



Review

The impacts of low-cost treatment options upon scale formation potential in remote communities reliant on hard groundwaters. A case study: Northern Territory, Australia

Andrew S. Kinsela ^{a,*}, Adele M. Jones ^a, Richard N. Collins ^{a,b}, T. David Waite ^a

^a UNSW Water Research Centre, School of Civil and Environmental Engineering, The University of New South Wales, Sydney, NSW 2052, Australia

^b Institute for Environmental Research, Australian Nuclear Science and Technology Organisation, Locked Bag 2001, Kirrawee DC, NSW 2232, Australia

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ABSTRACT

The majority of small, remote communities within the Northern Territory (NT) in Central Australia are reliant on groundwater as their primary supply of domestic, potable water. Saturation indices for a variety of relevant minerals were calculated using available thermodynamic speciation codes on collected groundwater data across the NT. These saturation indices were used to assess the theoretical formation of problematic mineral-scale, which manifests itself by forming stubborn coatings on domestic appliances and fixtures. The results of this research show that 63% of the measured sites within the NT have the potential to form calcium carbonate (CaCO_3) scale, increasing to 91% in arid, central regions. The data also suggests that all groundwaters are over-saturated with respect to amorphous calcium-bridged ferric-silica polymers, based on the crystalline mineral index ($\text{Ca}_3\text{Fe}_2\text{Si}_3\text{O}_{12}$), although the quantitative impact of this scale is limited by low iron concentrations. An assessment of possible low-cost/low-technology management options was made, including; lowering the temperature of hot-water systems, diluting groundwater with rainwater and modifying the pH of the source water. Source water pH modification (generally a reduction to pH 7.0) was shown to clearly alleviate potential carbonate-based scale formation, over and above the other two options, albeit at a greater technical and capital expense. Although low-cost/low-technology treatment options are unlikely to remove severe scale-related issues, their place in small, remote communities with minor scale problems should be investigated further, owing to the social, technical and capital barriers involved with installing advanced treatment plants (e.g. reverse osmosis) in such locations.

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* Corresponding author. Tel.: +61 2 9385 5532; fax: +61 2 9313 8624.

E-mail addresses: a.kinsela@unsw.edu.au (A.S. Kinsela), adele.jones@unsw.edu.au (A.M. Jones), richard.collins@unsw.edu.au (R.N. Collins), d.waite@unsw.edu.au (T.D. Waite).

1. Introduction

Owing to limited rainfall, scarcity of surface waters and high rates of evaporation, much of central Australia is dependent on groundwater for its primary water supply. Indeed, Northern Territory (NT) groundwater sources account for approximately 90% of its water usage to supply entire domestic needs (Phelts, 2008). Much of the water extracted from aquifers in the NT is from deeply weathered Pre-Cambrian or Cretaceous/Tertiary sediments including extensive evaporite deposits. Although variable in nature, these groundwaters have been shown to contain elevated concentrations of calcium, magnesium, carbonate/alkalinity and silica (PWC, 2010; Salvestrin and Hagare, 2009; Schafer et al., 2007; Swain, 2003).

When these ions reach concentrations which exceed mineral solubility limits, precipitation begins to occur. Although the most common minerals formed from ion-rich groundwaters are carbonates (such as calcite, CaCO_3 , and dolomite, $\text{CaMg}(\text{CO}_3)_2$), other problematic precipitates including calcium and magnesium sulphates, metal silicates and amorphous silica have been identified (Schausberger et al., 2009). These minerals collectively form deposits, which are henceforth referred to as 'scale', as a stubborn coating in a range of domestic fixtures.

Whilst carbonates have long been recognised as the primary constituents of groundwater scale formation, the presence of amorphous silica (SiO_2) and metal silicates ($\text{M}_x(\text{SiO}_4)_y$) is an issue of emerging concern, identified largely from membrane treatment processes of high-silica containing waters (Sheikholeslami and Tan, 1999). Solid amorphous silica forms when concentrations of monomeric silicic acid, $\text{Si}(\text{OH})_4$, exceed 100–120 mg/L at $\text{pH} < 9$ (Iler, 1979). When the solubility product is surpassed, precipitation occurs through polymerisation reactions, involving dehydration, cross-linking and aggregation as a result of van der Waals interactions (Ning, 2003). The deposition of these polymerised colloidal silica particles onto membrane surfaces results in the formation of a hard scale from an initial soft gel-like substance (Ning, 2003). However, the association of silica with multivalent ions including Fe^{3+} , Fe^{2+} , Al^{3+} , Ca^{2+} and Mg^{2+} is of greater concern as a result of; i) the possible formation of metal silicates which are of lower solubility than amorphous SiO_2 , ii) the ability of cations to promote silica polymerisation in neutral pH waters, and iii) the formation of cement-like scaling under more alkaline conditions (Sheikholeslami et al., 2002). Indeed, the addition of 300 mg/L of $\text{Mg}(\text{OH})_2$ to water reduces the soluble silicon concentration from 42 to 0.1 mg/L (Ning, 2003), albeit at alkaline pH, whilst the addition of minor amounts (1 mg/L) of $\text{Fe}(\text{III})$ drastically increases silicon-related fouling (Freeman and Majerle, 1995; Sahachaiyunta et al., 2002). There exists particular concern for metal silicate formation when $\text{Al}(\text{III})$ and $\text{Fe}(\text{III})$ -based compounds are added as flocculants, as is common practice for the pre-treatment of water prior to nanofiltration (Ohno et al., 2010) and/or reverse osmosis (Gabelich et al., 2005). Such a problem is exacerbated by the colloidal silicate compounds having an enhanced or synergistic fouling capacity with co-present organic molecules (Li and Elimelech, 2006; Tran et al., 2007).

Scale build-up resulting from groundwater supplies have been observed within numerous domestic appliances, including and not limited to; taps (and other plumbing fixtures), air conditioners (including evaporative coolers) and hot-water systems. The accumulation of scale on electrical appliances, such as water heating devices, results in the inefficient exchange of heat and mass, which aside from increasing the rate of appliance failure, also increases energy demand. Scale formation on plumbing fixtures requires a higher frequency of replacement (Downing, 2000), as evidenced by the extreme case shown in Fig. 1.

The problem of scale formation resulting from the use of hard groundwaters is not spatially isolated, with the phenomenon being a serious economic and social issue globally. This has been identified

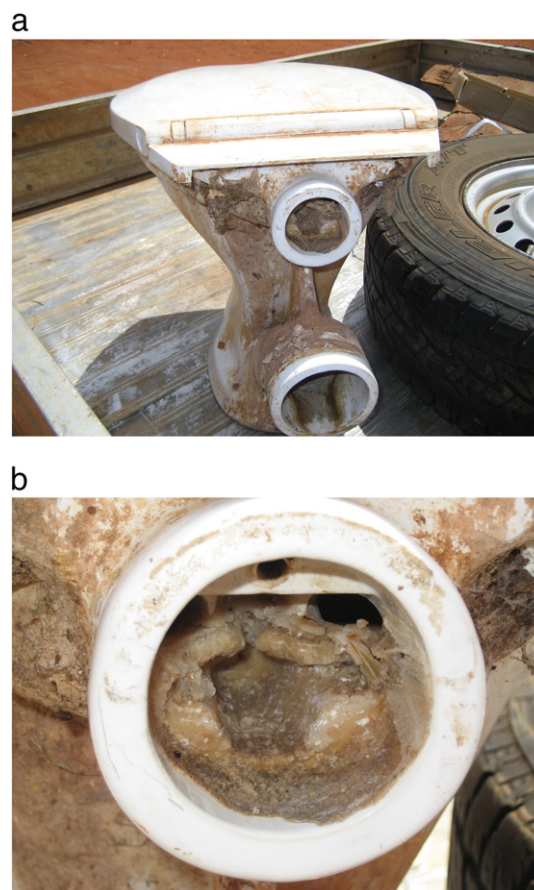


Fig. 1. Photograph of a scale-affected toilet bowl from a remote community (population 350 people) located approximately 250 km NE of Alice Springs (a), highlighting clogging of the inlet-connection (b).

Photo credit: Shire Manager, March 2010, with permission.

in arid regions of Northern America (Huff, 2006), the Middle East (Abdula'aly and Chammem, 1994) and northern Africa (Ketrane et al., 2010), where securing adequate supplies of drinking water is of vital, ongoing importance. However, in small communities which are reliant on groundwater, such as in remote central Australia, the problems associated with the failure of domestic fixtures or electrical devices are exacerbated by the cost and lack of immediate access to maintenance service providers. This is particularly the case for indigenous communities within the NT where approximately 88% of drinking water supplied to residents within these areas is derived from groundwater (PWC, 2010).

Scale formation has been successfully prevented by the installation of high-technology, expensive treatment options within larger population centres, where it becomes economically feasible to do so. These treatment options include the membrane- and/or electrode-based separation technologies of electrodialysis reversal, capacitive deionisation and high efficiency reverse osmosis (HERO). The HERO process, which involves intense water softening through ion exchange followed by alkaline reverse osmosis at high-recoveries, is becoming increasingly popular with one unit recently installed in a regional Australian community (Thomson et al., 2009). Despite being able to deliver 300 kL/d of potable water at up to 95% recovery, the high capital investment (estimated at >\$2M USD), ongoing maintenance costs (chemical consumption) and level of technical expertise required, makes this technology impractical for small, remote communities. As the majority of remote communities also have limited power access (small generators or photovoltaic arrays), the energy requirements necessary to operate high-technology options are often unavailable (Forstmeier

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