

Practical Measurement of Effluent Irrigation Water Quantity and Quality

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1. INTRODUCTION

It is important to know how much water is being used to irrigate crops. The crop uses water by evapotranspiration and this is taken from the soil moisture, which may be thought of as a reservoir. When this reservoir becomes depleted it needs topping up like any other dam or reservoir. However, it only needs sufficient water to restore the moisture which has been used up through evapotranspiration. It is thus necessary to know how much has been used, and to be able to supply just that correct amount to replace it. To supply too much will result in waterlogging, and maybe ponding and runoff as well, which with feedlot effluent can lead to pollution of streams. The quality of the effluent applied is also important, as this affects both the chemical and physical properties of the soil to which it is applied. The nutrients in the effluent should be beneficial to the crops, but other chemicals can damage the soil structure and even render it infertile.

2. QUANTITY MEASUREMENT

The components of the water balance for the soil moisture may be described by:

$$AS = (P+I) - (R+Et+D) \quad (1)$$

where: AS = change in soil moisture storage
P = precipitation R = runoff
I = irrigation Et = evapotranspiration
D = deep drainage

The objective of irrigation is that the R term should be zero. The AS term is measured, for example, by a neutron probe if available, and it is when this reaches a critical low value that irrigation water must be added. The Et term is usually estimated by use of a class A evaporation pan, although the more reliable Penman equation may be used if meteorological data are available. Precipitation or rainfall is measured with a conventional rain gauge and the deep drainage term is usually assumed zero and is not measured under normal circumstances. We are principally concerned here with the measurement of I, the irrigation quantity. There are a large number of ways of measuring water flow, and the method adopted depends very much on the way the water is supplied and on the method of irrigation.

Venturi Flume

This is an artificial constriction in the flow of water in an open channel, as shown in Figure 1.

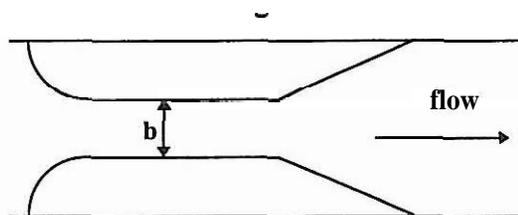


Figure 1: Venturi Flume (plan).

The flume works because the constriction causes the water level to drop and the velocity to increase as it passes through the flume. The flow changes from a deep slow moving stream to a fast shallow stream (sub to super critical flow) through the flume, and a hydraulic jump forms at the exit. When this set of flow conditions occurs there is a fixed mathematical relationship between the upstream depth and the quantity of water flowing.

$$Q = 1.71 C b h^{1.5} \quad (2)$$

where Q is flow rate in m³/s
C is a coefficient, typical value 0.98
b is width of flume constriction in m
h is upstream depth of water.

A stilling well or similar arrangement with a float or other device to monitor the water level is needed. The water level is then recorded continuously on a chart (or electronically) and the simple conversion to flow rate may be carried out using the equation, or from flowcharts.

The Venturi flume will only work where there is a suitable length of straight open channel to put it in. They are very accurate, but have the disadvantage that they can become very long structures when designed in accordance with the Australian Standard AS 3778.47 (1991). For this reason alternative types of flume are sometimes used, but these require some degree of precalibration to determine the relationship between depth of water and flow rate. Some care is required in setting up a Venturi flume, to ensure that both the backing up effect is not too great, and that critical flow is maintained in the throat without downstream water washing back through the flume.

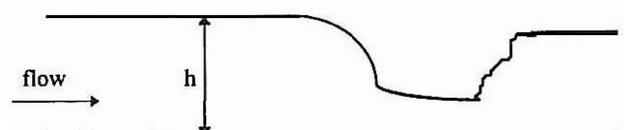


Figure 2: Venturi Flume (section).

Parshall Flume

This is also sometimes **known** as cut-throat flume, and is similar to the **Venturi** flume with a shorter throat section. The bed also dips down **through** the throat. Flumes pass **sediment freely**, which is an advantage where the supply water is partially treated effluent. They are also relatively insensitive to the velocity of approach.

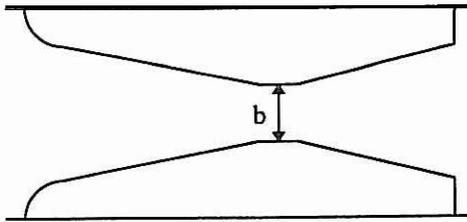


Figure 3: Parshall Flume (plan)

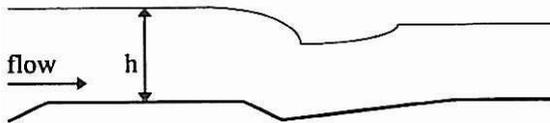


Figure 4: Parshall Flume (section).

Some standard dimensions are shown in Table 1. These flumes may be manufactured **from** wood, concrete, steel or prefabricated fibreglass, depending on size and location. For more details of these flumes see the Water Measurement Manual of the United States **Department** of the Interior, published by the Bureau of Reclamation. Alternatively, refer to Hansen *et al.* (1979).

Weirs (sharp crested)

These are overflow devices, where the water passes over a sharp crest. Also **known** as thin plate weirs. These can be accurate to within 2% or better, but have a more **limited** flow range than the flumes. Generally, weirs can only **measure up** to about 1000 L/s.

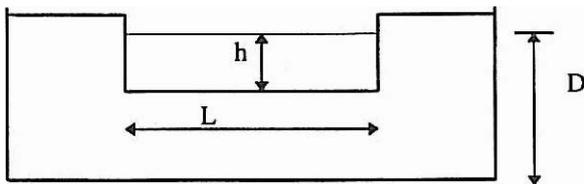


Figure 5: End View of Weir.

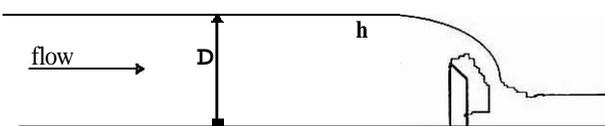


Figure 6: Section of Weir (showing overflow crest).

Table 1: Discharge for Parshall Flume

Head h (cm)	Throatwidth b(cm)				
	15	30	90	150	180
3	1.4				
4	2.3				
5	3.1				
6	4.5	9.8	27		
7	5.7	12	34		
8	7.1	15	41	67	79
9	8.6	18	51	83	99
10	10	21	60	97	116
11	12	24	69	112	133
12	13	27	78	127	152
13	15	31	90	148	176
14	17	35	101	165	190
15	19	38	111	183	218
16	21	42	122	201	240
17	23	47	137	225	270
18	25	51	149	246	295
19	27	55	161	266	317
20	29	59	173	286	342
21	32	64	190	312	374
22	35	69	204	336	404
23	37	73	216	358	430
24	40	78	234	383	464
25	43	84	266	414	495
26	45	89	276	440	525
27	48	94	286	463	555
28	51	100	299	496	595
29	54	105	309	522	625
30	57	110	320	550	660
32	63	122	350	612	734
34	70	134	380	680	810
36	76	146	410	740	880
38	83	157	440	810	970
40		170	470	880	1050
42		184	500	940	1140
44		198	530	1010	1210
46		210	560	1090	1310
48		230	600	1160	1400
50		240	630	1240	1490
52		260	670	1320	1590

The discharge Q over the weir is given by the equation:

$$Q = 2950LCh^{1.5} \tag{3}$$

Where Q is flow rate in L/s

L is width in m

h is head above weir in m

C is a coefficient, typical value 0.62.

Further information on these thin plate weirs is given in the Australian Standard AS 3778.4.1 (1991).

Pump Curves

It may be that a commercial flow meter is installed in the pipeline adjacent to the pump. In this case a **direct reading** of the flow can be made. However if there is no flow meter an estimate of the discharge may still be made by reference to the manufacturers curves for the pump characteristics. These show the discharge Q from the pump for given values of the Head H across the pump.

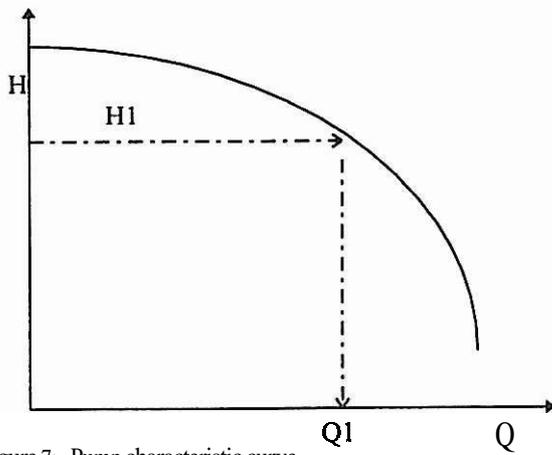


Figure 7: Pump characteristic curve.

Thus the head **H1** is read from the pressure gauge on the delivery side of the pump, and the flow **Q1** is read off the curve as indicated. If the head **H** is shown on the curve in metres and the pump gauge shows **kiloPascals (kPa)**, then the conversion of units is given by:

$$P = 9.81H \tag{4}$$

so a pressure (**P**) of 320 **kPa** is the same as 32.62 m head.

Jet Trajectory

A standard method of measuring the discharge from boreholes during water exploration is to measure the horizontal and vertical components of the jet trajectory as it emerges from the horizontal pipe attached to the bore. This same method can also be used where appropriate for measuring the flow from an effluent area prior to **utilisation** for irrigation.

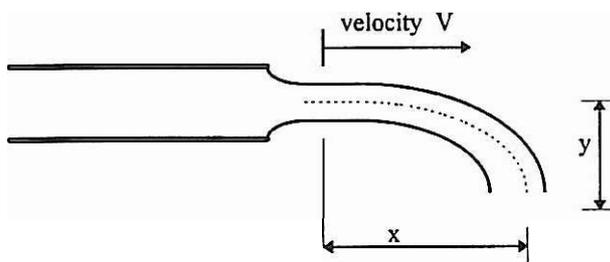


Figure 8: Jet trajectory.

This is shown diagrammatically in Figure 8. Note that the actual jet trajectory is a **parabola**. The jet contracts slightly as it emerges from the pipe. The dimensions **x** and **y** are measured with a rule as accurately as possible, to the centre line of the jet. Often this is done by means of two **rules** fixed together at right angles, which facilitates simultaneous measurement of both **x** and **y**. The velocity **V** of the jet as shown in Figure 7 is given by :

$$V = x(9.81/2y)^{0.5} \tag{5}$$

That is, the dimension **x** is multiplied by the square root of 9.81 divided by 2y. This is then **translated** to a flow rate by the following formula:

$$Q = VA \tag{6}$$

Where **Q** is flow rate in **m³/s**
A is area of jet after contraction in **m²**
V is velocity in **m/s**
x and **y** are in **m**.

The **units** can of course be manipulated, with care. It is probably best to keep all measurements in metres and then multiply the final result for **Q** by **1000** to convert to **litres** per second.

Modified Venturi Meter

The **Venhui** meter is a device similar to the Venturi flume, but it fits into a pipe rather than an open channel. It works on the principle that when a constriction or narrow section is placed in the pipe there is an increase in velocity head and a corresponding **decrease** in pressure head in the throat section.. The discharge of a conventional meter is given by:

$$Q = CK(2gh)^{0.5} \tag{7}$$

Where **Q** is flow rate in **m³/s**
C is a coefficient (for example, 0.98)
K is a constant for a given meter
h is pressure head drop in the throat

However, these commercial meters tend to be rather long and relatively expensive. A much simpler device is the orifice plate **which** is simply a **plate inserted into** the pipeline with a **hole** in it which is **about** half the diameter of the pipe itself. This also causes a pressure drop which provides a **means** of estimating the flow rate.. However, these devices cause considerable turbulence and head loss, and are not very accurate.

The author has developed a compromise between the expensive, accurate Venturi meter and the cheaper, but less attractive, orifice plate. This is a Venturi meter made up from available pipe components, so it is relatively cheap, but which involves the **gradual** change in flow path of the commercial **Venhui** meter. **Thus** the energy losses are small and the accuracy is high.

Flow measurement is facilitated by measuring the pressure drop across the meter and reading the corresponding flow rate from a calibrated chart. Current development indicates **high reliability** and that the device is relatively insensitive to small deviations from a horizontal alignment or rotation.

3. WATER QUALITY

The maintenance of water quality suitable for irrigation must be a **prime** objective in an environmental management plan. To dispose of water that may have a negative impact on the receiving soil and vegetation is counter-productive and will eventually result in degraded lands **and/or** loss of productivity. The aim of **effluent** disposal is to **maximise** the **return** of nutrients to the soil vegetation system, to enhance productivity and reduce the potential for off-site effects from **nutrients**. **Through** sound system monitoring the response of the **soil/vegetation** environment to

effluent disposal can be fine tuned to permit **sustainable disposal** options with a net production benefit.

4. BIOLOGICAL INDICATORS

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.

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

1. Those species normally present which can be usefully monitored for a change in quality;
2. Species not normally detected but if detected **in** certain concentrations can be useful indicators of altered quality; and
3. Indicators that are 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 pollution..

Species Richness

The biodiversity 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.

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.

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.

5. EXERCISE ONE - 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.

1. 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).
2. 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.

6. PHYSIO-CHEMICAL FACTORS

While the observation for 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.

Visual Clarity

The clarity of water is related to the distance at which a **Secchi** (black) disc can be viewed horizontally through the water. It is a measure of the transparency of the water to light. Turbidity is also a measure of visual clarity and is relatively easy to measure with **portable instruments**.

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.

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).

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 act as a shield, which prevents air-breathing organisms from reaching the atmosphere.

Odour

With experience, it is possible to train the 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.

Nuisance Plant **Growth**

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

7. **SOLID MATTER**

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). The test can be performed in a conventional oven set at 105°C, but a microwave oven may **volatilise** some of the organics.

**Total Solids = Total suspended solids (suspended, floating and settleable combined)
+ total dissolved solids.**

The quantity of solid **matter** in an irrigation supply will determine the type of pump, pipeline and irrigator nozzle configuration that can be employed 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.

8. EXERCISE TWO - 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**;
- 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:

1. Provide a settling sump at the pump pickup incorporating a large surface area filter to 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.
2. 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.
3. Complete each dirty water irrigation cycle with a **short** duration clean water application to make sure the **internals** of the irrigation system are clean.

9. 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 for carriage of many 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.

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 (<4) aluminium and many other metal ions become more soluble, such that in low pH water, aluminium and copper pipe 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 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.

10. EXERCISE THREE - 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.

1. Take a sample of water from the nominated location and dip a test strip into the water, remove and wait one minute before matching the colour pattern on the test strip with that indicated on the side of the box. Record pH to nearest unit.
2. Take a pH meter and calibrate according to manufacturer's instructions. The calibration will usually last 24 hours, 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 to 60 seconds) 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.

3. Take an electrical conductivity 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 ($1 \text{ dS m}^{-1} = 1000 \mu\text{S cm}^{-1}$).

To convert EC to an approximate value of TDS,

$$EC \text{ in } \mu\text{S cm}^{-1} \text{ multiplied by } 0.67 = TDS \text{ in mg/L.}$$

(Reference: APHA (1995) - Method 2510 Conductivity and Rayment and Higginson (1992) - Method B1b, page 218).

Sodicity and Salinity

The electrical conductivity 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} ($1000 \mu\text{S cm}^{-1}$) 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.

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 extracellular 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.

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 the ratio of the sodium concentration relative to the square root of half the sum of the calcium and magnesium concentration. All concentrations are in milli-equivalents per litre.

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

From the equation above, 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} ($1000 \mu\text{S cm}^{-1}$), a significant loss of hydraulic conductivity occurred on soils with a texture finer than a clay loam. Also refer to the demonstration of sodium effect on soil hydraulic conductivity in this workshop by Patterson and MacLeod (1996) "Soils and the effects of effluents - what do we measure?" (paper PEM007).

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.

Salt Leaching Fraction

Where the application of irrigation water is about 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:

Salt accumulation occurs where:

$$\text{rainfall} + \text{irrigation} < \text{evaporation} + \text{plant consumption}$$

(all units in mm effective depth)

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.

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).

A measure of the consumption of dissolved oxygen is given by the Biochemical Oxygen Demand - five-day test (**BOD5**), which records the consumption of oxygen over five days by bacteria consuming organic products 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 BOD5 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" (pages 2 to 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.

11. 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, **algacides** 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.

12. 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.

13. REFERENCES

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