently contribute sewage at La Cherguia. If the entire predicted population of

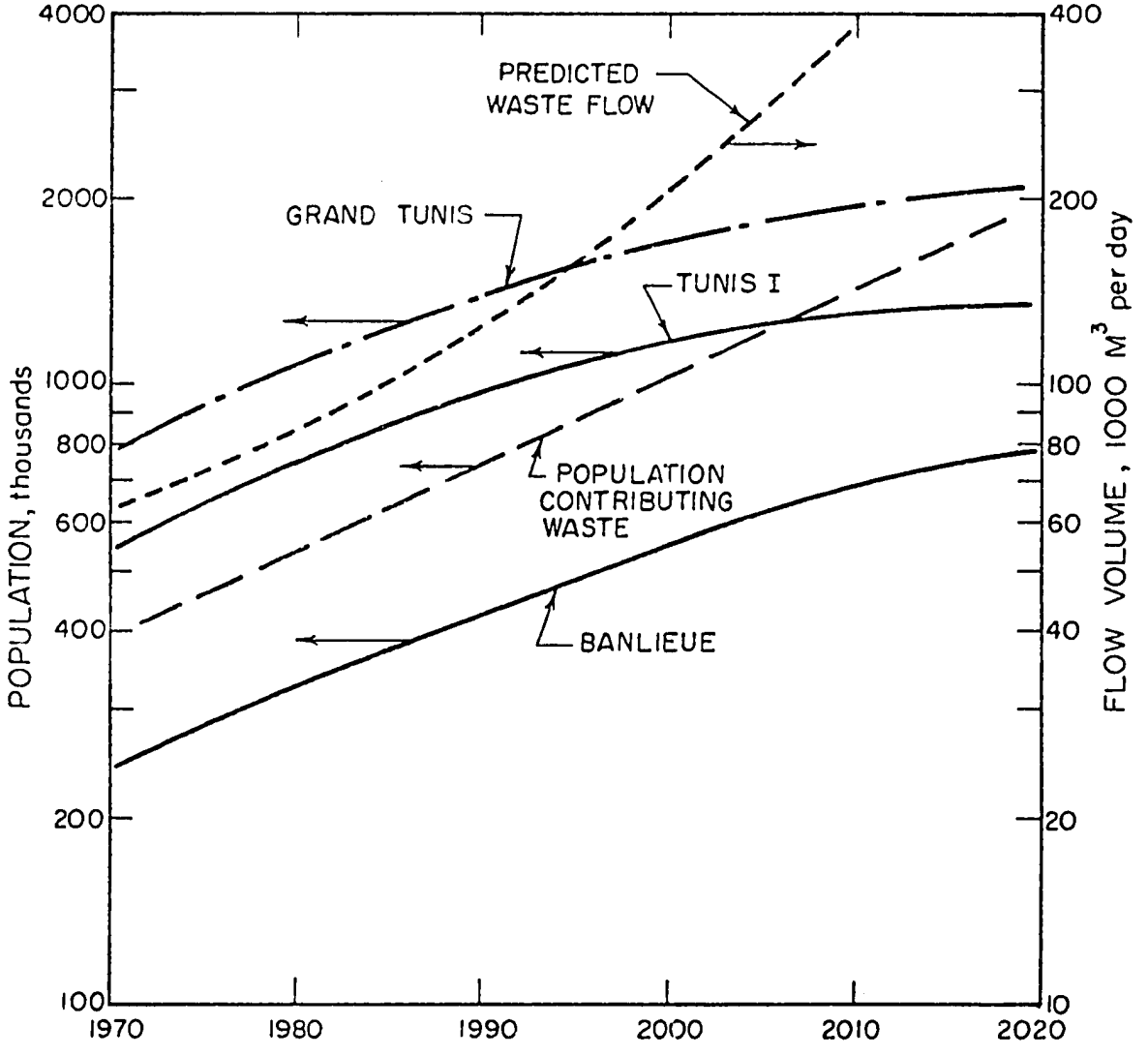


FIGURE 18. ESTIMATED POPULATIONS AND WASTE FLOWS FOR TUNIS ET BANLIEUE, 1970-2020

1,216,000 in 1985 were to contribute sewage, the flow at that time for greater Tunis would be 188,000 m^3 per day. However, because the contributing population is only slightly greater than half of the population, a flow of only slightly over 100,000 m^3 is expected by 1985. Beyond 1985, a larger and larger percentage of the population will be sewered and per capita waste flows are expected to increase. However, a fixed flow of 100,000 m^3 per day is assumed for this report as a base for cost comparisons.

Sewage Characteristics. Recent studies by HAR (6) gave the analytical results for Tunis sewage shown in Table V. Results are for waste at the influent to the La Cherguia plant.

Biochemical Oxygen Demand (BOD) of Tunis Sewage. The analytical work to determine the current five-day 20°C BOD of Tunis sewage at the influent of La Cherguia gave results of 118 mg/l and 175 mg/l on 2/3/72 and 2/7/72 respectively. The corresponding ultimate BODs were probably 173 mg/l and 256 mg/l. The corresponding per capita ultimate BOD values, assuming a flow of 154 liters per capita per day, are 26.8 gms/day and 41.3 gms/day. The average of these two values is 34 gms/cap/day which corresponds to the value of 30 gms/cap/day estimated earlier by Bonifica engineers (3); it does not, however, correspond to the normally presumed BOD of 75 to 80 gms/cap in Europe and the United States.

While several cultural differences may be involved, such as less fat consumption and food waste in Tunis than in Europe or the U.S.A., it is believed that the major differentiating factors are threefold.

TABLE V

ANALYSIS OF THE WASTE WATER OF TUNIS

Sampling Point: Entrance of the Treatment Station (La Cherguia, Skimmer System)

ELEMENT	CONCENTRATION	SAMPLING DATE	
		2/3/72	2/7/72
Calcium	mg/l	144	176
Magnesium	mg/l	43	43
Sodium	mg/l	264	230
Potassium	mg/l	50.8	52.8
Calcium	me/l	7.20	8.8
Magnesium	me/l	3.60	3.60
Sodium	me/l	11.50	10.0
Potassium	me/l	1.30	1.35
Dissolved Oxygen	mg/l	0.00	0.00
H_2S	mg/l	4.08	4.08
Chloride	mg/l	4.90	4.40
	mg/l	13.80	12.39
Sulfate (SO_4)	mg/l	313.12	354.32
	me/l	6.52	7.38
Dry Residue Total	mg/l	2,640	2,640
Mineral Materials in Dry Residue	mg/l	780	800
	%	29.5	32.5
Organic Materials in Dry Residue	mg/l	1,860	1,660
	%	70.5	67.5
NH_4 Released	mg/l	40	20
Conductivity	m mho/cm	2.45	2.22
BOD_5	mg/l	118	175
pH		8.50	8.20

1. A high degree of sedimentation and decomposition of organic matter in the sewers due to the relatively warm climate of Tunis and the low velocities in the sewers (this is evidenced by the high H_2S values found in the sewage).

2. The difference between the population and the number of actual sewage connections which would tend to weaken the sewage.

3. Intrusion of extraneous water into the sewers from infiltration of seawater inflow at the tide gates.

Future Biochemical Oxygen Demand of Tunis Sewage. Because of the current program to improve the sewers in Tunis, it is expected that when these improvements are complete there will be higher velocities and less sedimentation and putrefaction in the sewers; there will be a higher fraction of the population actually contributing waste to the sewage flow and there will be less intrusion of extraneous groundwater and tide water to the sewers. Also, with increased urbanization, it is expected that there will be more food waste.

Because of all these factors, it is anticipated that there will be a persistent increase in the per capita waste BOD and that by the year 1985 the per capita BOD will reach 50 gms/day.

Contributing Population and BOD

Based on a HAR study as shown in Figure 18, the contributing population in 1985 will be 650,000 persons, and at that time the total waste should have a BOD of 32,500 kg. Accordingly, 32,500 kg is assumed to be the BOD to be satisfied by the ponding systems for which design

calculations are shown in Appendices 5 and 6.

Flow Volumes and Factors of Safety

To avoid overloading the various systems, force mains, pumps, pumping stations and outfalls should be designed for peak daily and peak annual flow. To estimate daily variations, one may use Harmon's formula (12):

$$Q\ max = Q\ ave\ [1 + 14/(4 + P^{0.5})]$$

in which P is the sewered population in thousands.

To indicate the method of calculation, two sewered populations will be considered, that for 60,000 m^3 per day and that for 100,000 m^3 per day.

Assuming the per capita flow is 1.54 liters per day, for 60,000 m^3 per day, P = 388,000 persons; and for 100,000 m^3, P = 650,000 persons.

Applying the Harmon formula for 388,000, one has:

$$Q\ max = Q\ ave\ [1 + 14/(4 + 388^{0.5})]$$

$$Q\ max = 1.54\ Q\ ave$$

and for 650,000, one has:

$$Q\ max = Q\ ave\ [1 + 14/(4 + 650^{0.5})]$$

$$Q\ max = 1.475\ Q\ ave$$

According to Italconsult (5), peak annual flow occurs in June and is 1.24 x mean flow.

The corresponding high-high flow corrections are:

for 60,000 m^3 per day, 1.54 x 1.24 = 1.91,

or 60,000 x 1.91 = 115,000 m^3 per day = 1.33 m^3 per second;

for 100,000 m^3 per day, 1.47 x 1.24 = 1.82,

or 100,000 x 1.82 = 182,000 m^3 per day = 2.10 m^3 per second.

To provide for discontinuous pumping, pipeline and pumping capacities of 2.5 m^3 per second have been used in this report.

Factors of safety should be applied to activated sludge and trickling filter plants as well as pumping plants because they lack volumetric buffer capacity. However, the usual practice of engineering firms is to design waste treatment systems for flows sufficiently far into the future that the assumed flow for the future assumed population covers the lack of a factor of safety. Unfortunately, when this is done and the actual mean flow volume reaches the design flow volume, the plant will be overloaded and will fail to perform its function a substantial fraction of the time. Because of an inherent lack of buffer capacity, to perform properly at design flow activated sludge plants and trickling filter plants should be designed with a 50 percent factor of safety. Only then would they provide fail-safe treatment at peak design flow. For example, to faithfully treat a mean design flow of 100,000 m^3 per day, an activated sludge plant should be designed for 150,000 m^3 per day.

On the other hand, properly designed ponds need not be designed with such a factor of safety. Because of their enormous buffer capacity, they need only be designed for the predicted design flow.

In spite of the need for a factor of safety in mechanical treatment systems, no factor of safety has been applied in the calculations in this report, thus disregarding performance. The costs for the ponding system

and the activated sludge system are therefore compared strictly on the basis of equal flow volumes.

SELECTION OF ALTERNATIVES FOR EVALUATION

Because of the limited time in this study and space in this report, not all of the possible combinations of alternative collection, treatment, and disposal systems mentioned previously can be evaluated in accordance with the stated criteria. The specific evaluations will therefore be limited to four technically feasible alternatives for flows of 100,000 m^3 per day. Alternatives 1, 2 and 3 each have sub-alternatives A and B.

Mechanical Treatment with Activated Sludge - 1A

Treatment of 100,000 m^3 per day at the La Cherguia plant by activated sludge with chlorination and pumping and conveyance of the treated chlorinated water to a reservoir to be constructed in the vicinity of Djafar (c.f. Fig 1). Involved is a 100,000 m^3 activated sludge plant and a 100,000 m^3 pumping plant and a 5.5 kilometer conveyance system.

Mechanical Treatment with Trickling Filtration - 1B

Same as for Activated Sludge except for treatment in a 100,000 m^3 per day trickling filter plant.

Raw Reduction-Reclamation Ponds in Sebkhets 2A

Conveyance of 100,000 m^3 per day of raw sewage from the vicinity of La Cherguia to a complete reduction-reclamation ponding system in Sebkhet Er-Riana. Treatment of the sewage in the ponds and conveyance of the treated water to a reservoir near Djafar. Involved is a 2.5 m^3 per second pumping station, a 7.5 kilometer conveyance system to Er-Riana, a 100,000 m^3

per day ponding system at Er-Riana and a 100,000 m^3 per day pumping station and 3000 meter conveyance system to Djafar.

Raw Facultative Ponding in Sebkhets - 2B

The same as for Raw Reduction-Reclamation except for use of a facultative ponding system.

Primary Treatment and Reduction-Reclamation Ponding Near Djafar - 3A

Conveyance of 100,000 m^3 of sand- and grease-free raw sewage from the vicinity of La Cherguia to the vicinity of Djafar for treatment by intensive ponding in the reservoir area. (In this case, no profiles are available for the route from La Cherguia to Djafar; hence, a 10 meter lift is assumed.) To assure that no problems would occur with grease in the reservoir, the La Cherguia plant would be converted to a 100,000 m^3 per day grease and sand removal system with high temperature incineration of all removed floatable materials. The clean ash, together with the sand, properly washed could be used for clean fill to improve lake-front properties in the vicinity of La Cherguia. Involved would be a 100,000 m^3 per day primary station at La Cherguia, a pumping station and 5.5 kilometer conveyance system to Djafar and a waste pond system at Djafar.

Primary Treatment and Facultative Ponding Near Djafar - 3B

Same as Primary Treatment and Reduction-Reclamation Ponding except for use of a facultative pond at Djafar.

Primary Treatment with Deep Sea Disposal - 4

Removal and high temperature incineration of all floatables from 100 000 m^3 at La Cherguia followed by chlorination of the raw waste and

conveyance for injection into a deep outfall off La Marsa. Involved would be a 100,000 m^3 primary treatment at La Cherguia, a pumping station and 13 kilometer overland outfall and an eight kilometer sea outfall.

EVALUATION OF ALTERNATIVES

Within the alternatives selected for evaluation, there are a number of components in common. These are listed in Table VI, together with the alternatives in which they are used. The costs of each of these components in terms of capital costs and cost of debt retirement, interest, operations and maintenance are worked out in the Appendices. The number before the component in Table VI indicates the number of the Appendix in which the design and/or cost calculation is to be found.

Costs

The first cost, annual cost and unit cost of the alternatives explored are tabulated in Table VII.

According to the data, facultative ponding in Er-Riana is the most economical alternative, both with respect to first cost and annual costs. The next most economical is reduction-reclamation ponding in the Er-Riana.

Activated sludge treatment with conveyance to Djafar is the most expensive alternative, more than twice as expensive as facultative ponding in spite of the fact that the facultative pond included conveyance of raw sewage from La Cherguia to Er-Riana and from Er-Riana to Djafar.

Unless some value is ascribed to reclaimed water, the alternatives of discarding primary treated chlorinated waste into the sea is more economical

TABLE VI

LIST OF SYSTEM COMPONENTS AND
ALTERNATIVES IN WHICH THEY ARE USED

Appendix No.*	Component	Used in Alternative
1	100,000 m^3/day activated sludge plant with chlorination	1A
2	100,000 m^3/day trickling filtration plant with chlorination	1B
3	150,000 m^3/day pumping plant and 7.4 kilometer force main from La Cherguia to Er-Riana	2A, 2B
4	150,000 m^3/day pumping plant and 5.5 kilometer force main from La Cherguia to vicinity of Djafar	1, 3A, 3B
5	Reduction-reclamation pond for 100,000 m^3 per day	2A, 3A
6	Facultative pond for 100,000 m^3 per day	2B, 3B
7	80,000 m^3/day pumping plant and 4.0 kilometer force main from Er-Riana to vicinity of Djafar	2A, 2B
8	100,000 m^3/day primary plant	3A, 3B, 4
9	100,000 m^3/day pumping plant with 10 kilometer force main and 8000 meter gravity sea outfall	4

*Cost calculations for the alternative will be found in the indicated appendix.

TABLE VII

TABULATION OF ALTERNATIVE COSTS

ALTERNATIVE AND ELEMENTS	COSTS		
	First Cost 1000 Dinar	Annual Cost 1000 Dinar	Unit Cost, m^3 Milliemes
1A 100,000 m^3 activated sludge with chlorination	6,120	1,113	30.5
Conveyance to Djafar	960	165	4.5
TOTALS	7,080	1,278	35.0
1B 100,000 m^3 trickling filter with chlorination	6,000	1,072	29.0
Conveyance to Djafar	960	165	4.5
TOTALS	6,960	1,237	33.5
2A 100,000 m^3 pumping and conveyance to Er Riana	1,135	193	5.3
100,000 m^3 reduction-reclamation pond	2,147	381	10.5
100,000 m^3 pumping and conveyance to Djafar	497	99	2.7
TOTALS	3,779	673	18.5
2B 100,000 m^3 pumping and conveyance to Er Riana	1,135	193	5.3
100,000 m^3 facultative pond	1,735	273	7.5
100,000 m^3 pumping and conveyance to Djafar	497	99	2.7
TOTALS	3,367	565	15.5
3A 100,000 m^3 primary treatment with chlorination	3,240	631	17.3
100,000 m^3 conveyance to Djafar	960	165	4.5
Reduction-Reclamation pond at Djafar	2,147	381	10.5
TOTALS	6,347	1,177	32.3
3B 100,000 m^3 primary treatment with chlorination	3,240	631	17.3
100,000 m^3 conveyance to Djafar	960	165	4.5
Facultative pond at Djafar	1,735	273	7.5
TOTALS	5,935	1,069	29.3
4 100,000 m^3 primary treatment with chlorination	3,240	631	17.3
100,000 m^3 overland outfall and disposal at sea	4,514	530	14.5
TOTALS	7,764	1,161	31.8

than activated sludge treatment with pumping to storage, trickling filter treatment with pumping to storage, an impounding primary treated and chlorinated effluent at Djafar. If one assumes activated sludge treatment and a value of only 5 milliemes per m^3 for the water, it would be necessary to reclaim more than 65 percent of the treated water to overcome the cost advantage which deep sea disposal has over activated sludge.

Effectiveness

In order to examine the alternatives with respect to effectiveness, the candidate alternatives are, in Table VIII, assigned effectiveness numbers for the 11 effectiveness criteria. While subjective, the effectiveness numbers do clearly reflect the reasoning set forth previously in comparing mechanical treatment and impoundment.

Effectiveness Cost Ratios

In a comparison of effectiveness, cost ratios show the indicated, most effective alternative is impoundment of raw waste at Er-Riana. The least effective is deep sea discard.

Decision to Application Time

Also shown in Table VIII is an estimate of the decision to application time (D.A.) for the various alternatives. The shorter D.A. times are assigned to ponding systems which can be made primarily from local materials. Both activated sludge and trickling filtration would require fabrication of manufactured components after design and therefore are assigned a D.A. time of four years. Reduction-reclamation ponds would require special pumps

TABLE VIII

EFFECTIVENESS, COST, EFFECTIVENESS/COST RATIOS AND DECISION TO APPLICATION TIMES FOR ALTERNATIVE SYSTEMS

Criteria	Alternative No.						
	1A	1B	2A	2B	3A	3B	4
Effectivness							
Feasibility							
Technical	10	10	10	10	10	10	10
Flexibility	5	5	8	8	6	6	1
Reliability	5	5	9	9	9	9	9
Human Impact							
Health	5	5	8	7	8	7	9
Hygiene	3	3	9	8	9	8	9
Aesthetics	5	5	8	8	7	7	9
Occupations	10	10	8	8	8	8	5
Environmental Impact							
Conservation							
Biota	8	8	8	8	8	8	2
Water	10	10	8	8	8	8	0
Energy	0	0	7	7	5	5	3
Nutrients	7	7	5	5	5	5	1
Effectiveness Factor	68	68	88	86	84	82	58
Cost							
Total First Cost Thousand Dinar	7,080	6,960	3,779	3,367	6,347	5,937	7,764
Annual Cost Thousand Dinar	1,278	1,237	673	565	1,177	1,069	1,161
Cost Per Cubic Meter	35.0	33.5	18.4	15.5	32.3	29.3	31.8
Effectiveness/Cost Ratio	1.94	2.03	4.78	5.55	2.60	2.80	1.83
Decision to Application Time, Years	4	4	3	2.5	3	2.5	5

which could delay construction; hence, assignment of a three year D.A. time whereas simple facultative ponds are assigned D.A. times of 2.5 years. The deep sea outfall would require difficult construction and probably encounter weather delays which could extend the D.A. time to five years or more.

Water Reclamation

All of the land alternatives permit reclamation of water, but ponding would provide the most fail-safe method. On the other hand, the value assigned to the reclamation attained in a given alternative will depend on the fraction of the water reclaimed. In the case of ponds, the amount of water that can be reclaimed is a function of the net evaporation in the ponds.

According to the data provided by HAR (6), maximum water losses for the ponds will occur in July. At that time the rate of application of waste to the reduction-reclamation ponds will be 1.3 meters per month. The evaporation loss will be 0.25 meters per month and hence the maximum evaporative loss will be 19.2 percent. At that time the water will increase in solids from about 1000 mg/l to about 1200 mg/l and at other times will increase less and will therefore be useful at all times for irrigation. Allowing for some percolation loss, the minimum reclaimable water yield daily should be to 80,000 m^3 per day when the flow is 100,000 m^3.

In the case of the facultative ponds, the application of water will be about one meter per month and the maximum losses 0.25 m per month. At that time the solids level of the water would increase to 1250 mg/l and

the maximum yield of water would be 75,000 m^3 per day.

By assigning a value of 5 milliemes per m^3 to the reclaimed water and assuming various reclamation percentages, one obtains net costs for the various alternatives. These are presented in Table IX.

Best System

According to Table IX, the most effective, least cost system explored is conveyance of the raw waste from La Cherguia to Er-Riana, facultative ponding at Er-Riana and conveyance of the treated water to a Djafar reservoir for storage or direct use.

If raw facultative ponding could be effected at Djafar, this would be a less expensive alternative, the cost being about 12 milliemes without reclamation and eight milliemes with reclamation. Assignment of values for the storage attained at Djafar could further decrease the cost allocation. However, special additional studies would be required to make such an application possible.

Before a final decision is made regarding waste treatment and disposal or reclamation in Tunis, comprehensive studies of each of the general alternatives listed in Tables III and IV should be carried out.

INTERIM MEASURES

Inasmuch as it cannot be less than two years and possibly as much as five years before the necessary modifications can be made and a permanent solution to the Lake Tunis odor problem can be fully implemented, added losses to Tunis due to the discharge of sewage into Lake Tunis may be on the order of 2,000,000 Dinars in the next four to five years. It therefore

TABLE IX

INFLUENCE OF RECLAMATION ON NET UNIT COSTS* FOR ALTERNATIVE TREATMENT SYSTEMS, TUNIS, 1972

Alternative		Percent Reclamation					Effectiveness Cost Ratio Max.
		None	25%	50%	75%	100%	
1A	Activated Sludge with Storage at Djafar	35.0	33.7	32.5	31.2	30.0	68/30 = 2.26
1B	Trickling Filter with Storage at Djafar	33.9	32.6	31.4	30.1	28.9	68/28.9 = 2.35
2A	Reduction-Reclamation Ponding at Er Riana and Storage at Djafar	18.4	17.1	15.9	14	----	88/14.6 = 6.00
2B	Facultative Ponding at Er Riana and Storage at Djafar	15.5	14.2	13.0	11.7	----	86/11.7 = 7.36
3A	Primary Treatment with Reduction-Reclamation Ponding and Storage at Djafar	32.3	31.0	29.8	28.5	----	84/28.5 = 2.94
3B	Primary Treatment with Facultative Ponding and Storage at Djafar	29.3	28.0	26.8	25.5	----	82/25.5 = 3.22
4	Primary Treatment and Disposal at Sea Off La Marsa	31.8	----	----	----	----	58/31.8 = 1.83

*Milliemes per m^3.

seems most important now to implement emergency measures to quickly reduce the odor and other problems.

It is believed that effective emergency measures can be taken to greatly reduce the odors and fish deaths in Lake Tunis due to raw sewage. Removal of raw sewage probably would not eliminate the odors due to decomposition of sea lettuce, but the sea lettuce decomposition is not as vile or as rapid as sewage putrefaction and would probably occur mainly in the late fall after the tourist season is over. Thus, it is believed that elimination of the odor and oxygen depletion due to sewage putrefaction would be a great improvement and would substantially improve tourist trade and fish survival.

Two alternative methods of emergency improvement appear feasible. One would be complete oxidation of all sewage entering the Lake in an interim oxidation pond using floating surface aerators. The second would be construction of La Cherguia-Er-Riana pumping station and force main to convey the sewage to Er-Riana where an interim pond could be built.

Oxidation with Floating Surface Aerators

A cost evaluation of the temporary aeration system is presented in Appendix 10.

According to the Appendix 10 analysis, for about 100,000 Dinars per year the sewage could be fully aerated before entering Lake Tunis and odors should be substantially decreased.

This would not be a permanent solution for the following reasons:

1. Sludge would build up in the system in a few years and cause

it to fail.

2. Oxidized sewage nutrients would continue to go into the Lake eventually stimulating excessive growth of algae.

3. No freshwater recovery from the sewage would be effected. Thus, the objective of water recovery would be lost.

Emergency Ponding

Installation of an interim pond at Er-Riana would require an immediate substantial capital investment in the pumping station and force main but these components would be an integral part of the future permanent system of alternative 2 and hence would not have to be discarded. A design and cost evaluation of a temporary pond suitable to receive and treat up to 60,000 m^3 per day of sewage without nuisance is presented in Appendix 11. For this alternative the added capital cost would be 360,000 Dinars and the added annual cost 59,000 Dinars. This temporary pond system, if built, could later be used in alternative 2 as a receiving body for saltwater in the case that salt intrusion occurred into the sewers during storms.

It appears that the use of emergency ponding has a slightly lower cost and is attractive because of its general utility in the future systems. However, it is doubtful that emergency ponding could be carried out as quickly as aerator treatment. Either remedy is preferable to continued odor and economic losses.

DISCUSSION

While according to the estimates in Table VII the cost of waste treatment by the use of ponds will be below one-half the cost of treatment by activated sludge, cost is not the only factor. Ponds should also provide a much more hygienic and fail-safe effluent than activated sludge and will provide substantial storage as well. The land they occupy will also be permitted to remain as open space and the beauty of their surroundings will be enhanced.

If, as a result of detailed studies, it is found that the Sebkhets can be effectively used for ponding of waste water for treatment and reclamation, it may be expected that excess water from the ponding system will make it possible to eventually leach salt from those areas of the Sebkhets beneath portions of the ponds and hence bring them into a condition suitable for productive agricultural use; however, it is beyond the scope of this report to enter into a discussion of all of the ramifications and advantages of a plan to utilize waste water to reclaim land.

It is important to emphasize that all of the plans considered herein involve removal of any sewage intrusion into Lake Tunis and therefore will aid in the ultimate restoration of Lake Tunis to a beautiful and unpolluted body of water.

Because it has been emphasized that ponds will improve the bacterial quality of the water, an estimate of the final quality should be made. The bacterial properties of water from the ponding systems are accordingly likely to be as follows: The most probable number of coliform bacteria per

100 ml (MPN) is expected to be about 5000 maximum during winter. In spring, the MPN will decrease to about 1000; in summer, there should only be about 10 per 100 ml and in fall about 20. The water should contain negligible quantities of BOD and small amounts of algae. It should also be extremely low in viruses.

FUTURE STUDIES

It should be emphasized in closing that while ponds appear promising for Tunis, there is no experience with the application of ponding systems in Tunis. For this reason, before any irreversible decisions are made concerning waste disposal, a full-scale ponding system should be constructed for one of the small communities in Tunisia, preferably near Tunis. This pond system should incorporate all of the most up-to-date design information and be constructed according to rigidly controlled specifications and be studied for approximately one year. This will permit any unforeseen factors to reveal themselves. While the author has had a considerable experience with ponds and is confident that they will find widespread successful use in Tunis, there is no precedent in the author's experience for the impoundment of high sulfate sewage. The waste water of Tunis contains more than 350 mg per liter of sulfate which if reduced would form enormous quantities of H_2S (as has been experienced in Lake Tunis). In the demonstration plant recommended, it is intended that provision for micro-algal growth and oxygen production together with deep alkaline fermentation will prevent the formation and emission of H_2S. While one may predict chemically that H_2S will not be emitted, a wrong

prediction in a system for a small town is vastly preferable to having 300 hectares emitting H_2S. Thus, the recommendation for a small-scale system.

A pilot system operating on a small fraction of the sewage from some source may be suggested, but experience dictates against the use of pilot units. The difficulties in maintaining accurate flow for small amounts of sewage are so grave that most pilot studies with sewage have ended in chaos, if not disaster, and, as a consequence, a waste of unnecessary amounts of public funds. Accordingly, a full-scale plant for a small community is greatly preferred to a pilot plant for detailed model studies.

While treatment plant studies are in progress, detailed studies can also be made of the Sebkhets as ponding sites. These studies should be complete hydrological, geological and soils engineering studies of the Sebkhets to determine their physical and chemical properties as pond sites. Should it be found that it is not physically feasible to use the Sebkhets for treatment ponds, other areas such as the reservoir area near Djafar or areas near the airport would also probably make excellent ponding sites.

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APPENDIX 1

COST OF ACTIVATED SLUDGE AND CHLORINATION

Table A1-1

Cost of 100,000 m^3 Per Day Activated Sludge Plant

Capital Cost from Figure 12 (no redundancy)	5,000,000 D
Engineering and Contingencies @ 20%	1,000,000 D
Total	6,000,000 D
Annual Cost:	
Capital (15%) Per Annum	900,000 D
Power--7,500,000 kw hrs/yr @ 10 m/kw hr	75,000 D
Labor--12 @ 150 x 12	21,000 D
Contingency	50,000 D
	1,046,000 D
Daily Cost	2,860 D
Cost Per 1000 m^3	28.7 D
Cost Per m^3	28.7 m
Cost of Chlorination	1.8 m
	30.5 m

Cost of 30,000 m^3 Per Day Activated Sludge Plant

Capital Cost	2,000,000 D
Engineering and Contingencies @ 20%	400,000 D
	2,400,000 D
Annual Cost:	
Capital and Interest 15%/Annum	360,000 D
Power--2,190,000 kw hrs @ 10 m	22,000 D
Labor--6 @ 150 x 12	10,800 D
Contingency	25,000 D
	418,000 D
Daily Cost	1,150 D/day
Cost Per 1000 m^3	38.2 D
Cost Per m^3	38.2 m
Chlorination (See Appendix 1	1.8 m
Total Cost of Activated Sludge Treatment with Chlorine.	40.0 m

Table A1-2

Cost of Chlorination of Activated Sludge
or Trickling Filter Effluent, 100,000 m^3/day

Capital from Figure 14	100,000 D
Engineering and Contingencies @ 20%	20,000 D
Total	120,000 D
Fixed Cost--120,000 D @ 15%/Annum	18,000 D
Chlorine--365,000 kg @ 120 milliemes	45,000 D
Labor	2,000 D
Miscellaneous	2,000 D
Total Annual Cost	67,000 D
Daily Cost	183 D
Cost Per 1000 m^3	1.83 D
Cost Per m^3	1.83 m
Use 1.8 m	

Table A1-3

Cost of Chlorination of Primary Effluent, 100,000 m^3/day

The only difference in cost would be an increase in chlorine demand from 10 mg/l to 20 mg/l and an increase in labor cost; thus, we would have:

Fixed Cost	18,000 D
Chlorine	90,000 D
Labor and Miscellaneous	4,000 D
Total Annual Cost	112,000 D
Daily Cost	308
Cost Per 1000 m^3	3.08 D
Cost Per m^3	3.08 m
Use 3.1 m	

APPENDIX 2

COST OF TRICKLING FILTER AND CHLORINATION

Table A2-1

Cost of 100,000 m^3 Per Day Trickling Filter Plant

Capital Cost from Figure 13	4,900,000	D
Engineering and Contingencies @ 20%	980,000	D
Total	5,880,000	D
Annual Cost:		
Capital--15%/Annum	884,000	D
Power--5,000,000 kw hrs @ 10 m/kw hr	50,000	D
Labor--12 @ 150 x 12	21,000	D
Contingency	50,000	D
Total	1,005,000	D
Daily Cost	2,720	D
Cost Per 1000 m^3	27.2	D
Cost Per m^3.	27.2	m
Chlorination from Appendix 1	1.8	m
	29.0	m

APPENDIX 3

CONVEYANCE FROM LA CHERGUIA TO SEBKHET ER RIANA--COSTS

The conveyance of waste from the vicinity of La Cherguia to Sebkhet Er Riana is a plausible alternative because of the fact that the Sebkhet land is flat and can be utilized for ponds with no land cost. The ridge between the two points is approximately five meters high.

A profile of the land surface between La Cherguia and Er Riana is shown in Figure A3-1. The total distance involved, including a 600 meter feed pipe, into the pond is about 7,400 meters. A study was made to compare costs of a combination of force and gravity mains and various sized force mains. The gravity main alternative becomes clearly uneconomical in connection with the pond alternative because of the need to have two pumping stations, one to pump from La Cherguia to the crest and one to pump from the edge of the Lake into the ponds. Also, because the available slope is only about 0.001, the required conduit size for even 2 m^3/sec would be 1,600 mm minimum.

An open ditch from the crest of the lake bed is rejected because it would also require two pumping stations and on hygienic grounds because one could not convey raw sewage in a surface ditch without fencing and guarding and be certain that those next to the ditch would not use the water prior to treatment.

One is then left with a single choice of conveyance of the waste in a pressure conduit. Determination of optimum pipe size for the pressure conduit is required.

The low water surface at La Cherguia will be 0 meters; the high water surface in the receiving station will be 4 meters. Thus, the static head is 4 meters.

Installed pump capacity, while initially small, should ultimately be 182,000 m^3 per day. With expected variations in flow, Q max will then be 2.1 m^3 per second, but to provide for additional contingencies one should design for 2.5 m^3 per second. Thus, the pipeline to be used may provide for unforeseen increases in flow at little added cost.

While substantial savings would perhaps result from casting the conveyance pipe in place, it will be presumed that standard precast pipe will be used. The pipe sizes which appear plausible are 800 mm, 1000 mm, 1200 mm, 1400 mm, and 1600 mm. Accordingly, calculations were made of pumping station, conveyance and power costs for each pipe size as shown in Table A3-1, which yields the optimization curve shown in Figure A3-1.

The curve has a clear minimum for the pipe size of 1400 mm, but there is probably little significant difference in 1200, 1400, or 1600 mm systems. The 1600 mm line would require a minimum of electrical power whereas the 1200 mm line would have the least first cost. The 1400 mm line minimizes the sum of these two.

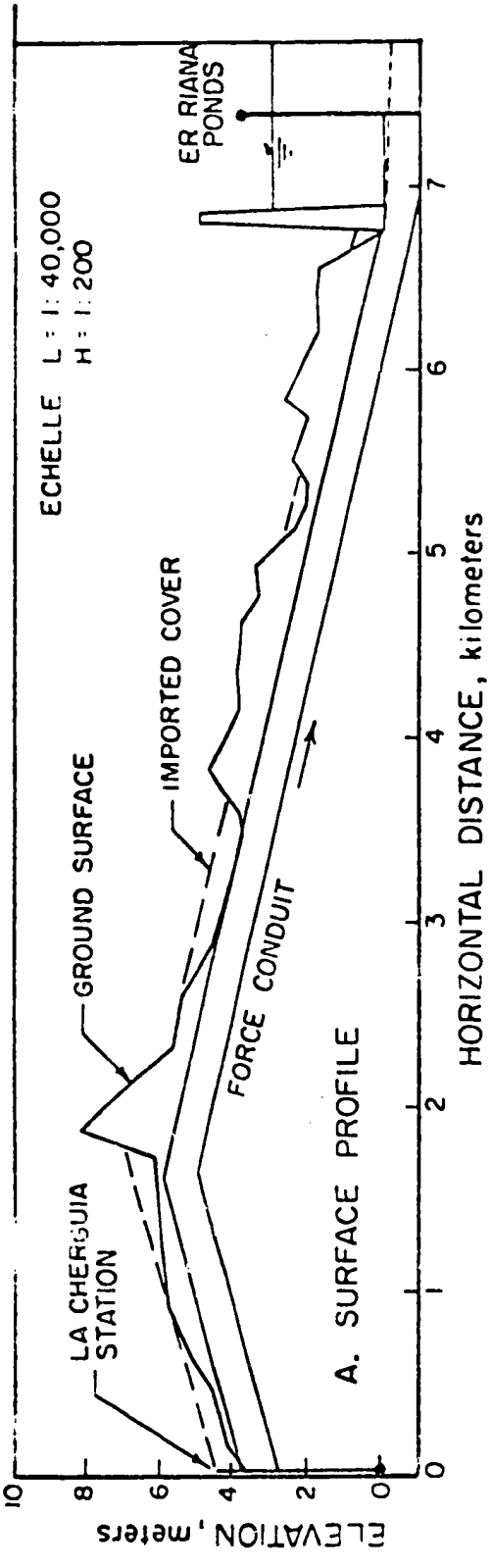
Table A3-1

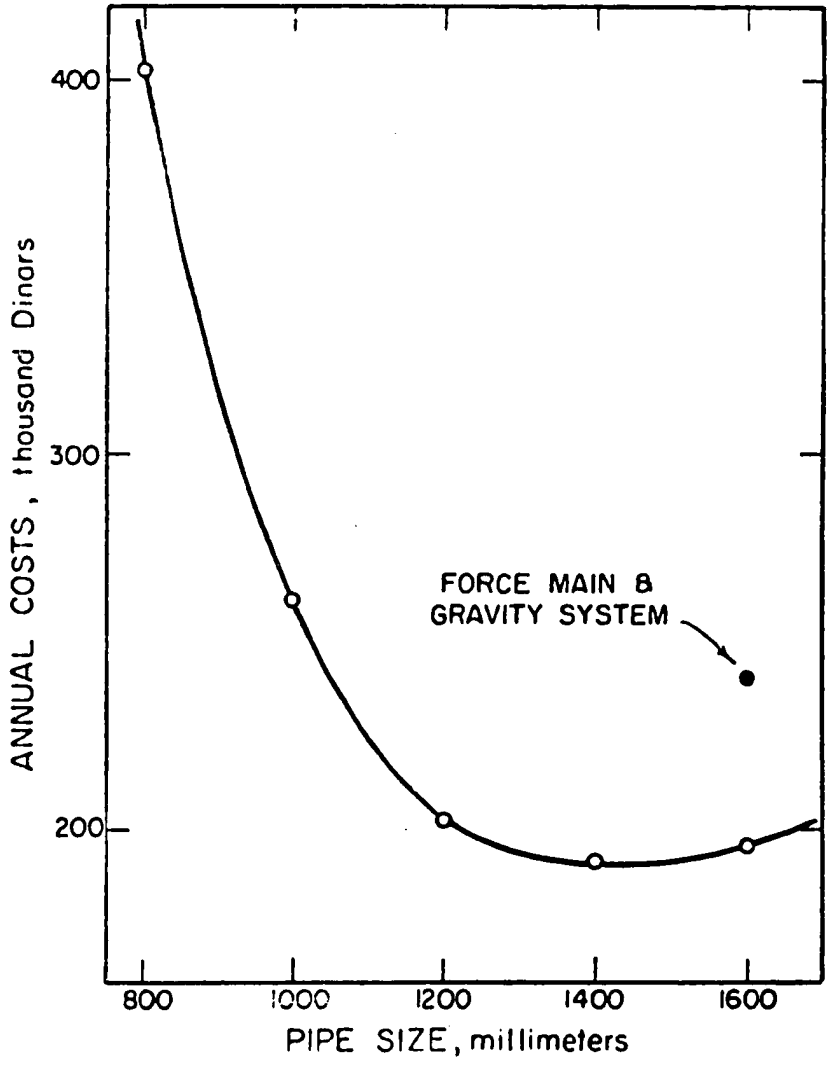
CONVEYANCE LA CHERGUIA TO ER RIANA: COST CALCULATIONS FOR PRESSURE SYSTEM

ITEM	PIPE SIZE mm				
	800	1000	1200	1400	1600
Q m^3/sec	2.5	2.5	2.5	2.5	2.5
Area m^2	0.5	0.786	1.13	1.54	2.05
Velocity m/sec	5.0	3.18	2.22	1.63	1.22
$V^2/2g$	1.28	0.51	0.25	0.135	0.076
1/d	9,300	7,400	6,170	5,280	4,630
f*	0.016	0.015	0.015	0.014	0.013
Δh m	190	56.5	23.4	10.0	4.6
Total head m	194	60.5	27.4	14.0	8.6
Qγh/550 e (U.S. hp)	7,970	2,480	1,130	575	352
kw	5,950	1,850	845	430	262
Time hrs/day	11.2	11.2	11.2	11.2	11.2
kw hrs/day	65,500	20,700	9,470	4,820	2,930
Dinar/yr	240,000	99,000	34,600	17,600	10,700
Pipe Unit Cost, Dinar/m	31	43	58	75	93
Dinar/7,400 m	230,000	318,000	429,000	555,000	685,000
Engin. and Cont. 20%	46,000	68,000	86,000	111,000	137,000
Total Pipe Cost	276,000	386,000	515,000	666,000	823,000
Pipeline Annual Cost, 11% of Capital	30,500	42,600	56,700	73,000	91,000
Labor and Miscellaneous Costs, Dinar/yr	45,000	40,000	36,000	32,000	28,000
Pumping Station Debt & Interest, Dinar/yr	**86,000	81,000	76,000	71,000	66,000
Total Annual Cost, Dinar	201,000	262,000	203,000	193,000	195,000
Daily Cost, Dinar	1,100	72.0	555	528	534
Cost Dinar/1000 m^3	11	7.2	5.55	5.28	5.34

*Friction factor from: Davis, V. D., Handbook of Applied Hydraulics, page 7.

**It is assumed that the lower heads associated with larger pipes will result in decreases in pump costs and wear and tear equal to 2500 Dinar per 100 mm pipe size increase per year.





B. OPTIMIZATION OF ANNUAL COSTS BASED ON CONSTANT VOLUME OF 2.5 m^3/sec PUMPED THROUGH PRESSURE CONDUITS OF VARIOUS SIZES (PUMPING TIME 11.2 HRS. PER DAY)

FIGURE A3-1. CONVEYANCE PROFILE, LA CHERGUIA TO ER RIANA PONDS AND PIPE SIZE OPTIMIZATION

APPENDIX 4

CONVEYANCE FROM LA CHERGUIA TO DJAFAR--COSTS

Cost evaluation, pump station and pipe system to convey primary treated sewage from La Cherguia to Djafar.

Assumed Distance, 5.5 kilometers.

Assumed head loss, both friction and lift, 20 meters.

For Q max of 2.50 m^3/sec, use 1200 mm pipe.

Table A4-1

Pipeline:	
5,500 m 1200 mm pipe @ 58 D/m	320,000 D
Engineering and Contingencies @ 20%	64,000 D
Total Pipe Cost	384,000 D
Pumping Station:	
180,000 m^3/day (50% redundancy)	360,000 D
Engineering and Contingencies @ 20%	72,000 D
Total Pumping	432,000 D
Total Cost	816,000 D
Annual Costs:	
Pipe Debt and Interest, 384,000 @ 11%	42,000 D
Pump Station Debt and Interest, 432,000 @ 15%	64,000 D
Power--6000 kw hr/day @ 10 m/kw hr, 365 days	22,000 D
Labor	12,000 D
Miscellaneous Expenses	25,000 D
	165,000 D
Daily Cost	450 D
Cost Per 1000 m^3	4.5 D
Cost Per m^3	4.5 m

APPENDIX 5

DESIGN AND COST EVALUATION OF REDUCTION-RECLAMATION PONDS

The primary ponds of the reduction-reclamation ponding system should be designed on the basis of detention period. It has been established that a 40-day detention period is adequate for excellent methane fermentation and treatment; consequently, the required volume of primary ponds for a flow of 100,000 m^3 per day is

$$100{,}000 \times 40 = 4 \times 10^6 \ m^3$$

To permit and protect methane fermentation, a depth of three meters is needed. The area is therefore 1/3 of 4×10^6 m^3, or 1.33×10^6 m^2 and at 10^4 m^2/hectare one needs 133 hectare. Should one use 4 - 35 hectare units, each unit should be about 600 meters each way. The applied BOD loading on these units will be 227 kg per hectare, about 70 percent of the loading now being used successfully at St. Helena, California. BOD removal in these units should be about 75 percent. To conform to size requirements, each side should be 600 meters at the water line. Actual size of ponds will be 36 hectare at the water line.

Typical levee sections and type designation are shown in Figure A-1. Because of the strong winds, rip rap, and a free-board of 1.6 m, should be provided. The pond levees will have a volume of 4.33 x 4 = 17.3 + 4.33 x 13 = 57 = 74 m^3 per meter, or say 74 m^3/m. Levee length along one side for two ponds is 1,224 meters. Six levees, 7,344 m @ 74 m^3/m, gives a volume of 540,000 m^3. Rip rap and gravel may decrease this slightly.

Design of Digester (Volumes in Ponds)

Volume of digester: assume BOD removed in reduction ponds = 75 percent. Removal is 250 mg/l. The digester will receive:

$$\frac{100{,}000{,}000 \text{ liters} \times 250 \text{ mg/l}}{1{,}000{,}000 \text{ mg/kg}} = 25{,}000 \text{ kgs}$$

of BOD per day. Allowable load is 400 gms/m^3/day. At 0.4 kg per m^3, need 25,000/0.4 = 62,500 m^3. Use 1.5 meters depth digesters to protect sludge. Need 41,800 m^2, or an area 100 meters by 100 meters in each pond, but use 200 meters x 200 meters to provide sludge storage. Use three cells at right angles to the wind. According to Figure A5-1 Type VI, submerged levees will contain 12 m^3/m, 4800 m @ 19 = 58,000 m^3.

Aeration and Mixing Pond (HRP)

Five-day detention, locate around reduction ponds for good hydraulic characteristics. Length of HRP = 5200 m; width, 100 m; depth, 1 m; total area will be about 52 hectare.

Levees will be at least 3.2 meters high, 32 m^3 per meter length of low levee's 4200 meters (see Figure A5-1 Type VI).

Total volume of low levees is $32 \times 4.2 \times 10^3 = 10.5 \times 10^4 = 134{,}000$ m^3. Rip rap for entire interior requires 11,200 m^3.

Decanting Ponds (2 units)

Width, 150 m; length, 1200 m; depth, 3 m. Three levees, 1250 m at 74 m^3/m = 266,000 m^3 + 300(74) = 22,200; total = 288,000. Rip rap interior, 6000 m = 6000 m^3 (see Figure A5-1 Type II).

Final Pond (1)

Width, 150 m; length, 300 m; depth, 3 m. Levee, 900 x 74 = 67,000 m^3.

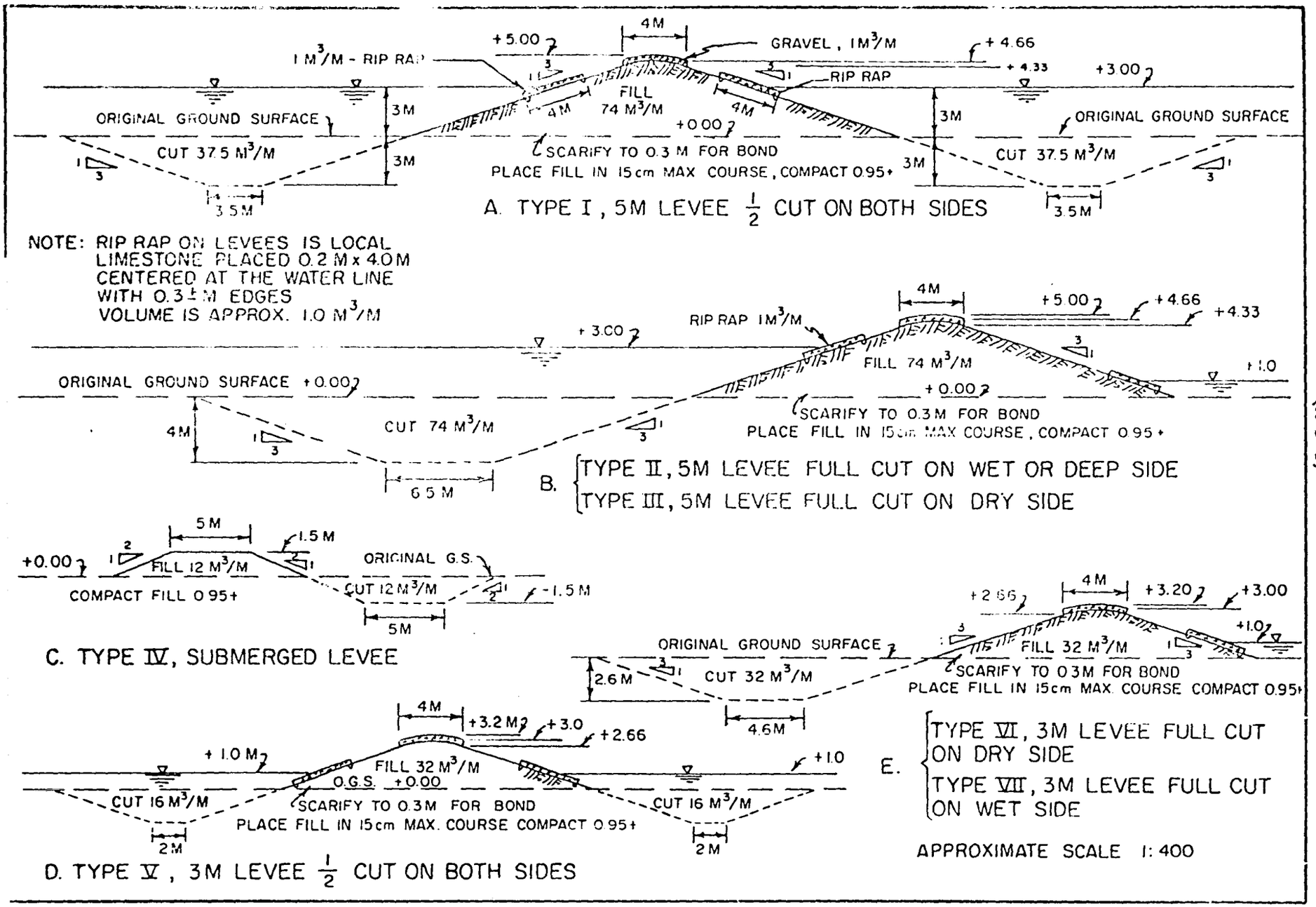


FIGURE A5-1. POND LEVEE PROFILES

(A-5-3)

Rip rap interior, 900 meters of length = 900 m^3 (see Figure A5-1).

Table A5-1

Summary of Earthwork

Reduction ponds	540,000 m^3
Digesters	58,000 m^3
Aeration pond	134,000 m^3
Decanting ponds	288,000 m^3
Final pond	67,000 m^3
Total	1,087,000 m^3

Table A5-2

Summary of Rip Rap

Reduction ponds	10,000 m^3
Aeration ponds	11,200 m^3
Decanting ponds	6,000 m^3
Final pond	900 m^3
Total	28,100 m^3

Piping (Prices Include Installation

Salty water bypass line, 1400 lin. meters, 1000 mm @43.0 = 60,000 D.

Feed: 1700 L. meters, 800 mm pipe @ 31 Dinars/m = 52,000 Dinars.

Distributor: 10,000 Dinars.

Transfer pipes: 12 @ 5,000 = 60,000 Dinars.

Table A5-3

Summary of Piping

Item	
Bypass--1400 m, 1000 mm	60,000 D
Pond feeders	52,000 D
Distributor	10,000 D
Transfer units--12 @ 5000	60,000 D
Total Piping	182,000 D

Table A5-4

Recycle Pumping Station

4-125 hp Low Head Propellar Pumps and Installation	125,000 D
Intermediate Pumping Station	155,000 D
Electrical Installation and Controls	100,000 D
Total Recycle Pumping Station	380,000 D

Miscellaneous

Grading and Final Clean-up and Planting Levees	100,000 D

The Total Pond System

A plan view of the entire pond system is shown in Figure A5-2.

Table A5-5

Summary of Estimated Capital Costs for 100,000 m^3/Day Reduction-Reclamation Pond System

Excavation, 1,087,000 m^3 @ 1.0 Dinar	1,087,000 D
Rip Rap @ 2.0 Dinar m^3 in place	56,000 D
Pipe	182,000 D
Engineering and Contingencies @ 20%	265,000 D
Total Levees and Pipe	1,590,000 D
Pumping Station and Electrical	380,000 D
Engineering and Contingencies @ 20%	77,000 D
Clean-up and Planting and Gravel	100,000 D
Totals	557,000 D
Total Construction Cost	2,147,000 D

NOTE: ROMAN NUMERALS INDICATE TYPE OF LEVEE
SEE FIGURE A5-1 FOR TYPE DETAILS

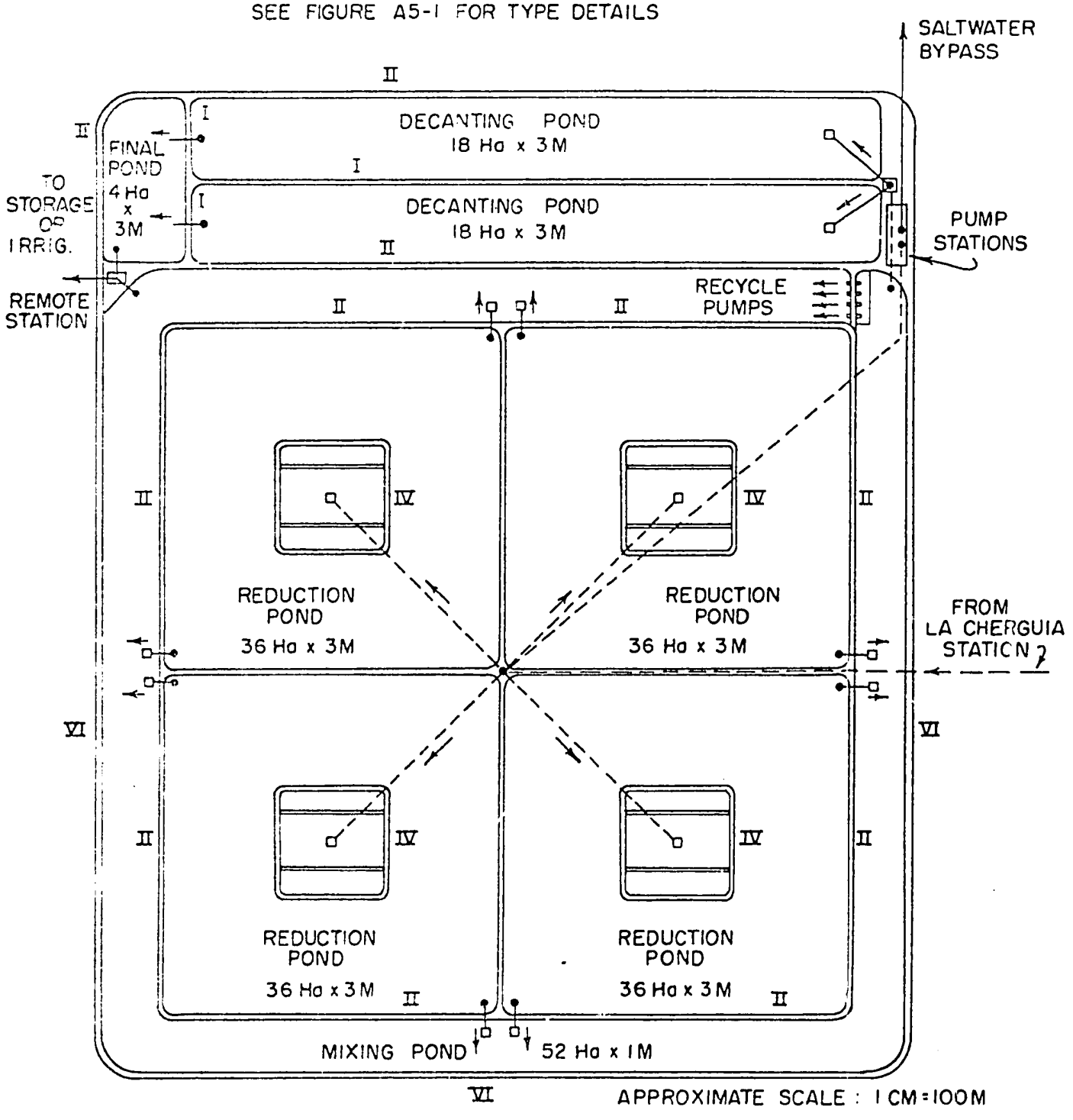


FIGURE A5-2. PROPOSED 236 HECTARE REDUCTION-RECLAMATION PONDING SYSTEM FOR TUNIS CAPACITY = 100,000 m^3/day

(A-5-7)

Annual Cost for Reduction-Reclamation Pond System

Interest and Depreciation on Pipe, Rip Rap, Ponds, 11% of 1,590,000	175,000 D
Interest and Depreciation on Pump Station, 15% of 557,000	83,000 D
10 Men @ 150 D/month	18,000 D
Electrical Power--500 KVA, 0.5 use factor @ 10 milliemes/kw hr	20,000 D
Miscellaneous Equipment	25,000 D
Miscellaneous Chemicals and Supplies	10,000 D
Miscellaneous Expense	50,000 D
Total	381,000 D

Cost Per Day = 1,050 D/day
Cost Per 1000 m^3 = 10.5 D
Cost Per m^3 = 10.5 milliemes

Alternate method of costing reduction-reclamation pond based on cost curves of Figure 15.

184 hectare of 5 meter high levee and 52 hectare of high-rate ponds.

Table A5-6

From Cost Curves of Figure 15 (Top Curve).

184 hectare, 3 m deep pond without land	1,200,000 D
52 hectare high-rate pond	560,000 D
Engineering and Contingencies	350,000 D
Total	2,110,000 D

This checks closely with the 2,147,000 estimate based on Tunis data. Consequently, the higher value of 2,147,000 will be used.

APPENDIX 6

DESIGN AND COST EVALUATION OF FACULTATIVE POND

Facultative Pond Design and Cost Evaluation

This design is based on the assumption of minimizing the mechanical systems and operations required. It cannot provide the same assurances against short circuiting and as high a degree of disinfection as the reduction-reclamation ponds. It will, however, provide a high degree of disinfection and adequate treatment for irrigation water.

The primary reduction pond system consisting of 4 - 36 hectare reduction ponds will be identical to those proposed for the alternative in Appendix 5. Following the four reduction ponds, a series of ponds is designed on the basis of loading. All ponds will be two meters deep.

Secondary Ponds

Initial load = 32,500 kg.

BOD removal in primaries is 75 percent.

Remaining BOD = 32,500 - .75(32,500) = 8,300 kg.

Use loading of 80 kg per hectare; therefore need 100 hectare.

Use two ponds: length will be 1200 meters; therefore total width will be 850 meters or width of individual ponds, 425 meters. Use 400.

Tertiary pond. BOD removal in secondary pond will be 50 percent of applied; therefore final BOD will be 8,300 - .5(8,300) = 4,150 kg. Use loading of 80 kg per hectare; therefore required area is 50 hectare to conform with other ponds. Use length of 1,625 meters; width will be 307 meters. Use 300 m.

(A-6-2)

BOD removal in tertiary pond will be 50 percent.

Quaternary pond will receive 2,125 kg. Use loading of 80 kg per hectare; need 27 hectare. Length is 1,625 meters; width is 165 meters; use 150.

A series of small final ponds will be used to assure no short circuiting. Layout of system will be as shown in Figure A6-1. The design is intended to maximize the disinfection potential of the pond system by having a large number of cells.

Table A6-1

Facultative Pond Earthwork

	7,344 M Type I @ 74 m^3	540,000 m^3
	10,850 M Type 4M @ 57 m^3	619,000 m^3
	14,800 M Type IV @ 12 m^3	58,000 m^3
Totals	22,994	1,217,000 m^3
Assume earthwork cost is 1 Dinar/m^3		1,217,000 D
Rip rap, 28,600 m^3 @ 2 Dinar		57,000 D
	Sub-total	1,274,000 D
Transfer Structures:		
23 Transfer @ 1000 D		23,000 D
Pipe, 1700 M of 800 mm @ 30 D		51,000 D
Concrete, 50 m^3 @ 50 D		2,500 D
	Sub-total	1,350,500 D
Clean-up, Planting and Road Surfacing		104,000 D
Engineering and Contingencies @ 20%		280,000 D
	TOTAL	1,734,500

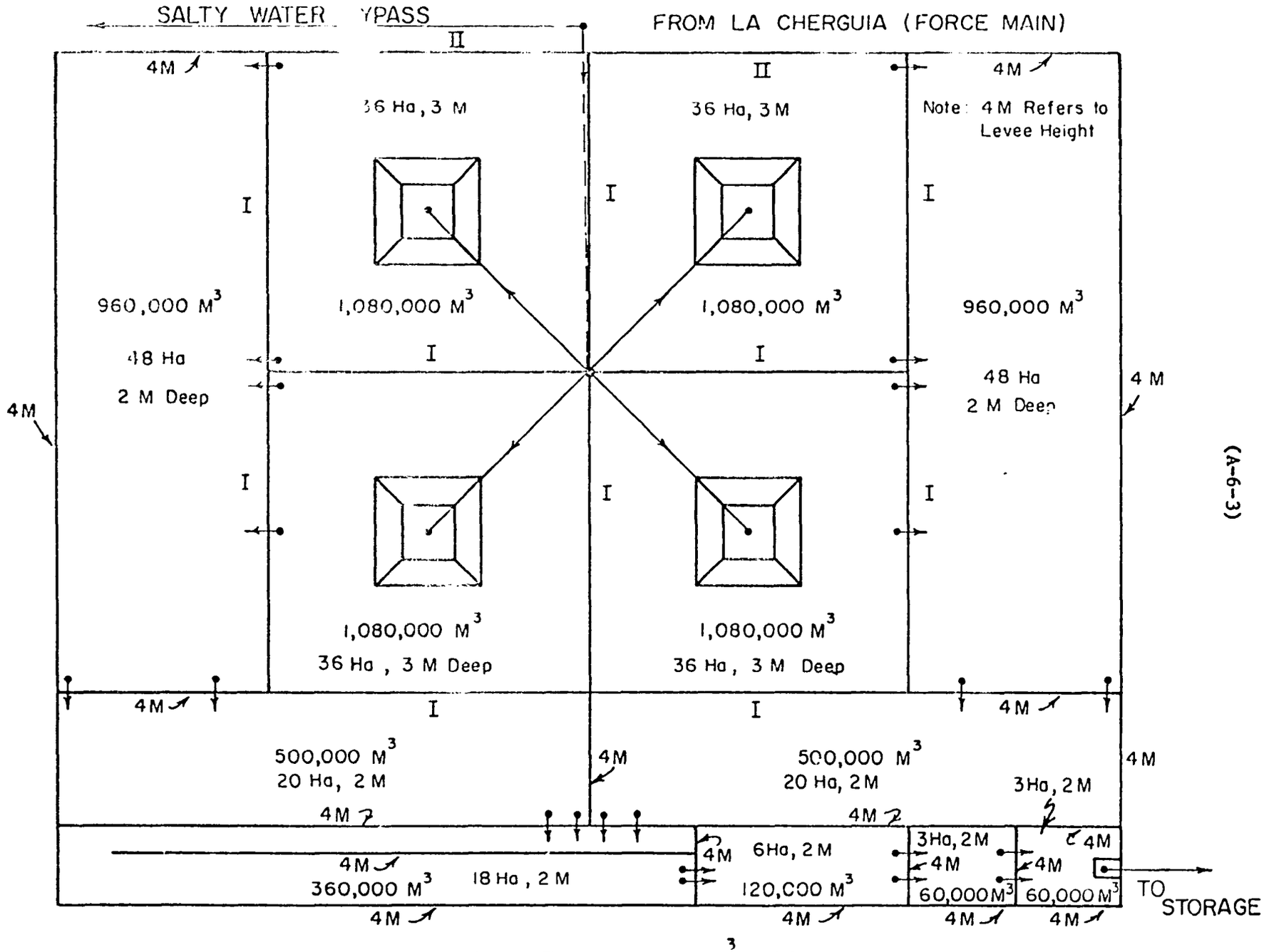


FIGURE A6-1 PROPOSED 320 HECTARE, 7,800,000 M^3 FACULTATIVE POND SYSTEM

(A-6-3)

Annual Costs:	
11% of 1,735,000	191,000 D
Labor	12,000 D
Miscellaneous Supplies	25,000 D
Engineering and Contingencies @ 20%	45,000 D
	273,000 D
Daily Cost	750 D
Cost Per 1000 m^3	7.5 D
Cost Per m^3	7.5 m

Alternate method of costing facultative pond using cost curve of Figure 15

Table A6-2

144 hectare, 5 meter ponds	950,000 D
176 hectare, 5 meter ponds	500,000 D
Total	1,450,000 D
Engineering and Contingencies	290,000 D
	1,740,000 D

This is again sufficiently close to the 1,735,000 Dinar obtained by the other method of calculation that recalculation is unnecessary.

APPENDIX 7

COST EVALUATION OF PUMPING POND EFFLUENT TO STORAGE ER RIANA TO DJAFAR

Maximum amount of water is 100,000 m^3/day. 80,000 m^3/day minimum because of evaporation. No factor of safety is required because of buffer capacity in the ponds. It will be assumed the pumping station is adequate to convey the water a distance of 3000 meters and inject it into the storage reservoir. Pipe size requires is 1200 mm. Assume static head is 5 m.

Table A7-1

3000 meters, 1200 mm pipe @ 58 D/m	174,000 D
Engineering and Contingencies @ 20%	35,000 D
Total	209,000 D
Pumping Station, 100,000 m^3/day	240,000 D
Engineering and Contingencies @ 20%	48,000 D
Total	288,000 D
Total Capital Cost	497,000 D
Annual Costs:	
Pipe, 209,000 D @ 11%	23,000 D
Pump Station, 288,000 D @ 15%	43,000 D
Power-- h = 7 meters, 100 kw req. cont.	9,000 D
Labor--5 men, 5 x 150 x 12	9,000 D
Miscellaneous Expense	15,000 D
Total	99,000 D

Cost Per Day = 270 D/day
Cost Per 1000 m^3 = 2.7 D/1000 m^3
Cost Per m^3 = 2.7 milliemes/m^3

APPENDIX 8

Table A8-1

Cost Evaluation of 100,000 m^3/Day Primary Plant

Cost from Figure 11 (no redundancy)	2,600,000 D
Engineering and Contingencies @ 20%	520,000 D
Total	3,120,000 D
Annual Costs:	
Fixed Costs, 15% of 3,120,000	470,000 D
Power--1,000,000 kw hrs	10,000 D
Labor--8 x 150 x 12	14,400 D
Contingency	25,000 D
Total	519,400 D

Daily Cost = 1,420 D
Cost Per 1000 m^3 = 14.2 D
Cost Per m^3 = 14.2 m
Chlorination (see Appendix 1) = 3.08

Total = 17.3 milliemes

APPENDIX 9

COST EVALUATION OF OCEAN DISCHARGE

100,000 m^3 per day pumping plant with 10 kilometer force main from La Cherguia to La Marsa. Assume 1600 mm main, 50-year life. The gravity outfall from La Marsa 8 kilometers to sea will also be a 1600 mm main, operated to assure scouring velocity and avoidance of gas entrainment.

Table A9-1

Pumping Plant from Figure 17 (50% redundancy)	320,000 D
Engineering and Contingencies	64,000 D
Pumping Plant Totals	384,000 D
Outfall:	
Pipe--10,000 m, 1600 mm main, 94 D/m	940,000 D
La Marsa receiving station est.	100,000 D
Sea outfall, 8000 m, 1600 mm main, 300 D/m*	2,400,000 D
Engineering and Contingency	690,000 D
Total	4,130,000 D
Fixed Costs:	
Pumping Plant, 384,000 D @ 15%/Annum	58,000 D
Outfall, 4,130,000 @ 9%/Annum	370,000 D
Power--75 KVA, 43,500 hr @ 10 milliemes	34,000 D
Labor-- 10 men, 12 months	18,000 D
Miscellaneous	50,000 D
Total	530,000 D

Daily Cost = 1,450 D
Cost Per 1000 m^3 = 14.5 D
Cost Per m^3 = 14.5 milliemes

*No data is available for sea outfall in or near Tunis. U.S. outfall costs are from three to five times the cost of placing similar pipe on land.

APPENDIX 10

TEMPORARY AERATOR STATION AT LA CHERGUIA--COSTS

The BOD deficiency at the La Cherguia station is about 10,000 kg/day and one may expect to obtain 1 kg of oxygenation capacity per kw hr. The requirement is for installation of 10,000 kw hr system. Operating 24 hours per day, the required capacity would be 400 kw. This would be provided by 11-50 hp floating aerators. To have a reserve unit, 12 units should be purchased. The cost of 12 units should be about 100,000 Dinars. Temporary installation of electrical power should cost about 50,000 Dinars. The units would be installed in a temporary pond having a 4-day retention period and a volume of 210,000 m^3. Assuming a depth of 2.5 meters, the area required would be 9.6 hectares = 96,000 m^2. This would be retained by a levee 310 meters each way. Assuming the levees to be three meters high and three meters at the crest, and with side slopes of three to one, we have an earthwork volume of 36 m^3/m of length or for 1,240 meters of levee and allowing about 10 percent wastage. The required levee volume is 50,000 m^3.

Assuming that the land would be available for nothing, the capital costs would be:

Table A10-1

Item	Cost/Dinar
12 floating surface aerators	100,000 D
Installation of 11 aerators, electrical	50,000 D
Pond levee 50,000 m^3 @ 1 D/m^3	50,000 D
Temporary lift station	10,000 D
Piping and controls	10,000 D
Engineering and Contingencies @ 20%	44,000 D
Total	264,000 D

(A-10-2)

Item	Annual Cost/Dinar
Electrical Power	20,000 D
Operations and maintenance	20,000 D
Depreciation and interest @ 25%	55,000 D
Engineering and Contingencies @ 20%	10,000 D
Total	105,000 D

APPENDIX 11

DESIGN OF INTERIM PONDING SYSTEM

This is an emergency pond to be constructed either in Sebkhet Er Riana or in the Djafar area to hold and treat sewage temporarily. There would be no partitions in the pond, but provision would be made for a central digester and central feed to protect the environment from odors and to protect the levees. The design detention period would be 60 days; the pond would overflow to the Er Riana. Since this would be a temporary system, it would provide for the current flow of 60,000 m^3/day.

60,000 m^3/day 60 days,

volume = 3,600,000 m^3. Take depth of 1.5 meters. Then area = 3,600,000/1.5 = 2,400,000 m^2 = 240 hectare. Side length would be 1,550 meters. The total peripheral levee length will be 6,200 meters. Levees would be 3 meters high with rip rap. According to Figure A5-1, the 3-meter levees will have a volume of 32 m^3/m or a total volume of 198,400 m^3.

Rip rap, 6,200 meters @ 1 m^3/m = 6,200 m^3. For digester, excavate 2 hectare, 1 meter deep. Have 20,000 m^3; construct into low berm around the area, Type IV submerged levee.

Feed pipe. Use central feed diversion from receiving station for future ponds. 1400 Line meters of 1000 mm pipe @ 43 D = 60,000 D. Effluent overflow 10,000 D.

Table A11-1

Cost of Temporary Ponding System

Levees, 198,400 m^3 @ 1 D/m^3	198,400 D
Rip rap, 6,200 L/m_3@ 2 D	12,400 D
Digester, 20,000 m^3 @ 1 D/m^3	20,000 D
Feed pipe, 1400 Line m, 1000 mm	60,000 D
Overflow	10,000 D
Totals	300,800 D
Engineering and Contingencies @ 20%	60,000 D
Total Cost	360,800 D

This unit may be used for saltwater receiving in future years; therefore, annual recovery rate may be 11 percent.

Fixed Costs, 360,000 @ 11%	40,000 D
Labor--5 men @ 150 D, 12 months	9,000 D
Miscellaneous Costs	10,000 D
Total	59,000 D

Daily Cost = 162 D
Cost Per 1000 m^3 = 2.7 D
Cost Per m^3 = 2.7 milliemes

This does not include cost of conveyance from La Cherguia to receiving station which was computed in Appendix 3.