SECONDARY CITIES PROJECT IN EGYPT

FINAL DRAFT

FEASIBILITY STUDY FOR WASTEWATER
REUSE SCHEME
FOR
NUWEIBA

SUBMITTED TO
US AGENCY FOR INTERNATIONAL DEVELOPMENT,
CAIRO, EGYPT
PROJECT NO. 263-0236

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DECEMBER 1997

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EXECUTIVE SUMMARY

Within the framework of the Secondary Cities Project (No. 263-0236), the Government of Egypt (GOE) and United States Agency for International Development (USAID) initiated a feasibility study on wastewater reuse.

The purpose of the Secondary Cities Project is to expand and develop reliable water/wastewater facilities in selected urban centers of Egypt. The quality control criteria developed for the program require the protection of surface water and groundwater and the optimum use of available resources.

Within this context, USAID assigned a DATEX team the responsibility to review, analyze, and verify the following salient factors:

- The possibility of constructing wetlands to remove nutrients from the effluent;
- The feasibility for a private firm to design, construct, and operate a wastewater reuse scheme through the Build, Operate, Transfer (BOT) mechanism;
- The advisability of establishing an effluent management plan which includes constructed wetlands and BOT reuse concessions; and
- The probability that risks associated with constructed wetlands and with a BOT reuse concession would be manageable.

The requirement for protection of the Gulf of Aqaba coral ecosystem guided all investigations and recommendations formulated by the Activity Review Team.

The team carried out site activities in Nuweiba and other locations, reviewed available proposals and literature from USAID/Cairo, and discussed relevant issues with local authorities, agricultural researchers, Bedouin farmers, and Egyptian specialists in fulfilling its responsibility to evaluate the preliminary analysis for Nuweiba.

The team agrees with the USAID preliminary analysis on the feasibility of contracting a private enterprise to operate a wastewater reuse scheme for agriculture through a BOT approach.

The Activity Team has selected an agricultural reuse scheme that will utilize the nutrient levels that would have posed a threat to the environment while providing economic benefits in the sale of crops in the local market and in increased land value for Nuweiba.

The Activity Team suggests that the project be initiated with a combination of constructed wetlands, windbreak plants, and agricultural and ornamental plant projects. The constructed wetlands system can be used to treat the effluent nutrients in the initial startup period, until the agricultural crops reach the intended water consumption capacity.

In addition, the existing ponds can be cleaned and restored for use as added storage in the reuse scheme. The city's mulberry tree farm could be continued until the new plantation of perennial trees are old enough to reach maximum water requirement for the North system. This arrangement should prevent the discharge of wastewater to the surface water or groundwater.

CHAPTER ONE PURPOSE

1.1 Introduction

Fresh water resources are diminishing at alarming rates all over the world. In fact, many areas within most countries are facing water shortages. This is a major regional problem in the Middle East that is experiencing rapid population growth and water demand, where water resources are scarce and becoming more contaminated from human industrial and agricultural activities. Agricultural activities, specifically irrigation for food production, is estimated to represent 65% of the total global water demand (Postel, S., 1992). Egyptian agriculture uses 88% of its total water demand (The World Bank, 1995). The World Bank predicts that over the next 40 years, production of food must increase by 300 percent and recommends that nutrients from wastewater should be utilized in agriculture instead of fossil fertilizers and pesticides in order to decrease environmental pollution as well as any potential economic burden. Sustainable development is interrelated to water conservancy, wastewater treatment and reuse programs.

In Egypt over 55% of the population live in rural areas and earn their income from agriculture (Middle Eastern Regional Cooperation (MERC), 1997). According to the MERC team's estimations, Egyptian rural areas generate approximately 500 million cubic meters (MCM) of sewage per year, and are projected to generate 1500 MCM by the year 2015. In most of the rural areas in Egypt this sewage/wastewater is improperly treated or goes untreated. Untreated wastewater presents a risk of transmission of numerous diseases in Egypt. However, if treated properly, it is valued for its nutrients and as an alternative water source for agriculture.

1.2 Objectives of Water Reuse

Water reclamation and reuse around the world has become a viable alternative for conservation and management of available water supplies. Water reuse can also present a method of pollution prevention when it replaces effluent discharge to sensitive water bodies. Wastewater reuse can eliminate or reduce the need for costly and complicated advanced wastewater treatment processes. In particular the removal of nitrogen and phosphorus is unnecessary for most non-potable water reuse.

Reclaimed wastewater can be used for landscape and recreational grounds irrigation, industrial processes, cooling towers, air conditioning, stack gas scrubbing, toilet flushing, construction, firefighting, crop production, and environmental enhancement such as maintaining certain stream flows and wetlands.

1.3 Nuweiba

The proposed activity in Nuweiba is part of a larger project on water/wastewater improvement, the Secondary Cities Project (No. 263-0236).

1.4 The Secondary Cities Project

The Secondary Cities Project is in furtherance of the AID Mission's country program goals of improving quality of life and building sustainable local infrastructure for operation of vital community services.

1.5 Goal of the Secondary Cities Project

The goal of the Secondary Cities Project is to provide a sustainable foundation for improved health and living conditions in urban cities.

1.6 Purpose of the Secondary Cities Project Activity

The purpose of the Secondary Cities Project activity is to expand and develop sustainable, reliable, water/wastewater facilities in selected urban population centers of Egypt. The implementing agency within the Government of Egypt (GOE) is the National Organization of Potable Water and Sanitary Drainage (NOPWASD).

1.7 The Nuweiba/Mansoura/Luxor/Aswan Activity

The present activity focuses on water/wastewater needs in four locations: Mansoura, Nuweiba, Luxor, and Aswan group (Kom Ombo, Darawo, and Nasr City). Because of its location adjacent to a coral ecosystem on the coast of the Gulf of Aquaba (South Sinai), Nuweiba presents unique problems for wastewater reuse. The feasibility study for Project activities in Nuweiba noted that sewage treatment is an important environmental challenge because the coral reef system can be damaged by nutrient pollution.

CHAPTER TWO ACTIVITY DESCRIPTION

2.1 Background

Since 1977, the GOE and USAID have collaborated in the expansion and upgrading of both water and wastewater facilities in Egypt, mainly in Cairo, Alexandria, the three canal cities, and to a lesser extent with the Provincial Cities Project. The National Organization for Potable Water and Sanitary Drainage (NOPWASD) is the Egyptian agency responsible for the implementation of water and wastewater projects for all of Egypt, with the exception of Cairo and Alexandria. There is a backlog of more than 200 cities which have requested assistance from NOPWASD, to construct water and wastewater treatment facilities. NOPWASD has, in turn, sought assistance from USAID for funding to meet some of these requests.

The Secondary Cities Project activities have been developed to assist the GOE in amplifying such reforms. For the cities concerned it includes implementation of needed facilities for Egypt. As a whole it may be viewed as a pilot, or demonstration project, for its institutional reform aspects. Of the more than 200 cities requesting aid, seven have been selected, in part because of their diversity. The cities range from: Mansoura, a large city in the agricultural/industrial delta; to Nasr City, an upper Egypt township of villages relocated more the 30 years ago from the rising waters of lake Nasser; to Nuweiba, a small Sinai Coast town now quickly expanding due to tourism.

Basic background data and information for the Secondary Cities Project were gathered and presented in a report in support of a project paper (referred to as the WASH Report). This March 1994 project paper formed the basis for the Environmental Assessment (EA) Report (CDM, April 1997) for Nuweiba Water and Wastewater design consequences. The EA Report is a culmination of existing information and data, such as the WASH Report, and interviews with citizens and professionals involved with the project.

Camp Dresser McKee (CDM) also prepared and presented the “Basis of Design Report for Nuweiba” which describes the water distribution and wastewater collection, conveyance, and treatment improvements.

2.2 Activity Setting

This activity report presents the evaluations of wastewater effluent reuse schemes for the Secondary Cities Project activities in Nuweiba.

2.3 Location

Nuweiba is located on the eastern side of the Sinai Peninsula on the Gulf of Aqaba (See figure 1.1). More specifically, Nuweiba is located at 29°00’ North latitude and 34°40’ East longitude. Nuweiba is a port city and the western terminal of an international ferry service connecting Egypt with Aqaba, Jordan.

Nuweiba is divided into two distinct areas by the Wadi Watir, a flood fan that annually separates the North and South parts of the city. North Nuweiba contains the original city center, government offices, the hospital, residential and tourist areas. South Nuweiba includes the port facilities, hotel and condominium developments, the desalination plant, the UN Multinational Force and Observers (MFO) Camp, along with residential and industrial areas.

2.4 Project Objectives

In order to assist the Government of Egypt (GOE) in expanding and improving its institutional reform efforts in the water and wastewater sector, the United States Agency for International Development (USAID) is funding the Secondary Cities Project.

The existing project focuses on Water/Wastewater needs in Mansoura, Luxor, the Aswan group (Kom Ombo, Darawo and Nasr cities) and Nuweiba, which is the focus of this phase of the project statement of work (SOW) (presented in attachment B). In addition to design and construction of facilities, USAID/Cairo will also finance a technical assistance contract to provide institutional support for the water/wastewater organizations in these Secondary Cities.

Although there are no provisions in the project for management of effluent from new sewage treatment facilities, several cities/governorates have expressed interest in the development of reuse schemes to take advantage of the water and nutrients contained in the effluent, while at the same time avoiding discharge into surface waters and groundwater. More significant, the Environmental Assessment report, prepared and completed by Camp Dresser & McKee (CDM) for project activities in Nuweiba, pointed out that proper management of effluent from the Nuweiba sewage treatment system is an important environmental consideration because the Gulf of Aqaba coral reef system, located adjacent to Nuweiba, can be damaged by nutrient pollution.

Presently, effluent from the existing Nuweiba sewage treatment system is discharged onto the land surface and percolates to the groundwater which eventually flows to the Gulf. USAID is assisting the city/governorate in considering whether it is feasible to contract with a private firm to design, construct, and operate a reuse scheme through a "Build, Operate, and Transfer" (BOT) mechanism.

It is the purpose of this activity of the project to identify and evaluate wastewater effluent reuse schemes and to develop plan criteria for managing the Nuweiba sewage treatment system's effluent in a manner that will avoid pollution of surface and groundwater and the Gulf of Aqaba's Coastal Reef Systems.

2.5 Need for Water Reuse in Nuweiba

The amount of potable water available for the city of Nuweiba is very limited and as the city and the tourism industry continue to grow this limited resources becomes very valuable. Already the city and all hotels rely on desalination plants to supplement their water needs. The growth of Nuweiba is driven by the growth in the tourism industry which is directly related to the Gulf of Aqaba beaches and the coral reefs in the area. Any discharge of wastewater to the gulf requires advanced treatment levels to meet pollutant concentration limits that will not have any significant effect on the coral reefs and the beaches of the Gulf. For these reasons, a wastewater reuse scheme will enable the reclamation of valuable resources and the abatement of pollution.

CHAPTER THREE NUWEIBA WASTEWATER CHARACTERISTICS

3.1 Introduction

The city of Nuweiba is located on a relatively uniform sloped alluvial plain between the sea coast and the mountains to the west. The alluvial deposits were created by the Wadi Watir flood fan which divides the city into two distinct and separate areas, North Nuweiba and South Nuweiba. North Nuweiba contains the original city center commercial areas, government offices, most public facilities and new touristic villages (Tarabin). South Nuweiba contains the port facilities and new hotel development. Both areas contain residential areas and Bedouin settlements. Two separate wastewater collection and treatment systems are provided for each area.

3.2 Wastewater Flows

CDM estimated that approximately 80% of the water supply flow is discharged into the sewer system. The following are the projected wastewater flows as estimated by CDM.

	North Nuweiba	**South Nuweiba**
Year 2000	1700 m^3/day	2500 m^3/day
Year 2015	2600 m^3/day	4100 m^3/day

Following the wastewater treatment in the ponds, the effluent flow will be reduced due to water losses through evaporation, seepage, and sludge. It is estimated that 10% of the wastewater flow will be lost through the treatment ponds. The available wastewater effluent which may be reclaimed will be.

	North Nuweiba	**South Nuweiba**
Year 2000	1530 m^3/day	2250 m^3/day
Year 2015	2340 m^3/day	3690 m^3/day

3.3 Effluent Quality

The wastewater treatment systems proposed for South and North Nuweiba are two ten cells waste stabilization ponds. The effluent design criteria projected by CDM are as follows:

Total Suspended Solids (TSS) - mg/l	40
Biological Oxygen Demand (BOD)- mg/l	60
Chemical Oxygen Demand (COD)- mg/l	80
Total Dissolved Solids (TDS)- mg/l	2000
Phosphate (P) - mg/l	N/A
Nitrates (N) - mg/l	50
Focal Coliform - Colonies /100ml	5000
Intestinal Nematodes - Number /l	Less than 1

Dissolved Oxygen - mg/l	Greater than 4

The potable water quality analysis for the desalination plant and Ain Furtaga wells are attached in the appendix section of this report.

The major pollutant of concern for effluent reuse is the degree of salinity. The Ain Furtaga wells have a salinity ranging from 800 mg/l to 1,400 mg/l. these values were presented in CDM water quality analysis and were confirmed by city staff and the Water Resources Institute in Nuweiba and in Cairo. Domestic water use, brackish water infiltration into the collection system, and evaporation at the treatment ponds increase the salinity of the effluent. Salinity of the effluent is expected to range between 2,000 and 3,000 mg/l.

3.4 Salinity

Salinity is the most important parameter in evaluating the suitability of water for irrigation. The tolerance of plants to salinity varies widely and crops must be carefully selected to ensure their tolerance to the salinity of the reclaimed water. Also, the soil must be properly drained and leached to prevent salt buildup. Leaching is the over-application of irrigation water in excess of crop needs to establish a downward movement of water and salt away from the root zone.

The U.S. Bureau of Reclamation uses the following formula to estimate the leaching requirements (LR):

LR = Eciw / Ecdw x 100

Where: Eciw = Electrical conductivity of irrigated water

Ecdw = Electrical conductivity of drainage water and is determined by the salt tolerance of the crop to be grown.

Salinity is usually determined by measuring the electrical conductivity (EC) of the water, also it may be reported as total dissolved solids (TDS). EC and TDS values are interchangeable by the following equations:

TDS (mg/l) x 0.00156 = EC (mmho/cm).

The total dissolved solids for Nuweiba reclaimed water is projected to be approximately 3,000 mg/l. Thus, the electrical conductivity will be around 4.7 mmho/cm. If the sources of water supply are changed the effluent salinity will change accordingly.

3.5 Potential Uses of Reclaimed Water

Water supplies are treated to satisfy the requirements for potable use i.e. drinking, cooking, bathing, laundry and dishwashing. In most cases, potable use represents only a fraction of the daily urban use of the water supply. The remainder may not require water of potable quality.

The use of reclaimed water for non potable purposes presents a potential of replacing the potable water used which does not require potable water quality.

The Nuweiba wastewater effluent may be used by any of the following categories:

- Major water users
- Landscaping
- Agriculture
- Environmental enhancement.

3.5.1 Major Water Users

Major water users are defined as those institutions needing a lot of water which does not have to meet the potable quality. Two major water users were identified in Nuweiba, the Hilton Hotel resort and the Center for Agricultural Research.

3.5.1.1 The Hilton Resort

The Hilton Head Island Resort in South Carolina has been using reclaimed wastewater since 1982 to irrigate golf courses and landscaped areas. The Hilton Resort in Nuweiba did not show interest in reuse of the effluent for two main reasons: the degree of wastewater treatment does not meet the public access criteria; and the high salinity will not be tolerated by most of the species used in the landscaped areas.

3.5.1.2 The Center For Agricultural Research

The Center is staffed with professionals with good knowledge of farming techniques and also salinity management practices. Unfortunately, the Center is a government entity and the decision making occurs in Cairo rather than in Nuweiba. The local staff showed interest in using reclaimed water for olive trees and wind breaking trees but they are not empowered to take any decisions on this regard.

3.5.2 Landscaping Use

Besides landscaped areas around hotels and resorts, the city of Nuweiba does not have any public parks or landscaped green area. The city chief expressed interest in providing what he called a wooded area or green zone for public access, however the city does not have the technical nor the financial means to operate and maintain such a project.

3.5.3 Agricultural Use

Worldwide, agriculture is the major user of reclaimed wastewater. The pollutants in reclaimed water that are of concern for agricultural irrigation are salinity, sodium, heavy metals or trace elements, excessive chlorine residual, and nutrients. Reclaimed water tends to have higher concentrations of these pollutants than the sources from which the water supply is drawn. The types and concentrations of pollutants in reclaimed wastewater depend upon the municipal supply, the domestic and industrial contributions, the amount and content of infiltration into the collection system, the wastewater treatment process and the type of filtration and storage facilities. Generally, the quality of reclaimed water is acceptable if the potable source quality is acceptable. An adverse impact on reclaimed water quality is usually caused by the following conditions:

- Elevated total dissolved solids levels;
- Industrial discharges of toxic compounds into the sewer system;
- Saltwater infiltration into the sewer system in coastal areas.

The impact of theses conditions will be discussed in the paragraph titled salinity.

3.5.4 Environmental Enhancement Use

The uses of reclaimed water for recreational and environmental purposes range from landscape ponds, water hazards on golf courses, and ornamental fountains to the enhancement or creation of marshlands and wetlands to serve as wildlife habitat and refuges. The objective of the reuse schemes are mainly to create an environment in which wildlife can thrive and/or to develop an area of enhanced recreational value to the community in addition to providing further treatment. Constructed wetlands are the only environmental enhancement use that was identified in Nuweiba.

The creation of wetlands by reclaimed water results in achieving further treatment, maximizing habitat diversity, and in some cases providing aquifer recharge. In most cases the primary intent of constructed wetlands is to provide additional treatment. However, this reason does not negate the need for design considerations which will maximize wildlife habitats resulting in an environmentally valuable system. Appropriate plant species should be selected based on the quality and quantity of reclaimed water. A salinity evaluation on any created wetland should also be performed since highly saline wetlands exhibit limited vegetation growth.

3.6 Health Risks Associated With Water Reuse

Health significant pathogenic micro-organisms and toxic chemicals clearly are present in untreated wastewater and present a health concern. It is also clear that wastewater treatment processes are capable of reducing these hazardous constituents to acceptable levels or eliminating them from the water. The principal infection agents which may be present in raw wastewater can be classified into three groups: bacteria, parasites, and viruses.

a) Bacteria

The genus salmonella is the most common of pathogens found in municipal wastewater. This group contains a wide variety of species that can cause diseases in man and animals. Salmonella can cause enteric fevers, septicemias, and acute gastroenteritis.

Shigella is a less common bacteria which causes an intestinal disease known as bacillary dysentery or shigellosis. Waterborne outbreaks of shigellosis have been reported where wastewater has contaminated drinking water wells. The survival time of shigella in wastewater is relatively short. There are a variety of other bacteria of lesser importance that have been found in raw wastewater.

b) Parasites

There are a number of parasites or protozoa and metazoa that are pathogenic to humans and are encountered in municipal wastewater. The most common of parasites is the Entamoeba histolytica which causes amoebic dysentery and amoebic hepatitis. The amoeba is found in raw wastewater in the form of cysts excreted by infected humans. The cysts enter a susceptible host by contaminated food or water, germinate in the gut and can initiate infection.

Several helminthic parasites are encountered in wastewater. The most common are intestinal worms, including the stomach worm Ascaris lumbricoides, tapeworms Taenia saginata and solium, whipworms, and hookworms etc. Many helminths have complex life cycles, including a required stage in intermediate hosts. The free living nematode larvae are not pathogenic to humans. The eggs and larvae are resistant to environmental stresses and may survive disinfection procedures. The eggs are easily removed by most wastewater treatment processes such as sedimentation, filtration, or stabilization ponds.

c) Viruses

More than 100 different enteric viruses capable of causing infections or diseases are excreted by humans. Not all types of enteric viruses have been determined to cause waterborne diseases. The most common human enteric viruses are the entero-viruses (polio, echo, and coxzackie), rotaviruses, reoviruses, parvoviruses, adenoviruses, and hepatitis A virus. Hepatitis A virus which causes hepatitis is frequently reported to be transmitted by water.

d) Health Hazards of Wastewater Reuse

The presence and concentrations of pathogenic micro-organisms in raw wastewater depends on a variety of factors, and it is not possible to predict with any assurance the infections agents in wastewater. The sources contributing to the wastewater, the general health of the served population, the existence of disease carriers in the population, and the ability of infectious agents to survive outside their host are all variables which affect the pathogenic characteristics of wastewater.

Pathogens can survive for long periods only under favorable conditions. Factors that affect pathogen die off include number and type of organism, temperature, pH, amount of sunlight and competitive microbial fauna. Table 3.1 shows survival times of microorganism. The proposed 55 day detention wastewater stabilization ponds for Nuweiba will reduce the concentrations of pathogenic micro-organisms to an acceptable level. The long detention time will affect the survival rate of pathogens by starvation, high temperature, other predictors, high pH during algae bloom and U.V. sunlight.

Viruses and other pathogens do not penetrate plants, fruits or vegetables unless the skin is broken. Although absorption of viruses by plant roots has been reported (Murphy and Syverton, 1958), it does not occur with sufficient regularity to be a mechanism for transmission.

Other sources of water supply and chloride bleach should be available at the water reuse facility for staff to wash in after being in contact with reclaimed water.

e) Chemical Hazards

Chemical components potentially present in wastewater are not a major concern when reclaimed water is used for irrigation and when none of the components causes phytotoxicity to crops. The processes of crop contamination by chemicals include: physical contamination where repeated application and evaporation may result in build up of contaminants on the crops, uptake through the roots from the applied water, and foliar uptake. With the exception of possible inhalation of volatile organics, chemicals are not a concern when sprinkler irrigation is not used.

3.7 Sources of Nutrient Enrichment in Nuweiba Groundwater

The staff analysis was constructed on the basis of a set of conditions observed and assumed to exist at the Nuweiba city site, including the following:

- the nitrogen loading of the groundwater that interfaces with the Gulf of Aquaba has been taking place for a period of years and continues;
- the city of Nuweiba sewage treatment ponds and septic tank and other private disposal systems are sources of this nitrogen;
- nitrogen is the nutrient most likely to adversely affect the reef. Nitrogen stimulates algae growth which competes with the coral; and
- phosphorus is considered to be a potential source of damage to coral.

3.8 Criteria Used in Developing the Staff Analysis Plan

The staff analysis of reuse schemes was designed to further the goal of preventing nutrient enriched water from reaching the groundwater under the wastewater reuse land and subsequently the waters of the gulf. The primary criteria for the land application reuse scheme included:

- application sites available through the year regardless of water use patterns associated with typical farming practices in the region;
- nutrient loadings in keeping with crop uptake rates, thus crop/plant selection must be made accordingly;
- future land applications systems designed to maintain loading nitrogen to present levels or to reduce the loading rate;
- population increasing in the time period from 2000 and 2015 requiring changes in the wastewater use scheme;
- insufficient nutrient load in the wastewater to support maximum economic yield (MEY);
- a total balance plan and a nutrient balance plan required of the scheme manager in order to use all wastewater at all time and to avoid loss of nitrogen from the root zone to the groundwater; and
- the irrigation use model for the wastewater reuse for a commercial crop/plant enterprise to accommodate two seemingly conflicting factors:
  - i. the season of maximal wastewater supply may not be the same as the seasonal period of greatest water demand by the crops/plants
  - ii. wastewater supply may exceed total crop water demand in the annual season of coolest weather.

The effluent reuse management design will work under a requirement to protect the environment of the region in preference to maximizing yields from the crops/plants produced on the site.

3.9 Nutrient Balance

The scheme manager would be required to present an annual plan that would account for the nutrients entering the production fields on the site. The goal of the nutrient balance plan for the reuse scheme will be to have nutrient uptake by crops/plants to be equal to or in excess of the nutrient loading rate from the effluent. These factors are expected to influence the plan for balancing nutrients received with nutrients taken up by the crops/plants.

The nitrogen requirement of crops with high water demand is greater than the nitrogen supply in the wastewater. In order to reach economic yields the scheme manager will apply supplemental nutrients. Supplemental nitrogen applied to the crops may leach beyond the root zone if crop production is to be maximized.

3.10 Water Balance

The goal of a water balance plan for the Nuweiba BOT will be to provide a crop rotation such that the total water demand of all crops/plants will equal or exceed the available effluent in any and all 10-day periods during the year.

Monthly irrigation demands can be projected from a production plan that includes the crops/plants selected for production and the relative proportion of the land that is to be occupied by each crop/plant type. The first estimates of land occupied by each crop/plant type will require adjustments to meet the water balance goal.

3.11 Parameters of Crop/Plant Growth for Nuweiba

Maintaining the quality of irrigation water is of particular importance in arid zones. High temperature and low relative humidity result in high rates of evaporation, with consequent deposition of salt in the soil profile.

The physical and mechanical properties of the soil, such as dispersion of particles, stability of aggregates, soil structure, and permeability, are very sensitive to the type of exchangeable ions present in irrigation water. Thus, when effluent use is being planned, several factors related to soil properties must be taken into consideration.

High concentrations of total dissolved solids (TDS) in the irrigation water will reduce the capability of the plants to use the water for the growth. Although most plants respond to salinity as a function of the total osmotic potential of soil water, some plants are susceptible to specific ion toxicity.

Some ions which serve as required micronutrients when present at low concentrations, may become phytotoxic at high concentrations.

3.12 Important Irrigation Water Quality Parameters

i. Total Salt Concentration

Total salt concentration or total dissolved solids (expressed as ppm or mg/l) is the most important irrigation water quality parameter. This is because the salinity of the soil water is related to, and often determined by, the salinity of the irrigation water. Accordingly, plant growth, crop yield and quality of produce are affected by the total dissolved salts in the irrigation water. Equally, the rate of accumulation of salts in the soil, or soil salinization, is also directly affected by the salinity of the irrigation water.

ii. Electrical Conductivity

Electrical conductivity (EC expressed in millimhos or deciSiemens) is widely used to indicate the total ionized constituents of water. Electroconductivity (EC) is directly related to the sum of the cations, as determined chemically and is generally closely correlated with the total salt concentration. (USDA Handbook #51)

iii. Potential Phytotoxic Elements

The most common phytotoxic ions that may be present in effluents in concentrations such as to cause toxicity are: Boron (B), Chlorine (Cl) and Sodium (Na). Hence, the concentration of these ions will have to be determined in order to assess the suitability of effluent quality for crops/plant production . (CDM report)

iv. pH

pH is an indicator of the acidity or basicity of water but is seldom a problem by itself. The normal pH range for irrigation water is from 6.5 to 8.4; pH values outside this range may serve as warnings that the water is abnormal in quality. Normally, pH is measured routinely as a part of irrigation water quality assessment.

3.13 The Constructed Wetlands (CW) Wastewater Reuse Scheme

One of the major decisions of the Statement of Work (SOW) for this activity of the Secondary Cities Project is whether constructed wetlands should be used to remove nutrients from Nuweiba's sewage treatment systems' effluent. Asigned trask related to this question include:

- Evaluate the feasibility of constructed wetlands, considering relevant technical, management, and cost issues; and
- Thoroughly evaluate and articulate risks associated with constructed wetlands.

As stated in section 2.4 the purpose of this activity is to identify and evaluate wastewater effluent reuse schemes and to develop plan criteria for managing Nuweiba's effluent in a manner that will avoid pollution of the groundwater and the Gulf of Aqaba. To accomplish this, the Activity Team conducted a site visit in Nuweiba to collect data and evaluate site conditions. In addition, the team reviewed CDM's Project Reports, parts of which are utilized in this report with or without reference. Other information sources include reference books, scientific reports, research papers, U.S. and Egyptian government documents, interviews and field trip observations (see attached field trips reports).

One of the field trips conducted by the team was to the city of Ismailia where a constructed wetland treatment system has been in operation since 1987 to treat municipal wastewater in a joint project between the Suez Canal University and Portsmouth Polytechnic Institute in the United Kingdom (Mc Brien, et al). Suez Canal University personnel are also overseeing the construction of a full scale CW treatment system to be used as secondary treatment for a new development in Takado Village in the North West Sinai. Several other CW studies are in place in Egypt including constructed wetlands in El Katamia, Alexandria, Port Said and El Fayoum.

3.13.1 Introduction to Constructed Wetlands

Wetlands are defined as land where the water surface is near the ground surface long enough each year to maintain saturated soil conditions (hydric soils), along with the related vegetation. Marshes, bogs, and swamps are all examples of naturally occurring wetlands. A "constructed wetland" is defined as a wetland specifically constructed for the purpose of pollution control and waste management at a location other than existing natural wetlands. There are two basic types of constructed wetlands, the free water surface wetland and the subsurface flow wetland. Both types utilize emergent aquatic vegetation and are similar in appearance to a marsh.

The free water surface (FWS) wetland typically consists of basins or channels with some type of barrier to prevent seepage, a sand, gravel or soil substrate to support the roots of the emergent vegetation, and water at a relatively shallow depth flowing through the system. The water surface is exposed to the atmosphere, and the intended flow path through the system is horizontal.

The subsurface flow (SF) wetland also consists of a basin or channel with a barrier to prevent seepage, but the bed contains a suitable depth of substrate. Rock or gravel are the most commonly used substrate types in the U.S. This substrate also supports the root structure of the emergent vegetation. The design of these systems assumes that the water level in the bed will remain below the top of the rock or the gravel substrate. The flow path through these operational systems is horizontal.

The SF type of wetland is thought to have several advantages over the FWS type. If the water surface is maintained below the substrate surface there is little risk of odors, public exposure, or insect vectors. In addition, it is believed that the substrate provides greater available surface for treatment than the FWS concept so the treatment responses may be faster for the SF type, which therefore can be smaller in area than a FWS system designed for the same wastewater conditions. The subsurface position of the water and the accumulated plant debris on the surface of the SF bed offer greater thermal protection in cold climates than the FWS type.

Subsurface flow constructed wetlands first emerged as a wastewater treatment technology in Western Europe based on research by Seidel commencing in the 1960s, and by Kickuth in the late 1970s and early 1980s. Early developmental work in the United States commenced in the early 1980s with the research of Wolverton, et al. and Gersberg et al.

The SF concept developed by Seidel included a series of beds composed of sand or gravel supporting emergent aquatic vegetation such as cattails (Typha), bulrush (Scirpus), and reeds (Phragmites), with Phragmites being the most commonly used. In the majority of cases, the flow path was vertical through each cell to an underdrain and then onto the next cell. Excellent performance for removal of BOD_5, TSS, nitrogen, phosphorus, and more complex organics was reported.

Kickuth proposed the use of cohesive soils instead of sand or gravel; the vegetation of preference was phragmites and the design flow path was horizontal through the soil media. Kickuth’s theory suggested that the growth, development and death of the plant roots and rhizomes would open up flow channels, to a depth of about 0.6 m (2 ft) in the cohesive soil, so that the hydraulic conductivity of a clay-like soil would gradually be converted to the equivalent of a sandy soil. This would permit flow through the media at reasonable rates and would also take advantage of the adsorptive capacity of the soil for phosphorus and other materials. Very effective removal of Biological Oxygen Demand(BOD), Total Suspended Solids (TSS), nitrogen, phosphorus, and more complex organics has been realized. As a result, by 1990 about 500 of these “reed bed” or “root zone” systems had been constructed in Germany, Denmark, Austria, and Switzerland. The types of systems in operation include on-site single family units as well as larger systems treating municipal and industrial wastewater. Many of the early systems were designed with a criterion of 2.2 m^2 of bed surface area per population equivalent(PE). A PE in European terms is equivalent to the organic loading from one person, or approximately 0.04 kg/d BOD_5, in typical primary effluent. That is equal to a surface organic loading of about 180 kg/ha/d (162 lb/ac/d). The more recently constructed systems in Europe have been designed for 5 to 10m^2/PE (40 - 80 kg/ha/d). The hydraulic loading at 5m^2 / PE (at an assumed 0.2m^3/d/PE) would be about 4 cm/d (1.6 in/d), which, in a commonly used term in the U.S., is equivalent to 23 acres/mgd of design flow, and would provide a hydraulic residence time (HRT) of about six days. For comparison, FWS wetlands in Europe are typically designed at 10 m^2/PE, which results in a surface area about twice that required for the SF type.

Commencing in 1985, a number of “reed bed” systems were constructed in Great Britain based on Kikuth’s concepts, but in many cases gravel was used as the bed media rather than cohesive soil due to concerns regarding soil hydraulic conductivity. Many of these beds were built with a sloping bottom (0.5 to 1%) and a flat surface. The slope is only critical at the beginning of each CW cell as reported by personnel at the Suez Canal University. The purpose of the sloping bottom was to provide sufficient hydraulic gradient to ensure subsurface flow in the bed. The flat upper surface would allow temporary flooding as a weed control measure to kill undesirable plants. Some of these systems also had an adjustable outlet which permitted the desired water level in the bed to be easily maintained.

Wolverton’s work in Louisiana began with experimental bench scale trays in a greenhouse containing rock or gravel media and supporting a stand of emergent aquatic vegetation. The trays were filled with wastewater, and then drained after a certain number of hours (range 12 to 48 hours). In essence the procedure was a fill and draw batch type process. Excellent performance was demonstrated for BOD_5, TSS, and NH_3, and moderate performance of phosphorus with a one-day HRT. The typical organic loading during these experiments (at one-day HRT) was about 58 kg/ha/d (52 Ib/ac/d), and the hydraulic loading was about 8 cm/d (3.5 in/d). Design criteria based on this work included one day HRT, about five acres of bed surface area per mgd, and up to 15:1 aspect ratio (L:W). These criteria, or variations have been widely applied and, as of 1991, there were about 60 systems in operation or in various stages of design in the south central U.S. based on these values. These systems range from on-site single family units to large-scale municipal systems (up to 4 mgd)

Gersberg’s work was conducted over a period of several years in Santee, CA, in large-scale, continuous flow field experiments using 0.76 m (2.5 ft) deep gravel beds. The removal of BOD_5, TSS, and NH_3 was correlated with the depth of root penetration for the plant varieties *(Typha, Scirpus, Phragmites).* The best removals occurred with the deepest root penetration (*Scirpus* the *Phragmites).* The organic loading was approximately 55 kg/ha/d (49 lb/ac/d and the hydraulic loading about 5 cm/d (2in/d). This hydraulic loading is equal to 18 million gallons per day (mgd)/acre using the common U.S. term. The HRT in this system was about six days, compared to only one day from Wolverton’s work and possibly up to six days in the new European systems.

Beginning in the mid 1980s, the Tennessee Valley Authority (TVA) began a program of research and technical assistance on constructed wetlands for treatment of a variety of waste streams (municipal wastewater, acid mine drainage, agricultural wastes and runoff, etc.). The criteria for subsurface flow wetlands designed for wastewater treatment, originally derived from the work of Kickuth, have been modified significantly in subsequent years. By 1991 there were probably at least 80 subsurface flow systems in operation in a number of states based on criteria and assistance provided by TVA. These systems range in size from on-site single family units to larger municipal systems (3785 m^3/d, 1 mgd).

Pilot studies performed in Egypt using CW as secondary treatment produced favorable regional information of greater loading rates and higher removal of Nitrogen, Phosphorus and Total Fecal coliform removal. Hydraulic loading rates were increased to 2000 m^3/ha/day while conforming to GOE's law 48 of discharges to non-potable surface waters.

3.13.2 Environmental Setting

The environmental setting is well characterized in CDM's April 1997 "Environmental Assessment Report." Additional information was also gathered during a field trip to Nuweiba (see field trip report November, 22 - 29, 1997) and with the review of CDM's "Basis of Design Report for Nuweiba." A summary of information and data of particular interest to the CW Effluent Reuse scheme are listed below:

- Favorable mean temperature is 22.8^0c;
- Indigenous wetland plants were located within the area;
- Nutrient values are within a treatable range;
- Salinity concentration through evaporation and evapotranspiration will not threaten wetland treatment processes but may affect further water reuse;
- Evapotranspiration of a CW system will equal evaporation rates of an open ditch or lagoon;
- The area experiences dangerous floods every couple of years;
- There is adequate land available for CW and/or water reuse;
- Nuweiba has very limited industry activities to effect the wastewater treatment system, yet observations and data show a volatile organic compound loading to the current treatment lagoons; and
- There are rare and endangered species of birds that use the area as a migratory pathway.

3.13.3 Proposed Wastewater Treatment Effluent Characteristics

The proposed wastewater treatment effluent characteristics are presented in section 3 of this report. Of particular importance are salinity concentration and the potential Nitrogen loading rates from the effluent. Salinity concentrations are projected to range between 2,000 and 3,000 mg/L in the effluent which will dictate the type and species of wetland plants used in a CW system.

According to the CDM's "Basis of Design Report" (Section 6.6.2), an uncontrolled discharge of treated pond effluent could result in significant nitrogen loading to the coastal waters and, over time, have a detrimental impact upon coastal coral reefs. Excessive Nitrogen loading to the marine environment can lead to eutrophication, a process which can cause algae blooms that can literally choke a reef to death. (Osborn, S., 1997). Conventional wastewater treatment systems cannot provide the level of nitrogen removal required to protect nearby coral reefs in the event of a continuous, direct, surface or subsurface discharge of treated effluent to coastal waters.

CDM's preliminary estimates indicate that nitrogen discharges to the coastal waters directly off Nuweiba should be limited to no more that 250 grams per day to avoid detrimental impacts to the sensitive coral reefs. This correlates to 30 mg/L at the effluent discharge based on the permissible volumetric loading rate of approximately 9m^3/day for each 1000 m of shoreline (calculations are presented in Appendix L of CDM'S Final EA Report). Therefore, CDM's recommendation for additional treatment to remove the Nitrogen is critical to prevent eutrophication impacts on Nuweiba's reef system.

The project phosphorus levels from effluent water will not pose a concern in the CW treatment process.

3.13.4 Wetland Treatment Processes

For hundreds of years, mankind has known and exploited the abilities of wetlands to purify water. Much of the early work in the 1970's on constructed wetlands for wastewater treatment was a result of observations of this purification process in natural wetland systems. Since the 1970's studies, the ability of wetlands to efficiently remove suspended sediments and nutrients, especially nitrogen and phosphorus has been shown time after time.

Wetlands accomplish water purification through physical, chemical and biological processes. These processes operate independently in some circumstances and interact in others.

Wetlands' water purification abilities depend upon five criteria - water, nutrients, vegetation, substrates, and microbial growth. Water transports substances and gases to microbial populations, carries off by-products, and provides the environment and water for biochemical processes of plants and microbes. Invertebrate and vertebrate animals harvest nutrients and energy by feeding on microbes and macrophytic vegetation, recycling and in some cases transporting substances outside the wetlands system. Functionally these components have limited roles in pollutant transformations, but they often provide substantial ancillary benefits in successful systems. In addition, vertebrate and invertebrate animals serve as highly visible indicators of the health and well-being of a marsh ecosystem, providing the first signs of system malfunction to a trained observer.

The vegetation in a wetland system functions to create additional environments for microbial populations. Not only do the stems and leaves in the water column obstruct flow and facilitate sedimentation, they also provide substantial quantities of surface area for attachment of microbes (reactive surface). In addition to the microbial environments in the water column of CW, they provide additional surface area on portions of plant roots within the water column. Plants also increase the amount of aerobic microbial environment in the substrate incidental to the unique adaptation that allows wetlands plants to thrive in saturated soils. Most plants are unable to survive in water-logged soils because their roots cannot obtain oxygen in the anaerobic conditions rapidly created after inundation. However, hydrophilic or wet-growing plants have specialized structures in their leaves, stems, and roots somewhat analogous to a mass of breathing tubes that conduct atmospheric gases (including oxygen) down into the roots. Since the outer covering on the root hairs is not a perfect seal, oxygen leaks out, creating a thin-film aerobic region (the rhizosphere) around each and every root hair. The larger region outside the rhizosphere remains anaerobic, but the juxtaposition of a large, in aggregate, thin-film aerobic region surrounded by an anaerobic region is crucial to transformations of nitrogenous compounds and other substances. Wetland vegetation substantially increases the amount of aerobic environment available for microbial populations, both above and below the surface. Wetland plants (alone) generally take up only very small quantities (5%) of the nutrients or other substances removed from the influent waters, although some systems incorporating periodic plant harvesting have slightly increased direct plant removals. It is the combination of wetland processes (i.e. microbial and plant activity) that are responsible for CW's ability to purify water.

Recent experiments have shown the plant's architecture increases gas exchange beyond levels expected from passive (air tube) transport. However, attempts to compute oxygen mass introduced into the substrates by radial oxygen loss have been confounded by a number of variables that lack precise definition. Although earlier experiments suggested the plants with deep root structures had higher removal efficiencies, recent results suggest that plant species with dense fibrous though shallow roots have lower radial oxygen loss per unit of plant biomass, and may input larger quantities of oxygen into the substrate because they tend to grow in denser stands.

Substrates (various soils, sand, or gravel) provide physical support for plants, reactive surface area for compelling ions, anions, and some compounds, and attachment surfaces for microbial populations.

Microbes (bacteria, fungi, algae, and protozoa) alter contaminant substances to obtain nutrients or energy to carry out their life cycles. In addition, many naturally occurring microbial groups are predatory and will forage on pathogenic organisms. The effectiveness of wetlands in water purification is dependent on developing and maintaining optimal environments for desirable microbial populations. Fortunately, these microbes are ubiquitous, naturally occurring in most waters and likely to have large populations in wetlands and contaminated waters with nutrient or energy sources. Only rarely, with very unusual pollutants, will inoculation of a specific type or strain of microbes be needed.

3.13.5 Wetland Construction Principles

Some general principles of ecotechnology that could be applied to the creation of constructed wetlands (Mitsch and Cronk, 1992) are outlined below:

1. Design the system for minimum maintenance. The system of plants, microbes, substrate, and water flows should be developed for self-maintenance and self-design (Mitsch and Jorgensen, 1989; H. T. Odum, 1989.

2. Design a system that utilizes natural energies such as the potential energy of natural gradient.

3. Design the system with the hydrologic landscape and climate. Floods, droughts, and storms are to be expected, and utilized if possible.

4. Design the system to fulfill multiple goals, but identify at least one major objective and several secondary objectives.

5. Plan for wetland plant establishment, nutrient retention, and microbial enhancement. Strategies that try to short-circuit ecological succession or over manage it often fail.

6. Design the system for function, not form. In other words, do not over-engineer the constructed wetland design.

7. Optimum residence time calculation must account for short circuiting of the CW system.

8. Individual wetland cells, phased in series or parallel, are more effective than large basins.

9. Design the CW system with an adjustable water height mechanism to be able to control mosquitoes and weeds.

10. Design the CW system for ease of plant harvesting.

Size and configuration of constructed wetlands for waste water treatment are determined by site characteristics, desired functional values and funding available for land acquisition, construction, and long term maintenance. The site characteristics of concern for a CW are the hydraulic rates based on the influent concentration of pollutants. The functional values are; the required effluent pollutants' concentrations and benefits derived from plant growth.

Design of CW wetlands can be calculated using first order areal models of treatment wetlands (Kadlec and Knight, 1996). These models are based on the "North America Wetlands for Water Quality Treatment Database" (USEPA, 1994). The generic model is as follows:

$$\text{Ln}\ \{(C_O - C_B) / (C_I - C_B)\} = K/q$$

Where:
- C_O = Pollutant outflow concentration (mg/l)
- C_B = Pollutant background concentration (mg/l)
- C_I = Pollutant inflow concentration (mg/l)
- K = First order areal rate constant (m/year)
- q = Hydraulic loading rate (m/year=Q/A)
- Q = Inflow rate (m^3/year)
- A = Wetland area (m^2)

An average hydraulic loading rate is approximately 1000 m^3/ha/day for CW used as a secondary stage of treatment.

CHAPTER FOUR FINDINGS

4.1 Constructed Wetlands - Design Selection and Water Reuse

The application of CW is particularly suitable to subtropic climates (i.e., the Sinai) because of year round plant growth and high microbial activity. The selection of the type or design of constructed wetlands depends on the following criteria, specific to this project:

- the tertiary treatment objectives for Nitrogen and Phosphorus;
- specifications for safe use as presented in this report;
- environmental impact considerations (i.e., endangered or threatened migratory birds, disease transfer, and coral reef impacts);
- salinity concentrations;
- management considerations; and
- cost and economic recovery issues.

Given the above criteria, the constructed wetland design selection for the Nuweiba project is a modified subsurface flow wetland (SF). The preliminary design parameters for a SF system that meets the above criteria are described in the following paragraphs:

4.1.1 Construction Configurations

The construction configurations, or the basin morphology, that has been proven effective is the multiple cell configuration. The wetland cells can be constructed using concrete walls and floors (soil/sand berms are not adequate for this area) with rubber liners. The SF cells configuration should be 100m long, 3m wide, and 0.75m in depth. Treated effluent should enter the cell via a valve operated distribution pipe. The distribution pipe should be located within the cell substrate so as to distribute water evenly across the front width of the cell. The gradient of the cell should be 1:100 sloping downward from front to back. The substrate should consist of a rounded gravel 5 to 10 mm in diameter. In the first and last meter of the cell, 5 to 10 cm size stone should be used around the distribution and effluent collection pipes to reduce clogging potential. The substrate height should be approximately 0.4 to 0.5 meters. The effluent collection pipe should have a valve or elbow configuration to allow for water height adjustment within the cell (see a diagram located in the appendix).

4.1.2 Residence Time/Hydraulic Loading Rates

The residence time is not as critical for tertiary treatment of the Nitrogen and Phosphorus levels as is hydraulic loading for the cell sizing. The hydraulic loading of the CW treatment system should be 1000 to 1100 cm^3/ha/day.

4.1.3 Planting of Wetland Cells

Ideally plants for use in constructed wetlands should initially be transplanted from an aerial natural wetland system. The wetland plants should be collected by removing (as a whole) the stems, rhizomes, roots and soil of seedlings (plant that are 0.3 to 1.0 meters in height). The plants should be transported and re-planted within the same day if possible. Wetland plants that will perform well for CW treatment in Nuweiba include:

- Phragmites australis - reeds
- Scirpus sp. - Bulrushes

4.1.4 Wildlife Impact Management

By using a subsurface flow wetland design, the wildlife impacts from this treatment system are very low. This SF type of wetland system does not make an ideal nesting place for birds because of the dense vegetation, nor does it attract birds to water or food sources since most insects, especially mosquitoes, can be controlled by water level adjustments.

4.1.5 Operation and Maintenance

After the startup of the system (water induction, planting, etc.) the operation and maintenance of the SF system is limited to water level control, harvesting of plants and verification of treatment.

4.1.6 Costs

The cost analysis of all of the references reviewed has calculated CW costs in the context of secondary treatment instead of tertiary as it is used here. However, even these costs were quite low at 5 - 15 U.S. Dollars per capita.

4.2 Alternative Effluent Reuse Schemes

4.2.1 Diversity of Crops/Plants Produced in the Region

The information collected by the Nuweiba Activity Team from various technical reports, project proposals, and from on-site inspection confirms that a diverse numbers of crops and plant species are produced in the Nuweiba region. The diverse crops/plants observed grow in all seasons of the year; therefore, wastewater could be utilized in all months of the year. The growth pattern characteristics of the crops/plants observed on the Southeast coast of the Sinai include species with high water demand and high nutrient demand. Crops such as Berseem (*Medicago*) and winter wheat (*Triticum*) that have proven to be well adapted to the sandy lands of the East and West Desert as well as Upper Egypt are expected to thrive in the climate at Nuweiba.

Napiergrass (*Pennisetum*), bermudagrass (*Cynodon*), and other perennial prolific grasses are tolerant to the saline conditions of Nuweiba, and have high water requirements and high nutrient demands. The ryegrasses (*Lolium*), durum wheat (*Triticum*), and barley (*Hordeum*) grow vigorously in the cool nights (20 degrees C) of winter. Olive, palm, and fig trees indigenous to the region are economic crops of the region. These native and adapted species will utilize a constant water supply essentially all year. They have the drought tolerance to survive when water is not abundant, and tolerate the salinity common to the area.

Windbreak tree plantings were observed to add to the comfort of the people and to the beauty of the area. The Australian pine is a known survivor under drought conditions but it can utilize a large amount of water when a supply is available. This tree and forage trees such as *Acacia* have deep root systems that explore a great volume of soil. This growth trait enhances their value as interceptors of nitrogen and other nutrients that might otherwise reach the groundwater and eventually the water of the gulf and the reef.

The hotels at Nuweiba and Sharm El Sheikh, such as the Hilton and Helnan, maintain extensive plantings of woody ornamental shrubs, herbaceous flowers and windbreak trees. A golf course is under construction at Sharm El Sheikh with sod greens and irrigated fairways. Bermudagrass sod is brought into the region from the delta area. Landscape companies maintain large stocks of tree in the 12-cm diameter range and market their stock in a timely way. These woody ornamentals were purchased from Cairo and Ismailia and transported to South Sinai. A limited number of feddans of woody ornamental production could be a profitable enterprise in Nuweiba. The ornamental and turf species in the landscaped hotels and villas meet all the requisites for a wastewater scheme—well adapted to the saline conditions, heat tolerant, and capable of using a great amount of water and nutrients.

Many local and introduced crops and cultivated lands have adapted well under the soils and climatic conditions in Nuweiba. These crops / plants are potential candidates for production under the proposed BOT reuse scheme:

Ornamental and Landscape Plants Propagated at the Nuweiba Hilton

Trees
Pines - 3 kinds
Acacia - 2 kinds
Palm - 3 kinds
Neem
Eucalyptus
Casuarina
Rubber Tree
Leucaena
Poinsiana
Guava
Frangipani

Lawn Grasses
Bermudagrass

Shrubs / Hedges
Bougainvillea - 6 kinds
Hibiscus - 6 kinds
Poinsitia
Tafia
Verbena
Dadonia

Herbs
Basil
Lantana
Mint
Coumarin

Crops observed growing at the MOA Farm, that are allowable in the reuse scheme included: figs, olives, palm, and pines.

Crops observed growing at the Bedouin Farm, that are allowable in the reuse scheme included: barley, wheat, pomegranate, olives, figs, and guava.

Bermudagrass is a perennial warm season grass. It will show a steady increase in growth to a peak in midsummer. Then a steady decline through late fall (see Appendices C and D). Water requirements will follow the growth curve - high water requirement in summer and steady decline through late fall. Bermudagrass is also an excellent remover of nutrients particularly nitrogen. Napiergrass is a perennial warm season grass and would follow the approximate growth curve of Bermudagrass. It has high water requirement and is an excellent remover of nutrients. Winter wheat is an annual winter crop and has a medium to high sensitivity to water deficit.

Olives and figs are highly adapted to the region and are known to be tolerant to water deficit. Australian pine is a perennial which has a relatively low water requirement, but is not sensitive to water stress.

4.2.2 Rigorous Crops/Plants Criteria of a Reuse Scheme

The major objective of a wastewater reuse scheme is to use all the effluent delivered to the scheme's storage tank at all times of the year without allowing nutrients to percolate beyond the root zone of crop/plants. These and other criteria were the guidelines followed in the Staff Analysis prepared from information available to the staff before the arrival of the Nuweiba Activity team. The two primary criteria for crops/plants to be used in this reuse scheme are: (1) high salinity tolerance, and (2) high nutrient removal.

These criteria for complete utilization of the wastewater supply without loss of nutrients to the groundwater can not be met by using a single species or type of plants. The unique characteristic of the tourist business in Nuweiba brings drastic changes in the volume of effluent within a few weeks of time. A combination of summer and winter crops, trees, grasses and shrubs can however utilize the water and survive the water deficit droughts that will occur in such a system. An example of a combination of crops and plants that could meet the criteria of the scheme follows:

Crop	**Season of Growth**	**Water Demand**	**Nutrient Use**
Berseem	Warm but long	3750 cu m/fd/year	Very High
Olives	Perennial	2050 cu m/fd/year	Moderate
Wheat	Winter	1850 cu m/fd/year	High
Australian pine	Perennial	Drought tolerant	Prolific roots

Plant water requirements are based on adjustments of the Water Requirements as calculated by El Din (MOA/Central Administration for Agricultural Statistics, 1992). Adjustments were made for this table by adding to the PET for each crop as measured for the delta by MOA and as estimated for the Western desert sandy lands (Newlands) by Towakol Eunis. The water requirement for olives in Nuweiba was taken from the information presented by the Agricultural Research Station at Nuweiba (1997). The highly productive olive trees on the experiment station received an average of 25 liters (l) of drip irrigation per day for each day of the year. Daily water use per feddan for 225 trees/fd (500/ha) at Nuweiba was 5.63 cu m/fd/day. (This is less than the open pan evaporation rate of 3.7 m/day because of the use of drip irrigation.) Berseem has an average of 10.27 cu m/day water requirement, if production and water demand were equal for all months.

The amount of water available for delivery to the field plants (2280 and 3636 cu m/day) were calculated by applying a leaching factor requirement of 33% and reducing the amount of water delivered to the plants by 10% to account for losses in the field delivery system. The potential evapotranspiration (PET) is the water requirement for a crop in a given climate zone and takes into account the water that moves through the plant and the water that evaporates from the soil within the feddan of field.

The combination of crops/plants in the example will be capable of utilizing the 2280 cu m/day of wastewater available for delivery to the field plants in the year 2000, and with increases and the 3636 cu m/day of wastewater estimated to become available by the year 2015. Except for the nutrients forced beyond the root zone from leaching excess salts that will accumulate from saline (4.5 mmho/cm) wastewater, plant nutrients will be intercepted by the prolific root systems of these plant species

4.2.3 Conflict Between Maximum Economic Yield and the Environmental Factors

The staff analysis plan (as reflected in the SOW) was not predicated on the scheme manager being free to add supplemental nutrients (fertilizers) to the point that crop yield could be maximized. At the rate of nitrogen that is economical for wheat production on sandy soil, the loss of nitrogen in deep percolation would be in excess of the amount allowed by the criteria used in the staff analysis.

The information reviewed and on-site observations made by the Activity Team indicate that the preliminary analysis for a multiple cropping wastewater reuse scheme at Nuweiba are valid. If the use scheme is planned and executed by the criteria described by the staff analysis and the Background Paper, a successful reuse scheme can be anticipated.

4.3 Wastewater Reuse in Egypt

Wastewater reuse in Egypt has been practiced since the beginning of this century. Practices of wastewater reuse have taken two forms: official and organized continuous practices and unofficial unorganized perennial practices.

Wastewater reuse has been officially implemented in Egypt since 1915 at the governmental farm of El-Gabal El-Asfr near Cairo. Many other farms have recently started such practices in many areas of the country. A number of farms at different locations of the country are using treated and sewage water. For example, farms at Ismailia, Helwan, Kena, and Abu-Rawash are currently officially operating on treated wastewater from the treatment plants. On the other hand, at many places in the delta, whenever irrigation water shortages occur, the local farmers unofficially practice wastewater reuse. Many villages (i.e., El-Mansoura) in the delta are deprived of a sanitary network and villagers are depending on septic tanks to drain their domestic wastes. Such tanks are being drained periodically using specially equipped trucks which, in turn, drain its contents in the nearest agriculture drain. During water shortages, farmers rely on drain water to irrigate their crops. This water is nothing but untreated wastewater mixed with drainage water.

Very little data are available on the official schemes, while no studies, as far as the authors know, have been conducted on the unofficial wastewater reuse. Due to its early start and large size, the El-Gabal El-Asfr scheme is probably the most studied scheme. The following are brief notes on the El-Gabal El-Asfr wastewater reuse scheme. Due to similarities between the lithology at El-Gabal El-Asfr and at the proposed area for the project, emphasis is placed upon the effects of the long practiced scheme on the groundwater.

4.4 Gabal El-Asfr Wastewater Reuse

Gabal El-Asfr area is located approximately 25 km north-east of Cairo, near the eastern desert area at the fringes of the Delta flood plain. The farm is about 3,000 feddans (i.e.1350 ha). The area has been irrigated with poorly treated sewage effluent since 1915. The average rate of application during 1992 was about 80,000 m^3/day. The sewage water is only going through sedimentation ponds.

Salinity of the effluent is around 1000 mg/l. Chloride and sulfate concentrations of 160 mg/l and 26 to 60 mg/l respectively were found in the effluent. Average COD contents is about 470 mg/l. Average total-N content in the effluent is about 14 to 60 mg/l with NH4 concentrations ranging from about 10to 65 mg, NH4/l and NO3 concentrations ranging from 25 to 45 mg/l. Relatively high average baron concentrations of 0.7 to 2 mg/l are found in the effluent.

Similar to the proposed area for the project, the groundwater is very vulnerable to pollution. The top clay cap is mainly absent, and vertical groundwater flow is generally downward. The aquifer in the area is the quaternary Nile Delta aquifer which is formed of mainly sandy deposits with some intercalation of clay layers.

A study conducted on the impacts of the scheme on groundwater (RIGW, 1992) indicated that groundwater quality in the area is adversely affected with regard to nitrogen contents (ammonium and nitrate), phosphate, heavy metals and fecal coliforms. Heavy metals were apparently partly removed from percolating sewage effluent. However this removal implies an accumulation of heavy metals in the soil, adversely affecting the soil system.

CHAPTER FIVE SPECIAL CONSIDERATIONS FOR WASTEWATER REUSE

The nutrients concentrations in the treatment ponds effluent will vary throughout the year. The nutrient removal efficiency will depend on several factors such as ambient temperature, wind action, length of the day, algae growth cycle, and sunshine duration. Also the volume of the effluent will vary throughout the year depending on the tourist season in Nuweiba. It is recommended that the BOT scheme manager monitor for the nutrient concentrations through the first year of operation and adjust crops and plants combinations accordingly.

The following are some of the technical issues that the BOT manager should identify and consider when planning for the reuse scheme:

- Storage requirements to balance seasonal and diurnal fluctuations in reclaimed water with the fluctuations in water use;
- Annual plan to achieve nutrients balance between crops/plants needs and effluent concentrations;
- Determination of the flexibility of the reuse scheme to allow future changes or expansions;
- What level of chemical and energy use would be associated with the scheme;
- The BOT scheme must be planned and designed to provide maximum reliability at all times;
- The BOT scheme should be capable to operate satisfactory during power failures, flooding, peak loads, equipment failure, and maintenance shutdowns;
- Definition of the general steps to follow throughout the implementation of the reuse scheme project;
- Development of a comprehensive realistic implementation schedule;
- An accurate assessment of cash flow needs to anticipate funding requirements, to formulate contract provisions, and to devise cost-recovery techniques;
- Preparation of operating budget and cash reserves to operate the project; and
- Analysis of the financial feasibility of the reuse scheme project.

CHAPTER SIX RISK ANALYSIS

6.1 Environmental Risks

The environment impacts, if a decision is made not to proceed with CW Treatment and/or agricultural reuse of the proposed treatment effluent water, are:

- Treated effluent would continue to be discharged to the ground and eventual Nitrogen loading of the Gulf of Aqaba would induce eutrophic conditions;
- Possible buildups of other toxic materials (i.e. organic compounds and heavy metals) in the discharge area which may impact the groundwater and Nuweiba's coral reef system; and
- Potential health hazards from misuse of the wastewater if a reuse plan is not implemented.

If a CW Treatment and/or agricultural reuse plan is implemented, possible detrimental environmental impacts include:

- Long term buildup of salinity in the soil unless flood waters are utilized to flush the reuse area on an annual basis (note: the Bedouin farmer in Nuweiba effectively uses the flood waters for this purpose).
- Health Hazards to workers if not properly trained who contact or misuse the treatment effluent; and
- Boron buildup, which is a phytotoxin from synthetic detergents.

The environmental impacts of any reuse scheme would be less severe than if the effluent is discharged to the environment.

Environmental risks would be involved if such as these two were to prevail:
- the manager did not carry out the program to reuse all wastewater, or
- the annual water balance and nutrient balance plans were not followed.

6.2 Economic Risks

The scheme manager would run certain economic risks if water quality or quantity were to change. For example:
- if water quantity of the effluent anticipated did not materialize, the scheme manager could not successfully produce crops; and
- if the salinity level of the effluent were to go above 3,000 ppm, additional water from wells of lower salinity level would be required.

If the city, which furnishes the effluent, and the scheme management were to experience problems such as the following, economic problems would arise:

- if the city did not deliver effluent free of oil and other petroleum contaminants;
- if the city and the scheme manager did not develop a feasible monitoring plan; or
- if the scheme manager did not monitor the salinity and nutrient levels.

CHAPTER SEVEN RECOMMENDATIONS

The recommendation of the Wastewater Reuse Activity Team for the long term is an **Agricultural Reuse Scheme** based on the proposed new treatment design and projected effluent constituent levels. The agricultural reuse of this effluent is the most viable option, which allows the beneficial use of the water as a resource while removing nutrients of concern, protecting the environment and providing:

- salable crops for local markets;
- beneficial economic labor force impacts; and
- an increase in land value for Nuweiba with aesthetic value.

The agricultural reuse option was chosen over the constructed wetlands scheme because of the benefits listed above and because CWs work more economically and efficiently as a secondary treatment process instead of a tertiary treatment. However, a CW could be utilized as a transitionary treatment system until the agricultural reuse system achieves the full absorptive capacity.

As described earlier in the text of this report, the agricultural reuse option would incorporate several different crop plants and, additionally, windbreak trees to accommodate excess effluent water.

Specifications and criteria for the reuse of the treatment plant's wastewater effluent in agricultural irrigation are:

1. Environmental Impact Assessments must be conducted for reuse of sewage water projects.

2. For safe use of sewage water in irrigation, these conditions apply:
    - Health precautions for farmers and end product users must be followed;
    - Standards for reuse waters must be followed;
    - Types of plants are defined, with limits on food plants; and
    - Irrigation methods are defined and related to soil texture.

3. For reuse of sewage water in irrigation, these technical conditions apply:
    - Treatment of sewage water is according to design criteria;
    - If the treatment plant does not meet its design criteria, the responsible office must take all precautions to safeguard the environment;
    - Conduct periodic analysis of sewage water; and
    - Place caution signs at the water outlets to indicate water is not safe to use and drink.

4. The owners (scheme manager) of the agriculture areas are obligated to:
    - Provide health and cultural awareness for the farmers and workers;
    - Make protective shoes and other medical and health facilities available;
    - Insects and pest fighting; and
    - Plantation is restricted to what is stated in the regulations and officials must be informed if unpredicted changes occur with any strange change to the plantations.

5. For irrigating lands with effluent, these conditions apply:
    - Method of irrigation must agree with the level of treatment;
    - No irrigation within two weeks of harvest, and destroy fruits that touch the ground;
    - Take precautions to avoid workers having direct contact with water from drip and line irrigation;
    - Periodical analysis of the root zone groundwater;
    - Proper drainage for the soil; and
    - Use of mechanical equipment for soil tillage.

6. Subject to provision described in Law 48 for the year 1982 and its executive statutes.

CHAPTER EIGHT CONCLUSION

Wastewater reuse in agriculture has been utilized successfully for many years and provides two main benefits: (1) it develops a new non-conventional water resource, and (2) it utilizes a low cost natural fertilizer. These benefits are extremely important to Egypt, since Egyptian agriculture uses 88% of the country's total water demand. The major restriction for the Nuweiba area is to assure that the agricultural water reuse scheme will not endanger human health and the environment. This is achievable through an Agricultural Reuse Scheme by balancing the water uptake needs of the crops to be grown with the effluent discharge rates, along with alternate and additional irrigation needs such as windrow trees.

In the event the sources of future water supply have an excessive salinity concentration, the wastewater treatment efficiency will decrease and the selected crops may not tolerate such high salinity, therefore jeopardizing the success of the reuse scheme.

Other objectives of the reuse scheme must also be met, such as proper training for operators and agricultural workers, and meeting the government's wastewater reuse standards and guidelines.

Table 8.1 Comparative Advantages and Disadvantages of Wetlands and Reuse Scheme

WETLANDS	
Advantages	**Disadvantages**
Low cost	Limited income potential
Easy to operate	Not effective use of nutrient resources
Low maintenance	Not as efficient as tertiary treatment
Good nutrient removal	
Operates year-round	
Generator of DO in the effluent	
Efficient removal of organic compounds and heavy metals	

REUSE SCHEME	
Advantages	**Disadvantages**
Optimum use of scarce water	High capital outlay required
Beneficial use of nutrients	Capital recovery only over long period
Potential for economic return	Higher operational cost
Creates local jobs	High maintenance cost
Increases land value	Requires skilled staff
Supplies local market	
Improves the landscape	

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Appendix A

List of Reuse Team Preparers and Contributors

Appendix A

List of Reuse Team Preparers and Contributors

This wastewater effluent reuse scheme report was prepared by Dr. Glenn Davis, Eng. Habib Ghali, Mr. Steve Osborn, Amr Fad El Malwa, PWSA and Dr. John Conje

The team expresses its appreciation to Tarek Behket Ernest Rojas, and Mostafa Dahy of USAID Cairo, and to Nuweiba City Chief Shabaan and his staff.

Appendix B

Water Parameters

Appendix C

Salinity - Tolerance of Selected Crop

Appendix D

List of Salt Tolerant Ornamental Plants

Appendix E

Field Trip Reports

Appendix F

General Design, Construction, and Operation Guidelines for CWs Wastewater Treatment Systems

Appendix G

Prequalification Report

Appendix H

Crop Production Water Requirements and Efficiencies

Appendix I

Domestic Sewage Sludge Reuse/Land Application Calculation Worksheet