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The Worth of Water

Designing Climate Resilient Rainwater Harvesting Systems

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Foreword

At the time of writing, the world faces two challenges to our continued existence on the Earth, the Covid19 pandemic and the global impacts of climate change. The worldwide response to both has been informed by science. Science provides evidence and advice, prompting governments to act and business and individuals to respond.

The worldwide adaptations we humans have made to combat Covid19 show how a shared global framework, informed by scientific evidence and advice, can motivate radical action. The Covid19 response proves that when faced with an existential threat to our survival, we humans can change how we act, how we think and how we interact. On the other hand, the pandemic appears to have pushed all discussion of climate change, and the corresponding individual lifestyle and governance changes required, down the priority list.

Numerous scientific reports have shown evidence of the impacts of global warming and of the necessary actions needed to keep within 1.5–2°C limits. The scientific approach to policy change to date has been to provide evidence and data to support an informed debate and trust our politicians, legislators and business leaders to act accordingly. The Covid19 response features government action and lifestyle interventions to combat the effects of the public health emergency. This has not been the case with climate change.

Low income countries across the world are characterised by low levels of daily income, lack of adequate housing, water and sanitation infrastructure, limited health capacities and weak governance. High income countries in the so-called developed world have not prioritised this cohort of our brothers and sisters who face the brunt of climate change. On the contrary, reduced development budgets from wealthy countries have accentuated and promoted divisions and inequalities in these countries. In terms of addressing climate change, middle and high income countries have turned inwards. The rich world which has reached a high level of income largely founded on the use of non-renewable resources is in effect pulling the ladder up after it and leaving low income countries to fend for themselves.

The utilisation and distribution of the planetary resources is not shared equally. It is estimated that humanity needs 1.7 Earths to meet present consumption, with some high income countries needing the equivalent of 4 Earths to sustain their current lifestyle. In the face of this, there is a need for low income countries, and for the communities that make up these nations, to develop resilience. Resilience is the ability of a community to cope with destabilizing forces. In terms of water supply, sanitation and hygiene, this will mean increased reliance on self-supply. Decentralised technology in the areas of water supply and storage, used water treatment and water reuse will lead to a plug-and-play world where locally available materials will be adapted to each biosphere, with systems designed, maintained and operated by locals. A feature of these systems will be the safe and efficient harvesting of rainwater.

Water has been central to the ability of societies to blossom. The collapse of many ancient civilisations and cultures was due, in no small part, to local water-related shocks. The current challenges that the society is facing are more complex and dangerous, the threat occurring at both local and global level.

The worth of water is a combination of the value of water, as a life-support system, and the value in water, as the basis of economic life. The future will see the worth of water becoming central and will involve water being at the centre of all government and economic decisions. Recognising this is the foundation of combating the current pandemic and climate change and creating the conditions necessary for our planet to support all its children sustainably and within the planetary boundaries.

> Thousands have lived without love, none without water.
>
> W.H. Auden.

Preface

Living as we are in a post climate change era, adaption and innovation are terms that point the way toward the future. The world needs to adapt to new climatic patterns. These new climatic conditions threaten the very survival of some countries, they threaten our cities and communities and they threaten our ability to feed ourselves. Given the importance of water in the lives of all humans, we simply cannot live without it; it is no surprise that major changes are occurring in how we use water. The first chapter considers the historical concept of the Linear Economy of Water (LEW). It goes on to show how the increased emphasis on sustainability and global demographics led to the adoption of the Circular Economy of Water (CEW). This lays the emphasis on recycling and reuse of water and views water and all of the contents of domestic, industrial and agricultural waters as a resource. The CEW also considers multiple water sources including surface water and ground water together with alternative sources such as rainwater, brackish and saline water, brines, and used water. These sources of different water qualities are available for different water use applications. Therefore, the CEW supplies multiple waters for multiple purposes for multiple users. In contrast to the LEW, which focused on supplying potable water quality, the CEW deals with varying water qualities and the principle of multiple waters gives rise to the term "fit for purpose". This denotes that the water from the used water source can be utilised by an application without the used water requiring treatment.

Water and its properties are a function of its peculiar molecular structure. Chapter 2 presents this molecular structure of water and discusses how this structure influences the behaviour of the water molecule. The influence of polarity and hydrogen bonding on the three states of water and other properties of water such as density, cohesion, adhesion and surface tension are also discussed. The high heat energy required to warm water and its role in moderating the Earth's climate and the effect that increased temperatures have on the global system are examined. Finally, the unique properties of water as a universal solvent are presented.

Water quality, potable water production, water quality parameters and the treatment processes involved in potable water production are presented in Chap. 3. The means of removing these parameters, referred to as the removal mechanisms, are defined. There is also discussion on the type of treatment afforded and the parameters removed. The role of these removal mechanisms in a conventional rainwater harvesting system is presented. The location of the removal mechanisms in the rainwater harvesting system is emphasised.

The term "the worth of water" was developed to reflect the importance of the social life of water. Chapter 4 presents a technology portfolio of the worth of water from the ancient world to the present. In contrast to the present global situation, ancient cultures were aware of the worth of water and the importance to society of the social life of water. Case studies are presented from these cultures showing the technology and the importance of this technology to the very existence of these cultures. Ancient technologies from Iran, Peru and Yucatan are illustrated. The chapter goes on to examine examples of the worth of water and their suitability and importance to developing countries. A particular example of an innovative method of promoting water and water technologies in developing countries is presented in a village technology education centre. Finally, the chapter presents case studies of rainwater harvesting systems and their adaptation in the developed world and such modern countries as Singapore and South Korea.

Rainwater harvesting (rwh) technology captures water and conveys it to storage. Chapter 5 considers the water flows in a typical roof rwh system. The components of the rwh system are also discussed. A summary of the three types of roof rwh systems – direct system, gravity system and indirect systems – is presented as are some alternative methods of rwh systems which utilise ground-based systems for irrigation water or groundwater recharge. These include lined underground reservoir, contour ridges, contour stone bunding, terracing contour bunds, permeable rock dams, recharge pits/trenches and check dams.

The health implications of using rwh are an important consideration, and Chap. 6 investigates if domestic water supply systems supplied with harvested rainwater present an increased risk to health over systems supplied with potable mains water. Several studies are reviewed which conclude that the main risk to public health of mains-supplied hot water systems is the operation, maintenance, age, location and temperature of the system. Rainwater harvesting systems contain an inherent water treatment train which improves the water quality at different parts of the rwh system. Results from laboratory experiments conducted using a variety of water-related bacteria to determine the time required to reduce a bacterial population by 90% at a given temperature are compared with international studies. The results show that after 5 min of exposure at 60 and 55 °C, respectively, Salmonella and Pseudomonas aeruginosa and total viable count at 22 and 37 °C concentrations were reduced to zero. The conclusion from this chapter is that hot water systems supplied with harvested rainwater do not present an increased risk to health over hot water systems fed with mains water.

A design methodology to establish if rwh is feasible and to enable the designer to select the optimum rwh storage tank size is presented in Chap. 7. The design methodology consists of two stages. Stage 1 involves the designer establishing the hydraulic efficiency for a site. This involves calculating the rwh demand profile and rwh supply profile for this location. The supply coefficient is then established which is defined as the percentage of demand that the rwh system can supply for a selected time period. Stage 2 involves the designer calculating the optimum rwh storage tank volume. This can be established according to one of three methods, basic method, intermediate tabular method and/or a detailed daily storage model. A number of worked examples are detailed to explain the design methodology.

Chapter 8 presents a number of financial management tools which can be used to evaluate the economic performance of a rwh system. The simple payback period is used to determine the length of time a rwh investment reaches a break-even point. This is calculated by dividing the initial cost of the investment by the annual savings generated. The second tool discussed is the net present value (NPV) method, which takes into account the time value of money to evaluate the cost of ownership of a rwh system over its entire lifetime. The third technique discussed is where the cost of ownership over the lifetime of an asset is annualised and the equivalent annual cost (EAQ) is calculated. A series of worked examples are presented which compare the costs of a rwh system compared to various alternative public water supply options.

The Sustainable Development Goals (SDGs) and the importance of water within each of the goals is addressed in Chap. 9. The fundamental concept of sustainable development is discussed within the growing uncertainties of climate change and global population growth. The SDGs have the potential to form a template for development, and the importance of water within each goal is addressed. Finally, a critical review of the SDGs is presented. Some of the contradictions inherent within the SDG agenda are discussed and critically evaluated.

Build Solid Ground is a project funded by the European Union Development Education and Awareness (DEAR) programme and implemented by a consortium of 14 organisations from seven EU countries. The focus of the project is building critical understanding and active engagement for sustainable development goal 11, “sustainable cities and communities”. Chapter 10 investigates the key components necessary to achieve a resilient city and community.

Chapter 11 presents a detailed discussion of the planetary boundaries. This is a framework, based on science, which identifies nine processes and systems that regulate the stability and resilience of the Earth system and the interactions of land, ocean, atmosphere and life that together provide conditions upon which our societies depend. The planetary boundaries (PBs) framework arises from the scientific evidence that the Earth is a single, complex, integrated system. Each of the planetary boundaries, climate change, biodiversity loss, stratospheric ozone depletion, ocean acidification, nutrient cycles, land system change, freshwater use, atmospheric aerosol loading and chemical pollution are discussed in detail in this chapter.

Human societies have been adapting to their environments throughout history by developing technology, cultures and livelihoods which are suited to local conditions. Climate change raises the possibility that existing societies will experience climatic shifts that previous experience has not prepared them. Chapter 12 discusses the role of rwh to enable society to adapt to climate change. It examines the fact that present infrastructure, with a maximum lifespan of 30 years, will not be the infrastructure of the future. Grey, green or hybrid infrastructure and the increasing role to be played by decentralised systems are examined. The role of rwh technology in future systems is compared to the role played by wind and solar energy resources. The chapter discusses that though rwh will not supply 100% of water demand, it can supply a substantial alternative source of water. The potential in developing countries for rwh technology to provide the opportunity to leapfrog capital-intensive water projects by going straight to decentralised water collection systems is stressed. The role of multiple waters in climate adaption is examined as is the concept of peak water. Finally, the potential for rwh technology to facilitate the rebalancing in society of the human technology environment nexus is addressed.

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Introduction

Organisation of the Book

The book is presented in three parts. Chapters 1, 2, 3, and 4 discuss some of the scientific principles and core concept within the book. Chapters 5, 6, 7, and 8 assess some of the technical, economic and health aspects of rainwater harvesting systems. Chapters 9, 10, 11 and 12 then discuss rwh within the context of sustainable development and climate adaption.

Chapter 1 introduces the concepts of the linear economy of water (LEW), the circular economy of water (CEW), the worth of water and multiple waters. In contrast to the LEW, which focused on supplying potable water quality, the CEW deals with varying water qualities, and the principle of multiple waters gives rise to the concept that the use of the water governs the water quality. Chapter 2 presents the molecular structure of water and discusses how this structure influences the behaviour of the water molecule. Water quality, potable water production and water quality parameters and the treatment processes involved in potable water production are presented in Chap. 3. The term "the worth of water" was developed to reflect the importance of the social life of water. Chapter 4 presents a technology portfolio of the worth of water from the ancient world to the present. Chapter 5 considers the water flows in a typical roof rainwater harvesting (rwh) system. A summary of the three types of roof rwh systems – direct system, gravity system and indirect systems – is presented as are some alternative methods of rwh systems which utilise ground-based systems for irrigation water or groundwater recharge. The health implications of using rwh are an important consideration and Chap. 6 investigates if domestic water supply systems supplied with harvested rainwater present an increased risk to health over systems supplied with potable mains water. A design methodology to establish if rwh is feasible and to enable the designer to select the optimum rwh storage tank size is presented in Chap. 7. Chapter 8 presents a number of financial management tools which can be used to evaluate the economic performance of a rwh system. The Sustainable Development Goals (SDGs) and the importance of water within each of the goals is addressed in Chap. 9. Chapter 10 gives a brief overview of the objectives of the EU DEAR project “Build Solid Ground” and the components of resilient cities and communities. Chapter 11 presents a detailed discussion of the planetary boundaries. This is a framework, based on science, which identifies nine processes and systems that regulate the stability and resilience of the Earth system and the interactions of land, ocean, atmosphere and life that together provide conditions upon which our societies depend. Chapter 12 discusses the role of rwh to enable society to adapt to climate change.

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The Worth of Water

1.1 Introduction

The way we view water has changed over the last decade of the twentieth century and the first decades of the twenty-first century. Previously water was subject to a linear form of treatment where it was abstracted, treated before use to drinking water (potable) standards, used and treated again before finally being discharged back to the environment through ground or surface water. Water Engineering involved the identification and evaluation of raw water sources, with a view to using a water source that required minimal treatment to remove natural pollutants such as nitrates. This raw water was then impounded, sometimes in reservoirs or dams. Quality issues arose in depth of draw off, as spring and autumn turnovers in the impounded water gave rise to chemicals being dissolved in the water and requiring treatment. All impounded water was then treated in water treatment plants to potable water quality standards.

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