THE ALEXANDRIA EFFLUENT AND SLUDGE REUSE STUDY

Jeremy Hall
Project Manager, WRc plc, Medmenham, UK

and

Eng. Hassan El Hakeh
Chairman, Alexandria General Organisation for Sanitary Drainage

BACKGROUND

The provision of sewage treatment in Alexandria has resulted in the production of substantial quantities of effluent and sludge. In an arid country such as Egypt, these materials should be regarded as valuable resources for agricultural irrigation and soil fertilisation, particularly as water resources are strictly limited and there is an urgent need for continued horizontal expansion of agriculture into the desert areas as the population increases.

However, effluent and sludge need to be treated and managed appropriately to avoid potentially adverse impacts on the environment and human health. The use of effluent and sludge must also be practicable and economic, to ensure operational sustainability.

The Alexandria Effluent and Sludge Reuse Study have been commissioned to establish the appropriate approaches to be adopted by the Alexandria General Organisation for Sanitary Drainage (AGOSD) to secure efficient and beneficial disposal of effluent and sludge. The Study is being funded under the Mediterranean Technical Assistance Programme (METAP) through the European Investment Bank, and is being carried out on behalf of AGOSD by WRc plc.

The principal objective of the Study is to allow safe and economically responsible reuse of treated sewage effluent and sludge from the city of Alexandria in order to make best use of existing resources and to protect the environment and human health.

The study, which commenced in October 1998, will evaluate the potential for effluent and sludge reuse, identify monitoring requirements, carry out demonstration field trials, and develop the strategic planning required to establish full-scale use of effluent and sludge.

The initial planning and evaluating phase of the Study has been completed, the recommendations from which provide the detailed structure for the following practical work and strategic evaluations.

STRATEGIC APPRAISAL OF THE POTENTIAL FOR EFFLUENT REUSE IN THE ALEXANDRIA REGION

Review of international and Egyptian experiences and controls

Wastewater has been used to support agricultural production in many countries over a considerable period of time. The area of land under irrigation with wastewater has increased significantly over the past two decades due to constraints on water supply and increasing concerns over the environmental implications of previous disposal routes. Effluent reuse can provide considerable social, economic and environmental benefits when used under carefully controlled conditions established to protect the health of farm workers, their families and consumers of the produce.

Legislation and guidelines on the minimum quality required for effluent reuse in agriculture have been published and implemented by international organisations (e.g. WHO 1989) and in many countries with different degrees of enforcement. These standards have been introduced principally to protect human health and thus mainly specify microbiological parameters. There are also guidelines on the overall suitability of water for irrigation to protect crop yield and soil fertility that cover chemical quality.

The decision to use reclaimed effluent for irrigation of crops has been adopted in many Mediterranean and Middle East countries, and in many other semi-arid and arid areas across the world. Most of these countries have adopted regulations or published recommendations based on guidelines published by international organisations such as WHO. Other countries have no regulations but wastewater reuse programmes have to be approved on a case by case basis.

In Egypt, there are few examples of planned reuse of effluent (e.g. Gabal El Asfar Old Farm, and El Saff served by Helwan WWTP), although much is reused unofficially through the use of drain water for irrigation in water-short areas. Egyptian legislation does not provide clear or comprehensive regulation of effluent quality for reuse, although improved standards are under consideration (i.e. draft Decree 256/1994).

Quantity and quality of Alexandria effluent and potential reuse options

Currently, no secondary treatment is available on the existing WWTPs in Alexandria and primary effluent is discharged to Lake Mariout. In addition to the imminent expansion of the existing WWTPs (USAID funded), it is planned that secondary treatment will be installed on the existing East and West Treatment Plants (ETP and WTP) by 2010. Two further secondary WWTPs are planned to be constructed to serve the Amriya district (French funded), and the Mex, Dekhila and Agamy areas (German funded) within a few years. Figure 1 summarises the growth in wastewater treatment capacity in Alexandria over the next 20 years, reaching 660 million m^3 y^{-1} by 2020.

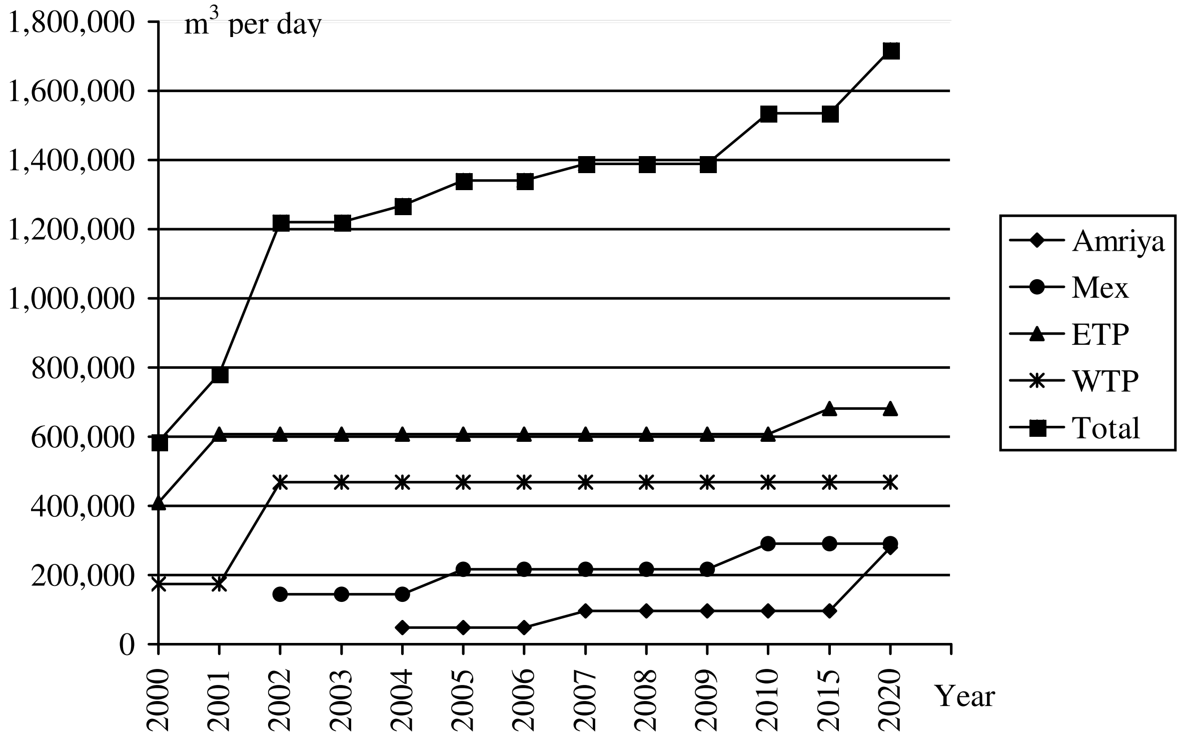

Figure 1 Current and future wastewater treatment capacity (design) in Alexandria (m^3 per day)

Only limited data is available on the likely quality of secondary effluent and this is derived from the pilot biotower (percolating filter) studies, carried out by Metcalf & Eddy in 1996. These data indicate that biotower treatment can achieve the quality requirements for discharge to non-potable water sources (i.e. compliance with Law 48/1982), although further treatment would be required to achieve the quality standards necessary for direct reuse of effluent for agriculture.

The available data indicate that the concentrations of potentially toxic elements (PTEs) in primary effluent are well below the commonly adopted international limits to protect crop production and quality, and are well within the limits set by the Egyptian draft Decree 256/1994 (see Table 1), despite the fact that the WTP receives a significant amount of industrial effluent. Secondary treatment will reduce the concentrations of PTEs even further in the effluent, but this will increase the PTE content of the sludge.

Effluent provides supplementary fertilisation to crops, and calculations show that the addition of nitrogen at normal irrigation rates will not supply a surplus of nitrogen, which may otherwise be lost to groundwater (see Table 2). Therefore, potential impacts on groundwater would be minimal. The effluent would supply more than sufficient potassium for crop production, which is the most expensive nutrient for farmers to purchase and often limits crop production through under-application.

Table 1 Potentially toxic element (PTE) concentrations of the primary effluent from the East and West Treatment Plants compared with US EPA and draft Egyptian standards (μg l^{-1})

PTE	ETP (mean)	WTP (mean)	US EPA (1992)	Egyptian Draft Decree 256/1994 Primary	Secondary	Advanced
Antimony	<2.5	2	ns	ns	ns	ns
Arsenic	<8.7	2.4	100	-	-	100
Beryllium	<1.0	1	100	ns	ns	ns
Cadmium	<1.0	1	10	50	10	10
Chromium	<6.0	6.1	100	-	-	100
Copper	52.5	29.4	200	-	200	200
Lead	52.5	14.0	5,000	10,000	5,000	5,000
Mercury	<2.1	0.21	ns	ns	ns	ns
Nickel	<15	15	200	500	200	200
Selenium	<5.8	2.6	20	ns	ns	ns
Silver	<4.0	3.7	ns	ns	ns	ns
Thallium	<3.0	1	ns	ns	ns	ns
Zinc	66.1	64.1	2,000	-	2,000	2,000
Cobalt		11	50	-	50	50
Iron		630	5,000	-	5,000	5,000

Note: ETP and WTP data from Metcalf & Eddy (Biotower study)
ns = not stipulated

Evaluation of salinity and sodicity resulting from the use of the effluent in the soils in the Nubaria area indicates that no problems are likely to develop, although chloride sensitive crops, such as banana and citrus, may not be advised.

Agriculture represents the largest potential outlet for the effluent, and the implications of effluent reuse have been considered in detail by the study. However, forestry, amenity (e.g. the proposed Alexandria green belt), industrial uses, and even aquaculture are potential alternatives. The quality requirements of these options vary according to use and the potential human and environment exposures.

Table 2 Percentage of total recommended quantity of macro-nutrients supplied by effluent irrigated at an annual water duty of 5,600 m^3 fd^{-1}

Nutrient	Wheat	Maize	Cotton	Sugar Beet
Nitrogen N	30	38	85	48
Phosphorus P	55	68	176	50
Potassium K	218	260	217	200

Water demand and resources in the Alexandria region

Agriculture in the region, with the exception of limited rain-fed agriculture along the northern coast, relies upon water supplied through the Nubaria Canal, which receives a fixed quantity of water from the River Nile. Irrigation water is distributed in the Nubaria area via the Nasr Canal in the south, and the Mariout/Bahig Canal in the north. Both canals will eventually converge on the Hamam project to the west, when completed. Groundwater is not used for irrigation in the Governorate to any great extent, apart from some extremely limited shallow aquifers along the coast, as the quality is variable and often brackish.

Calculation of irrigation water demand (based on a conservative water duty of 5,600 m^3 fd^{-1}) and availability indicates that the reclaimed land in the West Nubaria area is short of water, to the extent of 200 million m^3 y^{-1} over the cropped area of 144,000 feddans. This situation is expected to worsen as more land is brought under cultivation. GARPAD intends to reclaim additional land along the Nasr and Bahig Canals, of which 287,000 feddans are within the Governorate and would require a minimum of 1.6 billion m^3 y^{-1}. Present total demand from all water sectors in the region is about 2 billion m^3 y^{-1}, and this will increase to 3.6 billion m^3 y^{-1} by 2015, assuming all land scheduled for reclamation is provided with the required infrastructure.

To compensate at least in part for this, the Umoum Drain Project was developed. This will result in the reversal of the drain flow from a point near the Truga pump station, and through a series of lift stations, the drain water will be transferred to the Nubaria Canal, south of the Nasr Canal. Two scenarios were developed, initially the reclamation of 165,000 fd, implying a total demand of 924 million m^3 y^{-1}, half of which would be derived from the Umoum Drain, based on a drain/canal mixing ratio of 1:1. The second scenario considered the reclamation of 350,000 fd and supply of 1.1 billion m^3 y^{-1} from the drain. However, the quantity and quality of the drainage water in the Umoum may be expected to decline as Irrigation Improvement Programmes (IIPs) are implemented.

The overall future shortfall in water supply by 2015 is estimated to be 1.6 billion m^3 y^{-1}, of which 1.1 billion m^3 y^{-1} could be derived from the Umoum. The balance required matches the expected production of treated sewage effluent from Alexandria of 650 million m^3 y^{-1}.

Agricultural land proposed in the Alexandria region for effluent reuse

The site, or sites, recommended for consideration for reuse of a suitably treated effluent have been selected on the basis that the effluent is polished to an appropriate standard acceptable for irrigation. The West Nubaria area is critically short of sufficient water to meet the present demands for crop production and any planned extensions to the existing cultivated lands will exacerbate an already serious water-short situation.

In considering the possibility of reuse of the effluent that will be generated from Alexandria, an area of uncultivated desert land, comprising about 28,000 ha (70,000 fd) gross, situated to the south of the Nasr Canal, has been identified previously as suitable for an effluent reuse project, Most of the suitable land along the Nasr Canal has already been distributed and cultivated, and this land currently lies outside the GARPAD land reclamation programme. The altitude varies from around 40 m near the irrigated margin to over 100 m on the ridge trending approximately east to west, implying considerable pumping costs.

The region is already short of water and an increasing supply of good quality water from the Nile is unlikely, especially with the planned diversion of Nile water to the New Valley through Wad Toshka. An ever increasing demand for good quality water for municipal and industrial use leaves agriculture to adjust to further reduction in water supply or to utilise, to the fullest extent possible, those supplies likely to become available in the future. Drain water and treated sewage effluents are the only feasible sources. The proposed site for effluent reuse may be too costly to develop and alternative strategies for reuse, initially in the agricultural sector, are proposed.

Proposed scenarios for effluent reuse in the region

Four scenarios have been considered to efficiently use the effluent within the region. The land served by the Nasr and the Bahig Canals is short of water, and this will be exacerbated by the Hamam schemes when the canals are extended to this area. The scenarios proposed are:

Scenario A - To develop uncultivated desert land south of the Nasr Canal (the earlier proposed area). A lift of 70 m and piped conveyance of 70 km makes this a costly option, particularly bearing in mind the relatively low development potential of the designated area. Additional effluent treatment would be required for direct reuse.

Scenario B - To supplement the water supply in the Nasr Canal by direct transfer of effluent from Alexandria. Lift 50 m and distance 50 km, with discharge of the effluent into the start of the Nasr Canal and use existing lifts for the remaining distance. Direct discharge of effluent to canal not currently acceptable in Egypt, according to Law 48/1982. Additional effluent treatment would be required.

Scenario C - To supplement the water supply in the Nasr Canal by transfer of effluent through the Umoum Drain reversal scheme. A lift 10 m and distance 20 km would result in the lowest cost. Secondary effluent quality, as currently planned would be acceptable, and may potentially improve drain water quality. The Umoum scheme has been delayed until WWTPs at Shereshera and Abu Hommes are completed; the treated effluent from these plants will discharge to the drain. This implies acceptance of the principle of Alexandria effluent being similarly discharged. The effluent would supplement drain flows as these reduce in the future due to IIPs in the region.

Scenario D - To supplement the water supply in the Bahig Canal by direct transfer. With a lift 30 m and distance 20 km, this is a medium cost option but would involve direct discharge of effluent to the canal. Additional effluent treatment would be required.

Based on these early assessments, Scenario C is probably the most favourable as this would incur the lowest overall cost; it would require no additional expenditure on effluent treatment other than that already planned by AGOSD; it would comply with existing Egyptian law; and provide additional irrigation water in the West Nubaria and Hamam reclamation areas which will become progressively short of water.

Effluent demonstration trials

There is very limited practical experience of effluent reuse in Egypt (limited to Cairo at Gabal El Asfar and El Saff), although much probably occurs through unofficial use of drain water into which sewage is discharged.

Demonstration trials are considered an essential adjunct to the proposed controlled full-scale reuse of treated effluent from Alexandria. Such trials would provide practical experience of reuse, and to reassure farmers in the region that treated effluent is both a safe and beneficial alternative or additional source of irrigation water.

Since no secondary treated effluent is yet available in Alexandria, it is proposed to recommission the pilot biotower (trickling filter), proved by USAID and operated by Metcalf and Eddy (M&E) in their evaluation of secondary treatment options for the existing WWTPs in Alexandria. The pilot biotower effluent would be chlorinated to ensure that the hygienic quality of the effluent meets the necessary quality criteria for direct reuse of treated sewage effluent, and thus comparable to the quality of effluent that will be produced at the full-scale.

Two trial sites are proposed to reflect different options for effluent reuse in theNubaria area.

- A private farm, near Baghdad village has been selected as being typical of agriculture in the Nubaria area. The soil is calcareous clay loam and the normal method of irrigation is flood. A range of arable, fodder, vegetable and fruit crops are grown. The trial proposed would evaluate three arable crops grown in each season in a three year rotation, focusing on fodder and industrial crops, but excluding vegetables. Different rates of fertiliser would be used to evaluate the value of the nutrients from the effluent.

- Unused land at AGOSD's sludge disposal site (Site 9N) would be used for a trial dedicated to growing a range of relevant tree species of economic (timber, fuel, paper, etc.), agricultural (fruit, windbreak, etc.), or amenity (greenbelt, etc.) significance in the region. Flood or drip irrigation could be used. This would simulate the plantation type of agriculture, where the use of effluent is a conservative option, since the potential risks to human health are minimised

It is intended that the management of the trials would be continued by AGOSD after the Study, to provide a long-term demonstration facility for a number of years, from which useful practical and scientific information can be derived. A monitoring plan has been devised, which includes assessment of crop growth performance and yields, and chemical and microbial analysis of irrigation water, crops and soil.

SLUDGE MANAGEMENT

Quantity and quality of Alexandria sludge and potential reuse options

There is a high demand for alternative and additional sources of organic matter and nutrients in Egyptian agriculture. This is due to the decline in the use of draught animals for soil cultivation, the manure from which has been the traditional source of organic manure and nutrients. Also, since the removal of fertiliser subsidies, the costs of fertilisers have increased to world prices, restricting the farmers' ability to fertilise to optimum levels. Consequently, there is now a ready market for sewage sludge.

There is extensive international experience of using sludge in agriculture and this route usually represents the best practicable environmental option (e.g. Smith 1996; Hall and Davis 1998). However, sewage sludge inevitably contains contaminants and pathogens, the extent of which depends on the nature of the sewage catchment, particularly the presence of industry, and the general health of the population. These present potential risks to the environment, agricultural production and human health, unless the sludge is treated to appropriate standards and its use is controlled. Most developed countries have well-developed regulations, and the principles of these are relevant to Egyptian conditions.

Large quantities of sludge have only recently started to be produced in Egypt as more wastewater treatment plants (WWTPs) are being constructed. The largest sludge arisings are in Cairo (about 400,000 tonnes of sludge dry solids (tds) annually) from six very large WWTPs serving a population of about 15 million. A major study on the reuse of this sludge in agriculture is nearing completion (The Cairo Sludge Disposal Study, carried out by WRc - Hall and Shehata 1996; 1997), the results of which will have wide application in Egypt.

Currently, the sludge produced by the existing two WWTPs in Alexandria is disposed of by spreading on a dedicated land area (Site 9N) at Amriya, but this is not a sustainable option. Sludge production is currently about 450 m^3 d^{-1} (46,000 tds y^{-1}), but will increase to 112,000 tds y^{-1} by 2010, according to the current wastewater treatment development plans. The sludge from the two proposed WWTPs to serve western Alexandria will produce at least an additional 60,000 tds y^{-1} at full capacity. Total sludge production in Alexandria will reach about 180,000 tds y^{-1} by 2025. It is anticipated that all of the sludge will be composted at Site 9N and marketed for agricultural reuse, but the dedicated land disposal area will remain available for emergency use.

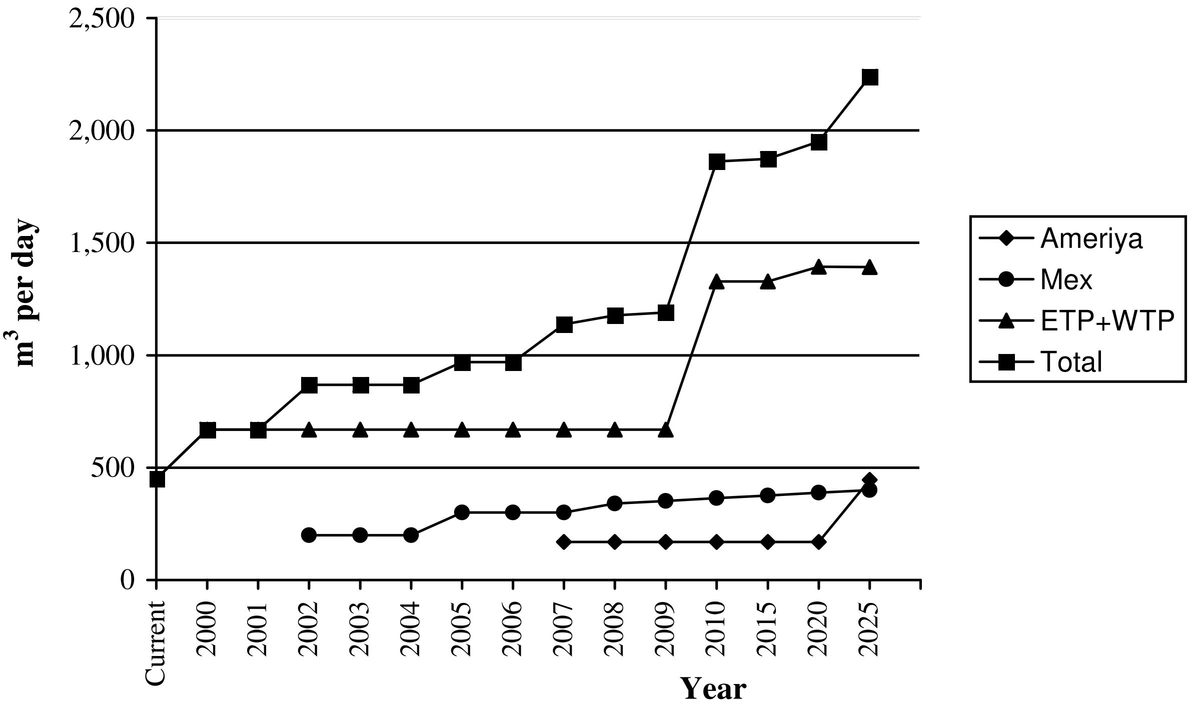

Figure 2 Current and future sludge production in Alexandria (m^3 per day)

The quality of the composted sludge from Site 9N is excellent, being dry and friable (and hence easy to spread on the land by hand), and has low concentrations of PTEs and pathogens, well below the Egyptian 'temporary' limit values in Decree 214/1997 (see Table 3).

Sludge demonstration trials

Field trials are a valuable means of demonstrating the practical use of sludge; to derive specific agronomic information, and to reassure farmers that the compost is safe and beneficial. The principal target area for sludge reuse is likely to be the reclaimed desert soils of the Nubaria area. Site 9N, as the compost production centre, is conveniently located to the north of this area; it is also close to the Alexandria/Cairo Desert Road, making transport easy to a considerable area of land. The delta farms are not regarded as a primary market outlet for sludge, as the demand for the sludge is likely to be lower and access for large lorries more difficult.

Table 3 Composition of Alexandria sludge compost in comparison with Egyptian Decree 214/1997 limit values

Determinand	Units	Compost (mean values)	Egyptian Decree 214/1997
Volatile solids	%	35	-
Dry solids	%	90	-
Nitrogen	%	1.82	-
Phosphorus	%	0.94	-
Potassium	%	0.34	-
Magnesium	%	1.1	-
Calcium	%	13	-
Iron	%	1.49	-
Copper	mg kg^{-1} ds	288	1,500
Cadmium	mg kg^{-1} ds	2.62	39
Chromium	mg kg^{-1} ds	66	1,00
Nickel	mg kg^{-1} ds	27	420
Lead	mg kg^{-1} ds	153	300
Zinc	mg kg^{-1} ds	653	2,800
Molybdenum	mg kg^{-1} ds	<1.0	18
Arsenic	mg kg^{-1} ds	<7.3	41
Selenium	mg kg^{-1} ds	<2.48	36
Mercury	mg kg^{-1} ds	<1.43	17
Coliforms	count g^{-1} ds	10^3	10^3
Salmonella	count g^{-1} ds	<LOD	3 per 4 g ds
Helminth ova	count g^{-1} ds	<1	1 per 5 g ds
Virus	count g^{-1} ds	nd	1 per 5 g ds

Four trial sites have been selected to represent the principal large-scale reuse options, and the major soil types, crop and irrigation methods in the Alexandria region. These are:

- Trial Site 1 - sandy calcareous soil, to the east of the Desert Road (km 84) near Nubaria. A range of arable crop and citrus will be tested with composted sludge in comparison with farmyard manure (normal farmer practice).
- Trial Site 2- loamy calcareous soil, near Baghdad village (10 km south of Site 9N), three neighbouring farms will host trials. The land is normally flood irrigated, and a range of arable, fodder, vegetable and fruit crops are grown. The trials proposed would evaluate the fertiliser value of the compost to arable crops grown in rotation, focusing on fodder and industrial crops, and excluding vegetables. Compost application to seedling and established apple and pear trees would also be tested. The effluent demonstration trials would also be carried out on one of these farms.
- Trial Site 3 - unused land at AGOSD's sludge disposal site (Site 9N) would be used for a trial dedicated to growing a range of relevant tree species of economic (timber, fuel, paper, etc.), agricultural (fruit, windbreak, etc.), or amenity

(greenbelt, etc.) significance in the region. Flood or drip irrigation could be used. This trial represents the use of sludge under plantation type agriculture.

- Trial Site 4 - it is proposed to continue one trial established by the Cairo Sludge Disposal Study which studied fruit trees using composted, raw and digested sludge under drip irrigation. The site is far from Alexandria (km 58 from Cairo on the Desert Road), but it is valuable to continue monitoring such trials to asses long-term effects.

With the possible exception of the site at km 58, the trials have been selected and designed so that their management can be transferred to AGOSD during the Study. The trials will continue to produce useful data and demonstration facilities for a number of years. The Site 9N trial could be usefully continued for ten years or more, since this site is under the direct control of AGOSD, and trees are essentially a long-term crop. A monitoring plan has been devised, which includes assessment of crop growth performance and yields, and chemical and microbial analysis of crops and soil.

REFERENCES

Hall, J.E. and Shehata, R. (1996) Development of a practicable, safe and economic wastewater sludge reuse programme for Egyptian conditions. Paper presented to 1st International Water Technology Conference, 26-29 February, Alexandria, Egypt.

Hall, J.E. and Shehata, R. (1997) The agricultural value of sewage sludge: Initial results from the Cairo Sludge Disposal Study**.** Paper presented to 2nd International Water Technology Conference, 28-31 March, Alexandria, Egypt.

Hall, J.E. and Davis, R.D. (1998) Production, treatment and disposal of sewage sludge in Europe. Paper presented to 3rd International Water Technology Conference, 20-23 March, Alexandria, Egypt.

Ministry of Housing, Utilities and Urban Communities (1997) Decree No. 214 for the year 1997 concerning processing and safe use of sludge.

Smith, S.R. (1996) Agricultural recycling of sewage sludge and the environment. CAB International, Wallingford, UK.

US EPA (1992) Guidelines for water reuse. US EPA and US Agency for International Development. EPA/625/R-92/004, Cincinnati, Ohio.

WHO (1989) Health guidelines for the use of wastewater in agriculture and aquaculture. Report 778 of a WHO Scientific Group, Geneva, Switzerland.