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Rural Towns - Liquid Assets: Analysis using Water Balance Modelling for Water Resources Availability for Rural Towns in Western Australia

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Abstract: In the dry climate of Western Australia there is a recognized need to make the best use of local resources including rainwater, grey water and Urban Runoff. Water balance modelling including the Sustainability Approach was used to evaluate best water management options for rural towns in Western Australia. This research addressed the yields of potential water resources in eleven Rural Towns including rainfall and storm water yields, which were linked with water demands both indoor and outdoor, considering harvesting options such as rainwater tank capacities and savings in scheme water use. A cost analysis was done for better management option. Comparison of the results of this analysis among the rural towns enabled a better choice for water management under various climatic conditions and rainwater tank sizes. This knowledge has the potential to secure local water resources among rural towns. The rain water and surface water (urban runoff) were found to be the best management options for rural towns.

Key words: Water Supply; Urban Strom Water; Rain Water Harvesting; Water Supply Reliability.

1. INTRODUCTION

The average residential water consumption varies among countries and has been reported to be 380 L/day (USA), 340 L/day (Canada), 265 L/day (Spain), 181 L/day (Australia), 85 L/day (Lithuania; EEA 2003; Loh and Coghlan 2003; Racoviceanu 2005). In Western Australia only a small portion of residential water use is of potable quality, which covers approximately 9% of indoor water use (Loh and Coghlan 2003). This means that in order to reduce scheme water use, non-potable water needs to be supplied from localised water such as rain water, grey water and locally harvested surface runoff. Decentralization of the Water Supply System has had considerable success in Tokyo and other large Japanese cities (Ogoshi et al. 2001, Yamagata et al. 2003). While stormwater runoff from cities is about equal to the amount of drinking quality water that is supplied at considerable cost each year, little Storm Water is captured, with most adding to the pollution of waterways.

Investigation by the Intergovernmental Panel on Climate Change (IPCC 2007) and CSIRO (2007) predicted continuing climate changes that are likely to increase the risks of further water shortages in Australia's major urban centers. Increased growth of industrial areas and population has increased the demand for water supply in major cities and urban centers (ABS 2006).A decentralized water supply helps to reduce energy cost and shifts infrastructure investment to water restricted areas increasing the efficiency of the centralized water supply system.

The increasing demand for water in Western Australia and the limited natural water resources in the Wheat belt areas have led to the need for investigation into local water resources, which may supplement current water supply practice, based on a long-distance water delivery through thousands of kilometres of pipes network as shown in Figure 1. However, management of the localised water supply is challenging due to limited water resources and the limited reliability, risk of surface runoff pollution and overall complex management of the decentralised water supply system.

This researcher undertook an -Assessment of water resources availability in February, 2010 for eleven rural towns in Western Australia deploying the Aquacycle model developed by Mitchell et al. in 2001. This model was used for determining storm water discharge, the rainwater tank capacities, imported water savings, indoor/outdoor use, and rainfall and evaporation intensity and linked to the eleven rural towns water use, water demands and climatic conditions. A cost analysis was carried out to determine the best management option.

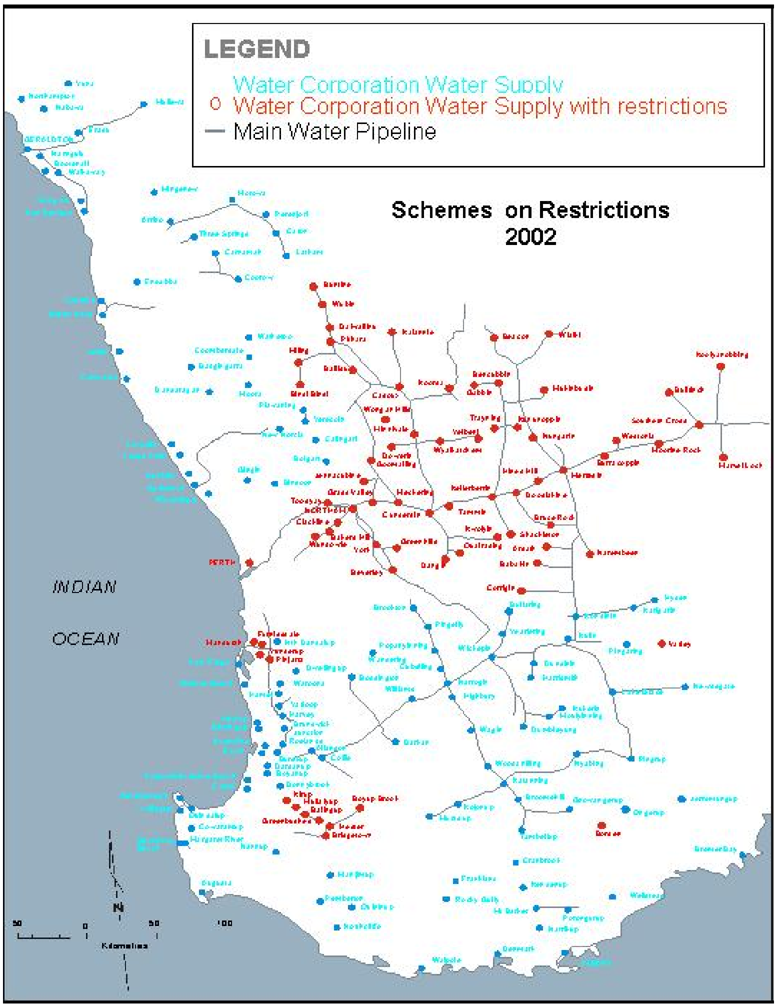

Figure 1: Water Supply Diagram for Rural Towns.

2. RURAL TOWNS

Eleven major towns were included in the analysis and their location is shown in Figure 2. The selection of the towns was based on the need to cover a large area of the Western Australia Wheatbelt, characterised by a variety of rainfall and evaporation rates. The town populations varied from 127 to 2807 residents (Table 1).

Table1: Summary of the climatic conditions and water use in selected towns.

	Pingelly	Tambellup	Wagin	Wongan Hills	Wooda-nilling	Perenjori	Dowerin	Lake Grace	Merredin	Moora	Nyabing
Location of Towns	32 33'S 117 06'E	34 02'S 117 38'E	33 18'S 117 20'E	30 54'S 116 42'E	33 33'S 117 25'E	29 24'S 116 42'E	31 12'S 117 03'E	33 06'S 118 27'E	31 29'S 118 17'E	30 39'S 116 00' E	33 32'S 118 09'E
Rain fall (Annual Average)	443	430	426	385	424	314	355	345	327	443	445
PEV (Annual Pan Evaporation)	1708	1490	1608	2184	1559	2451	2135	1762	2159	2161	1613
Scheme water Supply (kl/cap/year)	174	78	293	212	26	129	102	137	528	438	27
Population	729	299	1282	783	127	242	358	531	2807	1730	115

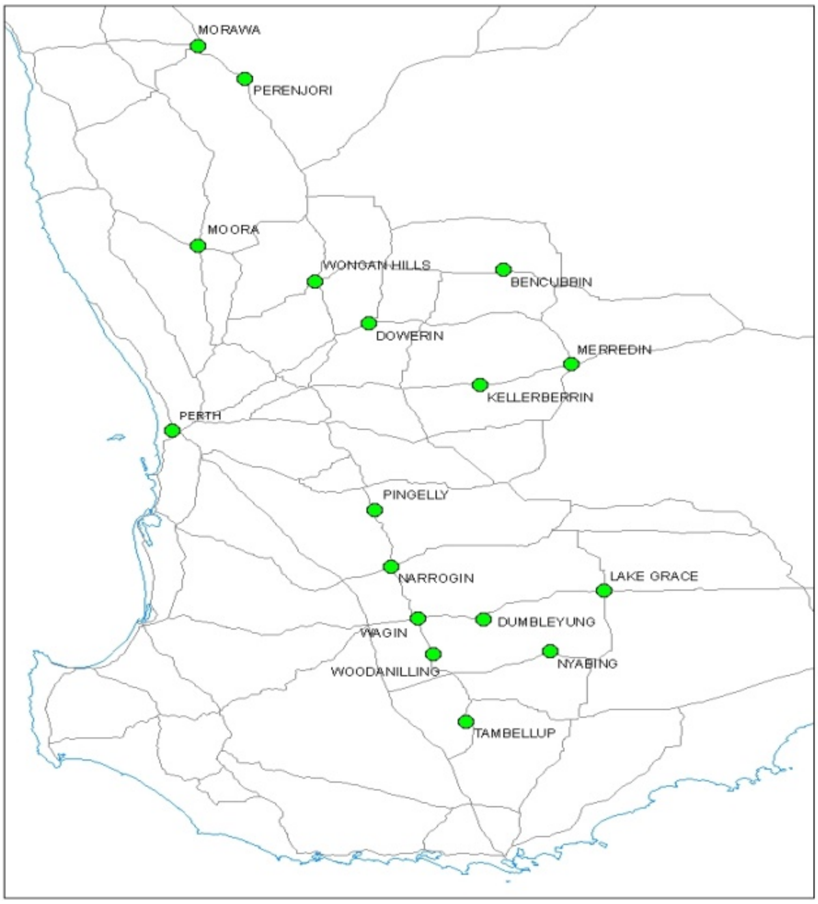

Figure2: Location of Rural Towns.

Variation in climate conditions was also significant with average annual rainfall from 314 mm to 445 mm and PAN evaporation from 2451 to 1613 mm. The rainfall is highly seasonal with the majority of rainfall between June and September. During these months, the rainfall may exceed PAN evaporation, which annually is up to 6 folds less than PAV evaporation. Long dry summers lead to an increase in monthly water consumption by 4 folds as illustrated in Figure 3.

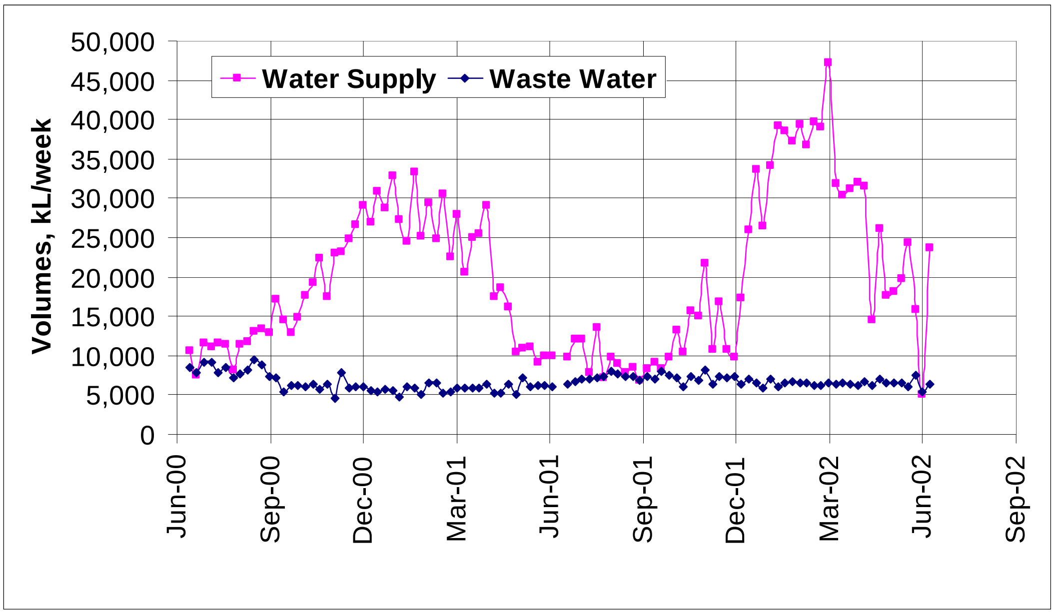

Figure 3: Consumption of water.

3. METHODOLOGY

3.1 Water Balance Modelling

Water Modelling Software AQUACYCLE (Mitchell et al 2001) was used to determine the address best water management options for the eleven Rural Towns. This computer model provided a holistic framework in terms of an integrated water management option by runs on daily time step, storm water flows, and waste water networks.

Climate data were adopted from SILO Data Drill (http://www.nrw.qld.gov.au/silo/datadril); data were edited as per reference Jeffrey et al. 2001. Population data were sourced from the Australian Bureau of Statistics, 2007. Topographical and land use data were supplied by the Western Australian Department of Planning and Infrastructure.

In the scope of this study, imported water, storm water and wastewater were considered as an integrated water system instead of separate ones. Water balance results obtained from the computer program were based on average roof area 249 sq.m and 2.4 persons for an average block. Toilet flushing and garden irrigation were introduced as part of the rain water option.

In this study, the calibration parameters were determined by comparing the actual water consumption derived from the Water Corporation of Western Australia with the model outputs. Two measures of performance were used to judge the model's ability to simulate flows during the verification period: SIM/REC and the coefficient of efficiency, E. A running calibration parameter set fitted to the water balance Modelling is listed in Table 2.

Table 2: Parameters for different rural towns.

Parameters	Dowerin	Lake Grace	Merredin	Moora	Nyabing	Perenjori	Pingelly	Wagin	Wongan Hills	Wooda-nilling	Morawa
Area of pervious soil store 1 (%)	50	50	50	50	50	70	50	50	50	50	70
Capacity of soil store 1 (mm)	50	50	50	50	50	150	50	50	50	50	150
Capacity of soil store 2 (mm)	120	120	120	120	120	250	120	120	120	120	250
Roof area maximum initial loss (mm)	1	1	1	1	1	1	1	1	1	1	1
Effective roof area %	95	95	95	95	95	95	95	95	95	95	95
Paved area maximum initial loss (mm)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Effective paved area %	10	10	10	10	10	10	10	10	10	10	10
Road area maximum initial loss (mm)	1.5	1	1.5	1.5	1	1.5	1.5	1	1.5	1	1.5
Effective road area %	20	20	20	20	20	20	20	20	20	20	20
Base flow index	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Base flow recession constant	0	0	0	0	0	0	0	0	0	0	0
Infiltration index	0	0	0	0	0	0	0	0	0	0	0
Infiltration store recession constant	0	0	0	0	0	0	0	0	0	0	0
% surface runoff as inflow	0	3	0	0	3	0	0	3	0	3	0
Garden trigger to irrigate	0.27–0.33	0.05–0.60	0.27–0.33	0.27–0.33	0.05–0.60	0.85	0.27–0.33	0.05–0.60	0.27–0.33	0.05–0.60	0.5
Rainwater tank first flush	25	0	25	25	0	0	25	0	25	0	0

Volumetric reliability (Rv), as a percentage, is defined as:

$$Rv = 100.Sv/Dv \quad (1)$$

where Sv is the total volume supplied and Dv is the volume demanded in the simulation period. Volumetric reliability measures the severity of failure to supply water demanded.

3.2 Sustainability Approach

This research considered reliabilities of supply ranging from 80% to 100% for the eleven rural towns. Figure 4 shows how the reliability of supply influenced the adopted annual volumetric cap, i.e. the unrestricted time series shows the volume of water available for extraction through application of the rain period. More water is available for extraction in wet years, for example in the case of Dowerin. The unrestricted time series shows that 148.8 ml of water was available for extraction in the 5 years 1951, 1952, 1953, 1954, and 1955 of the 51 years of record. As the reliability increases, the SDL (Sustainable Diversion Limit) decreases so that the number of years in which it cannot be extracted reduces. For example in the case of Dowerin a reliability of 80%, translated to a SDL of 25.3 ml, can safely be extracted in 41 to 51 years.

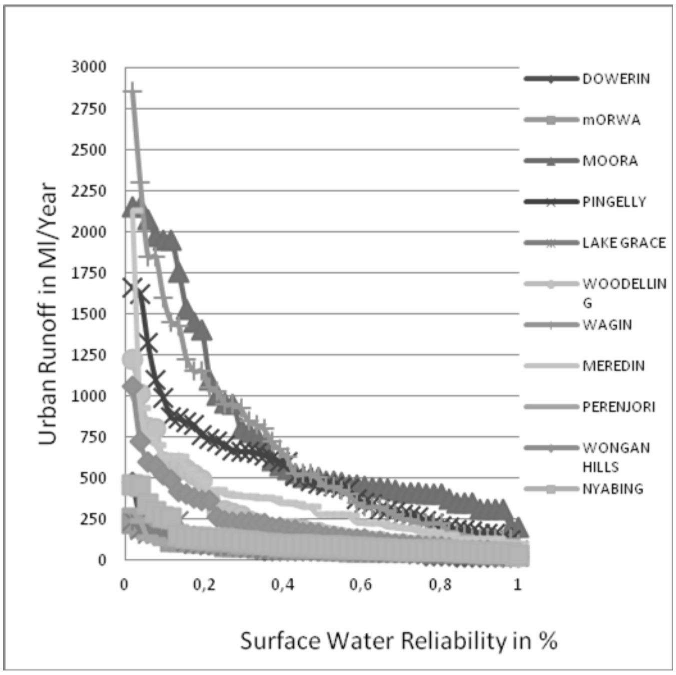

Figure 4: Surface Water Reliability for Different Rural Towns.

4. RESULT FROM AQUA CYCLE MODEL

The modelled and statistical results of the residential; development of the considered rural towns are shown in Figures 1 to 12 including Tables 1 to 7 for Grey water option , Rain water option and Storm water option. These options are described in this section.

4.1 Indoor and Outdoor Supply

Figures 5 and 6 show the schemes of water supply under indoor and outdoor conditions respectively. The scheme water supply for indoor is steady between 100 to 140 kl/cap/year with most of the population of rural towns below 1000. The scheme water supply for outdoor fluctuates between 90 to 190 Kl/cap/year as seen from Figure 6, with most of the population of rural towns below 1000.

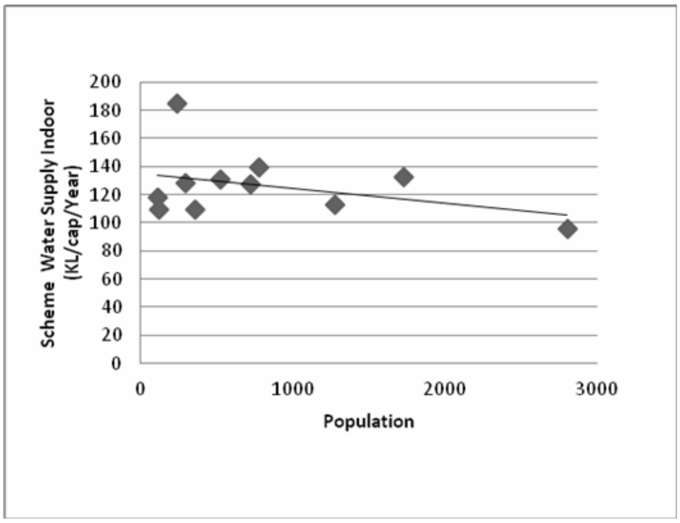

Figure 5: Scheme Water Supply Indoor.

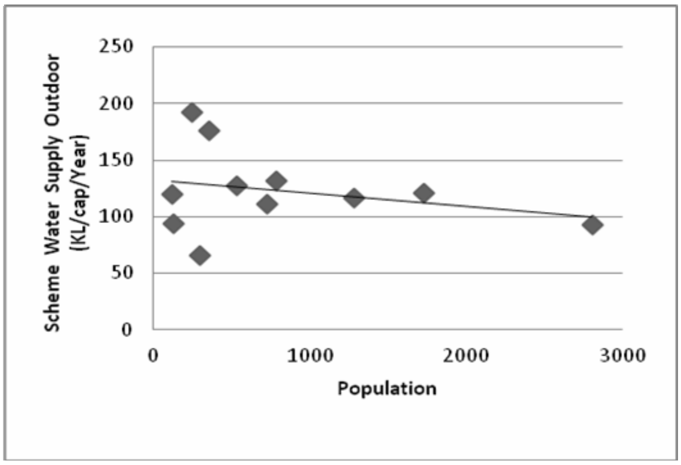

Figure 6: Scheme Water Supply Outdoor.

4.2 Rainwater use for garden and toilets flush

The graph (Figure 7) shows volumetric reliability for various sizes of rainwater tanks. The optimal size of rainwater tank is defined by the points where the curves begin to flatten with consideration of volumetric efficiency, costing and space. This graph allows finding the optimal rainwater tank size for a particular town when harvested rain water is used for toilet flushing and garden irrigation. The residential runoff generated in some of the rural towns like Nyabing, Morawa, Merredin are 2.38ml/year,14.5 ml /year, and 49 ml / year respectively from the total storm water. Table 3 shows the values of volumetric reliability and tank sizes. The rainwater use appears to be more effective in Moora, Wagin, and Pingelly where volumetric reliability is 21%, 20.5%, and 21% respectively and accordingly volume of tanks can be selected as 24 to 30 , 22 to 30,24-30 respectively. The lowest reliability was 15-16%. Figure 8 illustrates how annual average rainfall affects volumetric reliability of rainwater tanks. It can be seen that an increase in rainfall leads to a higher volumetric reliability for the particular size of the tank. The graph (Figure 9) shows the relation between tank costs vs. its capacity. It can be seen that cost increases with increase in tank size. The cheapest tank is the ARI plastic tank. The operation and maintenance costs are negligible for all the tanks.

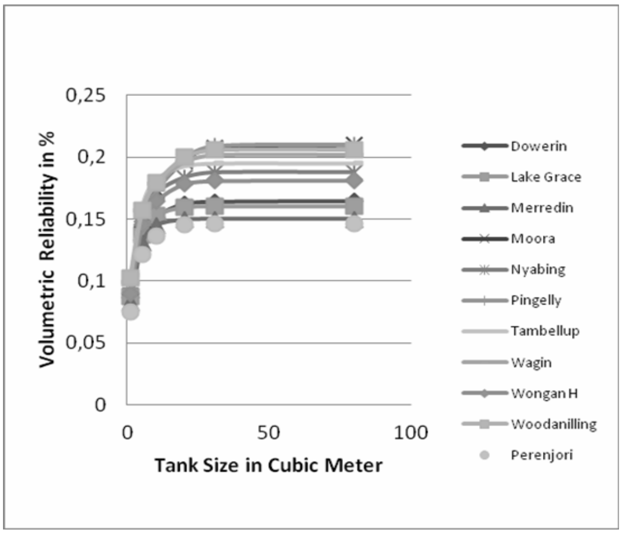

Figure 7: Volumetric Reliability for different Towns.

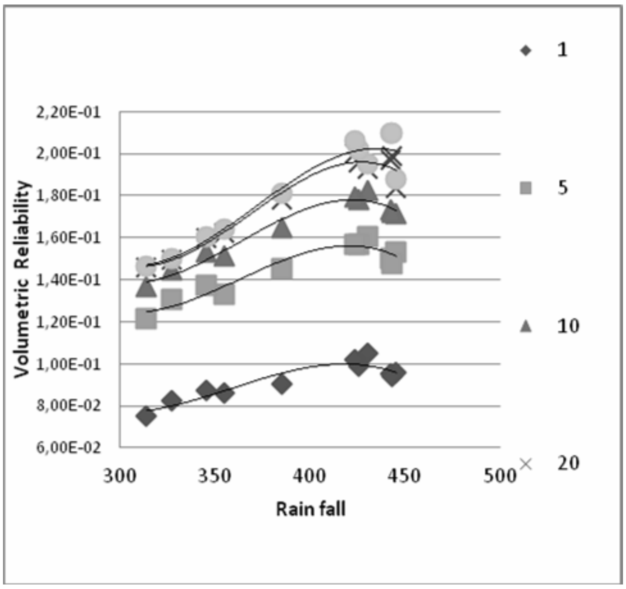

Figure 8: Rational Volumetric Reliability.

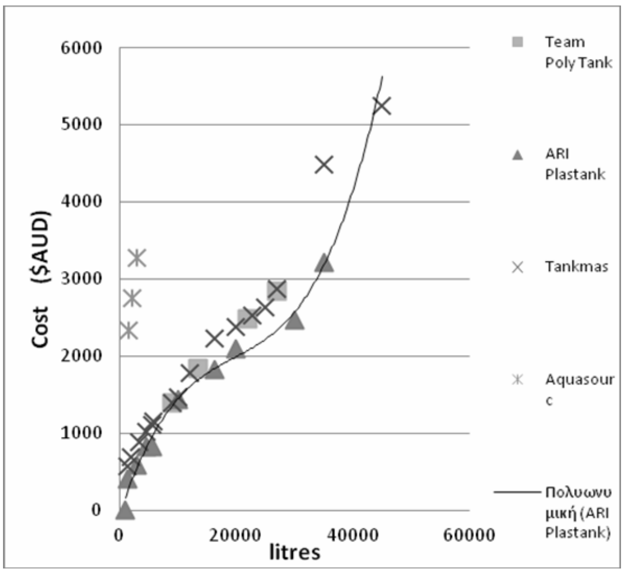

Figure 9: Cost analysis for various Tank.

Table 3: Volumetric reliability.

	Dowerin	Lake Grace	Merredin	Moora	Nyabing	Pingelly	Tambellup	Wagin	Wongan Hills	Wooda-nilling	Perenjori
Tank Size (Cubic Meter)	14-20	14-20	12-20	24-30	22-30	24-30	20-30	22-30	18-20	24-30	10-20
Volumetric Reliability	17%	16%	15%	21%	19%	21%	19%	20.5%	18%	20.5%	15%

4.3 Grey water use for garden and toilets flush

The estimation of grey water generation in the considered towns is shown in Table 4. In the majority of the rural towns waste water is collected, treated and used for POS irrigation. In such circumstances grey water reuse on a household level is unlikely to be a realistic option for non-potable water supply. Additionally the introduction of these water resources is not widely accepted by consumers due to higher operational and maintenance costs and perceived risks associated with water quality.

Table 4: Water balance results for grey water.

Towns	Potential Residential Grey Water Use	
	Storage & Treatment (kL/capita/year)	Direct Irrigation (kL/capita/year)
Dowerin	42.9	33.6
Merredin	40.0	29.5
Moora	38.4	27.5
Perenjori	48.4	41.0
Pingelly	39.0	29.7
Tambellup	40.6	27.2
Wongan Hills	41.5	32.7

4.4. Percentage of water saving in Rural Towns

Figure 10 shows that in the case of the grey water option, nearly 15 % of water saving can be done among all the Rural Towns. The graph (Figure 11) shows that in the case of the Rain water option, nearly 13 % of water saving can be done by Wagin and Woodenilling. The combined results (Figure 12) of grey water and rain water show that nearly 20 % of water saving of scheme water is achieved among all the Rural Towns.

5. RESULT FROM SUSTAINABILITY APPROACH

Surface runoff within the urban area of the Eleven Rural towns was also considered as a potential local water resource. Figure 4 shows the Surface Water Reliability in Percentage for the eleven Rural Towns. Table 5 shows the Surface water runoff values according to Surface Water Reliability. There is a potential for surface water pollution within the town site. Hence, some treatment may be required before stormwater is introduced for a localised water supply. The Figure shows that Wagin, Merredin and Moora have extremely high surface water reliability as 101 ml/year, 101 ml /year and 200 ml /year respectively.

Table 5: Surface water reliability.

Surface water Reliability	Dowerin (ml/year)	Lake Grace (ml/year)	Merredin (ml/year)	Moora (ml/year)	Nyabing (ml/year)	Pingelly (ml/year)	Morwa (ml/year)	Wagin (ml/year)	Wongan Hills (ml/year)	Wooda-nilling (ml/year)	Perenjori (ml/year)
10%	150	150	620	1950	250	900	180	1440	500	600	100
80%	25.3	36	150	400	55	210	48	224	80	90	14
100%	19	21	101	200	30	60	30	101	40	20	9

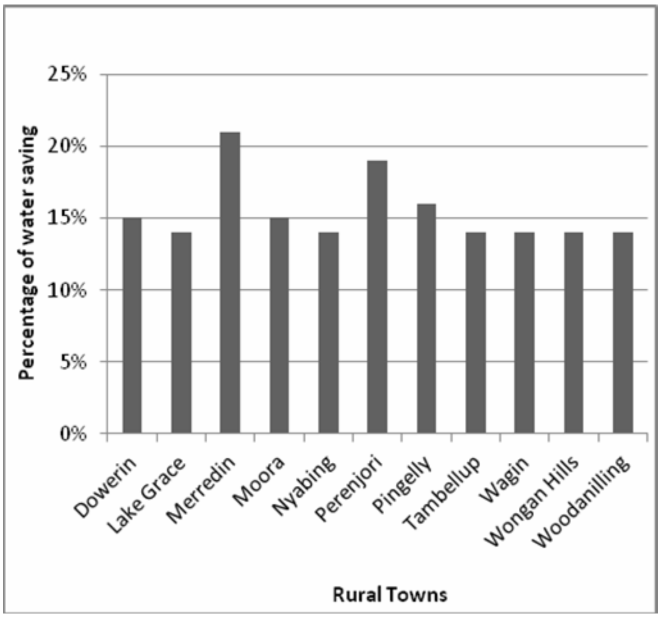

Figure 10: Percentage of water saving for Grey Water

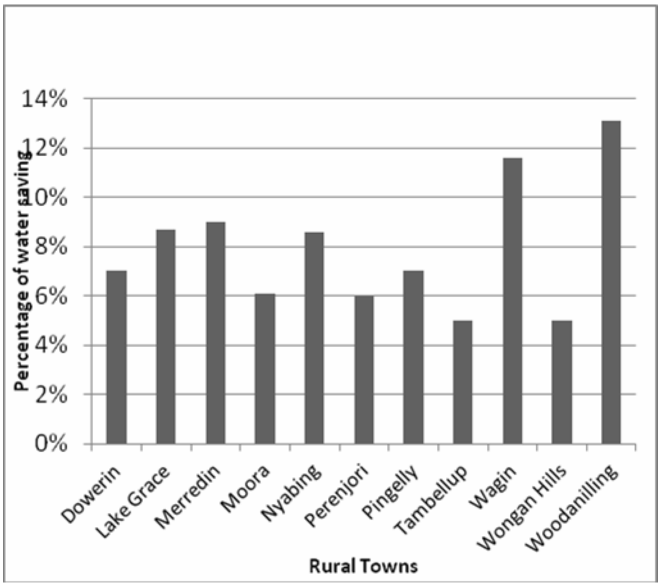

Figure 11: Percentage of Water Saving for Rain Water

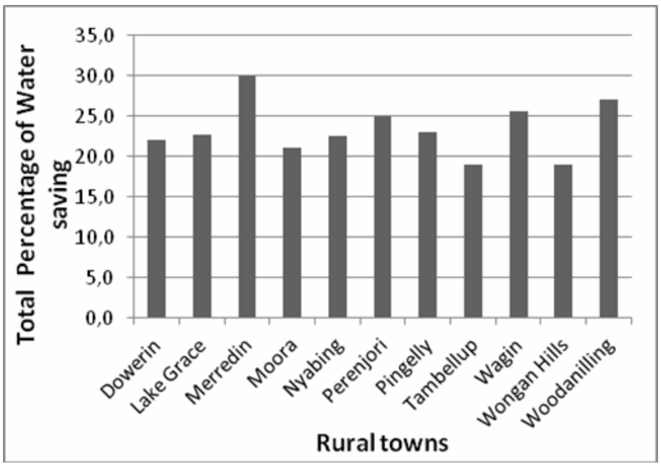

Figure 12: Total Percentage of Water Saving for Frey water and Rain water

6. DISCUSSION

6.1 Urban Runoff

Urban stormwater is defined as runoff from urban areas, including the major flows during and following rain, as well as dry weather flows. The urban runoff or surface runoff is generated because of Rain Water accumulating in Urban Areas. This research explains the importance of urban runoff as a potential water resource in rural towns. Urban water management becomes significant for urban centres. Storm water comes out as a good option in terms of cost, quality and reliability.

Shiroma Maheepala (2006) introduced a decision making framework for assessing the technical feasibility and financial cost of urban storm water schemes. Shiroma Maheepala (2006) compared all storm water use scheme options and pointed out four options as being superior in terms of financial costs, reliability, and quantity of storm water usage (Table 6).

Table 6: Summary of Cost Estimates for Case Study

Collection Option	Storage Option	End use Option	Distribution Option	Treatment Option	Average annual Reliability	Average Storm water use (Kl /Year)	Total $
Base case – No storm water use							88659
Pipe	In-ground open storage located on tom O'Brien Reserve	Outdoor	Dual pipe	Wetland	80%	7627	365851
Infiltration					80%	7627	399352
Pipe					80%	10784	408481
Infiltration		Outdoor and Indoor potable			80%	10784	441981

The rapid climate change can become a problem for Urban Water Management. Excessive rain creates flooding in most parts of Australia and insufficient rain creates drought. The organizations of the Urban Water Management need to adopt techniques which will accommodate rapid climate change. The wetland is used for storm water treatment when storage of excessive rain is needed and in case of less rain. The land used as a wetland creates problems in different parts of Australia. There are a numbers of wetlands in Australia, which are blocking agricultural areas and other land development. In the case of less storm water, the - wetlands become useless. In general, however, it costs $35,000 to 150,000 per acre for construction of treatment installation in wetlands. The operation and maintenance costs of Wetlands are quite low.

6.2 Sustainability Aspect

Now a day, the world is facing Sustainability issues. It is necessary that this research includes some discussion about it. Rainwater harvesting becomes positive to resolve sustainability issues. Some of the rural towns of Australia receive water through 1000 kms long pipelines. Bio-diversity is impacted due to cutting of trees and destruction of habit species to make routes for pipeline. The cost of installation of a water supply project is tolerable in some cases; however the operation and maintenance cost of supply water is quite high in millions of dollars. Moreover, gas emission from pumping stations creates environmental impact in millions of dollars. In addition, because of unwanted use of reservoir water, it is difficult to maintain its higher level.

A higher level of water is necessary to maintain good quality of water in the reservoir. The precautionary principal issue recommends use of different options of rainwater harvesting. The science has proved that water quality of rainwater is satisfactory for residential use. It is recommended that proper water treatment facilities should be required in every town. This research determined surface water reliability and proved that rural towns can use urban runoff with implementation of proper techniques.

Grey water is not a preferred option compared to other options. This research examined the annual progress report of Water Organizations as part of a feasibility study on the use grey water. It was found that the water organizations were not convinced of the feasibility of using grey water due to reasons such as High operation and maintenance cost, and Water Quality Aspects.

6.3 Water Quality

This research showed that the rainwater option and the surface water option were the best options for the eleven rural towns. The Water Quality Aspect is very important for the success of Rain Water Harvesting. There are few scientific studies to support the Feasibility of Rainwater Harvesting. Coombes (2003) mentioned that the quality of rain water collected from roofs was suitable for toilet flushing and other water uses. Herrman (1999) mentioned that the use of rain water for clothes washing is safe. The evidence suggests that the rain water harvesting option is good for toilet Flushing and garden watering.

There are impervious surfaces like roads, parking lots and sidewalks. These impervious surfaces create flooding in to the urban area. Proper drainage facilities are required to harvest urban runoff. The impervious surfaces contribute pollutants like gasoline, motor oils, heavy metals, and trash. Proper water treatment is required to treat urban runoff before adding in to the scheme water. Therefore, before adopting the rainwater option and the surface water option quality assessment would have to be done.

Table 7: Estimated residential indoor end use breakdown (Loh and Coghlan 2003).

Items	End Use (L/Capita / Day)
Toilet	38
Laundry	58
Bathroom	69
Kitchen	16
Total	181

7. CONCLUSION

In conclusion this research study showed that the local resources like local Urban stormwater, Rainwater harvested in Rainwater tanks and Greywater are the best options for Western Australian rural towns in view of climate change and scarcity of water. However the scheme water is more cost effective than Rain water and Grey water. The Rain water option is more cost effective than the grey water option. The volumetric reliability is high in the case of the Grey water option compared to the rain water option. The rain water option is more desirable because maintenance and operation costs are less compare to the grey water and because of the Water Quality Aspect. This study showed that Meredin, Moora and Wagin achieved the highest surface runoff reliability. Moora, Pingelly and Wagin achieved the highest volumetric reliability. The average result of the eleven rural towns for volumetric reliability and surface water reliability was enough to choose both the rain water option and the urban water runoff option. In the case of the rain water option 13 % water saving can be achieved by Wagin and Woodanilling. The use of rain water and Urban water (Surface runoff) led to savings in scheme water and local resources and less environmental impact. Lake grace and Perenjori are rural towns experiencing scarcity of water because of less storm runoff. The advanced technology like wetland and aquifer storage for Urban Storm water Management is able to resist rapid climate change and give safety to towns in case of flooding and drought. It has been proved that urban runoff is more reliable compared to the rain and grey water options. In future, urban runoff may take over from other options like grey water. The rural towns of Australia are drier compared to the coastal area towns. Hence, Urban runoff and the rain water tank option are good options in terms of cost, reliability and sustainability aspects for rural towns of Western Australia.

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