Consideration of soil salinty when assessing land application of effluent

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Introduction

Wastewater from domestic residences, whether treated in an on-site sewage treatment system or in a large scale sewage treatment facility, results in an effluent that has a salinity level higher than the clean water input. The sources of salt include those salts from the human diet, food preparation, and activities for personal hygiene and other household cleaning. When effluent is applied to land, whether for simple disposal or for some beneficial use, the environmental effects of the added salt may cause serious physiological damage to plants or physical and chemical deterioration of the soil's ability to accept and further treat that effluent. This paper examines the sources and effects of salinity from domestic effluent.

Salinity Defined

Soil salinity is a characteristic of soils relating to their content of water soluble salts (Charman & Murphy, 2000). Typically inorganic salts are crystalline ionic products that dissociate in water to form positively charged cations (Ca^{2+}, Mg^{2+}, Na^+ , K^+, Al^{3+}, Cu^{2+}, Zn^{2+}, Fe^{2+}) and negatively charged anions (Cl^-, NO_3^-, PO_4^{3-}, SO_4^{2-}, CO_3^{2-}, HCO_3^-). The proportions of cations and anions in the natural soil water solution are a function of soil type, climate and land use. While sodium chloride (dissociates to Na^+ and Cl^-) may be found in soils, there are many soils in which sodium sulphate, sodium carbonate and sodium bicarbonate, and the less soluble calcium carbonate and calcium sulphate and magnesium salts are dominant. Many of the insoluble inorganics may become soluble as pH alters. Other soluble compounds, such as organic products, may be present but do not dissociate into ions.

Saline soils contain relatively high concentrations of soluble salts. The term "salinity" does not differentiate between the type or proportion of ions (cations or anions) present in the soil solution. Many of the soluble salts are essential plant nutrients at 'normal concentrations' but may be 'toxic' at high concentrations and present 'deficiency' symptoms in plants at low concentrations. Thus, the concentration and relative proportions of these salts play a critical role in the "salinity hazard" of soil.

Soils have a salinity problem when the level of soluble salts increases to cause one or more of the following problems:
- loss of plant productivity or vigour;
- saline water discharges to surface water or saline leaching to groundwater;

- salt formation on the surface of the soil;
- increased erosion due to loss of vegetative cover;
- loss of soil permeability;
- formation of a sodic soil (sodium rich) from the sodium salts; or
- changes in soil pH due to exchangeable cations from the saline effluent.

Saline soil may have a favourable structure because the clay colloids are flocculated at high salinity levels (Foth, 1978), but the effects upon plant growth may be detrimental.

Measurement of Salinity

Soluble salts dissociate in water to release cations and anions that can conduct an electric current. Thus, the simple measurement of how much current an aqueous solution will carry can be related directly to the amount (concentration) of salt present. Electrical conductivity is measured using a conductivity meter and electrical conductivity (EC) reported in the international units of measure as deciSiemens per metre (equivalent to milliSiemens per centimetre).

Smaller units of microSiemens per centimetre are commonly used for low salinity recordings.

$$1 \text{ dS m}^{-1} \quad = \quad 1 \text{ mS cm}^{-1} \quad = 1000 \text{ uS cm}^{-1}$$

As with all scientific instruments, conductivity meters require calibration against a solution of known EC at 25°C and regular maintenance is critical to accurate measurements. Small pocket-type instruments are suitable and sufficiently robust for most field work and can be used for measuring EC in water or soil/water suspensions.

The measurement of soil salinity poses concerns about the accuracy of such measurements. While there is much debate about measuring the EC_{SE} of saturated extracts of soil solutions compared to the $EC_{1:5}$ of suspensions of one portion of soil to five portions of distilled water (1:5 soil/water suspension), the latter method is routinely used in laboratories because it is the easiest technique and produces the largest quantity of solution for analysis (Shaw, 1999). However, there is a significant difference between the two methods and the method of measuring EC should always be reported with the results as comparison between the two methods is difficult. When the subscript is not reported, the method is usually the 1:5 soil/water suspension method as described in Rayment & Higginson (1992).

A conversion factor for translating EC_{SE} to $EC_{1:5}$ will depend upon the clay content of the soil and should be used with caution. For example, Charman & Murphy (1998) quote a factor of 8.6 for converting a clay loam $EC_{1:5}$ to EC_{SE}, 7.5 for a light clay and 5.8 for medium or heavy clays. For example, if the $EC_{1:5}$ in a light clay was 0.45 dS m^{-1} then the approximate EC_{SE} would be 0.45 x 7.5 = 3.38 dS m^{-1} as EC_{SE}.

Soil salinity levels are dependent upon the nature of the clay minerals. Merry (1996) cites the work of Cass *et al.*, (1995) to indicate the range of soil $EC_{1:5}$ values that may be critical to plant growth. These values apply to effluent application whether by surface or subsurface irrigation.

Soil salinity is usually referred to in terms of EC (in units of dS m^{-1}) while the salinity of water may be referred to when the EC of a fresh sample is converted to a salinity reading in milligrams per litre (that is, a mass of salt per unit volume). The factor for converting EC (in dS m^{-1}) to total dissolved solids can vary from 550 to 900 depending upon types of salts dissolved, but for agricultural purposes Raymond& Higginson (1992) suggest:

Total dissolved solids (mg L^{-1}) = EC (dS m^{-1}) x 670

It is incorrect to report salinity or electrical conductivity with units of EC. The units of electrical conductivity are deciSiemens per metre (dS m^{-1}) and units of salinity are milligrams per litre (mg L^{-1}).

Salinity classes can be rated according to the measured EC:

Class 1 low salinity water   0 - 0.280 dS m^{-1}
Class 2 medium salinity water   0.280 - 0.800 dS m^{-1}
Class 3 high salinity water   0.800 - 2.300 dS m^{-1}
Class 4 very high salinity water   2.300 - 5.500 dS m^{-1}
Class 5 extremely high salinity water above 5.500 dS m^{-1}

Table 1. *Interpretation of Soil EC with respect to clay content*

Salinity Hazard	Effect on Plant Growth	Class	EC of 1:5 soil/water extract (dS m^{-1})				
			sand/loamy sand	loam	sandy clay loam	light clay	heavy clay
Non-saline	negligible effect	1	<0.15	<0.17	<0.25	<0.30	<0.40
Slightly saline	very sensitive crops affected	2	0.16-0.30	0.18-0.35	0.26-0.45	0.31-0.60	0.41-0.80
Moderately saline	many crops affected	3	0.31-0.60	0.36-0.75	0.46-0.90	0.61-1.15	0.81-1.60
Very saline	salt tolerant plants grow	4	0.61-1.20	0.76-1.50	0.91-1.75	1.16-2.30	1.61-3.20
Highly saline	few salt tolerant plants grow	5	>1.20	>1.50	>1.75	>2.30	>3.20

Sources of Soluble Salts

When soils are irrigated with effluent from various sources, both inorganic and organic salts are added to the soil from that source. In the case of domestic wastewater, soluble salts are derived from many sources including the potable water supply, human diet, and cleaning products such as soaps and laundry detergents. Some toiletries and medicines also contain heavy metals that become part of the wastewater stream. The organic compounds in these products do not alter the EC readings.

Potable water supply

The source of potable and other water supplies used in the domestic household may provide a significant source of soluble salts to the wastewater stream. Rainwater is very low in soluble salts (EC < 20 uS cm^{-1}) while groundwater (bores and wells) may be extremely saline (EC > 2 dS m^{-1}). Patterson (2000) indicated that potable town water supplies across northern New South Wales varied from an average of 0.140 dS m^{-1} for 25 coastal towns (max. 0.340 dS m^{-1}) to an average of 0.433 dS m^{-1} for 18 inland towns (max. 1.05 dS m^{-1}).

Figure 1 indicates the frequency analysis for the potable water supplies when EC is converted to total dissolved solids.
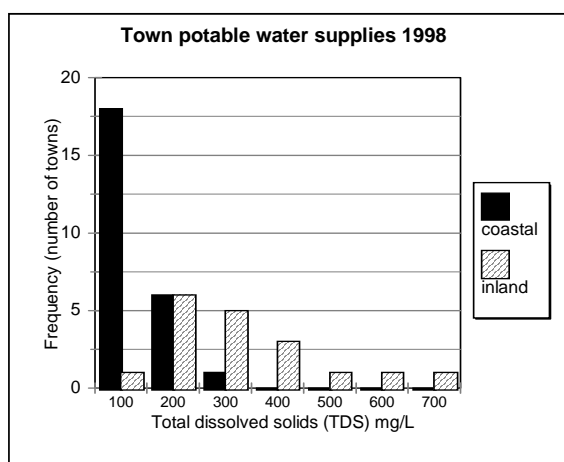

Figure 1. Frequency analysis for potable water supplies across northern NSW in late 1998

Other water supplies available for use in the home include groundwater (bores and wells) and surface waters. These supplies also vary considerably in their salinity levels depending upon the hydrogeology of the aquifer (water bearing stratum) and pollutants entering the water from drainage or surface runoff.

While the EC of groundwaters may be similar for granitic and basaltic aquifers, the composition and proportions of the various soluble salts may vary considerably. Patterson (1994) recorded salinity levels of 34 to 2418 mg L^{-1} in groundwater from sedimentary aquifers, 135 to 1870 mg L^{-1} from granitic aquifers and 220 to 2650 mg L^{-1} from basaltic aquifers. Many of these waters were used for domestic purposes and added to the total salinity of the wastewater, depending upon use and dilution with water from rainwater or town water.

Human diet

Soluble inorganic salts as well as organic compounds are added to the wastewater stream from toilet use (faeces and urine) that reflect the diet of the people in the household and vary accordingly, often from day to day. Nitrates, phosphates, sulphates as well as sodium chloride (common salt), salts of calcium and potassium are among the inorganic salts released from food preparation.

Detergents, soaps and cleaning agents

A significant proportion of inorganic salts enter the domestic wastewater stream from personal toiletries (hair conditioners, soaps, cosmetics) and from domestic cleaning products used in the laundry and kitchen. Powdered laundry products and dishwashing powders add significant levels of phosphates, sulphates and carbonates attached to sodium cations, elevating the EC of the wastewater into levels that present a salinity problem to the effluent disposal area. Significant changes to wastewater pH, above pH 10, may cause further displacement of salts from within the soil profile.

A range of 36 laundry powders and 16 liquid detergents were mixed at the recommended concentration for an automatic top loading washing machine's full water load. The EC of the water was
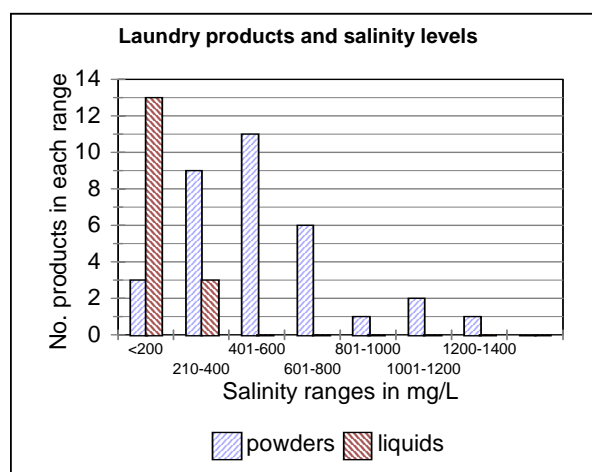

Figure 2. Salinity levels from recommended doses of laundry products in rainwater.

measured and converted to total dissolved solids. Figure 2 shows the frequency analysis of the salinity levels measured on those samples. It is clear that laundry detergent powders impart a higher salinity level to domestic wastewater than from liquid laundry detergents. Not only do the laundry products directly add to soil salinity but increases in pH of the effluent may further influence soil properties and release additional soluble salts, including heavy metal release.

Figure 2 does not allow the determination of the concentration or proportion of individual ions, only the total measured salinity value. An important feature of the laundry wastewater is that the salts are mainly sodium phosphates and sodium carbonates, with sodium sulphate occurring as a filler, taking no active part in the washing action.

Typical domestic effluent salinity levels

The changes to salinity levels in domestic wastewater are a function of the individual household and the activities and chemicals used on a daily basis. Patterson (1994) reported EC values for a survey of 50 homes having a mean value of 1.4 dS m^{-1} for a range of 0.50 to 5.0 dS m^{-1}. These values convert to a salinity range of 335 to 3350 mg L^{-1} (mean 940 mg L^{-1}).

For a daily water use of 900 litres per household per day, the amount of salt added to the effluent application area, based upon the average salinity value, can amount to 308 kilograms of salt per year. Based upon a typical domestic on-site application area of 200 m^2, the average salt application is in the order of 5.5 tonnes per hectare per year. By any gauge the application of 5.5 tonnes per hectare per year is likely to cause a significant salinity hazard, even in the short term. At the highest salinity value (3350 mg L^{-1}) 1100 kilograms of salt per year, or 15 tonnes salt per hectare per year become part of the salinity hazard.

Many of the salts added to domestic wastewater are based upon sodium salts, such as sodium chloride (common salt) from the human diet, sodium nitrate from meat preservatives and food preparation, sodium sulphate, sodium tripolyphosphates and sodium carbonates in laundry products and sodium stearates in soap. Sodium salts, being extremely soluble, cannot be removed from solution by precipitation (forming an insoluble compound and settling out) nor can they be biologically degraded to non-ionic forms. Therefore preventing these salts from entering the wastewater stream is the only remedy to the high salinity hazard from domestic wastewater.

It is not sufficient to simply reduce the water consumption through the installation and use of water conservation devices if the commensurate reduction in salt loading is not implemented, otherwise the salinity levels increase, even though there is no change in the annual load.

Whether by conventional septic tank, aerated wastewater treatment system, sand filter, peat bed treatment, extended aeration or conventional sewage treatment, most of the salts remain in the effluent. When chemical dosing with ferric chloride ($FeCl_3$) is used to remove phosphorus from sewage effluent, the loss of phosphorus salts by precipitation is replaced by chloride salts moving into solution, often for an overall increase in salinity.

Land Application of Domestic Wastewater

The calculation of the annual salt load indicates that the salinity hazard from domestic wastewater is high, particularly where the effluent is applied to a small area of land, such as for on-site disposal. Salt (importantly all salts) are likely to build up in evapotranspiration areas, within traditional drainfields and rise to the surface of these systems and impinge upon the vegetation. Shaw (1999) stated that soil salinity can have major impacts on plant productivity and vegetation. For example, white clover (*Trifolium repens*) can suffer a 9.6% decrease in productivity for each 1 dS m^{-1} increase in soil solution $EC_{1:5}$.

High salinity values may impart a flocculated nature to soils (soil particles aggregated together to allow the development of micropores) and lead to an increase in permeability (movement of water through a soil) as shown by Quirk and Schofield (1955) in their development of a threshold electrolyte concentration. For this reason gypsum or lime can be added to a soil to overcome some of the problems with specific soil salinity problems and accelerate the leaching of salts from the root zone.

Recognising detrimental effects of salinity

Saline soils have sufficient soluble salts to impair plant growth, mainly by increasing the osmotic pressure of the soil (the soil water pulls against the suction by the plant) and restricts water uptake. Plants under this stress will appear to be water stressed or 'drought' stressed, with the margins of the leaves more seriously affected or dying. The soils require leaching to move the salts out of the root zone and deeper into the soil profile.

High salinity levels may cause soil inorganic fractions to coagulate (flocculate) but the concentration of salt may cause the organic colloids

to disperse and drain from the soil profile. Saline seeps are often coloured with dispersed organic colloids (Leeper & Uren, 1993). Thus the loss of coloured water from saline areas will signal the loss of important soil binders and plant nutrients as well as indicate a saline soil profile.

Salt blooms on the surface of an effluent application area indicate that the salts are moving to the surface with the capillary water (capillary water moves upwards in response to evaporation from the surface). The salinity will encourage only salt tolerant species to develop or may be sufficiently high to retard all growth and so present a severe erosion hazard. Couch grass (*Cynodon dactylon*) has a high tolerance for saline soils and is often used as an indicator species.   Under domestic on-site effluent disposal practices, the loss of soil permeability is difficult to measure or monitor and may not be related solely to salinity or sodicity but to design criteria. Soil structural stability and the maintenance of open soil pores for the movement of water and salts out of the root zone is important in the design of on-site systems. A soil without adequate drainage will simply accumulate salts until the effects of high salinity reduce the value of the effluent application area. All effluent application areas should be designed for some form of leaching to occur down the profile, either through excess irrigation or under natural rainfall.

When sodium salts reach high levels the soils may disperse (colloids separate in water) and the soil pores become blocked with the subsequent capture of the colloids. Such physical blocking of the soil pores cannot be reversed chemically and the permeability of the effluent application area will be reduced. In traditional subsoil drainfields, this loss of permeability may cause effluent to rise to the surface, bringing saline waters and adding to the overall salinity hazard.

Leaching salts from the root zone

While rain will provide some leaching of salt down through the soil profile out of the root zone, the low EC of rainwater (<0.02 dS m^{-1}) may cause salts within the soil profile to mobilise and increase the EC of the soil solution. Rengasamy and Olsson (1993) stated that when saline and sodic soils (sodium rich salts in the soil) are leached with rainwater, clay dispersion (opposite to flocculation) in the surface layers leads to water logging and soil erosion.

By providing additional effluent irrigation water, it is possible to leach some of the salts from the root zone into the deeper soil profile. This leaching fraction can be calculated for agricultural enterprises from the salinity of the effluent compared with the salinity of the soil solution. In evapotranspiration beds where no soil absorption is possible, the gradual accumulation of salts may be a serious problem as no flushing of the salts from the root zone is provided and only water is lost through evaporation from the system. In subsoil systems, such as traditional drainfields, some of the salt is leached from the profile as water moves laterally and vertically through the profile.

Conclusion

Saline soil has a detrimental effect upon plant physiology and soil physical and chemical properties. In domestic wastewater management, the prevention of salts entering the system is the only practical solution to problems arising from land application of the effluent. Treatment processes generally do not remove salts from the effluent stream and remediation of the land application areas may be expensive.

The above outline of salinity of soils and waters needs to be read in conjunction with the paper on "sodicity" with which it may be associated. Not all saline soils are necessarily sodic but the saline effluents may induce sodicity as may effluents that are alkaline (high pH).

The effects of salinity may be recognised by the effects upon plant productivity, leaf margin analysis or soil permeability. In many cases salinity will only "raise its ugly head" when the problem has reached environmentally hazardous levels. Domestic wastewater inputs need to be modified to avoid potential salinity and sodicity problems with land application area.

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