# Recent trends and developments: reuse of wastewater in agriculture

**Khaled M. Abu-Zeid**
Senior Water Resources Programme Assistant, Centre for Environment and Development for the Arab Region and Europe, Gize, Egypt

**Many countries all over the world are facing water shortages. As population increases, water is being perceived as a very valuable resource. Every effort is exerted to use water more efficiently and to make use of every drop of water to ensure the well being of future generations. New trends are developed and practiced in the area of water resources use and water saving. These trends vary from one country to another according to the degree of water scarcity, economic situations, and other factors. Developing non-conventional water resources is an example of the recent trends in developing new water resources and water savings. Unlike rainfall, rivers, and groundwater which are considered conventional freshwater resources, the non-conventional water resources include sea water desalination, agriculture wastewater reuse, and municipal wastewater reuse. This paper deals with the reuse of agriculture, municipal, and industrial wastewater as a new trend in developing additional water resources. Special interest is given to municipal wastewater, its characteristics and necessary treatment. Environmental and human health considerations for wastewater reuse, especially in agriculture, are also discussed. Possible consequences of wastewater reuse are introduced. Examples of wastewater reuse practices in some countries are also mentioned.**

Environmental Management and Health
9/2 [1998] 79–89

[ISSN 0956-6163]

## Introduction

Agricultural irrigation represents a significant fraction of the total demand for fresh water. Irrigation is estimated to represent 65 per cent of the global total water demand (Postel, 1992). In some places, such as the top four states in consuming irrigation water in the USA (Montana, Colorado, Idaho, and California), agriculture irrigation can reach 90 per cent of the total water demand (Crook *et al.*, 1992). In Egypt agriculture uses 88 per cent of the total water demand (World Bank, 1995).

Reuse of agriculture drainage water and reclaimed municipal and industrial wastewater in agriculture became a recent trend in relieving the burden on freshwater demand, especially in water shortage areas. In Egypt, reuse of agriculture drainage water in irrigation projects through mixing with fresh Nile water, amounted to $3.37 \times 10^9$ $m^3$/year as of 1990. Salinity of drainage water used in these projects ranges between 1090-1270 ppm and was reduced to 700 ppm after mixing with fresh water. Additional unofficial reuse of agriculture drainage water in Egypt are estimated to be $1.5 \times 10^9$ $m^3$/year (Amer, 1992). Crop productivity was medium in comparison to national averages. For rice, productivity was 1.4 ton/feddan as compared to 2.6 ton/feddan. For cotton, productivity was 6 kintar/feddan as compared to 8.25 kintar/feddan. About $0.6 \times 10^9$ $m^3$/year of treated municipal wastewater is reused for agriculture irrigation in Egypt as of 1993 (Abdeldayem, 1994).

A survey of agricultural systems, operating in California found no indications that crop, quality or quantity had deteriorated as a result of reclaimed water irrigation. In fact, several of the farmers using reclaimed water felt that crop production had been enhanced as a result of nutrients in the water (Boyle Engineering Corporation, 1981). In California, agricultural irrigation accounts for approximately 63 per cent of the total volume of reclaimed water used within the state. In California, Florida, and Texas, the volumes of reclaimed water, shown in Table I are being used for agricultural irrigation.

The percentage of population served with water supply and sanitation varies from one country to another. See Table II for selected Arab Region countries water supply and sanitation coverage. As more sanitation coverage is provided, the potential for reuse of treated wastewater increases. If we assume that 30 per cent of water used for domestic use can be recovered, treated and reused, we can come up with a reuse potential of domestic wastewater for agriculture of about $3 \times 10^9$ $m^3$ as shown in Table III. Assuming wheat's water requirements is about 2000 $m^3$/feddan/year, this potential treated wastewater may cultivate $1.5 \times 10^6$ feddan/year. Assuming the feddan of wheat produces 2180 kg of flour, and a person consumes on average 365 kg of flour per year, therefore the above mentioned potential treated wastewater can feed 9 million people with their needs of wheat per year. It has to be noted that the previous figures are very conservative since domestic wastewater can reach up to 80 per cent of domestic use if efficiently collected and countries are fully covered with sewage facilities which will result in more than double the above figures.

Municipal wastewater used for irrigation besides its "water value" has also a "fertilizing potential". The nutrients present in wastewater may supply most of the N, P, K and other essential macro- and micro-nutrients required by many crops. This nutritional value of wastewater is important to the agricultural economy of developing countries where fertilizer cost is a major burden on farmers. However, certain standards and restrictions should be followed in selecting the type of crop, type of irrigation, and degree of treatment.

## Wastewater constituents of concern

Certain quality parameters of the treated effluents, particularly those affecting environment and health aspects, depending on the treatment approach, should be monitored regularly (FAO, 1993). The constituents of concern in wastewater treatment and wastewater irrigation are listed in Table IV.

Khaled M. Abu-Zeid
*Recent trends and developments: reuse of wastewater in agriculture*
Environmental Management and Health
9/2 [1998] 79–89

**Table I**
Agricultural reuse in selected USA states

| State | mgd | $m^3$/day |
|---|---|---|
| **California** | 150 | $570 \times 10^3$ |
| **Florida** | 90 | $340 \times 10^3$ |
| **Texas** | 290[a] | $1,100 \times 10^3$ |

**Note:** [a]This is based on the design flow of the wastewater treatment plant providing water and may exceed actual use.
**Source:** Crook, J. (1992)

**Table II**
Water supply and sanitation coverage

| Country | Population (× 1,000) | Water supply coverage (% of population) | Sanitation coverage (% of population) |
|---|---|---|---|
| **Sudan** | 24,600 | 47.6 | 74.8 |
| **Tunisia** | 7,900 | 92.2 | 95.3 |
| **Oman** | 1,468 | 54.4 | 48.2 |
| **Syria** | 12,113 | 84.0 | 85.0 |
| **Yemen** | 10,620 | 36.0 | 65.2 |

**Source:** Water supply and sanitation sector monitoring report 1990 (Baseline Year), WHO, Water Supply and Sanitation Collaborative Council, and UNICEF

**Table III**
Potential of domestic wastewater reuse in most Middle East and North Africa

| Country | Annual ($\times 10^9 m^3$) | Domestic use (% of annual withdrawals) | Potential annual wastewater reuse (30% of domestic use) ($\times 10^9 m^3$) |
|---|---|---|---|
| **Algeria** | 3.0 | 22.0 | 0.198 |
| **Egypt** | 56.3 | 7.0 | 1.1823 |
| **Bahrain** | 0.2 | 60.0 | 0.036 |
| **Iraq** | 43.9 | 3.0 | 0.3951 |
| **Jordan** | 1.0 | 20.0 | 0.06 |
| **Lebanon** | 0.8 | 11.0 | 0.0264 |
| **Libya** | 2.8 | 15.0 | 0.126 |
| **Malta** | 0.02 | 76.0 | 0.00456 |
| **Morocco** | 11.0 | 6.0 | 0.198 |
| **Oman** | 1.3 | 3.0 | 0.0117 |
| **Qatar** | 0.15 | 36.0 | 0.0162 |
| **Saudi Arabia** | 3.6 | 45.0 | 0.486 |
| **Syria** | 3.3 | 7.0 | 0.0693 |
| **Tunisia** | 3.0 | 13.0 | 0.117 |
| **UAE** | 0.4 | 11.0 | 0.0132 |
| **Yemen** | 3.9 | 5.0 | 0.0585 |
| **Total** | 134.67 | | 2.99826 |

**Source:** For annual withdrawals and domestic use: "From Scarcity To Security: Averting a Water Crisis in the Middle East and North Africa", The World Bank (1995)

Specific characteristics of major constituents are also included in Table V.

The suspended, colloidal and dissolved solids present in wastewater contain macronutrients such as (N, P, K, Ca, Mg) and micronutrients (Cu, Fe, Zn, Mn, etc.). These nutrients in reclaimed municipal wastewater, used for direct irrigation, provide fertilizer benefits to crops and landscaping green areas. However, the nutrient content of wastewater may exceed the plant needs leading to nutritional imbalance. Besides, these nutrients pose a potential source for underground water pollution, and may cause problems related to excessive vegetative growth, delayed or uneven maturity, or reduced quality of the irrigated crops. Nutrients occurring in quantities important to agriculture include: nitrogen, phosphorus, and occasionally potassium, zinc, boron and sulfur. The organic matter in wastewater besides its long-term effect on the soil fertility can also contribute to the soil stability and structure.

Dissolved inorganics contribute to wastewater salinity which, if used for agriculture, affects the crop production. Table VI shows how different crops have different sensitivities to water salinity.

## Wastewater treatment processes

Different degrees of wastewater treatment may be achieved using conventional systems or natural systems. Conventional treatment systems include preliminary, primary, secondary, and sometimes advanced treatment processes according to the treatment level of the wastewater treatment plant. They usually involve high-rate biological treatment. Natural systems are lower in cost and less sophisticated in operation and maintenance. They involve low-rate biological treatment. One of the techniques of natural biological treatment systems is using Wastewater Stabilization Ponds which include anaerobic ponds, facultative ponds, and maturation ponds. Other techniques of natural biological treatment systems are: Land treatment technique; Nutrient film treatment technique; and Soil-aquifer treatment technique. Following is a brief description of the conventional treatment processes.

### Preliminary treatment

Preliminary treatment is the removal of large solids and trash. It includes coarse screening, grit (sand) removal, and crushing of large objects. Other preliminary treatment operations can include flocculation, odor control, chemical treatment, and pre-aeration (Crook *et al.*, 1992).

**Table IV**
Constituents of concern in wastewater treatment and irrigation with reclaimed wastewater

| Constituent | Measured parameters | Reason for concern |
|---|---|---|
| **Suspended solids** | Suspended solids including volatile and fixed solids | Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated waste water is discharged in the aquatic environment. Excessive amounts of suspended solids can cause plugging in irrigation systems |
| **Biodegradable organics** | Biochemical oxygen demand Chemical oxygen demand | Composed principally of proteins, carbohydrates, and fats. If discharged to the environment, their biological decomposition can lead to the depletion of dissolved oxygen in receiving waters and to the development of septic conditions |
| **Pathogens** | Indicator organisms, total and fecal coliform bacteria | Communicable diseases can be transmitted by the pathogens in wastewater: bacteria, virus, parasites |
| **Nutrients** | Nitrogen, phosphorous and potassium | Nitrogen, phosphorous, and potassium are essential nutrients for plant growth, and their presence normally enhances the value of the water for irrigation. When discharges to the aquatic environment, nitrogen can also lead to the pollution of groundwater |
| **Stable (refractory) organics** | Specific compounds (e.g. phenols, pesticides, chlorinated hydrocarbons) | These organics tend to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of the wastewater for irrigation |
| **Hydrogen ion activity** | pH | The pH of wastewater affects metal solubility as well as alkalinity of soils. Normal range in municipal wastewater is pH 6.5 – 8.5, but industrial waste can alter pH significantly |
| **Heavy metals** | Specific elements (e.g. Cd, Zn, NI, Hg) | Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of the wastewater for irrigation |
| **Dissolved inorganics** | Total dissolved solids, electrical conductivity, specific elements, (e.g. Na, Ca, Mg,Cl, B) | Excessive salinity may damage some crops. Specifications such as chloride, sodium, boron, are toxic to some crops. Sodium may pose soil permeability problems |
| **Residual chlorine** | Free and combined chlorine | Excessive amount of free available chlorine (>0.05 mg/l $Cl_2$) may cause leaf-tip burn and damage some sensitive crops. However, most chlorine in reclaimed wastewater is in combined form, which does not cause crop damage. Some concerns are expressed as to the toxic effects of chlorinated organics in regard to groundwater contamination |

**Source:** Pettygrove and Asano (1988)

## Primary treatment

Primary treatment is the removal of settleable organic and inorganic solids by sedimentation, and the removal of floating materials by skimming. This process also is effective for the removal of some organic nitrogen, organic phosphorus, and heavy metals, but does little for the removal of colloidal, dissolved constituents, biological species, and the level of viruses. Approximately 25 per cent to 50 per cent of the incoming BOD, 50 per cent to 70 per cent of the total SS, and 65 per cent of the oil and grease are removed during primary sedimentation (FAO, 1992a). In many countries, primary treatment may be considered sufficient treatment if wastewater is used to irrigate crops that are not consumed by humans or to irrigate orchards, vineyards, and some processed food crops, whereby human contact is reduced.

## Secondary treatment

Secondary treatment involves the removal of organic matter and in some cases nitrogen, and phosphorus utilizing an aerobic biological treatment process. Aerobic biological treatment occurs in the presence of oxygen whereby microorganisms oxidize the organic matter in the wastewater. Several types of aerobic biological treatment include: activated sludge, trickling filters, and rotating biological contractors (RBCs).

Environmental Management and Health
9/2 [1998] 79–89

**Table V**
Characteristics of some wastewater constituents

| Trace heavy metals | Remarks |
|---|---|
| **Aluminium** | Can cause non-productivity in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity |
| **Arsenic** | Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice |
| **Beryllium** | Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans |
| **Boron** | Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/l in nutrient solutions. Toxic to many sensitive plants (e.g. citrus) at 1 mg/l. Usually sufficient quantities in reclaimed water to correct soil deficiencies. Most grasses relatively tolerant at 2.0 to 10 mg/l |
| **Cadmium** | Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/l in nutrient solution. Conservative limits recommended |
| **Chromium** | Not generally recognized as essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants |
| **Cobalt** | Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils |
| **Copper** | Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solution |
| **Fluoride** | Inactivated by neutral and alkaline soils |
| **Iron** | Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum |
| **Lead** | Can inhibit plant cell growth at very high concentrations |
| **Lithium** | Tolerated by most crops at up to 5 mg/l; mobile in soil. Toxic to citrus at low doses recommended limit is 0.075 mg/l |
| **Manganese** | Toxic to a number of crops at a few-tenths to a few mg/1 in acid soils |
| **Molybdenum** | Nontoxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum |
| **Nickel** | Toxic to a number of plants at 0.5 to 1.0 mg/l; reduced toxicity at neutral or alkaline pH |
| **Selenium** | Toxic to plants at low concentrations and to livestock if forage is grown in soils with low level of added selenium |
| **Tin, tungsten and titanium** | Effectively excluded by plants; specific tolerance levels unknown |
| **Vanadium** | Toxic to many plants at relatively low concentrations |
| **Zinc** | Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils |
| *Other parameters* | |
| **pH** | Most effects of pH on plant growth are indirect (e.g. pH effects on heavy metals toxicity described above) |
| **TDS** | Below 500 mg/l, no detrimental effects are usually noticed. Between 500 and 1,000 mg/l. TDS in irrigation water can affect sensitive plants. At 1,000 to 2,000 mg/l. TDS levels can affect many crops and careful management practices should be followed. Above 2,000 mg/l, water can be used regularly only for tolerant plants on permeable soils |

**Source:** Adapted from EPA (1973)

## Tertiary/advanced treatment

Advanced wastewater treatment is utilized when high quality reclaimed water is necessary, such as for irrigation of urban landscapes and raw edible food crops. Advanced treatment removes nitrogen, phosphorus, detergents, water softeners, heavy metals such as Zn, Cd, Ni, Fe, and reduces BOD, SS, and TDS. However, nitrogen and phosphorus are major essential plant nutrients and thus their presence in wastewater is an asset for irrigation at certain plant growth stages. Principle advanced wastewater treatment processes include filtration, nitrification, denitrification, biological or chemical phosphorus removal, coagulation-sedimentation, carbon adsorption, ammonia stripping, breakpoint chlorination, selective ion

**Table VI**
Crop salt tolerance

| Sensitive | Moderately sensitive | Moderately tolerant | Tolerant |
|---|---|---|---|
| Bean | Broad Bean | Cowpea | Barley |
| Paddy Rice | Corn | Kenaf | Cotton |
| Sesame | Flax | Oats | Guar |
| Carrot | Millet | Safflower | Rye |
| Okra | Peanut | Sorghum | Sugar Beet |
| Onion | Sugarcane | Soybean | Triticale |
| Parsnip | Sunflower | Wheat | Semi-dwarf Wheat |
| Pea | Alfalfa | Barley (forage) | Durum Wheat |
| Strawberry | Bentgrass | Grass Canary | Alkali Grass |
| Almond | Angleton Bluestem | Hubam Clover | Nuttail Alkali |
| Apple | Smooth Brome | Sweet Clover | Bermuda Grass |
| Apricot | Buffelgrass | Tall Fescue | Kallar Grass |
| Avocado | Burnet | Meadow Fescue | Desert Salt Grass |
| Blackberry | Alsike Clover | Harding Grass | Wheat Grass |
| Boysenberry | Ladino Clover | Blue Panic Grass | Fairway Wheat |
| Cherimoya | Red Clover | Rape | Crested Wheat |
| Sweet Cherry | Strawberry Clover | Rescue Grass | Tall Wheat Grass |
| Sand Cherry | White Dutch Clover | Rhodes Grass | Altai Wild Rye |
| Currant | Corn (forage) | Italian Ryegrass | Russian Wild Rye |
| Gooseberry | Cowpea (forage) | Perennial Ryegrass | Asparagus |
| Grapefruit | Grass dallis | Sundan Grass | Guayule |
| Lemon | Meadow Foxtail | Narrowleaf Trefoil | Jojoba |
| Lime | Blue Grama | Broadleaf Trefoil | |
| Loquat | Love Grass | Wheat (forage) | |
| Mango | Cicer Milkvetch | Durum Wheat (forage) | |
| Orange | Tall Oat Grass | Standard Crested Wheat Grass | |
| Passion Fruit | Oats (forage) | Intermediate Wheat Grass | |
| Peach | Orchard Grass | Slender Wheat Grass | |
| Pear | Rye (forage) | Beardless Wild Rye | |
| Persimmon | Sesbania | Canadian Wild Rye | |
| Plum; Prune | Sirato | Artichoke | |
| Pummelo | Sphaerophysa | Red Beet | |
| Raspberry | Timothy | Zucchini Squash | |
| Rose Apple | Big Trefoil | Fig | |
| White Sapote | Common Vetch | Jujube | |
| Tangerine | Broccoli | Papaya | |
| | Brussel Sprouts | Pomegranate | |
| | Cabbage | | |
| | Cauliflower | | |
| | Celery | | |
| | Sweet Corn | | |
| | Cucumber | | |
| | Eggplant | | |
| | Kale | | |
| | Kohlrabi | | |
| | Lettuce | | |
| | Muskmelon | | |
| | Pepper | | |
| | Potato | | |
| | Pumpkin | | |
| | Radish | | |
| | Spinach | | |
| | Scallop Squash | | |
| | Sweet Potato | | |
| | Tomato | | |
| | Turnip | | |
| | Watermelon | | |
| | Castorbean | | |
| | Grape | | |

**Source:** Tanji (1990)

Khaled M. Abu-Zeid
*Recent trends and developments: reuse of wastewater in agriculture*
Environmental Management and Health
9/2 [1998] 79–89

breakpoint chlorination, selective ion exchange, and reverse osmosis.

## Disinfection

Disinfection may be needed if guideline effluent quality is not achieved. Disinfection is important for the destruction of microorganisms. The most common disinfectant is Chlorine. Ozone and Ultraviolet light are other prominent disinfectants used at wastewater treatment plants. Chlorine contact basins are designed to allow for a contact time of about 30 minutes. In specific irrigation uses, a contact time of 120 minutes may be needed. Inspite of the chlorination efficiency in reducing the number of bacteria, it will leave helminths eggs totally unaffected (FAO, 1992a).

**Table VII**
Reclaimed water standards for reuse in irrigation in Kuwait, Saudi Arabia, Tunisia, Egypt, and the USA

| | Kuwait | | | | Egypt | | | | USA-EPA | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** <br> **Level of treatment** | **Irrigation of fodder and food crops not eaten raw, forest land** <br> **Advanced** | **Irrigation food crops crops eaten raw** <br> **Advanced** | **Saudi Arabia Maximum contaminant level for unrestricted irrigation** | **Tunisia Maximum concentration for reuse in agriculture** | **Maximum concentration for reuse of different categories of reclaimed wastewater (see Table VIII)** <br> **Preliminary** | **Preliminary** | **Secondary** | **Advanced** | **Long term use** | **Short term use** |
| **Trace heavy metals** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **ppm** | **ppm** | **ppm** | **ppm** | | |
| **Aluminium** | | | 5.0 | | | | | | 5.0 | 20.0 |
| **Arsenic** | | | 0.1 | 0.1 | | | | 0.1 | 0.10 | 2.0 |
| **Beryllium** | | | 0.1 | | | | | | 0.10 | 0.5 |
| **Boron** | | | 0.5 | 3 | | 5 | 5 | 5 | 0.75 | 2.0 |
| **Cadmium** | | | 0.01 | 0.01 | | 0.05 | 0.01 | 0.01 | 0.01 | 0.05 |
| **Chromium** | | | 0.1 | 0.1 | | | | 0.1 | 0.1 | 1.0 |
| **Cobalt** | | | 0.05 | 0.1 | | | 0.05 | 0.05 | 0.05 | 5.0 |
| **Copper** | | | 0.4 | 0.5 | | | 1 | 0.2 | 0.2 | 5.0 |
| **Cyanide** | | | 0.05 | | | | | | | |
| **Fluoride** | | | 2.0 | 3 | | | | | 1.0 | 15.0 |
| **Iron** | | | 5.0 | 5 | | | 5.0 | 5.0 | 5.0 | 20.0 |
| **Lead** | | | 0.1 | 1 | | 10 | 5.0 | 5.0 | 5.0 | 10.0 |
| **Lithium** | | | 0.07 | | | | | | 2.5 | 2.5 |
| **Manganese** | | | 0.2 | 0.5 | | 0.2 | 0.2 | 0.2 | 0.2 | 10.0 |
| **Mercury** | | | 0.001 | 0.001 | | | | | | |
| **Molybdenum** | | | 0.01 | | | | 0.05 | 0.01 | 0.01 | 0.05 |
| **Nickel** | | | 0.02 | 0.2 | | 0.5 | 0.5 | 0.2 | 0.2 | 2.0 |
| **Nitrate** | | | 10.0 | | | | | | | |
| **Selenium** | | | 0.02 | 0.05 | | | | | 0.02 | 0.02 |
| **Tin, tungsten, titanium** | | | | | | | | | | |
| **Vanadium** | | | | | | | | | 0.1 | 1.0 |
| **Zinc** | | | 4.0 | 5 | | | 2.0 | 2.0 | 2.0 | 10.0 |
| ***Other parameters*** | | | | | | | | | *Recommended limit* | |
| **TDS *(mg/l)*** | | | | | 2,500 | 2,500 | 2,500 | 2,500 | 500-2,000 | |
| **SS *(mg/l)*** | 10 | 10 | 10.0 | 30[a] | | 350 | 40 | 20 | | |
| **BOD *(mg/l)*** | 10 | 10 | 10.0 | 30[a] | | 300 | 40 | 20 | | |
| **COD *(mg/l)*** | 40 | 40 | | 90 | | 600 | 80 | 40 | | |
| **Chloride *(mg/l)*** | | | 280 | 2,000 | | 350 | 350 | 350 | | |
| **Chlorine residual *(mg/l)* *after 12 hrs @ 20°C*** | 1 | 1 | | | | | | | <1 | |
| **pH** | | | 6-8.4 | 6.5-8.5 | | | | | 6.0 | |
| **Coliform *(count/100ml)*** | 10,000 | 100 | 2.2 | | | | 10,000 | 1,000 | | |
| **Turbidity *(NTU)*** | | | 1.0 | | | | | | | |
| **SAR *(per cent)*** | | | | | 25 | 25 | 20 | 20 | | |
| **Oil and grease *(ppm)*** | | | absent | | | | 10 | 5 | | |
| **Phenol** | | | 0.002 | | | | | | | |
| **Electrical conductivity *(US/cm)*** | | | | 7,000[b] | | | | | | |
| **Halogenated hydrocarbons** | | | | 0.001 | | | | | | |
| **Intestinal nematodes (arithmetic mean no. of eggs per liter)** | | | | < 01/1 | | 5 | 1 | 1 | | |

**Note:** [a] 24 hour composite sample
**Source:** Bahri, 1991; Crook *et al.* (Camp Dresser and Mckee Inc.) 1992; Egyptian Ministerial Committee Report, 1994; EPA, 1973; Kalthem and Jamaan, 1985

## Wastewater reuse considerations

In addition to irrigation supply and demand and water quality requirements such as those shown in Tables VII and VIII, there are other considerations specific to agricultural water reuse that must be addressed. Both the user and supplier of reclaimed water may have to consider modifications in current practice that may be required to use reclaimed water for agricultural irrigation. This requires that those investigating reclaimed water programs have a working knowledge of the appropriate regulations, crop requirements, and means of application. Important considerations include:

- system reliability;
- site use control and setback distances for irrigation;
- monitoring requirements;
- runoff controls;
- marketing incentives; and
- irrigation equipment.

Setback distances or buffer zones should be established between reuse irrigation sites and various facilities such as potable water supply wells, property lines, residential areas, and roadways. Setback distances vary depending on the quality of reclaimed water and the method of application. For example, Illinois requires a 15 m setback from the edge of the wetted perimeter of the reuse site to a residential lot for a non-spray application system, but requires a 45-m setback for a spray irrigation system. For restricted and unrestricted urban reuse and irrigation of food crops, Florida requires a 23-m setback to potable water supply wells; but for agricultural reuse on non-food crops, Florida requires a 150-m setback to water supply wells and a 30-meter setback to property lines. Florida will allow reduced setback distances for agricultural reuse on non-food crops if additional facility reliability and treatment are provided. Colorado recommends a 150-m setback distance to domestic supply wells and a 30-m setback to any irrigation well regardless of the quality of the reclaimed water (Crook *et al*., 1992).

Oregon and Nevada do not require setback distances when reclaimed water is used for unrestricted urban reuse or irrigation of food crops due to the high degree of treatment required; however, setback distances are required for irrigation of non-food crops and restricted urban reuse. In Nevada, the quality requirements for reclaimed water are based not only on the type of reuse, but also on the setback distance. For example, for restricted urban reuse and a 30-meter buffer zone, Nevada requires that the reclaimed water have a mean fecal coliform count of no more than 23/100 ml and a turbidity of no more than 5 NTU. However, with no buffer zone, the

**Table VIII**
Appendix of reclaimed water standards for reuse in irrigation in Egypt

| Category | Treatment level | Permissible crops | Environmental and health precautions | Appropriate irrigation method | Suggested soil type |
|---|---|---|---|---|---|
| **1** | Preliminary | Wood trees<br>Palm trees | Farms should be fenced<br>No direct water contact<br>No entrance permission of non-farm employees<br>No entrance for cattle<br>Follow health precautions<br>Protecting against transmitted diseases | Furrow | Light texture |
| **2** | Primary | Cotton<br>Flowers<br>Flax | As above | Furrow<br>Filter and drip | Light texture |
| **3** | Secondary | Animal food crops<br>Fields for livestock grazing<br>Crops with inedible skin<br>Fruits not in contact with water<br>Cooked vegetables<br>Heat processed fruits | Non-milk livestock grazing<br>Food should be cooked before eaten | Furrow<br>Drip | Light texture<br>Medium texture |
| **4** | Advanced | Raw consumed food plants<br>Crops with inedible skin<br>All types of crops and citrus fields | None | All methods except sprinkler | All types |

**Source:** Egyptian Ministerial Committee Report (1994) reclaimed water must have a mean fecal coliform count of no more than 2.2/100 ml and a turbidity of no more than 3 NTU.

## Examples of wastewater reuse in the Arab region

### Kuwait

With a population estimated at about 2,000,000, most of Kuwait can be considered urban. The country is arid, with average annual rainfall less than 125 mm. With no surface sources, water is drawn from groundwater at the rate of about 2,000 $m^3$/d, mainly for producing bottled water. Most water needs are met by desalination. About 85 per cent of the total population is on a central sewerage system. Kuwait provides tertiary treatment (activated sludge treatment, filtration, and chlorination) for reclamation for agricultural irrigation. Their standards are shown in Table VII. Three reclamation plants have a total capacity of more than 300,000 $m^3$/d, with plans to use all of it for agricultural and landscape irrigation (Crook *et al.*, 1992).

### Saudi Arabia

Saudi Arabia is committed to a policy of complete reuse. In 1978, the amount of reclaimed water used was estimated at 95,000 $m^3$/d, and the projection for the year 2000 is about 2.0 x $10^6$ $m^3$/d. By 2000 the Kingdom expects to meet almost 10 per cent of its water demand through reuse. Regulations require secondary treatment with tertiary treatment for unrestricted irrigation, with standards shown in Table VII (Kalthem and Jamaan, 1985). Of special interest are the projects at Riyadh, Jeddah, and Mecca and Jubail Industrial City. At Riyadh the trickling filter facility treats over 120,000 $m^3$/d. Of this, about 15 per cent is used by the General Petroleum and Minerals Organization (Petromin) for industrial reuse, and the rest is available for agricultural irrigation on about 7,800 acres (3,100 ha). A 40,000 $m^3$/d activated sludge facility at Jeddah is designed to exceed WHO standards and is the first in the region which was designed to meet the equivalent of drinking water standards. Advanced treatment includes reverse osmosis, desalination, filtration, and disinfection. Other plants are planned for Jeddah and Mecca. In both cities the reclaimed water will be used for municipal, industrial, and agricultural reuse. The City of Jubail is planned to have a 120,000 $m^3$/d treatment capacity by 1992, with plans for non-potable industrial, urban landscaping, and other reuses.

In all, 22 wastewater treatment plants are in operation, 19 of which are waste stabilization ponds. Most are currently discharging to wadis or to the sea, although plans are underway to increase reuse (Yanez, 1989).

### Sultanate of Oman

In Oman, water has been reused around Muscat since 1987. Currently effluent from two treatment plants, at Darsait and at Shatti al Qurm, is used mainly to irrigate extensive amenity planting by drip irrigation. Sprinkler irrigation is not used in recreation areas, but between 1a.m. and 6a.m. some sprinkler irrigation is conducted in controlled areas. Pressure in the distribution system, which extends to more than 4.0 km is some 2 to 3 bars. Effluent requirements are set in the Regulations for Wastewater Reuse and Discharge. The Darsait plant is currently operating at capacity and treating about 12,000 $m^3$/day of wastewater. This plant serves the local business district and also receives sewage and wastewater pumped from holding tanks. The treatment processes include screening, grit removal in aerated grit chambers, primary setting, activated sludge treatment by contact stabilization, dual-media filtration, and chlorination. If the chlorine concentrations exceeds 0.2 mg/l after chlorine contact, air is added to strip out the excess chlorine. Effluent is pumped to a storage tank that provides pressure to the water reuse transmission system.

The Shatti al Qurm plant is a package extended-aeration plant followed by filtration in pressure units and disinfection. This plant has a capacity of about 1,350 $m^3$/day, plant flow is about 700 $m^3$/day. The wastewater to this plant comes from embassies and residences in the area. Treated effluent is stored and pumped into the water reuse transmission system. A third plant, at Al Ansab, treats only wastes from septage and wastewater haulers. The plant capacity is about 13,000 $m^3$/day, and current flows are about 5,000 $m^3$/day (Crook *et al.*, 1992). Treatment process include screening, degritting, denitrification in an anoxic zone, nitrification, secondary setting, filtration, and disinfection, and storage. The plant has facilities to load trucks that can apply treated effluent. Plans are to connect the plant to the reclamation distribution system. During the summer, all the reclaimed water in the area is used, and demands are not met. But during the winter about 40 per cent of the effluent from the Darsait plant is discharged through an outfall to the Gulf of Oman. In the future, the reuse network will be expanded so that all the effluent is reused.

## Tunisia

Although all the countries of North Africa have an interest in water reclamation, Tunisia has done the most, making reuse a priority in their national water resources strategy (Bahri, 1991; Asano and Mujeriego, 1982). Some 1,500 acres (600 ha) of citrus and olive tree orchards near Tunis had been irrigated with groundwater from shallow aquifers since the 1960s but, because of overdraft and seawater intrusion, secondary effluent from a portion of Tunis wastewater was used for irrigation seasonally, in spring and summer. The effluent is pumped into a 5,800 $m^3$ pond and then to a 3,800 $m^3$ reservoir, and then flows by gravity about 8 km to the farmers. Currently, the effluent from four treatment plants, with a total flow of about 250,000 $m^3/d$ is used to irrigate about 12,000 acres (4,500 ha) of orchards, forage crops, cotton, cereals, golf courses and lawns. About 70 per cent of the irrigated area around Tunis will use about 60 per cent of the available wastewater effluent.

Considerable research has been undertaken, particularly to assess the fertilizer value of reclaimed water and the sewage produced in treatment. Reclaimed water irrigation produced higher yields than groundwater irrigation. Studies of the contamination of crops and groundwater when reclaimed water is used revealed little significant impact on soils, crops, or groundwater (Bahri, 1991). The National Sewerage and Sanitation Agency is responsible for the construction and operation of all sewerage and treatment infrastructure in the larger cities in Tunisia. When effluent is to be used for agricultural irrigation, the Ministry of Agriculture is responsible for execution of the projects, which include the construction and operation of all facilities for pumping, storing and distributing the reclaimed water. Various departments of the Ministry are responsible for the several functions, while regional departments supervise the Water Code and collection of charges, about $0.02-0.03/m3 . The Water Code, enacted in 1975, prohibits the use of untreated wastewater in agriculture to be eaten raw. More recent legislation covers the regulation of contaminants in the environment, including reclaimed water, and specifies the responsibilities of the Ministries of Agriculture and Public Health, and the National Environmental Protection Agency. Table VII illustrates the maximum concentrations for several contaminants in reclaimed water to be used in agriculture.

## United Arab Emirates

Extensive non potable reuse has been practiced in Abu Dhabi since 1976. The system, designed for 200,000 $m^3/d$, includes a dual distribution network which uses reclaimed water for urban irrigation of public gardens, trees, shrubs and grassed areas along roadways. The treatment facility provides tertiary treatment with rapid sand filtration and disinfection by chlorination and ozonation. The reclaimed water distribution system is operated at lower pressure than the potable system to reduce wind spraying; elements of the system are marked and labeled to avoid cross-connections. Al-Ain, with a projected population of 250,000 by the year 2000, produces reclaimed water that may be used only for restricted irrigation. The reclaimed water is pumped about 12 km outside the city where it is used for irrigation in designated areas. Treatment includes dual-media filtration and chlorination for disinfection.

## Egypt

The reuse of municipal wastewater has been practiced in Gabal ElAsfar sewage farm near Cairo City for more than 60 years (Ashmawy, 1990). Four-thousand acres of desert land has been reclaimed by surface irrigation of this primary treated sewage. After the first 20 years, the sewage flow reaching the treatment plant exceeded double the capacity. That is when entirely raw sewage was used for irrigation for the next 40 years. Productivity of land increased gradually and then dropped due to clogging of soil resulting from raw sewage use. The treatment plant is now being expanded, desert reclamation projects are planned, and standards for wastewater reuse are legislated. See Tables VII and VIII for Egyptian Standards for wastewater reuse in agriculture.

Other successful projects for wastewater reuse in agriculture are taking place in Abu-Rawash and El-Saf. There are huge wastewater collection projects that are being constructed in Cairo City to treat as much as 3 x 106 $m^3/day$. Large deep sewage tunnels (5 m diameter) are being installed. It is predicted that Cairo sewage flow will reach 4 x 106 $m^3/day$ by year 2000 (Ashmawy, 1990). According to the Ministry of Public Works and Water Resources of Egypt (MPWWR, 1994), it is planned to reclaim and cultivate a desert area of about 200,000 feddans using about 5.080 x 106 $m^3/day$ of treated wastewater by year 2020. Reclamation sites are distributed as shown in Table IX.

**Table IX**
Distribution of reclamation sites

| Site | Area (feddans) | Wastewater reuse (1994-2020) ($m^3$/day) |
|---|---|---|
| **ElBerka** | 30,000 | 750 x $10^3$ |
| **ElGabal ElAsfar (1st phase)** | 45,000 | 1,080 x $10^3$ |
| **ElGabal ElAsfar (2nd Phase)** | 25,000 | 600 x $10^3$ |
| **ElGabal ElAsfar (3rd Phase)** | 30,000 | 750 x $10^3$ |
| **Znein & Abu-Rawash** | 50,000 | 1,325 x $10^3$ |
| **ElSaf & Ghomaza** | 20,000 | 575 x $10^3$ |

## Conclusions

Wastewater reuse in agriculture is a successful trend that provides the two benefits of developing a new non-conventional water resource, and utilizing a low cost natural fertilizer. However, the most critical restriction in a wastewater reuse program is to assure that public health is not compromised. Other objectives, such as preventing environmental degradation, avoiding public discomfort, and meeting user requirements, must also be satisfied in implementing a successful wastewater reuse program. The starting point remains in the use of properly treated reclaimed water for the right crop in the right soil using the right method of irrigation.

Several wastewater reuse standards and guidelines have been demonstrated. It is important to follow wastewater reuse guidelines and standards regarding the degree of treatment for cultivating different crops, and the necessary precautions that need to be taken.

In general there are certain measures that are required for health protection. They include:

- *treatment of wastewater* – to reduce the concentrations of pathogens in the reclaimed water;
- *crop restriction* – to restrict the use of treated wastewater to restricted crops;
- *wastewater application* – to supply wastewater via subsurface, localized irrigation systems, and recommended method of irrigation for different crops;
- *human exposure control* – by limiting contact, inhalation, and ingestion of the reclaimed water;
- *continuous monitoring* – to assure the quality of treated wastewater, monitoring should be maintained on treated wastewater, groundwater in the vicinity, soils, and crops;
- *adherence to wastewater reuse standards and guidelines.*

Furthermore, investment in sewage collection systems and wastewater treatment plants have a number of advantages, especially in countries with scarce water resources. It, not only, prevents the environmental hazards of improper disposal of wastewater, but it provides the opportunity for implementing the recent trend of reusing wastewater in agriculture.

## References

Abdledayem, S. (1994), "Water quality issues in Egypt", *Italian-Egyptian Study Days on the Environment, Workshop on Water Protection*, 9-20 October, Cairo.

Amer, M. (1992), "Egypt's experience in the field of reuse of agriculture drainage water", *Proceedings of the Workshop on Irrigation Water Demand Management in the Mediterranean*, IME-World Bank (MEDWAN-METAP), France, pp. 384-5.

Asano, T. and Mujeriego (1982), "Tunisia: institutional aspects of wastewater reuse", *Report for UNDP-WB Water & Sanitation Program*, UNDP Project RAB/88/009.

Ashmawy, M.A. (1990), "Re-use of waste water for land reclamation and irrigation in Egypt", *Wastewater Reuse for Irrigation in the Mediterranean Region*, Mediterranean Action Plan Technical Report Series No. 41, Priority Actions Programme, United Nations Environment Programme (UNEP).

Bahri, A. (1991), "Present and future state of treated wastewaters and sewage sludge in Tunisia", Research Center for Rural Engineering, Tunis.

Boyle Engineering Corporation (1981), "Evaluation of agricultural irrigation projects using reclaimed water", Office of Water Recycling, California State Water Resources Control Board, Sacramento, California.

Crook, J., Ammerman, D.K., Okun, D.A. and Matthews, R.L. (1992), "Guidelines for water reuse", Camp Dresser & Mckee Inc.

Egyptian Ministerial Committee Report on Wastewater Reuse (1994).

EPA, United States Environmental Protection Agency (1973), "National Academy of Science – National Academy of Engineering Water Quality Criteria 1972: A report of the

Environmental Management and Health
9/2 [1998] 79–89

Committee on Water Quality Criteria", EPA – R3-73-033, Washington DC.

EPA (1980), "Guidelines for water reuse", Washington DC.

FAO (1992a), "Treatment of wastewater used for irrigation", *RNEA Technical Bulletin Series, Land & Water No. 2*, The Food & Agriculture Organization of the United Nations, Regional Office for the Near East, Cairo, Egypt.

FAO (1993), "Monitoring wastewater quality for irrigation", *RNEA Technical Bulletin Series, Land & Water No. 6,* The Food & Agriculture Organization of the United Nations, Regional Office for the Near East, Cairo, Egypt.

Kalthem, M.S. and Jamaan, A.M. (1985), "Plans for reuse of wastewater in agriculture and industry in the Kingdom of Saudi Arabia", FAO Regional Seminar, Cyprus.

MPWWR (1994), "Horizontal expansion policies and plans", Ministry of Public Works & Water Resources (MPWWR), Cairo, Egypt.

Pettygrove, G.S. and Asano, T. (Ed.) (1988), "Irrigation with reclaimed municipal wastewater", *A Guidance Manual Report No. 84-1 wr,* California State Water Resources Control Board, Lewis Publishers, Inc., Sacramento, CA.

Postel, S. (1992), "Last oasis (facing water scarcity)", *The Worldwatch Environmental Alert Series,* W. W. Norton & Company, New York, NY.

Tanji, K.K. (Ed.) (1990), "Agricultural salinity assessment and management", American Society of Civil Engineers, New York, NY.

WHO, Water Supply and Sanitation Collaborative Council, and UNICEF (1990), *Water Supply and Sanitation Sector Monitoring Report 1990 (Baseline Year),* WHO/UNICEF Joint Monitoring Programme, United Nations, New York, NY.

World Bank (1995), "From scarcity to security: averting a water crisis in the Middle East and North Africa", World Bank, Washington DC.

Yanez, F. (1989), "Survey mission on wastewater reuse in the Middle East", Report to the World Bank, Washington, DC.