Methodology for assessment of water management options

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1. Introduction

Current water management practice and townsite salinity issues in the WA Rural Towns–Liquid Assets (RT-LA) have certain similarities which are associated with their water supply schemes, the geological and geographical characteristics of the townsite catchments and their history of development. Commonly, all towns included in the RT-LA project experience certain damage to the local infrastructure due to the corrosive effects of saline soil and groundwater. There is also a concern related to fresh water availability, its quality and costs associated with water delivery to the towns. These similarities allow identifying urban salinity and rural water supply as the major objectives of the RT-LA project.

However, variations in townsite characteristics influence the town-specific water management issues and priorities.

Urban salinity and waterlogging may be related to the regional processes (such as rising regional groundwater levels or regular flooding), localised processes (such as enhanced infiltration as a result of water use in the towns or stormwater ponding in landscape depressions and upstream from local infrastructure such as roads) or both. Accordingly, water management options or their combination will be different in each case. For instance, in a case of a rising regional groundwater levels, stormwater management may provide only a limited capacity to control salinity in the towns, and groundwater abstraction may become an important component of the Water Management Plan. On the other hand, stormwater management may be adequate when salinity is caused by localised surface water accumulation.

It is important to note that the social survey, undertaken during 2004–2005 as a part of the project, indicated that local communities often do not consider townsite salinity as a pressing issue for their towns. Wall rendering is often used to protect local buildings, regular road repairs cover the damage caused by waterlogging, and overall salinity becomes a background feature of the townsite life which often remains unnoticed.

Similarly, issues related to the townsite water supply were not identified by the towns' residents as serious. Most of the towns included in the project have no restrictions on water use. However, shires are concerned with the cost of water used for irrigation of the towns' recreation grounds and parks. Although there are local non-potable water sources available to shires (such as treated wastewater and local dams), they do not provide a sufficient and reliable resource for shire water demand. Accordingly, scheme water is often used for watering townsite public areas.

Yet the current water price, while it may be considered high by shires, is nevertheless heavily subsidised by the State Government, so that the introduction of any new water supply schemes may be limited by the current water pricing policy. It is important to define conditions/circumstances, when an alternative water supply may be cost effective (such as government subsidies, price policy alteration, etc.).

Interestingly, there existed a desire, by many communities, to beautify their townsite, which largely relates to the improvement of townsite vegetation ('leafy streets') and therefore requires additional water resources for irrigation.

New alternative local water supply sources may be possible through:

- surface water harvesting in the vicinity of the townsite
- restoration of the existing large dams previously used for the water supply (and still owned by the Water Corporation); and/or

- desalination of groundwater, produced by methods to control groundwater levels under the towns.

Each town requires an evaluation and comparison of various, and sometimes conflicting, objectives and water management options. This prioritisation framework aims to navigate a path through townsite's specific issues and to facilitate development of the strategy for each townsite investigation and Water Management Plan design.

The nature of the task is well suited to an expert system (ES) methodology. An important outcome of this approach is in providing a transparent, while structured and knowledge-based appraisal of complex issues and solutions leading to a Water Management Plan that is more likely to be accepted by shareholders. Furthermore, this approach facilitates the integration of outcomes from multidisciplinary research employed in the project. The disciplines encompassed hydrogeology, geophysics, surface hydrology, water quality, urban drainage, social and economic studies.

A general description of expert system's approach is provided in Section 2. Section 3 details the methodology as applied to this project. The methodology is presented in several steps; each step is illustrated in Section 4 using the information collected/generated for the four towns currently undergoing investigations.

The described below approach has been developed and adopted within the project Rural Town–Liquid Assets and approved by the project management team.

2. Expert systems and their applications

The study of water related management issues and decision options are a complex interaction of disciplines and social and economic criteria. Development of expert systems (ES) and multi-criteria analysis (MCA) enables a simpler framework to tackle a complex problem for the decision maker. Use of MCA and ES provide a greater understanding of the problem for decision makers through a simplistic, transparent and systematic evaluation that can be repeated and modified as required (Özelkan and Duckstein 1996; Verbeek et al. 1996). MCA and ES provide a better general understanding of the structure of problems as well as a better understanding of possible outcome options and the prioritisation of options (Özelkan and Duckstein 1996). This is increasingly important as public awareness of environmental issues increase and valuable public input is included in a MCA or ES. (Khadam et al. 2003).

Expert systems are a branch of applied artificial intelligence (AI), which were broadly developed in mid 1960s (Liao 2005). The ESs allows expert knowledge to be transferred to a computer program in a structured manner, which can then be used if specific advice is needed. ESs often use heuristic reasoning rather then numeric calculations, focus on acceptable rather then optimal solutions, allow separation knowledge and control, and incorporate human expertise. They also tend to be suitable for ill-structured and semi-structured problems (Shepard 1997). ESs are usually developed for specific domains rather then for a generic application. ES development requires a degree of interaction between the system developer and the user.

ESs provide a powerful and flexible means for obtaining solutions to a variety of problems that often cannot be dealt with by other, more traditional methods. They are particularly useful when multi-disciplinary complex problems are addressed. There are a number of ES categories (e.g. rule-based systems, knowledge-based systems, neural networks, fuzzy expert systems, etc.) which may be applied to a variety of the subjects such as system development (Mulvaney and Bristow 1997), geoscience (Soh et al. 2004), environmental protection (Gomolka and Orlowski 2000), urban design (Xirogiannis et al. 2004), waste management (Fu 1998), ecological planning (Zhu et al. 1996), water supply forecast (Mahabir et al. 2003) and others.

The report presents the initial stage of an expert system development aiming to support decision making process on water management improvement in WA rural towns. As such it describes an algorithm which in the later stage could be translated to a commuter-based ES.

Key to the development of MCA and ES systems is the identification of decision objectives. Decision objectives will form the foundation of criteria used in the MCA and ES. The objectives can be translated into measurable criteria that reflect the common questions of the decision maker (Rosa et al. 1993; Verbeek et al. 1996; Khadam et al. 2003). Carter et al. (2005) and Chen et al. (2005) used MCA for water management based on a long term objective of water demand and consumption coupled with resource availability and efficiency of use. Objective based criteria and expert knowledge can be factored together with management policy, public values and political and administrative criteria that is difficult to quantify (Rosa et al. 1993; Verbeek et al. 1996). An integrated approach to water management is widely accepted, it can highlight the interactions between ground and surface water and between water and human factors (Carter et al. 2005). Carter et al. (2005) gives the example of urban development policy compromising groundwater recharge and quality. Rosa et al. 1993 used an ES to asses the field vulnerability of agrochemicals. The system combined local factors relating to soils, climate, water and chemicals with land management factors. Verbeek et al. 1996 used and MCA that combined various models and administrative policies to create an Integrated decision support system.

The majority of MCA and ES within water management can be classed into two groups. Those that assess the physical aspect of water management, such as risk assessment (Khadam et al. 2003), condition classification, vulnerability (Rosa et al. 1993), and those that assess the outcomes of water management such as, reactions to policy and various options (Bethune 2004). Khadam et al. (2003) used MCA to assess risk of contaminated groundwater, when risk was analysed as being un-acceptable a number of remedial alternative were identified. MCA analysis was also used to rank the remedial measures. Khadam et al. (2003) stated that when no one dominant measure can be identified as either the best or worst, MCA was a useful tool in ranking the outcomes. MCA has been used to assess options for the abstraction of bores at risk of chlorinated solvents. MCA was used in two parts, firstly problem identification and secondly for the prioritisation of monitoring strategies (Tait et al. 2004). Lee et al. (1997) studied the use of a fuzzy ES for the classification of stream water quality. The ES was focused on streams for which quantitative water quality data was not collected. Using ecological information to classify the streams, based on physical characteristics (eg turbidity) and biological indicator species, the results showed that the fuzzy ES represented the real world well and better than conventional ES on a comparison.

3. Framework for prioritisation of the water management options (FPWMO)

A proposed framework is schematically presented in Figure I1 and outlined below. The RT-LA project has two main objectives: mitigation of townsite salinity and opportunities for new water supply resources.

Within these objectives, FPWMO will help identify the townsite's specific issues, related to current water management and within existing and forecasted constraints such as

- policy changes
- consideration for regional priorities; and/or
- water pricing changes.

As shown in Figure I1, the identified issues could be outside the project scope (e.g. limitation in energy supply, demographic trends), but those which are relevant to the project objectives need to be considered within the context of the Triple Bottom Line (TBL). Those solutions may be directly related to water resources management (groundwater or surface water) or water use/demand management. Alternatively they may be addressed by measures unrelated to the water management options, such as infrastructure modification providing a barrier between infrastructure and soil moisture or water efficient appliances, reducing potable water demands in the town.

The proposed solutions can be ranked, costed and brought to the stakeholders' attention. The water management options selected as a result of community consultations will be recommended for an engineering evaluation and be included in the Town Integrated Water Management Plan.

The framework was developed to accommodate the project specific conditions, and as such is applicable at various stages in project development. It is also based on the data available to the project at its different stages.

3.1 Townsite investigation strategy.

The framework enables to help define the townsite specific issues and to guide the townsite investigations.

At this stage the decision-making process is largely based on the data generated by the Department of Agriculture And Food, Western Australia's (DAFWA) Rural Towns Program, which among other aspects includes groundwater monitoring records, preliminary geological/hydrogeological system description based on the drilling and a flood risk analysis.

3.2 Evaluation of the town's water needs and the availability of local water resources to satisfy demands.

At this stage the framework guide the 'water audit' process, when the local water resources, defined during the townsite investigations, are considered simultaneously with the town water demand and in the context of the current water supply.

The local water resources include stormwater generated within the townsite, waste water and local groundwater. The methodology for the townsite water balance evaluation is described in Appendix H.

Water supply data for each town has been provided by the Water Corporation, while shires supplied information on water use for community purposes within each town.

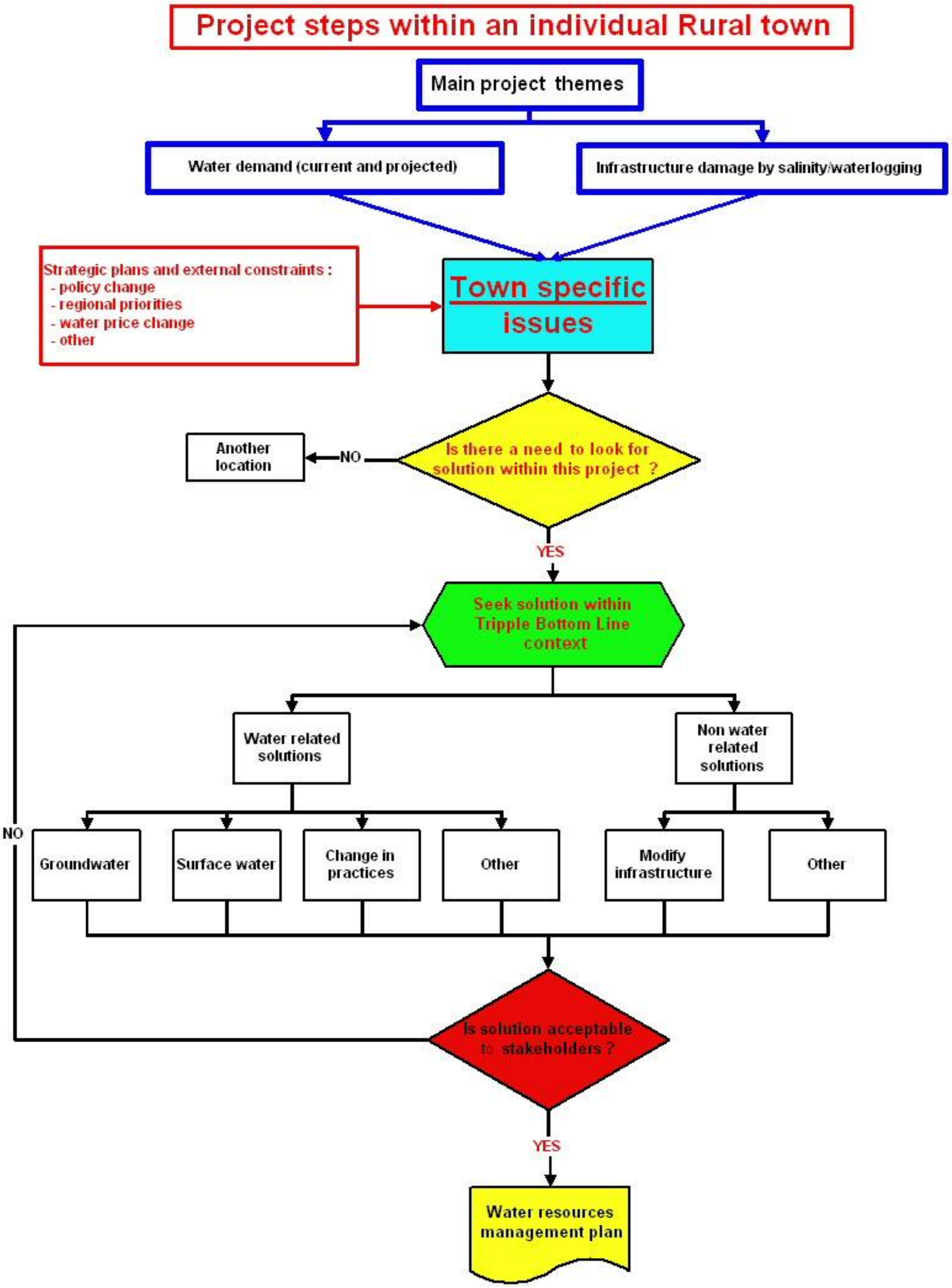


Figure I1 **Framework for townsite prioritisation.**

3.3 Selection of the townsite water management options. The framework leads to definition of the generic water management options and provides the basis for their prioritisation. It is particularly valuable that the framework facilitates engagement of the local communities in this process.

The main outcome at this stage is a final scope for the Water Management Plan (WMP) individually designed for townsite-specific conditions. Ideally WMPs also need to address new water demands for townsite beautification, new industry development and introduction of demand management options (alternative water appliances, third pipe, rain tank water use for toilet flushing and others).

Following on from the project objectives, an integrated townsite Water Management Plan is required to address both urban salinity and the potential for developing new water resources. FPWMO allows facilitating the selection of water management options, while clarifying three major questions:

- Is salinity a significant problem in a town?
- If so, how is it managed best?
- Is there sufficient demand for a new water supply?

4. Questions

4.1 Is salinity a significant problem in the town?

As mentioned above, townsite salinity is not often considered by the local communities as a pressing issue. However, in some cases this opinion may be contradicted by observed salinity-related damage of local infrastructure. There were also references to the estimated cost of the WA townsite infrastructure damage as close to $50M over the next 30 years (URS 2001).

Figure I2 illustrates a structured approach to verify the query if salinity control should be included in the RT-LA scope. The decision here is largely based on the available data generated during the townsite monitoring undertaken by DAFWA's Rural Town Program.

At this stage the framework required identification of the following:

4.1.1 Stormwater accumulation

If there is a potential for surface water accumulation within the townsite during storm events or flooding, then salinity may potentially become an issue within the affected areas.

4.1.2 Average annual groundwater level within townsite

For the purposes of the townsite prioritisation it is feasible to use the trigger value for the groundwater level (1.8 m) proposed by Nulsen (1989). It was assumed that this depth indicates an annual average groundwater level. For more detailed analysis a salinity risk assessment could be used (Barron et al. 2005).

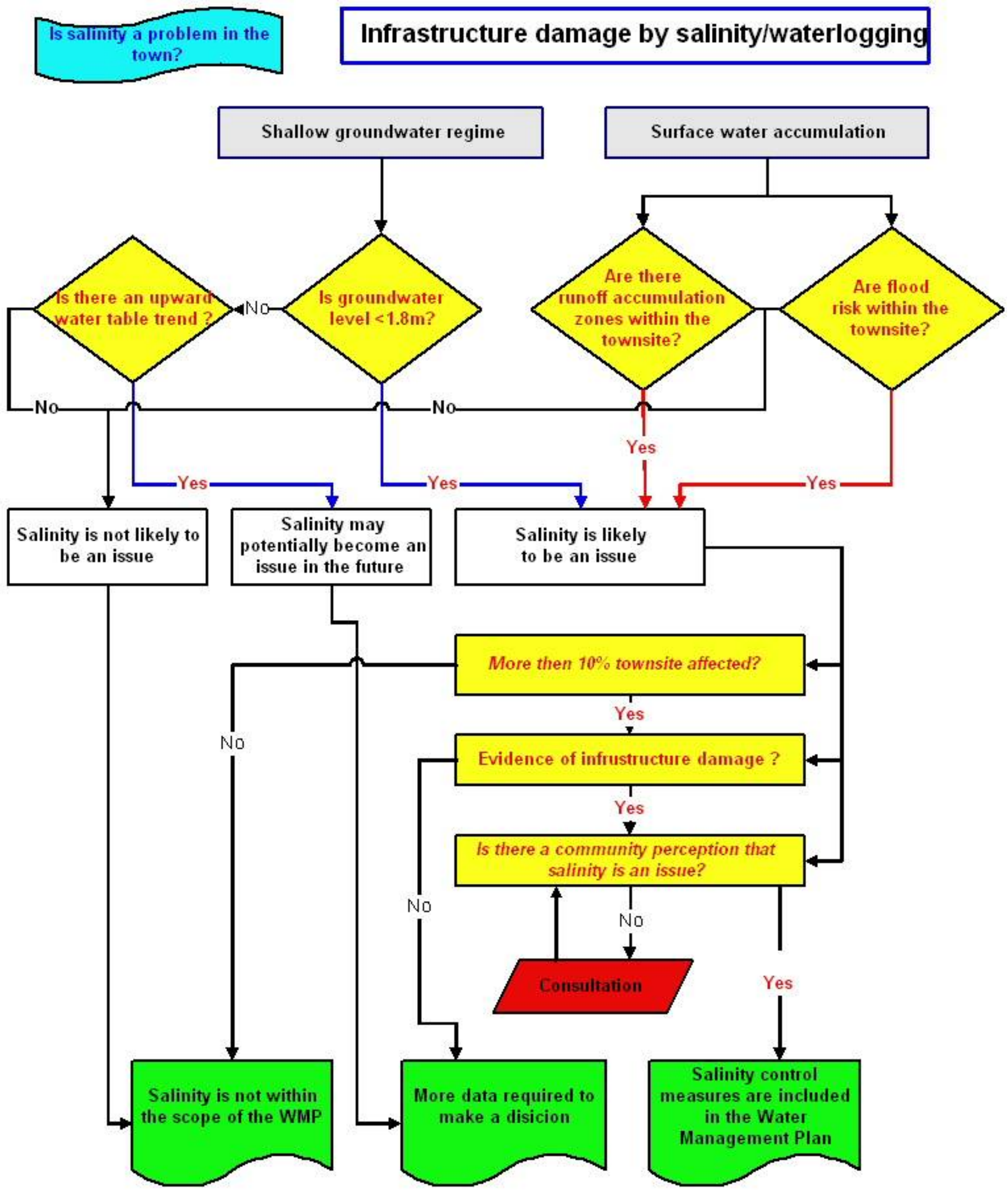


Figure I2 **Infrastructure damage by waterlogging and salinity.**

4.1.3 Groundwater level trends

If the groundwater level was found to be below the trigger depth, it is also important to define trends in the groundwater level fluctuation. If an upward trend is observed then salinity may potentially become an issue, and further investigations are required to support a decision making process.

4.1.4 Section of the townsite affected by shallow groundwater

Due to landscape, depths to the groundwater within townsites may vary, and salinity processes may affect only a limited part of the townsite. In this case the requirements for salinity management need to be defined based on an evaluation of infrastructure damage cost, and are unlikely to be significant if the annual average groundwater level <1.8m occur within less than 10 per cent townsite. At this stage the assessment is based on the up to date experience within RT-LA, but further evaluation is required.

4.1.5 Infrastructure damage within the area affected by salinity

The final decision on an individual case is made based on the type of infrastructure affected and should include consultation with community/shire representatives.

The proposed triggered values for an annual average groundwater level and extent of the affected townsite area are indicative at this stage and require further verification.

4.2 How is salinity best managed?

Once salinity is defined as a townsite issue, a number of options may be applied to control the process. They may include shallow and deep drainage, groundwater pumping or surface water rerouting. There may also be options which are not related to water management (such as the use of salt-resistant construction materials, infrastructure relocation or land use alteration). In order to develop the most appropriate salinity control measures, it is important to define the nature of the salinity process in the townsite, which will allow dealing with the causes of salinity development rather then its manifestation. The methodology to verify the answers to this question is shown in Figure I3.

Within the framework the characterization of the salinity is considered in the context of the shallow groundwater balance, where possible water fluxes within the shallow groundwater system are defined (Table I1).

Often the groundwater systems in the WA wheatbelt consist of shallow and deeper aquifers. The difference between the groundwater and hydraulic head of the deeper aquifer describes the vertical groundwater gradient, and provides an indication of the shallow water balance components. A downward gradient (the groundwater is positioned above the hydraulic head of the deeper aquifer (Figure I4) indicates a downward flux from the shallow to the deep groundwater system (providing the shallow and deep aquifers are hydraulically connected). In such a case the drawdown of the shallow groundwater may be achieved by reduction in the local groundwater recharge, such as the elimination of stormwater accumulation or alteration in the gardens/parks irrigation regime. This scenario provides an opportunity for surface water harvesting within the townsite (subject to water quality).

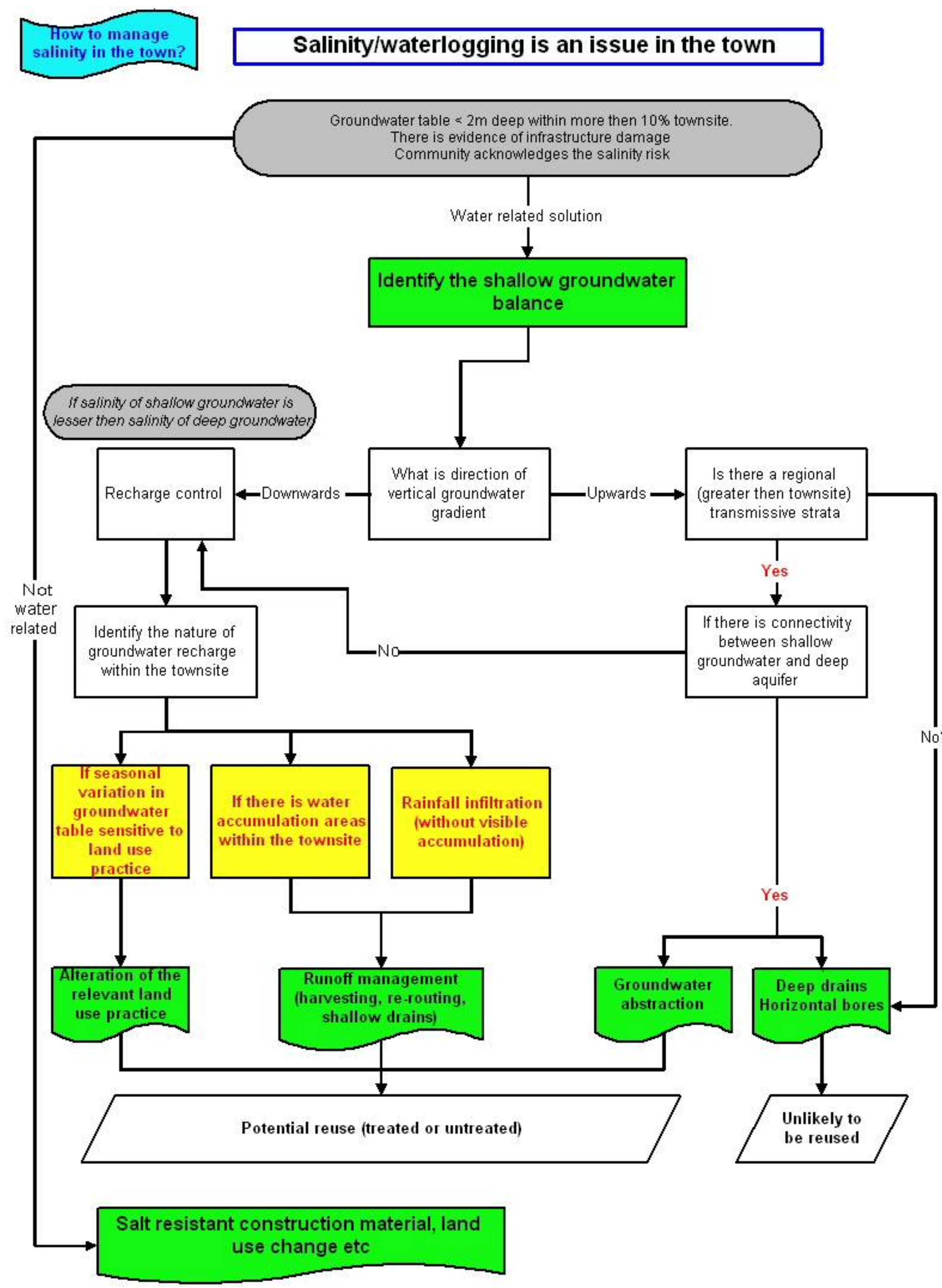


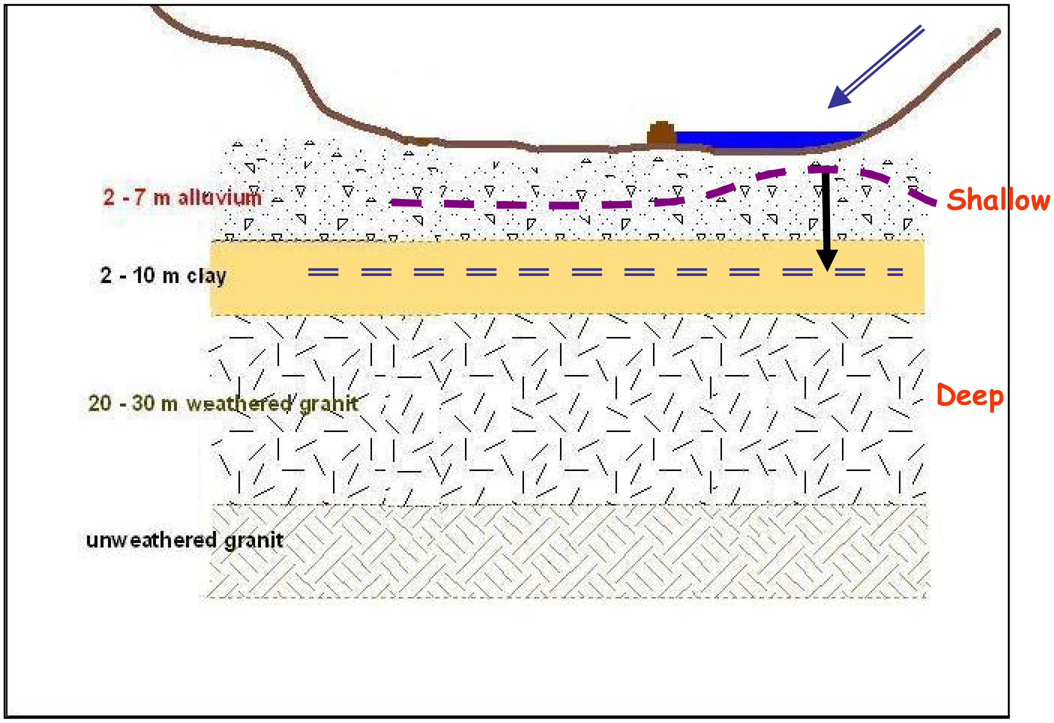
Figure I3 **Management options for waterlogging and salinity control.**

In the case where the hydraulic head in the deeper aquifer is above the groundwater (Figure I4), the upward groundwater fluxes are likely to contribute to the townsite salinity development (providing that there is a hydraulic connectivity between these two systems). In such a case, local groundwater recharge control may provide only limited capacity as a salinity control measure, and groundwater abstraction from the deeper groundwater system may be required.

The abstracted water is likely to be brackish or saline and may be reused after treatment (desalination). Additionally there may be an alternative use for saline water, such as irrigation of salt tolerant turf and shrubs. The effectiveness of this option will depend upon aquifer transmissivity, which may be limited.

Table I1 **Shallow groundwater fluxes**

Shallow groundwater recharge	Shallow groundwater discharge
Regional infiltration (rainfall)	Evaporation/evapotranspiration from the shallow groundwater
Local infiltration (surface water accumulation or water use practice, e.g. parks' irrigation)	Throughflow
Upwards fluxes from deeper groundwater systems	Downwards fluxes to deeper groundwater systems



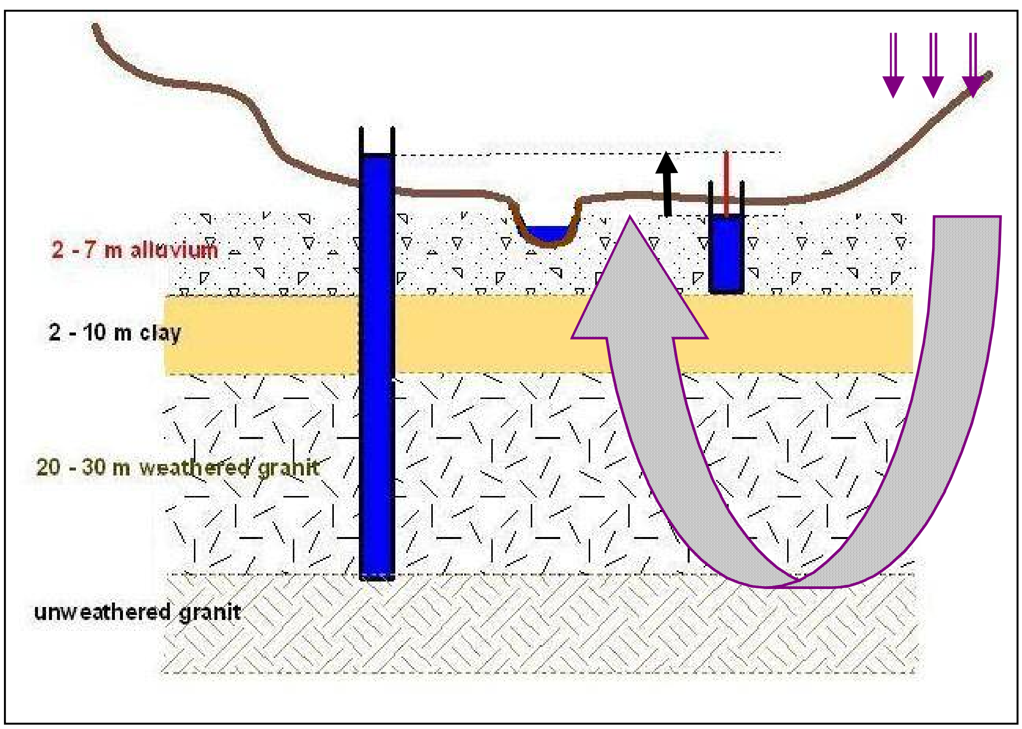


Figure I4 **Variation in the vertical groundwater gradient (downward and upward).**

4.3 Is there significant demand for new water supply?

Water use in WA rural towns predominantly relies on the scheme water supply, which is supplemented by treated waste water and surface water harvested in the local dams. Commonly water supply from the local resources combines up to 90 per cent treated waste water and up to 25–30ML harvested water. Local dam capacity in some towns is not sufficient to supply scheme water needs throughout the dry season, and the quality may be poor for drinking. The local fresh water resources are used by shires for irrigation of the town parks and sport grounds, often in combination with scheme water.

Drinking water demands in towns are commonly satisfied by the existing water supply scheme. Scheme water use is currently restricted only in towns located along the Goldfields and Agricultural Water Scheme.

It is important to identify the motivation of rural town communities to develop a new or alternative water supply. The requirement for new water resources is often driven by the water costs, which are considerable for the larger rural water users, such as shires and industrial groups. For instance, the annual water cost of the Katanning meatworks (WAMMCO) is in the range of $0.5M, while the Shire of Wagin scheme water use costs up to $20K per year (Woodanilling—up to $8K, Nyabing—up to $6K, Lake Grace up to $18K).

Rural water supply is subsidised by Community Service Obligations (CSOs) and as a result rural town water tariffs at the lower ranks of water use(350KL) are comparable with the metropolitan water prices. The introduction of new local water resources, potentially including desalination of saline groundwater, is likely to carry much greater cost, and as such could be a less favourable alternative to the current water supplies.

The Water Management Plan aims to address the current water demands and water quality constraints for townsite water supply. It also identifies potential water users if additional water supplies become available. This is preferably considered simultaneously with the water management options proposed to mitigate townsite salinity, as proposed within the FPWMO and demonstrated schematically in Figure I5.

On the other hand it is anticipated that there may be demands for three main water quality types:

1. Potable water for human consumption and some industrial use which may have specific water quality requirements: Supply of this water type is a subject to rigorous regulation and any new potable water resources will need to health standards and risk management.
2. Fresh water for non-potable use for irrigation of domestic gardens and townsite parks and ovals.
3. Brackish/saline water, which is not commonly used in towns, but the opportunities for brackish/saline water use for irrigation of salt-tolerant turf or aquiculture are within the scope of this project.

The potential sources for those water demands are summarised in Table I2.

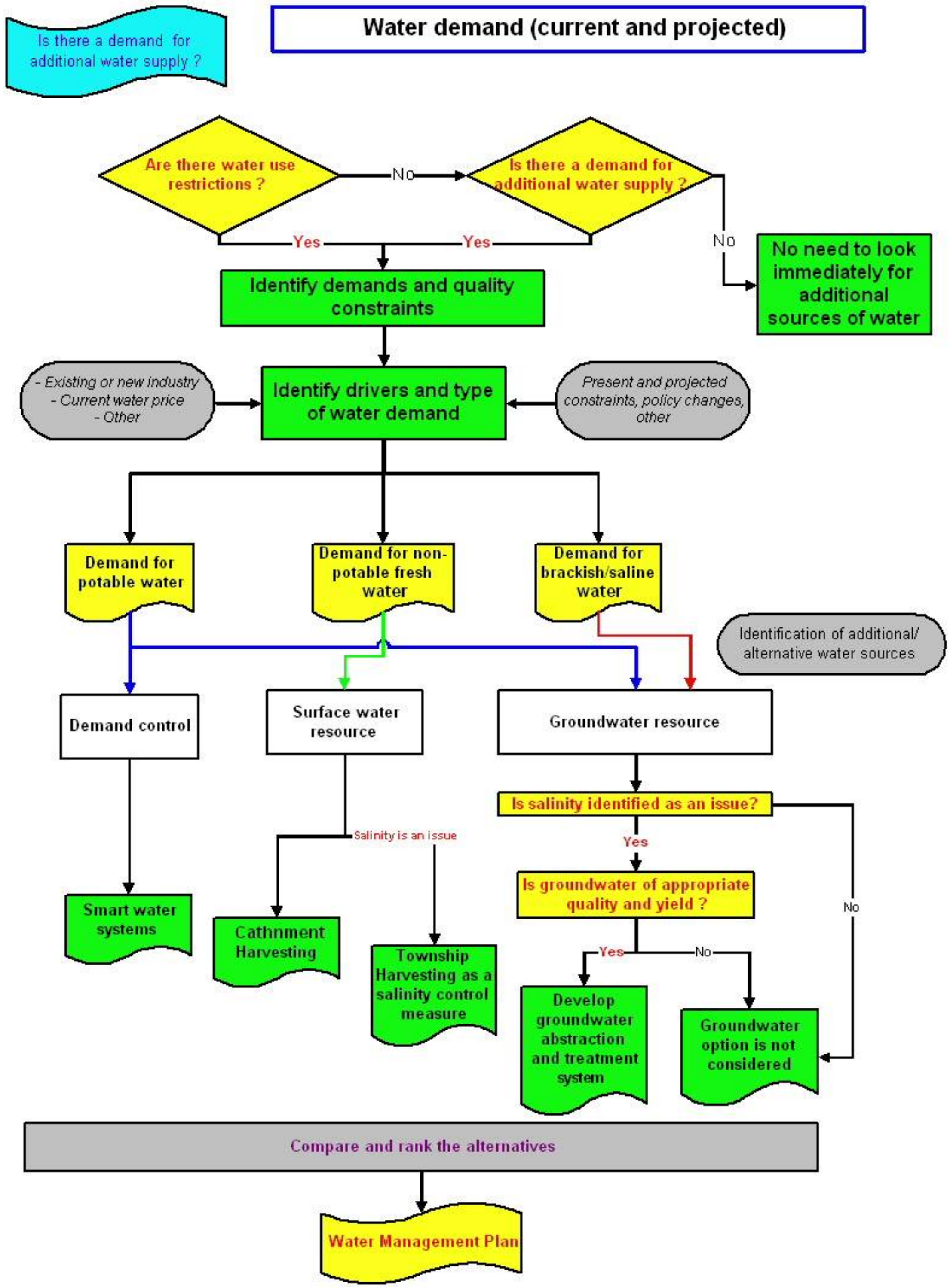


Figure I5 **Townsite water demands.**

Table I2 **Sources of the local water resources**

Water quality	Sources of water resources
Potable water	Potable water demand may be reduced by the introduction of alternative in-door water appliances or supplementing outdoor water use with fresh, but non-potable water supply. New potable water may be generated via groundwater desalination, providing the local groundwater water quality and quantity are adequate for desalination (contributing to salinity risk reduction).
Fresh water for non-potable use	New resources may be generated via townsite stormwater harvesting (contributing to salinity risk reduction). Catchment water harvesting or improvement of the existing dams (dam catchment enhancement, dams' alteration) may provide additional fresh water resources. In some cases (as in Lake Grace) this option will also reduce the salinity risk within the townsite. Abandoned Water Corporation dams, previously used for local water supplies.
Brackish/saline water	Brackish/saline water used for irrigation of salt-tolerant turf. Brackish/saline water used for aquiculture.

4.4 Identifying the scope for the townsite water management plan and ranking the water management options

As described above FPWMO is designed to identify both key issues and potential water management options which in turn lead to the definition of the townsite Water Management Plan scope.

The most commonly considered generic water management options are given in Table I3. The final decision on the WMP scope is based on comparisons and ranking of the preliminary selected options in view of the cost of their implementation and maintenance, local community preferences and environmental safety.

To guide community engagement in the process of water management option selection, a multi-criteria ranking system was employed. The method allowed the ranking of water management options, based on the following:

- Twelve selection criteria
- Criteria weighting as an identification of its relevance to an individual town's needs and/or community aspiration; and
- Option score identifying the relevance of an individual water management option to satisfy the relevant criteria.

Table I3 **Water management options aimed at improving rural town water management (the current batch of rural towns fit within a number of the shaded yellow boxes)**

			Additional water demands			
			Potable water	Non-Potable Water		*None*
				Fresh	Brackish/Saline	
Salinity is an issue	Townsite stormwater management	Direct use				
		Disposal				
		Treatment and reuse				
	Groundwater abstraction	Direct use				
		Disposal				
		Treatment				
	Improvement in townsite water use					
	Adoption of the salt resistant building materials					
Salinity is not an issue	*Catchment runoff harvesting*	*Use*				
		Treatment				
	Groundwater abstraction	*Reuse*				
		Disposal				
		Treatment				

An example of the criteria, their weighting and scoring system is given in Table I4. While there is a suite of common criteria, their final selection is town specific and needs to be defined in consultation with main stakeholders.

This approach may be further expanded to more refined multicriteria analysis.

Table I4 **Criteria for water management option selection**

Criterion	Weighing factor (1–10)	Option score		
		High (9)	Medium (3)	Low (1)
Reduction in infrastructure damage		> $100 000	$50 000-$100 000	< $50 000
Additional water supply		Reliable new water resource available for new user	Above current Shire water demand to support townsite beautiful	Below current Shire water demand
Capital cost for the option		< $250 000	$250 000–$1 000 000	> $1 000 000
Annual operating and maintenance cost		< $50 000	$50 000–$100 000	> $100 000
Is the technology proven?		Yes	Sometime used	No
Energy requirements		Low	Medium	High
Ease of operation		Fully automated	Some manual input	Manually operated
Downstream income		Economic Profitable	Positive benefit within TBL	Positive total benefit within TBL
Shire resources to implement the option		No resources required	Minimum resources required	Resources required
Potential external funding		Fully sponsored by external sources	Partly sponsored by external sources	Minimum sponsored by external sources
Employment		Long term employment	Short-term and long-term employment	Sort term employment only
Downstream environmental impact		Low risk	Medium risk	High risk

5. Conclusions

The proposed methodology facilitates prioritisation of water management options in Western Australian towns. The framework has been adopted by the RT-LA project team to guide the project through the investigations of the next 12 towns.

The framework identifies the most important issues related to townsite water management, which provides a number of benefits:

- Identification of the research focus area within each town
- Simultaneous identification of issues and opportunities which could be addressed by townsite Water Management Plans
- Linkage of water demands with potential water resources
- Engagement of local community in the decision make process
- The structured format for a further expert system development.

The framework is applicable at various stages of the townsite investigations and Water Management Plan development:

- Research initiation which can be focused on the identify priority issue
- Selection of water management options to utilise local water resources and match them to townsite water demands
- Prioritisation of the water management options in consultation with the local community.

It is anticipated that the framework will be advanced during the next stages of the RT-LA project with opportunities possible in the following areas:

- Advancement in the integration of the social aspects which will provide a greater community engagement in the Water Management Plan design and therefore ensure the community ownership of the plan and its implementation
- Deliver greater scientific platform for the expert system and multicriteria analysis
- Potential computerisation of the framework aiming for design of a user-friendly tool for decision making process by various stakeholders.

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