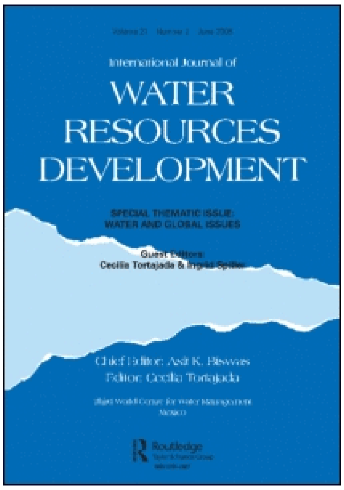

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Use of marginal quality water for plant production in Europe

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Use of marginal quality water for plant production in Europe

Asit K. Biswas and Abdullah Arar

The use of marginal quality water for plant production in Europe is analysed. The implications of using marginal quality water on plant, health and environment are reviewed. The status of current European research is outlined. On the basis of current experience, it can be concluded that marginal quality water can be safely used for plant production, provided certain precautions are taken to protect health and the environment.

Domestic and industrial wastewater constitute the most important source of marginal quality water in Europe. The use of marginal quality water for plant production in Europe is not new: it has been practised for thousands of years. For example, sewage effluents were used for irrigation in Greece more than two millennia ago. Similarly, farming with sewage was a common practice in Germany as early as the 17th century, and was practised in the United Kingdom until the late 19th century.

As the environmental movement in Europe gained momentum in the late 1960s, water quality degradation – due to human activities – became an important concern. An associated concern was the proper use of marginal quality water for different purposes, including plant production, without contributing to environmental deterioration. This issue was especially relevant in those areas where there were shortages of good quality water, and hence water of marginal quality had to be used for agricultural purposes.

While there is major and growing concern over the problem of water pollution in Europe, this awareness does not extend to issues involved in the actual use of marginal quality water. The present paper examines some aspects of this subject, particularly with regard to the use of marginal quality water for plant production.

Use of marginal quality water

There are several important aspects to the use of marginal quality water for plant production. A fundamental issue is what constitutes marginal quality water. Unfortunately, no clear-cut definition of marginal water quality is available that is universally applicable. This is not surprising since, primarily on technical grounds, quality of water can only be considered as 'marginal' with reference to its use for a specific purpose. Accordingly, a source of water that is marginal for growing certain types of crops may not be marginal for use in a specific type of industry, and vice versa.

Often 'marginal' quality water is considered to be that which is unsuitable for human consumption. Such a definition, though valid, covers many water sources since the requirements for drinking water quality are the most stringent. From the viewpoint of plant production, perhaps a more workable and appropriate definition of marginal quality water would be that for which there is moderate to severe restriction for use. In other words, water which is not restricted or is slightly restricted for use in irrigation may be considered to be good quality water, and the rest to be marginal quality water.

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Expressed differently, use of marginal quality water for agricultural purposes requires more complex irrigation management practices and more stringent monitoring processes than does good quality water. Some of the many factors influencing the usability of water for irrigation are shown in Appendix 1. These should be considered for guidance only (Ayers and Westcot, 1985), and may need to be modified to fit specific prevailing conditions.

The importance and the magnitude of the problem of marginal quality water and its use can only be assessed properly if it is viewed as an integral part of an overall policy framework that includes water, land use and agricultural production. While marginal quality water has been used in the past in Europe, through both planned and unplanned activities, it has recently become an increasingly important resource due to higher water demands, especially in areas where the availability of fresh water is far outstripped by total requirements. Even though technically it is possible to treat marginal quality water and bring its standards up to any desired quality, this may not be a practical solution for a specific type of water use because of associated high costs. Marginal quality water could be considered an additional source to supplement many of the traditional uses of conventional water sources. Because of the very nature of its quality, it generally meets the requirements of certain types of water use, such as agriculture or industry (with the exception of the food-processing industry), but these options can be increased through treatment and reliable quality control. If marginal quality water can be used for suitable purposes, it will release better quality water which might otherwise have been used for those purposes.

Marginal quality water can originate from two sources, natural and artificial. Natural sources include primarily brackish water, and humans contribute to water quality degradation mainly through domestic and industrial pollution. A third type can be identified, which is a combination of artificial and natural processes. This is acid rain, where artificial atmospheric emissions are transported and precipitated by natural processes. Acid rain is a serious concern in Europe, and it does affect plant production – both by direct and serious impact on plants and through acidification of soils. However, since it is not a deliberate use of marginal quality water for plant production by human activities, the topic – though important – is not discussed in this paper.

One increasingly important source of marginal quality water in Europe is treated wastewater from various sewage systems. As environmental considerations have become well established in most of the region, primary, secondary and tertiary treatments have become more and more common. This, in turn, has meant that the treated wastewater has become of fairly good quality for use for certain purposes. If proper groundwater recharge is practised, treated wastewater can supplement nearly all the various uses of groundwater, including subsequently being a potential source of municipal water supply.

Many different types of wastewater are produced by domestic and industrial sources. The final water quality produced depends on the type of treatment processes and the nature of the industry present in the area. Because the type of industry – as well as the specific industrial processes being used – varies from place to place, the pollutants present in wastewater vary considerably. Similarly, the presence of large feedlot operations can create some specific water quality problems. One major advantage of domestic and industrial wastewater is that these are point sources, and accordingly their water output can be collected and brought to specific locations for treatment. When water is used for agriculture, substances such as salt, pesticides, fertilizers, etc, can be leached from the soil and become non-point sources of pollution, making treatment difficult.

There are many characteristics of marginal quality water which need to be considered, depending on how the water will be finally used. Among the various characteristics that may need to be considered, the following are of particular importance.

(i) Aesthetic

Three aesthetic features should be considered: colour, odour and foam. The colour of water is directly influenced by the type of foreign substances that may be present. If water is used for washing mined materials, it can have various colours such as black, brown or red, depending on the material being mined. If it is municipal wastewater, the colour of effluents indicates their state of degradation and the presence of algae. The colour resulting from septic conditions is usually black, with green predominating where algae are present. The presence of undue amounts of algae may create problems for drip irrigation. Odour problems, due to anaerobic processes or the presence of different industrial waste products, could be of particular concern if they occur near residential areas. Foaming is a consequence of the type and quantity of detergents used, and is primarily considered an environmental nuisance, rather than an issue for plant production.

(ii) Solids

The amount of organic and inorganic solids present in marginal quality water, in both dissolved and suspended forms, is an important consideration for irrigation use. Unfavourable particle-size distribution of suspended solids may preclude the use of certain forms of irrigation, such as sprinkler and drip irrigation, and may also affect the permeability of the soil.

(iii) Nutrients

Some forms of marginal quality water, such as treated wastewater, contain significant amounts of nutrients in the forms of nitrogen, phosphorus and potassium, which can benefit plant growth and reduce the quantity of mineral fertilizers needed to be applied. Actual concentrations of the various nutrients are affected by the type of wastewater generated as well as the method and extent of treatment used. Properly managed nutrient-rich wastewater can be beneficial to plant production.

(iv) Salinity and sodicity

If the salinity of marginal quality water is high, and the water is used for irrigation, the salt tends to concentrate in the topsoil by evapotranspiration. As salt begins to accumulate in root zones, the yield of crops declines. The problem of salinity and sodicity development and its amelioration is a particularly important consideration when the quality of available water is poor.

(v) Bacteria

The bacterial quality of water, especially wastewater, is an important consideration for irrigation and groundwater recharge. Types of crops that can be irrigated depend upon the bacterial quality of the wastewater and the potential health hazards to humans and animals. For food crops, some restrictions may be imposed in terms of the termination of irrigation before harvesting.

(vi) Toxicity

Plants may accumulate certain constituents from marginal quality water which may create toxicity within the plant. The toxic substances that particularly need to be monitored are sodium, chloride and boron. In contrast to metals and other hazardous chemicals, which pose potential health risks to humans and animals, toxicity – at the concentrations normally found – is of concern primarily for plant production.

(vii) Metals and other chemicals

The presence of certain metals and hazardous chemicals in irrigation water may constitute a hazard to soil organisms, and to plants. Through the food chain, animals and humans consuming the plants may suffer potential health risks. Among these metals are cadmium, mercury, molybdenum, nickel, zinc and arsenic.

The health and environmental problems associated with nutrients, salinity, bacteria, toxicity, metals and chemicals are discussed later.

Examples of European practices

An overall picture of the status of marginal quality water in Europe is difficult to obtain, since no compatible water quality monitoring and analysis systems exist over the whole region. Different countries, as is to be expected, operate their own national water quality monitoring and data processing systems based on national requirements.

Returns to a questionnaire survey of European countries recently carried out by the FAO reveal that, overall, the presence of marginal quality water is not considered a serious problem in most European countries: only Cyprus, Hungary, Israel and Spain considered it to be a problem. This result, however, does not mean that marginal quality water is not present in other European countries: it is considered to be a localized problem that can be overcome by appropriate planning and management.

Considerable experience does exist in Europe on the use of marginal quality water for plant production. Most of such uses are local in character, and reliable data and documentation on these uses often do not exist, or if they do exist, are not readily available. On the basis of the questionnaire survey carried out, and published information, the following synthesis is provided of some European practices.

The United Kingdom

The UK had sewage farms as early as in 1650 in Edinburgh, and later in other major cities such as London and Manchester. It was also the first country in Europe where the land application of sewage effluents was officially approved. The First Royal Commission on Sewage Disposal, in its report of 1865, stated that the 'right way to dispose of town sewage is to apply it continuously to the land and it is by such application that the pollution of rivers can be avoided'. By 1870 there were some 60 land application sites, which subsequently gradually declined in number to the very few existing by 1955.

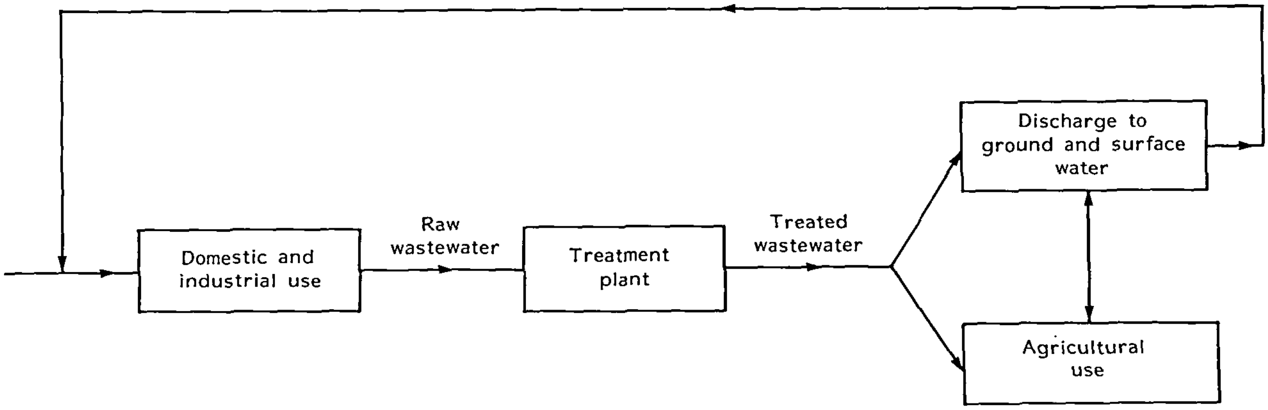

Figure 1. Interconnections between wastewater production, treatment and reuse.

Since then, however, renewed interest in wastewater treatment and reuse has increased the number of such sites to the earlier peak figure (Jewell and Seabrook, 1979). At present many water authorities, who are also in charge of the country's sewage systems, practise artificial groundwater recharge with treated wastewater. Whether treated wastewater is used for artificial groundwater recharge or discharged to rivers, it is also an indirect form of reuse since the water itself can be later reused for various purposes (including plant production), as shown in Figure 1.

Considerable experience has thus been accumulated in the United Kingdom on the artificial recharge of groundwater with sewage and sewage effluents. At present some 300 million litres per day (Ml/d) of wastewater are recharged to the ground, half of it to chalk formations and much of the remainder to triassic sandstones. At the largest recharge site at Winchester, about 11 Ml/d of sewage from the city is pumped to the top of a hill, where it undergoes sedimentation only. The effluent then descends from the hill through a series of trenches and lagoons, mixes with groundwater and finally reaches the river Itchen (Montgomery, Beard and Baxter, 1984). The recharge process removes biochemical oxygen demand (BOD) to the same level as by conventional treatment by biological filtration. Nitrogen removal is mostly 50% but sometimes reaches as high as 90%. Coliform bacteria and viruses are removed as well. Observations indicate that effluents have no impact on the nitrogen and phosphate concentrations of the river Itchen. Dichlorobenzene, however, is not removed during this land treatment process.

The UK experience confirms other findings that artificial recharge by sewage effluents is a remarkably effective method of removing organic matter, ammonia, bacteria and viruses from sewage effluents. Nitrogen can be partially removed by recharging into chalk and alluvial gravel aquifers, but residual nitrogen remains as nitrate. In terms of per unit length of flow, unsaturated zones are more effective than saturated zones in improving water quality. In terms of agricultural use of sewage effluents after such recharge processes, the main concern appears to be conservation of mineral contents such as calcium, sodium, magnesium, chloride and sulphate, which may restrict the use of such marginal quality water on a long-term basis.

Spray irrigation of pastures for disposal of abbattoir effluent has been practised successfully in the UK. Effluents containing blood are used for irrigation, and this does not appear to present any environmental or agricultural problems. Good growth of new grass can be observed.

The Federal Republic of Germany

The Federal Republic of Germany has also had considerable experience with sewage farms and wastewater irrigation. For example, Berlin had its first sewage farm in 1836, and by 1910 some 17 200 ha of land were being used for sewage farming. The overall operation, however, was not profitable, and had to be subsidized by city taxes. The extent of sewage farming has declined radically since the turn of the century, because the farms became overloaded with ever-increasing wastewater flows. Consequently, the farms were gradually abandoned and sewage treatment plants were built. There were 82 sewage farms covering 512 ha by the end of 1982 (Federal Republic of Germany, 1987; see Appendix 2 for details). However, wastewater irrigation was more significant by the end of 1982, when 1 068 enterprises irrigated 14 133 ha and used over 13 million cubic metres (MCM) of water annually. At present wastewater irrigation and/or sewage spreading is limited to 300 mm or 300 litres per square metre (l/m^2) per annum, applied in several doses.

One of the longest operational and best-documented cases of the use of wastewater for plant production in Europe is in Braunschweig, where some 44 500 m^3/d of wastewater are used for irrigation. This scheme has been operating since 1954 (see Appendix 2). A nearby city, Wolfsburg, has had a similar but smaller operation since 1942, where 16 000 m^3/d of wastewater are used for plant production. On the basis of experiences in these two cities, it can be concluded that from a total systems viewpoint wastewater irrigation is a feasible and desirable alternative since it not only meets the water and nutritional needs of plants but also acts as an advanced wastewater treatment system with sludge disposal possibilities. Since, after land treatment, almost tertiary effluent quality is reached, regardless of the degree of pre-treatment (Kayser, 1985), underground and surface water contamination has not been a problem at these two sites. The experience gained indicates that potential health and environmental hazards can be avoided by taking some simple precautions.

France

In France the reuse of treated wastewater is encouraged. There is also some demand for the reuse of wastewater by holiday resort areas on the coast, and in small rural communities. For example, the Mediterranean island of Porquerolles has been using the activated sludge process and three maturation ponds with a total retention time of 22 days to treat its sewage effluents. In summer, when crop water demand is high, the island has some 3 000 people (compared to 1 000 in winter) producing wastewater of around 300 m^3/d. The wastewater is used to irrigate citrus trees, some fruit trees such as apricot, peach and plum, and cypress trees. Trickle irrigation is used to maximize water use, and treated wastewater now represents nearly 60% of the irrigation water demand. In the winter season the effluent is applied on fallow land.

Land treatment and artificial groundwater recharge have been successfully demonstrated in Port Leucate, a resort near the Mediterranean. Until 1979 all sewage was discharged into the sea after biological treatment in a plant. The plant reached saturation point in 1980 during the critical tourist season of mid-July to mid-September. In order to resolve this problem six infiltration basins, each 50 m × 15 m in area, were used in the nearby Corrège dune. After purification in plant, 4 000 m^3/d of effluent was spread on the infiltration basins. The results were quite satisfactory. Infiltration rates were high, even with a relatively loaded effluent of total suspended solids (TSS) of at least 100 mg/l. BOD and carbonaceous oxygen demand (COD) removal reached an average of 90%. Nearly all phosphorus was removed, and around a 40% reduction of nitrogen was observed. The total investment cost was $100 000, which was 15 times lower than the alternative proposal of disposal in the sea through an outflow pipe, and with significantly less environmental impact (Bize *et al*, 1985).

Irrigation of forest areas with sewage effluents appears to be a promising alternative in some parts of France in terms of both enhancing plant growth and reducing fire hazards.

Portugal

In Portugal a research and demonstration project was initiated in 1985 on the use of treated wastewater for plant production at Evora in the Upper Alentejo, where demand for water for irrigation is high. The municipal wastewater of the city is treated by primary sedimentation, high-rate biological filtration and secondary sedimentation. Primary and secondary settled effluents are used to irrigate sorghum, maize and sunflower in 36 plots, each of 30 m^2 in area. Control plots, for comparison, were irrigated with freshwater and received mineral fertilizers.

On the basis of results obtained to date, crop yields from the three types of irrigation water tested (primary and secondary effluents with no chemical fertilizers, and freshwater with chemical fertilizers) were similar. Analyses indicated that treated wastewater provided all the nitrogen requirements for sorghum and sunflower, but only two thirds of the requirement for maize. Consequently, savings in terms of the non-use of nitrogenous fertilizers associated with wastewater irrigation amounted to around $145 per ha for sorghum and maize, and $67 per ha for sunflower.

At Evora lettuces were cultivated with spray irrigation with primary and secondary effluents. It was found that five days after irrigation was stopped, the level of contamination of the irrigated lettuces fell below those produced elsewhere and sold in local markets. Further work is being carried out in this area (Mara, 1987).

Cyprus

In Cyprus it is estimated that 30–40% of spring potatoes, fodder, industrial crops, olives and citrus are irrigated with marginal quality water. In Akrotiri wastewater is treated by trickling filters and chlorination, and then used mostly for irrigating sports fields, lawns and roadside areas. Elsewhere in the country activated sludge effluent is chlorinated and used to irrigate sports fields and alfalfa.

A pilot project has been initiated in Nicosia, where conventional secondary effluent is treated in a maturation pond with a retention time of 10 days. Trickle irrigation is subsequently used for producing fodder and crops such as cotton, sunflower and jojoba. No detailed results are available from this project at present.

Israel

In Israel some 300 MCM of marginal quality water is used annually for agricultural purposes, and accounts for 23% of total requirements. Total brackish water use is around 170 MCM annually, out of which about 120 MCM are utilized for agricultural purposes, including for use in fish ponds. Currently efforts are being made to use more brackish water beneficially. In terms of treated wastewater, annual production at present is about 250 MCM, and is expected to reach 320–350 MCM by the year 2000. Most of the wastewater (about 65–70%) at present originates from three or four main centres of population. Currently 100 MCM of wastewater are being used for irrigation every year. Another 80 MCM will be used annually when the Dan Project is completed within a year. Present plans are to use all available sewage effluents for irrigation. Brackish water is used to irrigate tomatoes, peppers, industrial crops, forage, watermelons, eggplants, asparagus, cucumbers, corn, onions, dates, wheat, sorghum, grapes and rhodes grass. Treated wastewater is used to irrigate primarily cotton, and also citrus, field crops and fruit orchards. Under the existing regulations, vegetables that are eaten uncooked cannot be irrigated with wastewater unless special permission is obtained from the Ministry of Health, which specifies the effluent quality required.

Italy

In Italy the advanced biological treatment systems developed can produce effluents that are not only suitable for irrigation but also consistent with drinking water quality requirements. Wastewater from food-processing industries such as beet sugar or tomato processing is often reused, since heavy metals and micro-organisms are mostly absent. Wastewater can be used after mechanical removal of suspended solids. Wastewater from the galvanizing process at a telephone-equipment factory is treated and reused for the irrigation of cultivated land near Rome.

Soviet Union

Even though limited information is available from the Soviet Union on the use of treated wastewater for irrigation, calculations for the Ukraine show that wastewater could provide 15–20% of requirements, which would result in a saving of 20 million roubles per year. Irrigation with partially treated sewage effluents has shown marked increases in soybean and maize yields. Irrigation water supplied was consistent with soil and weather conditions and crop requirements.

German Democratic Republic

In the GDR higher yields of cereals, sugarbeet, potatoes and fodder crops were also observed when irrigated with wastewater as compared to rainfed large-scale farming. Similarly forage production was significantly increased when land was irrigated throughout the year with effluents compared to irrigation in the growing season only. The animals consuming the resulting forage did not suffer from any health problems. Effluents from sugar factories have been used for plant production since 1979. While initial results were somewhat disappointing, the situation improved markedly after some modifications were made.

Hungary

In Hungary approximately 200 MCM of marginal quality water are used per year, mainly for irrigating field crops, pastures and meadows, rice and poplars. Some problems have been observed, such as algae formation in flood irrigation of rice and development of secondary salinity. Irrigation of a 145 ha poplar plantation, through a buried pressure pipe which carried municipal sewage and poultry processing plant effluents, resulted in significant enrichment in terms of nutrients and trace elements. Studies indicate that such land treatment is highly effective and also economic, costing less than half the cost of artificial treatment. Grassland has been effectively irrigated for six years with 300 mm of wastewater annually from a fertilizer factory containing 300 mg N/l. Thermal water resources available in Hungary are generally of a low quality because of high salt contents and thus unsuitable for agriculture. However, such water has been used successfully to heat glasshouses (Pinter, Jolankai and Hargitai, 1987).

Czechoslovakia

In Czechoslovakia irrigation with wastewater containing N, P, K, Na, Ca and Mg, from a starch factory, is reported to have increased production of clover and grass.

Poland

In Poland a major effort is being made to utilize treated wastewater for plant production. It is expected that 10 million ha will be irrigated with such low-quality water by the year 2000. On the basis of experience thus far, no nutrient deficiency or salinity problems have been observed with irrigation from wastewater from breweries. On the contrary, it was found that soil fertility, measured in terms of plant yields, had improved, which increased plant production.

Plant, health and environmental implications

The use of marginal quality water has a considerable impact on plants, health and the environment. While some water quality degradation problems arise naturally, due to the presence of materials – such as salt – in the soil, most water quality degradation problems are manmade. Components that contribute to the degradation of water quality, the sources from which these pollution components originate – domestic and industrial wastewater, agriculture and atmospheric fallout and rainfall – and their relative importance in terms of water quality degradation are shown in Table 1.

Table 1. Origin of water quality degradation components.

Components	Domestic wastewater	Industrial wastewater	Agriculture	Atmospheric fallout and rainfall
BOD	1	1	1	2
Nitrogen	1	1	1	1
Phosphorus	1	1	1	1
Detergent	1	2	3	3
Phenols	2	1	3	3
Oil/grease	2	1	3	3
Chromium	1	1	3	3
Lead	1	1	3	3
Mercury	1	1	3	3
Zinc	1	1	3	3

Sources: Adapted from Henze (1987) and WHO (1977).
Legend: 1 Important; 2 Average; 3 Not important.

Impact of metals

Important health and environmental considerations arise from the fact that metals may be present in wastewater, from both municipal and domestic sources, that is subsequently used for irrigation. Typical concentrations of metals in domestic wastewater in developed countries are shown in Table 2.

The metals present in water can be broadly divided into two categories: those that can pose significant health hazards, and those that do not. Generally, five metals have the potential to become serious health hazards. These are cadmium, copper, molybdenum, nickel and zinc, and of these cadmium unquestionably could present the most serious health concern because of its tendency to accumulate in human and animal livers and kidneys. Cadmium, however, is not phytotoxic to plants at the concentration levels generally found.

While copper is necessary for both humans and plants, at higher concentrations it can be toxic to plants and thus reduce yields. At even higher concentrations it causes animal toxicity, especially in sheep. Nickel, on the other hand, can be phytotoxic to plants at around 50 mg/kg of plant tissues, but is relatively non-toxic to humans and animals. Molybdenum is generally not a problem to humans and plants, but can be toxic to farm animals, especially cattle. Zinc is relatively non-toxic to humans and animals but, like cadmium, its uptake by plants is greater when the pH is below 6.5.

Other metals that may be present in water are aluminium, antimony, arsenic, chromium, iron, lead, manganese, mercury and selenium. Some of these metals, such as aluminium, iron and manganese, may be present in appreciable quantities in natural soils, and other metals, such as arsenic, mercury and selenium, are present in such minute quantities in treated wastewater that no documented case exists where they have posed a health problem.

Aluminium, beryllium, copper, manganese and nickel may cause problems in acidic soils and can especially retard the optimal growth of vegetables (Möhler, 1987). Excessive iron concentrations may lead to clogging and also contribute to corrosion of irrigation equipment. Recommended maximum concentrations of metals in irrigation water and their potential impacts on soils and water are presented in Appendix 3 (Ayers and Westcot, 1985).

Table 2. Typical concentrations of metals in domestic wastewater in developed countries.

Components	Typical concentrations in ppm
Aluminium	400–1 000
Arsenic	2–5
Cadmium	2–5
Chromium	15–40
Cobalt	1–2
Copper	40–100
Iron	600–1 500
Lead	40–100
Manganese	60–150
Mercury	1–3
Nickel	15–40
Silver	4–10
Zinc	130–300

Sources: Based on Henze (1987), American Society of Civil Engineers (1977), Triebel (1975) and Andersen (1978).

Table 3. Maximum permissible cumulative loading of metals in kg/ha for agricultural land.

Country	Cd	Cu	Cr	Pb	Hg	Ni	Zn
France	5.4	210	360	210	2.7	60	750
Germany, FR	8.4	210	210	210	5.7	60	750
Netherlands	2.0	120	100	100	2.0	20	400
Sweden[a]	0.075	15	5	1.5	0.04	2.5	50
UK	5.0	280	1 000	1 000	2.0	70	560

Source: Biswas (1988).
[a] Five-year loading, but can be repeated.

An important consideration with regard to the presence of metals in marginal quality water is their cumulative loading. At present in many European countries there are maximum permissible cumulative loadings of metals to agricultural land areas. Table 3 shows the maximum permissible cumulative loadings of seven metals in five European countries. There is wide variation in the allowable cumulative values, even though, scientifically, health hazards posed at specific levels of concentrations of the metals in these countries are likely to be somewhat similar. These differences are perhaps due to the imprecise nature of the present state of knowledge on dose–response relationships and differing perceptions of ensuing risks.

Toxicity

Problems with toxicity may be a consideration if chloride, sodium and boron ions present in the marginal quality water or soil are accumulated by plants to concentrations high enough to cause crop damage and reduce yields. Crop damage occurs when the toxic ions are absorbed in significant amounts with the water taken up by roots. These ions then continue to move up to the leaves, where they accumulate during transpiration. The degree of accumulation of toxic ions and the resulting damage depends upon crop sensitivity, the extent of concentration of toxic ions, the duration of exposure and the volume of water transpired.

If marginal quality water is used through overhead sprinklers, toxicity can also result by direct absorption of the sodium and chloride ions through leaves. If the concentration of these toxic ions increases in the irrigation water, occurrences of crop damage become evident and such damage progressively increases. Toxicity often accompanies and aggravates salinity and water infiltration problems.

Toxicity should be carefully monitored in greenhouses, where water consumption through evapotranspiration is much higher than in open fields. Under many European conditions, irrigation water requirements in greenhouses can be five times greater than in the open field, depending upon the season when crops are grown, the length of the vegetation period, the type of plants and radiation intensity. Accordingly, the limiting values of different constituents in marginal quality water, as a rule, should be lower in greenhouses when compared to irrigation of open areas.

Salinity and sodicity

If marginal quality water contains salt, due to either natural or artificial causes, salinity and/or alkalinity development can be a problem. The suitability of application of such water for agricultural purposes depends on a variety of factors such as the total amount of salt present, type of soil, climate, cropping pattern and water management skills of the farmers. The continuing use of marginal quality water will depend upon the long-term salinity build-up potential of the soil.

Salinity problems reduce crop yields as salt accumulation increases in the root zone, due to which plants find it increasingly difficult to extract adequate quantities of water from the saline solution. This increases water stress, as a result of which plants display many of the same symptoms as when subjected to drought, since in both cases water consumption is appreciably reduced. Crop yields decline progressively.

Salinity problems can also be observed in waterlogged areas with shallow water tables within 2 m of the soil surface. Salts accumulate in the groundwater and frequently move up to the root zone. Appropriate leaching and drainage are keys to effective control of soil salinity.

The presence of salt in irrigation water can also have an impact on the infiltration characteristics of the soil. If the water used has high salinity, its rate of infiltration will increase. However, if salinity is low, or the relative proportion of sodium ions to calcium plus magnesium ions is high, the infiltration rate is reduced. If marginal quality water is to be used for plant production in greenhouses, special efforts should be made to ensure that salinity content and sodium concentrations are appeciably lower than those being used in open areas.

Microbiological considerations

If treated wastewater is to be used for plant production, potential microbiological contamination of air, soil and plants, and possible health hazards to consumers, both human and animal, become important considerations. Experience from Cyprus, Denmark, the Federal Republic of Germany, France, Israel and Italy suggests that the potential health impacts of wastewater irrigation are minimal, provided some simple precautions are taken.[1]

Municipal wastewater invariably contains a substantial number of disease-creating agents – bacteria, protozoa, viruses and helminths – that are prevalent within the community. These agents naturally have to be removed during the various treatment processes so that the resulting wastewater does not pose health risks to people working and living in the irrigated area and also to those people and animals that consume the crops produced. For estimating potential health hazards, four factors need to be considered. These are:

- maximum persistence of pathogens in the environment;
- minimum infective doses;
- host immunity; and
- possibilities of concurrent routes of infection.

On the basis of available experience, potential health risks from wastewater irrigation can be classified as follows:

Low risk: Enteric viruses having medium persistence (maximum weeks), low infective dose, lifelong immunity, and main route of infection is the home or by personal contact.

Medium risk: Enteric bacteria and protozoa having medium persistence (maximum weeks to months), medium to high infective dose (10^2 to 10^6 or more organisms), variable and transient immunity, and their main routes of infection are personal contact, food and water.

High risk: Helminths having high persistence (months), very low infective dose (one egg), no immunity, and main routes of infection lie outside the home.

Since, for environmental and health reasons, municipal wastewater in Europe has to be generally treated – irrespective of whether it is used for plant production or not – different degrees of pathogen removal are achieved depending upon the type of treatment process used. Table 4 shows the present status of bacteria and helminth removal by different treatment processes.

1. It should be noted, however, that the state of California (USA) currently requires wastewater-quality standards compatible with drinking water quality requirements, if sewage treatment plant effluents are to be used for irrigating vegetables. Furthermore, many private farmers in California have even rejected this stringent water quality requirement for irrigation because of the potential risk of specific or class-action litigation in the American courts.

Table 4. Estimated enteric pathogen removal by wastewater treatment (in $\log_{10}$ units).

Treatment	Viruses	Bacteria	Protozoa	Helminths
Primary sedimentation	0–1	0–1	0–1	0–1
Trickling filters	0–1	0–2	0–2	0–1
Septic tanks, Imhoff tanks or anaerobic ponds (1 to 2 days)	0–1	1–2	2–3	3–4
Activated sludge	1–3	1–3	1–3	1–3
Stabilization ponds (20 days–4 cells)	2–4	4–6	4–6	4–6

Source: Gunnerson (1986).

At a meeting of environmental scientists and epidemiologists at Engelberg, Switzerland, in July 1985, some guidelines were proposed for the microbiological quality of treated wastewater for use in plant production based on an epidemiological appraisal of actual health risks as opposed to potential risks (IRCWD, 1985). These guidelines, shown in Table 5, can be especially useful in Mediterranean Europe because of climatic conditions.

It is now generally accepted that through proper wastewater treatment, choice of cropping pattern, good irrigation management practices to ensure the least possible contact between people and pathogens in water, disinfection of agricultural products at the

Table 5. Microbiological quality guidelines for the use of treated wastewater.

Type of irrigation	Intestinal nematodes (geometric mean no of viable eggs per litre)	Faecal coliforms (geometric mean no per 100 ml)
Restricted irrigation[a]		
Irrigation of trees, industrial crops, fodder crops, fruit trees[b] and pasture[c]	< 1	Not applicable
Unrestricted irrigation		
Irrigation of edible crops, sports fields and public parks[d]	< 1	< 1000

[a] Minimum treatment equivalent to at least a one-day anaerobic pond followed by a five-day facultative pond or its equivalent is required in all cases.
[b] Irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground.
[c] Irrigation should cease two weeks before animals are allowed to graze.
[d] Local epidemiological factors may require a more stringent standard for public lawns, especially hotel lawns in tourist areas.

household level – traditionally by cooking – and monitoring, treated wastewater can be used safely for plant production.

Other environmental impacts

In addition to the environmental and health impacts already discussed earlier, the use of marginal quality water can have other environmental impacts. An important potential problem is the contamination of freshwater by the use of marginal quality water. The problem could be of special concern for groundwater and enclosed stationary water bodies, which when contaminated with hazardous chemicals or metals prove to be very difficult to purify, since corrective actions are expensive, complex and take considerable time.

Surface water contamination with unwanted pollutants will not only reduce its potential uses downstream but could also have a direct impact on aquatic life. It could reduce biological diversity, and species substitution may also take place. If commercial fishery is an important activity, toxic contamination of water can reduce both the overall catch and the percentage of game fish, which require a better quality of water.

If marginal quality groundwater is pumped for plant production, the groundwater table may be lowered unless pumping rates are carefully controlled. Lowering of the groundwater table in coastal areas may result in salt water intrusion, which can further reduce the prevailing water quality.

The use of marginal quality water may have some limited impact on air quality, especially when overhead sprinklers are used. When wind velocities are high, aerosols, which may be contaminated with micro-organisms, may spread into areas which are not being irrigated. Even under these conditions, however, aerosol contamination will only affect the micro-climate of a very small area.

It is worth noting that while marginal quality water can be used beneficially for agricultural production, agricultural practices in Europe can also contribute to water quality degradation, which could constrain potential uses of water. A major issue at present is the increasing nitrate concentrations of shallow groundwater resources, which are often the primary sources of drinking water in many rural regions of Europe. The rise in nitrate concentrations is generally due to agricultural activities. For example, it has been estimated that 50% of the nitrogenous fertilizers applied to land in the United Kingdom are available for leaching and denitrification (Pinter, Jolankai and Hargitai, 1987). Furthermore, annual nitrogen evaporation from manure and fertilizer amounts to 4.32 and 0.9 million tons respectively from 11 European countries – Belgium, Denmark, the Federal Republic of Germany, France, the German Democratic Republic, Greece, Ireland, Italy, the Netherlands, Norway and the United Kingdom. The annual rate of evaporation ranges from a low of 1 kg/ha in Norway to a high of 32 kg/ha in the Netherlands (Henze, 1987). While the nitrogen concentration in drinking water is an important health issue in Europe, such concentration levels are beneficial rather than adverse in terms of plant production, and accordingly are not discussed further in this paper.

Research on the use of marginal quality water

Much research has ben carried out in various European countries during the past two decades on the use of low-quality water for plant production and other beneficial purposes. Currently numerous research projects are directed towards the treatment of marginal quality water – especially domestic and industrial wastewater – in order to reduce potential health hazards. The main thrusts of many of these research projects have been to determine the potential health hazards of numerous chemicals that find their way into industrial wastewater, and the determination of cost-effective methods for their removal. With the ever-increasing number of chemicals that are being marketed, such research projects will continue to be important in the future. Since many of the pollutants are present in wastewater in minute quantities, their accumulation in soil, and then through the food chain to humans, may take a long time. An even longer time may be necessary to determine the potential impact on human and animal health with some degree of confidence. Thus research on many of these issues has to be considered a long-term process.

Many research and development projects are now being carried out in the field in several countries such as Cyprus, Portugal and Spain on the interlinkages between the use of marginal quality water on soil fertility and the yield responses of various crops, especially when irrigation is practised on a long-term basis with different types of marginal quality water. The potential of nitrate build-up in groundwater and streams near the irrigation sites due to long-term use of treated wastewater is a problem of concern. Research is under way to determine more cost-effective ways of preventing such nitrate enrichment of water sources.

Some research is being undertaken on how best to determine the most appropriate irrigation and flow regimes that are consistent with maximizing plant production and minimizing adverse impacts on soil fertility, health and the environment. Attempts are also being made to develop and introduce new species of plants which can be grown more effectively through irrigation with marginal quality water. Ways of preventing the clogging of drippers by sewage effluents through different management techniques such as filtering and the treatment of water in storage reservoirs are also receiving some attention. Potential adverse impacts such as soil clogging, changes in soil micro-flora and eutrophication of water bodies are also receiving some attention.

Effective treatment of agricultural wastes, including agricultural wastewater from animal farms, is another important research area. The feasibility of directly using both solid waste and liquid waste is being investigated. The main problem is the risk of transmitting parasites.

An important aspect of the use of marginal quality water for plant production is the possibility of groundwater contamination with undesirable pollutants. Since cleaning of groundwater aquifers once they are polluted is a difficult, expensive and time-consuming process under the best of circumstances, the preferred alternative has to be the prevention of contamination. Further basic and applied research is necessary to preserve and/or improve the quality of groundwater from serious contamination due to the use of marginal quality water. In addition to research, improved legal and regulatory alternatives may need to be instituted in some countries.

Conclusions

While water quality degradation and its overall impact on the environment had been an area of major concern in Europe in recent years, less attention has been paid to the various aspects of the use of marginal quality water for plant production.

On the basis of the present analysis, it is clear that overall the issue of marginal quality water use in Europe is not a serious problem. It is equally clear that the existence of marginal quality water is a localized problem in most European countries, and the magnitude of this problem, even though localized, may vary significantly from one European country to another.

Increasing attention is being paid to marginal quality water for two reasons. First, as the demand for water increases, there is a perceived need to use this low-quality water beneficially. Especially in the drier regions of Europe, the use of marginal quality water for plant production could be a viable alternative to new sources of irrigation water. Second, with environmental awareness and regulatory requirements, domestic and industrial wastewater can be treated to improve quality and provide a useful source of water for supplementary irrigation.

Technologies are available for treating wastewater, and for its safe application to irrigation areas, even though in some instances further developments may be necessary to make them more advanced as well as cost-effective. Knowledge of the efficacy of land as an additional means of waste treatment has improved tremendously during the past two decades, and so has the state-of-the-art of the linkages between potential health hazards and the use of marginal quality water for plant production. Based on existing knowledge and experience from various European countries, it can now be stated with considerable confidence that marginal quality water can be safely used for plant production, provided certain precautions are taken to protect health and the surrounding environment.

References

Ayers, R. S. and D. W. Westcot (1985). *Water Quality for Agriculture,* Irrigation and Drainage Paper 29, Rev 1, FAO, Rome.

American Society of Civil Engineers (1977). *Wastewater Treatment Plant Design,* Manuals and Reports of Engineering Practice No 36, ASCE, New York.

Andersen, L. (1978). *Pollutants in Domestic Wastewater* (in Swedish), Report SNW PM 1103, Statens Natureärdsvesk, Stockholm.

Biswas, Asit K. (1988). 'Role of Wastewater Reuse in Water Planning and Management', in A. K. Biswas and A. Arar (eds), *Treatment and Reuse of Sewage Effluents for Irrigation,* Butterworth Scientific, Guildford.

Bize, J., D. Fougeirol, V. Riou and N. Nireault (1985). 'Soil Aquifer Treatment and Re-use of Sewage Effluent: A New Approach to Sanitation', *Proceedings,* FAO Regional Seminar on the Treatment and Re-use of Sewage Effluents for Irrigation, Nicosia, Cyprus, 7–9 October 1985.

Federal Republic of Germany, Ministry of Food, Agriculture and Forestry (1987). Information contained in the FAO Questionnaire Survey on the Use of Marginal Quality Water for Plant Production in European Countries.

Gunnerson, C. (1986). *Wastewater Management for Coastal Cities: Wastewater Disposal and Reclamation Options,* World Bank, Washington, DC.

Henze, M. (1987). 'Water Quality Problems in Rural Areas of Europe and Possibilities for Utilizing Low Quality Water for Agricultural Production', Report to Land and Water Development Division, FAO, Rome.

Jewell, W. J., and B. L. Seabrook (1979). *A History of Land Application as a Treatment Alternative,* Report EPA 430/9–79, Environmental Protection Agency, Washington, DC.

IRCWD (1985). 'Health Aspects of Wastewater and Excreta Use in Agriculture and Aquaculture: The Engelberg Report', *IRCWD News,* No 23, pp 11–18.

Kayser, R. (1985). 'The Use of Biologically Treated Wastewater Together with Excess Sludge for Irrigation', *Proceedings,* FAO Regional Seminar on the Treatment and Re-use of Sewage Effluents for Irrigation, Nicosia, Cyprus, 7–9 October 1985.

Mara, D. (1987). 'Water Quality Problems in Rural Areas of Europe and Possibilities for Using Low Quality Water for Agricultural Production', Report to Land and Water Development Division, FAO, Rome.

Möhler, G. (1987). 'Water Quality Problems in Rural Areas of Europe and Possibilities for Utilizing Low-Quality Water for Agricultural Production', Report to Land and Water Development Division, FAO, Rome.

Montgomery, H. A. C., M. J. Beard and K. M. Baxter (1984). 'Effects of the Recharge of Sewage Effluents upon the Quality of Chalk Groundwater', *Water Pollution Control,* Vol 83, pp 349–363.

Pinter, G. G., G. Jolankai and F. Hargitai (1987). 'Water Quality Problems in Rural Areas of Europe and Possibilities for Utilizing Low Quality Water for Agricultural Production', Report to Land and Water Development Division, FAO, Rome.

Tietjen, C., A. Bramm and H. O. Fleer (1978). 'Land Treatment of Wastewater in Braunschweig and in Wolfsburg, Germany', in *State of Knowledge in Land Treatment of Wastewater,* Vol 1, Proceedings of an International Symposium, Hanover, NH, 20–25 August 1978.

Triebel, W. (ed) (1975). *Lehr- und Handbuch der Abwassertechnik,* Vol II, Verlag von Wilhelm Ernst & Sohn, Berlin.

WHO (1977). *Report on a Study of Municipal Sources of Pollutants Discharged into the Mediterranean Sea,* WHO Regional Office for Europe, Copenhagen.

Appendix 1

Table 6. Guidelines for the interpretation of water quality for irrigation.

Potential irrigation problem		Unit	Degree of restriction on use None	Slight to moderate	Severe
Salinity (affects crop water availability)[a]					
EC_w		dS/m	<0.7	0.7–3.0	>3.0
or					
TDS		mg/l	<450	450–2 000	>2 000
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together.)[b]					
SAR = 0–3	and EC_w =		>0.7	0.7–0.2	<0.2
= 3–6	=		>1.2	1.2–0.3	<0.3
= 6–12	=		>1.9	1.9–0.5	<0.5
= 12–20	=		>2.9	2.9–1.3	<1.3
= 20–40	=		>5.0	5.0–2.9	<2.9
Specific ion toxicity (affects sensitive crops)					
Sodium (Na)					
surface irrigation		SAR	<3	3–9	>9
sprinkler irrigation		me/l	<3	>3	
Chloride (Cl)					
surface irrigation		me/l	<4	4–10	>10
sprinkler irrigation		me/l	<3	>3	
Boron (B)		mg/l	<0.7	0.7–3.0	>3.0
Trace elements					
Miscellaneous effect (affects susceptible crops)					
Nitrogen (NO_3–N)		mg/l	<5	5–30	>30
Bicarbonate (HCO_3) (overhead sprinkling only)		me/l	<1.5	1.5–8.5	>8.5
pH				Normal range 6.5–8.4	

Source: Ayers and Westcot (1985).

[a] EC_w means electrical conductivity, a measure of the water salinity, reported in deciSiemens per metre at 25°C (dS/m) or in millimhos per centimetre (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per litre (mg/l).

[b] SAR means sodium adsorption ratio. SAR is sometimes reported by the symbol RNa. At a given SAR, infiltration rate increases as water salinity increases. Evaluate the potential infiltration problem by SAR as modified by EC_w.

Appendix 2

Wastewater utilization in Braunschweig: a case study

Even though use of marginal quality water is not a serious problem in the Federal Republic of Germany, considerable experience is available in the country on the use of low-quality water, especially treated wastewater for plant production. Tables 7 and 8 show the use of sewage and treated wastewater for agriculture at the end of 1982 (FRG, 1987).

A noteworthy example of wastewater utilization for plant production is in Braunschweig in Northern Germany, where it has been used since 1954. The system has subsequently been modernized to irrigate some 3 000 ha. The city has a population of 325 000. Some 55 000 m^3/d of wastewater are treated in aerated lagoons and secondary sedimentation tanks. Subsurface asbestos cement pipes (300–500 mm in diameter, 100 km in length) are used to transport by gravity 44 500 m^3/d of wastewater, which includes 5 100 m^3/d of unthickened excess sludge and 5 000 m^3/d of raw wastewater from villages near the irrigated area. The irrigated area is divided into four districts, each with its individual pumping stations and wastewater balancing tank.

Table 7. Spreading with sewage in the Federal Republic of Germany as of 31 December 1982.

Federal state	Number of sewage farms	Spreading area (ha)	Water consumption (m^3)
Niedersachsen	19	280	28 000
Nordrhein-Westfalen	60	219	1 718 000
Rheinland-Pflaz	3	13	33 000
Total	82	512	1 779 000

Note: States not mentioned have negligible use.

Table 8. Irrigation with wastewater in the Federal Republic of Germany as of 31 December 1982.

Federal state	Number of sewage farms	Spreading area (ha)	Water consumption (m^3)
Niedersachsen	539	10 667	8 244 400
Nordrhein-Westfalen	104	1 079	3 221 000
Hessen	50	700	600 000
Bayern	375	1 687	1 217 000
Total	1 068	14 133	13 282 400

Note: States not mentioned have negligible use.

The earlier manually movable sprinkler system has been replaced by self-movable machines with flexible polyethylene plastic pipes. One hundred such machines are used to irrigate the area. The sprinklers have 20 mm nozzle diameter, and spread wastewater over a 60 m diameter circle at a delivery rate of up to 45 m^3 per hour. About 20 hours are required to apply 50 mm of wastewater on a 300 m × 60 m area. Normally about 50 to 60 machines are in operation, but in the summer season, when crop water demands are the highest, all of the 100 sprinklers may be in use.

Since there are no storage facilities and the daily flow of wastewater during the dry summer season is insufficient to meet crop water requirements, groundwater is extracted from installed wells to supplement the flow. The treated wastewater is sprinkled in six applications of 50 mm each, three in summer and three in winter. Water applications for various crops are as follows:

- potatoes : 2 applications of 30 mm
- winter grain; spring barley : 3 applications of 50 mm
- oats : 4 applications of 50 mm
- spring wheat; sugarbeets : 5 applications of 50 mm

The cropping pattern for the irrigated area is 29% winter grain, 22% summer grain, 25% sugarbeets, 8% grassland, 6% potatoes and 10% others.

On average, the Braunschweig Wastewater Utilization Association (BWUA) irrigates 2 800 ha of land with about 44 500 m^3 of wastewater per day, which is equivalent to an annual application rate of 578 mm. At this rate the annual nutrient loads in kg/ha are: nitrogen – 379, calcium – 305, phosphorus – 106, potassium – 105, and magnesium – 53. The soil is light and very permeable, and accordingly additional potassium and nitrogen fertilizers are used. In terms of crop yields in kg per ha, averages since 1979 have been as follows: winter grain – 600 to 1 600, summer grain – 600 to 2 000, sugarbeets – 500 to 2 400, and potatoes – 500 to 2 000.

The wastewater irrigation project is operated and managed by the BWUA, whose members are the city of Braunschweig and some 440 farmers who own land in the irrigated area. The staff of the BWUA are responsible for the operation of the entire wastewater irrigation project. The BWUA has

Table 9. Water quality (mg/l) in and around the Braunschweig treatment wastewater use area.

	Treated wastewater[a]	Oker river[a, b]	Erse river[a, b]	Groundwater inside[c] the irrigation area	Groundwater outside[d] the irrigation area
Ammonium-nitrogen	49.0	7.0	14.2	2.8	2.9
Nitrate-nitrogen	0.2	8.4	7.0	30.0	8.7
Phosphorus	13.0	0.9	0.7	0.5	0.4
Potassium	32.0	11.0	55.0	33.0	85.0
Iron	2.0	1.2	0.8	12.0	8.3
Zinc	0.9	0.6	0.5	0.4	0.7
Copper	0.15	0.03	0.04	0.06	0.05
Manganese	0.3	0.4	0.9	1.7	2.1
Cobalt	0.2	0.12	0.27	0.14	0.19
Cadmium	0.02	0.01	0.02	0.01	0.02
Lead	0.04	0.02	0.03	0.07	0.04

Source: Tietjen *et al* (1978).
[a] Values given are an average of 12 or more samples.
[b] Samples taken before the rivers reach the irrigation area.
[c] Values given are an average of 242 wells.
[d] Values given are an average of 58 wells.

instituted strict management practices to minimize potential health and environmental risks. With a mild climate, good rainfall and over-application of irrigation water, salinity has not been a problem, but liming has been necessary to maintain an appropriate pH balance (Kayser, 1985).

The Oker and Erse rivers flow around the reuse area. Table 9 shows the quality of groundwater within and outside the irrigated area and the water qualities of the Oker and the Erse. It indicates that nitrate concentration in groundwater is of some concern. Heavy metal or toxic chemical accumulation in water or soil has not been a problem thus far, but manganese, cobalt and cadmium concentrations are worth watching in the future.

The BWUA prohibits the growing of vegetables and fruits in the reuse area, and irrigation has to be stopped three weeks prior to the harvesting of crops. To prevent pathogen dispersion in form of aerosols to the neighbouring area, 10 m wide hedges are stipulated along the borders of the irrigated area, which must be at least 50 m from public roads and 100 m from houses. Low-level sprinklers must be used within 115 m of public roads and only when the wind direction is from the road to the irrigated area. So far no health and environmental problems have been encountered, with the exception of nitrate concentration in groundwater which is causing some concern.

If the scheme is analysed from a purely agricultural viewpoint, it is not economic since operating costs at DM7.9 million per year are high.[2] One reason for such high operating costs is the high energy requirement of 0.5 kWh per m^3 of wastewater treatment and irrigation, amounting to some 8 million kWh per year. Farmers currently pay 5% of the cost, at a rate of DM120 per ha of irrigated land, and the balance of 95% is borne by the city of Braunschweig. However, Braunschweig can justify the project from a total systems viewpoint, since it serves also as both an advanced tertiary wastewater treatment system and an effective and beneficial sludge disposal system.

2. Exchange rate at 9 March 1988: $1.00 = DM1.668.

Appendix 3

Table 10. The impact of metals in irrigation water on soil and biota.

Metal	Recommended maximum concentration	Impact on soils and biota
Aluminium (Al)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
Beryllium (Be)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cadmium (Ca)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Cobalt (Co)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Chromium (Cr)	0.20	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Copper (Cu)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
Iron (Fe)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Lithium (Li)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (< 0.075 mg/l). Acts similarly to boron.
Manganese (Mn)	0.20	Toxic to a number of crops at a few tenths to a few mg/l, but usually only in acid soils.
Molybdenum (Mo)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Nickel (Ni)	0.20	Toxic to a number of plants 0.5 to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Lead (Pb)	5.0	Can inhibit plant cell growth at very high concentrations.
Selenium (Se)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
Vanadium (V)	0.10	Toxic to many plants at relatively low concentrations.
Zinc (Zn)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine-textured or organic soils.