5. MISCELLANEOUS PROBLEMS

5.1 EXCESS NITROGEN

Nitrogen is a plant nutrient and stimulates crop growth. Natural soil nitrogen or added fertilizers are the usual sources, but nitrogen in the irrigation water has much the same effect as soil-applied fertilizer nitrogen and an excess will cause problems, just as too much fertilizer would. If excessive quantities are present or applied, production of several commonly grown crops may be upset because of over-stimulation of growth, delayed maturity or poor quality.

The most readily available forms of nitrogen are nitrate and ammonium but nitrate (NO_3-N) occurs most frequently in irrigation water. Ammonium-nitrogen is seldom present in excess of 1 mg/l unless ammonia fertilizer or wastewater is being added to the water supply. The concentration in most surface and groundwater is usually less than 5 mg/l NO_3-N but some unusual groundwater may contain quantities in excess of 50 mg/l. Drainage water from below the root zone frequently has higher levels of nitrogen due to deep leaching of fertilizers. Since nitrogen is present in so many water supplies, it is recommended that the nitrogen content of all irrigation water be monitored and the nitrogen present included as an integral part of the planned fertilization programme. Wastewater, especially from food processing and domestic sources, is known to be high in nitrogen with values ranging from 10 to 50 mg/l (1 mg/l NO_3-N = 1 kg N/1000 m^3 of water).

There are many ways of reporting nitrogen since it is combined in various organic and inorganic complexes. The most important factor for plants is the total amount of nitrogen (N) regardless of whether it is in the form of nitrate-nitrogen (NO_3-N), ammonium-nitrogen (NH_4-N) or organic-nitrogen (Org-N). By reporting in the form of nitrogen, comparisons can be made. For example, NO_3-N means nitrogen in the form of NO_3 while NH_4-N means nitrogen in the form of NH_4 reported as N in mg/l (10 mg/l N = 45 mg/l NO_3 = 13 mg/l NH_4, but each should be reported as 10 mg/l NO_3-N or 10 mg/l NH_4-N). In the guidelines of Table 1, it is reported as nitrogen in the form of nitrate (NO_3-N) because this is the usual form found in natural water.

Sensitive crops may be affected by nitrogen concentrations above 5 mg/l. Most other crops are relatively unaffected until nitrogen exceeds 30 mg/l. For example, sugarbeets, a sensitive crop, increase in size with excessive nitrogen fertilization but the sugar content and sugar purity are lower, thus the total quantity of recoverable sugar produced per hectare may actually be reduced. Grapes are also sensitive and may continue to grow late into the season at the expense of fruit production. Yields are often reduced and grapes may be late in maturing and have a lower sugar content. Experience in Libya indicated that almost no fruiting occurred in grapes when a water containing >50 mg/l of N was used continuously. Maturity of fruit such as apricot, citrus and avocado may also be delayed and the fruit may be poorer in quality, thus affecting the marketability and storage life. In many grain crops, excessive vegetative growth produces weak stalks that cannot support the grain weight, resulting in severe lodging and difficulties for machine harvesting. Lodging is especially serious in areas with high winds or periodic heavy rains. The new short-stature wheats are better adapted and are heavily fertilized without severe lodging. Ruminant animals are sensitive to nitrogen and heavy applications to pastures used for direct or indirect livestock feed may cause excessive quantities to accumulate in the forage. This may be hazardous to the animals' health.

The sensitivity of crops varies with the growth stage. High nitrogen levels may be beneficial during early growth stages but may cause yield losses during the later flowering and fruiting stages. High nitrogen water can be used as a fertilizer early in the season. However, as the nitrogen needs of the crop diminish later in the growing season, the nitrogen applied to the crop must be substantially

reduced. Blending or changing supplies during the later more critical growth stages should be helpful. Another option is to plant a less sensitive crop, such as maize, which can utilize the nitrogen from the irrigation water more effectively. For crops irrigated with water containing nitrogen, the rates of nitrogen fertilizer supplied to the crop can be reduced by an amount very nearly equal to that available from the water supply. Crop rotations can be planned to utilize residual nitrogen in the soil during the non-irrigation season. This may also be helpful in reducing the impact in succeeding years.

Less than 5 mg/l N has little effect, even on nitrogen sensitive crops, but may stimulate nuisance growth of algae and aquatic plants in streams, lakes, canals and drainage ditches. Very rapid growth of algae can occur when temperature, sunlight and other nutrients are optimum, and may result in plugged valves, pipelines and sprinklers requiring either mechanical controls such as screens and filters, or chemical control, with materials such as copper sulphate. Nitrogen in water also increases maintenance costs for clearing vegetation from canals and drainage channels.

Denitrification to remove NO_3-N from the water supply before use may be the only other alternative but is not used because of the high cost of equipment and energy. Since nitrogen is a valuable resource it should be utilized if possible.

5.2 ABNORMAL pH

pH is an indicator of the acidity or basicity of a water, but is seldom a problem by itself. The main use of pH in a water analysis is for detecting an abnormal water. The normal pH range for irrigation water is from 6.5 to 8.4. An abnormal value is a warning that the water needs further evaluation. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion.

Low salinity water (ECw < 0.2 dS/m) sometimes has a pH outside the normal range since it has a very low buffering capacity. This should not cause undue alarm other than to alert the user to a possible imbalance of ions and the need to establish the reason for the adverse pH through full laboratory analysis. Such water normally causes few problems for soils or crops but is very corrosive and may rapidly corrode pipelines, sprinklers and control equipment.

Any change in the soil pH caused by the water will take place slowly since the soil is strongly buffered and resists change. An adverse pH may need to be corrected, if possible, by the introduction of an amendment into the water, but this will only be practical in a few instances. It may be easier to correct the soil pH problem that may develop rather than try to treat the water. Lime is commonly applied to the soil to correct a low pH and sulphur or other acid material may be used to correct a high pH. Gypsum has little or no effect in controlling an acid soil problem apart from supplying a nutritional source of calcium, but it is effective in reducing a high soil pH (pH greater than 8.5) caused by high exchangeable sodium.

The greatest direct hazard of an abnormal pH in water is the impact on irrigation equipment. Equipment will need to be chosen carefully for unusual water (see Section 5.8).

5.3 SCALE DEPOSITS

Irrigation water containing a high proportion of slightly soluble salts such as calcium, bicarbonate and sulphate presents a continual problem of white scale formation on leaves or fruit when sprinklers are used. Although there is no toxicity involved, the deposits often build up on the leaves and fruit and are of special concern when flowers, vegetables or fruits are grown for the fresh market. The deposit reduces the marketability of fruit and foliage and, in the case of fruit like apples and pears, requires an expensive treatment (acid wash) before marketing. (Small drip emitters are also subject to deposits accumulating near small openings, resulting in clogging. This clogging problem is covered in Section 5.7.)

The principal problem is caused by calcium in combination with bicarbonate and occasionally with sulphate (gypsum). Deposits form even at very low concentrations if sprinklers are used during periods of very low humidity (less than 30 percent), resulting in a high rate of evaporation. Between rotations or cycles of certain sprinkler types, the droplets left on the leaves partially evaporate to concentrate the salts. If the concentration is great enough, the less soluble salts such as lime ($CaCO_3$) and gypsum ($CaSO_4$) will precipitate and once precipitated will not readily re-dissolve during subsequent wettings as the sprinkler rotates. Deposits then begin to build up. These may become a serious problem with certain water when newer types of sprinkler systems are used that apply light, frequent applications or have high pressure which presents a hazard from drift to adjacent areas.

Management options to prevent or correct a deposit problem will depend upon the concentration and the irrigation method. One technique is to add an acid material to the water supply to reduce the bicarbonate, which should in turn reduce the lime precipitate. This has been used for special ornamental and foliage crops grown in the greenhouse. One recommendation has been to add sulphuric acid to 90 percent of the HCO_3 equivalent (personal communication, Rhoades 1976). The acidifying effects of sulphuric acid are immediate, but the acid is difficult and hazardous to handle and application is normally made on a contract basis by experienced people. With the high level of skill needed for application, such an operation will most likely be costly and restricted to high income crops. As with any acid material, the low pH may cause damage to pipelines, sprinklers and other equipment, and careful choice of resistant materials will be necessary or pH must be carefully controlled. A pH not less than pH 6.5 seems to be safe for sprinklers.

An alternative approach might be to change the design and operation of the sprinkler system. This will probably not solve the problem but may minimize it so as to make the product more marketable. The same steps taken to reduce toxicity effects (leaf absorption) due to sprinkler irrigation will also reduce deposits on leaves and fruit (see Section 4.3). The most useful measures are:

- irrigate at night

- increase the speed of sprinkler rotation or use spray heads

- decrease the frequency of irrigation.

These management steps may reduce the problem but they must be cost efficient. Under some circumstances, it may be more economical to change to an alternative form of irrigation which keeps the water off fruit and foliage.

5.4 MAGNESIUM PROBLEMS

Soils containing high levels of exchangeable magnesium are often thought to be troubled with soil infiltration problems. The role of magnesium in causing or partly causing these problems is not well documented but researchers from several irrigated areas have studied the problem. At present there is reasonably good agreement that magnesium acts on soils in a way which is more like calcium than sodium, and that it is preferentially adsorbed by the soil to a much greater degree than sodium but to a slightly less degree than calcium.

In a magnesium dominated water (ratio of Ca/Mg < 1) or a magnesium soil (soil-water ratio of Ca/Mg < 1), the potential effect of sodium may be slightly increased. In other words, a given SAR value will show slightly more damage if the Ca/Mg ratio is less than 1. The lower the ratio, the more damaging is the SAR. Research findings show that at a given SAR of the applied water, a higher soil ESP than normal will result when using a water with a Ca/Mg ratio less than 1 (Rahman and Rowell 1979).

One concern, however, is that productivity is sometimes reported to be low on high magnesium soils or on soils being irrigated with high magnesium water even though infiltration problems may not be evident. The effect may be due to a magnesium-induced calcium deficiency caused by high levels of exchangeable magnesium in the soil. Some research evidence shows that yields of crops such as barley, wheat, maize and sugarbeets are reduced when the Ca/Mg ratio in soil-water is less than one. The function of calcium in plants is not totally understood, but calcium appears to reduce possible toxicities due to other ions (Na, Mg) in the root environment. If the Ca/Mg ratio is near or less than 1, the uptake and translocation of Ca from soil-water to the above-ground parts of the growing crop is diminished due to antagonistic effects of high magnesium or competition for absorption sites to such an extent that less calcium is absorbed. A calcium deficiency may then be experienced at a higher calcium concentration in the applied water or in soil-water than would occur if the Ca/Mg ratio were higher. Although not definitely confirmed, it can be anticipated that irrigation water with a similar ratio (Ca/Mg < 1) will produce a similar effect if a readily available source of calcium is not present in the soil.

Other limited research indicates that the ratio of calcium to total cations in the soil-water may also be critical. A calcium to total cation ratio of 0.10 – 0.15 or greater has been mentioned as needed for optimum root growth of barley and cotton.

There are insufficient data to make either the Ca/Mg ratio or the calcium to total cation ratio an evaluation factor when judging the suitability of a water for irrigation, but if an irrigation water is being used that has a Ca/Mg ratio less than one, or a calcium to total cation ratio less than 0.15, a further evaluation is needed. Although no conclusive recommendations can be made, such water may pose a

potential problem related to plant nutrition and an evaluation may be needed to determine if a readily available source of soluble calcium exists in the soil or whether further studies are needed to determine if calcium should be added as a fertilizer or soil amendment.

Additional references include: Paliwal and Gandhi (1976); Koenigs and Brinkman (1964); Howard and Adams (1965); Simpson **et al**. (1979); Carter and Webster (1979); Ulrich and Mostafa (1976); Fong and Ulrich (1970).

5.5 TRACE ELEMENTS AND THEIR TOXICITY

5.5.1 Natural Occurrence in Water

Trace elements occur in almost all water supplies but at very low concentrations, usually less than a few mg/l with most less than 100 micrograms per litre (μg/1). They are not often included in a routine analysis. Surface water normally contains lower concentrations than groundwater, but this is variable and no general guidelines can be given. As a rule of thumb, irrigation water supplies do not need to be checked for trace elements unless there is some reason to suspect toxicity. In almost all cases where trace elements are at high levels, they are the result of man's activities, particularly wastewater disposal. Any project using wastewater should check for trace elements.

5.5.2 Toxicities

Not all trace elements are toxic and in small quantities many are essential for plant growth (Fe, Mn, Mo, Zn). However, excessive quantities will cause undesirable accumulations in plant tissue and growth reductions. There have been few field experiments from which toxic limits could be established, especially for irrigation water. However, research dealing with disposal of wastewater has gained sufficient experience to prove useful in defining limitations. It is now recognized that most trace elements are readily fixed and accumulate in soils, and because this process is largely irreversible, repeated applications of amounts in excess of plant needs eventually contaminate a soil and may either render it non-productive or the product unusable. Recent surveys of wastewater use have shown that more than 85 percent of the applied trace element accumulates in the soil and most accumulates in the surface few centimetres (Figure 23). Although plants do take up the trace elements, the uptake is normally so small that this alone cannot be expected to reduce appreciably the trace element in the soil in any reasonable period of time.

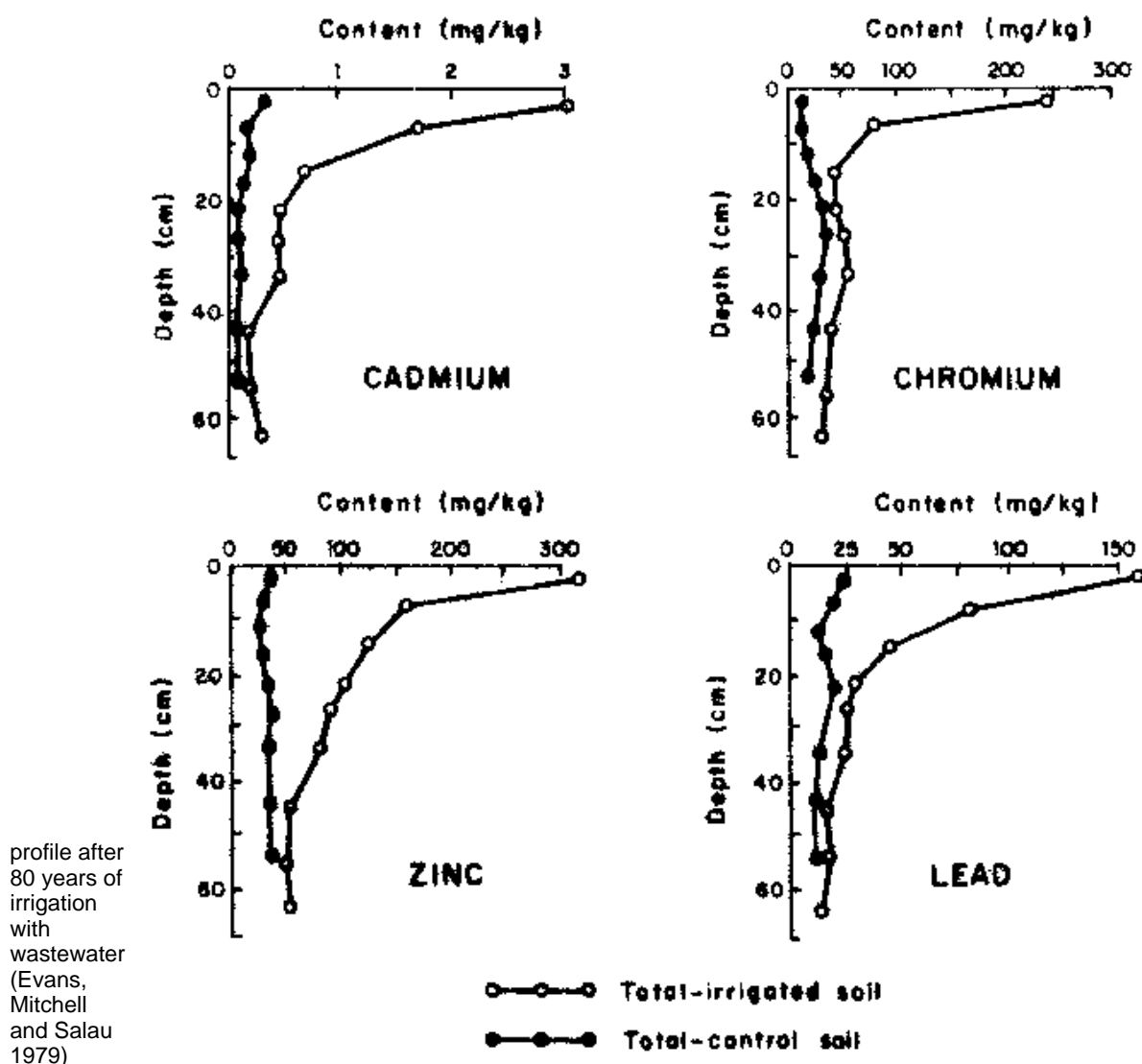Fig. 23
Heavy
metal
content of
the soil

profile after 80 years of irrigation with wastewater (Evans, Mitchell and Salau 1979)

Table 21 RECOMMENDED MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS IN IRRIGATION WATER[1]

Element	Recommended Maximum Concentration[2] (mg/l)	Remarks
Al(aluminium)	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.
As (arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Be (beryllium)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd (cadmium)	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.
Co (cobalt)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr (chromium)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu (copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
F (fluoride)	1.0	Inactivated by neutral and alkaline soils.
Fe (iron)	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.
Li (lithium)	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.
Mn (manganese)	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Mo (molybdenum)	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.
Ni (nickel)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd (lead)	5.0	Can inhibit plant cell growth at very high concentrations.
Se (selenium)	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.
Sn (tin)		
Ti (titanium)	----	Effectively excluded by plants; specific tolerance unknown.
W (tungsten)		
V (vanadium)	0.10	Toxic to many plants at relatively low concentrations.
Zn (zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

[1] Adapted from National Academy of Sciences (1972) and Pratt (1972).

[2] The maximum concentration is based on a water application rate which is consistent with goodirrigation practices (10 000 m^3 per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m^3 per hectare per year. The values given are for water used on a continuous basis at one site.

5.5.3 Evaluation Criteria

With the high retention rate in the soil and the low use by plants, ideally the maximum application rate should not exceed that which will allow normal crop growth and still not exceed any allowable concentration in the produce coming from the field. Suggested maximum concentrations of trace elements in irrigation water are shown in Table 21. These concentrations are set because of concern for long-term build-up of trace elements in the soil and for protection of the agricultural soil resource from irreversible damage. Under normal irrigation practices, these suggested levels should prevent a build-up that might limit future crop production or utilization of the product. Whether wastewater is used as all or only a part of the supply will not modify these guidelines as they are based on protection of the soil resource to assure its present and future production capability.

The guidelines reflect the current information available but as they are supported by only limited, long-term field experience, they are necessarily conservative, which means that, if the suggested limit is exceeded, a phytotoxicity still may not occur. The suggested limits in Table 21 are to ensure that the site can be used for all potential crops in the future. It is recommended that the values be considered as the maximum long-term average concentration based upon normal irrigation application rates. When more reliable data become available, the levels may be adjusted. If water above or close to the levels given in Table 21 is considered for use, an up-to-date review of more recent information is suggested to prevent possible future problems.

5.6 NUTRITION AND WATER QUALITY

Water quality has been discussed in this paper based upon four different effects on crops or soils: salinity, reduced water infiltration, toxicity, or effects related to a group of miscellaneous water constituents. These effects sometimes cause nutritional imbalances or interactions which result in nutritional imbalances.

5.6.1 Nutrition and Salinity

Excessive salinity stunts the crop by reducing the availability of soil-water, slowing crop growth and restricting root development. With higher salinity water, sodium and chloride toxicity are also likely to be

evident. As long as the crop is well supplied with fertilizer elements, application of extra nutrients to combat the salinity effects will not improve yield. However, if nutrients such as nitrogen are in short supply, raising the nutrient level will usually improve yield. Saline areas in the field are normally dark green to blue-green, indicating that they are well supplied with nitrogen. If yellow, additional nitrogen should improve yield.

Most fertilizers, however, are water soluble salts and placement and rates of use must take into consideration their potential salinity impact. (See Table 9 for relative salinity of representative fertilizers.)

Plant tissue analysis for an annual crop is useful to confirm the presence or absence of a calcium deficiency. For example, with potato, petioles or leaf material from the most recent fully-formed leaves are normally used. Calcium (dry weight basis) below 0.15 percent is probably indicative of a calcium deficiency, while values in the range of 0.15 to 0.20 percent may be suspect. Table 11 may also be used to predict a probable calcium deficiency through the Cax value. Cax values less than about 1 me/l are often associated with deficiency.

The ratio of Ca/Mg or calcium to total cations (Ca/TC) in the soil-water may also be used to predict a potential calcium deficiency. There are reports that Ca/Mg ratios less than 1 or Ca/TC less than 0.15 are sometimes associated with calcium deficiencies (Ca, Mg and TC in me/l) (see Section 5.4).

5.6.2 Water Infiltration Problems and Nutrition

A severe reduction in water infiltration rate due to water quality is usually related to either very low water salinity or to a high sodium adsorption ratio (SAR). In either case, the calcium content of the water may be at a relatively low concentration. If the calcium in the soil-water taken up by the crop is less than 2 me/l, there is a strong probability that the crop yield will be reduced due to a calcium deficiency (Rhoades 1982). A potential evaluation technique is to use the Cax values in Table 11 to prevent a possible calcium deficiency. Irrigation water for which a predicted equilibrium soil-water calcium (Cax) is less than 0.7 me/l at LF = 0.15 or is less than 1.0 me/l at LF = 0.30 may result in a calcium deficiency. In such cases, calcium fertilization using granular gypsum or a calcium source included in the fertilizer mix to supply calcium may restore production potential.

Iron chlorosis in susceptible crops (maize, sorghum, Sudan grass, and a few others) is sometimes caused by water with a relatively high sodium adsorption ratio (SAR > 6) and can often be corrected by repeated sprays of ferrous iron or iron chelate, or by using soil sulphur or gypsum to maintain soil pH less than 8.5 or, as with Sudan grass, withholding of water (delayed irrigation) for several days may improve aeration and correct the chlorosis.

Zinc deficiency of paddy rice, too, has been associated with sodic soils and a high soil pH (pH > 8.5). In other cases, zinc deficiency has been attributed to a high bicarbonate level in the applied water (HCO_3 > 2.0 me/l) (see Section 5.6.3).

If soils become waterlogged and temporarily flooded due to a reduced water infiltration rate for even short periods of a few days, and if they lack good aeration, much of the nitrate-nitrogen present may be quickly denitrified and lost from the soil to the atmosphere as N_2 gas. In such cases, the crop may soon show yellowed areas indicating depleted nitrogen and will benefit from added fertilizer nitrogen.

5.6.3 Nutrition and Toxicity

Sodium, chloride or boron from the irrigation water, taken up by the crop with the soil-water, gradually accumulate in the leaves. If these toxic ions accumulate to excessive concentrations, they cause chlorosis, bronzing and leaf burn (necrosis) primarily at the leaf top, leaf edges and, in more severe cases, symptoms may extend between the veins from the leaf edges toward the mid-leaf area.

Leaf necrosis caused by boron can sometimes be severe enough to reduce markedly the total leaf surface available for photosynthesis. For tree crops such as citrus, if boron accumulation threatens to reduce total leaf area appreciably, extra nitrogen fertilization has been applied to stimulate additional vegetative growth to counteract this effect.

In the case of sodium and chloride toxicities, reliance is placed upon selection of cultivars and rootstocks more tolerant to sodium or chloride. Additional fertilization does not appear to be effective.

Bicarbonate, although not ordinarily thought to be a toxic ion, is reported to cause zinc deficiency in

rice. Bicarbonate in excess of 2 me/l in the water used for flooding and growing paddy rice is reported to cause severe zinc deficiency (Mikkelson 1983). This can be remedied by adding zinc to soil before flooding or at the time of earliest appearance of the chlorosis. Actual zinc of 8 to 10 kg/ha from zinc oxide or zinc sulphate is surface applied to remain in the upper 5 to 10 cm of soil.

5.6.4 Miscellaneous

Nitrogen in the applied irrigation water is generally beneficial to most crops but may cause problems for some. Nitrogen in the irrigation water is readily available and if present should be considered as an important part of the fertilizer programme. For most crops, this nitrogen is equivalent to fertilizer nitrogen and should be included in the total nitrogen planned for application. For a few crops, however, the added nitrogen from the water may be too much and result in excessive and vigorous growth, delayed or uneven maturity, and reduced quality. These sensitive crops include apricots, grapes, sugarbeets and cotton, but there are probably others.

In such cases, the stimulating nitrogen can be reduced by applying less water: apply the minimum depth required to supply the crop water demand. If water applied nitrogen is still excessive, irrigate to cause a moderate but increasing water stress as the crop approaches maturity.

Soils high in magnesium or high magnesium water may cause a calcium-induced nutritional deficiency. This is discussed in Section 5.4.

5.7 CLOGGING PROBLEMS IN LOCALIZED (DRIP) IRRIGATION SYSTEMS

A localized (drip) irrigation system is designed to deliver a very low rate of water application to the plant. Understandably, the water must pass through very small openings or emitters which invite clogging problems. A completely blocked opening is easily noticed, but a partially clogged one is very difficult to detect. Detection of partial clogging might involve measuring the delivery of each opening which would be an endless task. Plugging results in decreased uniformity of application and higher operational costs due to increased labour requirements to detect and correct it. Plugging can be prevented if the system is properly planned and designed. Installation of proper equipment to prevent clogging at the beginning is usually less expensive than to try to correct the problem afterwards. Recognizing potential problems beforehand should, therefore, carry a high priority. References include: Nakayama (1982); Vermeiren and Jobling (1980); Bucks **et al.** (1979); Ford and Tucker (1974).

The potential for clogging problems is often related to water quality. The principal physical, chemical and biological contributors to clogging problems are summarized in Table 22. Often these factors are interrelated and the severity can be worsened by a combination; for example, bacterial slime growths inside distribution and emitter lines may cause further plugging when flow is reduced and suspended particles stick to the slime growths.

Table 22 PHYSICAL, CHEMICAL AND BIOLOGICAL CONTRIBUTORS TO CLOGGING OF LOCALIZED (DRIP) IRRIGATION SYSTEMS AS RELATED TO IRRIGATION WATER QUALITY[1]

PHYSICAL (Suspended Solids)	CHEMICAL (Precipitation)	BIOLOGICAL (Bacteria and algae)
1. Sand	1. Calcium or magnesium carbonate	1. Filaments
2. Silt	2. Calcium sulphate	2. Slimes
3. Clay	3. Heavy metal hydroxides, oxides, carbonates, silicates and sulphides	3. Microbial depositions:
		(a) Iron
		(b) Sulphur
		(c) Manganese
4. Organic matter	4. Fertilizers	4.Bacteria
	(a) Phosphate	
	(b) Aqueous ammonia	
	(c) Iron, zinc, copper, manganese	5.Small aquatic organisms
		(a) Snail eggs
		(b) Larva

[1] Adapted from Bucks et al. (1979).

It is recommended that a complete water analysis be conducted before a system is designed in order to allow for treatment to improve water quality before it reaches the small openings. It should be kept in mind that there can be large fluctuations in water quality during a single irrigation cycle, especially if surface water is used. Therefore, a series of analyses should be taken. This series will disclose water quality variations and also indicate how particular pieces of equipment will perform during certain times of the year.

The analysis needed will vary with each situation but localized irrigation systems are expensive and the cost of analysis is so small compared to the total investment that all the standard tests in Table 23 should be completed.

Table 23 STANDARD WATER QUALITY TESTS NEEDED FOR DESIGN AND OPERATION OF LOCALIZED (DRIP) IRRIGATION SYSTEMS

1. Major Inorganic Salts (see Table 2)   8. Micro-organisms
2. Hardness[1]   9. Iron
3. Suspended Solids   10. Dissolved Oxygen
4. Total Dissolved Solids (TDS)[1]   11. Hydrogen Sulphide
5. BOD (Biological Oxygen Demand)   12. Iron Bacteria
6. COD (Chemical Oxygen Demand)   13. Sulphate Reducing Bacteria
7. Organics and Organic Matter

[1] A calculated value from analyses included in Table 2.

For surface water, particular attention should be given to tests 1–4 as the major problems usually occur from suspended material or chemical deposits. It is recommended, however, that tests 5–8 be included as a check, especially if wastewater is suspected in the water supply. When groundwater is used, tests 1–4 and 9–13 are considered to be a minimum, especially if ECw > 1.0 dS/m.

There is not enough experience with localized (drip) irrigation systems to predict with precision if or when clogging problems will occur with a given water. Experience gained so far, however, does allow us to prepare a relative scale for situations when clogging problems may occur due to water quality. Table 24 presents a first approximation of potential problems but should not be used to provide firm criteria; rather, situations which indicate slight to severe potential for restrictions may need a testing programme to determine the economics of solutions that must be considered. A rating of no restriction may also develop a problem but the costs of solving the problem are usually within the capability of irrigated agriculture.

Table 24 INFLUENCE OF WATER QUALITY ON THE POTENTIAL FOR CLOGGING PROBLEMS IN LOCALIZED (DRIP) IRRIGATION SYSTEMS[1]

Potential Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Physical				
Suspended Solids	mg/l	< 50	50 – 100	> 100
Chemical				
pH		< 7.0	7.0 – 8.0	> 8.0
Dissolved Solids	mg/l	< 500	500 – 2000	> 2000
Manganese[2]	mg/l	< 0.1	0.1 – 1.5	> 1.5
Iron[3]	mg/l	< 0.1	0.1 – 1.5	> 1.5
Hydrogen Sulphide	mg/l	< 0.5	0.5 – 2.0	> 2.0
Biological				
Bacterial populations	maximum number/ml	<10 000	10 000 – 50 000	>50 000

[1] Adapted from Nakayama (1982).

[2] While restrictions in use of localized (drip) irrigation systems may not occur at these manganese concentrations, plant toxicities may occur at lower concentrations(see Table 21).

[3] Iron concentrations > 5.0 mg/l may cause nutritional imbalances in certain crops(see Table 21).

The chief cause of clogging is solid particles in suspension, but this is also the easiest problem to solve. Suspended particles are most frequent in surface water but can also occur in groundwater from sand and silt pumped from wells. Suspended particles consist of soil particles of different sizes, lime carbonates, solid material washed into canals, algae, and eroded material from reservoirs. Particles heavier than water can be filtered or settled out. The oldest and cheapest method is sedimentation but this may not provide the consistent quality needed. Filtration is more reliable and consists of screening or passage through a suitable medium, normally graded sand. Screening alone is not adequate to prevent clogging in all cases, as small particles may still get through the screens. Various screening materials and filters are available as well as new emitter designs, some of which are self-cleaning and these greatly reduce the plugging hazard.

Another cause of clogging is chemical precipitation of materials such as lime ($CaCO_3$) and phosphates ($Ca_3(PO_4)_2$). Normally this is gradual and difficult to locate. High temperatures or high pH are usually part of the precipitation problem. Precipitation can result from an excess of calcium or magnesium carbonates and sulphates, or from iron which is in the ferrous form but when in contact with oxygen is oxidized to the insoluble ferric form (reddish-brown precipitate).

The tendency of a water to cause calcium precipitation can be predicted although there is no proven practical method to evaluate how serious the problem will be since it depends upon many factors. A first approximation of the calcium precipitation can be made using the saturation index of Langelier which simply says that upon reaching the calcium saturation point in the presence of bicarbonate, lime ($CaCO_3$) will precipitate from the solution. The saturation index is defined as the actual pH of the water (pHa) minus the theoretical pH (pHc) that the water could have if in equilibrium with $CaCO_3$.

$$\text{Saturation Index} = pHa - pHc \qquad\qquad (18)$$

Positive values of the index (pHa > pHc) indicate a tendency for $CaCO_3$ to precipitate from the water whereas negative values indicate that the water will dissolve $CaCO_3$. The value of pHa is obtained from laboratory data, while pHc is estimated using the procedures described in Table 25. All water having positive values should be considered as potential problem water for use through drip systems and the need for preventative measures should be considered in design. For example, an irrigation water with a measured pH of 7.7, Ca = 3.65 me/l, HCO_3 = 3.80 me/l and total salts of 8.23 me/l (Ca + Mg + Na) will have a theoretical pH of 7.4, giving a saturation index of +0.3, which indicates a possibility of carbonate (lime) precipitation. This may or may not result in a plugging problem but if the pH is adjusted to 7.0 by acid addition, the saturation index becomes -0.4 and carbonate precipitation should not occur. From Table 24, a problem is much more likely at a measured pH greater than pH = 8.0; this is the pH of water close to equilibrium with finely ground limestone ($CaCO_3$).

Iron is more difficult to evaluate for its clogging potential as it is frequently a contributor to other problems, especially those of iron bacterial slime. The limitation given in Table 21 of 5 mg/l should be considered a maximum for drip irrigation systems but, in practical terms, a value above 2.0 may be near maximum since filtration costs become excessive above this limit. A concentration of 0.5 mg/l should be considered a potential problem if tannin-like compounds (often in acid waters) or total sulphides exceed 2 mg/l. The combination of the two normally produces undesirable slime growths.

To prevent iron precipitation in lines or at the emitters iron should be precipitated and filtered out before it enters the irrigation system. In order to filter out the iron, it must first be oxidized to the insoluble form, usually by chlorination to a residual of 1 mg/l chlorine. An alternative method is aeration in an open pond or by injection of air into the water supply by mechanical means. This causes oxidized iron to precipitate. Then it can be filtered and removed before the water enters the irrigation line. Both are expensive and difficult processes and the practicality of treatment plus filtering should be evaluated.

The most effective method of preventing problems caused by precipitation of calcium carbonate is to control the pH or to clean the system periodically with an acid in order to prevent deposits building up to levels where clogging might occur. A common practice among those with problems is to inject hydrochloric (muriatic) or sulphuric acid into the system periodically. The system may need to be flushed as often as once a week.

Table 25 PROCEDURE FOR CALCULATION OF pHc[1,2]

$pHc = (pK_2 - pKc) + pCa + p(Alk)$				
pK$_2$ - pKc is obtained from the concentration of Ca + Mg + Na in me/l pCa is obtained from the Ca in me/l p(Alk) is obtained from the concentration of CO$_3$ + HCO$_3$ in me/l				Obtained from the water analysis
Concentration (me/l)	pK$_2$ - pKc	pCa	p(Alk)	
0.05	2.0	4.6	4.3	
0.10	2.0	4.3	4.0	
0.15	2.0	4.1	3.8	
0.20	2.0	4.0	3.7	
0.25	2.0	3.9	3.6	
0.30	2.0	3.8	3.5	
0.40	2.0	3.7	3.4	
0.50	2.1	3.6	3.3	
0.75	2.1	3.4	3.1	
1.00	2.1	3.3	3.0	
1.25	2.1	3.2	2.9	
1.50	2.1	3.1	2.8	
2.00	2.2	3.0	2.7	
2.50	2.2	2.9	2.6	
3.00	2.2	2.8	2.5	
4.00	2.2	2.7	2.4	
5.00	2.2	2.6	2.3	
6.00	2.2	2.5	2.2	
8.00	2.3	2.4	2.1	
10.00	2.3	2.3	2.0	
12.50	2.3	2.2	1.9	
15.00	2.3	2.1	1.8	
20.00	2.4	2.0	1.7	
30.00	2.4	1.8	1.5	
50.00	2.5	1.6	1.3	
80.00	2.5	1.4	1.1	

[1] Procedure from Nakayama (1982).

[2] pHc is a theoretical, calculated pH of the irrigation water.

The acid can be added to the system on a continuous basis if the problem is severe enough but this is expensive and difficult and the acid is dangerous to handle. It is recommended that acid be added at a rate to maintain pH close to but not lower than pH 6.5. Sulphur burners have also been used to acidify the supply water for drip irrigation. The SO_2 formed is put into the irrigation water by means of water spray scrubbers that form H_2SO_3 and H_2SO_4 acidified solutions.

If fertilizers are injected into the irrigation water, possible precipitation due to water chemistry must be considered. For example, if calcium (Ca) concentration is greater than 6 me/l, most phosphorus fertilizers will cause clogging of emitters. Clogging is more severe if bicarbonates are high (>5 me/l). Anhydrous or liquid ammonia should not be applied through these systems as the ammonia can increase pH of the water to values above 11 and cause rapid precipitation of $CaCO_3$ which clogs the entire system.

Many cases of clogging have occurred from biological growths inside the irrigation lines and openings. These are caused by small quantities of micro-organisms such as algae, slimes, fungi, bacteria, snails, and miscellaneous larvae. These problems are difficult to evaluate and prevent since they are affected by a number of factors. Such problems occur when the water contains organics and iron or hydrogen sulphide. One of the most severe forms of clogging is caused by a white, gelatinous sulphur slime associated with sulphur bacteria. Another common one is the brown slime mass caused by filamentous

iron bacteria. These grow rapidly in water containing as low as 0.4 me/l iron and are especially troublesome in water containing soluble dark, tannin-like organics which act as a readily available food source for the bacteria. Algae and other growths can cause problems especially if their growth rates are enhanced by excess nutrient levels (nitrogen or phosphorous). The use of wastewater in localized (drip) irrigation systems would be especially troublesome since effluents normally contain nutrients, dissolved organics, and micro-organisms, all of which may increase the potential for clogging problems.

Chemical treatment (chlorine) is one of the most effective methods for controlling biological growths but is costly and requires close and careful management to use safely. Chlorine kills the organism, oxidizes the organic matter and may require filtering or flushing of the system to clear the organic matter. Continuous chlorine injection is an excellent method but may be too expensive for most agricultural use. Its efficiency is related to the pH of the water, with more chlorine required at higher pH. Table 26 gives examples of typical chlorine dosages used in localized (drip) irrigation systems to inhibit microbial growth, slime and bacterial development.

Table 26 CHLORINE DOSAGES FOR CONTROL OF BIOLOGICAL GROWTHS[1]

Problem	Dosage
Algae	0.5–1.0 mg/l continuous or 20 mg/l for 20 minutes
Hydrogen Sulphide	3.5–9.0 times the hydrogen sulphide content (mg/l)
Iron Bacteria	1.0 mg/l but varies with bacterial count
Slimes	0.5 mg/l continuous

[1] Data from Vermeiren and Jobling (1980).

5.8 CORROSION AND ENCRUSTATION

5.8.1 Metal Corrosion

Most corrosion and encrustation problems are associated with groundwater. Groundwater varies significantly in composition from one area to another but most types are at least mildly corrosive to iron and some will severely attack it and even affect more resistant metals. Corrosion is basically an electrolytic process which attacks and dissolves away a metal surface. The rate at which corrosion proceeds depends upon a variety of chemical equilibrium reactions as well as upon certain physical factors such as velocity, temperature and pressure. Most corrosion problems are associated with low salinity water; most encrustation problems are associated with higher salinity groundwater.

Other types of groundwater may cause unusual amounts of organic and inorganic materials to be deposited on equipment and in wells. These deposits may restrict water passage in well screens, pipelines, and outlets. Although an endless variety of dissolved and suspended solids can cause such effects, the more common ones are sand, silt, carbonate deposition, iron, and biological growths.

Corrosion and encrustation processes are complex and interactive. For this reason, no single test or index is an infallible indicator of the potential life of equipment. Nevertheless, certain accelerated performance tests and chemical indicators have proved to be of considerable value in planning equipment needs and evaluating performance. Considering the high cost of well construction and irrigation equipment, it is desirable to apply all known indicator tests and to use the most conservative (safest) in planning for fullscale development. Because of the varying nature of the tests, it is suggested that reputable reference guides be used to make the appraisal. One of the latest guides is Corrosion and Encrustation in Water Wells: A Field Guide for Assessment, Prediction and Control (Clarke 1980). Although this deals with water wells, the predictive tools could also be applicable to irrigation equipment.

5.8.2 Concrete Corrosion

Groundwater and certain surface water supplies can be corrosive to concrete. This corrosion may affect the life of an irrigation canal lining but the most frequent corrosion occurs when groundwater is pumped through a closed concrete pipeline.

There are three general types of corrosion that might result in deterioration in concrete canals and pipelines when they are exposed to a corrosive water:

TYPE I: Leaching corrosion is when lime in concrete is dissolved by low salinity soft water (low

carbonate hardness) or by water that contains free carbon dioxide (carbonic acid). This type of corrosion does not do excessive damage to good concrete but can be pronounced in poor quality, porous concrete. The rate of this type of corrosion in dense concrete is very slow to nonexistent but can be relatively rapid in jointing materials.

For water containing carbonic acid (H_2CO_3), the pH may vary from 4.5 to 7.9, therefore, pH should not be a sole indicator. A characteristic of low salinity water is that even though the pH may vary between 7.0 and 7.9, the water may still attack concrete. This is because it may be 'lime dissolving' instead of lime depositing. Therefore, it is advisable to check the Langelier Saturation Index of the water (see Section 5.7 and Equation 18). If the saturation index is negative, then some attack on concrete is likely but the rate of attack will be very slow. The Cax values in Table 11 may also indicate a corrosion potential since concrete would be a good source of lime ($CaCO_3$).

TYPE II: Ion exchange corrosion occurs as a result of base exchange reactions between the readily soluble compounds in the hardened cement and the alkaline cations (Ca, Mg, K, NH_4) in the water. The exchange products are then leached or remain in place in the concrete as non-binding components. Magnesium and salts are commonly involved.

TYPE III: Corrosion by expansion occurs from a chemical reaction that results in the formation of compounds which occupy a greater volume than the original cement compounds, thus causing internal stress which ultimately destroys the concrete by swelling. Sulphates are a known cause of this type of corrosion. The sulphates tend to combine with some of the calcium and aluminium compounds in the hardened cement and form calcium aluminate-sulphate or gypsum, which causes the concrete to swell. It should be noted that some sulphates are potentially more aggressive than others; these are magnesium and ammonium sulphates. The increased aggression by $MgSO_4$ and NH_4SO_4 is due to the fact that they decompose the hydrated calcium silicates (Type II corrosion) in addition to reacting with the aluminium and calcium hydroxide in the concrete. The action of ammonium sulphate may be enhanced in the presence of nitrate. Both may be present in water supplies especially if they are receiving industrial wastes or runoff from agricultural land.

As with metals, corrosion processes of concrete are complex, therefore, no single test or index is an infallible indicator. Guidelines have been suggested to estimate the potential of a water to be aggressive against concrete (Table 27). These are relative degrees of aggressivity of water of predominantly natural origin and do not take into account resistance of the concrete to corrosion. The developer of Table 27 suggests that even if only one of the values points to a potential, a further evaluation should be made.

Table 27 LIMIT VALUES FOR EVALUATING THE AGGRESSIVITY OF WATER AND SOIL TO CONCRETE[1]

Test	Intensity of attack			
	None to slight	Mild	Strong	Very Strong
Water				
pH	>6.5	6.5 – 5.5	5.5 – 4.5	<4.5
Lime-dissolving carbonic acid (CO_2), mg/l	<15	15–30	30–60	>60
Ammonium (NH_4), mg/l	<15	15–30	30–60	>60
Magnesium (Mg), mg/l	<100	100–300	300–1500	>1500
Sulphate in water (SO_4), mg/l	<200	200–600	600–3000	>3000
Soil				
Sulphate in soil (air-dry) (SO_4), mg/kg	<2000	2000–5000	>5000	

[1] Data taken from Biczok (1972).

Further references include: Biczok (1972); United States Bureau of Reclamation (1975); Taylor (1977); and Perkins (1981).

5.9 VECTOR PROBLEMS ASSOCIATED WITH WATER QUALITY

In most countries where there is a risk to health from vectorborne diseases such as malaria, lymphatic filariasis, encephalitis, onchocerciasis, schistosomiasis, there is an awareness of the possibility that

water development projects may have an impact on vector populations and human health. This is particularly true of irrigation schemes, which tend to increase opportunities for human/water/vector contact in addition to their creation of habitats well suited to vector production. Even in the absence of an associated disease, a similar problem may arise in relation to nuisance species of insects which cause personal discomfort and can be extremely disruptive of community life, work and leisure activities.

The existence of an aquatic environment is usually the primary cause of these problems, and there is ample-literature on vector control through chemical, biological and environmental management methods. However, there is less information on the relationships between water quality and vector production although quality aspects may often intensify a vector problem and may even create the physical conditions leading to the problem.

Put simply, the ideal conditions for good irrigation management are similar to those which will discourage vector production in irrigated agriculture or will at least assist in vector control. This implies a minimum of unnecessary water surface, well constructed and maintained supply channels, effective, unimpeded drainage of excess water and efficient, economical water application. When the quality of irrigation water causes a departure from these conditions, there is increased risk of vector production.

There are four ways in which water quality may affect the size and species composition of the populations of disease vectors and nuisance insects:

- by creating soil conditions which extend water surfaces in area, or in duration;

- by requiring irrigation practices which also result in the extension of water surfaces in area, or duration;

- by modification of the aquatic flora or fauna; and

- by direct influence on the vector.

Adverse soil conditions, with low rates of infiltration, may arise when the irrigation water has very low salinity or a high sodium content relative to the calcium and magnesium content. This has the obvious effect of extending the time when irrigation water is standing in the field and also results in longer periods of stagnant water, following rainfall, outside the irrigation season. Where the intensity of land use under irrigation is relatively low, this may mean that the exposed water surface is even greater than the irrigated area and that the period of standing water is sufficient for a number of breeding cycles of vector and pest insects or for the proliferation of populations of snail intermediate hosts necessary for the development and multiplication of schistosome larvae.

When salinity is high, it may be necessary to supply irrigation at very short intervals so that the soil surface is often wet, and depressions will always contain water. When salt accumulation must be corrected by leaching, this may call for the ponding of water in the field for periods of many days. In either case, with an inevitable carry-over period to complete drainage or drying out of low spots, there may be sufficient time for completion of the aquatic part of the mosquito life cycle (usually within two weeks under tropical conditions) and the production of a new generation of adults.

A problem which most commonly affects agricultural drains is that of growth stimulation of aquatic weeds due to excess nitrogen from fertilizers. This can also occur in irrigation canals where there is a mixing of the supply with agricultural runoff or with wastewater from domestic or food-processing sources. The associated issues of weed clearance and channel maintenance have been referred to earlier, but the presence of dense aquatic weeds and algal growth also introduces conditions which are suited to the development of some insect vectors, pest insects and snails. In addition, it makes control by chemicals such as larvicides and molluscicides more difficult, more expensive and less effective.

The use of chemicals in vector control and for the control of agricultural pests may be, in itself, a cause of degraded water quality where it creates problems for other water uses. Examples of this can be found in the damage to beneficial aquatic fauna such as fish cultivated for their protein value, deterioration of livestock water supplies and, most dangerous of all, the contamination of domestic water which, in many developing countries, is derived from the irrigation supply with minimum, or no treatment.

The use of domestic wastewater in irrigation can be an attractive way to raise crop yields, but it has been known to result in a dramatic increase in the breeding of mosquitoes. This led to a recent ban on wastewater re-use for rice irrigation in California (see Section 8.22).

Sometimes a change in water quality will have a marked impact on aquatic fauna other than the vector or pest species of primary concern. This can happen when water from different sources is used conjunctively, either by mixing or in sequence. If the affected organisms represent a food supply for the vector, it is likely to discourage the growth of vector populations. On the other hand, if the result is a suppression of species which are natural predators or competitors of the vector, an upsurge of vector populations is likely. In the case of a periodic quality change, as for seasonal groundwater used to supplement low-flow surface supply, the impact may be detrimental to either vector or predator or both. Experience from such examples suggests that vector species tend to be more resilient and to recover more quickly, with consequent progressive increase in their populations.

Direct influence of water quality on vector populations and species distribution is usually related to species preference. For mosquitoes, this ranges from fresh running water to brackish water, salt pools, mineral groundwater, water contaminated with domestic effluent and even to septic tanks and cesspools. Vector mosquitoes can be found within the whole range of these preferences, therefore the assessment of possible water quality impact on mosquito-transmitted diseases calls for a careful study of the actual and potential status of the diseases in the human population, the locally occurring mosquito species and the quality characteristics of the water. These characteristics may in fact vary with season and from place to place, even within a scheme, producing an extremely complex set of circumstances.

Snail intermediate hosts are fairly tolerant to water quality conditions which fall within the range of suitability for irrigation. The presence of calcium is advantageous to the snail whereas a low pH is not. There is often a snail preference for a sediment content and for some organic pollution and, where this latter is due to domestic effluent in the water, the risk of schistosomiasis transmission is evident within endemic areas.

It can be seen that the association between water quality and vector-borne diseases is both complex and specific to the site and the human population. Even the more limited relationship between water quality and the presence and production of vector and pest species is subject to many physical and biological influences. This section has therefore been restricted to a brief outline of some of the general issues to be taken into consideration where there is a possibility of a health problem arising or being modified as a result of water quality characteristics in agricultural development. The subject of disease transmission through the re-use of wastewater is a separate and distinct issue on which there is already extensive literature and for which there are many guidelines and examples of national control and legislation. This has not therefore been included in the present text, but the following list of references contains information and references related to this problem in addition to that of vector-borne diseases. References include: Agency for International Development (1975); Mather (1984); Feachem et al. (1977); McJunkin (1982); Tillman (1981); WHO (1973); and WHO (1982).

As a further source of information, the reader may always direct enquiries to the World Health Organization, 1211 Geneva 27, Switzerland.