Practical Measurements of Water Quality as it Affects Irrigation

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1   INTRODUCTION

The objectives of effluent irrigation are to maximise the return of nutrients to the soil/vegetation system, to enhance productivity and reduce the potential for off-site effects from nutrients. The maintenance of water quality suitable for irrigation must be a prime objective in a wastewater management plan. The water quality monitoring plan should, therefore, collect accurate and timely data so that management can be altered to account for potential impacts of the effluent on the irrigation area. The need for a sufficient number of accurate measurements to account for water quality variations, brought about by temporal and spatial variations and trends over time, is of highest priority.

"The result of any testing method can be no better than the sample on which it is performed" (APHA, 1995) suggests that it is important that the collected sample represents the proportions and concentrations of constituents in the water body being sampled at that time. A set of Australian Standards is available for water quality sampling (AS/NZS 5667:1998) and should be consulted in the development of water monitoring programs. Protocols for sampling frequencies, sample methods, sample sizes, types of containers, sample preservation, transport and storage requirements can be mandated in a monitoring program. The number of samples required to present statistically valid data needs to be considered.

This paper examines some of the practical aspects of monitoring water quality and provides simple exercises to reinforce the requirements of maintaining clear sampling protocols.

2   SAMPLING TECHNIQUES

2.1   Sampling Sites

Sampling sites should be clearly identified in the field and the location accurately recorded, either as a map reference or easily identifiable feature. Access may be of key importance, but the sampling sites should be safe and within reach during changes in weather conditions.

The sampling location will be chosen having due regard to spatial variations in the wastewater stream or body, temporal variations during the day or from month to month, and the ability to obtain a representative sample of the particular water quality parameters. AS/NZS 5667 .10:
1998 provides guidance on sampling of waste water.

The mode of sampling will also determine the sampling location. Manual or automatic sampling equipment may require different sampling locations.

2.2   Sample Containers

Polyethylene or borosilicate glass containers are suitable for storage of samples for the determination of chemical and physical properties. Non-sterile plastic containers are suitable for most samples other than bacteriological.

The adsorption of chemicals onto the internal walls of the container or desorption (leaching) of chemicals from the container must be considered to avoid sample contamination. Chemically and biologically inert materials will avoid reactions between the sample and the container.

One litre, HDPE screw top bottles are suitable used for wastewater sampling. These containers can be frozen, if required, are resistant to breakage and are relatively inexpensive (about $0.95).

For biologically active waters, such as those with chlorophylls, samples should be collected in dark coloured containers and stored in the dark.

Sterile containers are commercially available in a range of sizes for microbiological samples. Care has to be exercised in obtaining accurate samples, uncontaminated by the observer or the wider environment.

2.3   Types of Samples

Grab (spot) samples:
Discrete samples representing quality at the time of sampling. Such samples are ideal for non-uniform flows, where quality varies over time or where unstable analytes are to be assessed.

Periodic samples (discontinuous):
Taken at fixed-time, fixed-flow or fixed-volume intervals. An automatic sampler is used for such sampling regimes.

Continuous samples:
Used to assess bulk quality. Can be taken at fixed or variable flow rates.

Series Sampling:
A series of samples taken from various depths, or particular depths in a water body.

Composite samples:
Can be obtained manually or automatically to show average composition. Be careful that samples do not deteriorate over the sampling period. Samples can be either flow-weighted or time-weighted.

2.4 Sample Preservation

The type of sample preservation is dependent upon the changes which may occur within the sample between the time of collection and the time of analysis. Certain constituents should be measured *in situ*, such as dissolved oxygen, pH in easily oxidisable compounds, or waters with significant biological activity that may continue functioning during transport or storage. Chlorine residual and chlorine dioxide must be measured within 5 minutes.

Refrigeration (0-4°C) or freezing (to -20°C) is only effective if applied immediately the sample has been taken, however, this is not always possible. Thawed samples should not be refrozen.

Preservatives such as acids, alkalis, biocides or specific reagents may be necessary to prevent the deterioration, precipitation or interference with other components occurring during transport and storage.

In the case of BOD_5, COD, solids, sulphide, sulphite, surfactants, EC, iron, magnesium, calcium, boron, carbon dioxide, acidity, alkalinity and others, the container should be filled to exclude air. However, for acidic herbicides, oil and grease, pesticides, phenolic compounds, PCBs, PAHs, it is essential that the container is not filled completely.

Other samples have a fixed holding time, even with refrigeration. Often these times are not achievable from remote sample locations. Field measurements or pre-treatment in the field may need to be considered.

2.5 Frequency and Timing of Sampling

The frequency of sampling will be determined from the objectives of the monitoring program, whether sampling for compliance, after rainfall events, for monthly or seasonal variations. Changes in water quality during the day may influence the timing of the sampling event.

The number of samples taken may be determined by applying the following formula:

$$N \geq \left(\frac{ts}{U} \right)^2 \qquad \text{Equation 1}$$

where N = number of samples
  t = Student-*t* statistic for a given confidence level
  s = overall standard deviation
  U = acceptable level of uncertainty

The use of the Equation 1 requires an understanding of the statistics of previous sampling events. In most cases only one grab sample will be taken, therefore correct protocols and representative sampling are essential.

3 BIOLOGICAL INDICATORS

3.1 Water Examination

Biological indicators of water quality can be used to identify and measure change in environmental values. For example, the change from clear water to one of high algal concentrations will indicate a potential deterioration in water quality and the likely drop in dissolved oxygen levels triggered by an increased phosphorus loading.

The choice of biological indicators of water quality fall into three broad categories (ANZECC, 1992):

  a. Those species normally present which can be usefully monitored for a change in quality;

  b. Species not normally detected but if detected in certain concentrations can be useful indicators of altered quality; and

  c. Indicators normally present but the absence of which reflects an environmental change.

There is a need to protect the aquatic ecosystem because it has the potential to process pollutants up to certain levels (ANZECC, 1992). For effluent storage from which irrigation will be undertaken, the water body must remain at a suitable quality without further deterioration and additional risk of pollution.

3.2 Species Richness

The bio-diversity of plants and animals which inhabit the edges, shallow water, bottoms and the water body itself should not be diminished by management activities. Each plays an important role in maintaining a particular water quality and is indicative of that condition.

3.3 Species Composition

A change in species composition will usually signal a change in the environmental conditions that may signal a deterioration in water quality. For example, the impact of European carp on stored water bodies increases turbidity and reduces light penetration. The loss of species dependent upon clean water may follow.

3.4 Primary Production

The net primary production within the water body is the basis of food chains and ensures that the above two factors operate to maintain a stable stored water environment. It is possible that the nutrients added to the water from runoff and waste disposal are degraded through predation and incorporation into the aquatic biota without altering the quality of that ecosystem. This is the principle of "assimilative capacity" (ANZECC, 1992) and provides an opportunity to biologically treat stored effluent without degrading the potential for irrigation use and plant uptake of nutrients.

3.5 Nuisance plant growth

Floating plants and organic debris in the water have the potential to clog pump intakes and other irrigation facilities. It may be wise to inspect pump intakes regularly and clear the intake to preventing pump system failure.

3.6 Visual Assessment

A visual examination of the water stored in the irrigation ponds at "Tullimba" is made in several ways. An observation of the whole water body may provide a cursory indication of quality while many grab samples may be required to observe subtle changes within the water.

! Observe the pattern of plants and animals on the shore line, plants (phytoplankton) and animals (zooplankton) suspended in the water, those attached to submerged plants (periphyton) and those living in sediments (benthic organisms).

! Observe unusual patterns on the water body such as algal blooms, large expanses of water weeds, areas of dirty water.

Do any of these indicators suggest there may be a problem with irrigation management? Algae, mosquito larvae, reeds or floating material may clog pump inlets, while excess turbidity may lead to sediments settling in irrigation pipes.

3.7 Biochemical Oxygen Demand

The level of dissolved oxygen in water depends upon the consumption by aquatic biota (respiration), the diffusion from the atmosphere (varies with temperature and turbulence of air and water) and the salinity of the water. The measurement of dissolved oxygen (DO) is performed using a calibrated electrochemical probe, but the readings must be interpreted in view of what has been measured - a single spot measurement, the value of which depends upon temperature, biological activity, wind speed and turbulence, season and the time of day (solar radiation input). Dissolved oxygen must be measured in the field.

A measure of the consumption of dissolved oxygen is given by the Biochemical Oxygen Demand - 5 day test (BOD_5), which records the consumption of oxygen over five days by bacteria consuming organic compounds in the water. The higher the organic load, the greater the oxygen load required to maintain a reserve of DO for other aquatic plants and animals.

ANZECC (1992) states that no guideline level of BOD_5 is given for irrigation waters as there is no limiting factor where the effluent is applied to well structured soils. ANZECC further suggests that DO readings are "possibly the most abused water quality parameter" (p2-15) because of the daily and seasonal fluctuation of DO levels. For this reason, DO readings should be recorded to show a profile of the aquatic environment rather than a definitive statement of water quality.

4 PHYSIO-CHEMICAL FACTORS

While the observation of biological indicators proceeds as in Exercise One above, the observer may also note some physical conditions which can be used to compare changes to the aquatic environment. Light can be scattered or absorbed by particulate matter as well as dissolved matter.

4.1 Visual clarity

The clarity of water is measured using a 200 mm Secchi disc. The disk is lowered into the water until the boundary between the black and white quadrants can no longer be distinguished. The depth corresponds roughly to the euphotic (light transparent) zone. Turbidity is also a measure of visual clarity and is relatively easy to measure with portable instruments.

4.2 Light penetration

The measure of light penetration is the depth at which the photosynthetically available radiation is reduced to 1% of the level at the water surface. Light is the energy source for photosynthesis and drives much of the food chain.

4.3 Colour

Simple photometers can be used to compare the colour of a filtered water sample with known standard colours. Colour will indicate likely sources of pollution such as the tannins and humic acids from manure runoff, or the pale blue colour in acid runoff. Colour in an unfiltered sample may indicate pollutants such as clays (colour associated with local clay colours), algae (green) or humic materials (black, brown).

4.4 Oils, greases and scums

A record of the appearance of the surface of the water will indicate poor water quality or contamination from machinery spills. Many of the scums forming on the surface of waters exclude the free diffusion of atmospheric oxygen into the water and a shield, preventing air-breathing organisms from reaching the atmosphere.

4.5 Odour

With experience, it is possible to train one's olfactory senses to remember smells which may warn us of potential loss of water quality. For example, the smell of hydrogen sulphide (rotten eggs) is easily recognised and associated with anaerobic (without air) decomposition.

5 SOLID MATTER

5.1 Settled samples

The solid matter in water is made up of settleable solids (those which settle when water is still), suspended solids (TSS)(those particles able to be removed by filtration) and dissolved solids (TDS) (those solids of a very small size and those in solution). Solids may be mineral (soil, rock, chemicals) or organic in form (algae, plant materials). The measure of total solids (TS) is obtained by evaporating a known volume of water to dryness, weighing the residue and recording the TS load in milligrams per litre ($mg\,L^{-1}$). The test can be performed in a conventional oven set at 105ºC, but a microwave oven may volatilise some of the organics.

$$TS = TSS + TDS \qquad \text{Equation 2}$$

Where   TS   = Total Solids
       TSS   =Total suspended solids (suspended, floating and settleable combined)
       TDS   = total dissolved solids
              (all units in mg L^{-1})

The quantity of solid matter in an irrigation supply will influence the type of pump, pipeline and irrigator nozzle configuration to effectively distribute the water.

High solids loads in water, as measured by Total Suspended Solids (TSS) will require consideration of pump pickup, inlet clogging, settling of the solids in low spots in the irrigation line when the system is at rest, and clogging of the sprinkler nozzles by solid particles as well as the potential to coat the plants with light inhibiting material and chemical residues.

EXERCISE ONE -- Settleable solids
A simple method for determining the settleable solids load for particles which have the potential to affect the irrigation system by settling in still water is to use a 1 L plastic soft drink bottle as follows:
,   with the screw lid in place, remove the base of the bottle using a knife or saw,
,   invert the bottle to form a rough Imhoff Cone,
,   fill the cone with water of the same quality as you will pump (a 1 L well mixed sample),
,   let the solids settle for 45 min, gently agitate sample near sides of cone, settle 15 min longer, record volume of settled solids in mg L^{-1},
,   consult pump and irrigator manuals for suitability of liquid for solids handling.

Refer APHA (1995) Method 2540 F. Settleable solids for the laboratory method of this test.

Solutions to high settleable solids load
Simple methods to overcome water with high settleable solids loads - TSS > 10 g/L may include the following:

a. Provide a settling sump at the pump pickup incorporating a large surface area filter in the system. The screen should stop particles of a size smaller than the smallest orifice in the irrigator head. Water freezing in pipe may also cause ice crystals to temporarily block pipeline and nozzles.

b. Avoid low spots in the irrigation system, where solids could settle when the system is turned off, especially when water fails to completely drain from the system. It may not be possible to arrange a self-draining system.

c. Complete each dirty water irrigation cycle with a short duration clean water application to make sure the internals of the irrigation system are clean.

5.2 Total Dissolved Solids
The dissolved components in water will pass through a filter system (about 5 micron fibres), some as colloidal material (<2 micron) others as microscopic particles, while solution will provide a mechanism of transport for dissolved chemicals.

Total dissolved solids (TDS) include those which form ions such as the positive ions (cations) sodium, calcium, potassium, magnesium; the metal cations copper, iron, manganese, zinc, aluminium; and the negative ions (anions which pair with the cations) such as chlorides, sulphates, phosphates, nitrates, bicarbonates and hydroxides. There are other salts which do not ionise (dissociate into positive and negative ions) but are suspended as minute particles or molecules and will move with the water, small enough to pass through the filter system and remain in suspension. The latter include many pesticides and hydrocarbons.

There are several conversions which allow electrical conductivity to be correlated with an estimate of TDS. Unfortunately, each water resource has a unique and highly variable dissolved load and any conversion should be made with caution. For practical purposes, because EC is relatively simple to measure, EC will give an indication of the changing water chemistry relative to an estimated TDS load, but not discriminate components.

The total dissolved salt (TDS) load of an irrigation water can change as pH changes, causing some components to become more soluble while others become less soluble. At low pH (<pH4) aluminium and many other metal ions become more soluble, such that in low pH water, aluminium and copper pipes will dissolve causing severe corrosion and weakening of the conduits. At high pH aluminium, calcium and other minerals become less soluble and will precipitate onto walls of the pipe. Around the heads of sprinklers the effects of calcium salts become evident where deposition of a scale and corrosion under the scale lead to equipment malfunction.

The inflow of some salts to the system may cause the precipitation of salts, with perhaps a loss of a valuable nutrient. As an example, inflows of water high in calcium may lead to the precipitation of phosphates, hence a loss of a plant nutrient. The phosphate becomes bound in bottom sediments and is temporarily lost from the system.

It is important to monitor the pH and EC of the irrigation water as the inflow of other salts or a change in pH may cause flocculation (aggregating together) or dispersion.

EXERCISE TWO -- Measure pH and EC
Two simple methods exist for monitoring the pH of water; the first uses an indicator strip while the second method uses a calibrated pH meter.
a. Take a sample of water from the nominated location and dip a test strip into the water, remove and wait 1 min before matching the colour pattern on the test strip with that indicated on the side of the box. Record pH to nearest unit.

b. Take a pH meter and calibrate according to manufacturer's instructions. The calibration will usually last 24 hr, but the probe must be kept moist at all times. Dip the temperature compensated probe into the water, simulate a stirring action to ensure water moves past the glass probe.

When the reading has stabilised (30-60 sec) record the pH to the nearest 0.1 unit. Rinse the probe with distilled water between samples, store in water.

pH of irrigation waters should be in the range of 4.5 to 9 to avoid restrictions on nutrient solubility or increasing solubility of toxic metals.

Take an electrical conductivity (EC) meter, calibrate according to manufacturer's instructions. Similarly the calibration should remain stable for 24 hr, the probe must be kept in tap water when not in use, washed in distilled water between samples.

Dip the probe into the water sample, do not stir. When the reading has stabilised, record the EC in either microSiemens per centimetre or deciSiemens per metre. (1 dS m^{-1} = 1000 uS cm^{-1}).

To convert EC to an approximate value of TDS,

TDS (mg L^{-1})   = EC (μS cm^{-1}) x 0.67   Equation 3

(Reference: APHA (1995) - Method 2510 Conductivity and Rayment and Higginson (1992) - Method B1b)

6.   SODICITY AND SALINITY

The EC of water is an effective measure of total salinity, that is, all the dissolved materials which may form salts when the water evaporates. It follows that a low EC is consistent with a low salinity. For irrigation purposes, EC above 1 dS m^{-1} (1000 uS cm^{-1}) should start to ring alarm bells with respect to salinity.

High salinity levels may relate to physiological effects upon animals and plants exposed to the water, corrosion and/or encrustation of equipment and detrimental effects on soil structure and chemical fertility. The latter two topics have been covered previously in this workshop.

There is a difference between the effects that total salinity may have on a soil and plant environment compared to the effects that sodium salts may have. Sodium, an essential biological extra-cellular fluid, is toxic in large amounts. It is possible, and probable that water may have a low EC but a high sodicity. Sodium is not simple to measure because most of the salts that we encounter are always and forever soluble, however, that should not prevent the monitoring of sodium in the water and soil.

6.1   Sodium adsorption ratio

An indicator of the potential for sodium to adversely affect plants and soils is related to the sodium adsorption ratio

(SAR) which is given as function of the sodium concentration relative to the concentrations of calcium and magnesium. All concentrations are in milliequivalents per litre.

$$SAR = \frac{\left[Na^+\right]}{\sqrt{\dfrac{\left[Ca^{2+}\right] + \left[Mg^{2+}\right]}{2}}}$$

Equation 4

From Equation 4, the SAR can be reduced by increasing the concentrations of calcium and magnesium or reducing the quantity of sodium. The former is achieved by adding lime (increases pH) or gypsum (no change to pH) , both of which also change the EC of the soil solution. It is important to remember the following statements:

High SAR and Low EC = potential sodium problems

High SAR and High EC = reduced sodium problems, but may result in a high salinity problem.

It has been shown by Patterson (1994) that for effluents with an SAR as low as 3 and an EC less than 1 dS m^{-1} (1000 uS cm^{-1}), a significant loss of hydraulic conductivity occurred on soils with a texture finer than a clay loam. Also refer to the demonstration of sodium effects on soil hydraulic conductivity in this workshop by Patterson Effects of Effluent Chemistry on Soil Properties".

6.2   Dispersion by effluent effects

A simple test to determine the likely impact of the effluent on the receiving soils is to perform the Emerson's Dispersion Test on soils from the irrigation area using the irrigation water for the test. Refer to practical session by Patterson "Effects of Effluent Chemistry on Soil Properties" in these proceedings.

6.3   Salt leaching Fraction

Where the application of irrigation water is more than 1000 mm per annum, it is likely that the majority of the salts from saline irrigation water will remain in the top 150 mm of the soil profile (ANZECC, 1992). A simple algorithm for determining the potential salinity problem is given in Equation 5.

Salt accumulation occurs where:

$$P + I < E_o + E_t \qquad \text{Equation 5}$$

where   P   = precipitation (mm)
I   = irrigation (mm)
E_o = evaporation (mm)
E_t = plant transpiration (mm)

To overcome the potential for salt to accumulate, it is necessary to increase the irrigation quantity to wash the

salts deeper into the profile, out of the root zone. A leaching fraction can be calculated to determine the volume of excess irrigation water required to leach the salts from the root zone, provided drainage occurs.

7.   HEAVY METALS

Heavy and other metals often occur in agricultural effluents, being derived from additives to animal diets and excreted with manures. Other sources include the natural environment, particles of which may enter the water body through natural and enhanced erosion processes, corrosion of engineering services (pipes, paintwork), from combustion products such as internal combustion engine emissions, from waste disposal facilities and degradation of organics.

Typical metal contaminations may occur from copper (pipes, ration additives, algaecides such as copper sulphate), cadmium from superphosphate, zinc from dietary and fertiliser additives together with corrosion of galvanised facilities, selenium from veterinary sources and lead from atmospheric pollution by combustion of leaded fuels.

Samples for heavy metal determination are preserved with nitric acid at pH 1 to 2, about 2 mL conc HNO_3 / L.

8.   PESTICIDES, HERBICIDES

The escape of chemical residues into irrigation supplies may have an impact upon the aquatic biota while the potential for contaminating stock feed when subsequent irrigation of pasture occurs is high.

Managers should be aware of, and record likely sources of chemical residues while protecting the water and soils.

Samples for pesticides are collected in glass containers with PTFE cap liners. Do not fill completely.

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Table 1.   Record of water quality

Parameter	Group 1	Group 2	Group 3
Description of surface			
Description of water (in white container)			
Secchi depth (m)			
Settleable solids (mL)			
pH			
EC (μS cm^{-1})			
Salinity			

Salinity (mg L^{-1})   =   EC in μS cm^{-1} x 0.67