Performance assessment and economic analysis of Calgon™ polyphosphate sequestering agent at Yuelamu, NT

October 2007

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A report prepared for Indigenous Essential Services (IES), Northern Territory Department of Planning and Infrastructure
Abstract
Communities in central Australia rely on groundwater aquifers for primary sources of water supply. Groundwaters can contain high concentrations of dissolved minerals that reduce the functional life and increase the requirement for maintenance of community infrastructure, such as water supplies, hot water systems and air conditioners. In some cases, hard waters cause the failure of key health hardware and this has an associated impact on the health and amenity of residents.

Management options for scale avoidance focus on source substitution (e.g. use of rainwater or surface runoff) and mitigation measures which include dosing with ameliorating water additives (e.g. lime, polyphosphates, soda ash, caustic soda), or utilisation of size-separation or molecular processes (reverse osmosis, ion exchange).

Polyphosphates have been touted as a method for scale prevention for over 60 years. They are also used widely in the United States for a range of other water quality management issues such as reduction of copper and lead release from pipes. However, their performance varies widely with varying water quality parameters and there are few studies performed in hard waters with high alkalinities similar to central Australian conditions.

A trial of the polyphosphate, sodium hexametaphosphate (SHMP, commercially known as Calgon™) in a remote community in Central Australia provided an opportunity to monitor rates of scale accumulation under the influence of the treatment.

Mass of scale accumulation was monitored on solar and electric hot water system elements in seven households over a 15-month period and the cumulative mass analysed against hot water use. Hot water use at all seven households was far below hot water use rates recorded for other remote communities. Under an SHMP dosing regime of approximately 2mg/L, the five electric hot water system elements monitored all presented measurable rates of scale accumulation throughout the monitoring period. Despite comparatively higher water use, scale accumulation on the two solar hot water system elements was barely measurable, and this was attributed to the different material characteristics of these elements.

Subsequently, approval was sought to conduct a ‘control’ trial and this was monitored in the same way for a period of five weeks to provide baseline rates of scale accumulation under local water quality conditions. Rates of scale accumulation were appreciably greater during this period (without SHMP dosing); however, hot water use was also greater, as the control monitoring was conducted during the winter months. The data do however provide some evidence that SHMP may reduce scale accumulation in the given water quality.

However, it is difficult to predict the effectiveness of sodium hexametaphosphate given the array of variables known to affect polyphosphate performance. A literature review reveals that water temperature, dissolved oxygen concentration, flow regimes, pH and changes in hardness and TDS in ground water supplies can all affect the performance of polyphosphates. Controlling for these variables was not possible in a field trial of this nature.

In order to provide an evaluation of possible economic benefits of SHMP dosing, a range of assumptions were made about the best performance of SHMP, and this was compared to two alternative hard water management scenarios. Annualised and five-year costs of failure management and preventive maintenance approaches were estimated and compared to those of an SHMP dosing regime, in a fictional community of 40 houses. The four main areas of household health hardware most vulnerable to scale impacts were evaluated: hot water systems, toilet cisterns, evaporative air conditioners and minor tap fittings. Failure management under an annual failure frequency was estimated to be the most
expensive hard water management strategy and preventive maintenance the least, assuming a benefit of increased service life of five-years.

Non-fiscal benefits of each hard water management scenario were also compared. Preventive maintenance provided the most additional benefits to the community such as local job creation, increased utility of health hardware and reduced water wastage from regular maintenance. Failure management required the most external assistance from skilled tradespersons and provided the least additional benefits.

Certainty of costs and benefits is often an important determinant in financial decision-making. Preventive maintenance provided the greatest certainty of both benefits and costs, the costs being more predictable under planned preventive maintenance than ad-hoc failure management. Failure management did however also provide a certainty of benefit (through replacement of health hardware). Whilst the costs of SHMP dosing are reasonably certain, this regime provided the greatest uncertainty of benefit due to uncertainty over the effectiveness of the treatment. This uncertainty rests on the lack of clarity over how long the use of SHMP will delay the failure and need for replacement of necessary household health hardware, namely hot water systems.

The economic evaluation of SHMP dosing reveals that the polyphosphate would only need to double the life of hot water systems to be economically competitive over current failure management approaches to hard water management. However, polyphosphate dosing would need to extend the service life of hot water systems five-fold to be economically competitive with preventive maintenance approaches to hard water management, but still would not deliver the multitude of other benefits such as reduced failure rates in cold water health hardware, increased local ownership and local employment.

It is recommended that funds currently available for investment in the protection of infrastructure from hard water impacts in remote Indigenous communities be targeted towards preventive maintenance strategies. Cooperative arrangements may need to be fostered between service providers and remote local governments for training and administration of hard water maintenance programs. The installation of large capacity solar hot water systems with vitreous enamel bobbin elements is also recommended for installation in locations with acutely hard waters (500mg/L or greater), as these accumulated significantly less scale deposits than electric sickle elements.

Further research is required to determine the range of water qualities over which SHMP will perform to avoid unnecessary future capital investment and possible diversion of vital funds in locations where the dosing agent will be ineffective. It is recommended that further research utilises multiple trial sites with groundwaters of varying hardness, and that relevant parameters be monitored for a period of not less than six months for control monitoring and six months for monitoring under SHMP dosing. Other relevant parameters such as final phosphate concentrations and any changes in bacteriological quality should also be monitored. A trial of this kind would develop the necessary understanding of the effectiveness of sodium hexametaphosphate as a mitigation strategy for the failure of hot water systems caused by calcite scaling in hard water areas.
Acknowledgements

This study was made possible with funding from the Northern Territory Department of Planning and Infrastructure, Indigenous Essential Services (IES) Division. This work could also not have been completed without ongoing support funding from the Cooperative Research Centre for Water Quality and Treatment for the author’s position of Technology Transfer Officer, based at the Centre for Appropriate Technology.

Thanks to Norman Hagan, Essential Services Officer at Yuelamu for his field assistance and cooperation throughout the trial. Thanks also to the Yuelamu householders and community facilities coordinators who participated in the trial and for giving us access to their homes and community buildings for monitoring. Ralph Hutchins from PowerWater Corporation provided historical information on the Yuelamu water supply and project support for field work. Thanks to Robyn-Grey Gardner, who developed the initial project proposal and provided professional advice and critical discussion over the early project research results. Gratitude must also be extended to Tracey May of Alice Springs Water Laboratory (NT Department Primary Industry, Fisheries and Mines), who provided laboratory assistance beyond the call of duty and participated in critical analytical discussion over the results.

Thanks also to Ruth Elvin, Andrew Crouch and Mark Moran who provided comment on earlier drafts of this report that significantly improved the final document.

Nerida Beard, October 2007.
# Table of Contents

1 **INTRODUCTION** ........................................................................................................... 10

1.1 **TERMS OF REFERENCE** ........................................................................................ 10
1.2 **IMPACT OF HARD WATER** ..................................................................................... 10
1.3 **SCALE MITIGATION AND COST** ............................................................................ 11
1.4 **SCALE CHEMISTRY** ............................................................................................... 12
1.5 **POLYPHOSPHATE USE** .......................................................................................... 13
1.6 **POLYPHOSPHATE ACTION** ..................................................................................... 14
1.7 **SHMP OPTIMAL DOSING CONCENTRATIONS** ...................................................... 15
1.8 **HEALTH AND SODIUM HEXAMETAPHOSPHATE** ................................................ 16
1.9 **POSSIBLE SIDE-EFFECTS OF SHMP** ................................................................... 16

2 **STUDY LOCATION** ..................................................................................................... 16

3 **METHODOLOGY** ........................................................................................................ 17

3.1 **STUDY DESIGN** ..................................................................................................... 18
3.2 **HOT WATER SYSTEM ELEMENTS** ........................................................................ 19
3.3 **FIELD MONITORING REGIME** ............................................................................. 20
3.4 **SCALE MEASUREMENT** ....................................................................................... 21
3.5 **LIMITATIONS OF METHOD** ................................................................................ 22

4 **RESULTS** ................................................................................................................... 25

4.1 **SCALE DEPOSITION** ............................................................................................ 25
4.2 **HOT WATER USE** ................................................................................................ 27
4.3 **OCCUPANCY** ....................................................................................................... 29
4.4 **SCALE DYNAMICS** ............................................................................................. 30
4.5 **SCALE ACCUMULATION RATES** ......................................................................... 35

5 **DISCUSSION** .............................................................................................................. 38

5.1 **MASS SCALE DEPOSITION** .................................................................................. 38
5.2 **LINEARITY OF SCALE ACCUMULATION** ............................................................. 43
5.3 **SHMP EFFECTIVENESS** ....................................................................................... 44
6 ECONOMIC EVALUATION ......................................................... 46

6.1 TERMS OF REFERENCE .................................................... 46
6.2 DEFINITIONS ................................................................. 46
6.3 UNCERTAINTY AND FAILURE RATES ................................. 46
6.4 IMPACTS OF SCALE ACCUMULATION .............................. 47
6.5 COSTS OF HARD WATER .................................................. 47
6.6 POTENTIAL BENEFITS OF SHMP TREATMENT .................. 47
6.7 ALTERNATIVE MANAGEMENT SCENARIOS ..................... 48
6.8 ASSUMPTIONS .............................................................. 49
6.9 COST EVALUATION OF SCENARIOS ............................... 52
6.10 SUMMARY OF COSTS AND BENEFITS ............................ 59

7 CONCLUSIONS ........................................................................ 61

8 RECOMMENDATIONS .......................................................... 63

9 AREAS FOR FURTHER RESEARCH ...................................... 64

10 REFERENCES ........................................................................ 65

11 APPENDICES ........................................................................ 67

Appendix 1: Original Terms of Reference from IES. ................................. i
Appendix 2: Yuelamu groundwater quality chemical composition (DLPE, 1998)
and metals over page (PWC, 2004). ......................................................... iii
Appendix 3: WA Water Corporation Document - Laboratory method for
determination of sodium hexametaphosphate dose rates for scale mitigation in
water supplies. ...................................................................................... v
Appendix 4: Some indicative 2007 costs of hot water system repairs and
replacements. ......................................................................................... vi
List of Figures

Figure 1: Packaged water delivery pallets stored at Yuelamu, 9 March 2005. .... 17
Figure 2: Sickle-shaped elements used in electric hot water systems at Yuelamu. .............................................................................................................................................................................. 20
Figure 3: Solar hot water system bobbin element with vitreous enamel sheath (top) and ceramic inner element, which remains shielded from the bulk water (bottom). .............................................................................................................................................................................. 20
Figure 4: A scaled electric sickle element, bagged and photographed in preparation to return to the laboratory. .................................................................................................................................................. 22
Figure 5: Example of the scale deposits that could be dislodged from electric hot water system elements during removal ............................................................................................................................................................................. 24
Figure 6: Comparison of total mass of scale deposited on hot water elements, under SHMP dosing and control conditions................................................................. 26
Figure 7: Average hot water use by household hot water system (litres per day) at Yuelamu community, June 2005 – June 2007. Where only single data records were collected*, the lone value is presented in place of the mean. ................. 28
Figure 8: Mean data on average hot water use during dosing and control* trial periods, during the months of each monitoring period. ...................................................................................................................... 29
Figure 9: Scale deposition and litres of hot water used during the two-year monitoring, households A-E (electric elements).............................................................................................................. 31
Figure 10: Scale deposition and litres of hot water used throughout the trial, households F and M (electric elements). Note that the plot for household F required a higher maximum value for the accretion data scale. Solar hot water system data is not presented here due to barely measurable scale accumulation rates. ........................................................................................................................................ 32
Figure 11: Relationship between total mass of scale deposited on the electric hot water elements and the total hot water consumption of the system.......... 34
Figure 12: Cumulative scale deposition and hot water use in each hot water system monitored for the entire 2 year trial................................................................. 35
Figure 13: Average rates of scale accumulation on electric hot water system elements and average daily hot water use for the corresponding hot water system. Scale accumulation data (g/KL) from the five-week control trial is compared to that from the two-year dosing trial. ................................................................. 37
Figure 14: Overall mean comparative data on scale accumulation rates and water use, with and without Calgon dosing........................................................................... 38
Figure 15: A sickle-shaped electric hot water system element, with visible scale layer over the entire surface, and additional scale precipitate deposit visible at the arc. .............................................................................................................................................................................. 40
Figure 16: Household solar hot water system bobbin element surface that has been compromised by pitting, possibly caused by corrosion, subsequently enabling mineral scale adhesion to the element. ......................................................................................................................... 40
Figure 17: Loose ‘scale’ deposits on the inside of a hot water system, through the opening where the hot water element fitting is inserted. ........................................ 44
Figure 18: Distribution of investment for alternate management scenarios........... 54
Figure 19: Sensitivity analysis of key household infrastructure components; evaluated for every one, two and three year failure frequencies respectively. ... 57
Figure 20: Costs of an SHMP dosing regime under variable benefit scenarios, by reducing hot water system replacement frequencies from annual to every five, three or two years.................................................................................................................. 58
List of Tables

Table 1: Household hot water systems monitored for scale accumulation at Yuelamu. ................................................................. 19

Table 2: Cumulative mass of scale deposited on monitored hot water system elements during SHMP dosing, the control period and overall totals. .......... 25

Table 3: Comparison of total mass of scale accumulated on electric hot water system elements between dosing and control periods ....................... 27

Table 4: Occupancy data for discrete sampling dates for all households. .......... 30

Table 5: Key data on scale accumulation over two-year monitoring period (g/kL) ........................................................................................................ 41

Table 6: Guiding assumptions for analysis of hard water management scenarios 51

Table 7: Cost estimates of alternate hard water management regimes............. 53

Table 8: Summary characteristics of the three proposed hard water management scenarios ....................................................................................... 56
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADWG</td>
<td>Australian Drinking Water Guidelines</td>
</tr>
<tr>
<td>Ca</td>
<td>Calcium (mineral)</td>
</tr>
<tr>
<td>Mg</td>
<td>Magnesium (mineral)</td>
</tr>
<tr>
<td>POU</td>
<td>‘Point of Use’ water treatment</td>
</tr>
<tr>
<td>RO</td>
<td>Reverse Osmosis</td>
</tr>
<tr>
<td>SHMP</td>
<td>sodium hexametaphosphate</td>
</tr>
<tr>
<td>ESO</td>
<td>Essential Services Officer</td>
</tr>
<tr>
<td>mg</td>
<td>milligrams</td>
</tr>
<tr>
<td>L</td>
<td>litre</td>
</tr>
<tr>
<td>kL</td>
<td>kilolitre (1000 litres)</td>
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1 INTRODUCTION

Many Australian cities and towns rely on groundwater aquifers for primary or supplementary municipal water supplies (WCWA 2006; PWC 2005; SA Water 2005). In large tracts of arid and central Australia the aquifers are often deep and ancient, and can produce ‘hard’ water, containing high concentrations of naturally occurring dissolved minerals; sodium, chloride, calcium and magnesium amongst others (PWC 2005). Calcium (Ca) and magnesium (Mg) ions are the major ions that contribute to water hardness. Although not of concern in low concentrations, these ions are undesirable in concentrations above 200mg/L (NHMRC & NRMMC 2004) in municipal water supplies, as they contribute to the formation of ‘scale’ deposits on essential infrastructure, contributing to their premature failure.

1.1 Terms of Reference

The Centre for Appropriate Technology (CAT) was commissioned by the Northern Territory Department of Planning and Infrastructure, Indigenous Essential Services (IES) Division in mid-2005 to monitor the effects of dosing a hard, reticulated ground water supply with a brand of polyphosphate sequestering agent, Calgon™, at Yuelamu community, NT. This polyphosphate, chemically named as sodium hexametaphosphate (SHMP), is thought to reduce the formation of scale deposits on water infrastructure. Calgon™ will be generally referred to in this report by its chemical name, sodium hexametaphosphate, or SHMP. Monitoring was required to assess its performance for this application. The terms of reference for the study can be summarised as follows.

The study was required to:

- monitor scale accumulation in heating appliances in a minimum of five households
- cease after six months monitoring or ‘until such time as the bore water is no longer in use’;
- prepare a report that provides sufficient information to determine the economic cost or benefit of dosing with sodium hexametaphosphate.

For the unabridged terms of reference, refer to Appendix 1.

1.2 Impact of hard water

Hard waters reduce the ability to lather soap and inhibit the action of surfactants for cleaning (Mercer, Lin, and Singer 2005) and therefore the ability to clean people and clothing. Hardness in drinking water is generally not considered of direct health risk to humans, therefore there is no health-related drinking water guideline; but it is both aesthetically undesirable and a nuisance (WHO 2006a; 2006b; NHMRC & NRMMC 2004).
Indeed, background concentrations of a number of important minerals found in groundwater may be beneficial in improving certain medical conditions such as cardiovascular disease. However, excessively high levels (i.e. greater than 500mg/L), have been weakly linked to a higher risk of the development of gall stones and kidney stones. (WHO 2006a; 2006b)

High concentrations of Ca and Mg ions in water can result in a solid crystalline build-up or ‘scale’ developing on pipes, fittings and water-using appliances in households and industry, resulting in reduced capacity in pipes and particularly thermal efficiency of heating elements (Mercer, Lin, and Singer 2005). This has a direct impact on the functioning of hot water systems, evaporative air conditioners, taps, shower fittings, toilet cisterns and reticulation pipes (Lloyd, Wilson, and Adams 2000; Marshall 1999) and therefore the environmental health benefits those facilities afford (FaCSIA 2007).

The Australian Drinking Water Guidelines (ADWG) state that total hardness should not exceed 200mg/L, to minimise the unacceptable build-up of scale in hot water systems (NHMRC 2004). When these systems are not functioning, the health of residents is negatively impacted by their inability to access the services provided by essential household health hardware (FaCSIA 2007; Territory Health Services 2002; Nganampa Health Council Inc. 1987). Hard water effects lead to shorter life cycles for household technologies and associated costly repair, maintenance and replacement schedules for water reticulation systems.

1.3 Scale mitigation and cost

In arid regions where groundwaters are the only major water source for desert communities, the ADWG recommended maximum value for hardness is frequently exceeded (PWC 2005:40-52; Territory Health Services 2002; Hostetler, Wischusen, and Jacobson 1998). In such areas, means of treating or substituting water supplies or means to remove or avoid the negative impacts associated with scale build-up on household and community appliances are required. Such means include:

- surface water recycling
- source substitution (e.g. use of rainwater)
- point of use (POU) treatment (e.g. for a small quantity of high-quality drinking water or for use before hot water systems)
- treatment of the bulk water supply, such as addition of ameliorating water additives (e.g. lime, polyphosphates, soda ash, caustic soda)
- Utilisation of size- or ion-specific exclusion processes (e.g. reverse osmosis, nanofiltration, ion exchange) or
• Regular preventive scale removal maintenance regimes for the worst affected infrastructure.

A number of these methods require considerable capital expenditure and some involve a high level of complexity in their operation. Due to diseconomies of scale in small water supplies, cost-benefit analyses do not tend to favour costly treatment technologies. In externally or agency-managed water supplies, cost-benefit assessments may also underestimate the ongoing maintenance costs of hard waters due to incomplete accounting of the diffuse costs borne across the different levels of governance and management structures. Scaling clearly has major implications for repair and replacement of major water supply infrastructure such as pipes, pumps and storage tanks (costs borne by governments). It can also have high economic costs from reduction in heating efficiency, usually borne by residents through private costs for energy consumption, and in ongoing maintenance and replacement costs for heating appliances, borne by community councils and subsidised by governments. If lifecycle cost accounting was employed and these diffuse costs were quantified, it may prove economically rational to invest in a higher level of treatment and/or support at the servicing and maintenance level.

Appropriate technology approaches also do not favour highly technological treatment responses to scale amelioration, due to increased operation and maintenance demands, particularly in self-managed community water supplies. There is therefore a need for simple methods of scale prevention.

One of the simplest methods is polyphosphate dosing which has been used for decades overseas and more recently in West Australia. It has been used as a method to reduce the amount of scale deposited on reticulation systems and hot surfaces, such as hot water systems. However, the effectiveness and conditions of success of the method have not been well studied in Australian ground water supplies.

1.4 Scale chemistry
‘Scale’ is a general term given to describe the deposits formed by a range of chemical processes between metals and bulk water supplies (e.g. inside pipe walls). This two-step process has been studied for over 50 years and involves first the development of by-products of metal corrosion and second, the adsorption of metals in solution to those by-products (Sarin et al. 2001; Lehrman and Shuldener 1952). Understanding this process informs the common understanding that scale accumulates more readily on hot surfaces. The prevailing theory is that heat provides a catalyst to speed the chemical adsorption
process (Sarin et al. 2001; Lehrman and Shuldener 1952; Hatch and Rice 1945). This theory also fosters an understanding of how scale mitigation additives function and the conditions under which they will be effective.

1.5 Polyphosphate use

The compound known commercially as ‘Calgon’ is the substance sodium hexametaphosphate. Sodium hexametaphosphate is one of a large family of polyphosphate compounds that was first introduced over 60 years ago for amelioration of calcite scale and ion precipitation in water distribution systems (Hatch and Rice 1945; Edwards and McNeill 2002). In the 1940s, SHMP gained popularity as a ‘wonder chemical’ that offered simultaneous control of calcite scaling and iron precipitation and corrosion (McNeill and Edwards 2000). Polyphosphates have also been used as a preservative in the food and beverage industries, and SHMP is known to the food industry as preservative ‘E452’ (WU 2006).

Perhaps reflecting its use for a diversity of purposes in a broad range of industries, SHMP has a number of different names internationally and this makes review of the scientific literature untidy. Throughout the course of this study, it was found that internationally, the substance is referred to in the literature under at least five alternate names: the more general ‘polyphosphate’ (Cantor et al. 2000), sodium polymetaphosphate (Anghileri 1964), glassy polyphosphates (McElroy, Hazel, and McNabb 1965), polymeric phosphates (Stover 1997), and the more chemically correct, sodium hexametaphosphate (Edwards, Hidmi, and Gladwell 2001). The author has chosen to use the chemical nomenclature that describes the composition of the substance, sodium hexametaphosphate (SHMP), throughout this report.

SHMP is reported to ameliorate scale on hot fittings (taps, showers), in hot water systems and for industrial use in boilers and cooling towers by causing an increase in the amount of calcium (Ca) ions held in suspension by around 30%, or 90-95% of the total raw water Ca concentration (Shafizadeh, pers. comms. 23/1/2007). However, SHMP has a negligible effect on magnesium (Mg) suspension. It also does not ameliorate scale deposits on evaporative air-conditioners as the process of evaporation will always yield a residue of the total solids in solution (Marshall 1999).

Polyphosphates are still widely used today, especially in the United States where they have been used to reduce heavy metal release from reticulation systems to meet the 1992 USEPA ‘Action Limits’ for metal reduction in water supplies (USEPA 2004; McNeill and Edwards 2002; Edwards and McNeill 2002). However,
McNeill and Edwards (2002) found that although 56% of 264 US water utilities surveyed used a phosphate inhibitor of some kind for a range of purposes, in most cases they relied on only one to two information sources and rarely any scientific data or verification to support their choice of product. Only 10% of those surveyed used phosphate-based inhibitors for calcium scale prevention (McNeill and Edwards 2002).

Despite a host of research spawned to understand polyphosphate action since the USEPA action limits were announced, a clear understanding of how and under what conditions they work has not emerged (Mercer, Lin, and Singer 2005; Ebrahimi-mehr, Shahrabi, and Hosseini 2004; McNeill and Edwards 2002; Edwards, Hidmi, and Gladwell 2002; McNeill and Edwards 2000).

1.6 Polyphosphate action

It is generally understood that SHMP binds with Ca ions making them soluble, a process sometimes called sequestration (ACC 2004). Other water quality parameters such as the presence of natural organic matter and Mg ions may also influence rates of Ca precipitation (Mercer, Lin, and Singer 2005). SHMP preferentially binds with Ca ions rather than pipe linings, preventing the adsorption (described above) of those ions to pipe walls, thereby reducing Ca precipitation and the growth of crystal ‘tubercules’ (Hatch and Rice 1945; Edwards and McNeill 2002; McNeill and Edwards 2000), and most noticeably when the water is heated (Shafizadeh 2007; Lehrman and Shuldener 1952).

The effectiveness of SHMP in reducing leaching of copper, lead and iron into water supply pipes in low alkalinity waters is now under scrutiny and these studies may inform an increased understanding of the behaviour of SHMP generally in waters. In many of 22 studies reviewed from 1941 until 2002, SHMP reduced metal corrosion but in some circumstances increased it or had no effect (McNeill and Edwards 2002). Only two studies tested SHMP in high alkalinity waters and reported highly variable and even adverse effects at higher alkalinites (Colling et al 1987 and Dodrill & Edwards 1995 in McNeill and Edwards 2002). Several recent studies have found that for many water qualities polyphosphate dosing increased corrosion and calcite precipitation (McNeill and Edwards 2002, 2000).

The effectiveness of SHMP sequestration on iron or steel pipes is dependent on pH, temperature, water flow velocities, background Ca concentrations, dissolved oxygen and time since addition (Edwards, Hidmi, and Gladwell 2002; Sarin et al. 2001; Hatch and Rice 1945).
SHMP is found to work best at neutral pH, whilst other polyphosphates have been found to work optimally in alkaline conditions (ACC 2004). In fact, except for a single replicate in each of two studies (Mercer, Lin, and Singer 2005; McNeill and Edwards 2000), most of the studies that assessed the performance of SHMP and polyphosphates were in soft, low alkalinity waters, typically <150mg/L CaCO₃ (McNeill and Edwards 2002; Sarin et al. 2001; Edwards, Hidmi, and Gladwell 2002; Ebrahimi-mehr, Shahrabi, and Hosseini 2004).

It has also been established for some time that SHMP will not reduce scale under stagnant conditions or in low flow velocities (under 0.5m/s) (Hatch and Rice 1945). In fact the effects of stagnancy at pipe ‘dead ends’ were found to reverse the inhibitor effect of SHMP so that scale formation increased (McNeill and Edwards 2000). Research on polyphosphates is complicated by the fact that they are also prone to transform to orthophosphates in the dosing and reticulation system, a poorly understood but inevitable process known as ‘reversion’ (McNeill and Edwards 2002; Edwards, Hidmi, and Gladwell 2002). Orthophosphates are commonly used for the opposite purpose, to increase the development of a protective film on the inside of pipes in corrosive soft waters, and have been found to be effective at doing so (Edwards, Hidmi, and Gladwell 2002). Overall, there was little data on the effectiveness of SHMP as an anti-scalant generally, and few scientific studies performed in hard waters with high alkalinites, such as those encountered in Central Australia. Further research is needed under different water quality scenarios to improve understanding of SHMP action and to determine specific doses and suitability of SHMP for individual systems. A rapid-test assessment method is also needed to assist utilities to determine economically and easily if polyphosphate dosing is likely to meet their needs.

1.7 **SHMP optimal dosing concentrations**

The Western Australian Water Corporation has been using SHMP in at least five rural water supplies in Western Australia (Esperance, Hope Downs, Albany, Christmas Island and Mandurah) for over a year (Shafizadeh 2007). Optimal dose rates for SHMP are typically less than 10mg/L and usually around 1-2mg/L (Shafizadeh 2007; Edwards, Hidmi, and Gladwell 2002). Determination of optimal dose rate is by laboratory methods (see Appendix 3) and it is estimated that this will result in a 2-4 times decrease in calcium precipitation after boiling. Once optimal dose rates are determined, the dosing regime is a simple process of continuous automated addition of small volumes of concentrated solution, requiring minimal training but continual monitoring.
1.8 Health and sodium hexametaphosphate

The use of sodium hexametaphosphate has been approved for consumption as a food preservative and as a drinking water softening agent (WU 2006). However, due to the action of the SHMP that keeps calcium and magnesium ions in suspension, people may be exposed to up to 30% higher concentrations of Ca and Mg remaining in solution than would otherwise be the case from drinking the raw bore water (after Shafizadeh, 2006). International studies have shown that consumption of minimum levels of Ca and Mg salts is beneficial for reducing lifestyle diseases (WHO 2006a; 2006b). However, the upper acceptable limits of hardness concentrations in drinking water of 500mg/L were defined based on studies linking consumption of waters above 500mg/L with higher risk of gall stones and kidney stones (WHO 2006a; 2006b). Although consumption of SHMP is not believed to be of concern to health, the extent to which SHMP increases the consumption of Ca and Mg salts above the upper hardness limits would need to be considered carefully before use in hard water supplies.

1.9 Possible side effects of SHMP

It has been calculated that for every milligram (mg) of SHMP added, 0.3mg of phosphorous is also added. This may have implications for control of algal and bacterial growth in drinking water systems as phosphorous is a limiting nutrient for algal growth in freshwaters (Boulton and Brock 1999; McNeill and Edwards 2002). Ca and Mg are macronutrients for algal and bacterial growth; however, in ancient groundwaters there is usually little phosphorous. In remote community reticulation systems, sewage ponds are often used for evaporative disposal of sewage and increases in the ratio of phosphorous to nitrogen could increase primary production of undesirable algae leading to eutrophication and anoxic conditions in wastewaters. Blue green algae are known to prosper when ratios of phosphorous increase relative to nitrate, but the ratios differ widely (Boulton and Brock 1999). In arid groundwaters, there is often an abundance of nitrates and so the phosphorous input required to boost this kind of growth appears unlikely, but problems could arise in low nitrate systems.

2 Study location

Yuelamu Community is situated approximately 250km north-west of Alice Springs, along the Tanami Highway. The community receives a mean annual rainfall of 350mm/year. This is highly variable, with a median of 298mm/yr and a range of 55-866mm/year (BOM 2005). The usual community water supply is sourced from a dam to the west of the community which traps overland storm flows. Due to high evaporation rates and gradual siltation of the dam, the water storage capacity has reduced over time, with the water drying out in 1992 and again in 2004.
Since 2004, the community reticulated water supply source was switched to the only other water source, a non-potable groundwater. This groundwater supply has high concentrations of hardness ions (460mg/L), sodium chloride (1120mg/L), nitrate (110mg/L), fluoride (3.9mg/L) (DLPE 1998), total dissolved solids (TDS) (2600mg/L), uranium (201ug/L) and selenium (15ug/L) (PWC, 2004) (see Appendix 1 for water quality data). As it is non-potable, this water source was supplemented by packaged water deliveries to the community to provide a potable supply of drinking water (Figure 1).

![Figure 1: Packaged water delivery pallets stored at Yuelamu, 9 March 2005.](image)

The town has a recorded usual population of 300 people (ABS 2001) with approximately 50 houses and a range of community facilities such as a Women’s Centre, School, Crèche, Social Club, Clinic, Council Office, Store, Sports and Recreation Hall, and a large workshop for automotive mechanical work and construction.

3 Methodology

At Yuelamu, a SHMP dosing system was installed by PowerWater Corporation in early 2005. The system doses the bulk mains water to the community via automatic injection of concentrated 20g/L SHMP solution into the approximately 100 000L twin storage tanks, for an approximate final bulk water concentration of 2mg/L SHMP. In cooperation with the community Essential Services Officer (ESO), Norman Hagan, the Centre for Appropriate Technology monitored the mass build-up of solid deposits on hot water system elements as an indicator of the impact of using a sequestering agent on scale accumulation rates in the overall water supply system. As SHMP is supposed to be most effective on hot surfaces, and because hot water elements are one of the major sites of scale build-up in community water supplies, hot water systems provide an indicative testing site to monitor scale accumulation rates under SHMP and control conditions to enable an estimate of SHMP effectiveness.
Concerns about the effect of the hard groundwater on the community water infrastructure drove the terms of reference to require that the project begin once the SHMP dosing plant was installed, thus preventing the opportunity to monitor control conditions prior to treatment. Control condition monitoring was subsequently negotiated and monitored over a comparatively shorter period to enable a comparison of scale formation without SHMP use.

3.1 Study Design

Six electric and two solar hot water systems were monitored over two years during operation of the Calgon (SHMP) dosing unit. Ten electric and four solar hot water systems were further monitored for five weeks under control conditions (no Calgon dosing).

Replicates of system type and capacity were limited to what was already installed in homes at the community, although the numbers for each were deliberately increased during the control trial given failure rates and findings in the initial Calgon monitoring period. The hot water systems monitored during each period therefore were spread across a range of types and capacities, enumerated below in parenthesis (Calgon, control):

- electric instantaneous hot water systems (6, 10)
- solar hot water systems (2, 4)
- community facilities (2, 2) and residential households (6, 12)
- varying capacities of electric instantaneous units; 25L (0,2); 50L (3,4);
  80L (1,1); 125L (1,1); 160L (1,2)
- inclusion of both Indigenous (4,9) and non-Indigenous households (2,3)
- solar hot water systems all of 200L capacity (2,4)

Participating households were first nominated by the Community Council members themselves or based on their suggestions and then approached individually for consent before the study proceeded. At community buildings, the respective coordinators provided consent. Table 1 below provides details of the hot water systems at the households involved in the trial monitoring.
<table>
<thead>
<tr>
<th>Monitoring Regime</th>
<th>House Ref No.</th>
<th>Building use</th>
<th>Make</th>
<th>Model</th>
<th>Power source</th>
<th>element kW rating</th>
<th>Capacity (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casual Dosing Trial</td>
<td>A</td>
<td>Indigenous Household</td>
<td>Hardie Dux</td>
<td>50V1-36B</td>
<td>electric</td>
<td>3.6</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Non-Indigenous household</td>
<td>Hardie Dux</td>
<td>HDE 80V</td>
<td>electric</td>
<td>3.6</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Non-Indigenous household</td>
<td>Hardie Dux Forte</td>
<td>125F1-36</td>
<td>electric</td>
<td>3.6</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>Indigenous Household</td>
<td>Hardie Dux Proflo</td>
<td>50V1-38C</td>
<td>electric</td>
<td>3.6</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>Community facility</td>
<td>Hardie Dux Proflo</td>
<td>160F-136</td>
<td>electric</td>
<td>3.6</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>Community facility</td>
<td>Hardie Dux Forte</td>
<td>50V1-36B</td>
<td>electric</td>
<td>3.6</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>Indigenous household</td>
<td>Solahart</td>
<td>unreadable</td>
<td>solar</td>
<td>2.4</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>Indigenous household</td>
<td>Solahart</td>
<td>31748</td>
<td>solar</td>
<td>2.4</td>
<td>200</td>
</tr>
<tr>
<td>Additional systems monitored under ‘Control’ Trial</td>
<td>I</td>
<td>Non-Indigenous temporary accom</td>
<td>James Hardie</td>
<td>160F-136</td>
<td>electric</td>
<td>3.6</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>J</td>
<td>Indigenous Household</td>
<td>Solahart</td>
<td>Not recorded</td>
<td>solar</td>
<td>3.6</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>Indigenous Household</td>
<td>James Hardie</td>
<td>Not recorded</td>
<td>electric</td>
<td>3.6</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>Indigenous Household</td>
<td>James Hardie</td>
<td>Not recorded</td>
<td>electric</td>
<td>3.6</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>Indigenous Household</td>
<td>Rheem 101 Series</td>
<td>Not recorded</td>
<td>electric</td>
<td>3.6</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Indigenous Household</td>
<td>Solahart</td>
<td>Not recorded</td>
<td>solar</td>
<td>3.6</td>
<td>200</td>
</tr>
</tbody>
</table>

Five electric and two solar hot water systems were monitored for the duration of the SHMP dosing trial. One electric hot water system was excluded from the trial due to damaged bolts that prevented multiple changes of element.

Ten electric hot water systems and four solar hot water units were commissioned for monitoring during the Control period of five weeks. Four of the ten electric hot water systems had to be discarded from the control trial due to hot water system malfunction and inaccessibility issues. All four solar hot water systems were monitored during the control trial.

### 3.2 Hot water system elements

**Electric hot water system elements**

The electric instantaneous hot water systems at Yuelamu have 3.6 kilowatt sickle-shaped elements (Figure 2). These are directly immersed in water full-time and are similar in style and shape to those used in automatic kettles.
Figure 2: Sickle-shaped elements used in electric hot water systems at Yuelamu.

Solar hot water system elements

Solar hot water systems were fitted with bobbin-style elements. Bobbin elements have a ceramic 2.4 kilowatt element in a cylinder inside a sheath (Figure 3 below).

Figure 3: Solar hot water system bobbin element with vitreous enamel sheath (top) and ceramic inner element, which remains shielded from the bulk water (bottom).

The element is fixed in place with a cap and held on with six bolts. This element may accumulate scale on the outside of the sheath. It is made of vitreous enamel and may be easily damaged when scraping off scale. The danger is chipping off the covering and exposing the steel which will then be vulnerable to corrosion.

3.3 Field monitoring regime

The field component of the study was undertaken with the cooperation of the community ESO for field sampling, negotiation for entry with householders and technical assistance. A certified plumber with qualifications enabling removal of electrics on hot water systems was also required on each trip for removal of the elements and disconnection of the two electrical wires.
It was initially estimated that the monitoring frequency should be at monthly or bi-monthly intervals, dependent on scale accumulation observed in the field, ending after six months or extended by negotiation with the funding agency. It was soon realised during the SHMP dosing period that such short time frames were insufficient to quantify measurable scale accumulation. The time scale between intervals was increased to approximately four months, ending after sufficient data was collected to draw conclusions or continuing by negotiation for as long as the SHMP system was operating. Mitigating factors such as the availability of contractors also modified planned sampling dates, on two occasions by two and three months. Subsequently, monitoring events during the dosing trial were conducted at intervals of four to seven months.

Field monitoring began with the removal of old hot water system elements from the systems indicated on 20 June 2005. The hot water systems were cleaned of scale and retrofitted with new elements. This was repeated during the following field monitoring events on 8/12/05, 19/04/06, 24/11/06 and 21/05/07. The control trial was bounded by two monitoring events, 21/05/07 and 25/06/07. Wet season access concerns were planned for in advance and did not influence the timing of field sampling trips.

3.4 Scale measurement

Scale accumulated during each sampling period will increase the mass of the element and is also visible upon collection. Water use was also monitored through the installation of analog meters before the hot water system, and flow volumes recorded manually when elements are removed. The following process was conducted for all monitoring trips.

1. New hot water system elements were weighed and clearly labelled prior to taking to the field for use.
2. Old hot water system elements were photographed, labelled and wrapped in clip-seal bags or alfoil for containment of scale in transit to the laboratory (Figure 4). Any scale lost through the element removal process was scraped up as was reasonably possible and included with the wrapped element.
3. Relevant details about the hot water system, house/occupancy and element, such as appearance, condition, scale losses and removal process, were recorded.
4. Each element was then replaced with a new weighed and labelled element.
5. Water flow meter readings were recorded.
6. Upon return to laboratory, scaled elements were air-dried and weighed (oven drying at 60degC overnight was tested on electric elements; however, it was deemed unnecessary).

7. Scaled element weights were then compared to their corresponding pre-installation clean element weight to determine a mass of scale deposited.

The mass of scale accumulated for each interval is then divided by the amount of hot water used in the period, and a unit mass per unit volume, or rate, of scale accumulation can be reported, in grams per kilolitre (g/kL).

![Figure 4: A scaled electric sickle element, bagged and photographed in preparation to return to the laboratory.](image)

### 3.5 Limitations of method

#### 3.5.1 Water quality

The main limitation of the SHMP trial is that potential change in groundwater quality over time was not quantified in this study. Whilst water chemistry is thought to be relatively stable for three to five years with little change, it is possible that changes in water chemistry (particularly Ca and Mg) could influence SHMP performance. The most recent available groundwater chemistry data from Yuelamu is a composite of data from 2003 and 2004. It would be useful to now obtain more recent water chemistry data analysis on the Yuelamu groundwater to preclude any significant changes in groundwater quality over the study period from influencing the performance assessment.
3.5.2 Control trial duration

The most obvious limitation to the control trial was its necessarily short duration, leading to a comparison between data under SHMP dosing of two years’ duration, to ‘control’ conditions of just five weeks. Factors influencing the duration of the control period included stakeholders’ fear of infrastructure failures should scale accumulation be significant and an imminent water supply source change.

Service providers were understandably reluctant to turn off the SHMP dosing system, given the perceived benefits and likely economic and human impact if the hot water systems in the community rapidly scaled and became inoperable. The other factor involved was the pressure to return the community’s primary water supply source from non-potable groundwater to the potable and preferred surface water, after their reengineered dam had filled from earlier summer rainfall.

3.5.3 Element exchange

Given that ‘scaling’ has been defined as a two-step process consisting of metal corrosion and adsorption (Sarin et al. 2001; Lehrman and Shuldener 1952), the implications of exchanging hot water system elements to assess their change in mass requires some discussion. Exchanging already ‘scaled’ elements, where corrosion has occurred and adsorption is occurring, for new ones implies that the rate of scale is consistent and linear. Scale formation is not well understood, and the rates of each of the above processes are not known. If both processes are linear (occur at the same rate) then the effect of exchanging already scaled elements for new ones and forcing the corrosion process to begin again would not be expected to influence overall scale accumulation rates. However, if the initial corrosion process is slow and the secondary adsorption process faster, then the effect would be that scale accumulation rates would be underestimated. This is because the act of replacing old elements with new ones every 4-7 months would force the corrosion process to begin again and a ‘lag’ in adsorption of Ca and Mg ions (scale accumulation) would occur. The degree to which the exchange of elements affects the data obtained would be greater if scaling is an exponential process as opposed to a linear one. However, this cannot be determined from this data and for the purposes of this study is assumed to be negligible.

3.5.4 Capture and measurement of scale

The method of removal of electric elements was an imprecise process in the field, due mostly to incomplete pressure release via the valve by the contractor, and on one occasion due to a blocked pressure valve. For these reasons, the contractors frequently removed elements in a high pressure spray of hot water. This was not only a safety issue, but the resultant spray also contained flakes of accumulated scale, as shown in Figure 5. It was not always possible to tell if the
scale had come from the element or the inside of the hot water tank. The other issue was that due to the sickle element shape, the element could not be removed without scraping it against the inside of the entry/exit hole on removal. Where it was possible and identifiable, scale lost during element removal was collected and bagged with the relevant element.

It is estimated from field observation that in some cases this would account for an underestimate of scale of up to 25% (maximum 12.5g). This error did not apply to the solar hot water elements as the tank had to be emptied to access the element and then it could be extracted unobstructed.

![Image](image.png)

**Figure 5: Example of the scale deposits that could be dislodged from electric hot water system elements during removal.**

Additionally, scale left behind inside electric hot water systems was found to be difficult to remove without damage to the internal tank lining, so scraping this out was excluded from the methodology. Damage to the tank lining can lead to corrosion and rapid degradation of the hot water system unit.

Electric elements weigh around 450g and were weighed to two decimal places. For weighing the heavier solar elements (>2.5kg) it was only possible to obtain scales with a precision of one decimal place, reducing the overall precision of the study.
4 Results

4.1 Scale deposition

There was measurable scale deposition on all elements by the end of the trial. The quantities were lower than expected. This cannot be directly compared to other studies as none were found in the literature that quantified scale accumulation rates.

Measured scale deposition on the hot water system elements was below 70g for most elements during the SHMP dosing period (there were two only above this mass), and under 50g at the end of the five week control sampling period (Table 2). No elements failed due to scale accumulation during the monitoring, which was as expected due to their frequent exchange.

Table 2: Cumulative mass of scale deposited on monitored hot water system elements during SHMP dosing, the control period and overall totals.

<table>
<thead>
<tr>
<th>Hot water system element</th>
<th>SHMP dosing period</th>
<th>Control</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Date</td>
<td></td>
<td>25/06/07</td>
<td></td>
</tr>
<tr>
<td>30/06/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/12/05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19/04/06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24/11/06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21/05/07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days of trial</td>
<td>0</td>
<td>35</td>
<td>725</td>
</tr>
<tr>
<td>Days of trial</td>
<td>161</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>A (electric, 50L)</td>
<td>20</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>B (electric, 80L)</td>
<td>12</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>C (electric, 125L)</td>
<td>5</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>D (electric, 50L)</td>
<td>12</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>E (electric, 164L)</td>
<td>5</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>F (electric, 50L)</td>
<td>7</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>G (solar, 200L)</td>
<td>0</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>H (solar, 200L)</td>
<td>0</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>I (electric, 160L)</td>
<td></td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>J (solar, 200L)</td>
<td></td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>K (electric, 25L)</td>
<td></td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>L (electric, 25L)</td>
<td></td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>M (electric, 50L)</td>
<td></td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>N (solar, 200L)</td>
<td></td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>(BDL = Below detection limit, ND = No data, NS = not sampled)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The mass of scale deposited on electric hot water system elements under the dosing period appeared to be consistent, approximately doubling every five to six months. The maximum scale deposit was 130g on a 50L electric hot water system. Other electric units accumulated 60-90g of scale during the SHMP dosing period. The solar hot water system elements were very resistant to scale accumulation, and took 18 months during this period to exhibit any measurable scale deposits.
Maximum mass scale deposition at the completion of the five-week control trial was 50g (standard deviation, SD=13g), measured in an electric hot water system. Figure 6 below presents data on the total mass of scale accumulated on all hot water elements during the monitoring. Mass of scale deposits on solar hot water systems were below detection limits, regardless of whether the water supply was dosed with SHMP. This is thought to be due to the differing material properties of the vitreous enamel bobbin sheath.

![Graph showing mass deposition comparison](image)

**Figure 6: Comparison of total mass of scale deposited on hot water elements, under SHMP dosing and control conditions.**

Despite the limitations of the differing durations of monitoring of SHMP dosing and the Control trial, a comparison of the scale deposition data from both periods is revealing. In comparison to total mass of scale deposited during the two-year data dosing regime, scale deposited during the five-week Control trial was between 25 and 45 percent of the scale mass, despite being only 5 percent of the duration (Figure 6, Table 3). Analysis of hot water use data is necessary to determine if this higher accumulation could be explained by increased water use.
Table 3: Comparison of total mass of scale accumulated on electric hot water system elements between dosing and control periods

<table>
<thead>
<tr>
<th>Period of monitoring (days)</th>
<th>SHMP</th>
<th>Control</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>electric, 50L</td>
<td>690</td>
<td>35</td>
<td>0.05</td>
</tr>
<tr>
<td>electric, 80L</td>
<td>61</td>
<td>15</td>
<td>0.25</td>
</tr>
<tr>
<td>electric, 55L</td>
<td>62</td>
<td>17</td>
<td>0.27</td>
</tr>
<tr>
<td>electric, 164L</td>
<td>68</td>
<td>30</td>
<td>0.45</td>
</tr>
<tr>
<td>electric, 50L</td>
<td>89</td>
<td>26</td>
<td>0.29</td>
</tr>
<tr>
<td>electric, 50L</td>
<td>130</td>
<td>37</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>na</td>
</tr>
</tbody>
</table>

4.2 Hot water use

As scale deposition is a function of the concentration of hardness ions, the volume of hot water heated in each system was also recorded at each sampling interval to determine the rate of scale deposition per quantity of water throughput.

During the entire two-year monitoring, average daily hot water use across all household hot water systems monitored was 34L/day (standard error, SE=12, n=36). Average hot water use in each monitored system is presented in Figure 7. Average daily hot water use was almost always higher in solar hot water units than in electric hot water units. An average of only 12 L/day (SE=2, n=26) was drawn from electric hot water units during the entire two-year monitoring period. Quantities drawn from solar hot water units over the same period resulted in an average of 93 L/day (SE=40, n=10). It is not known whether this was due to possible greater efficiencies of reheating performance of the systems, but all electric and solar hot water systems were functioning at each trial sampling event. Hot water systems with faster water heating recovery times would be expected to have more hot water drawn from them given the higher occupancies of Indigenous households.

Hot water use was slightly higher across most households during the control trial than that measured during previous monitoring periods, but this was not significant. Daily hot water use in electric hot water systems during the SHMP dosing trial was between 1 and 34L/day, with an overall mean of 10L/day (SE=2, n=20). Daily hot water use across all electric hot water systems during the control monitoring period were between 5 and 52 litres per day, with an average use of 17 L/day (SE=7, n=6). Conversely, hot water supplied by solar hot water units during the SHMP dosing trial was slightly higher at 102L/day (SE=65, n=6), compared to 78 L/day (SE=39, n=4) under control conditions, but this consumption was also not significantly different between the two periods.
Figure 7: Average hot water use by household hot water system (litres per day) at Yuelamu community, June 2005 – June 2007. Where only single data records were collected*, the lone value is presented in place of the mean.

Significantly higher water use and lower rates of scale accumulation observed in the solar hot water system bobbin elements indicate a profound resilience to scale precipitation. For this reason, further analysis of the effectiveness of the SHMP in reducing scale precipitation will focus on the systems where it is most likely to have an effect, namely electric hot water system elements.

Seasonality was expected to have a strong impact on hot water use, but this was not apparent in the data. Water use data for the electric hot water systems is presented below for each sampling period in Figure 8. Given the low mean water use and standard deviation, it was found that seasonality did not impact significantly on hot water use in the households monitored. However, monitoring periods in the trial were usually between five to seven months and across seasons. Integrating water use over durations longer than a three month season will have the effect of shielding high and low water use periods if seasonal fluctuations are subtle.

An average hot water consumption across all household hot water systems at Yuelamu of 34 L/day is at the low end of comparative published household hot water use data from remote communities, of 50L/day to 1400L/day with a mean of 240L/day (Lloyd, Wilson, and Adams 2000). Maximum hot water use in a single household at Yuelamu was 98kL over the two-year study period, an average use of 136L per day.
Figure 8: Mean data on average hot water use during dosing and control* trial periods, during the months of each monitoring period.

These low hot water use rates could be in part due to periods of vacancy between sampling dates reducing average hot water use rates, unknown duration of periods of occupancy when occupancy was noted or purely influence of climate on resident hot water use rates.

4.3 Occupancy

Occupancy impacts upon household hot water consumption. Occupancy varied throughout the two-year period. Occupancy was recorded at the beginning of the study and in consultation with local knowledge from the Essential Services Officer, any obvious changes noted (e.g. if the household was completely vacated) (Table 4). From these data it is not possible to tell if two recorded instances of vacancy are in fact one continuous period or multiple short periods.

There were five out of the original eight households that remained with the same primary occupants over the period. One household vacancy was due to staff leaving their employment at the community.

As detailed occupancy data (number of residents or users per household) was not collected as part of this study, it is not possible to present per capita hot water use rates.
Table 4: Occupancy data for discrete sampling dates for all households.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>residential</td>
<td>occupied</td>
<td>occupied</td>
<td>vacant</td>
<td>vacant</td>
<td>occupied</td>
<td>occupied</td>
</tr>
<tr>
<td>B</td>
<td>residential</td>
<td>occupied</td>
<td>occupied</td>
<td>occupied</td>
<td>vacant</td>
<td>occupied</td>
<td>occupied</td>
</tr>
<tr>
<td>C</td>
<td>residential</td>
<td>occupied</td>
<td>occupied</td>
<td>occupied</td>
<td>occupied</td>
<td>occupied</td>
<td>occupied</td>
</tr>
<tr>
<td>D</td>
<td>residential</td>
<td>occupied</td>
<td>occupied</td>
<td>vacant</td>
<td>occupied</td>
<td>occupied</td>
<td>occupied</td>
</tr>
<tr>
<td>E</td>
<td>community facility</td>
<td>in use</td>
<td>in use</td>
<td>in use</td>
<td>in use</td>
<td>in use</td>
<td>in use</td>
</tr>
<tr>
<td>F</td>
<td>community facility</td>
<td>in use</td>
<td>in use</td>
<td>in use</td>
<td>in use</td>
<td>in use</td>
<td>in use</td>
</tr>
<tr>
<td>G</td>
<td>residential</td>
<td>occupied</td>
<td>occupied</td>
<td>occupied</td>
<td>Occupied</td>
<td>occupied</td>
<td>occupied</td>
</tr>
<tr>
<td>H</td>
<td>residential</td>
<td>occupied</td>
<td>occupied</td>
<td>occupied</td>
<td>Occupied</td>
<td>occupied</td>
<td>occupied</td>
</tr>
<tr>
<td>J</td>
<td>residential</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not monitored (Control trial only)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>N</td>
<td>residential</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>occupied</td>
<td>occupied</td>
</tr>
</tbody>
</table>

4.4 Scale dynamics

Little is known about the dynamics of scale accumulation in hot water systems, how quickly it accumulates and what the key drivers are. This study provides data to assess this in more detail.

It is useful to plot the scale accumulation rates in g/kL in hot water units for each household, with data from each sample period alongside rates of water use between periods to obtain a better understanding of the conditions to which the systems were subjected and why rates might be different across different systems. This is useful because overall mean rates of scale accumulation over long periods may hide these dynamics. Mean scale accumulation rates in the six household electric hot water systems are presented below in Figure 9 and Figure 10. Data from both the SHMP dosing and control periods are presented.

What is most interesting about this data is that a sudden change in the rate of scale deposition during the control period is discernible in all five electric hot water systems continuously monitored over the two-year period. The slope of the scale accretion line in each plot clearly begins to steepen after the May 2007 sampling event, when the SHMP dosing ceased, despite negligible increases in water consumption. Despite low water consumption, Household M accumulated almost 60g of scale in just 5 weeks during the control period (Figure 11). In other systems under the SHMP dosing period it took 18 months to accumulate this much scale. This may provide some indication that the SHMP dosing was having an effect on inhibition of scale growth.
Figure 9: Scale deposition and litres of hot water used during the two-year monitoring, households A–E (electric elements).
Figure 10: Scale deposition and litres of hot water used throughout the trial, households F and M (electric elements). Note that the plot for household F required a higher maximum value for the accretion data scale. Solar hot water system data is not presented here due to barely measurable scale accumulation rates.
Scale accumulation on the electric element for the 50L system at household A consistently increased approximately proportionally to the water use, with a final mass of 76g and water use of 5.3kL. The hot water system at household B (electric, 80L capacity system) exhibited similar characteristics under similar quantities of water use, with final scale build-up of 79g and water use of 4kL.

Household E also had a similar total water use to A and B at 4.8kL, but higher scale accumulation at 115g. However, as this is only slightly more than the 25% sampling error range, this is not considered significant.

Total hot water use through the system at households D and F (both electric, 50L capacities) were similar (each approx 13.5kL, or an average of 14-19L/day), however the total amount of scale accumulated was roughly double in the system at household F (note difference in plot scale) which had just under 170g of scale, compared to just under 100g in system D. The reasons for this may be that household F appeared to have consistently high water use over the two-year study period, whereas household D had a period of high water use towards the end of the sampling period, which boosted overall water consumption but did not proportionally increase scale deposition.

Household E is a community facility and has a 164L electric instantaneous hot water system. Household F is also a community facility, equipped with a 50L electric instantaneous unit. Household E and F consistently consumed similar quantities of hot water between June 05 and Dec 06. Interestingly, the water use increased during the final sampling periods in household F, but not in household E. This resulted in only a 50% greater scale deposition of 170g compared to 120g respectively, despite consuming a total of three times the water in household F of 14kL (F) compared to 4kL (E). The lower scale proportionate deposition of hot water system F may be partially explained by the high turnover of water. This would likely ensure that very little of the water in the tank is re-heated multiple times, which would be expected to increase the concentration of precipitable minerals. This also illustrates that scale deposition is not necessarily linearly proportional to water use.

The hot water system at household D heated three times the water of the system at household E (4.8kL), but resulted in a comparative final mass of scale deposition (115g). The hot water system at household E also had consistently low water consumption over the two-year monitoring period.
Household G (not shown above) was equipped with a 200L solar hot water system with a vitreous enamel bobbin element. This unit heated approximately 26kL of water over the two-year period, approximately double the volume heated in the highest use electric instantaneous units in households D and F, with barely measurable scale deposition (1g), compared to household F’s 167g element scale deposits. Household H was also equipped with a 200L solar bobbin-element hot water system. This unit produced 99kL of water, nearly seven times the maximum 13.5kL hot water produced in the next highest use electric hot water systems, with 10-17 times less scale accumulated (10g compared to 100 and 170g). The scale produced on element H was also as a result of what appeared to be a surface imperfection or fault which may have weakened the coating and enabled the scale to penetrate the bobbin surface coating.

Despite a few differences in the total amount of scale accumulated for given hot water quantities consumed, the results do indicate that there is indeed a slight but positive and proportional relationship between total water consumption and the mass of scale accumulated, as shown in Figure 11 ($R^2=0.56$).

Figure 11: Relationship between total mass of scale deposited on the electric hot water elements and the total hot water consumption of the system.

More data replicates (i.e. a greater number of hot water systems monitored) would provide greater predictive strength and certainty in the data.
4.5 Scale accumulation rates

4.5.5 Two-year rates

Given that scale accumulation is thought to be a function of water use, it is useful to examine trends in total scale deposition relative to water consumption in each system. Figure 12 below illustrates that scale deposition in each hot water system did increase as more water was used. The two solar hot water systems monitored only for the control trial are not displayed as scale accumulation was below detection limits. Rates of scale deposition with water use varied considerably among hot water systems, illustrated by the differing slopes. Solar hot water systems demonstrated a resistance to scale, with extremely low deposition.

![Graph showing cumulative scale deposition and hot water use in each hot water system monitored for the entire 2 year trial.]

Figure 12: Cumulative scale deposition and hot water use in each hot water system monitored for the entire 2 year trial.

4.5.6 Comparison of dosing and control data

All electric hot water system elements accumulated scale with and without SHMP dosing. An analysis of scale accumulation rates, analysed in grams of scale per kilolitre (1000L) of water heated, also provides a comparable metric for comparison of control conditions of scale accumulation due to the hard groundwater against the scaling rates during the use of SHMP. This also has the effect of removing the householder variables of occupancy and total water consumption through each hot water system from the analysis.

For the purposes of this analysis, scale accumulation rate data from the five-week control period was compared to that from the prior two-year SHMP dosing trial (Figure 13 following). The graph illustrates that for four of the five electric hot water systems on which there was comparative data, the rate of scale accumulation was significantly lower when the systems received water dosed with SHMP than under control conditions, despite comparative water use.

To more clearly compare data between Control and SHMP dosing conditions, overall mean data for scale accumulation rates during the SHMP dosing trial are displayed against that for the Control data (Figure 14). The overall mean scale accumulation rates for electric hot water systems during the SHMP dosing period was 19g/kL (SD=18, n=20). The comparative mean during the control periods was 71g/kL (SD=36, n=6). Water consumption was similar across both periods; 10L/day (SD=9, n=20) during SHMP use and 17L/day (SD=18, n=6) during the Control period.

The average water use and scale accumulation values at first glance appear to reflect a slight difference in scale accumulation rates. However, under treatment and control conditions, and due to the large standard deviations and the small sample size of the both trials and particularly the short duration of the control trial, there is not enough data to state with certainty that there is a true difference in effect from dosing the water supply with SHMP.
Figure 13: Average rates of scale accumulation on electric hot water system elements and average daily hot water use for the corresponding hot water system. Scale accumulation data (g/kL) from the five-week control trial is compared to that from the two-year dosing trial.
5 DISCUSSION

5.1 Mass scale deposition

Whilst it is not possible with the available data to conclusively quantify a reduction in scale accumulation rates from SHMP dosing, the quantities of scale accumulation measured during the study do appear low under the dosing regime for a groundwater supply with a hardness ion concentration of 457 mg/L and total dissolved solids of 2240-2600mg/L. No data was found in the literature that reported scale accumulation rates (mass over time or per kL of water) for different water qualities and so the results of this study could not be compared to other studies.

Electric elements accumulated scale, with a maximum amount deposited of 54g. All five electric hot water systems monitored over the two-year period (regardless of capacity, and SHMP) accumulated around 100g of scale (plus up to 25% due to field losses) for hot water delivery quantities of 0.6-13.5kL over two years.

This was unexpected, as there were different use regimes, quantities of hot water used, system capacities and ages and occupancy fluctuations. These variables may indeed influence scale accumulation rates, but the methodology was not designed to have the statistical power to detect a response to each of these
variables. Nonetheless, given the sameness of the scale result, it is possible that these factors are not true variables.

It is also unknown what mass of scale build-up on a hot water element it would take to cause the element to fail, i.e., is it 50g or 200g? However, scale accumulation causes inefficiencies for heating, and further research is required to characterise the subsequent cost increases from increases in electricity consumption for any measurable amount of scale coating on heating elements.

5.1.7 Influence of element type

Electric hot water system elements clearly accumulated scale faster than the solar hot water system elements. All five continuously monitored households with electric hot water systems produced measurable rates on all sampling occasions. The two solar hot water systems did not produce measurable scale mass deposits until 15 months, and arguably one of those was of negligible mass (1g).

Both element types had a surface which is exposed to the bulk water inside the hot water systems. However, the vitreous enamel bobbin sheath acts as a shield for an inner element (Figure 3). This protects the immediate heating surface from the bulk water. The enamel coating reduces the ability of Ca and Mg ions to adhere, and the location of the element in the centre of the hot water tank also means that these ions settle to the bottom and not on the element.

In electric systems, the element is at the bottom of the hot water tank, so it not only attracts Ca and Mg ions that adhere from solution in the adjacent water, but also catches those that precipitate out through the heating process. This was visible in many of the collected sickle-shaped electric elements (Figure 15).

One solar hot water system element showed signs of pitting, corrosion and scale adhesion where the bobbin element surface coating was exposed (Figure 16). It is uncertain how this process began, but this system had a considerably higher water use than the other solar hot water system, though still low when compared to other published remote community hot water use data (Lloyd, Wilson, and Adams 2000). If the damaged bobbin had been left in place, scale accumulation would be expected to increase dramatically as the underlying element surface was exposed. Solar hot water system bobbin elements were handled very carefully and so it is unlikely the bobbin was damaged from removal and
replacement handling. Discovery of this pitting has implications for maintenance regimes; given the difficulty in access to roof-mounted solar hot water systems, it is not likely that under ordinary management regimes that solar bobbin elements would be inspected after just 15 months.

Figure 16: Household solar hot water system bobbin element surface that has been compromised by pitting, possibly caused by corrosion, subsequently enabling mineral scale adhesion to the element.

Despite the damaged element, the use of the bobbin elements and solar hot water systems still illustrated a 5-50 fold less scale mass deposition (at 60-80°C) at the end of the two-year period than the electric elements. Compared to the
maximum precipitate reduction achieved by laboratory studies of SHMP at 90-95% at 100°C and by 5-30% after secondary boiling (Shafizadeh 2007), the use of bobbin elements are more resistant to scale than using SHMP on electric elements. Secondary boiling was found to be occurring from this field trial, and temperatures in hot water systems usually remain within the range of 60-80°C, so the highest efficiencies in the field would not be expected to be reached. No laboratory data was available that characterised lower SHMP effectiveness for subsequent boiling events, but even at 30% effectiveness, solar hot water systems compare very favourably as a mitigating measure for reducing hard water failures in hot water systems.

5.1.8 System capacity and throughput

Based on the information obtained from Water Corporation (Shafizadeh 2007) regarding the influence of reheating on reducing the efficiency of SHMP, consideration of the relationship between system capacity and scale deposition is necessary.

Table 5 below summarises the scale accumulation rates, total scale masses, hot water consumption rates and totals and the hot water system capacities. As the solar unit scale accumulation rates were below detection, only electric element data is presented below. There were three 50L electric units monitored over comparable time scales, each heating between 5.3 and 13.5kL of water as discussed above. The overall two-year scale accumulation rates for these systems were not the same, and no distinct pattern was observed that described the differences in rates. This does not account for a potential of 25%, as this was considered consistent for all electric elements. It is of interest, however, that the electric system which heated one of the highest volumes of water of the electric systems, system D, had the slowest rate of scale accumulation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>electric hot water system elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household</td>
<td>A  B  D  E  F  M</td>
</tr>
<tr>
<td>Mean scale rate (g/kL)</td>
<td>30  33 29 37 13 91</td>
</tr>
<tr>
<td>Total scale deposition (g)</td>
<td>76  79 98 115 167 50</td>
</tr>
<tr>
<td>Total water use (kL)</td>
<td>5.2 3.9 12.7 4.7 13.2 0.6</td>
</tr>
<tr>
<td>Average daily water use (L/day)</td>
<td>8   4  17  6  22  16</td>
</tr>
<tr>
<td>Hot water system capacity (L)</td>
<td>50  80 50 164 50 50</td>
</tr>
</tbody>
</table>
Given the influence of system capacity and use regime on how often hot water is heated, it is useful to determine if the rate of hot water use is static or related to system size. The three largest capacity hot water systems included the two 200L solar units (on houses) and the 164L electric unit (community facility). Both of the 200L units had comparatively higher use rates of 14L/day in household G and 35L/day in household H. The 164L unit had a much lower use regime with an average daily water use of 4.8L/day; as a community facility it only has use during the day and so these data are not easily compared with usage of the two solar units. In the solar units, as a proportion of the total volume of 200L, water could still be heated multiple times before leaving the system. Therefore it is not believed that the higher use rates in solar hot water systems contributed to the overall lack of scaling in those cases.

This would be consistent with laboratory trials by Water Corporation (Shafizadeh 2007; Appendix 3) that illustrate a reduced effectiveness of SHMP after re-boiling. It is also true that without the addition of SHMP, scale accumulates more rapidly on subsequent reheating. Therefore, regardless of SHMP effectiveness, a higher water turnover through the system would mean a reduction in parcels of water that have been heated twice and therefore a reduction in scale deposition.

Conversely, due to the smaller throughput volumes observed in all other hot water system units relative to their total capacity (4-16 L/day), by deduction, all the hot water systems monitored are regularly heating the same water multiple times. This would lead to the laboratory-tested effectiveness of SHMP being significantly reduced in practice due to re-heating. Other studies report that in stagnant or low-flow conditions, stagnation affects the rate of complexation of Ca and Mg ions with polyphosphates (Sarin et al. 2001) and a hot water system with poor circulation might require 10-20mg/L of the polyphosphate in order to attain the desired inhibition of corrosion (Hatch and Rice 1945). Low flows through the systems at Yuelamu therefore may have influenced the effectiveness of SHMP. One way to account for the stagnation effect in future studies would be to include multiple monitoring sites (e.g. hot water systems, pipe lengths, etc) for the measurement of scale accumulation. If possible, a future study should include treatments and a control in series at these multiple monitoring sites at another location.
The process of SHMP sequestration is not well understood, and other variables such as temperature, dissolved oxygen, changes in hardness and TDS, time since mixing and addition of SHMP concentrate need to be monitored to assess the relative effectiveness of SHMP dosing in specific water quality regimes.

The control trial did not find any significant trends indicating that hot water system capacity itself influenced the rate of scale accumulation. Lower hot water consumption regimes, independent of system capacity, does appear to result in increased scale accumulation in individual systems. Further investigation under an expanded study design would be necessary to determine sensitivities of the total throughput of water and its effect on the amount of scale accumulated on elements.

5.2 Linearity of scale accumulation

This study based its methodology on the knowledge that higher water use has the effect of exposing the hot water element to more minerals (concentration being a function of volume). This would be expected to cause higher rates of scale deposition. However, this study assumed that scale deposition is cumulative and linear, given its tendency to form physically hard ‘scale’ structures, as observed on elements. It was assumed that no scale is thought to be ‘washed off’ due to higher water use, nor should it fall off during periods of low or no water use. However, photographs taken of the inside of hot water systems during the Control trial indicate that ‘shedding’ of this scale layer may periodically occur, either from scale falling off the element or from the inside hot water system casing, as evidenced by large amounts of ‘scales’ present (Figure 17). This may indicate that scale deposits measured on a hot water system element between two points in time may not be representative of the total scale accumulated during that period. In other words, scale accumulation as measured on the element between two points may be non-linear.

It is not known under what conditions the scale layer would be caused to shed, or conversely, the amount of scale that would cause element failure. Possible causative conditions for shedding could include wetting, drying, cooling, high or low flows or mass saturation, where the mass of scale reaches a critical limit and breaks off. This prompts the consideration that scale deposits may be highly variable, and the mass of a scale deposit measured between two given points in time may not be cumulative and therefore not indicative of the total scale accumulation over that period. However, given that scaling on hot water
elements reduces efficiency of the hot water system, the ‘shedding’, if it occurs, would cause a short-term and partial restoration of the efficiency of the hot water system.

![Image](image.png)

**Figure 17:** Loose ‘scale’ deposits on the inside of a hot water system, through the opening where the hot water element fitting is inserted.

### 5.3 SHMP effectiveness

Data from this study provided some positive indication that SHMP dosing may have reduced scale accumulation at the trial site. However, given the short duration of the control period, and the low number of system replicates, the data does not provide the ability to conclude that SHMP is effective, other than to indicate that it shows promise.

The specificity of the monitoring trial to this particular location (i.e. that no other supplies were monitored for baseline comparison) also preclude the assumption that similar positive results from this study could be achieved in different groundwaters of varied chemistry. This is because the process of SHMP sequestration is not well understood.

Variables such as water temperature, time since mixing and addition of SHMP concentrate, dissolved oxygen concentration, changes in hardness and TDS in source water supplies and the addition regime of SHMP can all influence the effectiveness of SHMP dosing, and would need to be further understood to assess the relative effectiveness of SHMP dosing in specific source water qualities.
It is also worth revisiting that from published literature, SHMP dosing only acts to reduce scaling on hot surfaces, and so does not ameliorate scale deposition on showerheads, cold reticulation pipes, evaporative air conditioners, pumping systems and water storages.

The question of the effectiveness and future use of SHMP at other sites will be one of:

1. source water quality
2. the likely risks of increased bacterial growth in the water system (and therefore adequate disinfection)
3. the safety of wholesale dosing of drinking water supplies with a food industry preservative, and the likely ingested concentrations by residents
4. weighing the economic costs of regular replacement of elements as a management strategy for scale mitigation; compared to the economic cost of installation and management of an SHMP dosing system and likely benefits.

The first three aspects were not built into the monitoring regime for this study, and are areas requiring further research. Points four and five are further discussed and analysed in the Economic Evaluation in section six following.
6 ECONOMIC EVALUATION

6.1 Terms of reference
The terms of reference required an evaluation of the economic benefit of ‘Calgon’
dosing treatment, or sodium hexametaphosphate (SHMP). This requires
consideration of alternative intervention options for managing scale, and the
objectives of scale management. There are two primary objectives of a
treatment or management intervention in hard water supplies:
   a) to reduce the overall costs of scale impacts
   b) to reduce the negative, non-monetary impacts of scale on the amenity
      of health hardware to householders.

6.2 Definitions
The following terms are defined below for use in the economic evaluation.

Household health hardware here refers to those household appliances and
fixtures that use water and are necessary for environmental health of residents
(Nganampa Health Council Inc. 1987; Territory Health Services 2002), including
hot water systems, taps, shower heads and other minor plumbing fittings, toilets
and evaporative air conditioners.

Community water supply system here refers to the usual wet component
infrastructure necessary to deliver a reticulated community (ground) water
supply, including a groundwater bore, bore pump/s, mains pipes, bulk storage,
distribution mains pipes, and essential fittings and joins. For the purposes of this
analysis, it does not include sewerage infrastructure.

6.3 Uncertainty and failure rates
There is a lack of information in the literature on how much accumulated scale it
takes under various water qualities to cause health hardware and water supply
infrastructure to fail. During the five-week trial, no elements failed. There is an
inherent uncertainty in failure rates, both in the time to failure and overall failure
frequency of household and water system infrastructure due to scale
accumulation. The uncertainty exists both in a broader context and in the data
obtained in this study, and this lack of data does not readily permit a definitive
economic evaluation. However, estimates have been made to enable an
evaluation if certain failure rates were realised.
6.4 Impacts of scale accumulation

There are a range of fiscal, environmental health and environmental costs resulting from the impacts of excessive scale accumulation, such as:

- fiscal costs of replacement of household and community ‘wet’ infrastructure (health hardware and water supply components)
- health costs from reduced amenity, access to or functionality of primary essential health hardware, such as hot water systems, flushing toilets, showers, air conditioners (evaporative) and taps
- environmental costs of water wastage from broken or leaky taps, toilets, and showers. This can be acute in remote areas where repairs may take a long time to rectify and community groundwater resources are often limited.

These costs are potentially managed differently by different agencies to reduce the fiscal costs of scale.

6.5 Costs of hard water

The uncertainty about failure rates of key infrastructure from scale is likely as much due to the extreme variability in groundwater qualities and environmental conditions that cause scale to precipitate, as the diffuse costs borne of scale impacts. The diffuse nature of the costs of scale damage to infrastructure contributes to an uncertainty of the total impact of hard water on community and household hardware. The costs of scale accumulation and infrastructure failure are borne by a diffuse range of actors and agencies including householders, community housing organisations, local government councils, water service providers and State/Territory funding agencies. The number of players makes an estimate of the overall costs (as a whole or for individual agencies) attributable to hard water impacts difficult to quantify. There is no cross-sector monitoring of the cost of scale impacts. This inhibits the estimation of the economic benefits of a given treatment or management action and subsequently makes such benefits difficult to quantify.

6.6 Potential benefits of SHMP treatment

From the data obtained in this study, it was shown that SHMP had a slight inhibiting effect on scale accumulation at the study site. However, a number of limitations prevent generalisation of this finding to other water supply systems. The benefit of the treatment is questionable, due to the short duration of the control conditions, potential variability in groundwater quality, temperatures and dosing rates. However, if this inhibition effect was satisfactorily reproduced, the potential benefits of SHMP treatment would be discernable as a reduction in scale
accumulation rates on hot surfaces, and therefore likely increased longevity of hot water system elements, hot taps and tap washers. It would not provide benefit on cold/cool wet surfaces in water supplies and households and therefore would not reduce failure rates of air conditioners and cold water fittings.

6.7 Alternative management scenarios

Given the potential benefits of SHMP, an examination of broad cost implications requires comparison of the treatment to alternative hard water management strategies. This is made possible by comparing economic estimates of three likely hard water management scenarios:

1. Failure management of household scale impacts
2. Preventative maintenance of household scale impacts
3. Dosing treatment with SHMP for mitigation of household scale impacts

The costs incurred on maintaining the service of four main household infrastructure components that are usually impacted by hard water; hot water systems, toilets, minor tap fittings and evaporative air conditioners, will be considered under these three management regimes.

A fourth possible scenario exists, which is the use of SHMP in conjunction with a Preventive Maintenance program. However, this was not analysed here as we need first to ascertain the difference between alternate management strategies. It is of course possible to combine elements of these strategies according to the needs of a particular community water supply.

Although an alternative treatment method is also a possible scenario, it was beyond the scope of this study to provide data on costs and efficacy for a comparison of the host of alternative treatment options for scale mitigation and removal in hard waters.
6.8 Assumptions

Overall assumptions

A range of assumptions were required to frame the scope of the economic evaluation. An analysis period of five years was selected to enable an adequate consideration of capital and recurrent costs.

A community size of 40 houses was assumed as this is considered to be in the median range for medium to large communities. All houses were assumed to have electric hot water systems as these are the usual hot water system installation in remote Aboriginal communities. This is thought to be in part due to the fact that electric hot water systems have a lower capital cost (usually less than $500) than solar hot water systems (in the order of $3500) and take fewer person-hours to install (30 minutes compared to two hours for solar) (see Appendix 4). From the trial data discussed earlier in this report, bobbin element hot water systems have substantially lower rates of scale accumulation. These systems would therefore have lower failure rates than electric hot water systems and would require the analysis to account for a different failure rate. SHMP was also thought to have negligible influence on the scale rates on solar bobbin elements, and so for comparative analysis these failure rates may not be different between SHMP use and alternate management scenarios.

It was assumed that all houses had evaporative air conditioners. These are the most common air conditioners used in arid, remote communities, as they humidify the dry air and produce a more comfortable environment. Arid areas are also where hard water sources are most likely to be found, due to long retention times and low aquifer recharge rates.

It was assumed that the community was a round-trip travel distance of 600km from a major service centre, and from where a plumber could be sourced.

A water hardness concentration in the community water supply of at least 500mg/L (as at Yuelamu) was assumed to provide a reference point for estimation of failure rates. A hardness of 500mg/L was assumed across all three scenarios as it was considered to be indicative of sufficient scaling problems that would be likely to trigger a need for hard water management interventions. In the absence of failure data, the author based the assumptions of failures on observations from field experience and that of experienced colleagues.
**Management Strategies**

The activities of the management scenarios are explained below and a range of assumptions governing each are outlined explicitly in Table 6.

**Failure Management** refers to a regime of major repairs on or replacement of key infrastructure when broken. In this scenario, electric hot water systems, toilet cisterns, evaporative air conditioner components (e.g. filters & bleed pipes) and minor tap fittings would need to be replaced once every year, and that a plumber is required a total of four times over the year to make the replacements in all 40 houses. This ad-hoc replacement scenario results in major repairs/replacements being required on everything five times - once per year for five years.

**Preventive Maintenance** refers to a regime of regular maintenance of electric hot water systems, toilet cisterns, minor tap fittings and evaporative air conditioner components by a semi-skilled resident maintenance crew for a period of five years. Maintenance would be carried out by two people, conducting an average of eight hours maintenance per house twice per year. Electric hot water system elements would be replaced by a qualified plumber twice per year. Major repairs or replacements of electric hot water systems, toilet cisterns, evaporative air conditioner components (filters & bleed pipes) and minor tap fittings would occur once during the five-year period, and again this would require four trips by the plumber over five years to complete the necessary replacements in all 40 houses.

**SHMP Dosing** consists of the continuous operation of the SHMP dosing treatment plant over five years. It was assumed that the impact of this on failure rates was at least comparable to that of the preventive maintenance regime, requiring that electric hot water systems would need be replaced only once in five years. It was assumed that other household hardware would be ‘failure managed’, requiring that air conditioner, toilet cistern and minor tap components be replaced when broken which was expected to be once per year, or a total of five times, over the five-year period.
Table 6: Guiding assumptions for analysis of hard water management scenarios

| Overall Assumptions | a) Analysis period of five years  
|                     | b) Analysis is for a community of 40 houses  
|                     | c) All houses have electric hot water systems  
|                     | d) All houses have evaporative air conditioners  
|                     | e) Water hardness concentration in the community water supply is at least 500mg/L (as at Yuelamu).  
|                     | f) The above water hardness results in an annual failure of key household health hardware.  |

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>‘Failure management’ of household scale impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Hot water systems, toilets, tap fittings and evaporative air conditioners, receive no regular maintenance and then are replaced once broken.</td>
</tr>
</tbody>
</table>
| Assumptions | 1.1 Household health hardware requires major repair or replacement annually  
|             | 1.2 Hot water system failure results in total burn-out of element and wiring, requiring replacement of the complete hot water system  
|             | 1.3 Failure management requires that ad-hoc failure of household health hardware requires call-outs by a qualified plumber, which usually results in the need for four visits per year, and on each visit a quarter of the houses receive replacements. |

<table>
<thead>
<tr>
<th>Scenario 2</th>
<th>Preventative maintenance of household scale impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Hot water systems, toilets, tap fittings and evaporative air conditioners, receive regular maintenance and then are replaced once broken.</td>
</tr>
</tbody>
</table>
| Assumptions | 2.1 Preventive maintenance of toilets, taps and air conditioners occurs twice per year per house, with local labour  
|             | 2.2 Preventive maintenance consists of cleaning scale from air conditioner pads, air conditioner bleed pipes and toilet cistern mechanisms and replacing minor tap fittings such as shower heads and tap washers  
|             | 2.3 Hot water system maintenance requires a plumber to periodically replace each element (twice per year) and this requires two visits per year  
|             | 2.4 Preventive maintenance delays the need for major repair or replacement of hot water systems, toilet cisterns, minor tap fittings and evaporative air conditioner components to once every five years |

<table>
<thead>
<tr>
<th>Scenario 3</th>
<th>SHMP treatment for mitigation of household and community water supply scale impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>SHMP is added to bulk water supply by a community operator. Hot water systems, toilets, tap fittings and evaporative air conditioners receive no regular maintenance and then are replaced once broken.</td>
</tr>
</tbody>
</table>
| Assumptions | 3.1 That no preventive maintenance occurs on the other identified household health hardware components  
|             | 3.2 That SHMP reduces scale accumulation on hot surfaces, including hot water systems, hot taps and hot tap washers.  
|             | 3.3 That SHMP delays the failure of hot water systems, at least equal to that of preventive maintenance, by five years (probably an overestimate of its effectiveness) |
6.9 Cost evaluation of scenarios

Five-year costs

Major costs of the different management scenarios are estimated over a five-year period, based on real figures of recent 2007 plumbing and maintenance costs (Appendix 4). The costs of the differing configurations of these are then compared to the costs of operation of a SHMP water treatment program. Costs for each scenario are displayed as capital and labour, and a recurrent average annual cost over the five-year period. Table 7 presents key costs of the components and summary costs of each scenario.

The greatest difference in the five-year costs between the three management scenarios is that failure management was estimated to cost $360,000 over five years, approximately 30% (or almost $100,000) more than the alternatives. This is mostly due to higher capital costs and a greater dependence on external labour. Averaged annualised cost was estimated to be $72,000, although failure management costs would be expected to be less predictable than this in reality. However, an estimate of the number of trips was required to be made based on estimates of failure frequency for the example water quality to enable determination of approximate economic cost. The lack of predictability of a failure management approach to scale impacts is a significant disadvantage in agency monetary planning.

Preventive maintenance and SHMP dosing were estimated to cost approximately the same as each other, both around $275,000 over five years, or an average annualised cost of $55,000. However, this was somewhat expected, as the SHMP dosing was assumed to be as effective as preventive maintenance in delaying the need for replacement of hot water systems, but not for other infrastructure such as major repairs of air conditioners and toilet and tap components which were replaced annually under this regime. In the absence of real data estimating the increased life of hot water systems under SHMP dosing, there is also great uncertainty that this would be the achieved benefit of an SHMP dosing regime. Indeed, although this may be a significant overestimate of the effect of SHMP on increasing infrastructure life, it presents a ‘best case’ for comparison to the alternatives.
Table 7: Cost estimates of alternate hard water management regimes

<table>
<thead>
<tr>
<th>Item of expenditure</th>
<th>Failure management</th>
<th>Preventive maintenance</th>
<th>Calgon dosing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CAPITAL COSTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Hot water system 120L (40 @ $500 each x failure frequency x 5 years)</td>
<td>$ 110,000</td>
<td>$ 22,000</td>
<td>$ 22,000</td>
</tr>
<tr>
<td>2.4kW electric hot water system elements (40 @ $30 each x failure frequency x 5 years)</td>
<td>$</td>
<td>$ 12,000</td>
<td>$ -</td>
</tr>
<tr>
<td>Toilet cistern mechanism &amp; seals (40 @ $200 each x failure frequency x 5 years)</td>
<td>$ 40,000</td>
<td>$ 8,000</td>
<td>$ 40,000</td>
</tr>
<tr>
<td>Evaporative air conditioner filters, bleed pipe (40 @ $200 each x failure frequency x 5 years)</td>
<td>$ 40,000</td>
<td>$ 8,000</td>
<td>$ 40,000</td>
</tr>
<tr>
<td>Household tap seals &amp; minor fittings (40 @ $200 each x failure frequency x 5 years)</td>
<td>$ 40,000</td>
<td>$ 8,000</td>
<td>$ 40,000</td>
</tr>
<tr>
<td>Maintenance costs ($200 per house per year x 5 years)</td>
<td>$ -</td>
<td>$ 40,000</td>
<td>$ -</td>
</tr>
<tr>
<td>Hot water system transport costs ($5000 per delivery x failure frequency x 5 years)</td>
<td>$ 5,000</td>
<td>$ 5,000</td>
<td>$ 5,000</td>
</tr>
<tr>
<td>Treatment System, installed ($50,000)</td>
<td>$ -</td>
<td>$ -</td>
<td>$ 50,000</td>
</tr>
<tr>
<td>Dosing chemical, (@ $500/year x 5 years)</td>
<td>$ -</td>
<td>$ -</td>
<td>$ 500</td>
</tr>
<tr>
<td><strong>SUB TOTAL Materials</strong></td>
<td>$ 255,000</td>
<td>$ 103,000</td>
<td>$ 197,500</td>
</tr>
<tr>
<td><strong>LABOUR COSTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plumber labour (person hours per replacement x 40 houses @ $75/hr x replacement frequency x 5 years)</td>
<td>$ 82,500</td>
<td>$ 31,500</td>
<td>$ 58,500</td>
</tr>
<tr>
<td>plus travel costs per trip ($1.70 per km x 600km x no. of trips/yr x 5 years)</td>
<td>$ 20,400</td>
<td>$ 12,240</td>
<td>$ 10,200</td>
</tr>
<tr>
<td>Community labour (2 people, 8 hours/house x $20 per hour x twice/year x 5 years)</td>
<td>$ -</td>
<td>$ 128,000</td>
<td>$ 10,400</td>
</tr>
<tr>
<td><strong>SUB TOTAL Labour</strong></td>
<td>$ 102,900</td>
<td>$ 171,740</td>
<td>$ 79,100</td>
</tr>
<tr>
<td><strong>COST SUMMARY</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total capital</td>
<td>$ 255,000</td>
<td>$ 103,000</td>
<td>$ 197,500</td>
</tr>
<tr>
<td>Total labour</td>
<td>$ 102,900</td>
<td>$ 171,740</td>
<td>$ 79,100</td>
</tr>
<tr>
<td><strong>TOTAL 5-YEAR COST</strong></td>
<td>$ 357,900</td>
<td>$ 274,740</td>
<td>$ 276,600</td>
</tr>
<tr>
<td><strong>Average annualised cost</strong></td>
<td>$ 71,580</td>
<td>$ 54,948</td>
<td>$ 55,320</td>
</tr>
</tbody>
</table>
Investment profile of alternate management scenarios

The degree of investment required in capital, external labour and local labour for each strategy is referred to as the investment profile. The differing investment profiles of the alternative management scenarios were evaluated and are presented in Figure 18. These profiles may have important implications on how a community or water management agency evaluates alternate hard water management regimes, as the choice of strategy may to some extent depend on the needs and available skills and resources of the community at that location. For example, if a community is further away from expert labour, has a semi-skilled and work-ready pool of local workers, then they may choose a strategy which has a greater investment in the local labour force and stronger outcomes for the local economy at the remote location.

![Investment profile graph](image)

**Figure 18: Distribution of investment for alternate management scenarios**

From this analysis, Failure Management had the greatest capital cost, the greatest reliance on external labour and no local labour component to the work.

The capital and external labour costs of Preventive Maintenance were significantly lower than those of failure management or SHMP dosing. This reflects that minor repairs and cleaning of scale would require minimal expenditure on cleaning products, tools and small parts for minor repairs and that this maintenance would delay the need for replacement of and major repairs to household infrastructure to once in five years. This cost saving on capital and external labour is instead
utilised for local labour to conduct the preventive maintenance works and would have important implications for local job creation, providing the greatest local employment of the scenarios, at almost two full-time salary equivalents per year.

The SHMP dosing regime also involves a small local labour investment (one partial salary), but an additional 25% in external labour costs when compared to preventive maintenance. SHMP dosing has a considerably lower capital cost of approximately $60,000 and a reduced external labour cost of $30,000 when compared to failure management. These findings reveal the need for consideration of the nature of costs incurred and the return on these investments in the form of not just financial, but also non-monetary benefits. In order to further understand the implications of the different management strategies in reducing scale-related impacts on hardware and community residents, it is prudent to examine the expected benefits of the three management strategies. Table 8 provides an overview of the main perceived benefits of each management scenario.

Failure management appears to have little other benefits aside from the certainty of the benefit from the replacement of infrastructure. This scenario is reactive, governed by uncertain failure frequencies and would result in significant regular loss of utility to residents of key household health infrastructure.

Preventive Maintenance is a more proactive strategy and has many additional benefits, including delaying the need for replacement of key infrastructure, building local skills for maintenance (possibly reducing the need for external labour in the future) and increasing ownership over household health hardware. This scenario is also likely to increase the amenity of householders by improving their access to functional health hardware and reducing wait times between failure and repair of infrastructure. This scenario provides a certain benefit for certain costs and these are likely to be more predictable over the long term and therefore simpler to forecast expenditure.

The SHMP dosing regime provides a certain benefit in its contribution to local employment, and a certainty of costs for SHMP operation. However, there is a greater level of uncertainty about the likely benefit of delay in health hardware failures and therefore the scheduling of costs for replacement of infrastructure. Also, the benefits of both failure management and preventative maintenance scenarios will have broader implications on other household infrastructure components, such as taps, toilet cisterns and air conditioners, whereas SHMP will
not provide benefits to these household necessities. This may have the effect of providing cost efficiencies for management and perhaps favour these two strategies in the consideration of additional benefits.

**Table 8: Summary characteristics of the three proposed hard water management scenarios**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Failure management</th>
<th>Preventive maintenance</th>
<th>SHMP Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Benefits</strong></td>
<td>• Certain benefit when things replaced</td>
<td>• Certain benefit from increased maintenance</td>
<td>• Potential reduced rates of failure of electric hot water system elements (uncertain)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Replacement of capital delayed</td>
<td>• Replacement of electric hot water system delayed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reduced wait times between breakage and repair of air conditioners, taps, leaky cisterns</td>
<td>• Contribution to local ESO employment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increased reliability of electric hot water systems, other health hardware</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Regular repairs possible on plumber scheduled trips</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Likely decreased water wastage from regular preventive maintenance</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Likely improvements in environmental health from increased reliable access to hot water, functional showers, toilets, taps and air conditioners</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Local job creation for maintenance crew, builds local skills</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increased 'ownership' of health hardware</td>
<td></td>
</tr>
<tr>
<td><strong>Certainty of Costs and Benefits</strong></td>
<td>• Uncertain costs (due to uncertain failure frequency)</td>
<td>• Certain costs</td>
<td>• Certain costs related to SHMP operation</td>
</tr>
<tr>
<td></td>
<td>• Uncertain ad-hoc and ongoing costs for all wet hardware</td>
<td>• Certain benefits</td>
<td>• Uncertain costs related to failure frequency</td>
</tr>
<tr>
<td></td>
<td>• Certain benefit (replacement)</td>
<td></td>
<td>• Uncertain benefit in reducing overall scale accumulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Uncertain ad-hoc and Ongoing costs for cold water fittings</td>
</tr>
</tbody>
</table>

**Sensitivity Analysis**

Given the significant cost implications of the assumption of a one year failure frequency on the costs of each hard water management scenario, a sensitivity analysis was conducted. The sensitivity analysis evaluated the comparative costs of the three management scenarios with key infrastructure failure frequencies of one, two and three years for the failure management and SHMP dosing strategies, and a corresponding reduction in the proactive replacement of hot
water system elements in the preventive maintenance strategy, from twice per year to once per year and once every one and a half years, respectively.

As could be expected, the sensitivity analysis illustrates that the cost of the failure management strategy decreases by approximately half when hot water systems, air conditioners, toilet cisterns and minor tap fittings fail once every two years instead of once per year. The SHMP dosing strategy remains competitive with failure management for a two-year failure frequency, but under a three year failure frequency, failure management is the least expensive. The effect of replacing hot water system elements only once per year for preventive maintenance only slightly decreases the overall costs of that strategy, by approximately $15,000. This is because of the already low capital cost of

![Failure frequency of key household infrastructure components](image)

**Figure 19: Sensitivity analysis of key household infrastructure components; evaluated for every one, two and three year failure frequencies respectively.**

preventive maintenance and the greater investment in local labour for scale mitigation. The costs of preventive maintenance therefore can only be driven down by decreasing the frequency or duration of maintenance visits, or if the preventive maintenance strategy further extends the life of infrastructure beyond a five-year period.
Failure frequency delays from SHMP

In the above examples, the costs of SHMP were calculated based on the assumption that the treatment extended the life of hot water systems in hard waters from 1 (2 and 3 years) to five years. Given the uncertainty of the likely benefit of SHMP on scale accumulation, the costs of SHMP under this once-in-five year failure frequency are assessed here under lower rates of SHMP effectiveness. The following analysis illustrates the costs of an SHMP dosing strategy if the benefit of the treatment is that it only delays the need for replacement of hot water systems from once per year to once per three years or once in two years.

![Graph showing costs of failure management, preventive maintenance, and Calgon treatment over different replacement frequencies.]

Figure 20: Costs of an SHMP dosing regime under variable benefit scenarios, by reducing hot water system replacement frequencies from annual to every five, three or two years.

From the previous analysis it was shown that SHMP treatment and Preventive Maintenance scenarios would be financially competitive for an assumed annual hot water system failure frequency, where SHMP was assumed to reduce an annual failure rate to once in five years. The analysis in Figure 20 illustrates that if SHMP dosing only reduced the failure frequency of hot water systems to once in three years, or once in two years, the method ceases to be financially competitive when compared with a Preventive Maintenance regime. Despite this reduced effectiveness, an SHMP dosing regime remains competitive with the Failure Management scenario, even if SHMP dosing only doubles the life of existing infrastructure. Conversely, for SHMP dosing to be a financially competitive
strategy for managing scale in hard water areas, it would have to delay the failure of infrastructure by five times to be economical over Preventive Maintenance strategies.

6.10 Summary of costs and benefits

In source waters with hardness concentrations above 500mg/L, the management strategy likely to deliver the lowest costs and highest benefit for one-year failure frequencies of key household infrastructure is a regular preventive maintenance regime. This would require the mobilisation of local, semi-skilled labour, the development of a maintenance schedule and local stockpiling of minor spare parts for cleaning and maintenance. This has additional benefits of increasing local ownership of health hardware, improving local capacity to manage repairs and maintenance and likely increased benefits of more reliable infrastructure.

If SHMP dosing provides a benefit that is at least as effective as preventive maintenance in delaying the failure of hot water systems, SHMP could provide savings over failure management on the costs of replacement of household health hardware in locations where failure frequencies are of one, two or three year periods. However SHMP is known only to influence scale build-up on hot surfaces, so any potential benefits of the treatment scenario will be restricted to hot water systems, requiring that other health hardware such as toilet cisterns, air conditioners and taps be replaced upon failure. This provides less benefit in terms of reliability of key health infrastructure and amenity to householders.

The benefit of SHMP in reducing scaling is critical to this analysis. Should SHMP reduce the failure rate of key infrastructure by half or conversely, double the life of key infrastructure, then it will remain competitive against current failure management approaches and provide a benefit to residents of reduced failure of hot water systems. However, for SHMP dosing to be economically competitive over a Preventive Maintenance strategy, it would need to extend the life of hot water systems by five times. Even under this scenario, an SHMP dosing strategy does not offer the multitude of benefits of a Preventive Maintenance regime.

The critical constraint on the management of water hardness is therefore related to the governance and administration in the operation and maintenance of water supply systems. A Preventive Maintenance approach relies on the ability to mobilise a local workforce in remote locations and ensure they have sufficient skills, resources and guidance to carry out the maintenance work. This relies on a supportive local governance environment, through provision of employment,
training and supervision. Until this issue is addressed, SHMP and alternative treatments may present the only feasible option for scale mitigation, since they largely fall under the influence of service providers charged with responsibilities to oversee public health infrastructure. In the absence of effective governance systems, cost-effectiveness becomes less critical than feasibility. Alternative government investments into training and capacity building for water supplies could reverse this trend. There may be scope for cooperative agreements between community councils and government service providers to strengthen the ability of the local water management workforce and also help to increase the viability of remote settlements through increased local employment.
7 CONCLUSIONS

1. Visible and measurable scale accumulation did occur during field trials at Yuelamu with and without the use of SHMP dosing.

2. When compared to background levels of scale accumulation in the hard groundwater supply at Yuelamu, the use of SHMP (Calgon™) did have a slight positive effect on reducing the rates of scale accumulation in hot water systems. These results provide some evidence that dosing with SHMP may provide a benefit for scale reduction over the long-term. When compared to a relatively short period of background scale accumulation data at the site, scale accumulation rates were three times lower on hot water elements exposed to water that was dosed with SHMP. However, these data were insufficient to draw broad conclusions that this benefit could be reliably achieved. Results from overseas studies indicate a high variability in effectiveness of SHMP dosing and sensitivity to a range of water quality variables such as pH, temperature, dissolved oxygen and flow velocities, so more data is required to assess reproducibility of benefits at this site and in other water qualities.

3. SHMP only acts to reduce scaling on hot surfaces, providing little to no amelioration of scale deposits on other usual sites of scale nuisance caused by evaporative processes, such as air conditioners, and water drying on pipes, taps (excepting hot taps), pumping systems, etc.

4. Any benefit obtained through SHMP dosing is reduced by re-boiling, stagnation and low flows. Small quantities of water regularly used from hot water systems, regardless of SHMP, may therefore increase scale at a faster rate than emptying a whole hot water system each time, a hypothesis supported by this study.

5. A potential side effect of SHMP dosing is that it may cause increased bacterial growth in the water system and receiving waters, due to the introduction of higher concentrations of phosphorous to waters of already high temperatures. This was not monitored in this study and likely health impacts of this are unknown. Monitoring of bacterial counts should accompany any further trials of SHMP, and at minimum water systems may then require higher chlorine dosing to account for any increased growth.

6. Apparently unrelated to SHMP dosing, solar hot water systems with vitreous enamel bobbin elements experienced 5-50 times less mass
accumulation of scale deposits per volume of water, with and without SHMP dosing, which provides evidence that they may enjoy a longer service life in hard water areas and subsequently reduced maintenance and replacement costs.

7. An economic evaluation of the benefits of SHMP dosing reveals that the polyphosphate would only need to double the life of hot water systems to be economically competitive over current failure management approaches to hard water management.

8. The economic evaluation reveals that SHMP dosing would need to extend the service life of hot water systems five-fold to be economically competitive with preventive maintenance approaches to hard water management, but could not deliver the multitude of other benefits such as reduced failure rates in cold water health hardware, increased local sufficiency and ownership and local employment.

9. Intervention strategies for hard water management are ultimately constrained by the governance and administration in the operation and maintenance of water supply systems. In locations where there is an absence of effective community governance, SHMP dosing may present the only opportunity for scale amelioration by water service providers. There is scope for cooperative agreements between community councils and government service providers to help reverse this trend and build local capacity for hard water management through training and employment.
8 Recommendations

1. Governments should be encouraged to invest in preventive maintenance regimes to protect infrastructure investments in hard water areas.

2. Local government and Indigenous housing organisations should be encouraged to conduct regular preventative cyclical maintenance and repair programs for household water system components that are affected by hard water as a practical and effective means of reducing the impact of scale on health hardware.

3. Governments should pursue cooperative arrangements with local government (Community councils, Resource Agencies, Indigenous Housing Organisations) for economical management of the cross-sectoral impacts of hard water. This could take the form of contributions to service providers and local government for the training, supervision and resourcing of local hard water preventive maintenance crews.

4. Governments should consider funding large capacity solar hot water systems with bobbin-style elements for use in hard water areas, given their considerable resistance to scale accumulation and likely longer service life and lower maintenance requirements.

5. CAT should continue to conduct independent trials on alternative technologies and methods for the reduction of the impacts of hard water supplies in remote communities.

6. That further testing of SHMP be carried out by water providers or research organisations and the design should include:
   - multiple monitoring locations of variable water qualities
   - selection of multiple surfaces/water hardware of not less than thirty, for measuring scale accumulation within each site
   - cumulative measurement of scale accumulation where possible
   - the monitoring of influencing water quality factors such as temperature, flow rates, Ca and Mg concentrations and dissolved oxygen
   - the measurement of the concentration of SHMP added into the system as phosphorous and monitoring of the addition regime over time to ensure uniform dosing concentrations
   - Monitoring of bacterial counts over time to ascertain the effect of polyphosphate addition on public health
   - That control and treatment periods of future trials each be of not less than six months duration.
9 AREAS FOR FURTHER RESEARCH

There are a number of uncertainties uncovered by this study that are areas in need of further specific investigation. These include:

- Do elements accumulate scale faster with age (i.e. does scale attract scale?)?

- What is the impact on the rates of scale accumulation of using a 3.6kW element over a 2.4kW element? Although larger 3.6kW elements are installed to produce faster hot-water heating response times, they are thought by practitioners to accumulate scale faster. However no definitive data was found from previous studies to verify this. Such data would assist management of household heating appliances in hard water areas.

- Comparative testing of scale accumulation and decline in heating efficiency of hot water system elements (e.g. fill and empty hot water system while timing how long it takes and how much power it consumes to get to 60°C), to quantify how much accumulated scale it takes to make an element inefficient and subsequently cause failure. This information would be valuable for making more reliable cost-benefit analyses between different management actions, such as replacement of heating elements over whole water system treatment technologies.
10 REFERENCES


11 APPENDICES
Appendix 1: Original Terms of Reference from IES.

Study into the impact of "Calgon" treatment at Yuelamu

Purpose:
To quantify the effect of using the sequestering agent sodium hexametaphosphate (Calgon) to reduce scaling at Yuelamu so as to establish data to aid in determination of the economic benefit of the treatment.

Background:
Hard waters are common throughout central Australia and the consequent scaling can have a high economic cost in terms of reduction in heating efficiency and in maintenance and replacement costs for heating appliances.

Calgon is a recognised compound that if added to water reduces the amount scaling and has recently been used on a number of installations in Western Australia.

The situation at Yuelamu, where a Calgon dosing system is to be installed, presents an opportunity to undertake a study into the effect of Calgon treatment by measuring the before and after effect on hot-water appliances.

Methodology.

1. Determine the type of hot water appliances that are in use in the houses and note the exposure of heating elements directly to the water being heated.
2. Select the type of heating appliances that best suit monitoring for the study.
3. Select several (minimum 5) houses where the occupancy (and hence the water use has been constant) over the period and which have the type of heating appliances selected.
4. Take a history of water use in the houses.
5. When the Calgon unit is operational remove the heating elements and replace with identical new elements that have been pre-weighed. Install water meter on pipes prior to the system.
6. With the removed elements tag and take to a laboratory for examination and testing. This includes photography, weighing as is, remove the scale and weigh. Determine a rate of scale build-up.
7. With the replaced elements check scale build up at regular intervals (monthly) by photographing and weighing in the field.
8. The experiment will cease when the bore water is not longer used or after 6 months time of Calgon operation.

9. Prepare a report. The report will contain the raw data from the research project and an analysis of the rate of scale build-up on the hot water elements when Calgon is used in the water supply. The report will contain an assessment of the rate of scale accumulation on hot water elements and provide sufficient information to determine the economic cost or benefit of the water treatment.
Appendix 2: Yuelamu groundwater quality chemical composition (DLPE, 1998) and metals over page (PWC, 2004).

<table>
<thead>
<tr>
<th>Date Received in Lab:</th>
<th>Time Sampled:</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.9.95</td>
<td>15:30</td>
</tr>
</tbody>
</table>

**Analysis - Physical**

- **pH**: 7.0
- **Electrical conductivity**: 2810 µS/cm
- **Turbidity (NTUs)**: 24.40

**Analysis - Chemical** (mg L⁻¹)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium, Na</td>
<td>726</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>10</td>
</tr>
<tr>
<td>Calcium, Ca</td>
<td>95</td>
</tr>
<tr>
<td>Magnesium, Mg</td>
<td>51</td>
</tr>
<tr>
<td>Iron, Fe</td>
<td>0.1</td>
</tr>
<tr>
<td>Total Hardness (as CaCO₃)</td>
<td>457</td>
</tr>
<tr>
<td>Total Alkalinity (as CaCO₃)</td>
<td>428</td>
</tr>
<tr>
<td>Silica, SiO₂</td>
<td>74</td>
</tr>
</tbody>
</table>

**Analysis - Additional** (mg L⁻¹)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper, Cu</td>
<td>3111B</td>
</tr>
</tbody>
</table>

- **US** DENOTES UNSUITABLE FOR ANALYSIS
- **US** DENOTES INSUFFICIENT SAMPLE
- **F** DENOTES FILTRATE ANALYSIS
- **T** DENOTES TOTAL ANALYSIS

This report relates specifically to the "sample tested as received".


Some marked with an asterisk indicate:
- Levels are within the limits as quoted in the "Guidelines for Drinking Water Quality in Australia", 1987 N.H. & M.R.D. and the A.W.R.C.
- Levels exceed non-health related limits.
- Levels exceed health related limits

**Date**: 24 Feb 1998
**Checked by**: 
**Signatory**: 

---

Centre for Appropriate Technology
Appendices iii
Yuelamu Groundwater Chemistry (metals) Data, as provided by PowerWater Corporation 2004.

<table>
<thead>
<tr>
<th>Element</th>
<th>Abbreviation</th>
<th>ADWG</th>
<th>Units</th>
<th>Yuelamu bore 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids</td>
<td>TDS</td>
<td>500-1000</td>
<td>mg/L</td>
<td>2600</td>
</tr>
<tr>
<td>Silver - Filterable</td>
<td>Ag_F</td>
<td>100</td>
<td>µg/L</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Silver - Total</td>
<td>Ag_T</td>
<td>100</td>
<td>µg/L</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Aluminium - Filterable</td>
<td>Al_F</td>
<td>200</td>
<td>µg/L</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Aluminium - Total</td>
<td>Al_T</td>
<td>200</td>
<td>µg/L</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Arsenic - Filterable</td>
<td>As_F</td>
<td>7</td>
<td>µg/L</td>
<td>3</td>
</tr>
<tr>
<td>Arsenic - Total</td>
<td>As_T</td>
<td>7</td>
<td>µg/L</td>
<td>3.5</td>
</tr>
<tr>
<td>Boron - Filterable</td>
<td>B_F</td>
<td>4000</td>
<td>µg/L</td>
<td>760</td>
</tr>
<tr>
<td>Boron - Total</td>
<td>B_T</td>
<td>4000</td>
<td>µg/L</td>
<td>800</td>
</tr>
<tr>
<td>Barium - Filterable</td>
<td>Ba_F</td>
<td>700</td>
<td>µg/L</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Barium - Total</td>
<td>Ba_T</td>
<td>700</td>
<td>µg/L</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Beryllium - Filterable</td>
<td>Be_F</td>
<td>NGV</td>
<td>µg/L</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Beryllium - Total</td>
<td>Be_T</td>
<td>NGV</td>
<td>µg/L</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Bromine - Filterable</td>
<td>Br_F</td>
<td>NGV</td>
<td>µg/L</td>
<td>2820</td>
</tr>
<tr>
<td>Bromine - Total</td>
<td>Br_T</td>
<td>NGV</td>
<td>µg/L</td>
<td>3830</td>
</tr>
<tr>
<td>Cadmium - Filterable</td>
<td>Cd_F</td>
<td>2</td>
<td>µg/L</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Cadmium - Total</td>
<td>Cd_T</td>
<td>2</td>
<td>µg/L</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Chromium - Filterable</td>
<td>Cr_F</td>
<td>50</td>
<td>µg/L</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Chromium - Total</td>
<td>Cr_T</td>
<td>50</td>
<td>µg/L</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Copper - Filterable</td>
<td>Cu_F</td>
<td>2000</td>
<td>µg/L</td>
<td>10</td>
</tr>
<tr>
<td>Copper - Total</td>
<td>Cu_T</td>
<td>2000</td>
<td>µg/L</td>
<td>10</td>
</tr>
<tr>
<td>Iron - Filterable</td>
<td>Fe_F</td>
<td>300</td>
<td>µg/L</td>
<td>20</td>
</tr>
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<td>Iron - Total</td>
<td>Fe_T</td>
<td>300</td>
<td>µg/L</td>
<td>40</td>
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<tr>
<td>Iodine - Filterable</td>
<td>I_F</td>
<td>100</td>
<td>µg/L</td>
<td>830</td>
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<tr>
<td>Iodine - Total</td>
<td>I_T</td>
<td>100</td>
<td>µg/L</td>
<td>320</td>
</tr>
<tr>
<td>Manganese - Filterable</td>
<td>Mn_F</td>
<td>500</td>
<td>µg/L</td>
<td>5</td>
</tr>
<tr>
<td>Manganese - Total</td>
<td>Mn_T</td>
<td>500</td>
<td>µg/L</td>
<td>5</td>
</tr>
<tr>
<td>Molybdenum - Filterable</td>
<td>Mo_F</td>
<td>50</td>
<td>µg/L</td>
<td>10</td>
</tr>
<tr>
<td>Molybdenum - Total</td>
<td>Mo_T</td>
<td>50</td>
<td>µg/L</td>
<td>15</td>
</tr>
<tr>
<td>Nickel - Filterable</td>
<td>Ni_F</td>
<td>20</td>
<td>µg/L</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Nickel - Total</td>
<td>Ni_T</td>
<td>20</td>
<td>µg/L</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Lead - Filterable</td>
<td>Pb_F</td>
<td>10</td>
<td>µg/L</td>
<td>1</td>
</tr>
<tr>
<td>Lead - Total</td>
<td>Pb_T</td>
<td>10</td>
<td>µg/L</td>
<td>2</td>
</tr>
<tr>
<td>Antimony - Filterable</td>
<td>Sb_F</td>
<td>3</td>
<td>µg/L</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Antimony - Total</td>
<td>Sb_T</td>
<td>3</td>
<td>µg/L</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Selenium - Filterable</td>
<td>Se_F</td>
<td>10</td>
<td>µg/L</td>
<td>13</td>
</tr>
<tr>
<td>Selenium - Total</td>
<td>Se_T</td>
<td>10</td>
<td>µg/L</td>
<td>15</td>
</tr>
<tr>
<td>Tin - Filterable</td>
<td>Sn_F</td>
<td>NGV</td>
<td>µg/L</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Tin - Total</td>
<td>Sn_T</td>
<td>NGV</td>
<td>µg/L</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Uranium - Filterable</td>
<td>U_F</td>
<td>20</td>
<td>µg/L</td>
<td>177</td>
</tr>
<tr>
<td>Uranium - Total</td>
<td>U_T</td>
<td>20</td>
<td>µg/L</td>
<td>201</td>
</tr>
<tr>
<td>Zinc - Filterable</td>
<td>Zn_F</td>
<td>3000</td>
<td>µg/L</td>
<td>210</td>
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<tr>
<td>Zinc - Total</td>
<td>Zn_T</td>
<td>3000</td>
<td>µg/L</td>
<td>220</td>
</tr>
</tbody>
</table>

denotes drinking water guideline exceedence.
Method and Laboratory procedure for
Calgon dose rates.

Water Treatment Process Expertise
Document Preparation and Endorsement

Prepared By:

Name: Arash Shafizadeh
Position: Water treatment Chemist
Date: 18/04/2006

Reviewed By:

Name: Gary Ash
Position:
Date:
1.0 Background

The treatment of hard water with Calgon is used so to prevent scaling when water is boiled. Calgon T is a food grade linear polyphosphate which is used.

When water is treated with a small dose of Calgon, it binds with Calcium and Magnesium which helps keep them in solution and reduces scaling.

2.0 Equipment and Reagents

2.1 Equipment

- Hotplate
- Analytical balance (weighing to 0.0001 g)
- Erlenmeyer flasks 500ml
- Volumetric flasks 1000ml
- Turbidity meter (DRLANGE, HACH2100n)
- Stopwatch
- 125 ml plastic sample bottles
- Filter units 0.45 micron

2.2 Reagents

- Calgon T (Linear polyphosphate) dried
- Deionised water

3.0 Procedure

3.1 Sample collection and Storage

Samples should be collected in polyethylene or gloss containers and may be stored under refrigeration for up to 20 days. A bulk sample of 10 L is required for the experiment.
3.2 Reagents Preparation

Dry approximately 2.0 g of Calgon T in an oven for 1 hour, cool and weighing 1.000 g of it on an Analytical balance, transfer to 1000 mL volumetric flasks and dissolve with high purity water. This solution is 1000mg/L Calgon for dosing.

3.3 Calgon boiling test

Set up 5 Erlenmeyer flasks with 400 mL of sample in each. To each flasks add 0.5, 1.0, 1.5 2.0 mg/L dose of the stock Calgon solution. A blank should also be done as a control.

Table 3.3.1 Calgon boiling test set

<table>
<thead>
<tr>
<th>Flask number</th>
<th>Sample volume (mL)</th>
<th>Stock volume used (mL)</th>
<th>Final Calgon dose sample (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>400</td>
<td>0.4</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>400</td>
<td>0.6</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>400</td>
<td>0.8</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Boil and maintained the treated samples for exactly 5 minutes, before being cooled in a water bath. When at room temperature analysed for turbidity and filter 50 mL into a 125 mL polyethylene container for filtered Calcium. Repeate the boiling for another 5 minutes cool and retest for turbidity and filter a second 50 mL sample into a new 125 mL polyethylene container for filtered Calcium agene. Fill in the results in the table 3.3.2.
Table 3.3.2 Calgon boiling test Results

<table>
<thead>
<tr>
<th>Calgon Dose (mg/L)</th>
<th>Turbidity (NTU)</th>
<th>Filtered Calcium (mg/L)</th>
<th>Turbidity (NTU)</th>
<th>Filtered Calcium (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.0 Results
The best dosed sample is the one with the lowest turbidity and the highest filtered Calcium.
Appendix 4: Some indicative 2007 costs of hot water system repairs and replacements.

YUELAMU COMMUNITY INC.

PMB 67 Mt. Allan Station via Alice Springs NT 0872

Phone: 08 8956 4016    Fax: 08 8956 4088

Email: yuelamucouncil@yuelamu.nt.gov.au

Hi Nerida,

As requested, a costing in relation to the affects of water quality, on Yuelamu’s hot water services, from April 07 to Sep 07. (Duration of my time on site).

Plumber:
Travel @ $1.70 per km x 600kms, $1020.00
Labour travel, 6 hours, $450.00
Labour, per hour, $75.00
(Attended twice, also undertook other (non-related) plumbing tasks for their visits. To replace elements, 10 of @ 30 minutes labour each. To replace Electric H/W system, 2 of @ 2 hours labour each. To replace solar hot water system, 7 of @ 4 hours labour each. To replace expansion VV’s and temp relief VV’s, 28 of @ 20 minutes labour each).
*Total labour, approx $1375.00, (plus replacement of Solar H/W systems if a factor?).
*Total, labour plus travel, $2845.00.

Electrician:
Travel @ $1.65 per km x 600kms, $990.00
Labour travel, 6 hours, $231.00
Labour, per hour, $77.00
(Attended twice, also undertook other (non-related) electrical tasks for their visits. To rewire corroded cables from leaking tanks, 4 of @ 1.5 hours labour each. To replace elements, 4 of @ 30 minutes labour each).
*Total labour, approx $616.00.
*Total, labour plus travel, $1837.00.

Materials:
Element, bolted 2400w, $30.80 each (14x, $431.20)
Hot water system, electric, Dux 3.6 kw, 50 litre, $416.79.00 each (2x, $833.58)
Solahart, hot water system, complete, $3500.00 each (2x to be replaced shortly, split tanks. May not be a factor?)
Expansion VV, Solahart H50-600kpa, $54.65 each (2x $109.30)
Temp relief VV, Solar, 1000kpa, $70.20 each (2x $842.40)
Temp relief VV, electric, 1400kpa, $77.22 each (2x $926.64)
Expansion VV, cold water, electric, 1200kpa $32.40 each (2x $104.80)

If I can be of any further assistance, please don’t hesitate to contact me on the above phone #

Regards,
Benjamin Hall. Housing.