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So dium as a Source of Water Pollution

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SUMMARY Sodium may have the potential for greater environmental degradation from wastewater disposal than the pollutant nitrates and phosphates. The need for effluent disposal by on-site septic tanks or sewage treatment plants has not addressed the problems associated with exchangeable sodium percentages of the soil or the sodium absorption ratio or specific conductance of the wastewater. Two effects may be swelling and/or dispersion. The latter is irreversible requiring prevention before cure when disposing of wastewaters to susceptible soils. This paper addresses those problems and examines the qualities in relation to wastewater.

1 INTRODUCTION

On-site disposal of septic tank effluent to the soil system and the return of treated wastewaters to the hydrologic cycle are both regulated by codes of practice or standards based upon the effluent and the receiving medium. Soil potential for on-site disposal, as defined by Steele et al, (1986) is rated on seven categories: depth to bedrock, depth to fragipan, depth to seasonally high water table, soil percolation rate, slope, surface stoniness and landscape position. Anderson et al (1978) relate important site characteristics to soil type and thickness, groundwater proximity, hydraulic conductivity and topography. Each has neglected the effects upon soil structure and porosity of the characteristics of the effluent given by qualities such as Sodium Absorption Ratio (SAR) and electrical conductivity (EC).

The hydraulic conductivity measurement espoused by the common references to size drainfield absorption areas (Parker et al, 1978; Winneberger, 1984; USEPA, 1980) including New South Wales Health Commission (undated leaflet)and the Victorian Health Commission (1983) is based upon a modified Ryon's Curve (cited in Olivieri et al, 1981), commonly known as the percolation test. Few researchers have acknowledged the significantly higher percolation rates obtained in the test compared with the long term functioning of traditional on-site disposal trenches. Brouwer (1982) recommends for Victoria, that only by an identification of soil type with actual satisfactory functioning can a rating be placed upon suitable disposal criteria such as trench length and dosing rate.

That the need of effluent disposal to either soils or river systems has not addressed the problems associated with Exchangeable Sodium Percentages (ESP) and Sodium Absorption Ratios (SAR) in relation to specific conductivity is difficult to understand. None of the American literature available for on-site disposal indicates sodium concentrations in effluent. A study of New South Wales sewage treatment plants (SPCC, 1978) did not measure the SAR or sodium ion concentrations even though 60% of the plants emptied treated effluent into natural water courses. It is not denied that the qualities measured (BOD, TOC, TSS, nitrate, phosphate and coliforms) are not necessary for protection of the environment and the resources. The requirements for irrigation water downstream is one justification for monitoring and controlling the sodium ion concentration in wastewater disposal. Guidelines for disposal of wastewaters on land by irrigation in Victoria do address the salinity and sodicity limitations (EPA, 1983). The re-use of wastewater is now commonplace in semi-arid Australia as indicated by Phillips (1977). While the effects of sodium on the hydraulic conductivity of soils have been well researched (Blackmore and Marshall, 1965; Emerson, 1977; Frenkel et al, 1978; McIntyre, 1979; Jayawardane, 1979; and Bresler et al, 1982), their application to wastewaters is neglected. The Glenelg Plant in South Australia, offering much of its treated water for re-use, has an average salinity of 1500 mg/l and an SAR of 9, placing the water in a medium hazard class (Phillips, 1977). However, the sandy soils within the district allow salts to be leached through the profile without creating a sodic problem. The same could not be said of the potential for re-use around major New South Wales centres.

This paper reviews a background of research relevant to the effects of sodium on Australian soils with particular emphasis on the implications for subsoil disposal of septic tank effluent and treated wastewater into river systems. It becomes obvious that the sodium ions in wastewater should not be ignored in context with environmental and water resource protection. The quantification of sodium in domestic effluent is part of this analysis. Salinity in this used to refer to the total ionic concentration of all salts in the soil solution while sodicity refers specifically to sodium concentrations.

2 SODIUM IN THE ENVIRONMENT

2.1 Sodium - Toxic or Essential

Sodium is the predominant ion circulating in the plasma of warm and cold blooded animals alike. Its function is to provide a constancy of osmotic pressure, an acid-base balance and a fluid volume to protect the cells from the external environment (Denton, 1982). Body salts of sodium, potassium, calcium and magnesium are roughly in the ratios 150:5:5:2 in vertebrates alike. A deficiency in sodium invokes a "hunger for salt' innate in all animals (Denton, 1982), while an excess may reduce plasma potassium levels leading to circulatory inadequacies (MacFarlane, 1971). In plants sodium contributes to alterations in cellular ionic concentrations and membrane permeability (Campbell and Pitman, 1971). Plants are more sensitive to higher concentrations of sodium when potassium concentrations are low. Since plants, unlike animals are unable to excrete excess sodium, the leaf may have higher sodium levels than those exposed to the higher saline concentrations in the root system. This excess sodium may lead to leaf abscission, but not at the same concentration for all plants. Agronomists select grasses and crops able to tolerate varying levels of salinity.

Sodium, like all cations, can be transported in the soil by mechanisms such as: mass movement of the solution; mechanical dispersion between moving particles and the soil particles; and molecular diffusion without solution flow (Peck, 1971; Bresler, 1982). Factors which affect the movement patterns include soil moisture content, tortuosity of the diffusion path and concentration gradient. The two former conditions are interrelated to soil type, i.e. clay content. Kemper and Van Schaik, 1966 cited in Bresler et al (1982) have shown that the solute diffusion coefficient for clay/water systems is a positive exponential function of water concentration and for practical purposes is independent of salt concentrations. Thus Australian soils, generally higher in clay content than American soils have a greater ability to translocate salts and the higher surface area of the clay colloid means that the soil has a greater affinity for ions such as sodium and potassium.

Ions adsorbed to clay (or humic) colloids may be released at a later stage when the ionic concentration gradient reverses under conditions of leaching with dilute solutions. This can occur when soils high in adsorbed ions are leached with rainwater (of extremely low specific conductivity), thus increasing the concentration of the entering solution. This fact is appreciated by irrigation technologists who control the total salt concentration of all irrigation waters to avoid the release of adsorbed ions into the soil solution.

2.2 Sodium and Hydraulic Conductivity

Hydraulic conductivity as a measure of the infiltration capacity of a soil is dependent upon macroporosity. A decrease in the pore size may be induced by swelling of the soil particles, or blocking of the pores with transported material. The former, swelling, occurs preferentially in decreasing order of montmorillonite, illite and kaolinite clays. Briefly, the osmotic repulsive forces between clay plates give rise to the swelling, sodium clays providing almost twice the force as calcium clays (Quirk, 1971). Clays saturated with sodium ions may increase their volume 100% or more in the presence of dilute solutions. Thus porosity may be reduced by swelling, more in the sodium saturated clays than the calcium clays. Emerson (1977) states that for a given ESP, where magnesium was the principal cation rather than calcium, swelling was most pronounced. The waters examined in this paper have sodium as the principal cation. Soils high in organic colloids are more stable under adverse conditions (Bresler, 1982).

Dispersion is the complete separation of clay particle as a result of the'reduction in attractive forces between contiguous clay crystals to such an extent that thermal forces cause the particles to behave independently of one another (Quirk, 1971). In a dispersed state, particles are able to move separately within the soil solution and may become lodged within the microporosity of the soil medium. Thus, hydraulic conductivity may be reduced by blocking. While swelling is a reversible condition, that is under dehydration, blocking of pores by dispersed particle is irreversible. The implications of this for on-site disposal are paramount to prevention rather than cure.

2.3 American Versus Australian Soil Data

The majority of on-site disposal practices employed in Australia have been 'borrowed' from American research and development. The design and dosing rates in the American system are based upon soils which are more coarsely textured than Australian soils which are predominantly clays of fine texture (McIntyre, 1979). However, in designing traditional on-site drainfields, while clogging layers in the bottom absorption area have been addressed (Kropf, 1975) in relation to the decrease in hydraulic conductivity due to their slow permeability, no mention has been made of the effects of the sodium ion concentration in either the soil or the effluent. The notion of the effect of exchangeable sodium percentages on reduced infiltration is not new. United States Salinity Laboratory Staff (1954) and in Australia, Northcote and Skene (1972), Emerson (1977), Jayawardane (1979) and McIntyre (1979) have examined the effects of sodicity on hydraulic conductivity. There is general agreement between researchers of the two continents of the principles involved in the initiation of swelling and dispersion but not on the point of stability. The USSLS (1954) considers a soil of ESP 15 and above as unstable whereas a value of ESP 6 has been suggested as the lower limit for Australian soils (Northcote and Skene, 1972) or ESP 4 by McIntyre (1979). Whether the latter two figures are accurate is less important than the degree of variation between the two continents when referring to a quality of a soil for a particular use, in this case the disposal of wastewater.

2.4 Implication for Wastewater Disposal

The design of on-site disposal trenches is based upon modified Ryon's percolation tests. The sizing of the trench is calculated considering preferential infiltration of the bottom area over the sidewall area. While the reduction in bottom area infiltration is acknowledged in relation to the formation of a clogging layer (Kropf et al, 1975), no consideration has been made of the loss of hydraulic conductivity by the SAR and EC of the effluent. An example of the expected loss of hydraulic conductivity can be gauged from the graph below which indicates the loss in relation to EC and SAR. The implications to the soil disposal medium are that while an SAR of 10 is possible, ECs are usually less than 1.0me/1 (10mS/m).

A similar situation exists for the disposal of treated sewage wastewaters where downstream users are involved in irrigation, or where another community requires that water for re-use and treatment. The sodium ions in solution are not removed in the treatment process and the possibility of unacceptable levels of sodium compounding over time is high.

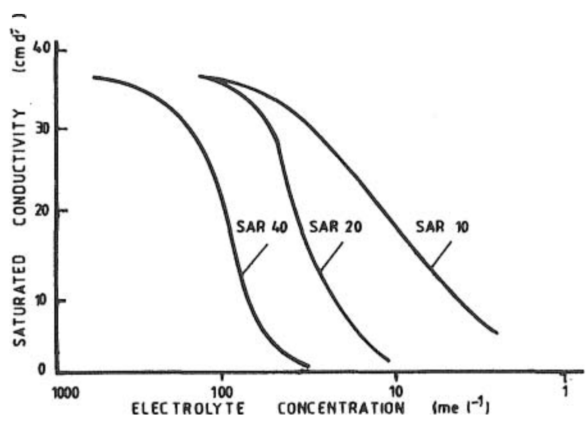

Figure 1 Relationship of Hydraulic Conductivity to SAR and EC (after Jayawardane, 1979)

3 FIELD RESULTS

3.1 Measured Sodium Levels

As part of a larger project specifically investigating on-site domestic effluent disposal, it became apparent that the high failure rate of disposal drainfields could not be attributed merely to a design fault or lack of maintenance. However, while Patterson et al (1986) found that trench lengths were inadequate for the volume of daily inflow to the system, the problem of sodium in the effluent was recognised.

Analyses were made of the effluents from domestic septic tanks in the Armidale area together with those of the water source. Measurements were also made of SAR and EC for the Armidale reticulated water supply and at various points in the sewage treatment system and discharge watercourse. Other readings were taken at the local livestock saleyards and at Dumaresq Creek and Martins Gully within the city boundary. These measurement were made simply to quantify the concentration of sodium ions in the environment of human activity and not to isolate particular problem areas.

3.2 Analytical Methods

Sodium and potassium concentrations were measured by flame photometry in milligrams per litre. Calcium and magnesium were measured on a Varian AA-175 Atomic Absorption Spectrophotometer and converted to milligrams per litre. Calculations of SAR (all values in milliequivalent) were made using' the equation:

$$SAR = \frac{Na^{+} + K^{+}}{\sqrt{(Ca^{++} + Mg^{++})/2}}$$

A sodium absorption ratio of 5 is considered the lower limit of suitability for water to be used for irrigation (Victoria EPA, 1983). Specific conductivity was measured as electrical conductivity in milliSiemens per metre and converted to milliequivalents per litre as defined by Hem (1982). 100 milliequivalents approximates 1 microSiemen per centimetre, variation occurring with different combinations of ions.

Exchangeable sodium percentages were measured using cation exchange methods of flushing a soil sample with alcohol and extracting exchangeable cations in an ammonium acetate solution. Cations were measured as for SAR. The sodium ion concentration was related to the total exchange capacity of the soil, expressed as a percentage. It was stated earlier that Australian researchers suggest an ESP of 5 as a limit significant for initiating soil structural problems.

3.3 Sodium Within the Household

Sodium, other than as an essential salt in the diet, is used in quantities approaching 50 kilograms of sodium per household per year as laundry detergent in which sodium sulphate is used as a filler. Additionally sodium perborate is used as a bleach, sodium tripolyphosphate, sodium silicate or sodium carboxymethylcellulose are used to assist surfacant activity. Sodium hypochlorite is the basis of many bleaches and disinfectants. A survey conducted of 27 households showed that the use of laundry powders and detergents was often in excess of manufacturer's recommendations of 120 grams per load for an automatic washing machine. Automatic machines were in use in 50% of all dwellings surveyed. Several manufacturers recommend half the volume of powder in a twin tub or front loading machine. Considering most of these types have only half the load washing capacity of automatics, the input of sodium to the system at the end of the washing day would be the same.

3.4 Sodium and Wastewaters

Sodium, as a constituent of the septic tank effluent, and specific conductivity as a measure of the total soluble salts (TSS) are given in Table I

TABLE I
SODIUM LEVELS AND SPECIFIC CONDUCTANCE OF DOMESTIC SEPTIC TANK EFFLUENT AND GROUNDWATER RESOURCES.

	sodium mg/1	SAR	EC mS/m (me)
Effluent mean	159	9.6	120 (0.12)
Effluent highest Na^{+}	206	12.3	110 (0.11)
Effluent lowest Na^{+}	136	8.6	140 (0.14)
Groundwater Mean Na^{+}	62	1.4	70 (0.07)
Groundwater Highest Na^{+}	36	2.1	245 (0.25)
Groundwater lowest Na^{+}	102	1.6	47 (0.05)
Armidale City Water Supply	35	2.0	30 (0.03)

below averaged over 16 septic tanks. The water input to each was rainwater collected from roof catchment and stored in concrete tanks. Average values of sodium ion concentrations for groundwater resources are included in the table to indicate the additional sodium concentrations input to the septic tank system. All the groundwater was derived from aquifers having basaltic landscapes as recharge areas, thus a high level of sodium is not to be expected. Pew groundwater resources are found in granites around Armidale.

Sodium is used in the treatment of water in the Armidale City Water Supply, as is the case in all treatment works. An average untreated water drawn from the Malpas Dam (mostly basaltic landscape) has a sodium value of approximately 20 mg/1.

The effects of septic tank effluent upon the receiving soil are such that at an SAR 10 and an electrolyte concentration of one tenth of one milliequivalent per litre (me/1), according to graph Figure 1 (Jayawardane,1979) the right most curve should be followed. At such a low electrolyte concentration the basaltic clay, as used to compile the graph, infiltration would be extremely low. Since the majority of septic tank effluent disposal fields in Armidale and the North Coast regions are constructed in the clay B horizon, the possibility of halting infiltration is quite high. Where ESP is higher, such as for the solodics, before the additional effects of the effluent, the potential for soil disposal is decreased rapidly. It may be also that at an SAR 2 and a low electrolyte concentration of 0.03me/1, that treated water is unsuitable for irrigation of soil which has an ESP above the ESP 4-6 documented previously.

In examining the influent/effluent from the Armidale City Sewage Treatment Works, as well as water from Dumaresq Creek and Martins Gully within the town boundary, a sample was taken from the overflow of the primary treatment lagoon at the Armidale livestock saleyards. The results of that examination are tabulated below. Due to the current drought (Dec. 1985-present, June 1986) there have not been any flows through the two watercourses or the saleyard complex since the project commenced. In effect there has been no flushing of the surface system either to remove sodium as runoff or to draw sodium into solution by the influx of low EC rainwater. Similarly there has been little dilution of the treated effluent in the receiving waters as given in Table II.

Martins Gully would, in times of overland flow include the runoff waters from the saleyards. The similarity of sodium ion concentrations bears this out while the loss of EC would be in the loss of organic salts in the watercourse to soil and organic matter sediments. The data indicates that the lower limit of SAR 5 is closely approximated for three of the waters. Evaluation of soil suitability before irrigation would be essential to avoid the potential for soil structural problems.

It is simply calculated that by irrigating with the treated wastewater, that the application of each millimetre of irrigation water adds 6 kilograms of sodium to each hectare, The use of 1 metre of water therefore adds 6 tonnes of sodium per hectare. That level of application would require careful management to prevent loss of production.

3.5 Effects of Effluent on ESP

The ESP of a failed soil absorption trench was measured at two control points (unaffected by effluent), 5 positions along and within 600mm of the trench sidewall and three downslope surface positions where effluent had been overspilling

TABLE II
SODIUM, SAR AND EC FROM INFLUENT/EFFLUENT AT ARMIDALE SEWAGE TREATMENT WORKS, AND OTHER LOCATIONS IN ARMIDALE.

	sodium mg/1	SAR	EC mS/m	(me/1)
ASTW raw water influent	60	4.7	70	(0.07)
settled wastewater	66	4.9	85	(0.09)
after aeration	54	4.9	77	(0.08)
pond exit	48	3.3	62	(0.06)
natural receiving waters	~~245~~ 25	1.6	34	(0.03)
downstream (5km)	46	3.0	52	(0.05)
Dumaresq Creek	54	2.7	74	(0.07)
Saleyards	100	3.6	215	(0.2)
Martins Gully	100	4.8	60	(0.06)

the surface for 15 months. The soil was a grey brown podzolic, a clay loam A horizon, a loam to sandy loam A2 and a medium clay B horizon having iron and manganese nodules and exhibiting mottling. From a control of ESP 2 in the B horizon, those positions along the trench rose to ESP 7 while the overspill sites rose to ESP 11. At one site where effluent was moving through a sandy loam A2 horizon, ESP 13 was measured. The latter did not disperse due to the sandy loam texture, however, all other samples greater than ESP 3 dispersed when placed in distilled water. Since the concentration of the septic tank effluent is also extremely low (0.1 me/1) similar dispersion within the soil profile could occur. The dispersed material providing a mechanism for irreversibly blocking the soil pores.

3.6 Design of on-site disposal drainfields

Brouwer (1982) has suggested that only by examination of existing drainfields is it possible to classify a soil type to a suitability class. That would require exhaustive analysis of the present dosing rates as well as the competency of the constructor, internal failures within the trench and solids carry-over from the septic tank into the drainfield, to name a few. Bresler et al (1982) have stated that empirical equations are of little value since they fail to account for the loss of hydraulic conductivity due to swelling and dispersion, while Kropf (1975) indicates that the infiltration rate is determined by the permeability of the clogging layer. While the latter may be so, the infiltration laterally into the sidewalls is not so affected by organic clogging but will be by swelling and dispersion. It remains, therefore, that analysis of the effects of the sodium to swelling and dispersion should be undertaken for each soil type in areas required for on-site disposal and for disposal of wastewater from treatment plants, relating both properties to the SAR and EC of the effluent, while measuring the ESP of the soil. This research will not improve the problems of failure in existing systems but will allow for amelioration of the soil prior to disposal to prevent dispersion in newly constructed systems.

4 CONCLUSION

Monitoring the SAR and EC of both septic tank effluent and sewage treated wastewaters will allow for development of a strategy for disposal based upon predicted impact of that effluent on the swelling and dispersion of the soil receiving medium. As the problem of high SAR, low EC water has been managed in irrigation farming by the use of appropriate electrolyte concentrations, so too must wastewater be amended to increase the electrolyte concentration to a level which will maintain a flocculated state within the soil. The problem of ameliorating domestic effluent is specific to household production of sodium and the specific soil ESP and texture.

Disposal of treated wastewater to a natural water course is not the answer unless the SAR and EC are environmentally acceptable for the particular downstream conditions. Downstream users, by adding their sodium wastes, compound the potential for sodic conditions.

Thus sodium may have the potential for greater environmental degradation than the nitrates and phosphates presently considered the contaminants of disposal areas. While nitrate and phosphate may be removed, at a cost, the ability to remove sodium is more difficult since nearly all sodium salts are highly soluble. Thus amelioration with divalent ions may offer a solution since prevention is better than cure when associated with dispersion. Emerson (1977) has indicated a potential problem with magnesium salts while aluminium will create a toxicity and iron may cause precipitation of essential plant nutrients. Calcium, preferably as calcium sulphate (gypsum) may provide the key to amelioration of both the effluent and the soil.

The alteration of design based upon both clogging layer and the effects of sodium does not negate the need for water conservation within the house or adequate maintenance of the septic tank and control of input to the system.

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