

**An investigation into Alternative  
Domestic Water, Sewer and Electricity  
Supply Systems in the EtheKwini  
Municipal Area.**

**David William Crompton**

**A dissertation submitted in partial fulfilment of the  
requirements for the Degree of**

**Master of Science  
In  
Construction Project Management.**

**In the Faculty of Engineering, University of KwaZulu  
Natal, Durban**

**July 2004**

## **ABSTRACT**

Millions of Black South Africans still lack access to adequate housing, mainly as a result of apartheid era development policies. The delivery of low income, state subsidised, housing includes the provision of water, sewer drainage and electricity supply services. These services are provided via individual connections to the bulk infrastructure, or grid, supply network. Whilst this delivery mechanism meets community aspirations, it masks the environmental impact of this access to natural resources. This research investigates the low income housing delivery mechanism in South Africa, both past and present, and considers the associated infrastructural service delivery in the context of what is understood as sustainable development.

In order to identify a more environmentally sustainable format of service delivery, the notion of autonomous housing is investigated. This investigative research establishes the body of knowledge in respect of rainwater harvesting and renewable energy sources capable of being harvested at a domestic level and uses this knowledge to inductively derive theoretical models for the provision of water and electricity supply as well as sewer drainage to low income housing in the Ethekewini Municipal area. The objective of the research is therefore to propose a more autonomous, or self reliant, system of service delivery that constitutes sustainable development.

This dissertation is dedicated to Fred Crompton, my life mentor and father,  
who passed away while Chapter 3 was being written.

## **ACKNOWLEDGEMENTS**

Acknowledgement for support goes to my supervisors, Professors Harber and Pearl.

My sincere thanks go to Patricia Mavian for her assistance with research and proof reading and to the University's library staff for their patience.

CONTENTS

	Page
ABSTRACT	ii
DEDICATION	iii
ACKNOWLEDGEMENTS	iv
CONTENTS	v
LIST OF FIGURES	xi
LIST OF TABLES	xii
ABBREVIATIONS	xiii
1. INTRODUCTION	1
1.1 An Introduction to Sustainability and Sustainable Development.....	1
1.2 Low Income Residential Township Development	1
1.3 Service Connections to Low Income Housing: Standards and Expectations.....	3
1.4 The Relationship of Residential Densities to Service Connections.....	4
1.5 The Sustainability of Service Connections.....	6
1.5.1 Water Supply.....	6
1.5.2 Sewerage Treatment.....	7
1.5.3 Electricity.....	8
1.6 The Autonomous Housing Concept.....	8
1.7 Problem Statement.....	9
1.8 Research Objectives.....	10
1.8.1 Primary Objectives.....	10
1.8.2 Secondary Objectives.....	10
1.9 Research Methodology.....	11
1.9.1 Research Method.....	11

1.9.2	Scope, Limitations and Constraints of Research.....	12
1.10	Hypothesis.....	13
1.11	Structure of the Dissertation.....	13
2.	THE SUSTAINABILITY OF SERVICE CONNECTIONS TO LOW INCOME HOUSING IN THE ETHEKWINI MUNICIPAL AREA	15
2.1	Introduction.....	15
2.2	Sustainable Development.....	15
2.2.1	Towards a Definition.....	15
2.2.2	Environmental Justice.....	17
2.2.3	Towards a Common Understanding of Sustainable Development.....	19
2.2.4	Cultural Considerations.....	24
2.2.5	Summary.....	25
2.3	A Review of Low Income Housing Delivery in the EMA.....	25
2.3.1	Mass Housing Delivery.....	26
2.3.2	Mortgage Financed Housing.....	27
2.3.3	A Policy Change: The Independent Development Trust (IDT).....	27
2.3.4	The National Housing Subsidy.....	28
2.3.5	Summary.....	29
2.4	The Sustainability of Service Connections.....	30
2.4.1	Water.....	30
2.4.1.1	The Global Perspective.....	30
2.4.1.2	The South African Perspective...	32
2.4.2	Sanitation.....	38
2.4.3	Electricity.....	40
2.4.4	Summary.....	42

3.	RESEARCHING AUTONOMOUS HOUSING	43
3.1	Introduction.....	43
3.2	Autonomous Housing: Towards an Understanding.....	43
3.3	The Autonomous Housing Movement.....	45
3.4	The South African Context.....	46
3.5	Research Methodology.....	49
3.5.1	The Body of Knowledge.....	49
3.5.2	Quantitative vs Qualitative Research.....	49
3.5.3	Research Methods Employed.....	50
3.6	Summary.....	53
4.	AUTONOMOUS DOMESTIC WATER SUPPLY	54
4.1	Introduction.....	54
4.2	Meeting the Demand for Domestic Water.....	54
4.3	Natural Water Sources.....	54
4.4	Rainwater Harvesting.....	55
4.4.1	Basic System Configuration.....	55
4.4.2	Water Quality.....	56
4.4.3	Ensuring Water Quality.....	58
4.4.4	Water Harvesting in the EMA: Storage Tank Capacity.....	61
4.4.5	Case Studies of Rainwater Harvesting.....	65
4.4.6	Case Study Summary.....	70
4.4.7	Model for Rainwater Harvesting in the EMA.....	71
4.4.7.1	Domestic Water Use and Tank Capacity.....	71
4.4.7.2	General Configuration.....	72
4.4.7.3	Proposed Filtration Details.....	73
4.4.7.4	Storage Tank Details.....	74

4.5	Sub-surface Water Harvesting.....	75
4.6	Water Conservation.....	76
4.6.1	Grey Water Systems.....	76
4.6.2	Grey Water Treatment.....	77
4.6.3	Case Studies.....	78
4.7	Summary.....	79
5.	AUTONOMOUS DOMESTIC SANITATION	80
5.1	Introduction.....	80
5.2	On-site Sanitation Systems.....	80
5.3	Waste Disposal and Sustainability.....	80
5.3.1	Human Waste Digestion.....	81
5.3.2	Soil Permeability.....	82
5.4	Septic Tanks.....	82
5.4.1	Septic Tank Function.....	82
5.4.2	The Septic Tank System.....	83
5.4.3	The Digestion Process.....	83
5.4.4	Sludge Removal.....	85
5.4.5	Effluent Disposal.....	86
5.5	Composting Toilets.....	87
5.6	Pit Latrines and Aqua-Privies.....	87
5.7	Oxidation Ponds.....	88
5.8	Case Studies.....	89
5.9	An Autonomous Sanitation Model for the EMA.....	89
5.9.1	Black Water Disposal.....	89
5.9.2	Grey Water Disposal.....	90
6.	AUTONOMOUS DOMESTIC ENERGY SUPPLY	92
6.1	Introduction.....	92
6.2	Sources and Applications of Renewable Energy...	92
6.3	Passive Solar Design.....	93

6.4	Heating of Spaces.....	93
6.5	Solar Heating of Water.....	95
6.5.1	Solar Collectors.....	96
6.5.2	Circulation Systems.....	97
6.5.3	Heat Distribution Systems.....	98
6.5.4	Storage Tanks.....	98
6.5.5	Sizing of a Solar Water Heating System....	99
6.5.5.1	Solar Collectors.....	99
6.5.5.2	Storage Tanks.....	99
6.5.6	Meeting Domestic Hot Water Demand.....	100
6.5.7	Solar Water Heating Model for the EMA....	103
6.6	Photovoltaics.....	106
6.6.1	An Overview of Photovoltaics.....	106
6.6.2	Meeting Domestic Energy Demand.....	109
6.6.3	A PV Model for Low Income Housing in the EMA.....	112
6.6.3.1	Assessment of Electricity Demand.....	112
6.6.3.2	Meeting the Demand with a PV System.....	114
6.6.3.3	Accommodating the Demand Peaks.....	116
6.6.3.4	Layout of the PV System.....	117
6.7	Wind Energy.....	118
7.	CONCLUSIONS AND RECOMMENDATIONS	120
7.1	Introduction.....	120
7.2	Financial Sustainability.....	120
7.3	A Review of the Sustainability of the Models Proposed for the EMA.....	122
7.3.1	Futurity.....	122
7.3.2	Environment.....	123

7.3.3	Public Participation.....	123
7.3.4	Equity.....	124
7.4	Practicality of Theoretical Proposals.....	125
7.5	Testing the Hypothesis.....	126
7.6	A Review of the Research Objectives.....	127
7.7	Recommendations.....	128
REFERENCES		130
BIBLIOGRAPHY		144

## LIST OF FIGURES

Figure No.		Page
1.	Timeline of Environmental Milestones: EMA.....	48
2.	Research Process.....	51
3.	Typical Domestic Configuration for Rainwater Harvesting	56
4.	Baffle Tank to Hold Back Sediments and Debris.....	59
5.	First Flush Rejection Detail.....	59
6.	Required Water Storage Capacity: EMA.....	62
7.	Rainfall Deviation from Mean: EMA: 1993 to 2002.....	63
8.	Rainwater Harvesting from a 30 m <sup>2</sup> Roof: EMA.....	64
9.	Comparison of Household Water Demand and Harvested Rainfall: EMA.....	71
10.	Proposed Storage Tank Capacity.....	72
11.	Proposed Configuration for EMA.....	73
12.	Proposed Rainwater Filtration Unit .....	74
13.	Water Storage Tank Details.....	75
14.	Septic Tank Process and System.....	84
15.	Drainage Bed Proposal for EMA.....	90
16.	Nicol Graph for the EMA.....	94
17.	Circulation Systems for Solar Water Heaters.....	97
18.	Batch Type Solar Collector.....	102
19.	f-Chart for Liquid Systems.....	104
20.	Heating Load Contribution: Comparison of Solar Collectors by Area.....	105
21.	Construction and Workings of a PV Cell.....	107
22.	Electricity Usage Profile: Low Income House: EMA.....	113
23.	Relationship between Solar Radiation Levels and Generation of Electricity by PV Module.....	115
24.	Comparison of Supply and Demand Peaks: EMA.....	116
25.	Proposed PV System Layout for EMA.....	118

## LIST OF TABLES

Table No.		Page
1.	Means of Access to Potable Water.....	35
2.	Household Densities in Low Income Housing Areas: EMA.....	36
3.	Water Consumption Charges: EMA: April 2004.....	37
4.	Estimated Vs Actual Water Consumption: House Vale.....	67
5.	Summary of Case Study Lessons: Rainwater Harvesting.....	70
6.	Grey Water Systems: Case Studies.....	78
7.	Solar Water Heating: Case Studies.....	101-102
8.	f-Chart Variables for EMA.....	104-105
9.	Efficiency of Increasing Size of Solar Collectors.....	106
10.	Types of PV Modules.....	108
11.	PV Systems: Case Studies.....	110-111
12.	Domestic Demand Profile: Low Income House: EMA..	112
13.	Consumption Levels Adjusted for Water Heating Requirements: EMA.....	114
14.	Calculation of PV Module Area.....	115

**ABBREVIATIONS**

A	Amps
AmpHr	Amp Hours
EMA	Ethekwini Municipal Area
KWh	Kilowatt Hour
PV	Photovoltaic
T	Temperature
UN	United Nations
UNEP	United Nations Environmental Programme
W	Watts
WHO	World Health Organisation

# **CHAPTER 1                      INTRODUCTION**

## **1.1     An Introduction to Sustainability and Sustainable Development**

Visser and Sunter (2002, p.60.) believe that the notion of sustainability “began as an ideological crusade about fifty years ago when a few voices in the wilderness gave a clarion call about how our civilisation was on a path to self destruction”. This notion, which is now an international movement, covering a myriad of issues, is based on a number of key principles, including that of circularity, defined by Hunt (2004, p.121.), as “If a system is to be sustainable, matter and energy removed from the system cannot exceed matter and energy put in to the system”. Simply put, mankind cannot continue to plunder the earth’s natural resources at a rate exceeding that at which they can be regenerated.

Rohmann (2000, p.393.) describes sustainable development, an applied form of general sustainability, as a “concept in international development that seeks to balance the needs of the present with the future viability of natural resources and planetary ecology”, noting that the primary debates in this context relate to the planet’s carrying capacity, its adaptive and restorative potential and the definitions of the terms ‘sustainability’ and ‘development’. Advocates of sustainable development urge the implementation of measures including conservation, recycling, population control and the development of alternative renewable energy sources (Rohmann, 2000).

## **1.2     Low Income Residential Township Development**

The term “residential township development” summarizes a process in which new erven are created on land, which was previously natural open space or land used for agricultural purposes. This is achieved by creating legal

subdivisions of the parent property and constructing a service infrastructure comprising access roads and footpaths, a sewer drainage reticulation system, a potable water supply reticulation, an electricity supply network and a stormwater drainage control system. The final stage in the process is the construction of a residential dwelling, on each subdivision, inclusive of separate connections to the water, sewer and electricity services provided.

The development process is driven by constantly growing population levels and the derived need for housing and services. In the South African context, the problem has been intensified by a “backlog” of housing need that emanated from the separatist development policies implemented during the apartheid era. By the end of the 1980s, Bond (2002, p.194.) estimates that there were “a limited number of approximately 200 000 households receiving good level of service (full electricity and fully-reticulated water and sewerage)” and an estimated three million households were without adequate shelter.

Whilst there has been substantial effort since South Africa’s first democratic elections in 1994 to address this backlog, there is some debate as to the effectiveness of these efforts. Mbeki, the South African president, reported to the United Nations (UN) in 2002, “Since the victory of democracy in 1994, seven million people have access to clean water, over one million homes for poor people have been built, over two million more homes now have electricity and every child has a place in school”. Bond (2002, p.190.) believes that these claims cannot be sustained, stating that the challenges embodied in providing infrastructural services to the poor black communities, “all proved too intimidating” for the new government. Whatever the progress achieved since 1994, it is clear that a substantial backlog still exists, “Despite our achievements...Many South Africans are still homeless” (Department of Housing, 2002, p.4.).

In addition to the physical backlog of housing and services, the apartheid legacy of income distribution has a significant impact on the provision of low income housing. Bruggemans (2003, pp.25-26.) defines this “severely skewed income distribution along racial lines”, in noting that in a 1998 survey done by the South African Advertising Research Foundation, “70% of Black Households had less than R1 400 of claimed income per month. In contrast, over 60% of White households and over 45% of Indian and Coloured households, as opposed to only 3% of Black households, claimed income of R6 000 or better per month”. This racial based income profile highlights the need for affordability, in respect of both housing and services and explains the importance of social equity as part of the housing delivery process.

### **1.3 Service Connections to Low Income Housing in the EMA: Standards and Expectations**

The physical form of low income residential development is a product of the technical and social standards implemented. Technical specifications for housing funded via the National Housing Subsidy are prescribed by the Department of Housing and Local Authorities (Department of Housing, 2000; Ethekwini Municipality Minimum Standards, 1996). Clearly, social standards reflect the expectations of the resident communities, which are based on what has historically been provided elsewhere and has become the norm or the minimum expectation. In addition, these social standards incorporate a desire by poorer Black communities to attain a standard of services enjoyed by other racial groups.

The Housing Act (1997) requires Local Authorities to adopt the minimum standards prescribed by the Department of Housing in the National Housing Code issued in terms of the Act. Thus, from an academic perspective, there is little variation in the standards prescribed by the two bodies. In practice, however, Local Authorities resist the implementation of these standards in

urban areas unless particular circumstances exist based on concerns regarding maintenance recurrent expenditure. In the Ethekwini Municipal Area (EMA), the Local Authority provides additional 'top up' funding to raise standards on the basis of long term cost savings in reduced maintenance (Kimber, 2004).

Community expectations, based on convenience and equity, generally include a piped connection to a water reticulation system, a piped connection to a waterborne sewer reticulation and a connection to an electricity supply grid as "minimum standards". As already discussed, this notion of equity is founded in the country's political history and is an important social aspect of all low income housing projects. A level of unity exists therefore, particularly in respect of service connections, between community aspirations and Local Authority requirements, but not the minimum requirements laid down by the National Housing Code (discussed more fully in chapter 2).

The result of this unity of standards and expectations is the routinely 'standard' provision of individual piped water supply and sewer drainage connections as well as electricity supply connections to the grid for each site. Whilst this may appear to represent a development solution that satisfies all role-players, the environmental sustainability of this approach must be considered and questioned.

#### **1.4 The Relationship of Residential Densities to Service Connections**

A direct result of providing piped and cable connections to the services infrastructure network, or grid, is that of facilitating increasing development densities, i.e. the reduction in area of residential sites.

Escalating development costs and the limited supply of urban undeveloped land suitable for development, have resulted in the current trend in

residential township development to increase development densities by reducing the size of the individual subdivisions. Prior to 1987, the smallest permissible residential sub-division acceptable, in terms of Durban's town planning scheme, was 650 square meters in area with high income developments generally having considerably larger sites of between 2000 and 4000 m<sup>2</sup>. Currently, upmarket projects in EMA areas such as Umhlanga Ridge and Hillcrest are being developed with site sizes of 800 to 1000 square meters with low income projects incorporating sites as small as 120 square meters (Cato Manor Development Association, 1997).

This densification of residential development is supported by town planners as an effective method of combating the problems associated with urban sprawl, which is considered unsustainable in respect of the cost of providing social facilities, such as schools, libraries and clinics, and bulk infrastructure to new residential areas.

Whilst the advantages of developing new residential areas at higher densities are obvious in respect of land use, initial development costs and social facility provision, the process is underpinned by the provision of piped water supply and sewer drainage reticulation connections to each subdivision. The smaller land area allocated to residential subdivisions is considered by local authorities such as Ethekewini Municipality too small to support "on-site" sanitation and drainage systems such as septic tanks, VIPs, etc (Ethekewini Municipality, 1996).

Thus there is a clear and self-reinforcing relationship between increasing residential densities and the provision of piped infrastructure service connections to the grid.

## **1.5 The Sustainability of Service Connections**

The primary issues in considering the sustainability of water, sewer and electricity services, in the format of piped and wired connections, are the availability or scarcity of natural resources and the degradation of the ecological environment resultant from the supply. This 'supply-side' assessment of sustainability must be viewed in the context of the household 'demand-side' needs that are necessary for survival and basic hygiene, social equity and the affordability of the services to low income households. An overview of the sustainability of 'grid' connections for potable water, sewer drainage and electricity highlights the pertinent 'supply-side' issues.

### **1.5.1 Water Supply**

Most known life forms on Earth depend on access to a water supply of adequate quality and quantity. This undeniable importance of potable water highlights the importance of conserving the environment. Hunt (2004, p.1.) explains this relationship, "Nature is the source of water; therefore our ability to support additional human lives on planet Earth depends upon the protection of nature and the continued operation of the water cycle".

Barlow (2001) warns that by the year 2025 as much as two thirds of the worlds population will be facing serious water shortages. This global problem relates not only to the quantity of water available, but the quality of the water, which is under threat from pollution and misuse (Tolba, 1992).

South Africa, being a semi-arid country, is not exempt from the impending water crisis. Based on present trends in water use, South Africa will reach the limits of its economically usable, land based fresh water resources before 2030 (Van Niekerk, 2000). This impending water supply crisis has

lead to legislation such as the National Water Act (No. 36 of 1998), which provides for a new integrated approach to water resource management utilising groundwater catchment management plans. Whilst such steps allow for the improved management of water resources, the problems of steadily increasing demand, due to population growth and lifestyle changes, still needs to be addressed (Roaf *et al.*, 2001).

The situation in the EMA is a reflection of the global and national reality, where existing fresh water sources have been fully harnessed and new sources are being investigated with pollution levels threatening water quality (Hindson *et al.*, 1996).

### **1.5.2 Sewerage Treatment**

Methods of dealing with sewer waste in South Africa are the land based conventional treatment or the disposal of waste into the ocean, used primarily in the coastal regions such as the EMA (Chetty, 2002; Teurlings, *et al.*, 1997).

Land treatment of sewerage results in precipitates, referred to as 'sludge', typically 10 ml of sludge per litre of sewerage processed, which require disposal (Terblanche, 2001). Due to the existence of industrial effluent in the sewerage, the sludge from municipal treatment plants contains heavy metal oxides and toxins. Dumping, burying or incineration of these wastes have, until recently, been considered the only disposal methods suitable (Serykh and Bagrov, 1994). Disposal of this sludge in an environmentally acceptable manner has become more complex and problematic, due to legislation such as the National Environmental Management Act and general environmental sensitivity (Murphy 2000; Chetty 2002). Disposing of sludge to landfills provides increased pressure on an already overburdened facility (South

African Yearbook, 2004) and incineration results in air bound environmental health consequences.

The use of the ocean as an accepting system, although validated at a technical level, has not garnered public support (Bailey, 2000; Hindson *et al.*, 1996). This process is monitored by constant testing by the CSIR, required in terms of the approval, by government, to construct an ocean sewer outlet. In the local context, when evidence of high toxicity levels in ocean water is detected, it is difficult to determine the exact cause leading to public concern (Natal Mercury, 5 October 2001).

### **1.5.3 Electricity**

Due to an abundant supply of coal as a natural resource, South Africa has a reliance on and oversupply of coal-generated electricity (Bond, 2002). This method of energy production is the root cause of South Africa's most serious environmental problems, including global warming and acid rain (The Environmental Monitoring Group, 1992).

Nuclear energy production is being retarded internationally. Daglish (1978) comments that informed opinion is arguing that nuclear power is unlikely to have a significant direct role to play in meeting the aspirations of the less developed countries.

Alternative forms of energy production that are less environmentally damaging need to be established and implemented.

## **1.6 The Autonomous Housing Concept**

The autonomous housing movement began in the 1970's, motivated by the oil crisis and dire future predictions for energy availability (Roaf *et al.*, 2001).

The first research project, the Cambridge Autonomous House, began in 1971 resulting in a completed prototype house in 1974 (Vale and Vale, 2000).

The term 'autonomous house' describes houses that are 'off the grid' in that they do not, by choice, have piped or wired connections for water supply, sewer drainage or electricity.

Much of the early research work concentrated on house design issues promoting designs, materials and techniques that would harness renewable energy to supplement conventional energy supply (Wright, 1978; Lambeth and Delap, 1977). Szokolay, in 1977, warned that the age of cheap energy was definitely over, capturing the understanding reached in the mid-1970's that the issue of renewable energy sources was with us to stay. This explains the prominence of focus of this aspect of autonomous housing.

### **1.7 Problem Statement**

Having examined the issue of the sustainability of infrastructure services provided in low income residential township developments, the emergent problem statement is as follows:

***The provision of piped service connections for water and sewer drainage and wired electricity connections, expected by communities, supported by approving authorities and provided by developers, have ecological consequences and is therefore unsustainable in the longer term.***

***The lack of alternative, ecologically acceptable forms of service provision renders the low income housing delivery mechanism and methodology synonymous with unsustainable development.***

## **1.8 Research Objectives**

### **1.8.1 Primary Objective**

The primary objective of the study relates to identifying alternative systems of water supply, sewer drainage and electricity service provision, that meet the objectives of sustainable development, to low income housing. This objective is described as follows:

***To identify alternative systems of water supply, sewer drainage and electricity supply, which constitute sustainable development, capable of being implemented as part of low income housing delivery in the Ethekwini Municipal Area, thereby achieving housing that is independent or autonomous from reliance on the normal services reticulation networks.***

### **1.8.2 Secondary Objectives**

In achieving the primary objective, a number of secondary objectives will be investigated and analysed. A description of these secondary objectives is as follows:

- To determine the practical feasibility of the application of solar energy, rainwater harvesting and on-site sanitation treatment, in a domestic low income context.
- To investigate the sustainability of domestic 'grid' connections.
- To analyse and quantify the extent to which alternative service provision can supplement conventional 'grid' connections, thereby reducing, if not eliminating the dependence on and ecological effect of grid connections.

- To assess the sustainability, in the context of sustainable development, of the autonomous housing concept.
- To assess the practicality of the autonomous housing concept.

Although the assessment of sustainability of the autonomous housing concept is stated as a secondary objective, the issue of sustainable development is adopted as an underlying objective in all aspects of this research.

## **1.9 Research Methodology**

### **1.9.1 Research Method**

In essence the research methodology adopted is descriptive research based on an expository investigation of the existing body of knowledge (Melville and Goddard, 1996). The body of knowledge relating to alternative service provision and natural systems will be revealed via a literature review. A combination of both qualitative and quantitative analysis will be applied to determine a theoretical working model for the area of study (May, 1997).

This grounded theory research approach will make use of crosstabulation techniques to project quantitative aspects of the model (Hellevik, 1984; Fellows and Liu, 1997). Descriptive research will be used in the analysis of case studies to determine the nature of achievements by 'pioneers' in the autonomous housing movement. For the purposes of this study, these case studies will constitute field tests.

### 1.9.2 Scope, Limitations and Constraints of Research

The scope of the research is not intended to cover all aspects of autonomous housing nor all aspects of renewable energy sources. The primary limitation will be in respect of the scope of the research, which will be limited to the water supply, sewerage disposal and energy requirement aspects of low income housing. Building design, site selection, orientation and material selection issues that make structures more efficient and therefore less energy consuming, are specifically excluded from this research.

Further limitations and the relevant motivations are as follows :

- The study is limited to the geographical area defined as the Ethekwini Municipal area. The motivation for this limitation is to reduce climate and weather variables that impact on household energy demand patterns.
- Low income housing financed by the National Housing Subsidy Scheme is the only sector of housing considered. Simplification of the demand and consumption patterns, in respect of services, provides motivation for this limitation.

The research is further limited by some practical constraints, namely :

- The physical location of case studies precludes the opportunity for *in loco* visits.
- Experimental testing of theoretical models was not possible due to funding constraints.

### **1.10 Hypothesis**

Based on the issues discussed and the resultant problem statement, the hypothesis to be tested in this dissertation is:

***That sewer, water and electricity service connections, supported by a piped or wired reticulation network, provided to low income housing in the EMA can be replaced with alternative forms of service provision, without reducing the quality of the service provided, in an urban environment, thereby achieving a more sustainable form of development.***

### **1.11 Structure of the Dissertation**

The ideology underlying the structure of the dissertation will be a logical development of the various research issues and arguments. A correlation exists between the research methodology and the chapters facilitating a systematic progression from the expository investigation of the existing body of knowledge to the formulation of theoretical models.

The structure of the dissertation is as follows:

***Glossary of Abbreviations*** defines abbreviations used throughout the document.

***Chapter two*** investigates, by literature review, the meaning of sustainable development and provides a background in respect of low income housing provision in South Africa. Using this background, the sustainability of natural resources supplied to housing via conventional 'grid' connections is examined.

**Chapter three** provides an understanding of the notion of autonomous housing and explains, in detail, the research methodology employed.

**Chapter four** investigates alternative methods for an autonomous domestic water supply and proposes a theoretical model for implementation in the EMA.

**Chapter five** investigates alternative domestic sanitation options and proposes a theoretical model for implementation in the EMA.

**Chapter six** investigates the use of renewable energy in a domestic context and proposes a theoretical model for implementation in the EMA.

**Chapter seven** contains the conclusion of the research and analyses whether the hypothesis is supported. In addition, recommendations for the implementation of the proposals are formulated.

**References** lists all material cited or referred to in the dissertation.

**Bibliography** lists all material not cited or referred to in the dissertation but which have constituted part of the body of research documentation.

## **CHAPTER 2      THE SUSTAINABILITY OF SERVICE CONNECTIONS TO LOW INCOME HOUSING IN THE ETHEKWINI MUNICIPAL AREA.**

### **2.1      Introduction**

This chapter will provide a background to low-income housing provision in South Africa inclusive of service connection delivery, explain the need and rationale for the adoption of a sustainable approach to development and explore the extent to which service connections to low-income housing projects are sustainable.

### **2.2      Sustainable Development**

#### **2.2.1   Towards a Definition**

The Oxford Universal Dictionary defines the word “sustain” as “to keep going continuously”. This definition serves as a basis for an intuitive understanding of the term *sustainable development* as an approach to development that can be continued indefinitely, taking cognisance of the use and consumption of natural resources. A more precise definition was proposed by the Brundtland Commission (World Commission on Environment, 1987), in describing sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. This intergenerational definition was adopted by the United Nations’ “Earth Summit” conference held in Rio de Janeiro in June 1992 and remains the most widely accepted definition of sustainable development.

The principles embodied in the Brundtland definition were incorporated into *Agenda 21*, the primary document of the earth summit conference. This document represented a synthesis of the commitments made at the conference and has been a focal point for political action on the environment ever since (Visser and Sunter, 2002).

Critics of the Brundtland definition describe it as a “lowest common denominator” approach (Bond, 2002, p.30.). Visser and Sunter (2002, p.67.) support this view, elaborating that “the concept was crafted essentially as a political tool, tactfully allaying the fears of powerful business lobbies in the developed countries of the North by not being ‘anti-economic growth’. At the same time, it soothed the governments and civic organisations of the developing world in the South by talking about development and intergenerational equity. It also befriended and found a guardian-for-life among the environmental pressure groups by putting their ‘green’ issues on the world map”. Roddick (2001, p.136.) believes that governments and international environmental conferences will inevitably revert to the lowest common denominator approach, “Instead of setting minimum standards for environmental protection, World Trade Organisation agreements and rulings effectively place a ceiling on environmental standards. This ensures that environmental regulations sink to the lowest common denominator”.

Fundamental to the Brundtland definition is the rate of growth and consumption that can be maintained. Classic capitalism takes the view that growth and consumption can be maintained indefinitely, as human ingenuity creates synthetic replacements for depleted resources (Rohmann, 2000). Others believed that the limit on the earth’s ecosystems to absorb developmental effects limit, in turn, the absolute size of the global economy. Daly (1996, p.88.), supporting this view, highlighted the difference between growth and development, defining sustainable development as “development without growth beyond environmental carrying capacity, where development means qualitative improvement and growth means quantitative increase”. Daly’s definition, based on his view that “we should strive for sufficient per capita wealth – efficiently maintained and allocated, and equitably distributed – for the maximum number of people that can be sustained over time under these conditions” (p.220.), introduces the notion of environmental justice absent from earlier definitions.

The most recent United Nations conference, the 'World Summit on Sustainable Development' was held in Johannesburg in August 2002. The conference put sustainable development at the center of the international agenda (United Nations, 2003). One of the key outcomes of the summit was "The understanding of sustainable development was broadened and strengthened as a result of the Summit, particularly the important linkages between poverty, the environment and the use of natural resources" (United Nations, 2002, p.1.). Although no new definition was adopted, this broadening of understanding demonstrates the need for a more holistic and realistic definition of sustainable development and supports Daly's proposals.

### **2.2.2 Environmental Justice**

The notion of environmental justice, introduced by Daly (1996) into the definition of sustainable development, combines the sentiments of the environmental or 'green' movement with the concept of social justice. This combination gives rise to the notion of environmental equity, in terms of which minority, disadvantaged or poor sectors of society should not suffer the environmental consequences of actions by other sectors of society.

"The ambit of environmental policy and activism that focuses on patterns where the poor and 'people of colour' bear the brunt of the nation's pollution problem became known as 'environmental justice'" (Getches and Pellow, 2002, p.3., citing Chavis, 1993). Many believe that the issue is underpinned by racism. Getches and Pellow (2002, p.3.), support this in stating "The absence of environmental justice is environmental racism" whereas Bryant (1995, p.5.) goes further, "It is an extension of racism".

The movement was originally concerned with the issue of the location of land-fills, polluting industries and chemical plants nearby to poorer communities. "The intersection of racial discrimination and environmental insult, both of which are eschewed in modern political rhetoric and public opinion, is where the environmental justice movement began" (Getches and

Pellow, 2002, p. 4.). The context of environmental justice has now moved to a wider forum. The Environmental Justice conference held in Australia in October 1997, highlighting the issues of global ethics and human rights in the context of environmental preservation, demonstrated this movement in focus.

The U.S. Environmental Protection Agency (1998) defined environmental justice as fair treatment and meaningful involvement of all people regardless of race, colour, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations and policies although the essence of the movement seems to be contained in principles rather than definitions. These principles were first defined in 1991 at the *National People of Colour Environmental Leadership Summit* held in Washington DC where 650 delegates adopted seventeen 'Principles of Environmental Justice' (Bullard, 2001).

Implicit in the implementation of environmental justice is a 'bottom up' approach where communities are informed and consulted in respect of actions with environmental consequences supporting a 'prevention rather than cure' system. Critics argue that much of the reality of environmental justice is based on the so-called '*Nimby*' (not in my back yard) defense without real consideration of the bigger picture. Bond (2002, p.32.) acknowledges this potential problem in commenting on the fight for South African post-apartheid environmental justice, "Sometimes invoking the notion of justice requires resort to cultural defenses and symbolic critique, which brings its own dangers. But mainly, the use of rights based arguments by social, labour, women's and environmental movements in post apartheid South Africa has been rational, progressive and capable of the nuance required to transcend 'Not In My Back Yard', the '*Nimby*' defense, with 'Not In Anyone's Back Yard'".

Getches and Pellow (2002) believe that environmental justice underpins environmental sustainability, noting that the environmental justice cause, especially the economic and social dimensions, is essential to achieving

sustainability. These comments highlight the importance of the environmental justice issue in South Africa, given the effects of the apartheid era, particularly the unequal allocation of resources to the different racial groupings. This importance is also highlighted in the South African Constitution's *Bill of Rights* that states, "everyone has the right to an environment that is not harmful to their health or well-being" (Republic of South Africa, 1996).

Clearly, central to the implementation of sustainable development in South Africa will be consideration of the environmental justice issues.

### **2.2.3 Towards a Common Understanding of Sustainable Development**

Whatever the accuracy or otherwise of the definitions proposed for sustainable development, what is clear is that they are too vague to provide guidelines for implementation. This difficulty is highlighted by Visser and Sunter (2002, p.68.) commenting on the private sector's inability to implement the Brundtland definition, "as the 1990's marched on and companies tried to turn the concept into action, it became obvious that the political definition was far too broad and vague to be useful as anything more than a public relations sound bite. If sustainability was going to be taken seriously.....as something requiring implementation, more specific definitions were needed".

Palmer *et al.* (1997) support this view, noting that the terms 'sustainability' and 'sustainable development' have become 'fuzzy buzz' words that appear to encapsulate a discrete notion while in reality there are multiple interpretations. This has resulted in different people having different understandings of the terms and a belief there is unlikely to be effective progress until society as a whole begins to have a more common understanding of what constitutes, as well as a common aspiration for, sustainable development (Curwell and Cooper, 1998).

In addition to the problems relating to the vagueness of terms and definitions, the situation is further complicated by the notion of interdependence. Clearly, there are a wide range of issues to be considered under the sustainable development 'umbrella', issues that are generally interdependent on one another. Capra (1997,p.290.) highlights the importance of interdependence in sustainability by stating "Based on the understanding of ecosystems...we can formulate a set of principles of organisation that may be defined as the basic principles of ecology, and use them to guide and build sustainable human communities. The first of those principles is interdependence". Thus as decisions are taken that effect one system, the effect on other systems must be considered if sustainability is to be achieved. From a built environment perspective, Graham (2003) believes that three basic interdependent systems must be considered, namely the built environment, global biochemical cycles and ecosystems.

Attempts to provide frameworks and guidelines, at varying levels, have been made towards achieving a greater degree of common understanding, a prerequisite to effective implementation. An overview of this activity can be divided into those who provided details of the systems to be considered, such as Graham (2003), discussed above, and those who defined criteria that needed to be adhered to. In respect of the systems approach:

- Probably the best-known set of guidelines is Agenda 21, the international blueprint for sustainable development, formulated and adopted by 179 countries at the 'Earth Summit'. This document covered all sectors of society and calls for local authorities to achieve consensus on a 'Local Agenda 21' (United Nations, 1992).
- The Habitat Agenda was formulated by the United Nations Human Settlements programme in 1996, specifically to address human settlement in the context of sustainable development, as explained in item 1 of the preamble, "We recognise the

imperative to improve the quality of human settlements". Three systems were identified in item 4 of the preamble, "...sustainable development of human settlements combines **economic** development, **social** development and **environmental** protection....".

- In seeking to achieve a 'Local Agenda 21', numerous locally based guidelines have been produced. An example of this, in the South African context, is the 'Agenda 21 for Sustainable Construction in Developing Countries' published in 2002 by the Council for Scientific and Industrial Research as a discussion document.

These proposed guidelines acknowledge the vagueness of definitions but propose that while the scope of the term sustainability is evolving, it is "generally agreed to place demands on human activity in the three systems central to development" (CSIR, 2002, p.6.). These systems are defined as the **economic**, **social** and **environmental** aspects of sustainable development supporting the Habitat Agenda.

- Mitchell *et al.* (1995) reviewed material containing guidelines for sustainability or sustainable development and identified four common principles:
  1. **Futurity.**  
Concern for future generations
  2. **Environment.**  
Concern to protect the integrity of the eco-systems

### 3. **Public Participation.**

Concern that individuals can participate in decisions affecting them

### 4. **Equity**

Concern for today's poor and disadvantaged

These principles seem to place less emphasis on the economic aspects, concentrating more on the social aspects, although the issue of equity would incorporate a degree of economic consideration.

- Hill and Bowen (1997) proposed four pillars of sustainable construction, a specific branch of sustainable development. The systems, or pillars, defined were **social**, **biophysical**, **economic** and **technical** sustainability.
- Adapting the concept of pillars, each supporting but interdependent, the South African Department of Housing also proposed four pillars of sustainability, explaining that "Sustainability in housing and human settlement can be understood in terms of four pillars that support sustainable development. Projects should address **environmental** challenges, generate **economic** empowerment, enhance **social** capital and build **institutional capacity**" (Department of Housing, 2002, p.6.).

This overview indicates widespread agreement in respect of the environmental, social and economic systems being foundational to sustainable development.

In contrast, criteria based guidelines focus on providing essential rules or laws.

- Robert *et al.* (1995) used the first and second law of thermodynamics to define four 'system conditions' that would underpin sustainable society, now known as the 'Natural Step'.

Condition 1: Substances from the earth's crust must not be systematically increased in Nature.

Condition 2: Substances produced by society must not be systematically increased in Nature.

Condition 3: The physical basis for the productivity and diversity of Nature must not be systematically degraded.

Condition 4: We must be efficient enough to meet basic human needs.

(Robert *et al.*, 1995)

- Supporting the approach taken by Robert *et al.* (1995), Graham (2003, pp.139-146) proposes "non-negotiable condition(s) or law(s) for ecologically sustainable building", also based on the laws of thermodynamics.

1. Consume resources no faster than the rate at which they can be replenished.
2. Create systems that consume maximum energy-quality (i.e. establish autocatalytic feedback loops as explained in the 4<sup>th</sup> law of thermodynamics).
3. Create and use by-products that are nutrients or raw materials for resource production.

- Hawken (1994), defined a similar set of criteria.
  1. In Nature, all waste equals food.
  2. Nature runs off current solar income.
  3. Nature depends on diversity.

What is evident from the criteria approach outlined above is a concentrated focus on the ecological aspects of sustainable development as the primary system.

Read as one, the guidelines indicate **ecological**, **economic** and **social** interdependent foundational systems that need to be considered in implementing sustainability but with an emphasis on the ecological system. Whilst the formulated guidelines may represent an improvement in clarity from the definitions, they are still broad and over-arching, leaving much scope for individual interpretation.

#### **2.2.4 Cultural Considerations**

Agenda 21, in calling for the production and implementation of local agendas, demonstrated an understanding of the cultural differences between regions that would affect the specifics of implementation. Highlighting the importance of understanding the cultural issues in Africa, du Plessis (2001, p.374.) makes the point, "When attempting to describe sustainability, and by implication sustainable construction in Africa, it is necessary to understand the developmental priorities, as well as the cultural context within which building and construction take place in the continent".

More specifically, there are a number of finite cultural issues that must be considered in the ambit of sustainable development in Africa and, by extension, South Africa.

- The World Bank (2000) believe that Africans still have close links to the land resulting in an acute awareness of the amount of energy required to access water and to turn raw materials into food, shelter and clothing.
- African communities differ from those of the West in that there is an acceptance of the cycles of nature and the impermanence of things. Time is of little value (du Plessis, 2001)
- Africans live in interconnectedness and interdependence. This understanding is known in Southern Africa as *Ubuntu*. It results in the interest of the community and not the individual being paramount. Social responsibility dictates that decisions are taken for the benefit of the community through a process of consensus (du Plessis, 2001)

### **2.2.5 Summary**

A precise definition of sustainability or sustainable development is less important than a framework for implementation. Such a framework, as discussed in detail above, must incorporate an understanding of the underlying systems and concepts, in particular, those that relate to specific areas or community groups, such as cultural considerations.

## **2.3 A Review of Service of Low Income Housing Delivery in the EMA**

Whilst this document does not represent a study of low income housing provision *per se*, an understanding of housing delivery methodology and the associated service connection delivery, is fundamental to the analysis of the sustainability of the service connections provided as part of the housing package.

### 2.3.1 Mass Housing Delivery

Low income housing was, from the election of the Nationalist government in 1948, until the scrapping of the Group Areas Act in 1991, provided by the state on a racially segregated basis. Minimal housing delivery for the Black community was implemented until the establishment of the Bantu Housing Board in 1957. Thereafter mass housing, consisting of typical house types, was constructed at scale on a country wide basis.

The type 51/6 (one of the standard house designs implemented for low income housing), a 40,4m<sup>2</sup> four-roomed structure was the most typical house type constructed in all Black townships (Morris, 1981). Other, 'family home' houses were larger, having floor areas of between 50 and 60 m<sup>2</sup>.

By 1977, more than 368 000 of these housing units had been constructed for occupation by the Black communities in "white urban areas" (Department of Community Development, 1979). These housing units, constructed as rental housing stock, were provided with water and electricity connections as well as waterborne sewer drainage. Typically, service connections were to shared external ablutions, such as those provided to L section of KwaMashu. Internal ablutions were provided to houses constructed during and after the late 1970s (Møller *et al.*, 1978)

From the mid-1970s until the late 1980s, low income housing was constructed, also on a typical house plan basis, for the Indian and Coloured communities. This era also heralded a decrease in the provision of mass low income housing for the Black communities. Areas such as Phoenix, for the Indian community and Marianridge, for the Coloured community, were created as part of this initiative. Units were 2, 3 and 4 bedroom detached and semi-detached units with internal ablutions, for sale or rental (Urban Foundation, 1977). Whereas the rental housing for Black communities was not subject to a limit of family income, that provided for the Indian and Coloured communities was limited to "sub-economic" families whose income

did not exceed R150 per month and “economic” families whose income did not exceed R540 per month (Department of Community Development, 1979). In all cases, individual water, electricity and waterborne sewer connections were provided to each unit.

### **2.3.2 Mortgage Financed Housing**

Changes to legislation in the mid 1980s, such as the introduction of the Black Communities Development Act (Act 4 of 1984), initiated a wave of private sector involvement in the provision of new housing to Black communities. This housing, generally financed by mortgage finance secured by 99-year leasehold rights, was affordable only to middle to upper middle income Blacks or those, such as state employees, who qualified for employer housing subsidies.

### **2.3.3 A Policy Change: The Independent Development Trust (IDT)**

The late 1980's witnessed a change in state policy away from public low income housing provision to that of 'site and service' delivery. The notion was to provide sites with infrastructural services but leave the provision of the actual houses to the individuals themselves. Bond (2002, p.195.) suggests that the formation of the IDT signified this change in policy with its associated reduction of standards, stating that, “The first key statement of the late-apartheid government's intent to establish infrastructure at inadequate levels for slightly-better formalized shack settlements was the 1991 IDT housing grant”.

Established in August 1990, under the leadership of Jan Steyn, the IDT was granted two billion Rand in funding to facilitate community upliftment. One of the IDT's first projects was the allocation of approximately 100 000 capital subsidies of R7 500 each (Robinson *et al.*, 1994). The subsidies were applied to projects to provide infrastructure services and land ownership, on a 'site and service' basis.

In the EMA, approximately 10 000 subsidies were granted to projects in Ntuzuma / Inanda and Pinetown South. Typically the sites developed were provided with limited access (a high proportion of pedestrian 'footpath' access), ventilated pit latrines and communal water stand pipes serving a radius of up to 200 meters.

Steyn referred to the projects as 'beacons of hope' but the projects were deemed unsatisfactory within the Black townships. Bond (2002, p.195.) points out that "civic association critics quickly labeled them 'I Do Toilets', because the IDT financed the construction of merely a toilet".

### **2.3.4 The National Housing Subsidy**

"South Africa's housing capital subsidy scheme was introduced in the 1994 White Paper for all households with a monthly income of less than R3500, who have not owned property previously, and who satisfy a range of other criteria" (Department of Housing, 2002, p.7). The subsidy represented a modification of the apartheid government's site and service policy in that 'incremental' starter homes would be provided as part of the package. Bond (2002, p.198.) notes that the 1994 subsidy of R15 000 was "half of that required to build a decent house" adding that this under-financing would "obviously have ramifications for water/sanitation and electricity because the subsidy grant was meant to pay for household infrastructure".

Housing delivered in the EMA, primarily by local authorities and private sector developers, financed by the national housing subsidy, generally consisted of an unfinished cement block 'starter' house with individual water, electricity and waterborne sewer connections.

In March 2000, the National Department of Housing published the National Housing Code, as required in terms of the Housing Act (1997). The code established minimum service levels (referred to as norms and standards) to

be provided in projects financed by the national housing subsidy. Most significant of these service levels was the minimum requirement for a 30 m<sup>2</sup> housing unit. Minimum levels for infrastructure services were as follows:

- **Water** Single metered standpipe per erf
- **Sanitation** Ventilated pit latrine per erf
- **Roads** Access to erf with graded road
- **Electricity** Non specified

(Department of Housing, 2000)

In addition, the code limited the maximum amount that could be spent on infrastructure services. In 2000, at the time of publishing the housing code, the maximum subsidy amount was R16 000 of which only R7 500 (47%) could be spent on services and the remainder (53%) on the top structure. Clearly this imposed pressure on housing developers to reduce the level of infrastructure services to the minimum levels specified in the National Housing Code in order to achieve a 30 m<sup>2</sup> top structure.

Many local authorities, such as the Ethekwini Municipality, believed that the norms and standards represented an excessive burden in respect of future maintenance recurrent expenditure, and elected to provide additional funding to capital subsidy funded projects, to improve the level of infrastructure services. This 'top up' funding resulted in the provision of individual waterborne sewerage and electricity connections in capital subsidy funded projects within the EMA (Kimber, 2004).

### **2.3.5 Summary**

The provision of low income housing in South Africa is characterised by racially segregated provision, which has continued well beyond the country's democracy due to established socio-economic patterns. Funding of housing via a capital subsidy is a cornerstone of the housing delivery system, which

has influenced the nature of the product delivered. With the exception of the units delivered via the IDT capital subsidy scheme, the majority of houses in the EMA were provided with service connections although not always on an individual basis.

## **2.4 The Sustainability of Service Connections**

This section represents a review of the sustainability of conventional grid water, sewer and electricity connections, considering the ecological, economic and social interdependent systems.

### **2.4.1 Water**

Water is essential for life. The importance of making potable water available to the world's population is therefore self-explanatory. Despite this fundamental importance, mankind has given little regard to the preservation of the earth's natural water supplies.

#### *2.4.1.1 The Global Perspective*

On a global scale, there is general agreement that the mismanagement of the earth's fresh water supply already constitutes an issue of serious proportion that will become a critical issue in the future. "There is simply no way to overstate the water crisis of the planet today. Many now predict that the wars of this century will be over water" (Barlow, 2001, p.156.).

Pollution has degraded the quality of the earth's water supply to the extent that potable water has become a scarce commodity. Barlow (2001, p.156.) quantifies the situation, stating "already 31 countries face water scarcity and more than a billion people lack adequate access to drinking water", forecasting that "by 2025 as much as two-thirds of the world's population will be living in conditions of serious water shortage". Bright (2003) supports this quantification of the impending water crisis, suggesting that more than a half-

billion people already live in regions prone to chronic drought and that by 2025, this number is likely to have increased at least fivefold, to 2.4-3.4 billion.

The problem of an impending global water shortage is not new. The World Health Organisation estimated, in 1990, that 1230 million people did not have access to adequate drinking water projecting that this figure would rise to 900 million by 2000. Tolba (1992, p.46.) explains that approximately 9000 km<sup>3</sup> of water is available for human exploitation worldwide. Of this total, Tolba notes that "worldwide water use increased dramatically from about 1360 km<sup>3</sup> in 1950 to 4130 km<sup>3</sup> in 1990 and is expected to reach 5190 km<sup>3</sup> by 2000", clearly demonstrating the impending global crisis.

The obvious underlying problems of increasing world population, climate change and pollution are being compounded by an increasing level of household demand for water in the developed world. Hunt (2004, p.48.) points out that "since 1940, annual global water withdrawals have increased by an average of 2.5 to 3 percent per year, compared with an annual population growth of 1.5 to 2 percent". Roaf *et al.* (2001, p.216.) explain this increasing demand in more detail, "In England and Wales alone household water use is predicted to increase by 10-20 per cent between 1990 and 2021 under a medium growth scenario without climate change. Per capita demand for domestic water is predicted to rise owing to the projected increase in the use of dishwashers and other domestic appliances, with a further increase of 4 per cent with climate change owing to higher use of personal showers and garden watering".

The problem relates not just to the quantity of water available but the water quality. Tolba (1992, p.47.) explains "Assuring an adequate supply of water is not the only water problem: countries also need to worry about water quality". On-going pollution of natural water sources such as rivers and lakes is degrading the quality of water thereby making access to potable water more

difficult. Citing specific cases of aggravated pollution, Barlow (2001) highlights the effects of such pollution.

- 80% of China's major rivers are so degraded, they no longer support fish life
- 75% of Russia's lake and river water is unsafe to drink
- Mexico City is so desperate for water, the entire population may have to be relocated within a decade

#### 2.4.1.2 *The South African Perspective*

There are no boundaries to the natural environment and therefore South Africa is, by extension, subject to the same increasing demand and reducing supply of water as the rest of the world.

South Africa is a semi-arid country and, as such, does not have abundant natural water supplies. More than 80% of the country's water supply emanates from surface water that is dependent on rainfall. An average rainfall of 483 mm per year is received in comparison with a world average of 860 mm (The Environmental Monitoring Group, citing Weaver, 1992). Converting this rainfall level into available water, Bond (2002, p.35.) notes that "Each of 42 million South Africans have access each year to, on average, only 1,200 kl of available water". According to Swedish hydrologist Malin Falkenmark, countries with 1000 to 1700 m<sup>3</sup> of freshwater per person per year experience recurring problems of water scarcity whereas countries with 500 to 1000 m<sup>3</sup> per person per year have a chronic situation of water stress where lack of water is slowing down economic development and may threaten public health (Falkenmark as cited by Hunt, 2004). Clearly, water preservation and conservation is an imperative national issue in the South African context (1000 litres has a volume of 1 m<sup>3</sup>).

The EMA draws its freshwater supplies from a number of river systems that extend to the river catchment areas, far beyond the boundaries of the area.

For this reason the EMA has an 'ecological footprint' in respect of water supply extending to the boundaries of the KwaZulu Natal province. A 1996 study by Hindson *et al.*(p.19), described the condition of the freshwater supply to the EMA, as follows:

"Despite being regarded as a relatively water rich region of South Africa, freshwater supplies in the DMA (*Durban Metropolitan Area*) are not assured because rainfall is poorly distributed and irregular, and evaporation losses are relatively high across the catchments.

The capacity of the DMA's water supply, the Mgeni river, has been almost fully harnessed for urban use. The Mkomazi river is now being targeted to supplement an anticipated increase in demand in the DMA.

The Mkomazi basin, however, already sustains large industrial, agricultural, forestry and rural domestic needs. The Mkomazi also supports important conservation and recreational needs. There is thus great potential for conflict unless sustainable practices are followed in any further development of this catchment.

Sections of many of the DMA's rivers and streams have been severely polluted by industrial and/or human effluents, to a point where their ecological functioning is threatened. .... The estuaries are continually exposed to runoff from industry, return flows from sewerage works and agricultural activities, and contaminated stormwater from high density housing and informal settlements."

Thus the local EMA situation echoes the global problems that exist with freshwater supply.

In addition to the water supply and demand problems, social issues of environmental injustice complicate South Africa's water supply scenario. The

main issues of contention are the imbalance of supply of domestic water to racial groupings, due to past apartheid policies, and the quantum of water that is deemed adequate for domestic purposes.

Domestic water consumption is a small portion of the country's total consumption with agriculture and industry consuming the bulk. Analysis by Palmer and Eberhard (1994) indicated that household water demand was responsible for less than 15% of total consumption whereas the Environmental Monitoring Group: Western Cape estimated, in 1992, that domestic consumption accounted for about 8% of the total use.

Many believe that the quantum of water allocated for domestic use is, in itself, an inequity but by far the more emotive issue is the imbalance in distribution of domestic water. Bond (2002, p.36.) explains, "Around 12% of South Africa's water is consumed by households, but of that amount, more than half goes into (white people's) gardens and swimming pools, and less than a tenth is consumed by all Black South African households". The primary reason for this situation is the imbalance of access to potable water created by apartheid laws and policies.

The Department of Water Affairs and Forestry believe that a large portion of this imbalance has been corrected claiming that "In 1994, around 14 million people did not have access to safe drinking water.....Ten years later, 10 million people have been given access to clean water" (Kasrils, 2004, p.2.). This statement, made just prior to the 2004 national election, implies that millions of people who previously had no access to water, now have access to an adequate water supply. While it may be true that these people now have 'access to safe drinking water' or 'access to clean water', it cannot be assumed that this also constitutes access to an adequate potable water supply.

A large number of households in South Africa have access to potable water via communal standpipes.

**Table 1: Means of Access to Potable Water**

	<b>South Africa</b>	<b>KwaZulu Natal</b>
Piped into dwelling	32.3%	29.6%
Piped into yard	29.0%	19.8%
Communal standpipes less than 200 meters from dwelling	10.7%	9.0%
Communal standpipes more than 200 meters from dwelling	12.4%	13.4%

(Note: Table does not reflect all means of access to water)

Source: Census 2001

The scale of water distribution via standpipes begs the obvious question of whether communal standpipes constitute an adequate supply of potable water.

The World Health Organisation (WHO) recommends a minimum water consumption of 50 litres per person per day for normal health and hygiene (The Environmental Monitoring Group, 1992). Surveys of a number of Black urban housing developments in the EMA, indicated the following household densities.

**Table 2: Household Densities in Low Income Housing Areas:  
EMA**

<b>Project Name</b>	<b>No. of Erven</b>	<b>Average Household Density</b>
Welbedacht East	1548	4.54
KwaMashu L	2107	6.22
Bhambayi	880	3.44
Besters	6554	4.94
	<b>11089</b>	<b>5.01 *</b>

\* Weighted average

(Source: Project Management Project Databases)

The result of this sample survey is supported by the 2001 South African census, reporting an overall average household size of 4.2 persons in KwaZulu Natal.

Taken from the Table 2 survey, the average household minimum consumption in terms of the WHO criteria for normal health and hygiene is 250 litres per day. Given that water from communal standpipes is dispensed in 'lots' of 25 litres (based on the carrying capacity of one person), this household consumption would take 10 trips per day to collect. Clearly this cannot be deemed adequate access to potable water.

Applying this average household water consumption to developments where individual connections to each erf have been provided, an economic rather than quantitative inequity emerges, based on the inability of poorer communities to pay for the water. In 1998, the WHO's consumption recommendations and the World Bank's support for a subsidised 'lifeline' water supply together with 'increasing-block tariffs' (World Bank, 1994),

served as a foundation for the introduction of a 'lifeline' subsidised water supply on a national basis, announced as part of the National Water Pricing Policy. The effect of this policy was that households would be provided with the first 6 kilolitres free of charge and thereafter charges for water would be levied on an increasing 'block' basis.

Bond (2002) believes that even the implementation of this policy does not address the inequity issue. The Ethekwini Municipality provides the first 6 kilolitres of water per month free of charge, on a household basis, but also levies a fixed monthly charge, regardless of consumption, for consumers with a full pressure supply. The fixed monthly charge for full pressure systems is exempted on a property value basis for the first six kilolitres of consumption, effectively excluding low income housing from this cost, even where full pressure systems exist. A summary of consumption charges in the EMA area is shown in Table 3.

**Table 3: Water Consumption Charges: EMA: April 2004**

	Roof tank (Semi-pressure system)		Full Pressure System	
	Cost per kilolitre			
	<i>Water</i>	<i>Fixed</i>	<i>Water</i>	<i>Fixed</i>
Up to 6 kl	Nil	Nil	Nil	Nil
From 6 kl to 30 kl	R 3.34	Nil	R 5.02	R 27.41
More than 30 kl	R 10.04	Nil	R 10.04	R 39.22

(Ethekwini Municipality, 2004)

Based on the household of five people, established earlier, the consumption costs for the 50 litres per day would be R 5.01 per month for those with roof tanks and R 34.94 per month with full pressure connections. This apparent inequity where the water necessary for basic health and hygiene costs

almost 7 times more in one area than another, is countered by the ability of residents of properties worth less than R 30 000 (thirty thousand Rand) to apply for a rebate in respect the fixed charges. It should be noted that not all low income housing areas are served with semi-pressure reticulation (roof tanks), many have full pressure systems. Thus in the EMA area, apart from isolated instances of potential price inequity, where individual water connections exist, the 'lifeline' policy appears to have addressed this issue.

#### **2.4.2 Sanitation**

'There is no away' is a term cited by environmentalists, used to explain that in the environmental conservation context, moving waste or pollution from one area or country to another does not solve the problem, it simply relocates it. Thus, practices such as the 'exporting' of toxic waste to poorer African states, by developed countries, does not solve the problem of disposing of the waste.

Used in the context of waterborne sanitation, the piping of waste from buildings to a collective treatment facility, does not solve the problem of disposing of the waste, it simply relocates it. The result of the conventional treatment of sewer waste is a precipitant, referred to as 'sludge', a material of sand or mud consistency that has to be disposed of.

Treatment and disposal of sewer waste is complicated by the combining, in the drainage network, of household waste with industrial effluent containing toxins and chemicals. Lovins and Link (2001, pp.220-221.) maintain that this 'common sewer' system of drainage complicates an otherwise sustainable process, "Since Thomas Crapper invented the water closet, many sanitation experts have come to view it as one of the stupidest technologies of all time: In an effort to make them 'invisible' it mixes pathogen-bearing faeces with industrial toxins in the sewer system, thus turning 'an excellent fertiliser and soil conditioner' into a serious, far reaching and dispersed problem".

The South African context, given the use of combined sewers, is typical of the global problem. Murphy (2000) notes that South Africa has many sewerage treatment works that produce effluents not suitable for discharge to rivers, and faces major problems regarding the disposal of these effluents in an environmentally sustainable manner. In studying a local sewerage treatment works, Chetty (2002, p.1.) confirms the existence of the problem in the EMA, "biosolids treatment traditionally followed the process of sedimentation, thickening, dewatering, thickening, drying and incineration or disposal to land. However this approach is proving to be unsustainable due to land availability, bio-accumulative impact of heavy metals, toxins in the sludge and the secondary effects of odours and incinerator emissions".

Disposal of sludge to landfills is not a sustainable solution. South African landfills are already under pressure from other sources of solid waste, "At the current rate of disposal, it is predicted that over the next five years the generation of waste will exceed landfill capacity in five of the nine provinces, by up to 67%" (South African Yearbook, 2004). Incineration has been adopted as a partial solution in the EMA, but this process has associated air emission and resultant environmental health problems.

Pumping of waste or sludge into the ocean is a disposal method used by many coastal areas. Currently, in South Africa alone, 800 million litres of effluent is pumped into the ocean each day via 63 government licensed outlet points. Early pipelines discharged into the surf zone or onto the shore but the current trend is to extend the discharge point beyond the surf zone (South African Yearbook, 2004).

In the EMA, two methods of waste disposal are employed. Waste from coastal areas south of Umhlanga Rocks is pumped into the ocean via two deep sea outlets (Teurlings *et al.*, 1997). These outlets originally discharged into the surf zone but were extended to become deep sea outfalls in 1968/69 as a result of environmental assessments (Bailey, 2000). Pipeline outlets now discharge into the fast flowing Agulhas current, which disperses the

effluent rapidly. The environmental effects of this ocean disposal of waste is monitored by constant testing, undertaken by the CSIR, in respect of water quality. Hindson *et al.* (1996, p.21.) summarises the effects of this method of disposal, "Waste water discharge into the fast moving Agulhas current offers an option for marine disposal, although the loss of water from the natural systems impacts on water flow in riverine systems and effects the estuarine mouth dynamics and hence the ecology of the coastal systems. There is considerable sensitivity and public opposition to this form of discharge".

Waste from the remaining areas in the EMA is treated in the conventional way, with the sludge being placed in landfills or incinerated.

The sustainability of waterborne drainage is also dependant on the sustainability of an adequate water supply, given that the drainage system requires water for its operation.

#### **2.4.3 Electricity**

In a manner similar to that of sanitation, the sustainability of electricity supply relies on the sustainability of water sources. "Energy production relies heavily on water.....Fossil fuel, nuclear and geothermal plants require enormous amounts of cooling water." (Hunt, 2004, p.47.). Hydroelectric power generation is less wasteful, using water only via evaporation from the reservoir.

South Africa generally relies on fossil fuel generating plants for energy production. Bond (2002, p.37.) believes that the relative abundance of coal as a natural resource formed the basis for high levels of local energy consumption with the associated pollution, "The strength of the coal mining industry fostered a reliance on electricity, with per capita consumption in South Africa as high as it is in England despite the fact that until recently only a quarter of South Africans have had access to domestic sources. Most

strikingly, emissions of greenhouse gases are twice as high per capita as the rest of the world”.

South Africa's most serious environmental problems are associated with its patterns of energy use and are therefore “inherently unsustainable” (The Environmental Monitoring Group, 1992). A large part of this environmental problem is due to a failure on the part of Eskom, South Africa's parastatal responsible for energy production, to fit flue-gas scrubbers to power stations. These flue gases combine with moisture in the air and fall to earth in the form of acid rain (Bond, 2002; The Environmental Monitoring Group, 1992).

Eskom has looked to nuclear production as an alternative, cleaner source of energy production. This has met with resistance on environmental and safety grounds as well as the high cost of energy production. Earthlife Africa (2001) maintains that electricity generated from nuclear power in other countries costs up to 25% more than that generated from conventional fuels. In general, countries are not increasing nuclear power generating capacity, with demand for this form of energy growing just 0.7% annually for the past decade (Earthlife Africa, 2001).

As in the case of water, in the South African context, the social issue of environmental injustice in relation to the cost of and accessibility to an acceptable electricity supply has been the more emotive, ‘grassroots’ issue.

The lack of access is evidenced by the fact that, in 2001, only 47% of KwaZulu Natal residents used electricity for heating, 48% for cooking and 61% for lighting (South African Census, 2001).

To address the affordability issue, the Ethekewini municipality have introduced a lifeline system for electricity, similar to that used for water. Subject to certain conditions, residents using less than 130 kwh per month are provided with the first 50 kwh free of charge (Ethekewini Municipality, 2004). Whilst the lifeline policy represents an attempt to address the social inequity issue, it is

highly unlikely that a household of 5 people would be able to satisfy even basic household needs using only 1.6 kWh per day (based on a 30 day month). The household demand for electricity is more fully in chapter 6. Thus the quantitative aspect of the lifeline policy leaves the inequity issue unresolved.

#### **2.4.4 Summary**

Serious and far-reaching environmental consequences, reflecting similar problems on a global scale, indicate a lack of sustainability in respect of the provision of piped water supply, waterborne sewer and electricity connections even at a domestic level. Social injustice remains a critical issue in the EMA, particularly in the context of electricity supply.

Of the problems highlighted, the impending water resource crisis is of a critical nature particularly in South Africa, a country not blessed with abundant natural water supply systems.

## **CHAPTER 3      RESEARCHING AUTONOMOUS HOUSING**

### **3.1      Introduction**

This chapter will explain the concept of autonomous housing, provide a background to the autonomous housing movement and propose an appropriate method for its research.

### **3.2      Autonomous Housing: Towards an Understanding**

To describe a form of housing that is self reliant in respect of service connections, the terms 'autonomous' or 'independent' housing have been adopted. Most commonly applied to self reliance in respect of energy, the term describes houses that are 'off the grid' in that they do not, by choice, have municipal connections for water and electricity supply or sewer drainage.

Pike (1974, p.1.), who originally proposed the autonomous house concept, offered an early definition in describing the first research project, "The main object of this research is to devise a servicing system for houses which reduces dependence on limited localised consumables". A more formal definition was offered by Vale and Vale (1975, p.7.), "The autonomous house on its site is defined as a house operating independently of any inputs except those of its immediate environment. The house is not linked to the mains services of gas, water, electricity or drainage, but instead uses the income-energy sources of the sun, wind and rain to service itself and process its own wastes".

These definitions, although providing clarity of concept, are not always strictly applied. As early as 1974, Pike emphasised the difference between 'autonomous' and 'low-impact' housing in stating, "some confusion appears to have arisen in the use of the term *autonomous house*, which is now used, incorrectly, to describe a range of projects which seek to some degree, to

exploit the use of ambient energy and recycling methods for providing services supplementary to the conventional systems” (p.8.).

Nevertheless, the term has become common parlance for houses that have minimal, but not necessarily zero, energy and other resource demands (White, 1992). Avoiding this debate, Potts (1993) described this form of housing as *independent* housing, preferring to define the process in terms of human experience. By describing the change from dependent to independent housing as “moving towards a home place where we can all enjoy the best of modern life without taking our comfort at the price of another’s misery”, Potts (1999, p.XVII.) raises the two most salient aspects of autonomous housing.

Firstly, the notion is founded in sustainable development, discussed in detail in chapter 2, seeking to conserve today’s natural resources for future generations. This implies the use of renewable natural resources and systems to lessen the ecological footprint of the individual on the planet. While seeking sustainability, it also addresses the critical issue of environmental justice.

Secondly, achieving ‘the best of modern life’ is an objective. This distinguishes the autonomous house objective from a ‘back to the cave’ extremist movement, incorporating an understanding that standards of living must be maintained without extreme hardship or adjustment. To some, the level of lifestyle adjustment necessary between the normal urban housing format and an autonomous house is a measure of the success of the latter. Weaver (1999, p.XX.), in explaining the success of his ‘earthship’ house notes, “Moving back and forth between an on-the-grid and an off-the-grid house, you have to make an adjustment. It’s not all that hard”.

The notion of lifestyle adjustment raises another issue critical to the understanding of autonomous housing. The implementation of autonomous housing is not simply an application of advanced technology allowing the

use of natural resources and systems. Potts (1999, p.2.) explains of those who have made the transition, "They report that their efforts at integrating the best and most modern technology with ageless wisdom about the world is, together with parenting, the most rewarding work they have ever done". Thus the development of an autonomous house incorporates an implementation and integration of technology and natural systems to achieve an acceptable lifestyle minimising lifestyle adaption.

The concept of autonomous housing, by extension of the self reliance objective, incorporates a minimalist approach to the use of natural resources such as water and energy. This, in turn, introduces a design element into the process where the house structure is designed, located and constructed in a way to reduce resource requirements. Extending this design element into a more holistic approach has paved the way for 'Ecohousing', a design driven housing methodology that considers self reliance as well as the wider environmental effects of materials and components used in the construction process (Roaf *et al.*, 2001).

Definitions aside, the common understanding that may exist in respect of what autonomous housing means, is not reflected in a methodology of how this should be achieved. What has been achieved is the result of 'trial and error' by individuals or projects, each adopting a specific solution or approach. This process of incremental learning is described by Potts (1999, p.XVI.), "Pioneers might remember their hardships but sometimes neglect to tell us the full extent of the unknown territory they traversed, often with great difficulty, before settling themselves in a home".

### **3.3 The Autonomous Housing Movement**

The autonomous house movement began in the early 1970s. Alexander Pike's original research project, the Cambridge Autonomous House, began in 1971, resulting in a prototype house completed in 1974 (Vale and Vale, 2000). This work corresponded with an international increase of awareness

in respect of environmental issues and problems. Roddick (2001, p.166.) believes that the activities of environmental watchdog organization *Greenpeace* reflects this awakening, "It can mobilise the support of well over 2.5 million supporters in 140 different countries to focus on environmental issues in a way that is most meaningful to each locality. Since the early 1970s, those issues have included climate protection, nuclear testing, and GMOs".

Others believe that the trend towards seeking alternative or renewable forms of resources was based on more pragmatic motivation. "The shift towards green design began in the 1970s and was a pragmatic response to higher oil prices. It was then that the first of the oil shocks, in 1973, sent fossil fuel prices sky high and the 'futurologists' began to look at the life history of fossil fuels on the planet and make claims about how much oil and gas were left" (Roaf *et al.*, 2001, p1.).

Whatever the reason, the autonomous housing movement progressed via experimental or research projects and the experiential learning of individuals who decided to go back to the land. Whilst these early pioneers sought the ideal of self reliance, much of what has been achieved relates to the use of alternate energy supplies, reflecting the origins of the movement.

### **3.4 The South African Context**

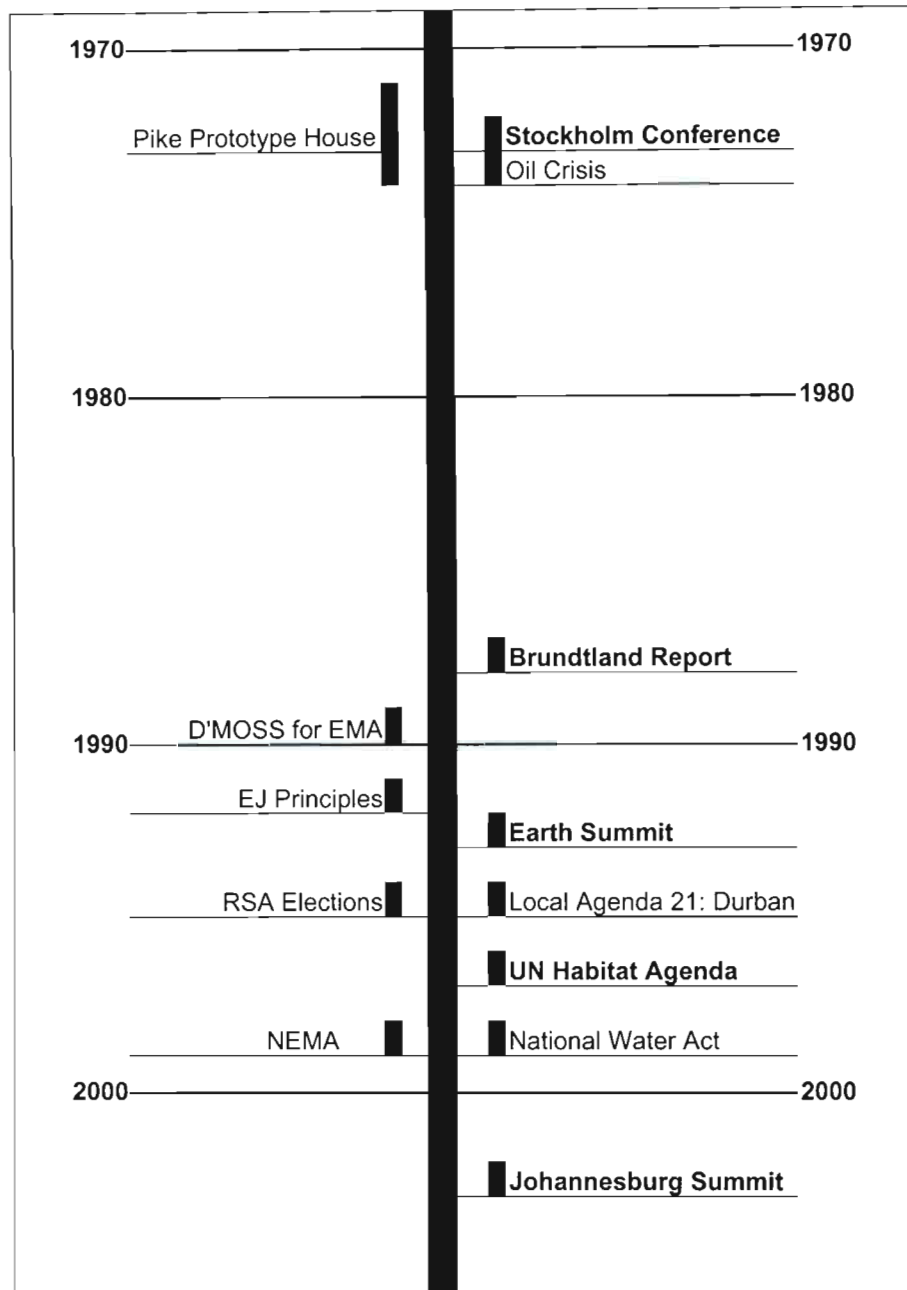
Perhaps due to a national preoccupation with resolving the political problems of the apartheid era, South Africa's 'green awakening' lagged that of the rest of the world. An overview of the environmental milestone events in respect of the EMA is shown below.

- The adoption by the Durban Metropolitan Council of D'MOSS (Durban Metropolitan Open Space System), an open space network that was ecologically viable and self-sustaining, in 1989 (Ethekwini Municipality, 2004).

- The publishing of a local agenda 21 for Durban in 1994 (Ethekewini Municipality, 2004).
- The promulgation of the National Environmental Management Act (NEMA) in 1998, calling for “co-operative environmental governance”.
- The promulgation of The National Water Act (NWA) in 1998, replacing the 1956 Water Act. This revised act called for sufficiency and sustainability in the public interest and the facilitation of social and economic development.

Viewing these milestones from a programmatic perspective (Figure 1), together with the international events discussed in Chapter 2, it is evident that much of the South African green awakening took place during the 1990s. Clearly the advent of democratic elections presented opportunities for South Africa to join the international green movement. Perhaps the best example of this focus on environmental issues was the hosting of the world sustainability summit in Johannesburg during 2002.

**Figure 1: Timeline of Environmental Milestones: EMA**



There has been little, if any, effort to develop autonomous housing on a regional or national level in South Africa. What progress has been made is limited to a number of research and demonstration projects concentrating on aspects of sustainability rather than the objective of self reliance from service

connections. These projects are best described as 'low impact' rather than autonomous. In 2002, the South African Department of Housing surveyed all low income housing projects, those completed and still in progress, to identify 'best practices' within the industry. Of the 47 best practices identified, only 5 related to ecological sustainability, reflecting, in the local context, the lack of progress on this front (Department of Housing, 2002).

### **3.5 Research Methodology**

#### **3.5.1 The Body of Knowledge**

Fellows and Liu (1997, p.IX.) propose that, "A discipline or profession is established by developing a body of knowledge which is unique". It follows, therefore, that the scope of the data and information constituting the body of knowledge for a discipline to be researched, must be determined before an effective research methodology can be selected as a foundation to successful research.

Based on the manner in which progress has been achieved in respect of autonomous housing, the body of knowledge for this discipline exists in 4 primary areas.

1. Research or Demonstration Projects
2. Experiential knowledge of individuals
3. Appropriate technologies
4. Natural systems knowledge

#### **3.5.2 Quantitative Versus Qualitative Research**

May (1997) explains that the quantitative analyst seeks to derive categories from data in order to facilitate comparison. This conventional approach to research is referred to by Robson (2002) as *fixed* research, who makes the

point that it requires a substantial amount of pre-specification about what you are going to do and how you are going to do it.

Conversely, "Qualitative approaches seek to gain insights and to understand people's perceptions of 'the world'" (Fellows and Liu, 1997, p.19.). This approach is described by Robson (2002) as flexible research, explaining that much less pre-specification takes place and the design evolves, develops and unfolds as the research proceeds.

Given the aspect of the human experience being one of the success factors for autonomous housing, the research must be both quantitative to establish the actual outputs of systems used and qualitative, to establish the human perspective and 'adjustment' necessary.

### **3.5.3 Research Methods Employed**

The nature and context of the body of knowledge for autonomous housing, to a large degree, determines the appropriate research methods.

Due to the wide geographical spread of actual projects and individuals, personal interviews, questionnaires or physical inspections are deemed not practical, given the limitations of this research exercise. Thus, literature reviews, case studies and physical inspection, where possible, are indicated as the appropriate methods to establish:

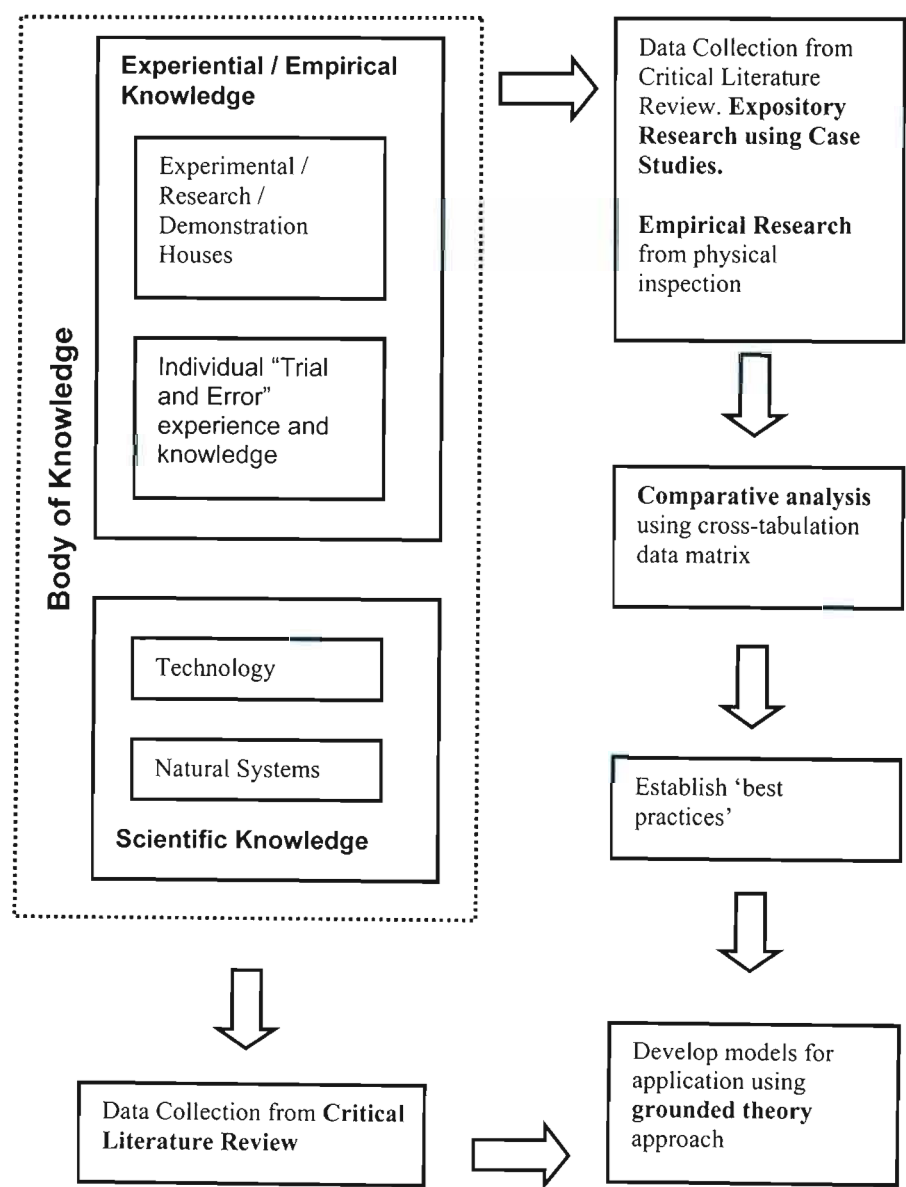
- What has been achieved to date
- What technology is available
- The limitations and workings of natural systems

This data will be analysed by comparative means to establish 'best practices'. Data analysis will be achieved using simple data matrix crosstabulation techniques (Hellevik, 1984).

Using a grounded theory research approach, established best practices are combined with appropriate and natural systems data to establish a model for the implementation of best practices in low income housing development.

This research process is shown graphically in Figure 2.

**Figure 2: Research Process**



For clarity, an overview of the research methods employed is provided.

- **Literature Review**

Melville and Goddard (1996) explain what is meant by the term *literature review*, in noting that the term *literature study* describes the process of finding out about previous work from a range of sources, only some of which are literary. Sources of this information are textbooks, scientific journals, conference proceedings, theses, dissertations, company reports, interviews, magazines and newspapers. Fellows and Liu (1997, p.52.) support this approach, explaining that a literature review is more than a mere rewriting of text, "Literature should not merely be found and reviewed, the body of relevant literature from previous research must be reviewed *critically*. The literature must be considered in the context of theory and other literature – the methodologies, data, analytic techniques, sampling, etc. – so that objective evaluation takes place".

- **Case Study**

Robson (2002) describes a case study as the development of detailed, intensive knowledge about a single 'case', or a small number of 'cases'. The features of a case study are the study of the case in its context and a collection of information via a wide range of data collection techniques including observation, interview and documentary analysis.

- **Grounded Theory Approach**

The aim of grounded theory analysis is described by Robson (2002) as the generation of a theory to explain what is central in the data. It is therefore an inductive research method. A grounded theory is inductively derived from the study of a phenomenon, in that it is

discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon (Strauss and Corbin, 1990). Applied to this research, the body of knowledge will be studied and developed to inductively derive theoretical models as proposals for implementation.

- **Cross-tabulation Comparative Analysis**

Data reflecting values in respect of units and variables can be presented as a data matrix. This matrix, in its simplest form, can then be used to compare results, constituting a form of analysis (Hellevik, 1984).

### **3.6 Summary**

The notion of autonomous housing has existed since the early 1970s. The self reliance objective has been shared by low-impact and eco-housing. Global progress in achieving autonomous housing has, to a large extent excluded South Africa.

Appropriate research methods have been determined by the form and location of the 'body of knowledge', having the objective of deriving a theoretical model for implementation in low income housing in the EMA. Specific models for domestic water supply, sanitation and energy supply are developed in Chapters 4, 5 and 6 respectively.

## **CHAPTER 4**      **AUTONOMOUS DOMESTIC WATER** **SUPPLY**

### **4.1 Introduction**

In this chapter, the practicability and feasibility of an autonomous water supply in the EMA is investigated. The technical feasibility of rainwater harvesting and wastewater reuse is determined and case studies evaluated. Ultimately a theoretical model for an autonomous water supply system capable of implementation in the EMA is sought.

### **4.2 Meeting the Demand for Domestic Water**

Roaf *et al.* (2001) make the point that meeting the demand for domestic water can be achieved by increasing the capacity of supply, known as *supply side management*, or by reducing the consumption of water, known as *demand side management*. An autonomous water source is limited by natural factors and therefore the opportunity for supply side management is extremely limited. The effect of this is that the demand side management of water, constituting water saving techniques and grey water re-use (discussed later on the chapter), is an integral part of an autonomous water system. Roaf *et al.* (2001, p.217.) explain that domestic water conservation does not imply a change in life-style, "A number of water conservation measures can be used in the home with little impact on the everyday lives of householders".

### **4.3 Natural Water Sources**

The sources of natural water supply for domestic use are:

- Rainwater harvesting
- Groundwater harvesting
- Freshwater system of rivers, streams, lakes, etc.

The use of the natural freshwater system such as rivers and lakes is location dependent and while it may be feasible for country lodges and farmhouses, housing development projects are rarely located beside a river or stream and therefore are not deemed a viable supply system for the purpose of this study.

#### **4.4 Rainwater Harvesting**

The process of collecting and storing of rainwater for human consumption or use is usually referred to as *rainwater harvesting*. It is a system that has been used for centuries, and continues to be used, on a global basis. "In earlier phases of human civilisation, major rivers were certainly exploited, but there was also a complementary and more extensive pattern of settlement in areas where rivers were few, and where the direct collection of rainfall was one of the few methods available for securing a water supply" (Pacey and Cullis, 1986, p.1.). It is believed that in the Negev Desert, in southern Israel, rainwater collection provided a water supply source for a considerable population from more than 2000 years ago until about 700 A.D. (Pacey and Cullis, 1986).

The practice of rainwater harvesting continues today in virtually all corners of the globe (Hunt, 2004). In the Caribbean islands, more than half a million people are still partially dependent on such supplies and large areas of Honduras, Brazil and Paraguay use rainwater harvesting as a source of domestic water supply in urban areas (United Nations Environmental Programme, 1998).

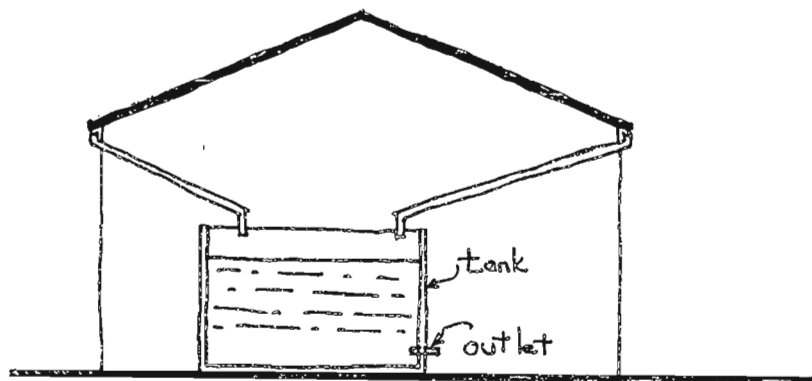
##### **4.4.1 Basic System Configuration**

In the domestic context, the basic water harvesting system configuration comprises the use of the roof of the structure as the catchment area for rain, which is collected via rainwater eaves gutters and piped to a storage tank or

cistern. Water is then drawn for use via a tap or valve or piped into the structure. The cistern or tank must be designed with due consideration to local rainfall levels, water demand and usage, water quality, area and condition of catchment surface and availability of materials. Pacey and Cullis, (1986) believe that the design and construction of storage tanks is technically the most interesting and difficult aspect of rainwater collection. Underground tanks are also used but this necessitates pumping of the water.

Materials commonly used for tank or cistern construction are plastic, mild steel (corrugated and flat sheeting), concrete, bricks and mortar, fibre cement and ferroconcrete. A typical domestic configuration is shown in Figure 3.

**Figure 3: Typical Domestic Configuration for Rainwater Harvesting**



#### **4.4.2 Water Quality**

Clearly, where harvested rainwater is used as a source of potable water, the issue of water quality becomes a health issue and therefore of critical importance. Despite its widespread use, Pacey and Cullis (1986, p.65.) note that "Controversy sometimes arises as to whether rainwater tanks should be advocated for drinking water supply if freedom from contamination cannot be guaranteed". Roaf *et al.* (2001, p.220.) comment on the purity of rainwater, "Waste water can include stormwater (rainfall) runoff. Although many people

assume that stormwater runoff is clean, it isn't. Contaminants such as hydrocarbons wash off urban surfaces such as roadways, parking lots and rooftops and can harm our rivers, lakes and marine waters". Pacey and Cullis (1986, p.63.) concur that "it should not be assumed that water from roofs is totally free of contamination". Birds, leaves and wind blown dirt all contribute to the pollution of harvested rainwater. This is aggravated when rain is harvested after a long dry period.

Vale and Vale (2000) believe that the issue of water quality harvested from roofs should be seen in a geographical context. While they acknowledge that "The use of unfiltered water collected directly from roofs might be expected to give rise to health problems" (p.119.), interviews with community health officials in Auckland, New Zealand, where the practice of drinking unfiltered rainwater is widespread, indicate that "no specific data had been collected, but very few cases of disease could be attributed to roof collected water, although it might be suspected in some cases". It is suggested that some form of water filtration might be considered necessary in countries like the United Kingdom, because of the greater population density and the risk that rainwater may be contaminated by atmospheric pollution.

Research undertaken by Uba and Aghogho (2000) in Nigeria indicated that the physico-chemical qualities of rainwater collected directly from the atmosphere were within the limits approved by the World Health Organisation but rainwater from roof catchments contained pathogenic bacteria, concluding that the quality of this water should not be taken for granted. Appropriate treatment measures were recommended before this water could be deemed potable.

In a local context, Alcock (1985) reported that water tested from rainwater systems (rainwater tanks) in Vulindela (a rural area in the Pietermaritzburg district) yielded an acceptable quality of water from a bacteriological perspective. Rainwater harvested from roofs revealed an E.coli F count of 2 per 100 ml compared to counts of 376 and 8 956 for dams and rivers

respectively. Even this relatively minor pathogenic contamination does not meet the requirements of SABS 241, the 'Specification for Water for Domestic Supplies', which requires a zero count. Alcock (1985) believes that in the context of rainwater harvesting, the SABS 241 standard cannot be regarded as absolute.

#### **4.4.3 Ensuring Water Quality**

Rainwater harvested from roofs can become polluted via three distinct sources.

- Dirt, leaves, bird droppings and other natural matter that is blown or dropped onto roof surfaces.
- Particles of roofing material.
- Absorption of air pollution by the water during precipitation, form so-called 'acid rain'.

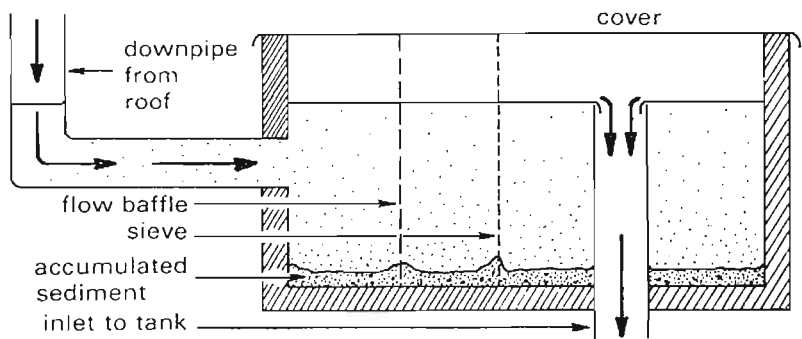
Some basic precautions can be taken to reduce the level of pollutants in harvested water. These include:

- Periodic cleaning of roof covering, gutters and tank.
- The use of galvanised mild steel roof sheeting in preference to aluminium, fibre cement or thatch (Uba and Aghogho, 2000).
- The use of coarse screening between guttering and downpipe and a finer screening or filter at the point where water enters the tank (Pacey and Cullis, 1986).
- In areas prone to malaria, standing water must be avoided and a fine gauze fitted over all openings to tanks as a precaution against mosquitos (Alcock, 1985).

Pacey and Cullis (1986, p.63.) note that precautions taken when collecting rain after dry periods can substantially reduce contamination levels, "When rain falls after a long dry period, water collected from a roof may carry

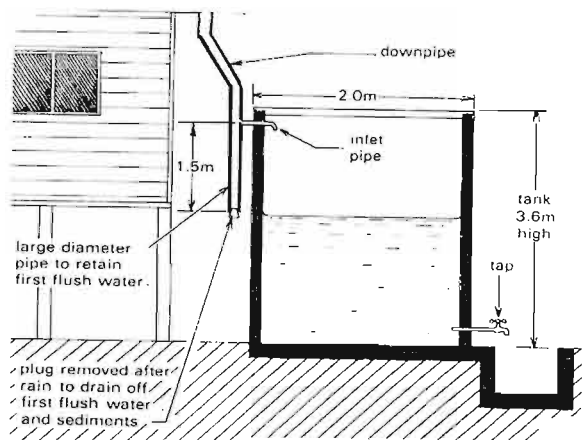
noticeable amounts of debris arising from dust and leaves which may have accumulated on the roofs and in gutters. Many authorities therefore recommend that water running off the roof during the first 10-20 minutes of a storm should be discarded, and many devices have been suggested for diverting this initial 'foul flush' away from the storage tanks". The United Nations Environmental Programme (1983) suggest that a baffle tank, shown in Figure 4, is installed to retain sediments before the water is drained to the storage tank.

**Figure 4: Baffle Tank to Hold Back Sediments and Debris**



An alternative solution is proposed by Pacey and Cullis (1986), based on a system used in Thailand, shown in Figure 5.

**Figure 5: First Flush Rejection Detail**



Steadman (1975) believes that rainwater, if used for drinking and cooking, should be filtered and treated using a 4-stage process.

- *Stage 1: Screening Process.* In this initial stage, large particles are removed with a series of wire meshes, each with a finer gauge.
- *Stage 2: Sedimentation.* The speed of the water is slowed and the larger suspended particles are allowed to settle. For smaller particles, a coagulate additive (such as aluminum sulphate) may be needed.
- *Stage 3: Filtration.* This is normally done by allowing the water to percolate through beds of sand and gravel, in layers of increasing fineness.
- *Stage 4: Sterilization.* This will ensure 'absolute purity'. Methods of sterilization include chlorination, exposure to ultraviolet light or 'candle' filters made with unglazed earthenware baked from diatomaceous earth and impregnated with silver. Distillation of water also achieves sterilization but the method is energy intensive.

Activated carbon and candle filter manufacturers claim that modern filters will remove the following pathogenic organisms from untreated water.

- Bacteria
  - E.Coli >99.99%
  - Vibrio Cholerae (Cholera) >99.99%
  - Shigella >99.99%
  - Salmonella Typhi (Typhoid) >99.99%
  - Klebsiella Terrigena >99.99%
- Cysts
  - Cryptosporidium >99.99%
  - Giardia >99.99%

(Source : Klomac Engineering, 2004)

Even at these high filtration levels, conformance to SABS 241 cannot be guaranteed, lending credence to Alcock's view that this standard is generally not achievable with harvested rainwater.

On-site sodium hypochlorite generators are now available that manufacture a chlorine based water treatment additive, designed for use at a community level (Envir-o-cell, 2004).

#### **4.4.4 Water Harvesting in the EMA: Storage Tank Capacity**

Based on the average low income household size of 5 people (established in Chapter 2), and the minimum water requirement of 50 litres per person per day recommended by the World Health Organisation, a household need of 7 500 litres per month is calculated, based on a 30 day month.

According to the South African Weather Service, the average rainfall for the EMA is 843 mm per annum based on rainfall figures from 1977 to 2002 inclusive. The same average rainfall is indicated by analysing rainfall for the period 1903 to 2002. In calculating the catchment area necessary to harvest the household demand, a runoff coefficient must be applied to allow for water loss via evaporation, spillage, etc (Pacey and Cullis, 1986; United Nations Environmental Programme (UNEP), 1983; Alcock, 1985). While the UNEP (1983) recommend a coefficient of between 0.8 and 0.9 for tiled roofs and 0.7 to 0.9 for corrugated metal sheeting, Pacey and Cullis (1986) believe that 0.8 is appropriate for most roofs. Alcock (1985) proposes a coefficient of 0.95 for roofs in good condition. Applying a coefficient of 0.8 to allow for disposal of the first foul flush, the catchment (roof) area is calculated as follows:

$$\text{Catchment Area (m}^2\text{)} = \frac{\text{Water Need (l/annum)}}{\text{Runoff Coeff. X Annual Rainfall (mm)}}$$

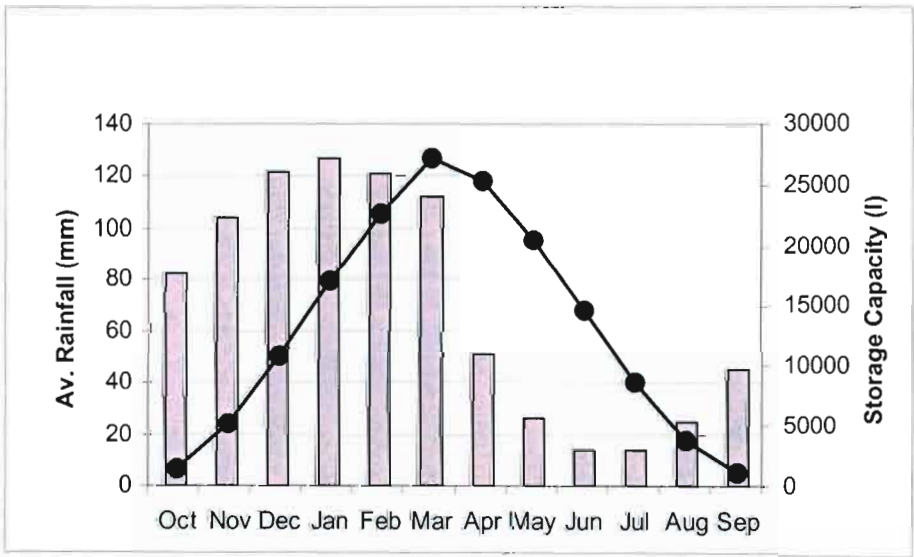
Applying the EMA data,

$$\text{Catchment Area (m}^2\text{)} = \frac{90\,000}{0.8 \times 843}$$

$$\text{Catchment Area (m}^2\text{)} = 133.45 \text{ m}^2$$

Thus a minimum roof catchment area of 133.45 m<sup>2</sup> (measured on plan) would be required to harvest the household water demand of 7 500 litres per month. Assuming that this roof catchment area could be achieved, the monthly capacity requirement of the storage tank, taking into account monthly consumption, would be as shown in Figure 6 below.

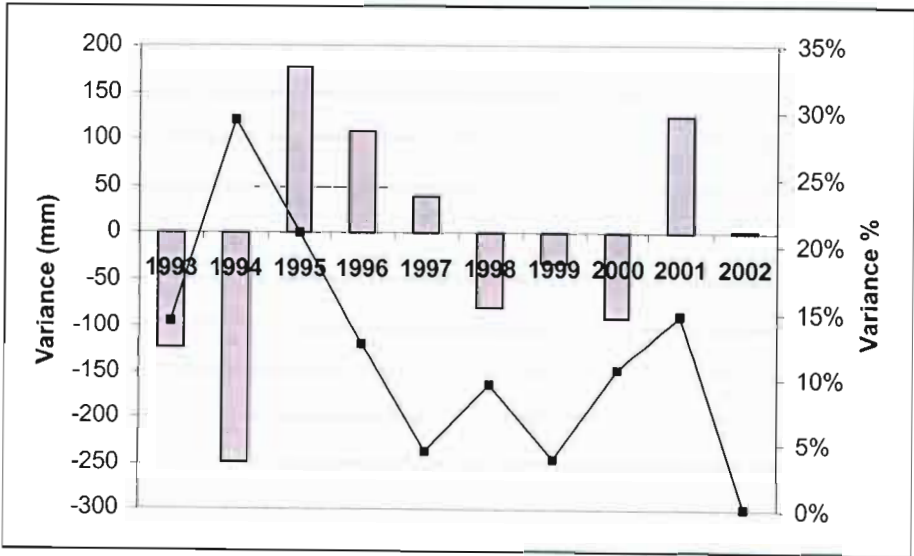
**Figure 6: Required Water Storage Capacity: EMA**



The average monthly rainfall for the region is shown as a bar chart (left hand axis) and the tank capacity requirement necessary to ensure continuous supply as line graph (right hand axis). As indicated in Figure 6, the maximum storage capacity is required in March, when 27 258 litres of rainwater would be in the storage tank. This then represents the minimum capacity of the storage tank if household demand is to be met via rainwater harvesting. Clearly this assessment of tank capacity is based on average rainfall figures starting in October. Variations of rainfall within a specific month as well as a different starting month may alter the result slightly, but would not significantly change the projected tank capacity required.

Since the calculation of storage tank capacity is based on average rainfall levels, a critical aspect of the feasibility of rainwater harvesting will be the extent of deviation of the actual rainfall from the mean. Analysing the actual rainfall for the 10-year period from 1993 to 2002 inclusive, relatively large deviations from the mean are evident, as shown in Figure 7.

**Figure 7: Rainfall Deviation from Mean: EMA: 1993 to 2002**

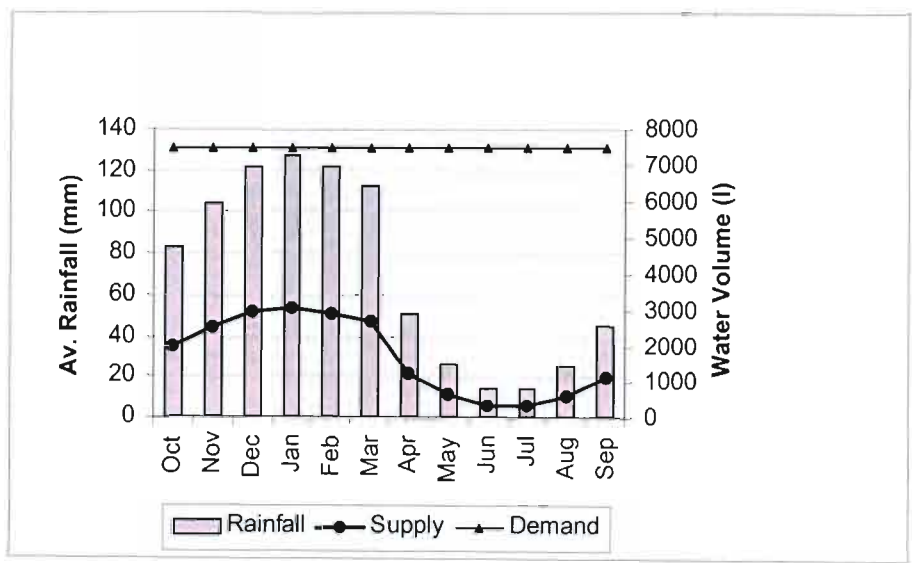


Actual rainfall variance from the mean (in mm) is shown in bar chart format (left hand axis) and percentage variance is shown as a line graph (right hand axis). Variances of up to 29% are indicated.

The effect of this relatively large variation is that the roof catchment area would have to be increased dramatically (to a minimum of 189 m<sup>2</sup>) or water harvesting would need to be supplemented in order for the system to be sustainable in the long term.

In terms of the National Housing Code, the top structures financed by the National Housing Subsidy are subject to a minimum floor area of 30 m<sup>2</sup> (Department of Housing, 2000). Using this as a catchment area for rainwater harvesting, it is clear that insufficient water would be collected to satisfy household demand. In this case, supplementary water supply would have to be made available on an on-going basis. The situation is shown graphically in Figure 8.

**Figure 8: Rainwater Harvesting from a 30 m<sup>2</sup> Roof: EMA**



From Figure 8 it can be seen that insufficient water would be harvested on a continuous basis to satisfy household demand.

#### 4.4.5 Case Studies of Rainwater Harvesting

Case Study No. 1		
	<i>Building</i>	Linacre College
	<i>Location</i>	Oxford, England
	<i>Date</i>	1995

This 'green' building was built as a test for grey water reuse and rainwater harvesting systems.

Lessons learned:

- Chlorine sterilization of water was found to be environmentally undesirable.
- "Rainwater is usually low in organic material and nutrients, and can be stored in water butts in the home. However, it was found that rainwater can collect material from roofs and down pipes and, when allowed to remain undisturbed for long periods, can become septic. A large amount of black sludge had formed in the collection tank and analysis showed that anaerobic conditions had developed. Care must be taken at the design stage to allow for complete cleaning of rainwater storage tanks where necessary".

(Source: Roaf *et al.* (2001, p. 233.))

Case Study No. 2		
	<i>Building</i>	Gledlow Valley Ecohouses
	<i>Location</i>	England
	<i>Date</i>	On-going

In this group of 3 houses, rainwater was harvested off the roof, primarily for drinking water. To avoid the use of chlorine or chemical treatment of water,

an ultraviolet unit was used for sterilization. In times of low water use, water was recycled through the unit to reduce risk of algae growth in the storage tank.

Lessons learned:

- Sterilization using a UV unit was not successful. Sediment build up in the unit prevented effective treatment. This method of sterilization does not have a residual effect and as a result bacteria was able to form in the pipework.

(Source: Roaf *et al.* (2001))

Case Study No. 3		
Building		House Duncan
Location		Waiheke Island, New Zealand

The house has a 25 000 litre storage tank that stores water for all domestic uses without treatment.

(Source: Roaf *et al.* (2001))

Case Study No. 4		
Building		House Johnson
Location		Monmouth, Wales

All domestic water is supplied by rainwater collected and stored in a 8000 litre tank. Water is filtered and passed through a UV sterilizer into a 200 litre holding tank which is plumbed to the house in the normal way.

(Source: Roaf *et al.* (2001))

<b>Case Study No. 5</b>		
	<i>Building</i>	House Vale
	<i>Location</i>	Southwell, Nottinghamshire, England

All domestic water is provided from harvested rainwater. Water is piped from the roof to a set of four interconnected tanks with a combined capacity of 30 000 litres. The interconnecting of tanks was an attempt to avoid water stagnation. All water is pumped through a composite sand filter before use. Drinking water is then filtered through an activated carbon filter.

Lessons learned:

- Prior to construction, the water demand for the 5 person household was estimated at 195 litres per day or 39 litres per person per day. The actual household water usage was found to be 170 litres per day or 34 litres per person per day, 13% less than the estimated consumption. Details of estimated versus actual water consumption are shown in Table 4.

**Table 4: Estimated vs Actual Water Consumption: House Vale**

	<b>Estimated Consumption Lts/head/day</b>	<b>Actual Consumption Lts/head/day</b>
Laundry	6	6
Dishes	2	2
Drinking & Cooking	5	5
Personal Hygiene (washing)	26	5
Personal Hygiene (showers)		16
Total	39	34
Household (5 people)	195	170

Of interest is the fact that both the estimated and actual consumption for a household of five people with modern appliances such as dishwashers and washing machines is significantly lower than the 50 litres per person per day recommended by the WHO.

- As a result of actual consumption being lower than estimated, the storage tanks designed on the basis of estimated consumption were found to be larger than that needed.
- No changes in lifestyle were required other than a consciousness for water conservation. “The lower water consumption in the autonomous house was not achieved by rigorous attempts to make the occupants of the house more water-conscious than usual; there is no sense of deprivation, compared with when the occupants lived in a conventional house with mains water supply.....it is different to, but not worse than a conventional house”.
- After about 6 months of use, the water acquired a sulphurous smell. The problem related to the sand filter lacking in oxygen and minerals. The sand filter was rebuilt using a fountain to aerate the water and the odour was removed.
- “Perhaps the aspect of the water supply that has proved most satisfactory in use is its simplicity and ability to be repaired by the user without any specialized tools or knowledge”.

(Source: Vale and Vale (2000,p.219-221.))

<b>Case Study No. 6</b>		
	<i>Building</i>	Nautilus House
	<i>Location</i>	Taos, New Mexico USA

All the water for domestic use is harvested from roof catchments. Rainwater is collected in a cistern, then pumped and filtered for potable use. Health

officials of the state of New Mexico and Taos County have approved the water treatment system.

(Source: Potts (1999))

<b>Case Study No. 7</b>		
	<i>Building</i>	House Anderson
	<i>Location</i>	Taos, New Mexico USA

Rainwater and snow-water are collected on the roof and flow to a catchment inside the “ship”. The water system consists of a simple arrangement of filters and an electrically powered pump. Drinking water is pumped from a 25 000 litre storage tank, through an activated carbon filter, into a pressurised tank.

The system provides adequate water to run modern appliances such as a washing machine. Combination ceramic and activated carbon filters remove bacteria, cysts and viruses without chemical additives or multiple pass through.

(Source: Potts (1999))

<b>Case Study No. 8</b>		
	<i>Building</i>	House Young
	<i>Location</i>	Haiku, Maui, Hawaii

Water for the house is harvested from the roof and piped into a ferrocement storage cistern. Although rainfall is plentiful, as a result of being dependent on harvested rainwater, conservation is practised naturally.

(Source: Potts (1999))

#### **4.4.6 Case Study Summary**

A summary of the critical lessons learned from the case studies is shown in Table 5.

**Table 5: Summary of Case Study Lessons: Rainwater Harvesting**

<b>Lesson</b>	<b>Case Study Reference</b>
Chlorine sterilization of water is environmentally undesirable	C/Study No. 1 C/Study No. 2
Stagnation of harvested water must be avoided to retain purity	C/Study No. 2
UV Sterilization ineffective	C/Study No. 2
Supply of all domestic water from harvested rainfall without sterilization is feasible	C/Study No. 3 C/Study No. 4 C/Study No. 5 C/Study No. 6 C/Study No. 7 C/Study No. 8
Actual water consumption in autonomous house less than WHO's recommended 50 litres per person per day.	C/Study No. 5
No lifestyle change necessary for use of harvested rainfall.	C/Study No. 5 C/Study No. 7 C/Study No. 8

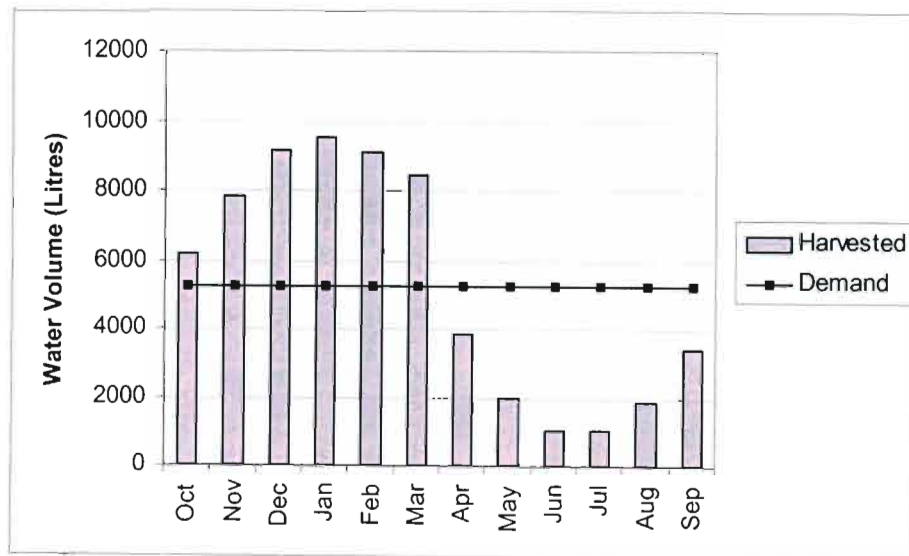
#### 4.4.7 Model for Rainwater Harvesting in the EMA

##### 4.4.7.1 Domestic Water Use and Tank Capacity

Based on the research, a model for the harvesting of rainfall for domestic water needs for a household comprising 5 people is proposed. Household water consumption is estimated to be 35 litres per person per day, based on the House Vale experience. This equates to a monthly household consumption of 5 250 litres. Applying the runoff coefficient of 0.8, a minimum roof catchment area of 94 m<sup>2</sup> is required to harvest sufficient water to meet the household demand.

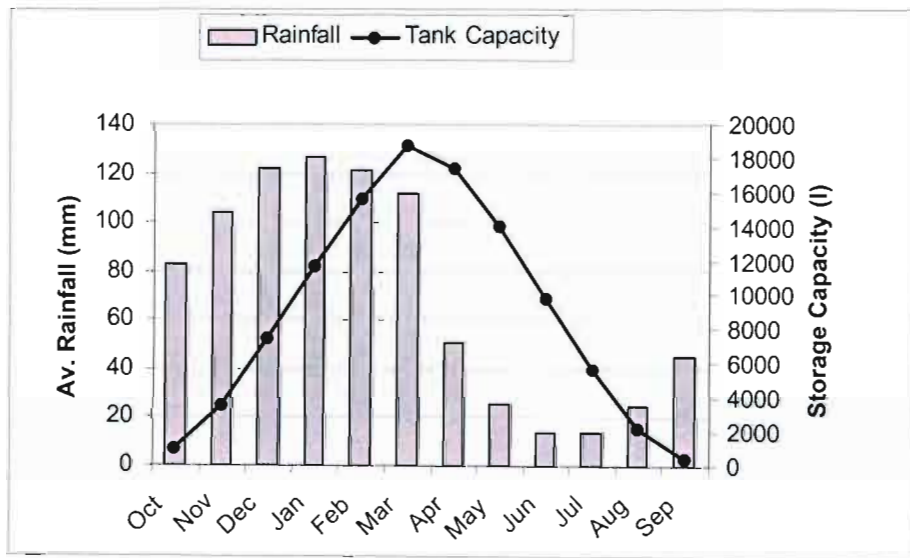
Based on the average rainfall for the EMA, a monthly comparison of the household water demand compared to the water harvested is shown graphically in Figure 9.

**Figure 9: Comparison of Household Water Demand and Harvested Rainfall: EMA**



Harvested rainfall during the 'wet' months of October to March exceed demand and this water must be stored to make up the shortfall for the 'dry' months, April to September. Clearly, therefore, the capacity of the storage tank will be critical if water is to be available throughout the year. The minimum tank capacity required, on a monthly basis, is shown in Figure 10, indicating that a tank of 18 813 litres would be required.

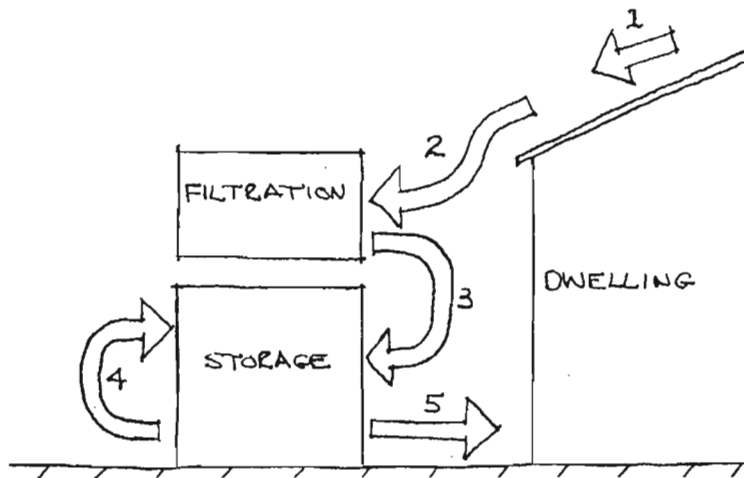
**Figure 10: Proposed Storage Tank Capacity**



#### 4.4.7.2 General Configuration

Incorporating the research and the case study lessons, the basic configuration proposed for rainwater harvesting in the EMA is depicted schematically in Figure 11.

**Figure 11: Proposed Configuration for EMA**

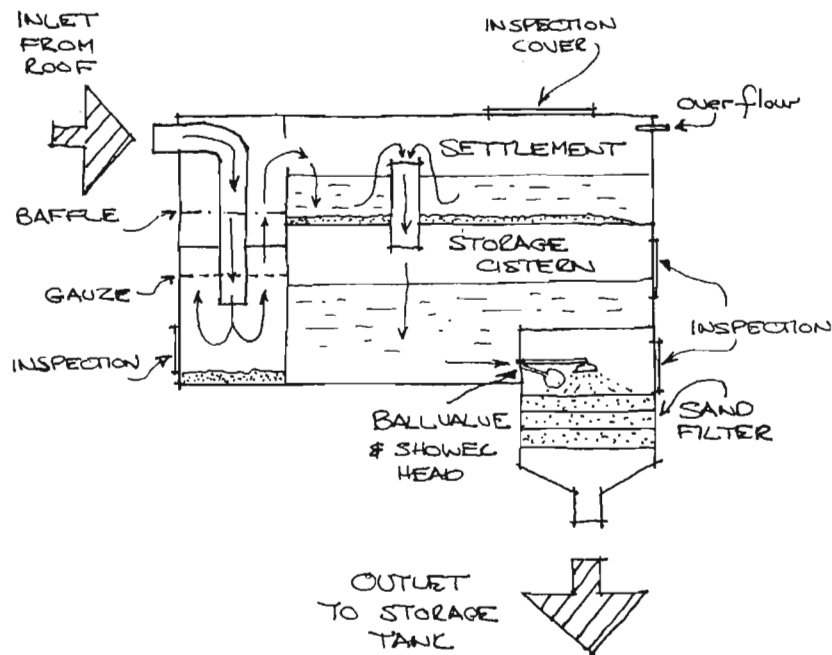


A five-stage process is shown. The roof runoff (shown as stage 1) is directed towards a separate filtration unit (shown as stage 2), thereafter to storage tanks or cistern (shown as stage 3). The filtered water in the storage tank is circulated to avoid stagnation (shown as stage 4) and finally piped into the dwelling for use (shown as stage 5). Adopting this approach, all domestic water would be of equal quality regardless of use.

#### *4.4.7.3 Proposed Filtration details*

Considering the case studies and adopting the water treatment process proposed by Steadman (1975), without sterilization, a combined filtration unit is proposed, shown diagrammatically in Figure 12.

**Figure 12: Proposed Rainwater Filtration Unit**



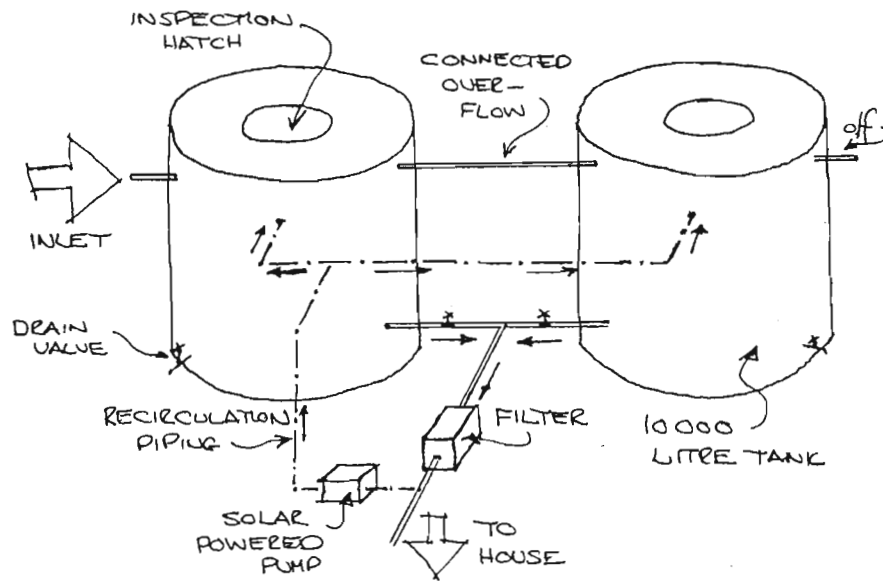
The unit incorporates an initial 'coarse' filtration to remove leaves, etc. followed by a settlement process to remove smaller particles. Finally, water is percolated through 3 removable sand filter trays each containing progressively finer filter medium (pebbles, gravel and fine sand) and separated by a layer of geo-fabric material.

Aeration of water is assisted by the dispersal of water via a shower rose into the sand filter chamber.

#### 4.4.7.4 Storage Tanks Details

Two 10 000 litre tanks are proposed to allow maintenance without disruption of the water supply. The tanks, as shown in Figure 13, would be interconnected and fitted with re-circulation piping powered by a solar pump to prevent stagnation.

**Figure 13: Proposed Water Storage Tank Details**



Water would be continuously filtered, both in the re-circulation flow and before being piped to the dwelling for use. This filter could be a basic fine sand filter, for low cost use, or a candle filter where water sterilisation is deemed necessary (noting that the cost of filter cartridge replacements is relatively high).

#### **4.5 Sub-Surface Water Harvesting**

Steadman (1975) notes that there are a number of cheap and simple methods of drilling wells to harvest sub-surface water. These wells can be drawn using wind energy via multi-vane windmills.

Despite this apparently cheap and plentiful source of water, environmentalists maintain that the harvesting of sub-surface water, sometimes referred to as groundwater mining, is both unsustainable and ecologically damaging. "More than three-quarters of underground water is non-renewable, meaning that it has a replenishment rate of centuries or more" (Hunt citing Jackson *et al.*, 2004, p.56). The pumping of groundwater causes depressions in the water table around the pump site resulting in

deeper wells, a reduction in water quality and ecological consequences for plant life (Hunt, 2004).

Examples of the effect of over harvesting sub-surface water are:

- The water table in Beijing has been dropping by roughly 2 meters per year and one-third of the wells have dried up (Hinrichson *et al.*, 1997).
- In India, the pumping of sub-surface water is estimated to be double the rate of aquifer recharge from rainfall and as result the country's grain harvest could be reduced by up to one-quarter (Hunt, 2004).

Clearly, harvesting of sub-surface water does not represent a sustainable source of water for an autonomous domestic water supply.

#### **4.6 Water Conservation**

As already stated, water conservation, or the prudent use of water is an integral part of maintaining an autonomous water supply. Measures that can be implemented at a domestic level, with little or no lifestyle impact include flow restrictors such as low-flow showerheads, dual flush toilet cisterns, composting toilets and leak detectors (Roaf *et al.*, 2001).

##### **4.6.1 Grey Water Systems**

The reuse of grey water, sometimes described as a grey water system, is a widely used demand side management technique, where used water, in lieu of fresh water, is used for particular functions. Steadman (1975) notes that this recycling of water through the home may be either with or without immediate treatment. The most popular uses for water emanating from grey water systems is toilet flushing and watering of gardens.

Generally, grey water is that which has been used for activities such as showers, bathing, washing and laundry whereas black water is contaminated

with sewerage (Roaf *et al.*, 2001; Steadman, 1975; Talbott, 1993). Potts (1999) describes grey water in simpler terms as all waste water except from the toilet.

At a more technical level, Roaf *et al.* (2001) explain that grey water contains only one-tenth of the nitrogen of black water, and as a result grey water requires less treatment to purify. In addition, grey water decomposes much faster than black water. "The amount of oxygen required for the decomposition of the organic content of grey water during the first 5 days (Biological Oxygen Demand over 5 days or BOD<sub>5</sub>) constitutes 90% of the total or Ultimate Oxygen Demand (UOD) required for complete decomposition. BOD<sub>5</sub> for black water is only 40% of the oxygen required" (Roaf *et al.*, 2001, p.221.). This faster rate of stabilisation for grey water allows its on-site treatment in a domestic context.

#### **4.6.2 Grey Water Treatment**

Treatment methods for grey water, where treatment is used, include:

- The addition of diluted sulphuric acid, which coagulates detergent and soap particles, causing them to form a scum, which can be removed (Steadman, 1995).
- Filtering through a soil or reed bed (Roaf *et al.*, 2001).
- Passing through a marsh and aerated lagoon, sometimes self-contained within a greenhouse (Talbott, 1993)

Naturally the use of untreated grey water is limited to watering plants that are tolerant to the pollutants and carries a high risk of ground water contamination (Roaf *et al.*, 2001).

#### 4.6.3 Case Studies

Actual implementation of grey water systems vary only in respect of whether the water is treated and the method of treatment. A summary of case studies identified is shown in Table 6.

**Table 6: Grey Water Systems: Case Studies**

<b>Case Study Name and Source</b>	<b>Treated (Yes/No)</b>	<b>Treatment Method</b>	<b>Grey Water Use</b>
House Stoumen, California (Potts, 1999)	No		Garden
House Edward, California (Potts, 1999)	No		Selected crops and garden
Nautilus, New Mexico (Potts, 1999)	Yes	Ground filtration through planter	Irrigation and flushing toilets
House Anderson, New Mexico (Potts, 1999)	Yes	Ground filtration through planter	Plants
BedZed, London (Dunster, 2003)	No		Garden
Linacre College, London (Roaf <i>et al.</i> , 2001)	Yes	Filtered through sand and then membrane	Garden and flushing toilets
Gledlow Valley Ecohouses, England (Roaf <i>et al.</i> , 2001)	Yes	Reed bed	Irrigation
House Vale, England (Vale and Vale, 2000)	No		Soakaway

Roaf *et al.* (2001) notes that a high level of contaminants can be present in grey water and therefore treatment systems need careful design and maintenance.

#### **4.7 Summary**

Rainwater harvesting is a relatively simple method of achieving an autonomous domestic water supply, although careful attention must be paid to water quality. An autonomous water supply must be supported by water conservation to reduce water demand. Reuse of grey water for high water use functions, such as watering gardens and flushing toilets, contributes to water conservation. The disposal of waste water will be discussed in chapter 5.

## **CHAPTER 5      AUTONOMOUS DOMESTIC SANITATION**

### **5.1      Introduction**

This chapter explores the on-site treatment of sewerage and the dispersal of waste water in a domestic context. The relationship between the technological possibilities, natural systems and what is practical is established, with a view to establishing an appropriate model for the EMA.

### **5.2      On-site Sanitation Systems**

The on-site treatment of sewerage and disposal of waste water is not a new concept and is practiced widely throughout the EMA. The systems employed range from VIP's (ventilated improved pit latrines) used in low income housing areas such as Inanda and Pinetown South to septic tanks used in up-market areas such as Kloof and Hillcrest.

Examples of on-site sanitation systems in use today are:

- Septic tanks
- Composting toilets
- Pit latrines
- Aqua-privies
- Oxidation ponds
- Solar Aquacells

(Hunt, 2004; Watt, 1984)

### **5.3      Waste Disposal and Sustainability**

The fundamental principle of sustainability, that the inputs to a receiving system cannot exceed the ability of that system to process the inputs on a perpetual basis, applies equally to waste disposal as to any other system (Hunt, 2004). In the case of on-site waste disposal, the digestion of human

waste and the ground dispersal of waste water rely on natural systems which are sensitive to overloading, processing time and interference.

### 5.3.1 Human Waste Digestion

The natural breakdown or decay of human waste, sometimes referred to as oxidation, is consistent with the process for all organic materials (Campbell *et al.*, 2001). This decay can take place under aerobic (with oxygen) or anaerobic (without oxygen) conditions, each a different and distinct process. Aerobic oxidation is a complex set of sequential reactions, carried out by heterotrophic bacteria that use the organic material as a food source (Campbell *et al.*, 2001; Gaudy and Gaudy, 1980). Anaerobic digestion is a two stage process carried out by different groups of bacteria, the first stage producing volatile acids which are in turn used by methanogenic bacteria, in a second stage, to produce gases and water (Watt, 1984; Wright, 1999). Common to both aerobic and anaerobic digestion is the conversion of human waste to largely carbon dioxide, methane and water.

Clearly the rate of digestion would be of vital importance in the implementation of an on-site sanitation system relying on the natural digestion of waste. The two most critical factors influencing the rate of digestion are:

- The 'strength' of the sewerage. "The quantity of organic material present in a water sample is normally expressed as an oxygen demand or the quantity of oxygen required to oxidize the organic material to CO<sub>2</sub> and H<sub>2</sub>O" (Campbell *et al.*, 2001, p.9.). Thus the strength of sewerage is usually defined as its BOD (Watt, 1984), as explained in Chapter 4.
- Temperature. Campbell *et al.* (2001, pp.9-10) explain, "The BOD indicates the concentration of the organic material present in the water body and the oxidation of this organic material will utilise oxygen at a rate equivalent to the decrease of the BOD. The rate constant depends on temperature". Watt (1984, p.23.), clarifies this relationship in simpler

terms, stating, "Digestion is also temperature-dependent, the bacteria increasing in activity as temperature increases, reaching a maximum at 35°C".

Naturally, aerobic oxidisation cannot function without sufficient aeration, the introduction of oxygen, whereas anaerobic digestion does not rely on aeration. Other factors such as pH and toxicity also effect digestion rates but to a lesser degree (Campbell *et al.*, 2001).

### **5.3.2 Soil Permeability**

Where waste water is introduced into the earth as a means of disposal, the rate at which the geology can absorb water is of obvious importance.

"Permeability is the characteristic of soil which governs the rate at which water moves through it" (Wright, 1999, p.7.). Percolation tests are normally used to measure soil permeability conducted by measuring water percolation from test holes over a fixed period of time. "The percolation test measures the rate at which clean water, under a constant or near constant hydraulic head, percolates into the surrounding soil, in both vertical and horizontal directions" (Wright, 1999, p.8.). Typically sandy soils have high percolation rates and clay soils have low percolation rates (Watt, 1984; Wright, 1999).

## **5.4 Septic Tanks**

### **5.4.1 Septic Tank Function**

Watt (1984, p.3.) defines the function of a septic tank as, "to separate and digest the solid constituents of sewerage". Rich (1980, p.159.) supports this definition is stating, "...settleable solids in the influent are removed and stabilised in a septic tank...". Wright (1999, p.3.) defines its function in respect of effect in the overall system, "The function of the septic tank is to condition raw sewerage, which has a clogging effect on the soil, thereby reducing the effective absorption capacity of the subsoil".

### **5.4.2 The Septic Tank System**

Although an on-site sanitation system, the septic tank system is waterborne, relying on the removal of human wastes from sanitary fittings with water flushing cisterns. It is therefore wasteful in respect of water usage unless grey water is used for flushing.

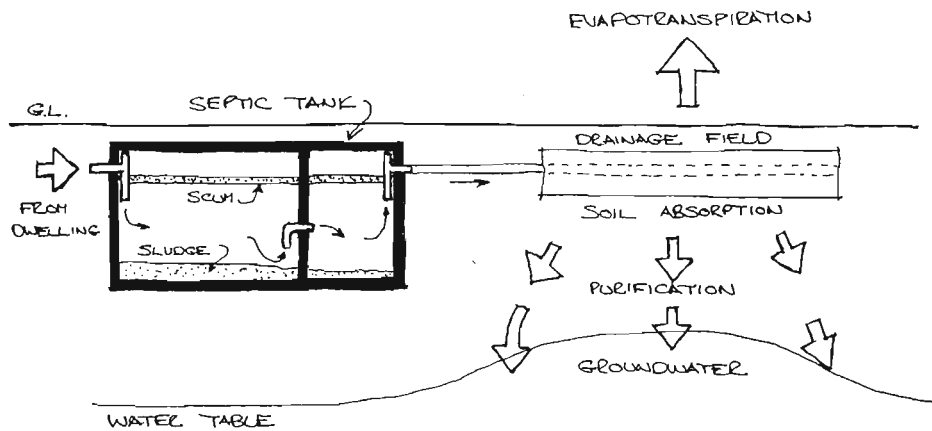
The physical form of a septic tank system is an underground tank, usually divided into 2 or 3 chambers, receiving raw sewerage influent at the one end, the processed effluent emerging from the other end being piped to a sub-surface drainage system consisting of soakaways and/or french drains, known as a drainage field. Whereas a 3 chamber tank is recommended by Rich (1980), Wright (1999, p.17.) believes that double chamber tanks are optimal for domestic conditions, "Any further advantage derived from dividing septic tanks into more than two tanks is usually insignificant". Internal divisions of the tank act as baffles to slow the water velocity, in order to allow settlement of solids.

### **5.4.3 The Digestion Process**

Wright (1999, p.3.) explains, "The processes taking place in the tank are complex and interact with one another". Watt (1984, p.21.) supports this description, "Treatment in the tank is a complex interaction of physical, chemical and biochemical processes not easy to isolate from each other".

"The still conditions in the tank allows solids more dense than water to settle to the bottom of the tank as sludge" (Watt, 1984, p.21.). Conversely, lighter particles float to the surface to form 'scum'. This scum layer maintains anaerobic conditions for the sewerage stored in the tank. Between the scum and the sludge is a body of relatively clear sewerage called 'supernatant liquor' which carries small particles in suspension (Watt, 1984; Wright, 1999). This process of settlement, aerobic and anaerobic digestion is shown diagrammatically in Figure 14.

**Figure 14: Septic Tank Process and System**



(Adapted from Wright, 1999; Roaf *et al.*, 2001)

Watt (1984, p.22.) points out that the efficiency of the digestion process in a septic tank is reduced by the nature of the combined processes taking place in the same tank, "Efficient digestion requires vigorous mixing to bring the bacteria into contact with the various foods, but this would interfere with the settling process. Digestion is therefore slow and incomplete in the sludge and scum layers. Some stabilisation of the supernatant liquid will take place during its passage through the tank".

In addition, retention or processing times for septic tanks is relatively low. Wright (1999) recommends that tank capacities are designed to retain liquid for at least 24 hours whereas Rich (1980) proposes that this period should be 2 days. Thus retention times of 1-3 days are used for septic tanks compared to 10-20 days in a full sized sewerage works (Watt, 1984).

Overall efficiency varies with sewerage strength and temperature. Rich (1980, p.159.) believes that "At least half of the BOD<sub>5</sub> can be considered as being removed in the septic tank", whereas Watt (1984, p.21.) maintains that "BOD removal may be less than 50 per cent in cold climates and up to 75 per cent in

tropical climates". Whatever the actual efficiency, clearly the commonly held notion that septic tank effluent is relatively uncontaminated, is incorrect.

#### **5.4.4 Sludge Removal**

Due to the inefficiency of the digestion system, septic tanks must be maintained by de-sludging. Failure to remove the sludge will gradually reduce the tank capacity, associated retention time and operational efficiency. Time between de-sludging can vary between 6 months and 3 years (Rich, 1980; Watt, 1984; Wright, 1999).

The rate of sludge and scum accumulation in low income areas in South Africa varies between 25 and 55 litres per person per year for toilet wastes only and between 40 and 70 litres per person per year where household sullage (grey water) is also processed, depending on the type of materials used for anal cleaning (De Villiers, 1987). The additional sludge and scum created by processing grey water supports the proposal that black and grey water should be treated separately. "There is a strong case to be made for separating faecally contaminated wastes (black water) from washing water (grey wastes) as this reduces the effluent load from the tank which is still highly charged with pathogens" (Watt, 1984, p.19.).

The need to de-sludge the tank on an on-going basis raises the question of the sustainability of the system, given that the sludge removed from the tank must be disposed of. Research undertaken by Pearson and Le Trobe (1999, p.IV.) indicated that, "Composting of pit latrine and septic tank sludge with domestic refuse, particularly garden wastes, is a viable method for the disposal and recovery of useful products from these wastes". The compost so produced is a useful agricultural resource but where the system is used in urban areas it is recommended that the composting site is located at least 500 meters from residential and commercial areas, due to odours and the associated attraction of flies (Pearson and Le Trobe, 1999). Vale and Vale (2000, p.173.) point out that although the composting of septic tank sludge may be feasible it rarely happens in practice, "Even on Waiheke Island, where

the septic tank is the accepted norm, the sludge that is removed from the tanks every three years is spread on to 'a couple of farm paddocks', which are then not used for agriculture".

#### **5.4.5 Effluent Disposal**

Septic tank effluent is normally dispersed into the earth via a drainage field consisting of french drains (trench soakaway) or soak pits. This represents a second treatment system where the soil filters out remaining solid and bacterial contaminants (Watt, 1984; Wright, 1999). Again, more than one process is employed, "Both absorption and transpiration processes take place concurrently, with effluent dispersing mainly through interflow during wet periods and through evapotranspiration during dry periods" (Wright, 1999, p.4).

Drainage fields must be designed with due consideration of the soakage area of soil required to absorb the volumes of effluent (soil permeability), the depth of the water table to avoid contamination, as well as rainfall patterns and soil characteristic (Watt, 1984; Wright, 1999). However, even a well designed and constructed drainage field has a certain lifespan. "All drainfields accumulate organic slime material at the junction of the drainfield and the native soil. This slime layer is referred to as a biological mat (biomat). Biomat formation is an inevitable process, eventually sealing the whole drainfield and restricting wastewater movement into the surrounding soil" (Roaf *et al.*, 2001, p.231.). Wright (1999) advises that the original absorption capacity of a drainage field can be restored, by allowing it to rest for between 6 and 12 months, recommending that alternating between drainage fields should be implemented. The biomat, or crust, is degraded by aerobic micro-organisms and larger life forms, such as worms, during the resting period (Watt, 1984).

Clearly the need for sufficient soakage area has an impact on minimum site sizes and therefore housing densities, a critical issue in the urban environment. On Waiheke Island, where the use of septic tanks is the norm, the minimum residential site size is 1000 m<sup>2</sup> (Vale and Vale, 2000). In the

EMA, the minimum site size for plots with septic tanks is 1800 m<sup>2</sup> compared to 180 m<sup>2</sup> where waterborne sewerage is used.

### **5.5 Composting Toilets**

Composting toilets constitute a dry sanitation system that requires no water or flushing. "These systems collect faeces and urine in separate compartments of toilets, composting the faeces so that it is useful as a soil additive" (Hunt, 2004, p.122.). Generally a composting medium, such as wood shavings has to be added to the faeces to aerate the waste. One disadvantage of the system is that electrical power is normally required to enable the composting action to occur (Roaf *et al.*, 2001).

The toilets vary in design and operation but can broadly be divided into two different types. Those using a batch system require the replacement of containers where the waste is stored. With these systems, the composting process takes place inside the sealed container. Continual process systems allow composting on an on-going basis in a single container where the waste is deposited (Composting Toilet World, 2004).

The general configuration of a composting toilet is a toilet pan, similar in appearance to a conventional pan, without a cistern. Waste passes down through a chute into a composting chamber located either externally or below the floor. The design of these toilets prevents odour emission thereby allowing internal installation.

### **5.6 Pit Latrines and Aqua-Privies**

A pit latrine is a dry sanitation system where waste is collected in a pit located under the toilet. An aqua-privy is a water based processing tank similar in design and operation to a septic tank, where the tank is located under the toilet seat.

Both pit latrines and aqua-privies are suited to externally located toilets only and both require de-sludging on an on-going basis (Pearson and La Trobe, 1999; Watt 1984).

VIP's do not have the problems of disposal associated with waterborne sewers in respect of sludge disposal but when constructed in high densities tend to leak and pollute the ground water causing environmental health problems.

## **5.7 Oxidation Ponds**

Pond systems are widely used and represent an advantageous method of treating waste waters in hot climates (Cairncross and Feachem, 1993).

"Treatment occurs through natural physical, chemical and biological processes with no machinery or energy input (except for the sun) being required for most pond systems" (Campbell *et al.*, 2001, p.27.).

The term oxidation ponds, sometimes referred to as stabilisation ponds, is a general term describing a number of different pond types but the treatment mechanisms do not vary substantially between different pond types. The efficiency of the ponds is high, removing approximately 90% of suspended solids and reducing pathogenic micro-organisms to levels well below that obtained with other technologies. However, pond systems require a lot of space in order to achieve satisfactory results and maintenance is required (Campbell *et al.*, 2001). Maintenance of ponds includes dredging to remove sludge and cutting back of vegetation encroaching the pond.

Watt (1984) recommends the use of oxidation ponds as a secondary processing method to be used in conjunction with septic tanks. The use of oxidation ponds in a domestic environment would seem to be limited to more rural areas where low development densities exist and probably only on a collective basis.

## **5.8 Case Studies**

Much of the emphasis placed on the construction of autonomous or ecohousing relates to the issue of energy supply and use. This, combined with the reluctance of local authorities to allow alternative forms of waste disposal, results in very little innovation in respect of autonomous sanitation systems. There are numerous examples of houses using composting toilets successfully such as House Wilberg in Sweden, House Vale in England, House Anderson in New Mexico and House Dolan in California where a home designed version was used (Potts, 1999; Vale and Vale, 2000).

An exception to this rule is Nautilus House in New Mexico. A solar heated septic tank was employed that accelerated the digestion process or in the owners words, “makes the septic tank run 10 times faster”. Effluent from the tank was piped to pits approximately 1 meter deep. The pits were rubber lined to prevent seepage and groundwater contamination with a base layer of pumice stone to encourage bacterial growth. In essence, a type of earth filled oxidation pond was created. Plant growth in the ‘incubation pits’ was described as “exceptional” with no reported side effects (Potts, 1999, p.306.).

## **5.9 An Autonomous Sanitation Model for the EMA**

### **5.9.1 Black Waste Disposal**

Contrary to popular belief, the septic tank system is not a self-sustaining autonomous sanitation system. The wasteful use of water, the removal of sludge from the tank and the disposal of effluent constitute problems in the urban, high-density environment. Similarly, oxidation ponds used either independently or in conjunction with a septic tank do not represent a viable solution in the urban environment.

The use of dry composting toilets therefore represents the most viable autonomous sanitation system for urban environments such as the EMA.

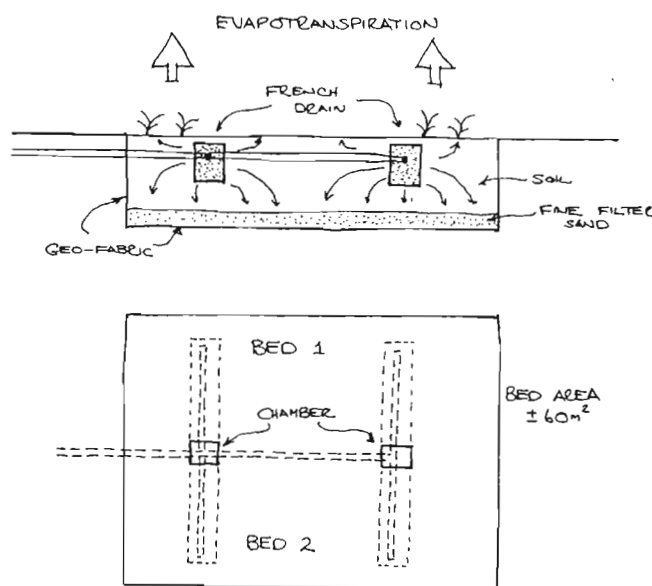
### 5.9.2 Grey Water Disposal

Given the lower level of contamination, drainage of grey water into the earth via a drainage field is indicated as both functionally and ecologically sustainable on an on-going basis.

The area of drainage field would vary depending on site specific soil conditions, but using the percolation guidelines suggested by Watt (1984) of 50 mm per day for sandy soil and 10 mm for clayey soil and the household water demand of 5250 litres per month (established in Chapter 4), nominal drainage areas are indicated. Areas would vary between 3.5 and 17.5 m<sup>2</sup>, confirming that for low water usage, drainage area is not a significant restraint.

Wright (1999) notes that evapotranspiration is an important issue in South Africa, particularly in the coastal areas and drainage fields should be designed accordingly. On this basis and taking cognisance of biomat formation, the proposal for grey water disposal in the EMA is indicated diagrammatically in Figure 15.

**Figure 15: Drainage Bed Proposal for EMA**



The drainage bed allows for the alternate use of bed 1 and 2, by placing stoppers in the chambers, facilitating breakdown of the biomat. In areas where high water table levels exist, contamination can be avoided by replacing the geo-fabric lining with plastic sheeting, thereby creating a soil filled oxidation pond.

**6.1 Introduction**

This chapter will establish the various sources of an autonomous domestic energy supply and investigate their use in the EMA taking cognisance of normal household energy demand. As for water and sanitation, a model for implementation in the EMA is sought.

**6.2 Sources and Applications of Renewable Energy**

Energy can be harvested on a sustainable basis from the following sources of renewable energy.

- Solar energy (from the sun).
- Wind energy.
- Energy from ocean wave action.
- Tidal energy.
- Geothermal energy.
- Hydro energy (from water).

(Steadman, 1975; Talbott, 1993)

Of these energy sources, only solar and wind energy are practical for harvesting at a domestic level, mainly due to the infrastructure and equipment needed to harvest the other energy sources. Application of renewable energy harvesting, in a domestic context, takes the form of:

- Solar heating of spaces.
- Solar heating of water.
- Photovoltaics (solar generation of electricity).
- Windmills or rotors (to generate electricity).

### **6.3 Passive Solar Design**

Much can be achieved in the design of a building and its components to reduce the demand for energy, mainly in respect of heating the internal spaces. This design component, referred to as 'passive solar design', can provide between 30 and 70% of residential heating requirements (Roaf *et al.*, 2001). Such design issues are beyond the scope of this research and in any event are very rarely an aspect of low income housing provision in South Africa.

### **6.4 Heating of Spaces**

The need for heating the internal spaces of a dwelling is obviously related to the climate of the region, colder climates requiring more heating and warmer climates less. Piani (1998) calculated the maximum required amount of heating energy needed by each person to keep warm for the different climatic regions in South Africa, proposing a maximum of 0.84 kWh per month per person per m<sup>2</sup> of dwelling for the EMA. This quantum must be seen in the context of the range for the country being from 0.84 to 4.46 Kwh/month/person/m<sup>2</sup>, the lower heating energy requirements for the areas located on the east coast reflecting the moderating influence of the warm Agulhas current. Piani (1998) believes that insulating of houses for winter heating is not required where the maximum heating energy requirement is less than 2.2 Kwh/month/person/m<sup>2</sup>.

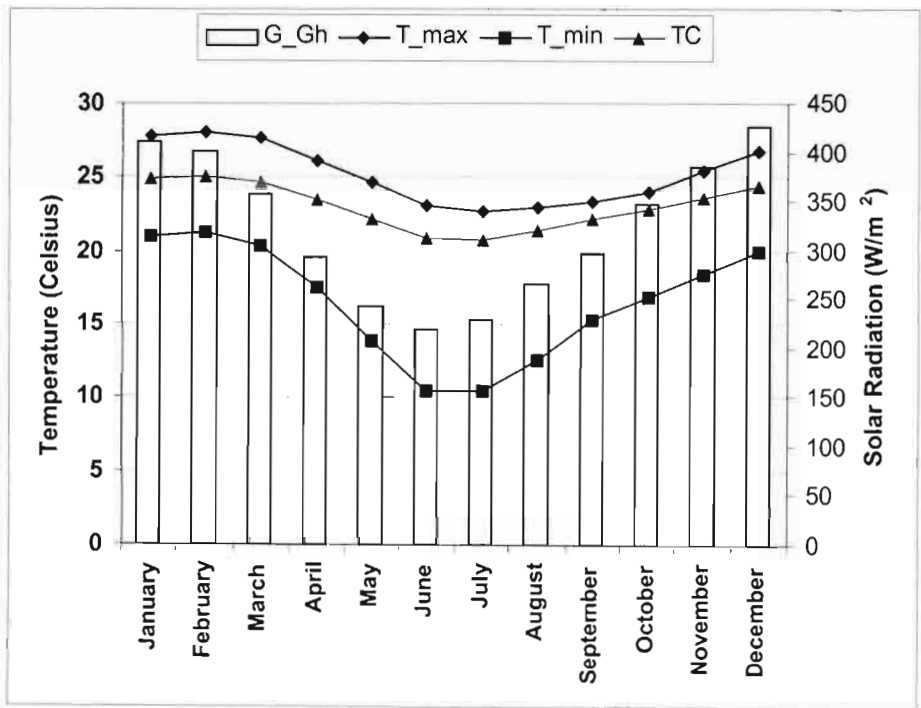
Roaf *et al.* (2001, p.35.) make the point that the heating of internal spaces is an attempt to achieve "comfort conditions required by building occupants" and therefore human tolerance must be considered, noting that "People can adapt to the most remarkable range of temperatures". This observation is based on research conducted by Humphreys (1978), which showed that for free running (naturally ventilated) buildings, the neutral or comfort temperature is related to the mean monthly external temperature by the formula

$$T_n = 0.53 T_m + 11.9$$

where  $T_n$  is the neutral temperature in degrees C and  $T_m$  is the mean outdoor temperature. Neutral temperature, is defined by Humphreys (1978), as that temperature at which 50% of a sample population will indicate on a 7-point thermal sensation scale as in the range 1-4 and 50% in the range 4-7, the term being considered synonymous with comfort temperature.

This relationship between the mean outdoor and comfort temperature was used by Nicol *et al.* (1994) to develop a graph, now known as the Nicol graph, as a guide to establish the amount of heating and cooling that a building will require each month. The Nicol graph for the EMA is shown in Figure 16.

**Figure 16: Nicol Graph for the EMA**



In addition to the monthly mean maximum ( $T_{max}$ ) and minimum ( $T_{min}$ ) outdoor temperatures and the comfort temperature (TC), the Nicol graph depicts solar radiation levels in Watts per  $m^2$ , in bar chart format (data provided by the South African Weather Services). The solar radiation data gives a guide to the amount of solar energy available where the need for

heating is indicated. It should be noted that the comfort temperatures are for naturally ventilated buildings and for an indigenous, local, adapted population.

Roaf *et al.* (2001, p.36.) explain the use of the Nicol graph, "In a good passive, high mass building the indoor air will tend to revert, without the aid of heating and cooling, to a temperature half way between the mean outdoor maximum and minimum temperature. So a line can be drawn half way between the two to indicate the free running indoor temperature. If this is below the TC, then the building will need heating up to make the occupants warm. If the air temperature line is above the TC then the building will need to be cooled to make the occupants comfortable". This does not imply that any difference between the TC and the mean outdoor temperature should be countered with heating or cooling of internal spaces. Roaf *et al.* (2001, p.37.) note that a well designed passive building "should be able to give up to 3°C free cooling or heating even in a humid climate".

Thus in the case of the EMA, where the TC exceeds the outdoor mean temperature in winter by up to 4.2°C (July), heating of internal spaces is not indicated. This together with the research undertaken by Piani (1998) indicates that heating of internal spaces of domestic dwellings in the EMA is not required and thus does not represent a necessary demand for energy.

## **6.5 Solar Heating of Water**

Roaf *et al.* (2001) believe that a solar water heater is a type of solar hot water system that gathers energy from solar radiation and turns it into heat that is distributed to where it is to be used or stored until needed. In its simplest format, a solar water heater will consist of a collector, circulation piping and a storage tank, but may also include a pump (McCartney, 1978). In freezing climates, a heat exchanger and expansion tank will also be required (Roaf *et al.*, 2001).

### 6.5.1 Solar Collectors

McCartney (1978, p.19.) explains the workings of a solar collector in comparative terms, "Solar collectors are to a solar water heating system what a boiler is to a conventional system. It is in the collectors that the water is heated". A solar collector consists of a translucent cover, an absorption plate and insulation, all mounted inside a casing (McCartney, 1978; Roaf *et al.*, 2001). Whilst the detailed design of solar collectors may vary, the working principle does not.

When solar radiation reaches the translucent cover, normally a sheet of glass, some is reflected away, a small part is absorbed by the cover itself, whilst the bulk passes through the cover to the absorption plate below. This energy, now in the form of heat, is transmitted to water channels, which are either integral or bonded to the plate. Thus the solar energy is extracted as heat energy by circulating water through the water channels in the collector (McCartney, 1978; Howell, 1979; Roaf *et al.*, 2001). Solar energy is 'trapped' in the casing due to the created greenhouse effect from the glass cover (Talbot, 1993). Insulation is placed behind the absorption plate and on the sides of the casing to retain this heat.

Modern absorption plates are generally constructed of copper tubing waterways bonded to a copper, aluminium or steel plate, of size approximately equal to the cover, coated black to improve absorption (McCartney, 1978). The method of bonding tubes to plate is critical to the efficiency of the system. "Simply wiring or clamping the tubes to the plate will produce discouraging results" (Roaf *et al.*, 2001, p.201.).

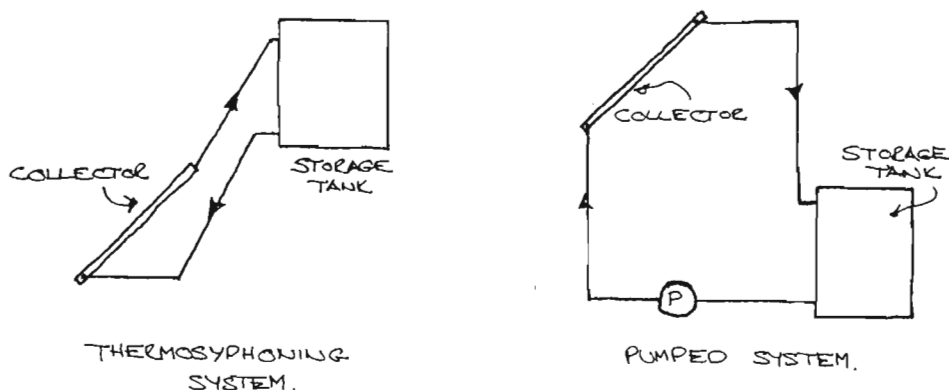
Naturally, heat loss from the absorption plate to the casing and air introduces a level of inefficiency. "When people talk about the efficiency of a collector they are referring to the quantity of energy extracted by the circulating stream of water expressed as a fraction of the total amount of solar energy falling on the cover of the collector" (McCartney, 1978, p.20.). Factors contributing to the efficiency of collectors are:

- An ordinary sheet of glass transmits about 84% of energy received. This is reduced to 70% in the case of double glazing (McCartney, 1978).
- Dirt accumulation of the face of the glass cover will reduce energy transmission by about 20% (McCartney, 1978).
- Howell (1979) believes that a 85% efficiency for a black coated absorption plate is reasonable whilst McCartney (1978) believes that a 98% efficiency can be achieved.
- Howell (1979) notes efficiency can be improved by increasing the complexity of the waterways. However, a greater complexity results in increased resistance to water flow, often necessitating the use of pumps.
- Collector efficiencies are not consistent. All collectors get more efficient at lower temperatures (Howell, 1979). Air temperature, wind velocity and solar intensity effect collector efficiency (McCartney, 1978).

### 6.5.2 Circulation Systems

Two basic configurations are used, namely thermosyphoning and pumped systems (McCartney, 1978), as shown graphically in Figure 17.

**Figure 17: Circulation Systems for Solar Water Heaters**



Source: McCartney (1978)

In the thermosyphoning system, no auxiliary energy is required to circulate the water, the circulation occurring from natural convection. "When water in the collector is heated by the sun, it expands (becomes less dense) and rises up the collector, through a pipe and into the top of the storage tank. This forces cooler water at the bottom of the tank out another pipe leading to the bottom of the collector. This water, in turn, is heated and rises up into the tank. As long as the sun shines, the water will quietly circulate, getting warmer" (Anderson, 1977, p.130.). To avoid reverse thermosyphoning and the associated heat loss when the sun is not shining, the bottom of the storage tank must be located higher than the top of the collector (Anderson, 1977).

### **6.5.3 Heat Distribution Systems**

Roaf *et al.* (2001) point out that two methods of heat distribution can be employed, either direct or indirect. A direct system is one where the water to be heated is circulated directly through the solar collector and an indirect system is one that employs a separate fluid circuit to transfer heat from the solar collector to the storage tank. Anti-freeze solutions are widely used in the indirect fluid circuit in freezing climates (Anderson, 1977).

Effectively, the indirect system creates a heat exchanger that reduces efficiency of the heating system as a whole. McCartney (1978, p.51.) estimates that, "Only between 60 and 90% of the heat absorbed by the collectors will reach the water in the storage tank through the exchanger".

Both pumped and thermosyphoning reticulation systems can be used with direct and indirect heat distribution systems.

### **6.5.4 Storage tanks**

The importance of hot water storage is emphasised by Roaf *et al.* (2001, p.203.), "Heat storage is a key feature of the solar hot water system. Without it the hot water would be available only when the sun is actually shining. A

storage system allows the solar system to operate whenever energy is available and to supply the energy when it is needed". The important aspects of tank selection are fabrication material, where strength and corrosion resistance must be considered, size and insulation (McCartney, 1978). Roaf *et al.* (2001) recommend the equivalent of a 75mm thick layer of fibre glass wool as tank insulation, whereas Anderson (1977) and McCartney (1978) believe a minimum of 100mm insulation should be used.

### **6.5.5 Sizing of a Solar Water Heating System**

#### **6.5.5.1 Solar Collectors**

Roaf *et al.* (2001) and Howell (1979) note that the rule of thumb for the sizing of solar collectors is  $1\text{m}^2$  of collector for every 50-65 litres of hot water needed per day. Anderson (1977) supports this rule, estimating that a good collector in a moderately good location will heat approximately 75 litres per  $\text{m}^2$  per day. These design rules attempt to achieve a balance between cost and effectiveness given that manufactured solar collectors are generally quite expensive.

Where weather data and collector performance specifications are available, the f-chart method can be used to calculate the size of collector needed (Beckman *et al.*, 1977).

#### **6.5.5.2 Storage Tanks**

Roaf *et al.* (2001, p.204.) believe that tanks, as a minimum, should store sufficient water to meet the household demand over a 24-hour period, noting that, "a storage strategy of at least two days is a good option". Anderson (1977) notes that this 'two day strategy' is the norm for most systems. McCartney (1978) believes that the rule of thumb is 50 litres of storage for every square meter of solar collector and notes that larger storage tanks increase inefficiency by lowering the water temperature in the tank unless special precautions are taken to encourage temperature stratification.

### 6.5.6 Meeting Domestic Hot Water Demand

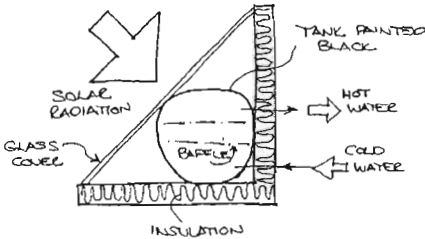
"A problem common to all types of solar heating is the variable nature of sunshine" (Anderson, 1977, pp.125-126.). As a result of weather variations, few people are prepared to rely solely on solar heating as a source of hot water. Howell (1979) believes that very few people can reasonably expect solar energy to completely replace their existing heat sources, stating that in temperate climates it will get very close with domestic water but less close with home heating with an achievement of 75% of the hot water being considered good. Roaf *et al.* (2001, p.208.) indicate that technology has done little to improve the status quo, "A 5 m<sup>2</sup> solar collector provides 60 per cent of the hot water needs for the Oxford Ecohouse in the UK. The same system provides 75 per cent of the solar hot water system for the Bariloche Ecohouse, Argentina".

Some technological advances have taken place. Solar hot water tubes, with a higher efficiency than flat plate collectors, have been developed although at a higher cost. Dunster (2003, p.125.) explains the workings of these tubes, "Modern tubes have a black metal absorption element in the center of a semi evacuated glass tube. Fixed to the absorber is a copper tube containing acetone in a reduced pressure environment. As the absorber heats up the acetone boils and the hot vapour rises to the top of the tube. Here it passes its heat to a copper pipe circuit containing the domestic water supply to be heated. It then condenses and drains back down inside the absorber pipe again to restart the process."

To establish the extent to which solar water heating is capable of meeting domestic hot water demands, case studies will be examined.

**Table 7: Solar Water Heating: Case Studies**

Case Study Details	Specifics of Application
<i>Findhorn House</i> Findhorn, Scotland (Source: Roaf <i>et al.</i> , 2001)	Flat panel solar collectors mounted on roof, with area of 4m <sup>2</sup> , provided 70% of annual hot water demand.
<i>Hamamatsu House</i> Hamamatsu, Japan  (Source: Roaf <i>et al.</i> , 2001)	An air heat solar collection system used that heats air rather than water. The hot air is then used to heat water via a heat exchanger. The system provides up to 310 litres of hot water per day at 40-60°C. Auxiliary water heater used for winter.
<i>Solar House</i> Inagi, Japan  (Source: Roaf <i>et al.</i> , 2001)	During 1980, only 904 kWh energy consumption for the heating of water and spaces. Flat panel, roof mounted, solar collectors of 24 m <sup>2</sup> area provided energy for water and space heating (hybrid system). Indirect system using a heat exchanger and a 950 litre hot water storage tank reduced reliance on external energy sources even during inclement weather.
<i>Bariloche Ecohouse</i> Bariloche, Argentina  (Source: Roaf <i>et al.</i> , 2001)	A 5m <sup>2</sup> roof mounted flat solar collector with indirect heating of two hot water storage tanks, formed a system designed to provide 76% of household hot water needs. Gas boiler used to supplement heating during winter months.
<i>Pen-y-llyn</i> Wales, UK  (Source: Roaf <i>et al.</i> , 2001)	Home made solar collector system constructed as an integral part of the roof structure. During summer, the system provided 100% of hot water requirements. Between seasons, solar collector energy

	used to pre-heat water. In winter, no solar heated water available.
<p><i>House Rassman</i> Genesee Valley, New York State  (Potts, 1999)</p>	<p>Roof mounted 'batch' type (see Figure 18) solar collector used to preheat water. Two water storage tanks (270 litres combined capacity) used with heating from excess solar electricity.</p> <p><b>Figure 18: Batch Type Solar Collector</b> (Source: Potts, 1999)</p> 
<p><i>House Potts</i> Casper, California  (Potts, 1999)</p>	<p>'Batch' type solar collector. Supplemented by gas heater during winter. Water heated to 46°C.</p>
<p><i>House Cowden</i> Hanalei, Kauai Island, Hawaii  (Potts, 1999)</p>	<p>Roof mounted flat panel solar collector of 7m<sup>2</sup> and a hot water storage tank of 545 litre capacity heats water to 60°C. All household need for hot water supplied from the system.</p>

Whilst the use of solar collectors for heating domestic water appears to be widespread and functional, the system is rarely used without a supplementary heating system. Proprietary water solar heating systems manufactured in South Africa are generally used to 'pre-heat' water in conjunction with a normal electrical water heater. Where this is not the case, a supplementary

heating system in the storage tank, normally an immersion heating element, is supplied as part of the system.

### 6.5.7 Solar Water Heating Model for the EMA

Vale and Vale (2000) claim that of the total domestic water consumption of 34 litres per person per day<sup>1</sup>, 13 litres were hot water. Using the rule of thumb for sizing of solar collectors discussed earlier, this hot water consumption of 65 litres per day for the household indicates the need for a 1m<sup>2</sup> solar collector.

Using the f-chart method proposed by Beckman *et al.* (1977), the contribution of solar collectors of varying sizes to the heating energy load can be calculated. The monthly heating load for a household, for water heating, is calculated using the following expression.

$$T_w = N \times W_D \times (T_w - T_M) \times C_P \times \rho$$

where

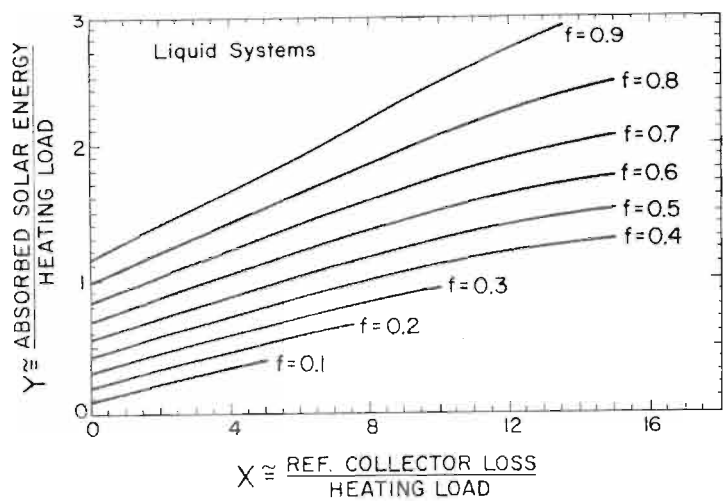
- N is the number of days in the month
- T<sub>w</sub> is the minimum acceptable temperature for hot water
- T<sub>M</sub> is the temperature of the water supply
- W<sub>D</sub> is the daily demand for hot water
- C<sub>P</sub> is the specific heat of water
- ρ is the density of water

This heating load can, in turn, be used to calculate 'dimensionless system variables' X and Y, for a specified area of flat plate solar collector, using local radiation data as well as efficiency coefficients (Beckman *et al.*, 1977). The calculated X and Y may then be used to plot the proportion of monthly total heating load provided by the solar collector, on the f-chart, shown in Figure 19.

---

<sup>1</sup> Discussed in chapter 4

Figure 19: f-Chart for Liquid Systems (Beckman *et al.*, 1977)



Assuming the household hot water usage of 65 litres per day and a minimum acceptable hot water temperature of 50°C, the X and Y variables as well as the proportion of heating load provided, ‘f’, for a 1, 2, 3 and 4 m<sup>2</sup> solar collector in the EMA are shown in Table 8<sup>2</sup>.

Table 8: f-Chart Variables for EMA

	1m <sup>2</sup> Collector			2m <sup>2</sup> Collector		
	X	Y	f	X	Y	f
January	5.03	1.90	0.94	10.05	3.79	1.08
February	5.09	1.87	0.92	10.19	3.74	1.07
March	4.92	1.61	0.83	9.84	3.22	1.03
April	4.39	1.16	0.65	8.79	2.33	0.91
May	3.87	0.86	0.49	7.74	1.72	0.76
June	3.46	0.71	0.41	6.91	1.43	0.67
July	3.43	0.76	0.45	6.85	1.52	0.71
August	3.61	0.94	0.55	7.23	1.87	0.83
September	3.89	1.12	0.65	7.78	2.25	0.92
October	4.10	1.39	0.78	8.20	2.79	1.02
November	4.42	1.62	0.86	8.83	3.25	1.06
December	4.77	1.90	0.95	9.54	3.80	1.10

<sup>2</sup> f values calculated by formula

	3m <sup>2</sup> Collector			4m <sup>2</sup> Collector		
	X	Y	f	X	Y	f
January	15.08	5.69	1.31	20.11	7.59	2.51
February	15.28	5.61	1.29	20.38	7.48	2.41
March	14.76	4.83	1.11	19.69	6.43	1.62
April	13.18	3.49	0.98	17.58	4.66	1.06
May	11.61	2.58	0.88	15.48	3.44	0.94
June	10.37	2.14	0.81	13.83	2.85	0.89
July	10.28	2.28	0.85	13.70	3.04	0.92
August	10.84	2.81	0.94	14.45	3.74	0.98
September	11.66	3.37	1.00	15.55	4.50	1.05
October	12.30	4.18	1.06	16.40	5.58	1.27
November	13.25	4.87	1.14	17.67	6.49	1.65
December	14.31	5.70	1.33	19.08	7.60	2.52

For comparative purposes, the proportion of heat load energy supplied by the collector, 'f', for all four sizes of collector is shown graphically in Figure 20.

**Figure 20: Heating Load Contribution: Comparison of Solar Collectors by Area**

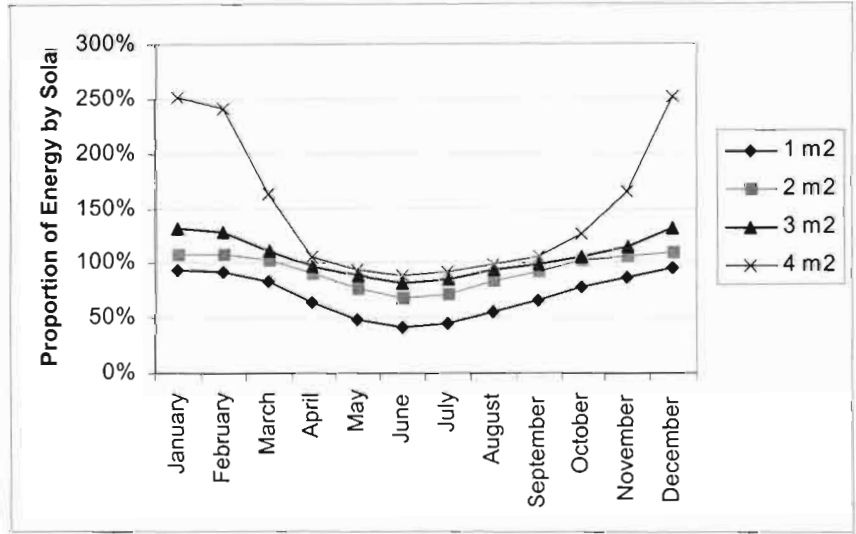


Figure 20 indicates clearly that whilst the rule of thumb proposed by Roaf *et al.* (2001) and Anderson (1977) provides an estimate for the size of a solar collector that supplies the majority of the household water heating energy requirements during summer, the energy provided by the panel will be less than 50% of the requirement, in the EMA, during winter.

The increase in size of collector from 1 m<sup>2</sup> to 2 m<sup>2</sup> results in a significant improvement in the proportion of energy generated during winter, whilst the increase in performance during the same period for larger collectors reduces progressively. This trend is shown numerically in Table 9.

**Table 9: Efficiency of Increasing Size of Solar Collectors**

	1 m <sup>2</sup> f	2 m <sup>2</sup> f	% Increase	3 m <sup>2</sup> f	% Increase	4 m <sup>2</sup> f	% Increase
April	0.65	0.91	40%	0.98	8%	1.00*	2%
May	0.49	0.76	54%	0.88	16%	0.94	7%
June	0.41	0.67	62%	0.81	21%	0.89	9%
July	0.45	0.71	59%	0.85	19%	0.92	8%
August	0.55	0.83	50%	0.94	13%	0.98	5%
September	0.65	0.92	42%	1.00	8%	1.00*	0%
<b>Average</b>			<b>51%</b>		<b>14%</b>		<b>5%</b>

\* Value reduced to 1 to show effective change

Table 9 indicates that a 2 m<sup>2</sup> solar collector is probably the most effective solution for the EMA. The proposed solar water heating model for the EMA is therefore a 2 m<sup>2</sup> flat plate collector mounted at roof or ground level with a thermosyphoning reticulation system. Given that the f-chart method of designing solar heating systems assumes a 75 litre storage tank per m<sup>2</sup> of collector, a 150 litre storage tank is proposed.

Clearly a supplementary heating system will need to be provided for the winter months.

### **6.6 Photovoltaics**

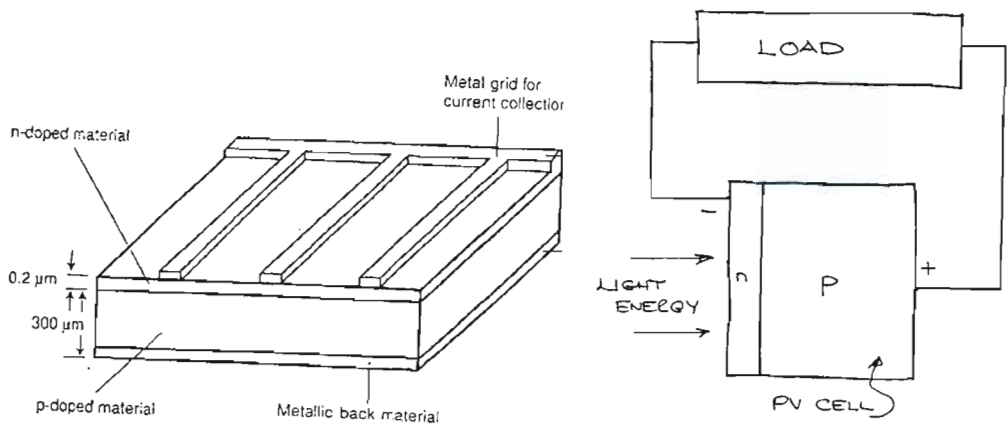
#### **6.6.1 An Overview of Photovoltaics**

Photovoltaic, or solar, cells convert sunlight into electrical energy. Hall and Page (1978) explain that the solar cell is a simple, but scientifically a very elegant device that converts the incident light energy directly into electrical

energy using a suitably layered semi-conductor device with the right physical properties. Howell (1979) points out that light energy constitutes about 40% of sunlight but Steadman (1975) clarifies that only the shortwave radiation is converted into electricity resulting in a theoretical upper limit of efficiency for solar cells of 22% of solar radiation received. Efficiencies of up to 16% have been achieved in manufacturing cells using microchip technology (Roaf *et al.*, 2001).

Typically, PV cells consist of a sandwich of semi-conductor materials, usually pure silicone, 'doped' with different elements to achieve the required characteristics, referred to as the 'p' and 'n' doped materials. When exposed to light, an electric charge is generated between the 'p' and 'n' material, similar to that between an anode and cathode (Roaf *et al.*, 2001; Hall and Page, 1978). Electrical contacts on both sides of the cell allow harvesting of this charge. The construction and workings of the cell are shown diagrammatically in Figure 21.

**Figure 21: Construction and Workings of a PV Cell**



(Source: Roaf *et al.*, 2001; Chauliaguet *et al.*, 1977)

PV cells provide direct current (DC) that can be stored in batteries. Given that most domestic appliances require alternating current (AC), an inverter is normally required to convert DC to AC. Even at a domestic level, a PV system requires a number of components to make it useful. "A PV system consists of

one or more PV modules, which convert sunlight directly into electricity, and a range of other system components that may include an AC/DC inverter, back-up source of energy, battery to store the electricity until needed, battery charger, control centre, mounting structures and miscellaneous wires and fuses” (Roaf *et al.*, 2001, p.167.).

Three basic types of PV panels are available, each with differing efficiencies and durabilities, a summary of which is given in Table 10 below.

**Table 10: Types of PV Modules**

Module Type	Appearance	Efficiencies (%)	Durability (Yrs)
Monocrystalline	Module composed of circular polygonal shapes	10-16	25-30
Polycrystalline	Sparkling crystal chaotic surface	8-12	20-25
Amorphous	Matt dull surface	4-12	15-20

(Source: Roaf *et al.*, 2001, p.179.)

Concerns regarding the widespread use of PV cells, as a source of domestic energy, focussed during the 1970s on the relatively high cost of the panels (Hall and Page, 1978; Chauliaguet *et al.*, 1977). This stigma remains with photovoltaics, “The problem with this free energy from the sun is that it takes a very expensive panel to harvest it” (Dunster, 2003, p.125.). Roaf *et al.* (2001, p.169.) however, believes that “prices are expected to fall significantly over the next decade as demand grows and the PV industry achieves economies of scale in production”. It should be noted that the comparison of cost per unit of electricity between PV generated energy and that supplied via the national grid uses only the actual production or supply costs, with no

allowance being made for the costs of the environmental degradation associated with providing electricity via the grid (discussed in chapter 2).

Vale and Vale (1999) highlight the difficulties relating to the storage of electricity generated from PV systems using batteries. In countries where extended periods of sunless or frozen days are experienced, battery capacity must be sufficient to accommodate this unless a back-up source of electricity supply is available. This requires large, high efficiency battery systems that are expensive. In addition, batteries do not last indefinitely and need to be replaced. Besides the cost of replacement, many batteries have lead components and therefore disposal of used batteries can have environmental consequences. "Batteries wear out, and when they do, they must not be disposed of carelessly. The active ingredients in these batteries, lead and sulphuric acid, can be highly toxic and dangerous and need to be handled with great respect" (Pratt, 1995, cited in Vale and Vale, 1999, p.126.).

### **6.6.2 Meeting Domestic Energy Demand**

The management of the varying supply and demand levels of domestic electricity, which are an integral part of a PV system, is made easier in countries such as the UK and USA where import / export connections to the electricity supply reticulation are available. This allows the "exporting" of excess energy back to the network, off-setting the use of energy in times of low production (Vale and Vale, 2000; Roaf *et al.*, 2001). This type of connection is not available at a domestic level in South Africa.

Household consumption for a typical European house is approximately 8 kWh per day, 6.5 kWh for appliances and cooking and 1.5 kWh for lighting (Vale and Vale, 2000). Potts (1999) believes that normal usage is higher than this, noting that, despite careful conservation, his house consumes an average of 11 kWh of energy per day.

In order to establish the extent to which PV systems can satisfy domestic demand, a number of case studies are examined.

**Table 11: PV Systems: Case Studies**

Case Study Details	Specifics of Application
<p>Oxford Ecohouse, England</p> <p>(Source: Roaf <i>et al.</i>, 2001)</p>	<p>48 PV monocrystalline roof mounted panels with a combined area of 34 m<sup>2</sup> provided a peak output of 4 kW. An import / export connection was used resulting in a reduction of household energy costs of 70%.</p>
<p>Duncan House, Waiheke Island, New Zealand</p> <p>(Source: Roaf <i>et al.</i>, 2001)</p>	<p>The house is entirely self contained in respect of electricity supply, using both wind and solar energy. 20 Polycrystalline panels provide a capacity of 1.16 kW, representing 92% of electricity generation. Lighting, refrigerator, television and radio have been converted to operate on DC to reduce power loss via inverter inefficiency. The stereo, computer, fax and washing machine run on AC provided via the inverter.</p>
<p>Bariloche Ecohouse, Bariloche, Argentina</p> <p>(Source: Roaf <i>et al.</i>, 2001)</p>	<p>The location receives approximately 7.8 hours of peak sun in summer but only 1.7 in winter. 16 Modules with a combined capacity of 700 W were used with an inverter. The system is connected in parallel with the electricity supply network. Provides about one-third of annual electricity demands.</p>
<p>Middleton House, Ontario, Canada</p> <p>(Source: Roaf <i>et al.</i>, 2001)</p>	<p>The house is powered off grid with a range of conventional appliances for the kitchen, as well as computers, fax, satellite television and other conveniences. An array of PV panels providing 600 W is</p>

	backed up by a small generator. The lesson learnt was that although individual components performed well, problems were experienced with the integration of the system.
House Vale, Nottinghamshire, England  (Source: Vale and Vale, 2000)	36 Polycrystalline panels generated 1616 kWh of electricity during a one year period (1994/5). This constituted 51.9% of total household consumption used via an import / export connection.
House Edwards, Ettersburg, California  (Source: Potts, 1999)	34 Roof mounted panels backed up with a micro-hydro system provide all electrical needs. Inverter is used to convert current to a 24 Volt AC system.
House Robertson, Willits, California  (Source: Potts, 1999)	Yard mounted PV panels backed up by a generator in winter provide all electricity requirements. Inverter used to provide a 24 Volt AC system. Appliances include dishwasher, washer, dryer, microwave, computers, etc.

Clearly, generating sufficient electricity to satisfy household requirements appears to be difficult all year round without an alternative source of electricity supply. The effectiveness of a PV system to provide all, or a high proportion, of domestic demand is a function of location, with varying levels of solar radiation available for harvesting and the varying quantum of the demand for electricity.

### 6.6.3 A PV Model for Low Income Housing in the EMA

#### 6.6.3.1 Assessment of Electricity Demand

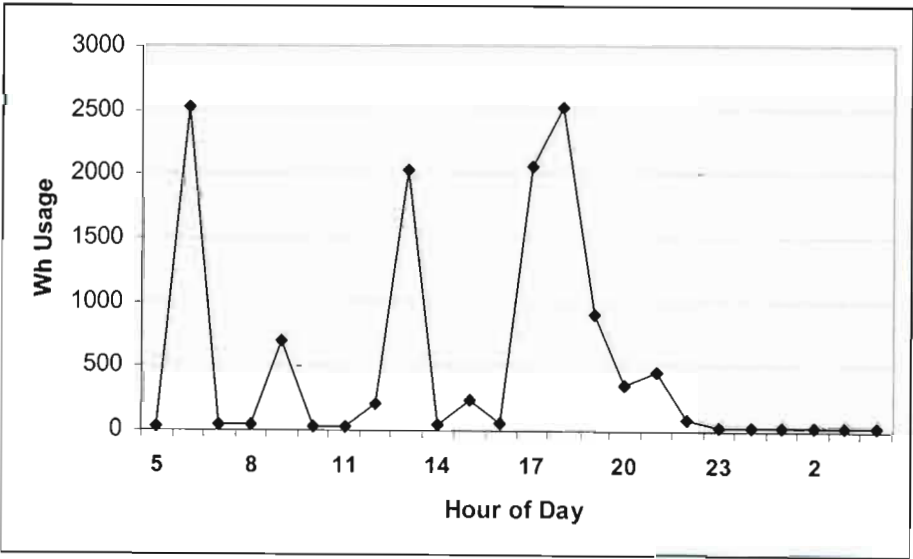
In order to establish the likely usage pattern of an 'average' low income household of five people, a typical electrical usage projection for a 24 hour period is shown in Table 12. The projection is based on a typical 30 m<sup>2</sup> low income unit and eight random interviews with dwelling occupants to establish load types and usage patterns.

**Table 12: Domestic Demand Profile: Low Income House: EMA**

		Type of Load											Totals (Wh)
	Watts Min/Hr	Fridge	2-plate hot plate	Kettle	Toaster	Iron	Radio	Stereo	TV (portable)	Bedroom light	Bathroom light	Livingroom light	
	200 10	2000 60	2000 5	800 10	500 60	5 60	30 60	200 60	60 60	60 60	60 60		
Hour of Day	05h00	33											33
	06h00	33	2000	167	133		5			60	60	60	2518
	07h00	33					5						38
	08h00	33					5						38
	09h00	33		167		500							700
	10h00	33											33
	11h00	33											33
	12h00	33		167			5						205
	13h00	33	2000				5						2038
	14h00	33					5						38
	15h00	33		167			5	30					235
	16h00	33						30					63
	17h00	33	2000					30					2063
	18h00	33	2000	167					200	60		60	2520
	19h00	33				500			200	60	60	60	913
	20h00	33							200	60		60	353
	21h00	33		167					200			60	460
	22h00	33									60		93
	23h00	33											33
	24h00	33											33
	1h00	33											33
	2h00	33											33
	3h00	33											33
	4h00	33											33

Table 12 estimates the daily demand for electricity to be 12.6 kWh per day, supporting the comments made by Potts (1999) in respect of consumption levels. Of equal importance to the quantum of electricity consumed is the peak demand. The peak load is the maximum amount of electricity that is required at any one time, which will influence the design of the PV system. Peaks can be managed by only undertaking one high energy activity at a time. In Germany, it has been found that people who use their PV electricity in their homes best are retired people who are home all day and can manage their chores to reduce peak loads (Roaf *et al.*, 2001). Two peaks are indicated in Table 12, both of 2.5 kWh, experienced at 06h00 and 18h00. A third, lesser peak of 2 kWh, takes place at 13h00. This usage pattern is shown graphically in Figure 22.

**Figure 22: Electricity Usage Profile: Low Income House: EMA**



The electricity load projection shown in Table 12 excludes any allowance for water heating (typically low income housing in the EMA are not provided with water heaters). Assuming the adoption of a solar water heating system, as proposed earlier, electricity demand in the winter months of April to September will be higher than that shown in Table 12, the additional power being needed to supplement water heating, with consequently higher peaks

than those shown in Figure 22. Estimated electricity consumption levels adjusted for water heating requirements are shown in Table 13.

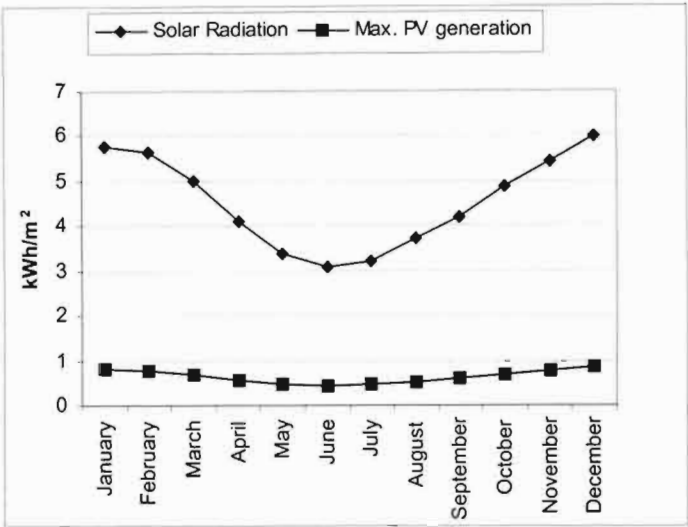
**Table 13: Consumption Levels Adjusted for Water Heating Requirements: EMA**

	Normal Consumption	Water Heating kWh	Average daily Consumption
January	12.578		12.578
February	12.578		12.578
March	12.578		12.578
April	12.578	0.192	12.770
May	12.578	0.559	13.137
June	12.578	0.829	13.407
July	12.578	0.733	13.311
August	12.578	0.415	12.993
September	12.578	0.186	12.764
October	12.578		12.578
November	12.578		12.578
December	12.578		12.578

6.6.3.2 Meeting the Demand with a PV System

The relationship between the level of solar radiation received in the EMA and the electrical energy that can be generated by 1 m<sup>2</sup> of PV module is demonstrated graphically in Figure 23.

**Figure 23: Relationship between Solar Radiation Levels and Generation of Electricity by PV Module**



Note : A PV efficiency of 14% has been assumed.

Thus the area, or number, of PV modules required to meet the household electricity demand can be calculated. This calculation must include an allowance for the efficiency levels of inverters, loss of power in wiring, etc. Roaf *et al.* (2001) suggests an allowance of 15%. Table 14 shows the result of this calculation.

**Table 14: Calculation of PV Module Area**

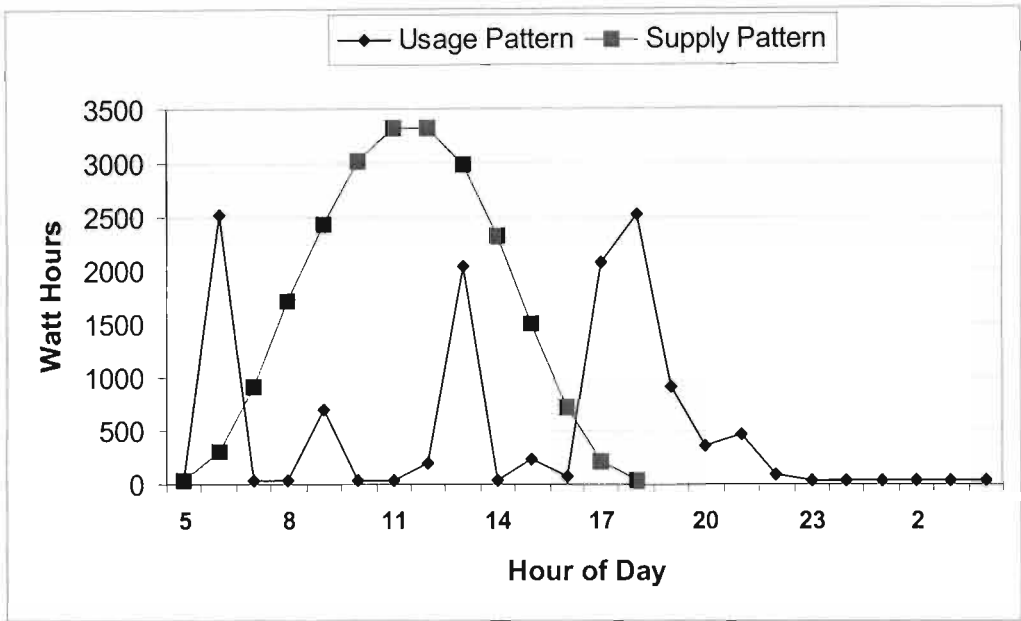
	Average daily Consumption kWh	Max. PV per m <sup>2</sup> KWh	Efficiency Allow. 15%	Module Area Required M <sup>2</sup>
January	12.578	0.80	0.70	18
February	12.578	0.79	0.68	18
March	12.578	0.70	0.61	21
April	12.770	0.57	0.50	26
May	13.137	0.47	0.41	32
June	13.407	0.43	0.37	<b>36</b>
July	13.311	0.45	0.39	34
August	12.993	0.52	0.45	29
September	12.764	0.58	0.51	25
October	12.578	0.68	0.59	21
November	12.578	0.76	0.66	19
December	12.578	0.84	0.73	17

Thus an array of PV modules with a surface area of 36 m<sup>2</sup> would be required assuming a module efficiency of 14% and a power loss of 15% due to components, such as inverters and wiring. This correlates with the experiences of the case studies identified earlier.

6.6.3.3 Accommodating the Demand Peaks

Figure 24 compares the peak in electricity supply by the PV array to the peaks in demand.

Figure 24: Comparison of Supply and Demand Peaks: EMA



What is clearly evident from Figure 24 is that the two main peaks in demand for electricity cannot be drawn directly from the PV array since demand peaks correlate, in timing, with minimum supply. Demand peaks therefore have to be accommodated by the battery storage system. It follows, therefore, that the peaks in demand for electricity have little or no influence on the number, type or area of PV modules required but are pertinent to the specification of the battery storage capacity.

Assuming that domestic appliances are to be run on the South African standard of 220 volts AC, the current required from the battery store to meet the demand peak of 2.5 kWh is calculated to be 12 Amps<sup>3</sup>. The storage battery system would need to be capable of providing 12 Amps for two hours, or 24 AmpHr, in order that demand peaks could be met. Given that batteries should not be depleted of more than half their capacity to prolong battery life (Roaf *et al.*, 2001; Potts, 1999; Vale and Vale, 2000), a minimum battery store rating of 48 AmpHr is indicated.

Naturally, the larger the capacity of the battery store, the longer the periods of electricity can be provided without re-charging from the PV array.

#### 6.6.3.4 *Layout of PV System*

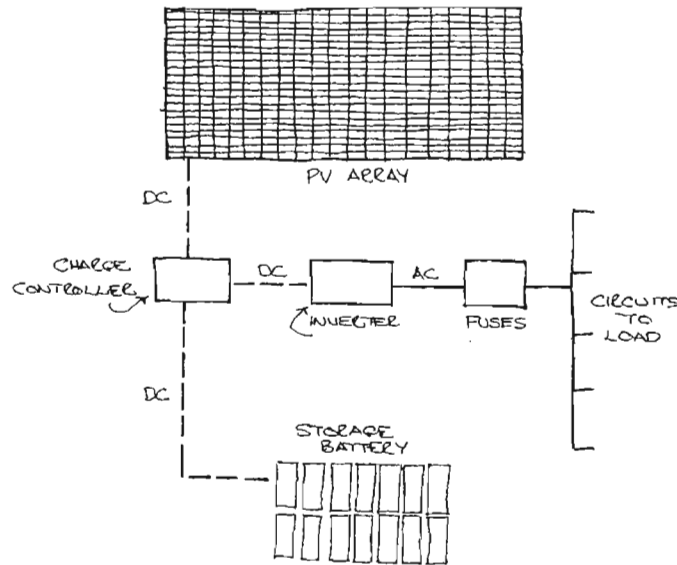
In addition to the array of PV modules and storage battery, the system will require a charge controller and a power inverter. A charge controller is a manufactured unit that regulates the relationship between the electrical energy generated by the PV modules, that stored in the batteries, and the load at any particular time. Thus electricity from the PV array will be used to satisfy load if necessary and if not will be diverted to the batteries for storage. An inverter converts the DC electricity generated by the PV modules into AC for use by household appliances (appliances in South Africa are generally rated for 220 Volts AC). Fuses, rated according to the amount of current expected in the circuit, will be required to protect supply circuits from overloading and possible damage to the system and appliances.

Figure 25 shows a diagrammatical representation of a system layout for a low income house in the EMA.

---

<sup>3</sup> Power = Voltage X Current

**Figure 25: Proposed PV System Layout for EMA**



## **6.7 Wind Energy**

Calnan (1978) points out that the harvesting of wind energy is an ancient technology with a history of some 4000 years. It is an inexhaustible, substantial source of energy that is difficult to harness at a domestic urban level. Howell (1979) believes that if a windmill were put on top of each electricity pylon, they would produce twice the power of all the power stations that feed the pylons.

The primary difficulty with harvesting wind energy relates to the random nature of the wind, in particular its speed and low density. Howell (1979) explains that wind speed is higher as it gets clear of the Earth, due to the lack of friction with the ground surface. Generally 'full wind speed' occurs at approximately 50 meters above ground level, reducing to 85% at 25 meters elevation, 75% at 15 meters and 50% at 5 meters (Howell, 1979). This change in wind speed with elevation is referred to as the 'vertical wind speed gradient' (Steadman, 1975). Given that the power output from a wind turbine is dependent upon the cube of the wind speed, the height of the collector turbine is a critical factor (Calnan, 1978).

Air density also impacts on harvesting. The low density of air results in large devices being needed to generate energy in any quantity, the power output of a wind turbine being dependent on the square of the diameter of the rotor (Steadman, 1975; Calnan, 1978).

Given the infrastructure requirements of a high mast and turbine, application may be feasible in a peri-urban or rural environment but not in urban, high-density developments. In addition, although not a technical obstacle the aesthetics of a large number of wind turbines in close proximity is seen to be problematic to local authority planning officers (Vale and Vale, 2000).

Thus, wind energy harvesting is not deemed appropriate for low income housing.

## **CHAPTER 7      CONCLUSION AND RECOMMENDATIONS**

### **7.1      Introduction**

This chapter provides conclusions on the study, reviews the objectives stated in Chapter 1 and tests whether the hypothesis has been proved or disproved. In addition, recommendations are proposed for the implementation of alternative forms of domestic service provision in the EMA.

In deviation to the norms expected of a concluding chapter, the financial aspect of sustainability in respect of the theoretical models, not discussed in previous chapters is explored in this chapter, primarily to avoid unnecessary duplication of a common theme.

### **7.2      Financial Sustainability**

In general, attempts to establish the financial sustainability of alternative methods of service provision, such as the use of a solar water heating system in lieu of a conventional electric water heater, are a comparison of the total costs i.e. the capital and recurrent expenditure, in each case. The result of this is the computation of a 'pay back' period, reflecting the time needed to recoup the capital investment required for the alternative system from the savings on consumption charges (Roaf *et al.*, 2001, Potts, 1999). Whilst this approach gives an indication of the level of consumption charges saved as a proportion of the capital investment, it does not always represent an accurate assessment of sustainability.

In the context of the EMA, attempts to achieve social equity reflected in the determination of consumption charges, such as 'lifeline' and cross-subsidisation pricing policies, render 'pay back period' type assessments unrealistic. Clearly any method proposed for the evaluation of financial sustainability must consider the actual cost of providing services and not pricing mechanisms deemed socially appropriate by local authorities.

Pricing mechanisms aside, the 'pay back period' approach attempts to evaluate the cost effectiveness of an alternative servicing system, only from the perspective of the dwelling owner or occupant. No allowance is made for the cost of external factors such as environmental degradation, which has an effect on society as a whole. By way of example, a 'pay back period' analysis of a solar water heating system using actual costs of supplying electricity via a wired reticulation system may indicate a lengthy or infinite pay back period implying a lack of financial sustainability. However, if the cost of removing the air pollution from the atmosphere, caused by the energy generation from burning coal, was calculated and added to the cost of providing the electrical energy, a different result would probably emerge. A representative portion of the cost of designing, installing and maintaining the reticulation network could also be an external cost.

The notion of accounting, in financial terms, for environmental degradation is supported by environmentalists seeking a more holistic cost of goods and services to society as a whole. Daly (1996) proposed to the world bank that governments should stop counting natural capital as income. The effect of this in the South African context is that if the country's GDP were adjusted to exclude non-renewable resources such as those harvested in the mining industry, negative growth would be indicated (Bond, 2002). This would encourage governments to seek a more sustainable means of capital accumulation.

Others suggest that the principles of environmental justice are used to establish the right to the use of, or pollution of, natural resources as a real right. Simms (2001, p.163.) explains, "No one owns the atmosphere yet we all depend on it. So we can assume that we all have an equal right to its services – an equal right to pollute". The right to dispose of the rights to these resources, between countries, is suggested by environmentalists as a mechanism to place a realistic value or cost on the use of natural resources. In the context of air pollution, the term "carbon credits" is used to describe

this approach. Simms (2001, p.163.) notes that industrialised countries generate more than 62 times more carbon dioxide pollution than the least developed countries and as a result, these countries are “running up a massive carbon debt”.

Whilst these and other proposals have individual merits, before financial sustainability can be assessed in a realistic manner, an agreed framework for assessing the real costs, to society, of the use of non-renewable or scarce natural resources is required.

### **7.3 A Review of the Sustainability of the Models Proposed for the EMA**

Chapter 2 of this study established that the provision of piped and wired service connections, under present conditions, have serious environmental consequences or represent the ‘on tap’ supply of scarce resources and is therefore not sustainable in the longer term. However, the mere fact that one service provision system is found to be unsustainable does not necessarily imply that alternative proposals are sustainable.

The theoretical models proposed in chapters 4, 5 and 6 must therefore be reviewed in terms of the guidelines for achieving sustainability, discussed in chapter 2. Having discussed economic sustainability in 7.2, the social and environmental systems are reviewed using the principles proposed by Mitchell *et al.* (1995).

#### **7.3.1 Futurity**

Chapter 2 of this study has established that unless the earth’s natural fresh water supplies are conserved, water is used more frugally and alternative sources of water are found, the earth will be no longer be able to support the ever increasing population levels. Rainwater harvesting is ancient technology that represents an alternative source of domestic water supply without

consequential environmental effects, thereby allowing the access of future generations to water.

Similarly, the earth's atmosphere cannot regenerate itself at the rate at which it is being polluted. Energy production by the burning of coal in South Africa contributes significantly to these pollution levels. Solar energy converted into electricity represents a pollution free source of electricity, thereby contributing to improved future air quality with obvious benefits to future generations.

On site domestic sewerage treatment removes from future generations the burden of an accumulation of sludge and the associated problems of disposal.

It is submitted, therefore, that the theoretical proposals are sustainable in terms of the principle of futurity.

### **7.3.2 Environment**

The essence of environmental sustainability is the protection of the integrity of the eco-systems and the associated bio-diversity. As discussed in 7.3.1, the theoretical models proposed support the reduced dependence on non-renewable natural resources, reduced air pollution levels and lessen usage of natural resources such as water and land necessary for eco-system survival.

It is submitted, therefore, that the theoretical proposals are sustainable in environmental terms.

### **7.3.3 Public Participation**

The issue of public participation is defined as the extent to which individuals can participate in decisions affecting them. In the South African context, the culture of *Ubuntu*, discussed in chapter 2, where the interests of the community are paramount, makes public participation a complex and critical

aspect of any implementation project. The case studies analysed in this study are, for the most part, the experiences of people and families committed to the notion of autonomous housing with a desire to achieve autonomy from grid supplied services. Clearly, implementation at a community scale would not always be met with the same pioneering, 'make it work' ethos. Thus, without extremely focused public participation and support, both at a community and individual level, the implementation of the theoretical models is unlikely to be successful.

#### **7.3.4 Equity**

The issue of equity has been discussed in this study in the context of environmental justice and social equity between racial groups, the later being a highly emotive issue given the apartheid policies of South African history.

Whether or not the implementation of the proposed theoretical models represent equity or not, low income Black communities in South Africa would probably perceive the proposals as lacking in both social equity, in that more affluent communities generally use grid connected services, and environmental justice, with communities wanting equal access to natural resources and an equal 'right to pollute'. It is suggested that this perceived lack of equity will prevail until similar, alternative servicing systems are implemented in the more affluent communities of racial groups other than Black.

With the process of implementing alternative servicing systems becoming more widespread, responding to the increasing severity of the problems associated with grid connected services, discussed in chapter 2, the perceived lack of equity by low income communities will diminish.

In reality the proposals represent an exceptionally equitable system where individuals not only exercise their rights to natural resources but can determine the quantum of resource required by changing the design of the

system, in a manner that does not diminish the rights of others to a share of natural resources.

Thus, problems relating to a perceived lack of equity by low income Black communities emanating largely from South Africa's political history are likely to be short, or medium term in duration. Future changes in levels of social integration and income distribution between racial groupings will have the effect of negating, to some extent, perceptions of social inequity.

#### **7.4 Practicality of Theoretical Proposals**

As critical as the issue of the sustainability of the theoretical proposals is the ability to implement the proposals as part of a low income housing project in the EMA. Case studies have demonstrated that the proposals could be implemented, but other issues relating to practicality must be considered. A outline of these is issue is given below.

- Chapter 2 explains that the harvesting of sufficient rainfall to supply the needs of a typical household of 5 people in the EMA, requires a collection or roof area of 94 m<sup>2</sup> (see section 4.4.7). This is more than twice the roof area of the minimum 30 m<sup>2</sup> structure required in terms of the National Housing Code. Given the financial constraints of the National Housing Subsidy, such a roof area could not be provided as part of the subsidy financing.
- Clearly, the capital expenditure required for the implementation of the proposals, such as solar panels, PV panels, water tanks, electrical controllers, inverters and water tanks could not be financed by the National Housing Subsidy in its present format.
- The additional land required for the accommodation of rainwater collection areas, solar and PV panels, water storage tanks and grey water drainage would require substantially larger sites than those

typically provided in low cost housing projects. The relationship between housing density and piped or wired service connections is discussed in chapter 1.

- Case studies indicate that only in isolated cases have the alternative methods of servicing been employed without a 'back-up' supply. The variation in rainwater levels for the EMA, highlighted in chapter 3, demonstrate that some form of alternative water supply would be necessary in the event that rainwater harvesting was used. Given that the theoretical model designs are based on average weather and climatic data, such as solar radiation, the need for some form of back-up service supply is indicated where severe deviations from the mean are experienced. This observation negates, to some extent, the advantage of autonomous service systems in that reticulated services must be supplied as a back-up system.
- From the perspective of the householder, the use of alternative service systems represents new technology and systems. Intensive training in the use of the equipment would be required prior to implementation, resulting in even higher costs.

Clearly the implementation of the proposals would be not be practical in a low income housing project in the EMA, given the existing conditions and constraints.

## **7.5 Testing the Hypothesis**

The hypothesis as stated in chapter 1 is restated.

***That sewer, water and electricity service connections, supported by a piped or wired reticulation network, provided to low income housing in the EMA can be replaced with alternative forms of service provision, without reducing the quality of the service provided, in***

***an urban environment, thereby achieving a more sustainable form of development.***

A review of the hypothesis, based on issues investigated in this study, indicates that the hypothesis is invalid, for the following reasons.

- Whilst it may be technically feasible to implement alternative service supply systems, the capital cost of the equipment could not be financed from National Housing Subsidy funding in terms of existing subsidy arrangements.
- The quality of service provided, in terms of the capacity of the systems to deal with peaks of demand, would not be equal to that of conventional systems without a back-up supply system.
- The perceived lack of social equity by low income Black communities would result in resistance to implementation in the short to medium term.

## **7.6 A Review of the Research Objectives**

The primary objective, that of identifying alternative autonomous servicing systems that could be implemented as part of low income housing projects, has been achieved. These theoretical proposals are detailed in chapters 4, 5 and 6. In addition, the proposals constitute sustainable development in terms of the existing frameworks and definitions. The issue of social equity would apply equally to any alternative system and therefore does not impact on the research objectives.

A review of the secondary objectives indicates that all secondary objectives have been achieved. The practicality, sustainability, contribution and usefulness of the proposed alternative theoretical models have been investigated and defined.

## **7.7 Recommendations**

The fact that the hypothesis has been proved to be invalid does not undermine the importance of the use of alternative systems or imply that the theoretical systems proposed should not be implemented. Clearly changes in government and local authority policy as well as public perceptions will be required. Based on the research, a number of recommendations are made which, if implemented, would facilitate the use of alternative servicing systems.

- The capital investment for equipment necessary for the use of alternative servicing systems should be subject to taxation or municipal rates rebate to encourage such investment by individuals. This would decrease the effective capital cost rendering 'pay-back' periods of shorter duration with more obvious, short-term benefits to consumers.
- Alternative forms of service connections, such as an electricity export / import connection or a trickle feed connection for the purpose of recharging storage batteries, should be investigated. These connection types could constitute back-up services at a reduced consumption level and cost of installation
- The cost of excessive use of resources such as electricity and water should reflect the inherent problems with their provision. Whilst the block pricing systems used by the Ethekewini Municipality reflects this approach, the consumption charges do not reflect the seriousness of the situation.

- Public information campaigns, informing the public in respect of issues such as the global and national water crisis, should be sponsored and implemented by the government.

The implementation of these recommendations would facilitate the use of alternative servicing systems and validate the hypothesis.

## References

Alcock, P.G. (1985)

*The Upgrading of domestic rainwater systems in peri-urban / rural KwaZulu*

University of Natal, Pietermaritzburg

Anderson, B. (1977)

*Solar Energy: Fundamentals in Building Design*

McGraw Hill Book Company

Bailey, T. (2000)

*Durban Metro: Deep Sea Sewerage Outfalls*

Paper presented at the Biennial Conference of the Water Institute of Southern Africa,  
May 2000

Barlow, M. (2001)

*Dying for a Drink – Water in Take it Personally: How Globalisation effects you and  
powerful ways to challenge it*

HarperCollins Publishers Ltd, London

Beckman, W.A., Klein, S.A. and Duffie, J.A. (1977)

*Solar Heating Design by the f-chart Method*

John Wiley & Sons

Bond, P. (2002)

*Unsustainable South Africa, Environment, Development and Social Protest*

University of Natal Press, Pietermaritzburg

Bright, C. (2003)

*A History of our Future in State of the World 2003: Progress Towards a Sustainable  
Society*

Earthscan Publications Ltd, London

Bruggemans, C.W. (2003)

*Change of Pace: South Africa's Economic Revival*

Wits University Press, Johannesburg

Bryant, B. (1995)

*Environmental Justice: Issues, Policies and solutions*

Island Press, Washington

Bullard, R.D. (2001)

*Environmental Justice in the 21<sup>st</sup> Century*

Environmental Justice Resource Centre, Washington

Cairncross, S. and Feachem, R. (1993)

*Environmental Health Engineering in the Tropics*

John Wiley & Sons, Chichester

Calnan, C. (1978)

*Blowing Around the World in Must the World Run Out of Energy*

The Crown Agents for Oversea Governments and Administrations, London

Campbell, L.A., Coleman, T. and Brooksbank, L. (2001)

*Options for the Interception and Appropriate Treatment of Urban Runoff*

South African Water Research Commission, Report No. 598/2/01

Capra, F. (1997)

*The Web of Life: A new synthesis of mind and matter*

Flamingo, HarperCollins, London

Cato Manor Development Association (1997)

Greater Cato Manor Structure Plan : Second Draft

Unpublished Planning Document

Chauliaguet, C., Baratsabal, P. and Batellier, J.P. (1977)

*Solar Energy in Buildings*

John Wiley & Sons

Chetty, S. (2002)

*An Ecological Approach to Wastewater Biosolids Management: Results from a study of the sludge lagoon at Dassenhoek Wastewater Treatment works.*

Paper presented at the Biennial Conference of the Water Institute of Southern Africa, May 2002

City of Durban (1986)

Town Planning Scheme Regulations

Composting Toilet World [Online], 2004, Available:

[www.compostingtoilet.org](http://www.compostingtoilet.org) [30 May 2004]

CSIR (2002)

*Agenda 21 for Sustainable Construction in Developing Countries : A discussion document*

Council for Scientific and Industrial Research, Pretoria

Curwell, S. and Cooper, I. (1998)

*The implications of urban sustainability*

Building Research and Information

Daglish, J. (1978)

*Hopes and Fears of Nuclear Energy in Must the World Run Out of Energy*

The Crown Agents for Oversea Governments and Administrations, London

Daly, H. (1996)

*Beyond Growth: The Economics of Sustainable Development*

Beacon Press

Department of Community Development (1979)

*Community Development: The South African Scene*

Hortors & CTP, Johannesburg

Department of Housing (2000)

*National Housing Code*

The Government Gazette, Pretoria

- Department of Housing (2002)  
*Towards Sustainable Development : Case Studies from South Africa*  
STE Publishers, Pretoria
- De Villiers, D.C. (1987)  
*Septic Tank Systems*  
NBRI Report, BOU 93, CSIR, Pretoria
- Dunster, B. (2003)  
*From A to ZED: Realising Zero (fossil) Energy Developments*  
Bill Dunster Architects ZEDfactory Ltd, London
- du Plessis, C. (2001)  
*Sustainability and sustainable construction; the African context*  
Building Research and Information 29, Pretoria
- Earthlife Africa (2001)  
*Other Energy Related Developments*  
Earthlife Africa, Johannesburg
- Envir-o-cell (2004)  
On-Site Sodium Hypochlorite Generators: Technical Brochure  
Natal Eagle CC Manufacturers
- Ethekwini Municipality (1996)  
*Minimum Residential Standards for Residential Development Schemes*  
Urban Development Section
- Ethekwini Municipality [Online], 2004, Available:  
[www.durban.gov.za](http://www.durban.gov.za) [29 April 2004]
- Fellows, R. and Liu, A. (1997)  
*Research Methods for Construction*  
Blackwell Science

Gaudy and Gaudy (1980)

*Microbiology for Environmental Scientists and Engineers*

McGraw-Hill Inc., New York

Getches, D.H. and Pellow, D.N. (2002)

*Beyond "Traditional" Environmental Justice in Justice and Natural Resources : Concepts, Strategies and Applications* (Edited by Mutz, K.M., Bryner, G.C. and Kenney, D.S.)

Island Press, Washington

Graham, P. (2003)

*Building Ecology : First Principles for a Sustainable Built Environment*

Blackwell Science Ltd.

Hall, D. and Page, J. (1978)

*Solar Power in Must the World Run Out of Energy*

The Crown Agents for Oversea Governments and Administrations, London

Hawken, P. (1994)

*The Ecology of Commerce: A Declaration of Sustainability*

HarperBusiness

Hellevik, O. (1984)

*Introduction to Causal Analysis: Exploring Survey Data by Crosstabulation*

George Allen & Unwin, London

Hill, R.C. and Bowen, P.A. (1997)

*Sustainable construction : principles and a framework for attainment*

Construction Management and Economics

Hindson, D., King, N. and Peart, R. (1996)

*Durban's Tomorrow Today: Sustainable Development in the Durban Metropolitan Area*

Durban Metro Council

Hinrichson, D., Robey, B. and Upadhyay, V.D. (1997)

*Solutions for a Water Short World*

World Resources Institute, Washington

Howell, D. (1979)

*Your Solar Energy Home including Wind and Methane Applications*

Pergamon Press

Humphreys, M.A. (1978)

*Outdoors Temperatures and Comfort Indoors*

UK Building Research Institute

Hunt, E.H. (2004)

*Thirsty Planet, Strategies for Sustainable Water Management*

Zed Books Ltd, New York

Kasrils, R. (2004)

*Water: Washing Away Poverty*

South African Department of Water Affairs and Forestry

Klomac Engineering (2004)

*Filter Specifications for Candle Filters*

Technical Brochure

Kimber, G. (2004)

*Personal Interview, 26 April 2004*

Lambeth, J. and Delap, J.D. (1977)

*Solar Designing*

Privately Published

Lovins, H. and Link, W. (2001)

*Insurmountable Opportunities – Steps and Barriers to Implementing Sustainable Development*

Rocky Mountain Institute, Colorado

May, T. (1997)

*Social Research: Issues, Methods and Process*

Open University Press

Mbeki, T. (2002)

*Address by the President of the Republic of South Africa, on the Occasion of the Torch Handing over Ceremony*

Rio de Janeiro, 25 June 2002

McCartney, K. (1978)

*Practical Solar Heating*

Prism Press

Melville, S. and Goddard, W. (1996)

*Research Methodology: An Introduction for Science and Engineering Students*

Juta & Co Ltd

Mitchell, G., May, A. and McDonald, A. (1995)

*PICABUE : a methodical framework for the development of indicators of sustainable development.*

International Journal of Sustainable Development and World Ecology.

Møller, V., Schlemmer, L., Kuzwayo, J. and Mbanda, B. (1978)

*A Black Township in Durban: A study of needs and problems*

University of Natal

Morris, P. (1981)

*A History of Black Housing in South Africa*

South Africa Foundation

Murphy, K.O.H. (2000)

*Guidelines for Sustainable Reuse of Effluent on Land – A suggested approach*

Paper presented at the Biennial Conference of the Water Institute of Southern Africa, May 2000

Natal Mercury, 5 October 2001

*Bacteria and Faecal counts “unacceptable”, Bathing beaches fail laboratory tests.*

Nicol, F., Jamy, G. N., Sykes, O., Humphreys, M., Roaf, S. and Hancock, M. (1994)  
*A Survey of Thermal Comfort in Pakistan: Towards New Indoor Comfort Standards*  
Oxford Brooks University

Oxford Universal Dictionary (1981 edition)  
Oxford University Press

Pacey, A. and Cullis, A. (1986)  
*Rainwater Harvesting: The Collection of Rainfall and Runoff in Rural Areas*  
IT Publications

Palmer, I. and Eberhard, R. (1994)  
*Evaluation of Water Supply to Developing Urban Communities in South Africa: Phase 1 – Overview*  
South African Water Research Commission, Pretoria

Palmer, J., Cooper, I. and van der Vorst, R. (1997)  
*Mapping out funny buzzwords – who sits where on sustainability and sustainable development*  
Sustainable Development Volume 5

Pearson, I. and La Trobe, B. (1999)  
*Co-disposal and Composting of Septic Tank and Pit Latrine Sludges with Municipal Refuse*  
South African Water Research Commission, Pretoria, Report 599/1/99

Piani, C.B. (1998)  
*Novel, Easy to Use Energy Saving Guidelines for South Africa*  
Ph.D. Thesis, Department of Mechanical Engineering, University of Pretoria

Pike, A. (1994)  
*The Autonomous House Research Programme*  
Cambridge University

Potts, M. (1993)

*The Independent Home*

Chelsea Green Publishing Company, Vermont

Potts, M. (1999)

*The New Independent Home: People and Houses that Harvest the Sun, Wind, and Water*

Chelsea Green Publishing Company, Vermont

Project Management Project Databases

Unpublished Database Information used for Management of Projects

Republic of South Africa (1996)

*The Constitution of the Republic of South Africa, Act 108 of 1996*

The Government Gazette, Pretoria

Republic of South Africa (1997)

*The Housing Act, 107 of 1997*

The Government Gazette, Pretoria

Republic of South Africa (1998a)

*National Water Act, Act 36 of 1998*

The Government Gazette, Pretoria

Republic of South Africa (1998b)

*National Environmental Management, Act 107 of 1998*

The Government Gazette, Pretoria

Rich, L.G. (1980)

*Low Maintenance, Mechanically Simple Wastewater Treatment Systems*

McGraw-Hill Inc.

Roaf, S., Fuentes, M., and Thomas, S. (2001)

*Ecohouse: A design guide*

Architectural Press

Robert, K-H., Daly, H., Hawken, P. and Holmberg, J. (1995)

*A compass for sustainable development*

The Natural Step for Britain, Bristol

Robinson, P., Sullivan, T. and Lund, S. (1994)

*Assessment of IDT's Capital Subsidy Scheme*

Unpublished report prepared for the IDT

Robson, C. (2002)

*Real World Research* (Second edition)

Blackwell Publishing

Roddick, A. (2001)

*Take it Personally: How Globalisation affects you and powerful ways to challenge it*

HarperCollins Publishers Ltd., London

Rohmann, C. (2000)

*The Dictionary of Important Ideas and Thinkers*

Arrow Books, UK

Serykh, R.L. and Bagrov, B.O. (1994)

*Technology of Production of Unburnt Pelletized Concrete Aggregates with the use of wastes of urban sewerage treatment plants.*

Sustainable Construction, Proceedings of the First International Conference of CIB

TG 16, Page 435

Simms, A. (2001)

*Choking on an Invisible Debt in Take it Personally: How Globalisation affects you and powerful ways to challenge it*

HarperCollins Publishers Ltd., London

South African Bureau of Standards

*SABS 241-1984 Specification for Water for Water for Domestic Supplies*

SABS, Pretoria

South African Census (2001)

Department of Statistics, Pretoria

South African Yearbook, [Online], 2004, Available:  
<http://www.gov.za> [30 April 2004]

Strauss, A. and Corbin, J. (1990)  
*Basics of Qualitative Research: Grounded Theory Procedures and Techniques*  
Sage Publications

Steadman, P. (1975)  
*Energy, Environment and Building*  
Cambridge University Press, Cambridge

Szokolay, S.V. (1997)  
*Solar Energy and Building (2nd Edition)*  
Halstead Press

Talbott, J.L. (1993)  
*Simply Build Green*  
Findhorn Press, Scotland

Terblanche, J. (2001)  
East Rand Water Care Company  
Interview  
20 November 2001

Teurlings, P.M.F.G., Begg, G.W., Schleyer, M., Carter, R., Schreiner, G., Visser, G.A., Howard, M.R., Matsabu, M.M. and Winters, H.N.S. (1997)  
*Southern Metro Wastewater Disposal Study, Volume 2, Pages 2 and 3.*  
Durban Metropolitan Council

Tolba, M.K. (1992)  
*Saving our Planet: Challenges and Hopes*  
Chapman & Hall

The Environmental Monitoring Group: Western Cape (1992)  
*Towards Sustainable Development in South Africa: A discussion paper*  
The Environmental Monitoring Group

United Nations Environmental Programme (1983)

*Rain and Stormwater Harvesting in Rural Areas*

Tycooly International

United Nations Environmental Programme (1998)

*Sourcebook of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean*

International Environmental Technology Centre, Nairobi

United Nations (1992) Department of Economic and Social Affairs

*Agenda 21*

Chapter 28

United Nations (2002)

Johannesburg Summit Press Release, September 2002

United Nations: Commission on Sustainable Development (2003)

*Follow up to Johannesburg and the future role of the CSD – The Implementation Track*

Report of the Secretary General, 18 February 2003

Urban Foundation (1977)

*African , Indian and Coloured Housing in the Durban – Pietermaritzburg area, December 1997.*

The Urban Foundation (Natal Region)

Uba, B.N. and Aghogho, O. (2000)

*Rainwater Quality from different Roof Catchments in the Port Harcourt district, Rivers State, Nigeria*

AQUA 49

U.S. Environmental Protection Agency (Office of Environmental Justice) (1998)

*Final Guide for Incorporating Environmental Justice Concern's in EPA's NEPA Compliance Analyses*

- Vale, B. and Vale, R. (1975)  
*The Autonomous House: Design and Planning for Self-sufficiency*  
Thames and Hudson, London
- Vale, B. and Vale, R. (2000)  
*The New Autonomous House*  
Thames and Hudson, London
- Van Niekerk, P (2000)  
*Water Resources Availability and Utilisation in South Africa*  
South African Department of Water Affairs and Forestry.
- Visser, W. and Sunter, C. (2002)  
*Beyond Reasonable Greed: Why Sustainable Business is a Much Better Idea*  
Human & Rousseau and Tafelberg Publishers, Cape Town (Joint Publishers)
- Watt, S.B. (1984)  
*Septic Tanks and Aqua-Privies from Ferrocement*  
Immediate Technology Publications
- Weaver, D. (1999)  
*Living with a House in The New Independent Home: People and Houses that Harvest the Sun, Wind, and Water*  
Chelsea Green Publishing Company, Vermont
- White, E. (1992)  
*The Voice of Renewable Energy in Canada*  
Solar Energy Society of Canada (Journal), November / December 1992
- World Bank (1994)  
*World Development Report 1994: Infrastructure for Development*  
Oxford University Press, New York
- World Bank (2000)  
*African Region Environmental Strategy – Draft 9/1/00*  
World Bank, Washington D.C.

World Commission on Environment (The Brundtland Report) (1987)  
*Our Common Future*  
Oxford University Press

Wright, A. (1999)  
*Guidelines for the Use of Septic Tank Systems in the South African Coastal Zone*  
South African Water Research Commission, Report No. TT114/99

Wright, D. (1978)  
*Natural Solar Architecture: A Passive Primer*  
Van Nostrand Reinhold Company

## Bibliography

Campbell, W.G., Ballou, S.V. and Slade, C.S. (1990)

*Form and Style; 8<sup>th</sup> edition*

Houghton Mifflin Company, Boston

Daly, H.E. (1999)

*Ecological Economics and the Ecology of Economics*

Edward Elgar Publishing Limited, UK

Harland, E. (1993)

*Eco-Renovation: The ecological home improvement guide*

Green Books Ltd

Hawkes, D., Owers, J., Rickaby, P., and Steadman, P. (1987)

*Energy and Urban Built Form*

Butterworths

Leben, R.M. (1980) (editor)

*Passive Solar Architecture in Europe: The results of the first European passive solar competition*

The Architectural Press Ltd: London

Reid, D. (1995)

*Sustainable Development*

Earthscan Publications Ltd, London

Renewable Energy World (Journal);

Sept/Oct 2001 Edition

James and James (Science Publications) Ltd, UK

Sterling, R., Carmody, J. and Elnicky, G. (1981)

*Earth Sheltered Community Design: Energy Efficient Residential Development*

Van Nostrand Reinhold Company

Storey, J.B. (1994)

*Eco-house: an environment, user, context friendly home.*

Sustainable Construction, Proceedings of the First International Conference of CIB

Tully, G.F. (1981)

*Solar Heating Systems; "Analysis and design with the Sun-Pulse Method"*

McGraw Hill Inc

Vale, B. and Vale, R. (1991)

*Towards a Green Architecture*

RIBA Publications Ltd