ABSTRACT

ENHANCING CHARACTERIZATION OF WATER USE PRACTICES
IN CEMENT MANUFACTURING AND RELATED CONSTRUCTION SECTORS

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This work presents an investigation into water use patterns for cement manufacturing, ready-mixed concrete production, and buildings under construction and after occupation. Cement is the main component in making concrete, which is the most widely used structural building material in the world, and therefore plays an important role in global water use in the construction sector. The data collection methodology included review of refereed journals, analysis of published Corporate Social Responsibility Reports from worldwide cement companies, as well as case studies conducted in two cement plants (one in Brazil and one in Canada), thus incorporating real-world operating conditions. Analysis of water usage at ready-mixed concrete plants and buildings under construction and after occupation was also undertaken in Brazil.

Water use at the two cement plants ranged from 250 to 2,000 litres per tonne of cement (compared to reported 147 to 3,500 L/tonne), indicating a wide range in water use
patterns. Eleven stages of water use were identified for cement manufacturing, but accurate water use data could not be obtained for all these stages. Identifying and implementing water saving opportunities in cement manufacturing was hampered by a lack of reliable water use data. To address this, an approach was developed for categorizing levels of data reliability according to methods of data acquisition, and this approach was used to characterize the reliability of data compiled during this research. Reliability for the collected data in this study was then characterized to be between A+ to C-. The proposed data reliability approach can help improve data collection, reporting and decision-making around water conservation, both locally within manufacturing facilities and on jobsites, and at the level of governmental policy.

This work therefore contributes to the field of water management by (a) shedding light on the lack of water usage data availability and reliability in the globally important sectors of cement manufacturing, concrete production, and buildings under construction and after occupation; (b) proposing an approach for improving the reliability of water usage data; (c) suggesting steps to improve knowledge of water usage in various sectors of construction industry; and (d) promoting best water management practices in this field.
DEDICATION

This work is dedicated to my son Emanuel.

“Water and cement when mixed together can turn into many shapes; even into a PhD dissertation.”

– Stella and Emanuel Cruz Bezerra.
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LIST OF ABBREVIATIONS

CEMBUREAU – The European Cement Association
CIB - International Council for Research and Innovation in Building and Construction
CSI – Cement Sustainability Initiative
CSR – Corporate Social Responsibility Report
EPD – Environmental Product Declaration
EN – Environmental Indicator of the Global Reporting Initiative
GDP - Total Gross Domestic Product
GRI – Global Reporting Initiative
GWT – Global Water Tool
KPI – Key Performance Indicator
LCA – Life Cycle Assessment
NOx – Nitrogen oxides
PH - Preheater tower
Psi - Pounds per square inch
SNCR – Selective non-catalytic reduction
WBCSD – World Business Council for Sustainable Development
WWTP – Wastewater treatment plant
CHAPTER 1
INTRODUCTION

Of all our natural resources water has become the most precious. By far the greater part of the earth’s surface is covered by its enveloping seas, yet in the midst of this plenty we are in want. By a strange paradox, most of the earth’s abundant water is not usable for agriculture, industry, or human consumption because of its heavy load of sea salts, and so most of the world’s population is either experiencing or is threatened with critical shortages. In an age when man has forgotten his origins and is blind even to his most essential needs for survival, water along with other resources has become the victim of his indifference.

– Rachel Carson, Silent Spring, 1962

1.1 Statement of the Problem and Significance

The research described in this dissertation presents an investigation into water usage by several sectors of the construction industry, including cement manufacture, concrete production, and buildings under construction and after occupation. Water is critical to human life on Earth and of the total amount of water on the planet, approximately 97 percent is seawater; of the remaining 3 percent that is freshwater, the amount accessible for potable use is less than 0.5 percent, not to mention that it is unevenly distributed among the world’s populations (Seneviratne 2007; Wouters 2010). At the same time, there is a continuing lack of recognition of the need to conserve freshwater, especially amongst those who still have it available in sufficient quantity and quality to meet their needs (WWAP 2009). The result is that its use is often inefficient. One of the key areas of water misuse is in the construction industry.
Selection of the three sectors of the construction industry was based on consideration of cement’s use as the main component in making concrete, which is the most widely used structural building material in the world (Mehta and Monteiro 2006). The motivation for this study arises from the lack of benchmarks for water usage mainly in the cement industry but benchmarks are necessary to identify and articulate best water management practices for the construction industry.

1.2 Freshwater Availability in the World

Over the last 100 years, the world’s population has grown from 1.7 to 7.1 billion (U.S. Census Bureau 2013). There are various numbers published for the percentage of the world’s population facing some level of water scarcity, in part because the concept of water scarcity has several different definitions. However, it is generally expected that with population growth the per capita freshwater availability decreases. Figure 1.1 shows a trend for the decrease in the per capita freshwater availability, based on the planet’s volume of renewable freshwater of around 50 thousand cubic kilometres (Gardner-Outlaw and Engelman 1997) and the world’s population over the last 100 years (U.S. Census Bureau 2013).
Beyond growth in human population, other factors also interfere in freshwater availability such as climate change, higher per capita consumption and higher pollution of water (Bates et al. 2008; Gleick et al. 2009; Hoekstra and Mekonnen 2012; McDonald et al. 2011; Parish et al. 2012; United Nations 1999; Vörösmarty et al. 2010; WBCSD-IUCN 2010; Wouters 2010). It is estimated that in 2050, one billion people will live in cities with less than 100 litres of water available per person per day (McDonald et al. 2011). It is noteworthy that the cost of more advanced water treatment technologies – to overcome the loss of quality resulting from pollution – may become another factor of some people having difficulties to meet their demand for freshwater.

1.3 Water Usage in the Construction Industry

In keeping with the steady and rapid growth in global population and the rise in demand for potable water, there has been an increase in the need for housing and infrastructure
such as drinking water and sanitation facilities, transport, communications, dams, canals, roads, bridges, and tunnels. The construction sector thus becomes critical for ensuring a good quality of life. Water is central to all aspects of the construction process, not only for the manufacture of building materials and for buildings under construction, but also for operating the entire building — commonly known as the built environment or building stock — which is resource-intensive and incurs an additional large freshwater demand (CIB, UNEP-IETC and du Plessis 2002; Crawford and Treloar 2005; Mehta and Monteiro 2006). Figure 1.2 shows a schematic of such water demands.

Figure 1.2. Schematic of water demand for growing population.

It is estimated that buildings under construction and in operation account for up to 20 percent of the world's freshwater withdrawals (McCormack et al. 2007; Retzlaff 2009; Roodman and Lenssen 1995). Rating systems for these operations come mostly from green building certification, which promote the use of water saving devices such as low-flow toilets and shower heads, aerators, and self-closing faucets. Although these rating systems encourage reuse of greywater and rainwater harvesting for non-potable needs,
they do not take into account the volume of water used for the process of building construction or water consumption for building materials manufacturing (Ding 2008; Fowler and Rauch 2006; Gowri 2004; Kibert 2007; Ortiz, Castells and Sonnemann 2009; Retzlaff 2009).

1.3.1 State of the Cement Industry

Despite the global economic crisis, the global economy grew by 3.8 percent in 2011, and cement consumption grew by 3.7 percent (Lechtenberg 2012). World cement consumption was projected to reach around 3 billion tonnes per year in 2020 (Alsop 2005). It is noteworthy that in 2012, cement production was already 3.7 billion tonnes (U.S. Geological Survey 2013). Lechtenberg (2012) states that the biggest challenges for cement companies are to keep up with rapid growth in demand in developing markets, and to establish a more sustainable cement industry for the future. The next section discusses the yearly volume of cement production worldwide and provides evidence of this rapid growth in demand in developing countries and of associated water requirements.

1.3.2 Cement Production Worldwide

Data for the countries with the largest cement production for the period when data collection for this research was performed, from 2005 to 2011, but also for the year of 2012, are included in Table 1.1. The countries are ranked by the largest producers in
2012, but for some years there was a change in position. The yearly global average for cement consumption is 300 kilograms per person (Lechtenberg 2012).

Table 1.1 shows that the three largest producers for the entire period investigated, from 2005 to 2012, are China, India and the United States. China produces around 60 percent of the world’s cement. This strong demand results from economic development and the consequent demand for housing and infrastructure for its population. Not only China, but also other emerging economies, called the BRIC countries (this acronym refers to Brazil, Russia, India, and China), are showing an increase in cement production over the years. Wilson and Purushothaman (2003) from The Goldman Sachs Group, Inc. (a global investment banking and securities firm) predicted that by 2050 the combined economies of the BRIC countries will surpass the combined economies of the six richest countries of the world (the United States, Japan, Germany, Britain, France and Italy).
Table 1.1. Cement production in the world from 2005 to 2012 for the largest producers

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>MONTHLY CEMENT PRODUCTION (thousand tonnes)</th>
<th>% OF WORLD IN 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005</td>
<td>2006</td>
</tr>
<tr>
<td>China</td>
<td>1040000</td>
<td>1100000</td>
</tr>
<tr>
<td>India</td>
<td>145000</td>
<td>155000</td>
</tr>
<tr>
<td>USA (inc Puerto Rico)</td>
<td>101000</td>
<td>101000</td>
</tr>
<tr>
<td>Brazil</td>
<td>36700</td>
<td>37000</td>
</tr>
<tr>
<td>Iran</td>
<td>32700</td>
<td>33000</td>
</tr>
<tr>
<td>Vietnam</td>
<td>29000</td>
<td>33000</td>
</tr>
<tr>
<td>Russia</td>
<td>48700</td>
<td>54000</td>
</tr>
<tr>
<td>Turkey</td>
<td>42800</td>
<td>45000</td>
</tr>
<tr>
<td>Japan</td>
<td>69600</td>
<td>68000</td>
</tr>
<tr>
<td>Korea</td>
<td>51400</td>
<td>52000</td>
</tr>
<tr>
<td>Canada</td>
<td>16047</td>
<td>16550</td>
</tr>
<tr>
<td>Other countries</td>
<td>697053</td>
<td>805450</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2310000</td>
<td>2500000</td>
</tr>
</tbody>
</table>

Note: N.A. indicates that data was not available.
It should be noted that cement is a key indicator of the economic growth and social development for any country, as its consumption is linked to per capita income (CSI 2013; Lechtenberg 2012). Growth in production comes with a demand for water requirements at cement plants, but at the same time if the population is growing, their own need for water usage also raises. Competition for water resources may result, especially in countries already facing some water scarcity. Further discussion around more sustainable water usage in the construction industry is presented in Chapter 2. In terms of the demand for cement production, this consumption increases as the total gross domestic product (GDP) per capita rises above US$3 thousand, but it tends to reach a plateau with a GDP higher than US$15 thousand (Alsop 2005).

Because the current study includes a focus on cement production in Brazil and Canada (see Chapter 4, Section 4.1), some aspects related to the economy of these two countries are now discussed. A report commissioned in 2008 by the professional services and auditing firm Ernst & Young (2009), entitled ‘Sustainable Brazil – Housing Market Potential,’ presents some important data on the Brazilian construction industry, primarily for housing and sale of building materials. The report states that housing will have an important position in the Brazilian economy for the next two decades, given Brazil’s present economic upswing. The housing sector of the construction industry accounted for 3 percent of the Brazilian GDP from 1990 to 2007, and it is estimated this will increase to as much as 8 percent between 2007 and 2030 (Ernst & Young 2009).
Along with construction firms, manufacturers of building materials in Brazil are predicted to experience a growth of 5 percent yearly in the volume of sales leading up to 2017. According to that report, sales of building materials for residences in 2007 were BRL$ 69 billion (Brazilian Real) and, considering an expected growth of 5 percent per year (and disregarding inflation), this may reach BRL$ 116 billion in 2030 (Ernst & Young 2009). Therefore, the construction industry in Brazil is under strong development. Moreover, the Brazilian government’s National Growth Acceleration Programme\(^1\) launched in 2007 and currently in its second phase, is contributing to investments in housing and infrastructure. Sports buildings for hosting the World Soccer Cup in 2014, as well as the Summer Olympic and Paralympic Games in 2016, are being built, as well as the auxiliary infrastructure to support both events. An organization from the United Kingdom called The Carbon Trust has investigated the opportunities for investments in Brazil, and has recognized that sustainable building designs and the building materials market is gaining traction in Brazil, in order to improve business practices and sustainability of companies along the construction supply chain (Jennings and Beyer 2012). These last authors have also indicated that professionals with capabilities in sustainable design, including water management practices, would be well placed in the market.

The current economy in Canada is experiencing an opposite trend when compared to Brazil. The global economic and financial crisis affected the cement industry, and the years from 2008 to 2012 have had declining cement production (CAC 2013). However, the cement industry keeps a significant economic position and represents one of Canada’s\(^1\) Also known as PAC, from its acronym in Portuguese (Programa de Aceleração do Crescimento).
thirteen major manufacturing sectors, with a rise in demand expected in the coming years (CAC 2012).

1.3.3 Water Usage Measurement and Reporting for Cement Manufacture

There is little data published concerning quantities of water required for cement manufacture; data reported worldwide has varied from 147 to 3,500 litres of water per tonne of cement produced (GCC 2010; Kollar and MacAuley 1980). This variability may be explained by the differences in the process of cement manufacture, mainly related to the type of cement kiln in place. In addition, some plants consider water usage for processing but do not add any volume of water consumed by their employees and subcontracted labourers, or used outside the main production line as in, for example, overall cleaning. Alternatively, other plants report only those processes that have water measurement devices so that not all water consumed is reported. However, to implement water savings programs effectively, measuring and reporting water usage for all purposes at the plants is critical.

1.3.4 Water Usage for Concrete Production

For the production of concrete, the situation is not much different. Reports have shown the average volume of water as a component of the concrete, known as mixing water, but the quantity of water used in other plant processes for activities such as truck washing, water needs for workers, and laboratory work is not always reported, or even measured. Therefore, the total quantity of water usage at concrete plants needs to be reassessed to
implement water savings programs, particularly to advance the capacity for finding substitutes for potable water in the concrete production processes.

1.3.5 Water Usage for Buildings Under Construction and After Occupation

The consumption of water for buildings under construction is also rarely reported. The differences in building materials and techniques strongly influence the quantity of water consumed at the construction site. Construction in Brazil, for instance, involves walls in buildings that are mostly assembled with bricks and mortar; the mortar is often prepared on-site, requiring water. In addition, at the construction sites there is considerable water demand for dust suppression and for the needs of workers. Use continues after occupation, when buildings require freshwater on an ongoing basis. Some estimates note that buildings under construction and in operation account for approximately 12 to 20 percent of the world's freshwater withdrawals (McCormack et al. 2007; Retzlaff 2009; Roodman and Lenssen 1995). Reassessment of the total quantity of water usage for buildings will offer ways to implement water savings programs both at construction sites and when buildings are in operation. An important consideration is that the water quality for all uses does not necessarily have to be at the potable level. Use of rainwater harvesting systems may be highly beneficial, and re-thinking response to government policies can offer further opportunities for responsible water use.

1.4 Scope and Objectives of the Research

This researcher has indentified a lack of accessible benchmarks with which to measure and compare water usage performance for the construction sector. With the intention to
shed light on this aspect, this investigation provides information on the volume of water usage for cement manufacturing plants, concrete production, and buildings under construction and after occupation. Data are obtained from the literature and from case studies and are compiled and analyzed to establish data sets of water usage per unit of product, also known as water intensity. Water conservation strategies for the construction sector are also investigated.

The boundary for investigating water use practices for cement manufacturing was selected to include all activities and processes within the cement plants. It thus included water usage for the production line (from stockpiling of crushed raw material to cement dispatch), and also uses beyond the production line (namely employees’ and subcontracted labourers’ needs, laboratory work and overall housekeeping and dust suppression). This research scope excluded water usage at raw material quarrying operations and water usage after cement has left the plant.

The scope of investigation of water usage for ready-mixed concrete production included mixing water (the quantity used in the batch of concrete production), as well as all other uses at plants, such as workers’ needs, laboratory work, overall housekeeping and dust suppression, as well as washing concrete trucks. It excluded other operations outside the boundaries of the plant such as aggregate extraction.

The investigation of water usage at construction sites involved all activities at construction sites, through all stages of construction and building commissioning. Water
usage for workers’ needs is included in this scope of investigation. Commissioning activities involve tests to make sure the built environment meet its full potential, including testing water lines, which requires a considerable amount of water.

This work offers necessary information for improving global comparability of water usage in the construction industry to help shape best water management practices for some of its sectors. The main goal is to facilitate best water management decisions, but these data may also offer possible input for the development of policies and guidelines, for life cycle assessment inventories, water footprint calculations, and future green building certification programs.

The overall purpose of this research was to facilitate availability of reliable water usage data for cement manufacture, ready-mixed concrete production and buildings under construction and after occupation. In this work, the term reliable is used for data that are accurate, with their degree of uncertainty provided, and collected through correct methods of measurement by appropriate instruments or from well-founded estimates. Reliable data are also precise or repeatable, meaning that similar results will be obtained by successive measurements under the same conditions. This research is a significant step towards a better understanding of the subject of water usage in the construction industry, and it aims at converting knowledge into best water management practices, and fostering collaboration with the construction industry and policy makers to attain economic, environmental, and social sustainability. Communities that are home to water-efficient industries will eventually gain more freshwater availability for potable uses, hence
increasing their potential for meeting drinking water requirements and improving their quality of life.

The objectives of this research are:

1. To improve knowledge of water use practices in cement manufacturing, ready-mixed concrete production, building construction site practices, and in the built environment;
2. To develop a baseline for water demand for the cement manufacturing; and
3. To facilitate development of best water management practices in the construction industry.
CHAPTER 2

CHALLENGES FOR SUSTAINABLE WATER USAGE IN THE CONSTRUCTION INDUSTRY

A “sustainable construction industry” no longer means simply that the industry is able to continue its business and grow, but also that it supports the principles of sustainable development – which may mean that in some cases it needs to stop growing, or grow in different ways.

– International Council for Research and Innovation in Building and Construction, Agenda 21 for Sustainable Construction in Developing Countries, 2002

2.1 Overview of Sustainability in Water Usage in the Construction Industry

The construction industry requires water throughout various processes, starting with the extraction of raw materials and progressing through the manufacturing of building materials, the assembly of components on-site, and the use of the building after occupation (CIB, UNEP-IETC and du Plessis 2002; Haapio and Viitaniemi 2008; McCormack et al. 2007). For many types of water use, there are no substitutes for water; therefore its availability is a significant concern (Gleick et al. 2009; Hoekstra and Chapagain 2008; McMichael, Butler and Folke 2006). For this reason, there is controversy around the industry’s need for water because human populations have a competing need for potable water. Unfortunately, benchmarks of water usage for this industry are not yet available (Crawford and Treloar 2005; Kibert 2007; McCormack et al. 2007), suggesting that there are significant challenges for the construction industry in establishing efficient water management practices.
2.1.1 Sustainable Development, Human Settlements and Drinking Water Availability

Concerns regarding the impact of continued global human population growth on the natural environment and human health are not new. The industrialized and developing nations were brought together to discuss that very issue by the United Nations Conference on the Human Environment in Stockholm in 1972. The intent was to delineate the rights of the human family to a healthy and productive environment such as the rights of people to adequate food, housing, safe water and having the means of choosing the size of their families (UNEP 1972).

After the 1972 conference, there was a call to address the major challenges faced by the world community and establish a global agenda for change. The report *Our Common Future* – also known as the “Brundtland Report” in reference to Gro Harlem Brundtland, at that time Prime Minister of Norway, and Chair of the Report’s working group – was commissioned by the United Nations to fulfill this requirement. The group defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED 1987). This step initiated increased attention to sustainability worldwide.

Five years after the statement of sustainable development, the 1992 United Nations Conference on Environment and Development in Rio de Janeiro proposed *Agenda 21*. This document examines all the areas where human activities impact the environment in order to address global environmental problems, as well as seeking to accelerate sustainable development (UNCED 1992). In order to move towards these goals,
Agenda 21 proposed a global consensus and political commitment in a broad plan of action to be adopted globally, nationally, and locally by governmental and non-governmental organizations. Two subsequent documents were published by the International Council for Research and Innovation in Building and Construction (CIB) to guide the work in implementing the principles of sustainability for the construction industry: Agenda 21 on Sustainable Construction (CIB 1999) and Agenda 21 for Sustainable Construction in Developing Countries (CIB, UNEP-IETC and du Plessis 2002). The CIB is an organization created in 1953 (based in the Netherlands) with the mission to encourage and facilitate international cooperation and information exchange in the building and construction sector (CIB 2012). Beyond articulating the need to follow the principles of sustainable development - while providing adequate housing – these documents take into account water usage practices in the construction industry in terms of providing systems for drinking water availability and water consumption in its industrial processes.

The themes of adequate shelter for all and sustainable human settlement development in an urbanizing world are also promoted by The United Nations Human Settlements Programme (UN-Habitat). Starting with a 1976 Vancouver conference, many documents have been published outlining the mandate of the UN-Habitat such as the Vancouver Declaration on Human Settlements, Habitat Agenda, Istanbul Declaration on Human Settlements, Declaration on Cities and Other Human Settlements in the New Millennium, and Resolution 56/206 (UN-HABITAT 2011). These statements reinforce the understanding that human beings are at the centre of concerns for sustainable
development and are equally entitled to a healthy and productive life in harmony with nature (United Nations 1996).

As a milestone of the entrance into the new millennium, the United Nations General Assembly signed in New York, in 2000, the *Millennium Declaration* (United Nations 2000). This document called for meeting “Eight Millennium Development Goals” (MDGs), shown in Figure 2.1.

![Figure 2.1. A graphic representation of the eight United Nations Millennium Development Goals. Reprinted by permission from © UNDP Brazil (2007).](image)

The goal related to environmental sustainability (Goal 7) has the following four targets: (1) integrating the principles of sustainable development into country policies and programmes and reversing the loss of environmental resources; (2) reducing biodiversity loss; (3) halving the proportion of the population without sustainable access to safe drinking water and basic sanitation by 2015; and (4) improving the lives of at least 100 million people who live in slums by 2020 (United Nations 2010). The *Millennium Declaration* defines the chief goal as stopping “the unsustainable exploitation of water resources by developing water management strategies at the regional, national and local
levels, which promote both equitable access and adequate supplies” (United Nations 2000). Water availability to world population is addressed under Goal 7 but also directly affects the achievement of all eight MDGs, including, notably, the first goal of the eradication of extreme poverty and hunger (United Nations 2000).

Subsequent to the Millennium Summit, The United Nations General Assembly proclaimed the years 2005 to 2015 to be the “International Decade for Action: Water for Life”. The primary goal of this decade is to promote efforts to fulfill international commitments made on water and water-related issues by 2015, as well as to promote the MDGs (United Nations 2004). This is yet one more initiative to raise awareness that safe drinking water and basic sanitation are crucial in alleviating poverty, increasing the quality of human health, and achieving sustainable development. These efforts outlined in Agenda 21, Habitat II, and Millennium Declaration offer the construction industry a crucial role to play in achieving many of the commitments presented by the documents. These targets can be met not just by providing housing and infrastructure for human settlements, but also by the construction industry’s taking action to use water more efficiently in its diverse industrial processes.

Beyond its role in providing housing and infrastructure for improving the quality of life, the construction industry is also responsible for its economic impact on society. Construction is one of the largest industries in the world, and it is expected to continue to grow (Economy Watch 2010). This industry not only provides jobs but also influences sales of building materials, equipment for construction, infrastructure services, and the
real estate market. Its activities involve suppliers, contractors, real estate agents, engineers, designers, and approval agents (Figure 2.2). Worldwide, it represents from 10 to 40 percent of total gross domestic product (GDP) and 10 percent of total employment (CIB, UNEP-IETC and du Plessis 2002; UNEP-SBCI 2009).

Figure 2.2. Economic relationships in the construction industry. Reprinted by permission from WBCSD (2008).

Construction-related activities can lead to a number of environmental problems (Chong et al. 2009; CIB 1999; CIB, UNEP-IETC and du Plessis 2002; Gomes et al. 2008; Roodman and Lenssen 1995; Sassi 2008; Spence and Mulligan 1995). Kibert (2008) discussed the construction industry’s environmental impact by indicating its “use of enormous quantities of natural resources” and the highly troubling issue of replacing natural systems with a built environment. That author points out a disproportionate environmental impact on the planet, and consequently a need to shift from wasteful practices to a “paradigm under which construction and nature work synergistically” (Kibert 2008). By taking actions to reduce overexploitation of natural resources,
especially such as the use of improved water conservation strategies, the construction industry can play a crucial role in helping to achieve not only economic but also social and environmental sustainability (Meyer 2009).

### 2.1.2 Environmental Impacts of the Construction Industry and its Water Usage

Some effects that accompany construction operations in the initial phases (clearing, excavating, and grading) are disturbance of topsoil and landscape quality, decrease of agricultural land, removal of historic sites, and increase in traffic. Construction activities therefore have a direct consequence for biodiversity, including disruption of breeding grounds for animal species through interference on ecosystems (CIB 1999). During storms, the exposed topsoil may be washed off construction sites and flow to nearby water bodies. These events may affect the quality of water and result in siltation, as a result decreasing depth of streams, lakes and reservoirs, which may lead to the need for dredging (USEPA 2007a; USEPA 2009; USEPA 2012).

Since the end of 2009, the United States Environmental Protection Agency (EPA) has imposed national monitoring requirements and enforceable numeric limitations for stormwater discharges from construction sites (USEPA 2009). The ruling also requires construction site owners and operators to implement a range of erosion and sediment control measures and pollution prevention practices for dealing with site stormwater, as well as effluent discharge from activities such as dewatering, soil stabilization, and concrete washout (the effluent from washing the drums and chutes of ready mixed concrete trucks, hoppers of concrete pump trucks, and hand tools used at sites) (USEPA
These requirements are expected to reduce the amount of soil, sediment and nutrients from construction sites that reach natural waters. The expected outcome is eventually to enhance the quality of drinking water supplies.

Another environmental impact resulting from the construction industry’s activities and the built environment is solid waste generation (Meyer 2009; Ortiz, Castells and Sonnemann 2009). It is estimated that approximately 13 percent by weight of all solid waste deposited in landfills worldwide is construction and demolition waste, with a 1:2 ratio of construction to demolition waste (CIB 1999). When it comes to energy consumption the construction industry takes approximately 40 percent of the total energy generated worldwide (CIB, UNEP-IETC and du Plessis 2002). In the United States, in 2002, buildings accounted for 39 percent of total energy consumed, and it is projected a related contribution of 38 percent of total carbon dioxide (CO₂) emissions annually (Retzlaff 2009).

With regard to the production of building materials, beyond the environmental impacts resulting from the extraction of natural resources, this sector is an ongoing consumer of energy (CIB, UNEP-IETC and du Plessis 2002). There are also gaseous emissions, solid wastes and effluents from their industrial processes that contribute to air, soil and water pollution. Among the many issues to overcome in the production of building materials, the reduction of water usage is beginning to be recognized (Mehta 2002, 2009; Mehta and Monteiro 2006, Meyer 2009; Sassi 2008). There is little data available in the literature about water consumption used in the manufacturing of building materials (CIB,
UNEP-IETC and du Plessis 2002; Crawford and Treloar 2005; Irbaris 2009; Kibert 2007; McCormack et al. 2007; Ortiz, Castells and Sonnemann 2009), but research indicates that buildings under construction and in operation account for approximately 20 percent of the world's freshwater withdrawals (McCormack et al. 2007; Retzlaff 2009; Roodman and Lenssen 1995).

2.1.3 Barriers in the Field of Sustainable Construction and its Water Usage

Support for and development of a concept of sustainable construction will be key to an adequate response to environmental impacts of the industry. The concept comprises principles of sustainable development as they are applied to the construction cycle, with the aim of maintaining and/or restoring harmony between the natural and built environments. In order to comply with this definition, a sustainable construction practice must also contribute to the alleviation of poverty, while creating settlements that affirm human dignity and encourage economic equity, and must also create a healthy and safe working environment (CIB, UNEP-IETC and du Plessis 2002). To meet sustainable development goals, the industry must consider the design and management of buildings, materials performance, energy requirements and natural resource consumption to attend to current needs for housing, working environments and infrastructure without compromising the ability of future generations to meet their own needs.

Therefore, the social, economic and environmental aspects of sustainable development are becoming of greater concern to the construction industry, in both developed and developing countries (Ortiz, Castells and Sonnemann 2009). At the same time, there are a
number of barriers to progress in the field of sustainable construction. Based on the literature, these barriers tend to be of the types:

- Current business practices that favor fast construction schedules, which do not always make allowance for the conservation of natural resources or for investments in innovation in environmental practices (CIB 1999; CIB, UNEP-IETC and du Plessis 2002; Mehta 2002).

- Considerations of what areas of risk and security exist in regard to sustainable construction practices, how profit can result from sustainable construction practices, and how extra costs can be avoided (Chong et al. 2009; CIB 1999; CIB, UNEP-IETC and du Plessis 2002; Helgeson and Lippiatt 2009; Mehta 2002).

- Challenges related to the mobilization of resources, or the coordination to manage them in a more efficient way, to support research, technological changes and feasibility studies for the production and marketing of new materials and technologies (CIB 1999; CIB, UNEP-IETC and du Plessis 2002; Mehta 2002).

- The tendency of the profession of civil engineering to be more conservative in relation to the other engineering disciplines, so that there is professional and institutional inertia repeatedly asking “why change?” (Chong et al. 2009; CIB 1999; CIB, UNEP-IETC and du Plessis 2002).
• Low awareness of sustainability concerns among students in civil engineering, showing the lack of focus on the issue at most universities (Chong et al. 2009; CIB 1999; CIB, UNEP-IETC and du Plessis 2002; Mehta 2002).

• Lack of expertise among construction professionals and an absence of understanding of which construction activities contribute to or conflict with sustainable development, leading to confusion over the question “what should I do and how can I do it?” (Chong et al. 2009; CIB 1999; CIB, UNEP-IETC and du Plessis 2002).

• The tendency for existing policies, legislation and regulations not to promote the implementation of sustainable construction (Chong et al. 2009; CIB 1999; CIB, UNEP-IETC and du Plessis 2002).


A number of strategies have been established to help address these challenges. The United Nations Environment Programme (UNEP) set up the Sustainable Buildings and Climate Initiative (SBCI) to facilitate information exchange on issues related to sustainability in the construction sector (UNEP-SBCI 2009). Another organization with similar intent is the International Initiative for a Sustainable Built Environment (iiSBE),
based in Canada, which has the overall aim of facilitating and promoting the adoption of policies, methods and tools to accelerate the specific movement toward a global sustainable built environment (Larsson 2001). The iiSBE Board of Directors includes participants from many countries, including Brazil (iiSBE 2012). In a local context, the Brazilian Council for Sustainable Building (CBCS for the name in Portuguese), which was launched in 2006, operates with the ideal of fostering sustainable building principles across the construction sector in the country (Gomes et al. 2008).

Beyond the concern for meeting the responsibilities of practicing sustainable construction, the construction industry faces challenges common to many industries in relation to water availability, even up to the possibility of competition for water with inhabitants of local communities (Irbaris 2009; Seneviratne 2007; United Nations 2011). There are three key issues according to the aforementioned authors:

- Physical risks that encompass changes in the quantity or quality of water related to increased water scarcity, declining water quality, and changing local hydrological conditions.

- Regulatory risks that may result from the inevitable policies related to water pricing, pollution, withdrawal rights or license to operate.

- Reputational risks that are associated with abuse of water withdrawal rights, pollution of water sources, and other negative effects concerning water availability for the population.
In considering the outlook for the industry and the possibilities for overcoming challenges resulting from environmental impact in construction, improvement of performance in water savings stands in the forefront. An important route to take is that of establishing benchmarks to support decisions regarding sustainable water usage in the construction industry. A key effort will be to obtain access to reliable data reports on the current quantity of water usage, with the aim of subsequently establishing efficient water management practices industry-wide.

Figure 2.3 presents a schematic of how the construction industry may respond to important challenges regarding sustainable water usage as it attempts to meet this demand. Certainly, knowledge of its water usage is required through them all.

Figure 2.3. Challenges regarding sustainable water usage in the construction industry.
2.2 Reporting of Water Usage in the Construction Industry

As concluded in a research report called The Social and Economic Value of Construction: “The industry cannot assess its performance if it does not have benchmarks to measure improvement” (Pearce 2003, 60). Formulating these benchmarks for water usage is challenging in the construction sector because, until now, neither the key methods nor robust data have been available (Helgeson and Lippiatt 2009). Some companies report their water usage data in their annual reports, particularly those that subscribe to corporate social responsibility certifications requirements (Seneviratne 2007). At the same time, these data are not always comprehensive or comparable (Irbaris 2009).

What has been available is the environmental performance-based data for the construction industry that have been established for meeting standards for certification systems for buildings being designed to operate according to the principles of sustainable construction. Also called green buildings, these systems have, among other criteria, promoted the use of water saving devices. Such performance-based data typically cover aspects of buildings in operation, both commercial and residential. However, these rating systems seldom give much credit to, or even consider, the quantity of water used for building material manufacturing (Crawford and Treloar 2005; Ding 2008; Fowler and Rauch 2006; Gowri 2004; Kibert 2007; McCormack et al. 2007; Retzlaff 2009).

One example of how the availability of this data makes a difference can be shown by the case of water demands involved with the use of cement, as part of making concrete, the most common structural building material worldwide for the currently booming
construction industry (Economy Watch 2010; Mehta and Monteiro 2006). Disclosure of water usage for cement manufacturing, concrete production, and buildings under construction and after occupation will serve not only to raise awareness of the quantity of water consumed by these sectors of the industry, but also provide the data necessary for establishing benchmarks for global comparison and promoting best water management practices in this industry.

An extensive review of the technical literature regarding the total quantity of water usage at cement and concrete plants, and in buildings under construction and after occupation, showed little data available. Following the search, e-mail contacts with international organizations related to water management practices and with research centers (Table 2.1) were initiated, but resulted only in the information that they did not have this kind of data available, despite a growing need for such information.

The Cement Sustainability Initiative (CSI), an international organization based in Geneva as part of the World Business Council for Sustainable Development (WBCSD), has shown interest in promoting a study on water use practices among the cement companies in its membership (Klee 2010). Currently the CSI have an active program on investigating water issues in the cement sector (Klee 2012; Leung 2012). It should be noted that the WBCSD launched in 2007 the ‘Global Water Tool’ (GWT). This tool allows the user to input data of site location and water withdrawal to generate a map for assessing water risks (Zabey 2009). The GWT was recently customized for the cement
sector (WBCSD-CSI 2013). However, this recent tool does not include data of water usage at stages of cement manufacturing.

One other exception in the somewhat barren water usage information landscape seemed to have been the Carbon Disclosure Project (CDP), which holds a database of climate change information provided from worldwide corporations. Recently, the CDP has received requests from its member companies to provide information regarding water-related issues. As a result, the CDP carried out a pilot in 2008 called the CDP Water Disclosure (Irbaris 2009). However, the sample in the pilot was small and did not include any company in the cement and concrete sectors (Norton 2010). The overall results from the pilot project for different sectors indicate that business awareness of water issues, risks and opportunities is limited, and investor understanding of the threats and opportunities in this arena is even less developed (Irbaris 2009).

The initial research on water usage and sustainability in the construction industry reveals a lack of data disclosure, both in the literature and through related water management organizations, on the quantity of water usage at cement plants, ready-mixed concrete plants, and buildings under construction and after occupation. This shortage of reporting of water usage in the construction industry translates into lack of awareness amongst key stakeholders such as managers, investors, and communities (Helgeson and Lippiatt 2009; Morrison, Schulte and Schenck 2010). It also translates into academics possibly not having sufficient data to conduct research on related issues (Chong et al. 2009).
Table 2.1. Organizations contacted regarding water usage in the construction industry

<table>
<thead>
<tr>
<th>ORGANIZATION (alphabetical order)</th>
<th>COUNTRY (where organization is based)</th>
<th>CONTACT PERSON</th>
<th>DATE (e-mail to author)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement Sustainability Initiative (CSI) with World Business Council for Sustainable Development (WBCSD)</td>
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<td>Howard Klee, Program Director</td>
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<td>Yvonne Leung, Project &amp; Communications Officer</td>
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<td>Conselho Brasileiro de Construção Sustentável (CBCS) - Brazilian Council for Sustainable Construction</td>
<td>Brazil</td>
<td>Marcelo Takaoka, Director CBCS</td>
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<td>EcoSmart Foundation</td>
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<td>David Barrie, Project Engineer</td>
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<td>International Initiative for a Sustainable Built Environment (iiSBE) and SBTool</td>
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<td>Nils Larsson, Executive Director</td>
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<td>David W. Hubble, Manager - Centre for Sustainable Infrastructure Research</td>
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<td>Michael J. Giroux, Director – Urban Infrastructure Program</td>
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<td>OneWorldStandards Ltd.</td>
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<td>Matthew Wenban-Smith</td>
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<td>Pacific Institute for Studies in Development, Environment, and Security</td>
<td>United States of America</td>
<td>Peter H. Gleick, President</td>
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<td>Water Footprint Network</td>
<td>The Netherlands</td>
<td>Erika Zarate, Programme Officer</td>
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<td>Arjen Y. Hoekstra, Scientific Director</td>
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Reporting alone is not sufficient for solving the problem, but it is fundamental to stimulating action leading to the most beneficial outcome – that is, development of best water management practices, new policies, and guidance based on performance benchmarks (Irbaris 2009). In addition, there is a need to develop water-performance metrics to support best water management practices for cement manufacturing, concrete production, and buildings under construction and after occupation. The same benchmarks can be applied for the assessment of these industries’ water risks related to water availability within communities.

2.3 Concepts Applied to Water Management Practices

Several distinctive concepts are related to water management practices, but they are not always used consistently throughout the literature. The following concepts are outlined to facilitate further discussion: water withdrawal, water consumption, virtual water, water footprint, water scarcity, water efficiency, water usage, and water intensity.

2.3.1 Water Withdrawal

Water withdrawal is the removal of water from any source, followed by returning it after use, even if sometimes it is contaminated with pollutants (Gleick et al. 2009).

2.3.2 Water Consumption

Water consumption in this research takes into account the amount of water that is used and not returned for immediate or short-term reuse within the same watershed - for
example, evaporation, incorporation into products, consumption by people, or other removal from the local resources (Gleick et al. 2009).

### 2.3.3 Virtual Water and Water Footprint

When water is considered a commodity embodied in the product being negotiated, the two concepts of *virtual water* and *water footprint* may be applied (Hoekstra and Chapagain 2008; Hoekstra et al. 2009). Virtual water is the quantity of water required to produce a product, measured over its full production chain; it is also referred to as embedded, embodied or hidden water. The water footprint concept is based on the virtual water concept but goes further, because it is an empirical indicator not only of the volume of water consumed but also of all water bodies polluted, whenever and wherever, in relation to the production of goods and services (Hoekstra et al. 2009). In terms of water footprint, there are three components: (1) *blue water footprint* refers to use of groundwater and surface water; (2) *green water footprint* is the rainwater used, both through the collection and soil moisture; (3) *grey water footprint* is the water used as a receptor to assimilate the load of pollutants in the effluents, based on local standards. Therefore, in the context of water footprint, the water applied for manufacturing processes is related to water availability at the specific locations at that time (Hoekstra and Chapagain 2008; Hoekstra et al. 2009). Current data on virtual water are available for many products but not yet for cement and concrete (Hoekstra et al. 2009; Hoekstra 2011).
2.3.4 Water Scarcity

Water scarcity, as defined in this research, goes beyond the lack of water in terms of quantity; it also covers the decrease in water availability resulting from degradation of water quality, as well as inappropriate water governance, which may lead to a lack of infrastructure or short supply (NBI 2006).

2.3.5 Water Efficiency

Water efficiency is the ratio between water actually necessary for an intended purpose and the amount of water used to achieve that purpose (WBCSD-IUCN 2010). This concept indicates that higher water efficiency is the result of a reduction in wasteful water usage practices.

2.3.6 Water Usage

In this work, the term water usage is applied to the total amount of water withdrawn from various sources, for all demands inside the limits of a plant, regardless of the quality and place it is returned to in the hydrological cycle. Accordingly, this concept includes the amount of water consumed, for example, by production lines, for employees’ needs, and by careless waste, as well as the water returned to the environment, treated or untreated.

2.3.7 Water Intensity

The concept of water intensity is based on the idea of having a ‘per unit’ of resource use related to the production of goods – also called a normalized performance metric
For the purpose of this research, this concept represents the total quantity in litres of freshwater usage at plants for cement manufacturing, per tonne of cement produced, as well as the total quantity in litres of freshwater usage at ready-mixed concrete plants, per cubic meter of concrete produced. This concept is also used to indicate the total quantity in litres of freshwater usage at construction sites, per square metre of floor space built. The water per capita consumption is also considered to be a measure of water intensity in terms of litres of potable water used per person per day. Water intensity will be further discussed in Chapter 3, Section 3.4.

2.4 Turning Challenges into Opportunities

The research presented in this chapter discussed some barriers to progress in the field of water management in the construction industry. In order to respond to this challenge, businesses are seeking standards, guidance and tools to enable changes to more sustainable water management practices (WBCSD-IUCN 2010).

It is essential to reinforce the idea that reporting water usage data provides an overview of who is doing what and with how much water. This understanding empowers managers to identify and adopt the initiatives that will most suit their needs, and better define tools for sustainable water management inside their industries. The compilation of this information and its accessibility, can also help policy-makers for developing guidelines for engaging in relevant initiatives to save freshwater in the construction industry.
Therefore, development of best water management practices start with the availability of reliable water usage data followed by action for water conservation. To achieve this in any industry, it may be necessary, for instance, to install improved water metering systems and further change production processes to be more water efficient. The implementation of appropriate policies and government regulations, water pricing, and tax incentives are also fundamental to achieving sustainable water usage in the construction industry (CIB 1999; Kibert 2007; Spence and Mulligan 1995).

2.5 Research Methods

This section presents an overview of the research methods used in this work. Detailed descriptions of each method are provided in individual chapters.

2.5.1 Selection of Metric

The indicator selected to represent water usage in this industry was water intensity, which is the total volume of water withdrawn to produce a specific quantity of a product. Water intensity was selected as the performance metric because of its prior use in this field (for example in corporate social responsibility reports). Further discussion of water intensity in cement manufacturing is included in Chapter 3, Section 3.4.

The units for water intensity applied in this work are:

- Litres per tonne of cement produced (L/tonne)
- Litres per cubic metre of concrete produced (L/m$^3$)
- Litres per square metre of floor space built (L/m²)

- Litres per person per day (L/person day)

2.5.2 Data Collection

Data regarding water use practices in the construction industry (cement manufacturing, concrete production, buildings under construction and occupied buildings) were collected from a variety of sources and using a variety of methods. Both academic and corporate literature was used to collect the preliminary water intensity data. Case studies conducted in both Canada and Brazil complemented the data collected from the literature. Other data was collected through personal communication with experts and practitioners in the field.

As discussed in Section 2.2, this research began with an extensive review of the literature on water usage in cement manufacturing, ready-mixed concrete production, and building construction. A variety of literature was examined for this purpose. A comprehensive investigation of the scholarly (peer-reviewed) literature revealed very few publications on the topics of interest. Further contacts with international organizations related to water management practices (for example, The Water Footprint Network) proved similarly unproductive. The complete list of organizations contacted is included in Chapter 2, Table 2.1.
In light of these limited resources, a decision was made to compile water usage information from Corporate Social Responsibility Reports (CSR) by companies that were members of the Cement Sustainability Initiative (CSI) and followed Global Reporting Initiative Guidelines (GRI). A complete description of data collection from selected CSR reports is presented in Chapter 3, Section 3.5.

2.5.3 Case Studies

Characterizing water use patterns at cement plants was the main focus of this work. Case studies were conducted in two plants, one in Brazil, and one in Canada. Both were integrated cement plants that manufacture clinker and cement powder. Quarrying operations of limestone and other raw material extraction was excluded from this work. Therefore, the research boundary was the cement production line from crushed raw material to dispatch.

This researcher developed a framework for identifying points of water usage at each stage of cement manufacturing. Detailed information for this framework is provided in Chapter 3, Section 3.3. Site visits, e-mail contacts, and telephone calls with experts and plant personnel were used to collect primary data on total water intake, water usage at each manufacturing stage, and effluent discharge under actual operating conditions. Data were compiled from the companies’ own measurement systems and from water bills. All data recorded by the plants’ measurement systems were compiled and several attempts were also made to collect additional data with a portable flowmeter (details are provided in Chapters 4 and 5, and in Appendix B). Data gaps were identified and estimates
performed to fill gaps where necessary (see Chapters 4 and 5).

Case studies for evaluating water usage for buildings under construction were conducted at two construction sites in Brazil (detailed information in Chapter 7, Section 7.3, and in Appendix C). Case studies for water usage at ready-mixed concrete plants were also conducted in Brazil, at two plants (details in Chapter 7, Section 7.4). However, one ready-mixed plant withdrew from the study after one year, citing concerns about confidentiality of data.

Both quantitative and qualitative approaches were used in this research. The initial objective of the research was to establish benchmarks for water intensity for the cement industry, based on quantitative evaluation of compiled data. However, when the available dataset for water intensity proved to be limited and of poor quality, the focus of the work shifted to the collection of more reliable water use data. The reliability of available data was then evaluated using a combination of quantitative methods (e.g., reported instrument error) and quantitative and qualitative estimates (e.g., based on experience of plant personnel, heat transfer calculations, and water balance). This researcher then developed an approach for categorizing levels of data reliability according to methods of data acquisition. A detailed description of this approach for data evaluation is provided in Chapter 6.

In summary, this research employed an inductive approach using a research question to narrow the scope: “How can water usage in this industry be made more sustainable?”
The objective of the current research project is to contribute to increasing the available information on water usage in the construction industry. Data were collected from the literature and from case studies for cement manufacturing, concrete production and buildings under construction and after occupation. As previously indicated, cement plays a major role as the main component of the concrete which is the most used structural building material worldwide. Therefore, these sectors were selected considering they are strong players in the construction industry. Following discussion of all data obtained from case studies and literature, data reliability is discussed. Results are expected to support construction industry decision-makers who are investing in improvements of their economic, environmental and social performance in relation to water usage, thus enhancing their potential for incorporating the principles of sustainable development into the industry.
CHAPTER 3
WATER USAGE AT CEMENT PLANTS: PUBLISHED DATA SOURCES

The systematic effort to monitor and improve the efficient use of water in the organization is directly linked to water consumption costs.
– Global Reporting Initiative, G4 - Sustainability Reporting Guidelines - Implementation Manual, 2013b

3.1 Water Usage for Cement Manufacturing

The previous chapters highlighted many barriers that restrict progress in the field of sustainable water usage in the construction industry. This chapter will demonstrate the current state of reporting of water usage in the manufacturing of cement. Investigation of water usage for cement manufacturing was selected to start this study of water usage in the construction industry because cement is the initial link in a supply chain for buildings after occupation.

The analysis accounts for the variety of cement manufacturing processes and creates a new scheme to understand the water requirements at cement plants by dividing these manufacturing processes into eleven stages, from raw material preparation through to overall cooling of equipment. This scheme also includes other uses beyond the production line, namely employees’ and subcontracted labourers’ needs, laboratory work, and overall housekeeping and road dust suppression. These stages are described in this chapter in Section 3.3 and are included in Figure 3.1. Stakeholders can have a better understanding of the overall water demands inside the plants, by knowing the quantity of
water used at each stage. The analysis will demonstrate the usefulness of this scheme by using it to estimate an average range for the quantity of water demand at cement plants.

The performance metric of water usage applied to this research is *water intensity*, defined as the volume of water used to produce one tonne of cement. Water intensity data were obtained or calculated from the information in corporate sustainability reports. Reports included in the analysis were limited to those published by members of the Cement Sustainability Initiative (CSI), and further limited by selecting only reports that followed the Global Reporting Initiative (GRI) guidelines. Both CSI and GRI are international initiatives; the first is based in Switzerland and the second is based in the Netherlands.

This chapter concludes with a compilation of all data obtained from the analysis of published data for both the overall process and the discrete stages of cement manufacturing. The data sets compiled in this study are critical in addressing a gap in the literature by providing significant information about water usage at cement plants worldwide. Two case studies were used to further investigate water usage at each stage of manufacturing. These case studies, which were conducted at a cement plant in Canada and one in Brazil, are described in Chapters 4 and 5.

This study offers an important contribution to raise awareness about the lack of both knowledge and reporting of water usage in the cement industry. This research represents a significant step towards the establishment of best water management practices, by
presenting a novel investigation of water usage in the cement industry, which is an essential action to assess opportunities for water savings by this industry.

### 3.2 Overview of Cement Manufacturing

The main aspects of cement manufacturing—including its definition, chemistry and stages of production—are described in this section. Understanding the basics of the manufacturing process provides a base for understanding the water requirements at each stage of this process.

#### 3.2.1 Definition and Chemistry

Cement is a finely pulverized dry material. When cement reacts with water, it forms a paste that, while drying, solidifies and holds its shape. Concrete is a different material: it is also a mixture of cement and water but with the addition of aggregates (such as sand and gravel). A schematic of the raw materials needed to produce cement and concrete is shown in Figure 3.1. Both cement and concrete are key materials of the construction sector because they can be cast into formwork where, through hydration, they set into a solid structure. Portland cement is the most widely produced type of cement in the world because it is the type most commonly used for making concrete for construction purposes (Blake 1989; Mehta and Monteiro 2006).
Figure 3.1. Schematic of raw materials needed to produce cement and concrete.
The chemical composition of Portland cement is complex but mainly consists of clinker with the addition of around 5 percent calcium sulfate, usually in the form of gypsum (CaSO4.2H2O) or anhydrite (CaSO4) (Alsop 2005). Clinker is an intermediate material in the cement manufacturing process (Figure 3.1). The function of the calcium sulfate is to prevent premature setting of the cement (also called “flash setting”) during hydration (Alsop 2005; van Oss and Padovani 2002). The detailed characteristics of the components of Portland cement are not discussed further in this research, as they vary according to local requirements. However, a typical mineralogical composition of Portland cement is included in Appendix A (Table A.1).

### 3.2.2 Summary of the Production Process

The following steps are present in any cement manufacturing process: quarrying of limestone and other raw materials; raw materials preparation; fuel supply preparation; heat treatment (inside a rotary kiln); clinker cooling; cement milling; product storage and packaging (if any); and eventual dispatch to the consumer (Figure 3.2). The kiln consists of a slightly inclined steel cylinder of 2.5 to 4.5 percent slope, lined inside with refractory bricks. Its length varies from approximately 50 to 200 metres, and its internal diameter is typically around 3.5 to 5.5 metres (Alsop 2005; CEMBUREAU 1999; European Commission 2010; van Oss and Padovani 2002).

Some cement plants produce only clinker, which will be ground to produce cement powder at another plant. Those facilities that make cement by grinding clinker made elsewhere are called grinding plants. The object of study for this research are the
integrated cement plants that manufacture both clinker and cement powder, excluding quarrying operations, thus the research boundary is the cement production line from crushed raw materials to dispatch.

![Diagram of cement production](image)

**Figure 3.2.** Schematic of cement production. Adapted by permission from CSI (2002).

The manufacturing of clinker consists of heating natural materials containing calcium, silicon, aluminum and iron to temperatures up to 1,550°C in a rotary kiln (Alsop 2005; van Oss and Padovani 2002, 2003). Calcareous materials such as limestone, shells, chalk, marl and marble provide the source for calcium carbonate (CaCO$_3$). Clay, shale, slate and iron ore are also added, to provide the proper amount of silica (SiO$_2$), alumina (Al$_2$O$_3$) and iron oxide (FeO$_3$) (Alsop 2005; European Commission, 2010; van Oss and Padovani 2002, 2003). Natural materials can also be partially replaced by several types of industrial waste, such as mill scale, fly ash, blast-furnace slag, and a variety of chemical wastes (Alsop 2005; European Commission 2010; van Oss and Padovani 2002). When wastes
serve as part of raw material, or serve as fuel substitutes for the kiln, the plant is called a co-processing facility (Alsop 2005; CEMBUREAU 1999; European Commission 2010; IEA-WBCSD 2009; van Oss and Padovani 2003).

The main processes that the raw materials undergo inside the kiln are drying, preheating, calcining, and clinkering. The raw materials enter the upper end of the slowly rotating kiln. The rotation occurs along its long axis, at about 0.5 to 5 times per minute (CEMBUREAU 1999; European Commission 2010). The combination of the kiln slope and rotation gradually moves the raw materials to the lower end of the kiln, where there is a flame projected from a burner tube. The fuel supply (raw material or industrial waste) is injected at the lower end of the kiln. The intense heat inside the kiln causes chemical and physical changes to the raw materials, partially melting them and then transforming them into clinker. Clinker is a nodular semi-fused 5 to 25 mm pellet (Figure 3.1). The clinker is cooled down after leaving the kiln and before going to the cement mill. At the mill, admixtures (additives) are added in order to produce the final cement, which is then a fine powder with an average particle size between 10 and 15 μm (Mehta and Monteiro 2006).

The chemical reactions in the cement manufacturing process begin at the upper end of the kiln, at about 600 to 1,000°C. At this point, the calcium carbonate (CaCO₃) is dissociated to calcium oxide (CaO) in a process called calcination (or calcining) that releases carbon dioxide (CO₂). The next stage occurs at higher temperatures, about 1,200 to 1,500°C. In this stage, the CaO reacts with other components to form calcium silicates (C₃S and C₂S).
and aluminates (C₃A and C₄AF) in a process called clinkerization (also known as clinkering or sintering) (CEMBUREAU 1999; European Commission 2010; van Oss and Padovani 2002). It should be noted that some chemical notation used by the cement industry does not always follow the same conventions used elsewhere.

It is noteworthy that the production of cement generates CO₂ emissions from the kiln, approximately 60 percent from calcinations of raw materials and 40 percent from combustion of fuel (CEMBUREAU 2009; Klee 2007; WBCSD-CSI 2009). Globally, the cement industry releases about 5 to 7 percent of the world’s CO₂ emissions; it is the second-highest producer of CO₂ after coal-fired utilities (Mehta 2002; Mehta and Monteiro 2006; Klee 2007; Pulselli, Simoncini and Marchettini 2008; van Oss and Padovani 2002, 2003). For each tonne of powder cement produced, one tonne of CO₂ is generated (Kibert 2008; van Oss and Padovani 2003). It is being recognized that these emissions from cement manufacturing contribute significantly to climate change (CEMBUREAU 2009; Klee and Coles 2004; Klee 2007; Mehta 2002, 2009; Mehta and Monteiro 2006). Moreover, the effects of climate change are also acknowledged to be impacting water availability in many regions of the world (Bates et al. 2008; Gleick et al. 2009; WWAP 2009). Research from the Intergovernmental Panel in Climate Change (IPCC), published in its Fourth Assessment Report, has concluded with high confidence that the negative impacts of climate change on freshwater systems outweigh its benefits (Parry et al. 2007). The cement industry has a major role to play by reducing its CO₂ emissions and consequently minimizing its impact on water availability.
3.2.3 *Wet and Dry Processes*

There are two major types of kiln system used in cement manufacturing: wet and dry. The wet process was developed at a time when handling of slurries was more developed than those of dry materials, before the 1950s (Alsop 2005). In the wet process, the grinding and homogenization of the raw material are carried out within aqueous slurry containing 30 to 40 percent water by weight (Alsop 2005; van Oss and Padovani 2002). Also in the wet process, the majority of cement manufacturing functions is performed inside the kilns (drying, preheating, calcining, and clinkering) and for this reason they are physically the largest kilns in operation (van Oss and Padovani 2002). Currently, cement plants tend to use dry processes, where raw materials in the form of a blended dry powder (called raw mix or raw meal) are fed into the kiln. The dry process is more efficient in terms of thermal energy consumption per tonne of cement produced, because it saves the energy used in the wet process to evaporate the water in the slurry inside the kiln (Alsop 2005; van Oss and Padovani 2002). The dry process is also more efficient in terms of water consumption per tonne of cement produced, because it saves the water that would be used for preparing the slurry. Wet processes are still used in some places; however, there has been a plant progression to dry systems (Alsop 2005; van Oss and Padovani 2002).

The wet and dry system can be further categorized based on the specific condition of the raw materials entering the kiln and on the use of additional equipment prior to the kiln. These variations are called dry process, semi-dry process, semi-wet process and wet process (CEMBUREAU 1999; European Commission 2010).
Among the dry processes, one of these variations is related to the use of a preheater, also called a cyclone or suspension preheater, which preheats the raw material before it enters the kiln. A preheater consists of four to six vertical cyclones, which the raw material passes through, coming into contact with swirling hot gases from the kiln. Heat is transferred from the kiln exhaust hot gas to the raw material, and significant calcination (about 20 to 40 percent) occurs before the raw materials enter the rotary kiln (Alsop 2005). Preheaters are included in more than 80 percent of cement plants worldwide and allow the length of the kiln to be reduced (Alsop 2005). In some cement plants, there is the addition of a precalciner that is a second firing point inside a combustion chamber, at the base of the cyclone preheater. Precalcination produces complete calcination before the raw meal enters the kiln (Alsop 2005). As a result, the clinkering reaction occurs more quickly and efficiently. Preheaters and precalciners are considered the most modern technology in cement plants which dimensionally have the smallest kilns in operation, with higher production capacity than the older installations (European Commission 2010; van Oss and Padovani 2002; WBCSD-CSI 2009).

Some plants have grate preheaters (also known as the Lepol system\(^2\)), which represented the first approach to allowing part of the calcination and clinkering reactions to take place outside the kiln (European Commission 2010). In this case, raw materials are either wet-milled and filter-pressed to yield a cake with about 20 percent moisture (known as semi-wet Lepol system), or dry-milled and pelletized with the help of a water spray to bring the moisture content to 11 to 15 percent (known as semi-dry Lepol system) (Alsop 2005; van Oss and Padovani 2002; WBCSD-CSI 2009).

\(^2\)The name “Lepol system” is in reference to the system’s inventor, Otto Lellep, and its manufacturer, Andreas Ernst Gottfried Polysius.
CEMBUREAU 1999). Either way, the materials are conveyed on a travelling grate permeated by hot kiln exhaust gas, and go through a closed channel before they enter the kiln (Alsop 2005; European Commission 2010).

These processes are summarized below and in Figure 3.3:

- **Dry process**: the dry raw material in the form of a powder is fed into a long kiln, or enters into a preheater, and sometimes also into a preheater with a precalciner, prior to entering the rotary kiln.

- **Semi-dry process**: the dry raw material is pelletized with water and fed into a travelling grate preheater (Lepol system) prior to entering the rotary kiln.

- **Semi-wet process**: the raw material in the form of slurry is first dewatered in the filter presses, and the resulting cake can either be extruded into pellets and fed into a travelling grate preheater (Lepol system), or fed directly into a filter cake drier prior to entering the rotary kiln.

- **Wet process**: the raw material in the form of slurry is fed directly into a long rotary kiln.
Figure 3.3. Processes for cement manufacture and their functional zones. Adapted from van Oss and Padovani (2002), Journal of Industrial Ecology, by permission from John Wiley & Sons. ©Copyright 2002 by the Massachusetts Institute of Technology and Yale University.
The data on water consumption being investigated for this research involve all four main systems mentioned above, but the case studies described in Chapters 4 and 5 are only for dry processes, as they are the current trend (Alsop 2005; European Commission 2010; van Oss and Padovani 2002, 2003). In the following section, data compiled from the literature is presented in order to estimate the water requirements of an integrated cement plant.

### 3.3 Water Requirements at Each Stage of Production

Because of site-specific factors at cement plants, it is challenging to provide a useful single estimate for the quantity of water used by an average cement manufacturer. One major factor influencing water usage for cement manufacturing is related to the process being wet or dry. Another factor is related to the combination of equipment with different ages, and respective impact of water requirements for equipment with old and new technologies. The cost of a new cement plant is equivalent to around three years of turnover, which ranks the cement industry among the most capital-intensive industries (European Commission 2010). For that reason, the older equipment has to run for enough time to make it economically feasible to be replaced with newer equipment (CEMBUREAU 1999; European Commission 2010). Therefore, a critical analysis of the water usage at cement plants has to consider all of the existing circumstances in order to evaluate whether the water consumption is reasonable, or whether there is room for promoting water savings.
In 2008, the European Cement Association (CEMBUREAU) published an environmental product declaration (EPD) for cement, including a figure of 226 litres of water use per tonne of cement produced (CEMBUREAU 2008). The EPD provides standard information about environmental effects, in compliance with the international standards ISO 14025:2006, ISO 14040:2006 and ISO 14044:2006. The details of these standards are not further discussed as they are not the focus of this work. However, it is noteworthy that EPDs normally apply life cycle assessment (LCA). The aforementioned EPD for cement takes into account exclusively the following stages of cement manufacturing: preparations of raw material, heat treatment (kiln system), cement milling, storage and dispatch. When including water usage for quarrying operations (such as mining limestone) the EPD reaches 1,693 litres/tonne of cement (CEMBUREAU 2008).

Previous investigations by Kollar and MacAuley (1980) and van der Leeden, Troise and Todd (1990) estimated that 600 to 3,500 litres of water are withdrawn to produce one tonne of cement. This range starts at a higher value than the 226 litres/tonne of cement from the EPD published by CEMBUREAU, but it is consistent with the higher EPD of 1,693 litres/tonne of cement (which includes quarrying operations). In terms of the distribution of water use inside the plant, according to estimates presented by Kollar and MacAuley (1980), one finds:

- 82 percent for noncontact cooling, mainly equipment cooling and air conditioning,

- 17 percent for process and related uses, including slurry production, spray cooling and fume scrubbing, and
• 1 percent for sanitary purposes and miscellaneous uses, including plant cleanup, grounds keeping and dust control.

With the limited information available, a novel investigation of water requirements per stage of production will be discussed in order to improve the understanding of the water usage at cement plants. A new scheme was created in this research by dividing the cement manufacturing processes into eleven stages. This scheme also includes uses beyond the production line compiled as: employees’ and subcontracted labourers’ needs, laboratory work and overall housekeeping and dust suppression (Figure 3.4). These eleven stages are:

1. raw material preparation;

2. fuel supply preparation;

3. cleaning of preheater tower;

4. kiln gas analysis;

5. clinker cooling;

6. cement milling;

7. cement cooling;

8. cement dispatch;

9. conditioning of gaseous emissions;

10. cooling of equipment; and

11. uses beyond the production line.
Figure 3.4. Proposed scheme for tracking water requirements at eleven stages of cement manufacturing.

References are: (A) CEMBUREAU 1999; (B) European Commission 2010; (C) Enotec 2012; (D) Undestvedt 2006.
Firefighting systems are not considered in this research because they do not represent a permanent requirement, and quarrying operations have not been included because in many situations they are outside the boundaries of the cement plant. Water requirements for in-house power generation units were also excluded because they are not present at all plants. However, water usage for both quarry operations and electricity production is recognized to be significant.

### 3.3.1 Raw Material Preparation

The stage of raw material preparation starts at the raw materials storage area, and involves crushing, grinding and blending the natural raw materials, or the industrial wastes when there is co-processing at the cement plant, to produce a material called raw meal or raw mix that will then be made into clinker (Alsop 2005; CEMBUREAU 1999). The main difference in terms of water requirements depends on the manufacturing process being wet or dry.

In terms of water requirements for cement plants operating under the wet process, the grinding and homogenization of the raw material are carried out in aqueous slurry (Alsop 2005; van Oss and Padovani 2002). It is noteworthy that this volume of water is evaporated and thus lost in the kiln line. For plants operating under the semi-wet process, the slurry is dewatered before being fed into the kiln, but the water consumption for preparing the slurry is very similar. Therefore, for both wet and semi-wet processes there is a significant consumption of water for preparing the slurry. Values reported range from 100 to 850 liters of water per tonne of clinker produced (CEMBUREAU 1999; European
Commission 2010). The wide range of values presented may be explained by the myriad of technologies and equipment used, in addition to the particular water management practices at the plants. A typical kiln size produces around 3,000 tonnes of clinker per day (European Commission 2010), meaning that the daily water requirement for this stage of manufacturing may range from 300,000 to 2,550,000 litres.

Water is used in smaller quantities for dry and semi-dry processes when compared to wet processes. In the semi-dry process, water is used for humidifying and pelletizing the dry raw meal. In regards to the dry process, although the raw material is not prepared as slurry or pellets, the fine (and dry) raw material may not be properly agglutinated inside the raw material preparation mill (called the raw mill), thereby causing material instability in the milling process. Therefore, spraying water inside the raw mill may be necessary to improve the grinding conditions due to dry or unstable materials (Alsop 2005; Flsmidth 2011; Schroeder 2011). The raw mill types that may require water include the tube mill, the ball mill, and the vertical roller mill (Alsop 2005; European Commission 2010). Currently, more than 80 percent of new raw mills are vertical roller mills (Alsop 2005). The vertical roller mill has been the choice at new plants, because its electricity consumption is reduced (WBCSD-CSI 2009). These mills are based on the action of grinding rollers that ride a horizontal table or grinding bowl, supported on hinged arms (European Commission 2010). In any case, the necessary amount of water depends on the characteristics of the raw material as well as on the size and type of the raw mill (Schroeder 2011). Reported values go from zero up to 350 liters of water
consumed per tonne of clinker produced by dry and semi-dry processes\textsuperscript{3}, (CEMBUREAU 1999). To sum up, as stated earlier, a typical kiln size, for both wet and dry processes, produces around 3,000 tonnes of clinker per day (European Commission 2010), meaning that the daily water requirement for dry and semi-dry processes can be up to 1,050,000 litres compared to wet and semi-wet processes that can be up to 2,550,000 litres. Irrespective of the process, dust generation can occur at the raw material preparation area. Dust suppression may require spraying water. This aspect is discussed in Section 3.3.11, along with other water needs outside the production line.

\textbf{3.3.2 Fuel Supply Preparation}

Mills are also used for grinding and blending fuel materials such as petroleum coke (also called petcoke), coal and different types of wastes. The main types of mills for fuel preparation, used mainly for coal but also for industrial wastes, are tube mills, vertical roller mills, and impact mills (CEMBUREAU 1999; European Commission 2010). For some types of mills water may be sprayed over the fuel materials, for improving milling performance. As well, dust generation can occur around the fuel supply stockpiles and sometimes water may be sprayed over them for dust control. Information on the volume of water consumption for the milling processes of fuel supply preparation was not found in the literature.

\textsuperscript{3}Although this data was published in 1999, it is still valid because the processes have not changed significantly since that time.
3.3.3 Cleaning of Preheater Tower

Preheaters are prone to build up scale at the bottom side of the preheater tower (known as the riser) and high pressure water-blasters can be very effective to clean this scale (Alsop 2005). Water consumption data for this process were not found in the literature.

3.3.4 Kiln Gas Analysis

Gases from the cement kiln may be analyzed through inlet systems by way of a probe. This probe is used to evaluate the composition of the inlet kiln gas in order to control the kiln combustion operating conditions. Combustion conditions are related to fuel supply choices, clinker quality, and gaseous emissions to the atmosphere. The outside surfaces of such probes have to be cooled down by water or other coolant in some cooling jacket systems. This cooling ensures that the probe can operate properly, considering the probe is installed inside the kiln at temperatures up to 1,550°C. The quality of cooling water must be similar to drinking water and the flow required can reach 3,000 litres per hour, when there is no recycling in place (Enotec 2012). Some plants have closed-loop systems for cooling, thus using less water (Brang 2013; Enotec 2012; Floor 2013).

3.3.5 Clinker Cooling

The hot clinker reaches temperatures of about 1,200 to 1,450°C when it is leaving the kiln, but its temperature must be reduced to around 100°C before the grinding stage, when it becomes the final cement powder. Thus, the hot clinker drops out of the kiln into a cooling apparatus to decrease its temperature. There are two main types of clinker
coolers at cement plants: rotary coolers and grate coolers (European Commission 2010). The main types of rotary clinker coolers are tube coolers and planetary (satellite) coolers (CEMBUREAU 1999; European Commission 2010).

Rotary tube coolers are arranged at the outlet of the kiln, often in reverse configuration, and underneath the kiln. The clinker passes a transition hood before it enters the cooler, which is equipped with lifters to disperse the product into the airflow. For rotary tube coolers, the water consumption for optional enhanced cooling may reach 60 liters of water per tonne of clinker (CEMBUREAU 1999). The other common type of rotary cooler is the planetary (satellite) cooler that is comprised of a ring of typically 9 to 11 tubes attached to the discharge end of the kiln shell. The hot clinker enters the cooler tubes through openings in the kiln shell. These cooler tubes have internal mechanisms for lifting and dispersing the clinker. The clinker exit temperature can be further reduced by water sprays into the cooler tubes or onto the shell (European Commission 2010). When these water sprays are added, planetary (satellite) coolers may consume up to 40 liters of water per tonne of clinker (CEMBUREAU 1999; European Commission 2010). Water usage for both types of rotary coolers is estimated to be around 5000 litres per hour (European Commission 2010).

However, among the clinker coolers, the grate cooler is the most common (Alsop 2005; CEMBUREAU 1999). In this case, cooling is achieved by cross-flow air blown from bottom to top, with a clinker layer moving slowly through a travelling grate
(CEMBUREAU 1999; European Commission 2010). In the grate cooler there is no water requirement to cool down the clinker.

3.3.6 Cement Milling

The final operation in the Portland cement manufacturing process is the grinding of clinker to result in final cement powder. This operation is carried out in a cement mill, also called a finish mill. The main types of mills for grinding clinker are ball mills and vertical roller mills, but the most common in operation currently are the ball mills (Alsop 2005; European Commission 2010).

The ball mill is a rotating horizontal steel cylinder, with external diameter up to 6 meters and 20 meters in length, filled with steel balls of different sizes (European Commission 2010). While the cylinder rotates, the steel balls inside it tumble and crush the clinker. One unwanted outcome is that friction between the steel balls results in an increase of the internal mill temperature, thereby transferring heat to the clinker being milled, and this heat compromises the final quality of the cement. In order to overcome this effect, it is necessary to lower the internal mill temperature by spraying water in its interior. The quantity of water sprayed has to be sufficient to lower temperature, but also to evaporate, and avoid cement hydration inside the mill (Alsop 2005). The quantity of water consumption for ball mills was not found in the literature.
A description of the functioning of vertical roller mills was presented in Section 3.3.1, as the same technology is also used for raw material milling. Vertical roller mills may consume up to 20 liters of water per tonne of clinker (CEMBUREAU 1999).

The quantity of water sprayed, for ball and vertical roller cement mill, is mostly depending on the clinker quality, the mill size, the product fineness, as well as the use of cement additives (Schroeder 2011).

### 3.3.7 Cement Cooling

The temperature of the final cement powder has to be under 60°C, in order to ensure its proper quality (Alsop 2005). For some situations, it may be necessary to “water jacket” a conveying line from the cement mill to the storage silos, meaning that water is applied to the underside of the conveyor belt, allowing heat to dissipate without contact between the cement and the water (Alsop 2005). The other option involves heat exchange through a cement cooler, which is a compartment with a slowly rotating internal vertical screw auger. Cement exits the cement mill at high temperatures and is lifted through the cooler by the screw auger. Cooling is caused by cold water passing over the external surface of the cement cooler; as with water jacking, this process allows heat to dissipate without contact between the cement and the water. Specific data for the volume of water consumption for cement storage were not found in the literature.
3.3.8  **Cement Dispatch**

The final cement is loaded for dispatch, in bulk or in bags, and shipped via truck, rail or barge (Alsop 2005; European Commission 2010). Ideally, flexible filling pipes should be used for loading cement in order to minimize dust diffusion, although a water spray injection system for dedusting is an alternative that can be installed, as close as possible to the dust source. Beyond the loading process, in some cement plants there are stations for washing trucks, or at least their wheels, before leaving the facility, in order to minimize dust diffusion outside their boundaries. These systems can be similar to car washing machines, equipped with high pressure water sprays. For the cement dispatch procedures, data on water consumption were not found in the literature.

3.3.9  **Conditioning of Gaseous Emissions**

The gaseous emissions from the fuel mill, raw material mill, preheater tower, kiln, clinker cooler, and cement mill, may need some adjustment in temperature and humidity to meet the requirements for dust collection before being released to the atmosphere. Conditioning of gaseous emissions to meet requirements for dust collection can be carried out inside two types of structures: conditioning towers for spraying water into the gases and heat exchangers for blowing cold air onto the gases. The dust collectors for gaseous emissions are generally fabric filters or electrostatic precipitators (European Commission 2010). Sometimes there are hybrid dust collectors composed of an electrostatic precipitator followed by a fabric filter in the same device to achieve optimum efficiency (Alsop 2005).
When fabric filters are used – also called bag filters or baghouse for the full structure – the hot gases pass through a conditioning tower, where water is sprayed to lower the gas temperature to a maximum of 280°C, to meet the acceptable temperature limit for traditional filtering material (Alsop 2005; European Commission 2010). Inside conditioning towers for bag filters, up to 75 litres of water is used per tonne of clinker produced (CEMBUREAU 1999). If electrostatic precipitators are used for dust collection, the gases go through an electrostatic field when the particulate matter in the gas is negatively charged by discharge electrodes, and further separated on collecting electrodes. This system requires that beyond proper temperature of up to 400°C, the gas also has to meet proper humidity content (CEMBUREAU 1999; European Commission 2010). Inside conditioning towers for electrostatic precipitators, from 25 to 75 litres of water are used per tonne of clinker produced (CEMBUREAU 1999). When hybrid filters are used, less water is consumed compared to electrostatic precipitators alone (European Commission 2010). However, no values were found in the literature.

In addition to dust, the kiln exhaust gas may have compounds such as nitrogen oxides (NO$_x$) and sulfur dioxides (SO$_2$) that need to be reduced before the gas can be released to the atmosphere. The first approach to mitigating these emissions should be related to the adjustment of operational conditions and the choice of fuels and raw materials (European Commission 2010). However, when those measures cannot be taken to minimize NO$_x$ or SO$_2$, other techniques are available, such as cooling the flame inside the kiln, using catalysts for the kiln exhaust gases, and wet scrubbing the kiln exhaust gases.
When flame cooling is the choice for lowering NO\textsubscript{x} emissions from the kiln, then a solution of water with ammonia is added to the fuel or directly to the flame inside the kiln (CEMBUREAU 1999; European Commission 2010). The volume of water added ranges from 3 to 20 litres per tonne of clinker (CEMBUREAU 1999).

For reducing NO\textsubscript{x} emissions from the kiln there is also the selective non-catalytic reduction (SNCR), where a solution of up to 25 percent of an ammonia compound (NH\textsubscript{3}) in water is sprayed on the gas inside the preheater or inside the kiln in order to reduce nitric oxide (NO) to nitrogen gas (N\textsubscript{2}) (CEMBUREAU 1999; European Commission 2010). Another technique for NO\textsubscript{x} reduction is the selective catalytic reduction (SCR). In this process a chamber is installed –before or after the dedusting unit– that holds the modules of catalysts, in combination with an injection of an ammonium solution of 25 percent concentration as the reducing agent (European Commission 2010). The volume of water used in either SNCR or SCR varies according to the volume of the solution sprayed, which is dependent on specific operational conditions.

For SO\textsubscript{2} emission control from the kiln, a wet scrubber process can be installed, besides operational adjustments related to the kiln system and the choice of raw materials (European Commission 2010). In this case, the exhaust gas from the kiln first passes through a heat exchanger before it enters the SO\textsubscript{2} scrubber, at a temperature of about 115\textdegree C (CEMBUREAU 1999). The sulfur compound is absorbed by a liquid which is sprayed in a spray tower (European Commission 2010). This system may increase the
risk of water contamination (European Commission 2010). The volume of water consumption for the wet scrubber is dependent on specific operational conditions.

3.3.10 Cooling of Equipment

Although water is widely used at cement plants for the cooling of equipment, no data were found in the technical literature for the related volume of water usage per tonne of clinker or cement but it may represent 82 percent of total water used at the plant (Kollar and MacAuley 1980). Equipment that might be cooled through water includes motor components such as reducers and roller bearings, and sometimes casings of kilns, grinders, crushers and compressors. Water requirements for air conditioning are also included in here. It has been recognized that closed-loop circuits for recycling water have the potential to provide significant reduction of water consumption for the cooling of equipment (Alsop 2005).

3.3.11 Uses Beyond the Production Line

Water is also required outside the cement production line, contributing to the overall demand for the cement plant. The water usage outside the production line is investigated in this research for employees’ and subcontracted labourers’ needs, laboratory work, overall housekeeping, road dust suppression, and a wastewater treatment plant (WWTP).

Employees and subcontracted labourers working at cement plants need water not just for drinking, but also for the preparation of their meals, as well as for hygiene purposes. Data
for the daily per capita consumption specifically for workers (employees and subcontracted labourers) at cement plants were not found in the literature, but an average water consumption of 180 litres per worker per day was found in a study conducted in mining, quarrying and manufacturing industrial sectors (Undelstvedt 2006). Considering the aforementioned study involved overall manufacturing sectors, the same value can serve as baseline for cement plants.

Cement plants also generally have laboratories inside the facility for running quality control tests. Many of these tests require water to be carried out. One example of water requirement is for preparing samples of cement, in the form of cubes, for testing strength. A higher number of tests are requested when using new materials for making cement, or when testing different mixtures of raw materials. In the literature published in 1999, it was found that the volume of water consumption for a laboratory was estimated to be up to 20,000 litres per day (CEMBUREAU 1999). However, it should be noted that the current control tests are performed with less water than at that time. Data of water consumption in laboratories –indicated per tonne of clinker or cement produced– were not found in the literature.

Finally, it is likely that the environment of cement plants contains airborne dust, either around the production lines and storage areas, or inside the offices. Around the production lines, when conveyors for transport of materials are not covered or channeled, water sprays may be used for dust suppression. Water sprays may also be used around storage areas for raw materials and fuel materials to minimize dust diffusion, by allowing
humidification of stockpiles and discharging points (CEMBUREAU 1999; European Commission 2010). In regards to areas inside administrative buildings—for example offices, laboratories, washrooms, kitchens and lunchrooms—some overall housekeeping activities also require water for dedusting and washing.

Dust generation may also occur from traffic over unpaved surfaces inside the cement plants (Alsop 2005; European Commission 2010). Watering of roads and parking areas, sometimes with the addition of chemical dust suppressors, is widely applied for dust suppression in these situations (CEMBUREAU 1999; European Commission 2010). Water consumption for dust suppression of roads and parking areas, as well as watering green areas at cement plants, increase in dry weather (European Commission 2010). The amount of water for overall housekeeping and for dust suppression inside cement plants is fully dependent on local practices.

Some plants also have their own wastewater treatment plant (WWTP). The operation of a WWTP requires some water for preparing solutions for chemical treatment. The amount of water is dependent on the volume of effluent treated.

3.3.12 Summary of Water Requirements at Each Stage of Cement Production

Table 3.1 presents an overview of the water usage per stage of cement manufacturing irrespective of the myriad factors existing at cement plants. Some of the data found in the literature are presented in terms of water consumption relative to clinker production.
(litres of water per tonne of clinker), and some data are presented as water consumption per unit of production time (litres of water per day or litres of water per hour).

As seen in this section, so far this research revealed that the available literature provides limited data for total water usage at cement plants and few details about water requirements for the stages of cement manufacturing. It was also noted by this researcher that there is no consistent reporting units, making it difficult to compare different scenarios. In spite of this, all data obtained thus far are useful to provide some baseline information.

The establishment of a global database with performance benchmarks for water usage at cement plants –accounting for different manufacturing processes– would enable stakeholders in the cement industry to compare water usage at cement plants worldwide. Therefore, the next sections will bring the proposal of water intensity as a key performance indicator, as well as a discussion of a new methodology –based on data available from the from the companies’ reports— to further pursue data and fill the information gaps of water usage at cement plants.
Table 3.1. Summary of water requirements at various stages of production at cement plants

<table>
<thead>
<tr>
<th>STAGE</th>
<th>EQUIPMENT/PROCESSES REQUIRING WATER</th>
<th>WATER USAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material preparation</td>
<td>wet and semi-wet processes</td>
<td>100 to 850 L/tonne clinker (^{(A,B)})</td>
</tr>
<tr>
<td></td>
<td>dry and semi-dry processes</td>
<td>none to 350 L/tonne clinker (^{(A)})</td>
</tr>
<tr>
<td>Fuel supply preparation</td>
<td>improve milling performance</td>
<td>N.A.</td>
</tr>
<tr>
<td>Cleaning of preheater tower</td>
<td>high pressure water-blasters</td>
<td>N.A.</td>
</tr>
<tr>
<td>Kiln gas analysis</td>
<td>water cooling for probe</td>
<td>up to 3000 L/hour (^{(C)})</td>
</tr>
<tr>
<td>Clinker cooling</td>
<td>any rotary coolers</td>
<td>up to 5000 L/hour (^{(H)})</td>
</tr>
<tr>
<td></td>
<td>rotary planetary (satellite) coolers</td>
<td>up to 40 L/tonne clinker (^{(A,B)})</td>
</tr>
<tr>
<td></td>
<td>rotary tube coolers</td>
<td>up to 60 L/tonne clinker (^{(A)})</td>
</tr>
<tr>
<td>Cement milling</td>
<td>ball mill</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>vertical roller mill</td>
<td>up to 20 L/tonne clinker (^{(A)})</td>
</tr>
<tr>
<td>Cement cooling</td>
<td>water for cooling down cement by non-contact</td>
<td>N.A.</td>
</tr>
<tr>
<td>Cement dispatch</td>
<td>dust control and washing trucks</td>
<td>N.A.</td>
</tr>
<tr>
<td>Conditioning of gaseous emissions</td>
<td>dust collector by fabric filter</td>
<td>up to 75 L/tonne clinker (^{(A)})</td>
</tr>
<tr>
<td></td>
<td>dust collector by electrostatic precipitator</td>
<td>25 to 75 L/tonne clinker (^{(A)})</td>
</tr>
<tr>
<td></td>
<td>hybrid dust collector (electrostatic and bag filter)</td>
<td>N.A. but less than by electrostatic (^{(B)})</td>
</tr>
<tr>
<td></td>
<td>flame cooling for lowering NO(_x) from kiln</td>
<td>3 to 20 L/tonne clinker (^{(A)})</td>
</tr>
<tr>
<td></td>
<td>SNCR or SCR for lowering NO(_x) from kiln</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>wet scrubber for SO(_x) control from kiln</td>
<td>N.A.</td>
</tr>
<tr>
<td>Cooling of equipment</td>
<td>overall at the plant</td>
<td>N.A.</td>
</tr>
<tr>
<td>Uses Beyond the Production Line</td>
<td>Workers’ needs</td>
<td>meals and hygiene purposes</td>
</tr>
<tr>
<td></td>
<td>Laboratory work</td>
<td>analysis and cleaning</td>
</tr>
<tr>
<td></td>
<td>Housekeeping, dust suppression, and WWTP</td>
<td>dust control, cleaning, watering and preparing solutions.</td>
</tr>
</tbody>
</table>

Notes: N.A. indicates that data was not available.
Sources: (A) CEMBUREAU 1999; (B) European Commission 2010; (C) ENOTEC 2012; (D) Undelstvedt 2006.
### 3.4 Definition of Water Intensity of Cement

An indicator used to measure the performance of products, services and practices is also known as a key performance indicator (KPI). The availability of a database of KPI on water usage at cement plants would help decision makers compare water usage across plants and investigate related water management practices.

For this research, the selected KPI is water intensity, generally defined as the total volume of water consumed to produce a defined unit of a product (Berrittella et al. 2007; Crawford and Treloar 2005; WBCSD-IUCN 2010). More specifically, in this research, the water intensity of cement is the total quantity of freshwater used inside the plant to produce one tonne of cement powder. The focus of study for this research is the integrated cement plants that manufacture both clinker and cement powder, excluding quarrying operations. This indicator was chosen as the key performance indicator for this research because it is representative of the total volume of freshwater used at cement plants to meet all water requirements at each stage of production, including uses beyond the production line, as described in Section 3.3.

Some data of water intensity were directly obtained from the companies’ reports (i.e. their own declared data) and some data were calculated (i.e. the author’s calculated data) based on the published environmental indicator for total water withdrawal (EN8 as further defined in Section 3.5.2) and the published total cement production during the same reporting period (Equation 3.1).
\[ WI = \frac{EN8}{CP} \]  

(3.1)

Where:

\( WI \) = water intensity of cement (litres/tonne of cement)  
\( EN8 \) = GRI indicator for the total water withdrawal (litres)  
\( CP \) = total cement produced (tonnes of cement)

3.5 Collection of Corporate Reports to Compile Data of Water Intensity

This section will present a methodology for obtaining a data set for water usage at cement plants –based on the key performance indicator of water intensity of cement manufacturing. It starts by collecting corporate reports from the 24 cement companies worldwide that are members of the Cement Sustainability Initiative (CSI, see Section 3.5.1). These data compiled are exclusively from selected corporate reports published based on the guidelines by the Global Reporting Initiative (GRI, see Section 3.5.2). Water intensity data were obtained or calculated from the information in those selected reports. All data sets obtained are then analyzed with the intention to establish a global database of water intensity for different scenarios at cement plants.

There are two reasons for selecting cement companies that are members of the CSI: first, its members have plants worldwide, and second, its members tend to be committed to promoting environmental sustainability, and are thus more likely to publish corporate social responsibility (CSR) reports. Information published on the CSR reports by these CSI members could be biased because these companies tend to be more environmentally conscious and therefore they could have lower water consumption rates. However, CSI
members are better candidates for disclosing their water usage, thus their CSR reports provide a start point for this research.

The reasons for limiting the selection to CSR reports that followed the GRI guidelines are that GRI guidelines set out specific standards to consistently measure and disclose data of the reporting organizations’ areas of economic, environmental, social and governance performance, as well as to evaluate them over time (GRI 2011). Moreover, the use of these guidelines is growing in popularity in the cement industry (Isaksson and Steimle 2009) and the standards for environmental performance include indicators of water usage. The CSR reports published based on guidelines from the GRI were also selected to ensure an international standard for collected information.

3.5.1 Selection of CSI Cement Companies

The Cement Sustainability Initiative (CSI) was established in Geneva in 1999 by ten of the world’s leading cement companies at that time, under the sponsorship of the World Business Council for Sustainable Development (Klee and Coles 2004). All 24 cement companies who are members of the CSI were selected for this research. These companies are listed in Appendix A (Table A.2), along with their countries of origin and websites. Among its members there are the world’s five largest cement producers: Lafarge, Holcim, Cemex, Heidelberg Cement, and Italcementi Group (European Commission 2010). Furthermore, the cement plants of CSI members are located in more than 100 countries (WBCSD-CSI 2012), meaning that CSI member data provides a global sample of water usage at cement plants.
The water intensity results compiled from CSR reports and the two case studies assessed for the current study will be of interest to the CSI in relation to its own research on water usage at cement plants (Klee 2010; Leung 2012).

### 3.5.2 Selection of GRI Guidelines and Related Indicators

The Global Reporting Initiative (GRI) is based in the Netherlands and is an independent, not-for-profit organization, and also a collaborating centre of the United Nations Environmental Program – UNEP (Hill 2007). The “GRI Sustainability Reporting Framework” sets out principles and indicators that organizations can use to consistently measure and report their areas of economic, environmental, social and governance performance, as well as to evaluate their own performance over time (GRI 2011). The GRI is assisting stakeholders to produce CSR reports with a globally-shared structure of concepts and consistent language and metrics about sustainability (Hill 2007; Morrison, Schulte and Schenck 2010). Data for this research were obtained from CSR reports that followed the GRI-G3 Guidelines document and its related indicators (GRI 2006). The latest version GRI-G4 was released in 2013, but the indicators of interest for this work have not changed from the last one (GRI 2013b). Therefore, the selected framework for this research is the GRI-G3 guidelines – launched in 2006 – to keep the same guidelines for CSR reports published under the period of this research and because the GRI-G3 guidelines are still recognized until December 31, 2015 (GRI 2013a).

The GRI-G3 guidelines include multiple environmental indicators, representing the impacts a business’s inputs and outputs have on living and non-living natural systems.
(GRI 2006). These environmental indicators are named ‘EN’ and are related to water, biodiversity, material, energy, emissions, effluents, waste, products, services, and transport. For this research, three indicators were selected for compiling data about the water intensity of cement, and also for investigating existing water management practices at cement plants:

- EN8 = total water withdrawal by source;
- EN10 = percentage and total volume of water recycled and reused; and
- EN21 = total water discharge by quality and destination.

The indicator EN8 was used to calculate the water intensity of cement, in conjunction with total cement production during the same reporting period (Equation 3.1). The total production of cement did not have a specific indicator, but this information was generally available in the corresponding corporate report. The other two indicators (EN10 and EN21) do not account for water intensity, but were helpful to evaluate water management practices, especially to estimate the potential for recycling effluents back into the process.

The EN8 indicator (total water withdrawal by source) accounts for the total volume of water withdrawn up to the boundaries of the reporting organization, for any use, over the reporting period (GRI 2006a). The GRI-G3 guidelines recommend considering water extracted from any source, whether withdrawn directly by the reporting organization or by water utilities. The EN8 indicator includes: the extracted volume of surface water, such as wetlands, rivers, lakes and oceans; groundwater; rainwater harvested; wastewater brought in from another organization; and also water supplied by the municipality or
from other water utilities. This latter information can be obtained from water meters or water bills, or can be based on the organization’s own estimate (if neither meters nor bills exist). The recommendation to also include the removal for cooling water is emphasized in the GRI-G3 guidelines (GRI 2006a).

The second indicator selected (EN10, the percentage and total volume of water recycled and reused) measures both water that was treated and water that was not treated prior to reuse (GRI 2006a). It is reported as the total water returned to the process by the organization per year by volume ($m^3$/year), or as a percentage of the total water withdrawal reported under indicator EN8. Rainwater and wastewater generated by domestic processes inside the industry—such as washing dishes, laundry, and bathing—are included. The EN10 may represent a measure of the efficiency of the organization in reducing total water intake from natural sources, as well as in reducing effluent discharges to the environment, therefore indicating the potential for improving water management practices and decreasing the costs of water intake and effluent treatment and discharge.

It should be noted that the volume of rainwater harvested is included in both indicators EN8 and EN10. This fact may generate some confusion so one has to be very careful when reporting rainwater harvesting at the organization.

The last GRI-G3 indicator investigated in this research is EN21, the total water discharge by quality and destination (GRI 2006). It represents the amount of effluents discharged
over the reporting period to subsurface waters, surface waters, or sewers that lead to rivers, oceans, lakes, wetlands, treatment facilities, or groundwater. The information about quality must be reported in terms of total volumes of effluent, using concentrations of standard parameters such as biological oxygen demand (BOD), total suspended solids (TSS), or any other parameter that is consistent with the organization’s product, services or operations. The information for the indicator EN21 must come from flowmeters and regulatory permits. However, estimates are allowed as long as their considerations and limitations are clearly disclosed (GRI 2006a). The indicator EN21 is directly linked to ecological impact on receiving waters and the surrounding environment (GRI 2006a).

With that stated the first step to compile data for proposing a global database of water intensity of cement manufacturing was to collect the largest possible number of CSR reports based on the GRI-G3 guidelines, from cement companies that are members of the CSI. The next section describes the process used for collecting CSR reports.

3.5.3 Sources of CSR Reports

CSR Reports were selected according to a standardized set of criteria. All selected reports were:

- exclusively from the 24 cement companies that are members of the CSI,
- provided information of water usage exclusively at integrated cement plants (with both clinker production and final grinding to cement powder), excluding the water usage at quarries,
- based on the GRI-G3 guidelines,
- reporting period between 2008 and 2010 (to encompass the years when CSR reports based on GRI guidelines were following the version GRI-G3); and
- published in English, Spanish or Portuguese (languages which this author reads fluently).

Wherever it was available, data provided by country of plant location were recorded in addition to aggregated data for the whole company.

The GRI organization does not require that companies send their CSR reports back to the GRI’s database, although they encourage this action to make reports available for all stakeholders. Therefore, the GRI’s website was the first source for collecting CSR reports for the selected cement companies for this research. However, since not all CSR reports were available at the GRI’s website, a new search was performed over the cement companies’ websites. A final search for CSR reports not published either on the GRI’s website or on individual company websites was performed through CorporateRegister.com website.

3.5.3.1 CSR Reports Obtained from GRI’s Website

The first search for CSR reports was performed through the GRI’s website at www.globalreporting.org. This website includes a database titled “Sustainability Disclosure Database” at http://database.globalreporting.org/. This database contains information on all companies that have sent their published CSR reports to the GRI under the GRI Guidelines since 1999 (GRI 2012).
To meet the objectives of this research, the GRI’s database was searched on June 13, 2012, using the following filters: GRI-G3 guidelines, publication years from 2009 to 2011 (one search was performed for each year), all organization sizes, sector of construction materials and all organization regions. Only CSR reports for the 24 companies that were members of the CSI—published in English, Spanish and Portuguese—were downloaded.

The results of this search are included in Table 3.2, where they are indicated as ‘Source (a)’. Eleven out of the 24, or approximately 46% of the 24 CSI member companies had submitted at least one CSR report to the GRI’s database. In total twenty four CSR reports were downloaded from the GRI’s website. In order to complete the search for CSR reports, an investigation was then performed using the cement companies’ websites.

3.5.3.2 CSR Reports Obtained from Cement Companies’ Websites

As stated earlier, the GRI organization does not require that the companies send their reports back to the GRI’s database. Thus, a new search was performed over the companies’ websites.

At the companies’ websites searched on June 13, 2012, fifteen CSR reports were downloaded. The results of this search are included in Table 3.2, where they are indicated as ‘Source (b)’. It is worth mentioning that all companies were searched, even the ones that had CSR reports available at the GRI’s website. The reason was that some companies publish CSR reports in more than one source or they submit CSR reports for
one year for the GRI’s database but for other years only upload reports to their own
cOMPANY websites. In order to complete the search for more reports, a last investigation
was performed over the CorporateRegister.com website.

3.5.3.3 CSR Reports Obtained from CorporateRegister.com Website

The search for CSR reports not published either in the GRI’s or in the companies’
websites was performed at CorporateRegister.com. This organization is based in the
United Kingdom and aims to provide access to corporate reports for stakeholders. At the
time of this research, it was free to search CorporateRegister.com and to download a
limited number of reports.

After logging in at CorporateRegister.com (www.corporateregister.com), the search for
reports was started by using the search term ‘cement’. The list available on June 13, 2012
resulted in the names for 257 related companies. From that list, all companies of interest
to this research were selected to perform the search for their CSR reports. Nine CSR
reports were downloaded. The results of this search are included in Table 3.2, where they
are indicated as ‘Source (c)’.

In total, for the criteria selected for this research, 48 CSR reports of 14 cement companies
were collected (Table 3.2). These results represent 58% of CSI members that have
published reports based on GRI-G3 guidelines between the years of 2009 to 2011. Data
presented in these reports were then used to compile information about the water
intensity of cement, as discussed in the next section.
Table 3.2. Available CSI member CSR reports that followed GRI-G3 guidelines, as of June 13, 2012

<table>
<thead>
<tr>
<th>CEMENT COMPANY</th>
<th>REPORTING PERIOD</th>
<th>TITLE OF REPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEMENTOS ARGOS</td>
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<td>Informe de Sostenibilidad 2008(^{(c)})</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>Informe de Sostenibilidad 2009(^{(c)})</td>
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<tr>
<td></td>
<td>2010</td>
<td>Informe de Sostenibilidad 2010(^{(c)})</td>
</tr>
<tr>
<td>CEMEX</td>
<td>2008</td>
<td>2008 Sustainable Development Report(^{(b)})</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>2009 Sustainable Development Report(^{(b)})</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>2010 Sustainable Development Report(^{(b)})</td>
</tr>
<tr>
<td>Cemex en España</td>
<td>2008</td>
<td>Memoria de Sostenibilidad 2008(^{(a)})</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>Memoria de Sostenibilidad 2009(^{(a)})</td>
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<tr>
<td></td>
<td>2010</td>
<td>Memoria de Sostenibilidad 2010(^{(a)})</td>
</tr>
<tr>
<td>Cemex México</td>
<td>2009</td>
<td>Informe de Desarrollo Sustentable 2009(^{(b)})</td>
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<td>2009</td>
<td>2009 Sustainable Development Report(^{(b)})</td>
</tr>
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<td>Cemex in the United Arab Emirates</td>
<td>2010</td>
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<td>Corporate Social Responsibility Report 2008(^{(a)})</td>
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<td>2009</td>
<td>Corporate Social Responsibility Report 2009(^{(a)})</td>
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<tr>
<td>GCC</td>
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<td>2009</td>
<td>Sustainability Report 2009(^{(b)})</td>
</tr>
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<td></td>
<td>2009/2010</td>
<td>Sustainability Report 2009/2010(^{(a)})</td>
</tr>
<tr>
<td>Heidelberg Cement Northern Europe</td>
<td>2009</td>
<td>Sustainability Report 2009(^{(c)})</td>
</tr>
<tr>
<td>HOLCIM</td>
<td>2009</td>
<td>Corporate Sustainable Development Report 2009(^{(a)})</td>
</tr>
<tr>
<td>CEMENT COMPANY (alphabetical order)</td>
<td>REPORTING PERIOD 2008-2010</td>
<td>TITLE OF REPORT</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>-----------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td><strong>Holcim Colombia</strong></td>
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<td>Informe de Desarrollo Sostenible 2008&lt;sup&gt;(a)&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>Informe de Desarrollo Sostenible 2010&lt;sup&gt;(a)&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>ITALCEMENTI GROUP</strong></td>
<td>2008</td>
<td>Sustainable Development Report 2008&lt;sup&gt;(a)&lt;/sup&gt;</td>
</tr>
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<td></td>
<td>2009</td>
<td>Sustainable Development Report 2009&lt;sup&gt;(a)&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>2010</td>
<td>Sustainable Development Report 2010&lt;sup&gt;(a)&lt;/sup&gt;</td>
</tr>
<tr>
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<td>2008</td>
<td>2008 Sustainability Report&lt;sup&gt;(b)&lt;/sup&gt;</td>
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<td></td>
<td>2009</td>
<td>2009 Sustainability Report&lt;sup&gt;(b)&lt;/sup&gt;</td>
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<td>Informe de Sostenibilidad 2008-2010&lt;sup&gt;(c)&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Lafarge in the United Kingdom</strong></td>
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<td>2008 Sustainability Report&lt;sup&gt;(c)&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>2009 Sustainability Report&lt;sup&gt;(c)&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>Environment Report 2010&lt;sup&gt;(c)&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>SCG - SIAM CEMENT GROUP</strong></td>
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<td>Sustainability Report 2008&lt;sup&gt;(b)&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2009</td>
<td>Sustainability Report 2009&lt;sup&gt;(b)&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>2010</td>
<td>Sustainability Report 2010&lt;sup&gt;(b)&lt;/sup&gt;</td>
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<td></td>
<td>2009-2010</td>
<td>6&lt;sup&gt;th&lt;/sup&gt; Corporate Sustainability Report 2009-10&lt;sup&gt;(a)&lt;/sup&gt;</td>
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<td><strong>TAIHEIYO CEMENT</strong></td>
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<td>Corporate Social Responsibility Report 2009&lt;sup&gt;(b)&lt;/sup&gt;</td>
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<tr>
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<td>2009-2010</td>
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<tr>
<td></td>
<td>2010-2011</td>
<td>Corporate Social Responsibility Report 2011&lt;sup&gt;(b)&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>TITAN CEMENT</strong></td>
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</tr>
<tr>
<td></td>
<td>2009</td>
<td>Corporate Social Responsibility and Sustainability Report 2009&lt;sup&gt;(a)&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>2010</td>
<td>Corporate Social Responsibility and Sustainability Report 2010&lt;sup&gt;(a)&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
### CEMENT COMPANY (alphabetical order) | REPORTING PERIOD 2008-2010 | TITLE OF REPORT
---|---|---
ULTRATECH CEMENT (Same group for Aditya Birla and Grasim) | 2007-2008<br>2010 | Sustainability Report 07-08<sup>(b)</sup><br>Sustainability Report 2010<sup>(a)</sup>

*Notes*: The letter in parentheses indicates the sources (a) GRI’s Database, (b) Company’s website, (c) CorporateRegister.com

#### 3.6 Results and Discussion of Data from CSR Reports

An extensive search was completed with the intention to compile a global database of water intensity for cement manufacturing at cement plants owned by member companies of the Cement Sustainability Initiative (CSI). This investigation used data published in CSR reports that followed GRI-G3 guidelines, for a reporting period of three years (2008 to 2010), by 24 cement companies worldwide, including the five largest cement producers.

This research examined information about water usage exclusively at integrated cement plants (with both clinker production and final grinding to cement powder), excluding quarrying operations of raw materials. The primary data investigated were kiln system (wet or dry process), cement production, indicator EN8 (water withdrawal), declared water intensity (as published in CSR reports), and calculated water intensity data (Equation 3.1). In order to analyze the impact of effluent recycling, indicators of wastewater recycled and reused (EN10) were also compiled and are further discussed in this section. All data are included in Table 3.3. The attempt to collect data of indicator
EN21 (water discharge) resulted in only one data point, but is also further discussed in this section. Results of water intensity from CSR reports are also included in Figure 3.5. The values published in CSR reports for cement production are measured in tonnes, and the values for the indicator EN8 are measured in cubic metres. These numbers are typically obtained using scales and flowmeters, which are all connected to a central control panel, and sometimes they are estimated. The accuracy of these values is dependent on the equipment used and assumptions made. Accuracy in this work is a qualitative expression of the degree to which a calculated or estimated data is close to real or expected value (UNIDO 2006). The values are indicated here exactly as they are published in the CRS reports. For the purposes of this research, all data obtained from the reports were considered valuable material for compilation, although possible sources of uncertainties are further discussed. Uncertainty may be caused by error, which is considered the difference between reported and real value (UNIDO 2006).
Table 3.3. Data compiled from CSI member CSR reports that followed GRI-G3 guidelines, as of June 13, 2012 – indicated by data of water intensity of cement from lower to higher value

<table>
<thead>
<tr>
<th>DATA order is from lower to higher value of water intensity</th>
<th>WATER INTENSITY</th>
<th>WATER INTENSITY</th>
<th>KILN SYSTEM</th>
<th>CEMENT PRODUCTION</th>
<th>INDICATOR EN8</th>
<th>INDICATOR EN10</th>
<th>REPORTING PERIOD</th>
<th>REFERENCE</th>
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<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
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<td>GCC 2010</td>
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<td>N.A.</td>
<td>N.A.</td>
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<td>GCC 2010</td>
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<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td>2009</td>
<td>Cemex-México 2010</td>
</tr>
<tr>
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<td>2010</td>
<td>Cemex-España 2011</td>
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<td>N.A.</td>
<td>N.A.</td>
<td>2009</td>
<td>Cemex-España 2010</td>
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<td>N.A.</td>
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<td>Italcementi 2011</td>
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<td>85</td>
<td>2009</td>
<td>Cemex 2011</td>
</tr>
<tr>
<td>DATA order is from lower to higher value of water intensity</td>
<td>WATER INTENSITY</td>
<td>WATER INTENSITY</td>
<td>KILN SYSTEM</td>
<td>CEMENT PRODUCTION</td>
<td>INDICATOR EN8</td>
<td>INDICATOR EN10</td>
<td>REPORTING PERIOD</td>
<td>REFERENCE</td>
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<tr>
<td>-------------------------------------------------------------</td>
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<tr>
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<td>N.A.</td>
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<td>GCC 2010</td>
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<td>N.A.</td>
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<td>2009-2010</td>
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<td>7,100,000</td>
<td>7,329,646</td>
<td>49</td>
<td>2010</td>
<td>Argos 2011</td>
</tr>
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</table>

Notes: (1) indicates that data was calculated according to Equation 3.1; (2) indicates that data was declared in the CSR report for their División Mexico; (3) indicates that data was declared in the CSR report for their División Estados Unidos; N.A. indicates that data was not available; N.C. indicates that data was not calculated because lack of information.
3.6.1 Data of Water Intensity of Cement

From the selected 48 CSR reports from the 14 reporting cement companies (Table 3.2), 23 CSR reports from 11 cement companies presented information related to water intensity of cement. This fact indicates that approximately 46% of the 24 CSI member companies had published at least one CSR report with the information of their own declared water intensity data, and/or the indicator EN8 with the related cement production data. The extensive search performed by this author resulted in only 35 data points for water intensity over the three-year reporting period investigated (Figure 3.5).

![Graph of water intensity figures](image)

**Figure 3.5.** Available water intensity figures - in ascending order - from CSI member CSR reports that followed GRI-G3 guidelines, as of June 13, 2012.

As seen in Table 3.3 and in Figure 3.5, the range of published water intensity data varied widely from 147 up to 1,220 litres/tonne of cement. Part of this variability may be due to the difference between wet and dry manufacturing processes. The older wet process
technology, which requires larger quantities of water than the dry process, is still in place for many plants, although many have switched to the new systems or are running both kilns in parallel. For the data set created for this research, it was expected that lower water intensity numbers were related to the dry process of cement manufacturing, in which there is no addition of water to the raw materials before they enter the cement kiln. Similarly, at the higher end of the values for water intensity it was expected that the respective processes were wet, i.e. water was mixed with the raw materials prior to entering the cement kiln. However, information about the process in place was not available in the majority of CSR reports and this assumption could not be confirmed. More specifically, out of the 35 data points obtained, only 6 have an indication of the cement manufacturing process. Even for those 6 data points that indicate the type of kiln, two companies indicated that their data encompass plants with both wet and dry processes. In any case, beyond the cement manufacturing process, it is expected that water management practices are also a factor in the wide range of compiled water intensity data for cement manufacturing.

Two out of the 23 CSR reports had published both their own declared water intensity data, and also the indicator EN8 and the respective cement production for the same reporting period. Therefore, for these two reports it was possible to do a comparison between the author’s calculated data of 867 and 1,237 litres per tonne of cement and the corresponding companies’ declared data of 830 and 1,220 litres per tonne of cement; this comparison showed a difference of less than 5% (for references 33 and 35 in Table 3.3). This similarity suggests that the water intensity published in the CSR reports are
following the criteria for water intensity defined for this research (Equation 3.1), although the small quantity of data does not allow for any conclusive statement.

As indicated earlier in this chapter, Kollar and MacAuley (1980) and van der Leeden, Troise and Todd (1990) estimated that a range from 600 to 3,500 litres of water is withdrawn to produce one tonne of cement. The results of the current investigation suggest 147 to 1,237 litres/tonne of cement, at the lower end of the range published by the aforementioned authors. The data compiled in this current research are representative of water usage exclusively inside the boundaries of the plants and possibly their numbers are higher because they include water withdrawal at quarries. Another reason that may explain those higher water intensity results is related to the inclusion of water requirements for in-house power generation units that sometimes are located inside the plants. The reports investigated for this research did not provide information on the existence of in-house power generation units, thus not allowing this researcher to perform any correlation with the respective water intensity.

The average for all water intensity data obtained in this research is approximately 400 litres/tonne of cement. For the two cases where both declared and calculated data were available, the declared data were used. The weighted mean, in terms of total cement production (Equation 3.2), was also calculated in an attempt to evaluate if higher cement production would translate into higher water intensity of cement. The hypothesis was that greater water intensity would result from the potential conditions for achieving higher cement production at larger plants, including a more complex structure, probably with
more washrooms, a larger laboratory, larger kitchens or lunchrooms, and more employees and subcontracted labourers.

\[ \overline{WI} = \frac{\sum (CP_n \times WI_n)}{\sum CP_n} \]  

(3.2)

Where:

\( \overline{WI} \) = weighted mean of water intensity of cement (litres/tonne of cement)

\( CP_n \) = total cement produced for the plant being evaluated (tonnes of cement)

\( WI_n \) = water intensity of cement for the plant being evaluated (litres/tonne of cement)

The weighted mean resulted in approximately 500 litres/tonne of cement. However, this evaluation is not conclusive in terms of the influence of higher cement production on water intensity, because only six reports published both cement production data and the related water intensity, to allow the specific calculation for weighted mean.

Once again, the average values obtained in this research are lower than those data published by Kollar and MacAuley (1980) and by van der Leeden, Troise and Todd (1990), possibly because water withdrawal at quarries and water requirements for in-house power generation units may have be included in their investigation. However, the means here compiled for water usage exclusively at plants, of around 400 (average) to 500 (weighted mean) litres/tonne of cement, are similar to the EPD data published by CEMBUREAU (2008), being 226 litres/tonne of cement for some requirements at plants and 1,693 litres/tonne of cement when including quarrying operations (see Section 3.3).

The search for values of water intensity for cement manufacturing revealed that there is considerable variation between the results of water intensity at cement plants that lead to
a high number of questions in terms of setting parameters for water intensity. One potential source of variation is that a publisher might declare water intensity for cement manufacturing including total water withdrawal for both plant and quarry, and sometimes in-house power generation units, without stating this clearly. Moreover, the indication for plants working with wet, dry and even both processes would be helpful to define scenarios in terms of water usage at plants. Many attempts were performed by this researcher to gather further data via e-mail and telephone. However, due to an inability to access information, or to confidentiality requests from the personnel of the majority of plants contacted, these contacts did not result in usable data. With that said, all conclusions of this research are based solely on the disclosed information available in the reports.

3.6.2 Data of Effluents from Cement Plants

As stated earlier, the GRI-G3 indicators EN10 and EN21 for effluents from cement plants were also investigated, with the intention to analyze the impact of effluent recycling on the water intensity of cement. However, this attempt resulted in the compilation of even fewer data than for water intensity. These results are indicated in Table 3.3.

From the available data for effluent recycled and reused (EN10), five out of the 24 reporting companies have reported that from approximately 70 to 85% of water is currently being recycled and reused at their plants. Although there are few data points available for the indicator EN10, the range of data shows a trend of lower water intensity relating to a higher percentage of recycling. One data point contradicts this trend,
indicating a 49% recycling rate with a high water intensity value of 1032 litres/tonne of cement.

Some CSR reports state that cement plants do not generate high volumes of effluents, but there is only one data point published for the volume of effluent discharge (EN21), and only eight data points published for effluents recycled and reused (EN10). The only data for the volume of effluent discharge (EN21) is around 2 million m³ per year and it is related to a cement production of approximately 7 million tonnes for that same year (for reference 34 in Table 3.4). This indicator EN21 was also supposed to provide the total water discharge by quality and destination, but the majority of CSR reports did not present this information. Because there was only one data point, this number is not included in Table 3.3.

3.7 Summary of Findings and Further Steps for Investigating Water Usage at Cement Plants

The GRI-G3 guidelines were the selected standard of reported information, in part because of their potential for comparability. One of the GRI principles is that all reported data should be presented in a manner that enables stakeholders to support analysis relative to other organizations (GRI 2011). However, in the CSR reports investigated, the data reported for water intensity of cement manufacturing was not accompanied by details about whether they were measured, estimated, or modeled, limiting the potential for comparison of data between different plants. Furthermore, there is also doubt if all water sources used are metered at the plants. Therefore, the companies’ declared water
intensity data might have been lower than that of the real scenario, where there may be water consumption at the plant that is not measured and not accounted for.

The data sets of water intensity compiled in this research are nevertheless beneficial to increase knowledge and raise awareness of the need to improve reporting of water usage for cement manufacturing. Approximately half of the cement companies that are members of the CSI, as well as nearly half of the CSR reports selected for this research, did not publish values of water usage at cement plants, although in some of those reports there is discussion of water issues. This fact indicates that water usage disclosure is not a regular practice in the cement industry, as opposed to the practice for reporting other environmental impact data such as energy consumption and greenhouse gas emissions. Moreover, one can assume that water usage may not be frequently monitored, or even measured, at a large number of cement plants worldwide. Therefore, this research revealed a serious problem with a lack of even basic reporting of water usage data in CSR reports of cement companies.

To pursue more data of water usage at each stage of manufacturing, as well as to obtain more data regarding water intensity at cement plants, two fieldwork-based case studies are described in the following chapter. These case studies were conducted at two cement plants, one in Brazil and one in Canada. Results from case studies, beyond investigating water usage at different stages of cement manufacturing, will also be combined with the compilation of data from corporate reports to test the application of proposed KPI of water intensity.
CHAPTER 4
WATER INTENSITY AT CEMENT PLANTS: FIELDWORK-BASED CASE STUDIES

We are not in business to make cement, we are in business to make money.

4.1 Case Studies Piloted at Cement Plants

Chapter 3 presented the results of an investigation of water measurement and reporting by cement manufacturers. Using published data from different sources, that investigation yielded data for both the overall process and the stages of manufacturing, but information gaps still exist. Therefore, further investigation by in situ data collection was used to develop two case studies. This chapter describes the methodology and analysis of case studies for the overall process, combined with data from the theoretical background compiled in Chapter 3. Chapter 5 will present analysis of water usage but specifically for the eleven stages of cement manufacturing, also based on case study data as well as data from the theoretical background compiled in Chapter 3.

Because this author is involved in research in Brazil and in Canada, the logical decision was to select one plant in each of these two countries for piloting case studies. In addition, this author intended to obtain water usage data from two different climate conditions. Canada is in a climatic region with large seasonal temperature differences (warm to hot summers and cold winters with snowfall). Brazil is in a climatic region with less variation (hot, humid summers and generally mild to cool winters). This research
design may provide insight about whether the local climate impacts water usage for cement manufacturing over the year, beyond influencing the demand for cement production. Extreme cold temperatures require more energy consumption to maintain the kiln system at the proper temperature, so the Canadian plant normally shuts down the kiln for a certain period of time in the winter, and uses that period to perform maintenance. All other activities are kept going at the plant (for instance, cement milling to grind stockpiled clinker), so there are continued requirements for water for other stages of manufacturing even when the kiln is shut down. In the cement plant in Brazil there is no specific month for shutting down the kilns for maintenance (there were two kilns at the Brazilian plant at the time data were collected). Technicians perform maintenance on each kiln twice a year, approximately once per six-month period. When required, they also work on maintenance of other equipment. Thus, data obtained for these two different routines may provide interesting information about water usage over the year for two different climatic conditions.

Another major difference between these two plants is that they were located in so-called “developing” and “developed” countries, respectively Brazil and Canada. Data about cement production collected from these two different economic zones are valuable to evaluate if specific economic conditions of these countries are affecting their yearly production, and consequently the related water withdrawal. Other economic aspects related to the cement production of these two countries—for example, whether each economy was growing, stable or declining were presented in Chapter 1, where the larger cement producers are ranked (see Table 1.1).
The two plants selected for case studies have dry processes for cement manufacturing; dry processes are the current trend worldwide. Therefore, this research is relevant to current water management practices and to promoting future directions for water saving strategies.

Data were collected for the years from 2005 to 2011, although they were not available for the entire period for both plants (Table 4.1). Data for monthly cement production and water withdrawal, when available, were directly obtained from each plant’s personnel, or by compiling information from their water bills and/or from the plant’s own measurement systems.

<table>
<thead>
<tr>
<th>DATA INVESTIGATED</th>
<th>COUNTRY OF CASE STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CANADA</td>
</tr>
<tr>
<td>Cement production</td>
<td>2007 to 2011</td>
</tr>
<tr>
<td>Water withdrawal</td>
<td></td>
</tr>
<tr>
<td>Groundwater</td>
<td>2007 to 2009</td>
</tr>
<tr>
<td>Surface water</td>
<td>Not used</td>
</tr>
<tr>
<td>Mains water (Public water supply)</td>
<td>2007 to 2011</td>
</tr>
<tr>
<td>Stormwater floor drainage</td>
<td>Not used</td>
</tr>
<tr>
<td>Effluent recycling</td>
<td>-</td>
</tr>
<tr>
<td>Total water withdrawal</td>
<td>2007 to 2009</td>
</tr>
<tr>
<td>Effluent discharge from settling pond</td>
<td>2008 to 2010</td>
</tr>
</tbody>
</table>

*Note: A dash (-) indicates that water was used but data was not measured.*
4.1.1 Background Information for Cement Plants Studied

Information on the name and specific location of each plant is not provided for reasons of confidentiality, as per the request of both plant managers. Table 4.2 shows a summary of non-confidential background information for the two case studies. At the time data were collected, the cement plant in Canada had a single production line (one kiln) and the cement plant in Brazil had two production lines (two kilns) running in parallel, namely 01 and 02. Both plants consume energy from the electrical grid and do not have in-house power generation unit. The results, details and the explanations of each case will be discussed in the following sections.

Table 4.2. Summary of background information for each stage of production for the two case studies piloted at cement plants, one in Brazil and one in Canada

<table>
<thead>
<tr>
<th>STAGE OF PRODUCTION</th>
<th>COUNTRY OF CASE STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CANADA</td>
</tr>
<tr>
<td></td>
<td>Single production line</td>
</tr>
<tr>
<td>Kiln system</td>
<td>Dry with PH' Length 75 metres Internal diameter 4.75 metres</td>
</tr>
<tr>
<td>Raw material preparation (raw mill)</td>
<td>Vertical roller mill</td>
</tr>
<tr>
<td>Fuel supply preparation</td>
<td>Ball mill (for pet coke)</td>
</tr>
<tr>
<td>Cleaning of preheater tower</td>
<td>High-pressure water blaster</td>
</tr>
<tr>
<td>Kiln gas analysis</td>
<td>No water requirement (cooling oil used)</td>
</tr>
<tr>
<td>Clinker cooling</td>
<td>Grate cooler</td>
</tr>
<tr>
<td>Cement milling</td>
<td>Ball mill</td>
</tr>
<tr>
<td>Cement dispatch</td>
<td>Wash trucks before leaving the plant</td>
</tr>
<tr>
<td>Cement cooling</td>
<td>Heat exchange by cooling water passing down the outside shells of a cement cooler</td>
</tr>
</tbody>
</table>

98
<table>
<thead>
<tr>
<th>STAGE OF PRODUCTION</th>
<th>COUNTRY OF CASE STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CANADA</td>
</tr>
<tr>
<td></td>
<td>Single production line</td>
</tr>
<tr>
<td>Conditioning of gaseous emissions</td>
<td></td>
</tr>
<tr>
<td>From raw material mill</td>
<td>Bag filter</td>
</tr>
<tr>
<td>From fuel mill</td>
<td>Bag filter</td>
</tr>
<tr>
<td>From preheater tower</td>
<td>One conditioning tower followed by electrostatic precipitator</td>
</tr>
<tr>
<td>From kiln</td>
<td>Two conditioning towers followed by bag filters and a selective non-catalytic reduction system (SNCR) in combination with injection of ammonium solution sprayed on the gas inside the PH for NO\textsubscript{X} reduction</td>
</tr>
<tr>
<td>From clinker cooler</td>
<td>Bag filter</td>
</tr>
<tr>
<td>From cement mill</td>
<td>One conditioning tower followed by bag filter</td>
</tr>
<tr>
<td>Overall cooling of equipment</td>
<td>Cooling oil and groundwater</td>
</tr>
<tr>
<td>Uses beyond the production line</td>
<td></td>
</tr>
<tr>
<td>Employees’ and subcontracted labourers’ needs</td>
<td>Drinking water and hygiene purposes</td>
</tr>
<tr>
<td>Laboratory work</td>
<td>Water for running quality tests</td>
</tr>
<tr>
<td>Overall housekeeping, dust suppression and WWTP</td>
<td>Water for cleaning purposes</td>
</tr>
<tr>
<td>Water sources</td>
<td>Groundwater, mains water and occasional effluent recycling from settling pond</td>
</tr>
</tbody>
</table>

*Notes: \textsuperscript{1} indicates preheater and \textsuperscript{2} indicates preheater with precalciner.*
4.2 Assessment of Water Intensity at the Plant Studied in Canada

This researcher contacted the Canadian plant manager in January of 2008 to ask for permission to develop a case study. After the plant manager agreed to the study early in 2008, more contacts followed by telephone, e-mail messages, and site visits, until the year of 2013. This investigation of water intensity compiled and analyzed data regarding cement production, water withdrawal, and effluent discharge for the years from 2007 to 2011.

4.2.1 Cement Production at the Canadian Plant

Data for cement production for the years between 2007 and 2011 are presented as they will be further used to calculate water intensity of cement manufacturing at this plant. Data of monthly cement production are included in Figure 4.1 and in Appendix A, Table A.3.

As seen in Figure 4.1, the cement production rate has some lows over the months from January through March, when the weather is cold in Canada. The reason for this lower productivity is that for some time over this period the kiln and some other equipment were generally shut down for maintenance, and thus the plant was not producing clinker, although the cement mill was generally grinding clinker stockpiles. The justification for shutting down the kiln during this period is that the demand for cement sales is lower during the winter months. In addition when the outside temperature is too cold, the kiln requires more energy to maintain its internal temperature, so it is less economical to keep the kiln working during the coldest months.
It is noteworthy that, according to plant personnel, the financial crisis that hit North America in 2007 has had an impact on the total cement production at their plant, and thus the total production in recent years is lower than for the year of 2007. Over the period evaluated, the total yearly cement production decreased from approximately 660 thousand tonnes in 2007 to 490 thousand tonnes in 2008, and reaching around 600 thousand in 2010. The average production for the total period investigated was around 50 thousand tonnes per month. However, the average for the months of more regular production, between April and November, is around 60 thousand tonnes per month.

In the following section, data of water withdrawal are presented to further evaluate the water intensity of cement manufacturing at that plant.

Figure 4.1. Monthly cement production for the years between 2007 and 2011, at the Canadian plant.
4.2.2 Water Withdrawal at the Canadian Plant

Groundwater and public water supply (in this work referred to as "mains water") were the water sources available at the Canadian plant and were accounted for in the total quantity of water withdrawal to the plant, in accordance with the indicator EN8, from the Global Reporting Initiative – GRI guidelines (please refer to Chapter 3, Section 3.5.2, for the selection and description of indicators).

It is noteworthy that certain volume of clarified effluent from that plant’s settling pond was occasionally recycled during the summer months, for road dust suppression at the plant. This volume of recycled effluent is not accounted for in the indicator EN8, but in EN10 (percentage and total volume of water recycled and reused). For that reason, effluent recycling was not accounted for calculating water intensity.

4.2.2.1 Groundwater Withdrawal at the Canadian Plant

Groundwater was withdrawn from two wells at the plant studied in Canada, called “A” and “B”. Data of the monthly water intake from these wells were measured by the plant’s measurement system and provided by plant personnel. This water was consumed for the industrial area of the plant, excluding the inside of the core building (where offices, lunchrooms, washrooms and the quality control laboratory are located). Mains water was supplied for the core building as indicated in the following section.

The flowmeter for measuring the water intake from well “A” was out of service in May of 2009 and from February of 2010 to February of 2012. During these periods, the
flowmeter did not register any intake, although according to the plant’s environmental coordinator the pump was withdrawing water from well “A”. It is noted from Figure 4.2 and data in Appendix A, Table A.4, the water intake in the year of 2009 was lower than the previous years. The reason for this lower intake could be that, at that time, this flowmeter was not measuring the flow correctly, before it completely stopped early in 2010. It is noteworthy that the water intake presented a larger variability for the first months of each year, probably because of the maintenance operations during the winter time. Irrespective of such variability over the first months of each year, the average water intake from well “A” for the 3-year period evaluated, including the lower numbers for 2009, was around 50 thousand cubic metres per month. The flowmeter for well “A” was fixed in March of 2012, after the selected period of data collection for this research.

Figure 4.2. Monthly groundwater intake from well “A” for the years between 2007 and 2009, at the Canadian plant\(^4\).

\(^4\)2010 and 2011 have no data because the flowmeter was not working.
The flowmeter for measuring the water intake from well “B” was also temporarily out of service, thus it did not register any intake for December of 2009 and February of 2010. According to the plant’s environmental coordinator the pump was also continuously withdrawing water from well “B”, even when it was not measuring the water intake. As seen in Figure 4.3 and in Appendix A, Table A.5, the water intake from this well was lower in 2008, with no apparent reason. The water intake over the first months of the year presented a large variability, probably related to the maintenance operations during the winter, as happened with well “A”. Irrespective of such variability over the first months of each year, the average water intake from well “B”, including the lower numbers for 2008, was around 70 thousand cubic metres per month.

Figure 4.3. Monthly groundwater intake from well “B” for the years between 2007 and 2011, at the Canadian plant.
The total groundwater withdrawal from both wells “A” and “B” could be calculated only for the years 2007, 2008 and 2009, when both wells had data concurrently, with the exception of May and December of 2009 (Figure 4.4 and in Appendix A, Table A.6).

From the available data it can be noted that the lower water withdrawal after 2007 may be related to the decreasing cement production following that year. As indicated before, one possible reason according to plant personnel is the financial crisis that hit North America from 2007, that could have resulted in lower cement production after that year. The average water intake from both wells for the 3-year period evaluated was around 110 thousand cubic metres per month.

Figure 4.4. Monthly groundwater intake from both wells for the years between 2007 and 2009, at the Canadian plant.

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52010 and 2011 have no data because the flowmeter for well “A” was not working.
The values presented here are the numbers that were possible to obtain, but may not reflect the real volume of water intake. The accuracy of the flowmeters over the years was not ensured. In any case, one conclusion is that although there are flowmeters installed, they were not frequently working, monitored or calibrated.

4.2.2.2 Mains Water Withdrawal at the Canadian Plant

Another source of water is mains water, which is supplied and measured by the municipality. This water is consumed inside the core building where offices, lunchrooms and washrooms are located, and also for the quality control laboratory. These water requirements will be discussed in the following chapter, when water usage at each stage of cement manufacturing, including uses beyond the production line, will be further evaluated. Monthly mains water intake data were obtained from the water clerk at the town hall. These data are included in in Figure 4.5 and in Appendix A, Table A.7.

The average mains water intake between 2007 and 2011 was approximately 400 cubic metres per month. However, as noted in Figure 4.5, this water intake is lower from January through April, reaching an average around 350 cubic metres per month. At that time, generally maintenance operations were being carried out but workers were all kept at the plant. It is likely that the larger mains water intake from April to November, when the monthly average reached around 500 cubic metres, was required for the larger number of cement quality tests performed at the plant’s laboratory at that time of year. There is no apparent reason why the year of 2009 did not show the trend of lower water intake between January and April.
4.2.2.3 Total Water Withdrawal at the Canadian Plant

It was not possible to evaluate the total water withdrawal for the entire 5-year period of this research, due to the fact that the flowmeter of one of the wells for the groundwater intake was not working from 2010 to 2011. However, the monthly total water withdrawal from all sources available at the Canadian plant studied — groundwater and mains water — is summarized for the years 2007 to 2009 (Figure 4.6 and Table A.8 in Appendix A). It is noteworthy to recall that the total water withdrawal at the plant represents the indicator EN8, based on the Global Reporting Initiative (GRI) guidelines, as discussed in Chapter 3 (Section 3.5.2).

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6Average for year is 400 m^3/month, for January to April is 350 m^3/month and for April to November is 500 m^3/month.
The trend of more variable total water withdrawal has been confirmed for the months from January through April, for the 3-year period that could be evaluated for all sources of water at that plant. As indicated before, maintenance operations were generally being carried out at that plant over that period, including some time when the kiln may have been completely stopped. The reduction in water withdrawal at that time should be because of the lower clinker and cement production for that period. The water withdrawal for the months from May until the end of each year was more regular. The average for the total water withdrawal for the period evaluated was approximately 110 thousand cubic metres per month. However, the average for the months of more regular cement production, between April and November, was around 120 thousand cubic metres per month. The intake of mains water was less than 0.5% of the total groundwater intake, thus it did not critically affect the total withdrawal. The trend of total water withdrawal

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72010 and 2011 have no data because the flowmeter for well “A” was not working.
also followed the total cement production during the same period, which saw a peak of cement production in 2007 and a decline in 2008 and 2009. This relation between total water withdrawal – EN8 – and cement production is further investigated in the next section, along with the results for water intensity of cement manufacturing at this plant.

4.2.3 Water Intensity at the Canadian Plant

Water intensity for cement manufacturing, as discussed in Chapter 3 (see Section 3.4), is being considered in this research as the total quantity of water withdrawal to the plant (indicator EN8, see Chapter 3, Section 3.5.2) to produce one tonne of cement (Equation 4.1).

\[
WI = \frac{EN8}{CP}
\]  

(4.1)

Where:

- \( WI \) = water intensity of cement (litres/tonne of cement)
- \( EN8 \) = GRI (Global Reporting Initiative) indicator for the total water withdrawal (litres)
- \( CP \) = total cement produced (tonnes of cement)

Water intensity at the plant studied in Canada was calculated based on total water withdrawal from all sources used: groundwater from two wells and mains water (Figure 4.7).
4.2.3.1 Water Intensity Based on Total Water Withdrawal at the Canadian Plant

The water intensity at the Canadian plant was calculated as the ratio between the total water withdrawal (EN8) and the cement production for the years of 2007 to 2009. As indicated before, this researcher attempted to investigate the period until 2011, but data for the total water withdrawal for 2010 and 2011 were not available because of failure of the flowmeters. The monthly results of water intensity are included in Figure 4.8 and in Table 4.3.

As seen in Figure 4.8 and in Table 4.3, the water intensity is higher over the winter months when maintenance operations are generally being performed. This fact indicates that a large volume of water is being withdrawn to the plant even though the cement production is lower during that period. It should be recalled that only cement production was considered for calculating water intensity. Even when the kiln was stopped for maintenance and not producing clinker, the plant could be grinding stockpiled clinker, so there was still cement production through most of the maintenance time. However, cement production was much lower earlier in each year than for the months after April.
The reason why water intensity in January of 2009 was lower than the other years could not be concluded, but an error in the data of water withdrawal is a possible explanation.

Figure 4.8. Average monthly water intensity of cement for the years between 2007 and 2009, at the Canadian plant. Note: January and February results are affected by lower production rates caused by maintenance operations at the plant.

2010 and 2011 have no data because the flowmeter for well “A” was not working, thus EN8 could not be calculated.
Table 4.3. Summary of water withdrawal, cement production and water intensity for the years between 2007 and 2009, at Canadian plant

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TOTAL WATER WITHDRAWAL</td>
<td>CEMENT PRODUCTION</td>
<td>WATER INTENSITY</td>
</tr>
<tr>
<td></td>
<td>EN8 (litres)</td>
<td>CP (tonnes)</td>
<td>WI (L/tonne)</td>
</tr>
<tr>
<td>January</td>
<td>171086910</td>
<td>20963</td>
<td>8161</td>
</tr>
<tr>
<td>February</td>
<td>102533800</td>
<td>4985</td>
<td>20568</td>
</tr>
<tr>
<td>March</td>
<td>81899500</td>
<td>17582</td>
<td>4658</td>
</tr>
<tr>
<td>April</td>
<td>166196170</td>
<td>53977</td>
<td>3079</td>
</tr>
<tr>
<td>May</td>
<td>128657290</td>
<td>63131</td>
<td>2038</td>
</tr>
<tr>
<td>June</td>
<td>140824340</td>
<td>68919</td>
<td>2043</td>
</tr>
<tr>
<td>July</td>
<td>133702870</td>
<td>73182</td>
<td>1827</td>
</tr>
<tr>
<td>August</td>
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<td>67347</td>
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</tr>
<tr>
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</tr>
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</tr>
<tr>
<td>November</td>
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<tr>
<td>December</td>
<td>128498840</td>
<td>61698</td>
<td>2083</td>
</tr>
</tbody>
</table>

AVERAGE YEAR (L/tonne) | 2367 | 2246 | 1952

AVERAGE APRIL TO NOVEMBER (L/tonne) | 1945 | 1940 | 1760

Note: A dash (-) indicates that data was not measured and N.C. indicates that data was not calculated because the plant was not producing cement or water intake was not measured.
The yearly average for the 3-year period that could be investigated (2007 to 2009) is approximately 2,000 litres of water per tonne of cement produced. However, the more regular pattern of water intensity happens from April to November. The average water intensity for the plant studied in Canada is larger than the water intensity data presented in Chapter 3. The range of those published water intensity data, from corporate social responsibility (CSR) reports, varied from 147 to 1,220 litres/tonne of cement and the mean was approximately 400 litres/tonne of cement. The water intensity at the plant studied in Canada is also larger than the environmental product declaration (EPD) number of about 226 litres/tonne of cement published by CEMBUREAU (CEMBUREAU 2008). Please refer to Chapter 3 (Section 3.3), for information on EPD.

The range of water intensity published by Kollar and MacAuley (1980) and van der Leeden, Troise and Todd (1990) of 600 to 3,500 litres/tonne of cement encompasses the data obtained for the plant in Canada. However, it is noteworthy to recall that the higher end in the reported results could be related to using the wet process for cement manufacturing, while the plant studied in Canada utilizes the dry process. Moreover, their higher results could encompass quarry operations and in-house power generation facilities that were not included for the Canadian plant.

Thus, one question arises: why data obtained at the plant in Canada were higher than the published data. One potential answer could be that in the majority of published data in the CSR reports, the water intensity was calculated based on the total water consumption and not the total water withdrawal. The concept of water consumption considered for this research, as indicated in Chapter 2 (Section 2.3.2), is the quantity of water used and not
returned for immediate or short-term reuse within the watershed, for example evaporation, incorporation into products and consumption by workers (Gleick et al. 2009). The average water consumption for cement manufacturing in the United States published by Kollar and MacAuley (1980) is approximately 620 litres/tonne of cement, but there is no indication of whether the process in place was wet or dry or a combination of both. Two of the 23 CSR reports compiled in Chapter 3 (Section 3.6) provide figures for total water withdrawal and cement production during a defined period, allowing a manual calculation for water intensity that uses total water withdrawal (EN8) rather than total water consumption. The results of these calculations were around 1,000 litres/tonne of cement. However, the average water intensity calculated for the Canadian plant is still higher than the published data. For that reason, the water intensity based on water consumption at the plant studied in Canada is investigated in the following section.

4.2.3.2 Water Intensity Based on Estimates of Water Consumption at the Canadian Plant

Water consumption at the plant studied in Canada was estimated based on the difference between the total water withdrawal (indicator EN8) and the estimates for total effluent discharge from the plant (indicator EN21), as indicated in Figure 4.9. The total effluent discharge from the cement plant studied in Canada —indicator EN21— was comprised of process water effluents from the industrial area (i.e. cement manufacturing processes) and domestic effluents from the core building (i.e. washrooms, lunchrooms and the quality control laboratory). The result may not represent an accurate figure but the intention here is to allow additional comparison with published water intensity data, with the intention
to evaluate reasons why water intensity at the Canadian plant is higher than published data.

Process water effluents were discharged into a settling pond, which was the only treatment performed. The domestic effluents consisted exclusively of spent mains water, further discharged into the local sewer system and treated at the municipality’s wastewater treatment plant. A schematic of the total effluent discharge – EN21 – from the plant studied in Canada is indicated in Figure 4.10.

Figure 4.9. Schematic of water consumption – EN8 minus EN21 – at the Canadian plant.
The only flowmeter in place for measuring effluents from the plant was installed at the discharge point from the settling pond into the river. For this reason, the indicator EN21 was estimated based on two assumptions. The first was that the volume of measured clarified effluent discharged into the river would be the same volume of process water discharged from the plant. In keeping with this assumption, it should be noted that precipitation, infiltration, evaporation and leaking are being considered null, although it is recognized by this author that they exist. A schematic of the water balance diagram for the settling pond at the plant studied in Canada is indicated in Figure 4.11, where such factors are included. Data for quantifying these factors were not readily available and working with more estimates would not provide a better figure for calculating the total process water from the plant, thus they were not further pursued.

Figure 4.10. Schematic of total effluent discharge – EN21 – at Canadian plant.
The second assumption was that the volume of domestic effluents was approximately 85 percent of the mains water supplied, after being consumed for housekeeping activities, workers’ needs, and the cement quality tests performed at the plant’s laboratory. This percentage is based on the average presented by Metcalf & Eddy et al. (2004) from 60 to 90 percent. It should be noted that using the lower or higher number would not represent a major impact on the final result for this estimate. As indicated earlier, the result may not represent a real figure but the intention here is to allow additional comparison with published water intensity data.

Data for the monthly volume of clarified effluent discharged from the settling pond into the river were available for the years 2007 to 2011 and are included in Appendix A, Table A.9. In 2007 data were available only for July, and in 2011 the flowmeter was not working from June to August. Therefore, only data for the years 2008 to 2010 were compiled as the volume of process water (Figure 4.12 and Appendix A, Table A.9).
Estimated monthly domestic effluent for the years 2007 to 2011 are included in Appendix A, Table A.10.

![Figure 4.12. Monthly clarified effluent discharge from settling pond for the years between 2008 and 2010, at Canadian plant.](image)

The indicator EN21 for total effluent discharge was then calculated by adding the estimated monthly volume of process water (Appendix A, Table A.9) to the estimated monthly volume of domestic effluents (Appendix A, Table A.10). Results for indicator EN21 are included in Figure 4.13 and in Appendix A, Table A.11. Data were calculated only for the years 2008 to 2010, when data for both process water and domestic effluent were available. As is noted in Figure 4.13, except for January of 2010 and December of 2009, the trend was not highly variable over the year. The average for the total effluent discharge (EN21) for the period evaluated (2008, 2009 and 2010) was approximately 100 thousand cubic metres per month. However, the average for the months of more regular
cement production (between April and November) was around 110 thousand cubic metres per month.

Figure 4.13. Monthly total effluent discharge – EN21 – for the years between 2008 and 2010, at Canadian plant⁹.

Water consumption was then calculated by subtracting the estimated EN21 values from the measured EN8 numbers. Data for EN8 were available from 2007 to 2009, but data for EN21 were available from 2008 to 2010, thus the water consumption could be calculated only for 2008 and 2009, when both parameters were available. Water consumption data for the plant studied in Canada are included in Figure 4.14 and in Appendix A, Table A.12. For those years of 2008 and 2009 the average for the total effluent discharge (EN21) was approximately 110 thousand cubic metres per month for the full year, as well as for the months between April and November. For those same years of 2008 and 2009 the average for total water withdrawal (EN8) was around 100 thousand cubic meters per

⁹2007 and 2011 have no data because not all monthly values were available for those years simultaneously.
month. Therefore, an unexpected finding was that for the years of 2008 and 2009 the majority of monthly results obtained for water consumption were negative, with the monthly volume of effluent discharge higher than the monthly volume of water withdrawal. This reflects the fact that the assumptions made were not realistic. For example, the assumption that process water effluent was equal to clarified effluent discharge may not be well-founded, because other factors also affected the water input and output from the settling pond (represented in Figure 4.11). Moreover, the flow measurements available could not be sufficiently accurate. The many monthly negative values of water consumption obtained resulted in related negative values of water intensity based on water consumption (Appendix A, Table A.13).

Figure 4.14. Estimated monthly water consumption for the years 2008 and 2009, at Canadian plant$^{10}$.

$^{10}$2007, 2010 and 2011 have no results because only 2008 and 2009 had values for both EN8 and EN21.
For this reason, this researcher attempted to manually measure the flow of process water at the cement plant in Canada. The attempt was to measure the time to fill a five litre receptacle at the discharge point to allow an estimated flow in litres per minute, but the end of the pipe could not be accessed because the bushes could not be passed through (Figure 4.15). It is likely that the pipe was submerged because no sound of effluent discharge was being heard around that locale. This researcher also attempted to use a portable flowmeter to collect *in situ* data regarding process water effluent at each stage of cement manufacturing at the cement plant in Canada, but the only available flowmeter could not collect data under the existing conditions at that plant. Although *in situ* monitoring of process water discharge did not yield usable data, the experiment is described and analyzed in the Appendix B, in order to record this experience, and help shape proper strategies for future studies.

Figure 4.15. Attempt to reach locale of process water effluent discharge into the settling pond at the Canadian plant. Photo by author.
Interestingly, a positive value of water consumption could be obtained by restricting the analysis to data from the months of more regular cement production (April to November), for all years when data were available. Using this subset of data (for the months from April to November), the monthly average of water withdrawal (EN8) was around 120 thousand cubic metres per month, the monthly average of total effluent discharge (EN21) was approximately 110 thousand cubic metres per month, and the average cement production was around 60 thousand tonnes per month\textsuperscript{11}. Using these figures, the water intensity based on water consumption would be approximately 200 litres/tonne of cement, as indicated in Equation 4.2.

\[ W_{1c} = \frac{EN8c - EN21c}{CPc} \]  
\[ (4.2) \]

Where:

- \( W_{1c} \) = water intensity of cement based on water consumption (litres/tonne of cement)
- \( EN8c \) = average GRI indicator for the total water withdrawal (litres/month)
- \( EN21c \) = average GRI indicator for the total effluent discharge (litres/month)
- \( CPc \) = average total cement produced (tonnes of cement/month)

\[ W_{1c} = \frac{120,000,000 - 110,000,000}{60,000} \approx 200 \text{ l/tonne cement} \]

This value of water intensity of 200 litres per tonne of cement, based on the estimated averages of water consumption for all available data for the months between April and November, would place the plant studied in Canada at the lower end of the range of the published water intensity data in CSR reports from 147 to 1,220 litres per tonne of cement.

\textsuperscript{11} The specific years for each parameter were: 2007 to 2009 for average EN8, 2008 to 2010 for average EN21, and 2007 to 2011 for total average cement production.
cement. This figure is also lower than the figure published by Kollar and MacAuley (1980), which was an average of 620 litres of water consumed in the United States cement plants to produce one tonne of cement. However, this figure of 200 litres per tonne of cement may not reflect the real water consumption at the Canadian plant, considering that only one parameter – volume of clarified effluent discharge from the settling pond – was measured to account for water consumption.

This preliminary evaluation of the water consumption for the plant studied in Canada was performed to allow a comparison with published water intensity data from the CSR reports, with the intention to determine if those reports were related to water consumption, instead of water withdrawal, but this question could not be answered. Nevertheless, this investigation has revealed the many difficulties in obtaining accurate numbers, because only a few data points were measured and the accuracy of flowmeters used was not regularly checked. It is recommended for future studies to further pursue accurate information about the volume of effluent discharge. This knowledge could provide proper information for water consumption, and also help to identify effluent recycling opportunities at the plant. Irrespective of lack of reliability around data obtained so far, the next section will present a discussion on all results obtained for water intensity at the Canadian plant.

4.2.4 Results of Water Intensity at the Canadian Plant

As indicated before, investigation of water intensity in this research is based on the total water withdrawal (indicator EN8), although some estimates of the water consumption at
the plant in Canada were also performed in an attempt to allow a comparison with
published water intensity data. The comparison with water consumption could not be
concluded because there were not enough data for the volume of effluent streams being
monitored at the plant.

The yearly average water intensity based on total water withdrawal (indicator EN8) was
around 2,000 litres per tonne of cement. This number dropped to around 200 litres/tonne
when assuming values for water consumption. However, a comparison with data
published in the CSR reports, from 147 to 1,220 L/tonne, did not result in a definitive
conclusion as to whether the lower numbers were due to inclusion of water consumption
data, or if they were related to dry production processes. Moreover, these results could
not be compared with the average water consumption for cement manufacturing in the
United States published by Kollar and MacAuley (1980), because there was no
identification of the processes (wet or dry), or whether the value was an average for both
processes. In terms of the large range of water intensity data from CSR, a more likely
conclusion is that some published data may be based on few measurements and many
assumptions, as made with the fieldwork performed for this research. This suggests the
existence of potential sources of error around published data.

Irrespective of conclusions around the comparison with available data from the literature,
it could be noted that seasonal variations had some influence on the results for the
average water intensity obtained for the plant in Canada. The higher results for the first
months of each year could just be reflecting that the plant was producing less cement
during the winter months but continued to have water requirements for regular operations, as well as for maintenance operations. Maintenance operations are performed at all plants in any climate. They either get distributed through the year, and the related water intensity is hidden in normal production, or they show up as a seasonal effect as in the Canadian data.

Moreover, in terms of economic scenario, it could be noted that a financial crisis hit North America in 2007, including Canada, and affected the cement production rates since that year. A decrease in production was noted at the plant studied but, although the economic scenario had an impact on the cement production, it apparently did not affect the water intensity for cement manufacturing. The indicator of water intensity was then not critically influenced by both local seasonal effects and economic conditions. To further evaluate water intensity at cement plants, the next section presents an investigation of water intensity for the cement plant studied in Brazil.

**4.3 Assessment of Water Intensity at the Plant Studied in Brazil**

This researcher contacted a manager at a cement plant in Brazil in November of 2007 to ask permission to develop a case study. After agreeing to the study, more contacts followed by telephone, e-mail messages, and site visits, until 2013. This investigation compiled and analyzed data regarding cement production, water withdrawal, and estimates of effluent discharge for the years from 2005 to 2011.
4.3.1 Cement Production at the Brazilian Plant

Data for cement production for the years between 2005 and 2011 are presented as they will be further used to calculate water intensity of cement manufacturing at this plant. Data of monthly cement production are included in Figure 4.16 and in Appendix A, Table A.14.

As indicated by data in Figure 4.16, the cement production rate has a small decrease in the month of January. The reason is that from mid-December to late January, when is summer season in Brazil, a large number of Brazilian companies give collective holidays for certain period of time, and consequently many businesses operate at a lower level, reducing demand for cement sales.

Figure 4.16. Monthly cement production for the years between 2005 and 2011, at the Brazilian plant.
Over the period evaluated, the total yearly cement production doubled from approximately 800 thousand tonnes in 2005 to 1.6 million tonnes in 2011. The economy in Brazil was experiencing significant growth and this expansion was linked to the increased in the demand for cement sales. The average production for the period investigated was growing from 70 thousand tonnes per month in 2005 to 130 thousand tonnes per month in 2011. The average for the entire period investigated was around 100 thousand tonnes per month.

In the following section, water intake data are presented to further evaluate the water intensity of cement manufacturing at that plant.

4.3.2 Water Withdrawal at the Brazilian Plant

The primary water sources available at the Brazilian plant are groundwater and surface water. Some recycled effluent mixed with stormwater floor drainage accounted for a small contribution, estimated by plant personnel at around 2,000 cubic metres monthly or approximately 10 percent of the surface water intake. Only the total quantity of water withdrawn from groundwater and surface water was accounted for in the indicator EN8, from the Global Reporting Initiative (GRI) guidelines (see Chapter 3, Section 3.5.2). In accordance with GRI guidelines, the volume of rainwater harvested (in this case the stormwater floor drainage) may be included in indicator EN8, but also under indicator EN10 (percentage and total volume of effluent recycled and reused). At this plant, the stormwater floor drainage was first sent to the effluent treatment system, and then recycled back to the plant, so the indicator EN10 is the one that accounts for both
stormwater and effluent recycling. The volume of water intake was only measured for surface water (river) and groundwater (well).

4.3.2.1 Groundwater Withdrawal at the Brazilian Plant

Groundwater was withdrawn from one well. The monthly water intake from this well was measured by the plant’s measurement system and provided by plant personnel. These data are included in Figure 4.17 and in Appendix A, Table A.15. Groundwater supplied two stages at the industrial area: cleaning of the preheater tower and cooling the probe of the kiln gas analysis system. Groundwater was also used outside the main production line for the restaurant, coffee rooms, washrooms, laboratory, for preparing solutions at a wastewater treatment plant (WWTP), and for overall housekeeping. More details for water requirements will be discussed in the following chapter, when water usage at each stage of cement manufacturing will be further evaluated.

Figure 4.17. Monthly groundwater intake for the years between 2005 and 2011, at the Brazilian plant.
The flowmeter for measuring groundwater was out of service for calibration from June to August of 2006. During this period, the flowmeter did not register any intake, although according to plant personnel the pump was withdrawing water from the well. It is noted from Figure 4.17 that the groundwater intake followed the same trend as cement production, so it has been increasing since 2005.

Overall, the groundwater intake did not fluctuate greatly from January to December for the entire period investigated. The water intake was following the trend of growing cement production at this plant, ranging from 3,000 cubic metres per month in 2005 to 4,500 cubic metres per month in 2011. The average groundwater intake for the 7-year period evaluated was approximately 4,000 cubic metres per month. It should be noted that the flowmeter was calibrated only once for the total period being evaluated.

4.3.2.2 Surface Water Withdrawal at the Brazilian Plant

Another source of water is surface water, collected from a river adjacent to the plant, which is also measured by the plant’s measurement system. Surface water was consumed for most requirements in the industrial area, such as raw material preparation, cement milling, conditioning towers, and cooling of equipment. Data for monthly surface water intake were also provided by plant personnel and are included in Figure 4.18 and in Appendix A, Table A.16. Recycled effluent and treated stormwater floor drainage are mixed with surface water but, as indicated before, the total was not measured, although the percentage of recycling was estimated by plant personnel at around 10 percent of the surface water intake.
Figure 4.18. Monthly surface water intake for the years between 2005 and 2011, at the Brazilian plant.

The initial period evaluated, from 2005 to 2007, showed some low values for the months of March and April, as well as for September and October, for no apparent reason. The flowmeter was out of service and was calibrated twice, from June to August of 2006 and from February to April of 2009. During this period, the flowmeter did not register any intake, although according to plant personnel the pump was withdrawing water from the river. Overall, there was also an increase in the surface water intake each year from 2005 to 2011, similar to the pattern for groundwater intake. It is likely that the increase in both surface water and groundwater intake reflected an increase in cement production. The average surface water intake was ranging from 15 thousand cubic metres per month in 2005 to 20 thousand cubic metres per month in 2011. The average surface water intake for the entire period was approximately 20 thousand cubic metres per month.
4.3.2.3 Total Water Withdrawal at the Brazilian Plant

The monthly total water withdrawal from both sources at the Brazilian plant, groundwater and surface water, is the indicator EN8 summarized in Figure 4.19 and in Appendix A, Table A.17.

Figure 4.19. Monthly total water withdrawal from all sources – EN8 – for the years between 2005 and 2011, at the Brazilian plant.

The monthly intake for total water withdrawal (EN8) did not fluctuate greatly, except for a few months. As indicated before, the yearly average was growing from 2005 to 2011. The average water withdrawal for the entire period was approximately 25 thousand cubic metres per month. This relation between total water withdrawal (EN8) and cement production is further investigated in the next section, along with the results for water intensity of cement manufacturing at this plant.
4.3.3 Water Intensity Based on Total Water Withdrawal at the Brazilian Plant

The schematic of water intensity for the plant studied in Brazil is indicated in Figure 4.20. The water intensity at the Brazilian plant was then calculated as being the ratio between the total water withdrawal (EN8) and the cement production (CP) for the years between 2005 and 2011, in accordance with Equation 4.1 (see page 104).

![Schematic of water intensity based on water withdrawal (indicator EN8) at the Brazilian plant.](image)

The monthly results of water intensity are included in Figure 4.21 and in Appendix A, Table A.18. As seen in Figure 4.21, the water intensity presented a regular pattern, without a large degree of variability month to month or year to year, with a few exceptions. The yearly average for the total period being investigated was approximately 250 litres of water per tonne of cement produced. It should be noted that this plant had two production lines and whenever one was undergoing maintenance, the other one was operating.
Figure 4.21. Average monthly water intensity of cement for the years between 2005 and 2011, at the Brazilian plant.

This figure of water intensity at the Brazilian plant falls into the lower end of the published data from the CSR reports of 147 to 1,220 litres/tonne, and is close to the EPD number published by CEMBUREAU of 226 litres per tonne. However, the range of 600 to 3,500 litres per tonne published by Kollar and MacAuley (1980) and van der Leeden, Troise and Todd (1990) is higher than the water intensity at the Brazilian plant. Thus, one question arises: why water intensity at the Brazilian plant is lower than data published by those authors. One potential answer could be that the effluent recycling system in place at the plant in Brazil contributed to the reduced water intensity, but at the time those authors published their data (just before 1990), there were fewer recycling systems in place, so their data of water intensity were higher. An investigation of the influence of the percentage of effluent recycling on water intensity could not be performed for this plant, because there was no measurement of volumes of effluent recycled nor effluent discharged. Effluents recycled were process water reused from the kiln gas analysis
system and from cooling of overall equipment, as well as treated effluent from laboratory and also stormwater floor drainage. As indicated before, plant personnel estimated recycling around 10 percent of surface water intake. Further aspects related to reliability of this estimate will be discussed in Chapter 6.

4.4 Comparison of Water Usage and Measurement at Plants Studied in Canada and in Brazil

The water intensity figures obtained from the two case studies described in this chapter showed a large difference. The water intensity for cement manufacturing at the plant in Canada (2,000 litres/tonne cement) was about eight times higher than at the plant in Brazil (250 litres/tonne cement). A possible partial explanation for this difference is that the recycling system in place at the Brazilian plant contributed to reducing total water withdrawal – indicator EN8 – and consequently lowered the water intensity for cement manufacturing. As indicated previously, plant personnel estimated the volume of recycling at around 10 percent of surface water intake. The investigation of water usage at each stage of production may provide further explanation and will be presented in the next chapter. One major difference that will also be discussed in the next chapter is the water used for cement cooling, which was used only at the plant in Canada, and required a large volume of water per tonne of cement produced.

Another difference between the two case studies was in patterns of seasonal variation. In Canada, cement production reaches its peak in the summer, because of the high demand for cement for supplying the many construction projects taking place at that time. The
average water intensity in the summer months at the Canadian plant, for the three-year period investigated, was around 2,000 L/tonne, compared to approximately 5,600 L/tonne in the winter. In Brazil, there is a slight decline in cement sales during the summer months, because a large number of Brazilian companies give collective holidays, and many businesses operate at a slower pace, but production is relatively steady and water intensity averaged 250 L/tonne for both summer and winter months. The seasonal variation found at the Canadian plant may reflect the fact that the plant was producing less cement in the winter while continuing to have water requirements for regular operations, as well as for maintenance operations. As discussed before, maintenance operations are performed at all plants in any climate. They either get distributed through the year, and the related water intensity is hidden in normal production, as happened at the plant in Brazil, or they show up as a seasonal effect as in the Canadian data.

Another contrast was noted in terms of each country’s economic conditions. In Canada, cement production decreased after 2007, as a consequence of the financial crisis that hit North America at that time. In Brazil, cement production was increasing throughout the period evaluated, as a result of the economic growth being experienced since 2005. However, the year-to-year water intensity was not influenced by the rate of cement production at either plant. Certainly the total volume of water withdrawal increased when the plants were producing more cement, but the water intensity obtained for these two case studies remained relatively constant from year to year, irrespective of the trend in cement production. Table 4.4 shows a comparison between the two plants.
It is interesting to note that two similarities between the plants studied were (a) the lack of definition of periodical routine for calibration of flowmeters to measure water withdrawal and (b) the lack of systematic measuring of effluent discharge or recycling. These facts suggest that considerable lack of reliability may surround some of the data obtained for this research. In Chapter 6, all data obtained are categorized by levels of reliability and a discussion is presented about approaches to improve methods of data acquisition.

Table 4.4. Comparison between cement plants studied in Canada and in Brazil

<table>
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<th>COUNTRY OF CASE STUDY</th>
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<th>BRAZIL</th>
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<td>250 litres/tonne of cement</td>
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<td>Permanently for raw material preparation,</td>
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<td></td>
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<td>emissions, and cooling of equipment – not</td>
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<td></td>
<td></td>
<td>measured</td>
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<tr>
<td>Measurement system</td>
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<td>Measured</td>
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<tr>
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<td>Economic factors</td>
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</table>
4.5 Challenges for Improving Knowledge of Water Intensity at Cement Plants

Lack of reliability around the volume of total water withdrawal and effluent discharge obtained for this research cause a certain degree of doubt in the calculated water intensity figures. Some analyses were based on relatively few measurements and many assumptions. However, given the difficulty in obtaining accurate measurements, one may be justified in asking if the water intensity data published in the CSR reports – from 147 to 1,220 litres/tonne cement – were also based on few measurements and many assumptions. Moreover, are the data published in the CSR reports related to volumes of water withdrawal or were they considering water consumption, i.e. total water withdrawal minus effluent discharge? It could be expected that the lower numbers were related to dry processes for cement manufacturing or that they were considering water consumption, but such information was not always provided with the data published in the CSR reports. The lower numbers could also be related to higher percentages of effluent recycling, but only a few reports published their indicator EN10 related to such recycling. As well, stricter water use policies may be in place in some regions and consequently companies in these regions would be forced to be less water intensive.

The reliability of water intensity data for cement manufacturing could be improved mainly by frequent monitoring of quantities of water withdrawal and effluent discharge at cement plants, as well as by keeping the monitoring equipment well calibrated. Eventually, at the industry level, the limitations around water reporting could be reduced by the availability of a more extensive water intensity dataset with more detailed
information about calculation methods used by each factory, for example stating what assumptions were made.

Results from the case studies described in this chapter suggest that knowledge of water intensity for cement manufacturing is not yet a priority for the industry. As a result, reliable data are not available and research to fill existing gaps is made more difficult. Recalling that in this work the term reliable is used for data that are accurate, with their degree of uncertainty provided, and collected through correct methods of measurement by appropriate instruments or from well-founded estimates. Reliable data are also precise or repeatable, meaning that similar results will be obtained by successive measurements under the same conditions (UNIDO 2006). Nevertheless, the data collected for this study provide a useful starting point because they were obtained within industries and reflect normal operational conditions. All of the data obtained from the case studies in this chapter will be used to supplement water intensity data compiled from the literature and to further investigate, in Chapter 5, the water usage at each stage of cement manufacturing at the plants studied in Canada and in Brazil. The investigation of water usage per stage of cement manufacturing will further increase the understanding of water usage and management practices at cement plants.
CHAPTER 5
WATER USAGE AT EACH STAGE OF CEMENT MANUFACTURING: FIELDWORK-BASED CASE STUDIES

Water reforms take time and persistence to succeed.
– The International Bank for Reconstruction and Development/
The World Bank, *Sustaining Water for All in a Changing Climate*, 2010

5.1 Reasons to Investigate Stages of Manufacturing at Cement Plants

Chapter 4 presented the results of an investigation of water intensity from fieldwork-based case studies performed by this author at two cement plants, one in Canada and one in Brazil, but questions remained with no answer around the reasons for differences in water intensity between the two plants. Therefore, in this chapter, water usage is analyzed based on the proposed scheme of eleven stages of cement manufacturing, to increase understanding of total water usage at plants. This chapter concludes with analysis of water usage at each stage of cement manufacturing, incorporating data from the theoretical background compiled in Chapter 3 and data obtained from the case studies for the overall process presented in Chapter 4.

As indicated before, because this author is involved in research in Brazil and in Canada, the logical decision was to select one plant in each of these two countries for case studies. Additional factors leading to this decision were described in Chapter 4 (Section 4.1). Information about the name and specific location of each plant is not provided for reasons of confidentiality, as per the request of both plant managers. Please refer to Chapter 4,
Table 4.2 for a summary of non-confidential background information for the two case study sites.

5.1.1 Stages of Cement Manufacturing Selected for this Research

The description of water requirements evaluated will follow the framework established in this research with eleven stages. More information about each stage is provided in Chapter 3, Section 3.3. The eleven stages selected for this research are as follows.

1. raw material preparation;
2. fuel supply preparation;
3. cleaning of preheater tower;
4. kiln gas analysis;
5. clinker cooling;
6. cement milling;
7. cement cooling;
8. cement dispatch;
9. conditioning of gaseous emissions;
10. cooling of equipment; and
11. other uses beyond the production line, namely employees’ and subcontracted labourers’ needs, laboratory work, overall housekeeping, road dust suppression, and a wastewater treatment plant (WWTP).

Water usage data for the two selected plants were collected for the years from 2005 to 2011, although not all data were available for that entire period. Data for water
requirements at each stage of cement manufacturing, when measured, were directly obtained from each plant’s personnel. Details of the available data are indicated in Table 5.1. Further attempts to complete the dataset of water usage at the eleven stages of cement manufacturing for each case study were performed by this researcher and are described in the following sections.

<table>
<thead>
<tr>
<th>STAGE OF CEMENT MANUFACTURING INVESTIGATED</th>
<th>COUNTRY OF CASE STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CANADA</td>
</tr>
<tr>
<td>Raw material preparation (raw mill)</td>
<td>2007 to 2011</td>
</tr>
<tr>
<td>Fuel supply preparation</td>
<td>-</td>
</tr>
<tr>
<td>Cleaning of preheater tower</td>
<td>-</td>
</tr>
<tr>
<td>Kiln gas analysis</td>
<td>No water usage</td>
</tr>
<tr>
<td>Clinker cooling</td>
<td>No water usage</td>
</tr>
<tr>
<td>Cement milling</td>
<td>-</td>
</tr>
<tr>
<td>Cement cooling</td>
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<tr>
<td>Cement dispatch</td>
<td>-</td>
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<tr>
<td>Conditioning of gaseous emissions</td>
<td>2007 to 2011</td>
</tr>
<tr>
<td>Cooling of equipment</td>
<td>-</td>
</tr>
<tr>
<td>Uses beyond the production line</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: A dash (-) indicates that water was used but data was not measured.

5.2 Water Usage at Each Stage of Manufacturing at the Plant Studied in Canada

The water sources available at the Canadian plant were groundwater, mains water, and occasional effluent recycling from an effluent settling pond. The primary source was groundwater that was distributed to the industrial area of the plant, followed by mains water that supplied the core building (which included lunchrooms, washrooms and a
laboratory). The recycled effluent was only used for road dust suppression during some months of the summer. The water intensity at this plant was calculated in Chapter 4 at 2,000 per tonne of cement. A description of water usage at each stage of cement manufacturing is provided next.

5.2.1 Raw Material Preparation at the Canadian Plant

At the stage of raw material preparation, groundwater was sometimes sprayed over the crushed limestone stockpile for dust control (Figure 5.1). The quantity of water for dust control was not measured.

![Figure 5.1. Point of occasional water spray for dust control over a crushed limestone stockpile, at the Canadian plant. Photo by author.](image)

Groundwater was also sometimes sprayed inside the vertical roller mill used to grind raw material to properly agglutinate the raw mix (limestone and other materials); this
technique improves grinding conditions. Water usage data from inside the raw material mill were collected by using a flow measurement device that provided minute-by-minute readings. Readings were retrieved by plant personnel in volumetric flow rate ($Q_{RM}$), in litres of water sprayed per minute, exactly at noon and at midnight every day, from January 1, 2007 until December 31, 2011. If it is assumed that the average of these two daily data points can be totalized for each month ($\overline{Q}_{RM}$), the average volume of water sprayed inside the raw mill ($V_{RM}$), for each month of each year is then calculated by the following (Equation 5.1).

$$V_{RM} = \frac{\text{volume}}{\text{month}} \left( \frac{\text{litres}}{\text{month}} \right) = \overline{Q}_{RM} \left( \frac{\text{litres}}{\text{min}} \right) \times 60 \left( \frac{\text{min}}{\text{hour}} \right) \times 24 \left( \frac{\text{hour}}{\text{day}} \right) \times N \left( \frac{\text{day}}{\text{month}} \right)$$

(5.1)

Where:

- $V_{RM}$ = average monthly volume of water sprayed inside the raw mill (litres/month)
- $\overline{Q}_{RM}$ = average daily volumetric flow rate inside the raw mill (litres/min)
- $N$ = number of days per month

It should be noted that the daily flow rate varied with the raw material’s moisture content and that the raw mill had some down time during each year, but the average figure obtained using Equation 5.1 provides a reasonable picture for the total volume of water sprayed inside the raw mill. The average monthly volume of water sprayed inside the raw mill was then divided by the respective average monthly mass of clinker production to have a value that could be compared with the literature (litres of water per tonne of clinker). Please refer to Appendix A, Table A.19 for the complete dataset of clinker production at the plant in Canada. The results for the monthly volume of water sprayed inside the raw mill, as well as the resultant water usage per tonne of clinker produced, are
included in Appendix A, Table A.20. The monthly average water usage inside the raw mill, for the total period investigated from 2007 to 2011, was around 20 litres per tonne of clinker produced. For cement manufacturing by dry and semi-dry processes, the available information indicated that water usage for raw material preparation ranged from 0 to 350 litres per tonne of clinker produced\(^{12}\) (CEMBUREAU 1999). At the Canadian plant the average figure was at the lower end of that range, probably because those figures are for dry process and not semi-dry process manufacturing. It is not clear in the literature whether the water sprayed for dust control over the crushed limestone stockpile was included. As indicated before, the Canadian plant did not measure water usage for dust control around raw material stockpiles.

Water usage inside the raw mill was also calculated per tonne of ground cement produced, reflecting the main objective of this research to investigate water usage at integrated cement plants that grind clinker to make the final cement powder. The results for water usage inside the raw mill per tonne of cement produced are included in Figure 5.2 and in Appendix A, Table A.21. The complete dataset of cement production at this plant is included in Appendix A, Table A.3. The monthly average water usage inside the raw mill, for the total period investigated, was around 20 litres per tonne of cement produced. The number is equal to that for clinker produced because the mass of clinker and cement manufactured at that plant were very similar. As seen in Figure 5.2, there is a more regular pattern of water usage for the months from April to December, when

\(^{12}\) Although this data was published in 1999, it is still valid because the processes have not changed critically since that time.
monthly cement production was also more regular. However, the monthly average of water usage (20 L/tonne cement) was not highly variable over the year.

Figure 5.2. Water usage inside the raw material mill per tonne of cement produced for the years between 2007 and 2011, at the Canadian plant.

5.2.2 **Fuel Supply Preparation at the Canadian Plant**

The fuel supply at this plant was mainly petroleum coke. Coal was occasionally added in small portions as a supplementary fuel. Natural gas was also mixed in the fuel supply but only when starting up the kiln. On the rare occasions when coal was being used and the weather was dry, groundwater was sometimes sprayed over the coal stockpiles for dust suppression. Groundwater was also sometimes sprayed inside the mill (a ball mill at this plant) to properly agglutinate the fuel for improving grinding conditions. This water was not measured at the plant, but according to plant personnel such requirements were rare and the quantity was not excessive. Therefore, this water requirement was assumed to be null at this plant.
5.2.3  Cleaning of Preheater Tower at the Canadian Plant

A high-pressure water blaster was used for cleaning the bottom part of the preheater tower (also called the riser). The quantity of water used, being groundwater, was not measured, although this operation ran twice a day, for an average of two hours at a time. The monthly volume of water used was estimated by this author based on the pressure of the water blaster used at this plant [approximately $34 \times 10^6$ Pa (5,000 psi)] and the inner nozzle diameter [4.75 x $10^{-3}$ m (3/16″)]. This estimate was based on the principle of mechanical energy balance from the Bernoulli Equation (Equation 5.2).

\[
\frac{1}{2} \rho v^2 = P
\]

(5.2)

Where:

$\rho = $ water mass density (kg/m$^3$)

$v = $ water velocity (m/sec)

$P = $ water blaster’s pressure (Pa)

From this equation, because both $\rho$ and $P$ are known, one can determine water velocity $v$ (Equation 5.3).

\[
v = \sqrt{\frac{2P}{\rho}} = \sqrt{\frac{2 \times 34 \times 10^6}{10^3}} = 261 \text{ m/sec}
\]

(5.3)

The water flow for cleaning the preheater tower ($Q_{PH}$) was then calculated by multiplying the estimated water velocity ($v = 261$ m/sec) by the area of the cross section of the high-
pressure water blaster’s nozzle (Equation 5.4). It should be noted that this result for $Q_{PH}$ (4.6 L/sec) represented the upper limit for water flow, as some pressure drop happens through the hose. The specific details of diameter and length of hose could not be obtained by this author, thus the pressure drop could not be calculated, but this result provided an adequate estimate of the maximum flow.

$$Q_{PH} = v \times \pi \left(\frac{d}{2}\right)^2 = 261 \times 3.14 \times \left(\frac{4.75 \times 10^{-3}}{2}\right)^2 = 4.6 \times 10^{-3} \text{ m}^3/\text{sec}$$

$$Q_{PH} = 4.6 \text{ L/sec} \quad (5.4)$$

Cleaning of the preheater tower was performed at this plant for four hours every day. The estimated water flow of 4.6 litres per second can be translated into a volume of approximately 2 million litres used per month (4.6 L/sec × 60 sec/min × 60 min/hour × 4 hour/day × 30 day/month). Based on this figure, the upper limit of water usage at this stage would be around 40 litres per tonne of cement (2 million litres/month ÷ 50 thousand tonnes/month). However, the water blaster was not working non-stop through the cleaning time and the resultant flow was not considering pressure drop through the hose. Therefore, it is reasonable to assume that the actual flow was around 50 percent of the calculated flow. Thus the flow was considered to be 20 litres per tonne of cement at this stage (i.e., water usage for cleaning of preheater tower).
5.2.4 **Kiln Gas Analysis at the Canadian Plant**

The probe for combustion gas analysis that was located inside the kiln was cooled by glycol at this plant, so there was no water usage directly at this stage. However, water was used to cool down the glycol. The quantity of water for cooling down glycol is included in the estimate for overall cooling of equipment (see Section 5.2.12).

5.2.5 **Clinker Cooling at the Canadian Plant**

Clinker is cooled down at this plant by passing through a grate cooler where the heat exchange happens by air contact, so there is no water usage at this stage.

5.2.6 **Cement Milling at the Canadian Plant**

As indicated in Chapter 3, temperature rises inside the cement ball mill because of friction between the steel balls that grind the clinker. High temperatures can affect the quality of the final cement. For that reason, groundwater was sprayed inside the mill to lower its internal temperature. The quantity of water sprayed has to provide enough humidity to lower the mill’s internal temperature, but cannot go beyond a certain limit without interfering with the condition of the final powdered product.

There was no flowmeter to record water usage at the cement ball mill at the Canadian plant, but the plant’s process engineer estimated that approximately 32 litres of water was sprayed per minute inside the cement mill (personal communication). His assumption was based on the time to fill the water tank that fed that system (shown in Figure 5.3).
This flow rate of 32 litres of water sprayed per minute inside the cement mill was an estimated average but this flow rate was variable across the year. Plant personnel indicated (based on work experience) that the cement mill operated continuously, but from 64 to 73 percent of the time per year. Using an intermediate figure of 70 percent of the year, the estimated flow of 32 litres/min can be translated into a maximum volume of 1 million litres of water being used per month (32 L/min × 60 min/hour × 24 hour/day × 30 day/month × 70% of the year). This monthly volume represents around 20 litres of water for each tonne of clinker or cement produced (recalling that average monthly production at this plant was 50 thousand tonnes for both clinker and cement). The available information in the literature refers to vertical roller mills requiring up to 20 litres of water for each tonne of clinker produced (CEMBUREAU 1999), but there is no data for ball mills.
Another attempt to quantify water usage for cement milling was made by this researcher based on heat transfer (using an energy balance equation) inside the cement mill. At this plant, an electric motor was rotating the cement ball mill. Inside the mill, friction between clinker and steel balls generated heat; thus clinker being ground into cement was heated, and water being sprayed inside the mill was also heated and completely turned into vapour. Figure 5.4 and Equation 5.5 present a schematic of such heat transfer balance.
Figure 5.4. Heat transfer balance inside the cement mill.

\[ P_{\text{motor}} = \dot{m}_c c_c \Delta T_c + \dot{m}_w c_w \Delta T_w + \dot{m}_w L_w \]

(5.5)

Where:

- \( P_{\text{motor}} \) = power of electric motor (W) = at this plant 4,000 kW = 4 x 10^6 W, considering efficiency 97% (both power and efficiency were indicated by plant personnel);
- \( \dot{m}_c \) = clinker mass flow rate = at this plant 100 tonnes/hour = 28 x 10^3 g/sec (indicated by plant personnel);
- \( c_c \) = clinker specific heat (J/gºC) = 0.188 J/gºC (Perry and Green 2008);
- \( \Delta T_c \) = cement temperature variation (ºC) = \( T_c_2 - T_c_1 \) = at this plant clinker enters the cement mill at around 65 ºC (\( T_c_1 \)), and cement exits the mill at around 102 ºC (\( T_c_2 \)), thus \( \Delta T_c = 37^\circ C \) (indicated by plant personnel);
- \( \dot{m}_w \) = water mass flow rate (g/sec);
- \( c_w \) = water specific heat (J/gºC) = 4.1868 J/gºC (Perry and Green 2008);
- \( \Delta T_w \) = water temperature variation (ºC) = \( T_w_2 - T_w_1 \) = at this plant groundwater is sprayed inside the mill at around 12 ºC (\( T_w_1 \)) and is entirely converted into vapour at 100 ºC (\( T_w_2 \)), thus \( \Delta T_w = 88 ^\circ C \) (indicated by plant personnel);
- \( L_w \) = water latent heat of vapourization (J/g) = 2,257.1 J/g (Perry and Green 2008).
Assuming that this heat was entirely transferred to both clinker being ground into cement and water sprayed inside the mill, then the water mass flow rate \( \dot{m}_w \) can be calculated using Equation 5.6. These calculations did not include potential losses of power in the electric motor due to aging of equipment, because such data could not be collected at the plant.

\[
\dot{m}_w = \frac{P_{\text{motor}} - \dot{m}_c c_c \Delta T_c}{c_w \Delta T_w + L_w} = \frac{4 \times 10^6 W - 28 \times 10^3 \frac{g}{\text{sec}} \times 0.7871 \frac{\text{g C}}{\text{g}} \times 37 \text{ C}}{4.1868 \frac{\text{J g C}}{\text{g C}} \times 88 \text{ C} + 2,257.1 \frac{1}{\text{g}}}
\]

\[
\dot{m}_w = 1.2 \times 10^3 \frac{g}{\text{sec}} = 1.2 \text{ L/sec}
\]  
(5.6)

This calculation resulted in an estimated flow of approximately 1.2 litres of water being sprayed inside the mill per second (approximately 72 litres per minute). Assuming that the mill operated for around 70 percent of the year, then this estimated flow of 1.2 L/sec can be translated into a maximum volume of 2 million litres of water usage per month (1.2 L/sec \times 60 \text{ sec/min} \times 60 \text{ min/hour} \times 24 \text{ hour/day} \times 30 \text{ day/month} \times 70\% \text{ of the year}). Based on this estimate, the average water usage at this stage was around 40 litres per tonne of cement (2 million litres/month \div 50 \text{ thousand tonnes}).

This estimated water usage considering heat transfer inside the cement mill (40 L/tonne cement) is higher than the one estimated by the plant’s process engineer based on the time to fill the water tank for the cement mill (20 L/tonne cement). Some reasons for this difference could be the seasonal variation of temperature of the water being sprayed, as well as the variation of operational conditions in terms of the temperature of clinker.
entering the mill and the temperature of cement exiting it. Because of that, the estimate based on heat transfer inside the cement mill may be higher than the regular water requirements, but it is useful to provide an estimated upper limit for water requirement. Therefore, it is reasonable to state that the flow of water sprayed inside the cement mill was between 20 to 40 litres of water per tonne of cement produced. However, there is not enough information to indicate which number has a higher reliability, as both results were based on estimates. Further discussion of the quality of data obtained in this case study for each stage of cement manufacturing will be presented in the next chapter, along with a characterization of levels of reliability for all data acquired from this research work.

5.2.7 Cement Cooling at the Canadian Plant

According to plant personnel, groundwater was used in large quantities to cool down the freshly ground cement, through the passage inside a cement cooler, located between the cement mill and the cement silos. A flow of around 100 tonnes of clinker per hour entered the cement mill and was ground and mixed with some additions, thus resulting in a flow of approximately 120 to 125 tonnes of cement per hour leaving the cement mill. This freshly ground cement was lifted through a cement cooler, which was a compartment with a slowly rotating internal vertical screw auger. The cement was cooled to around 65 °C by passing cold water over the external surface of the cement cooler without contact between the cement and the water (Figure 5.5). This heat exchange operation ran year-round but it required larger quantities of water in the summer than in the winter. After the cement cooler, the cement went to the silos and there was no further water requirement at this stage.
There was no flowmeter to measure water usage for the cement cooler, but plant personnel indicated that from the records of the design for the existing cement cooler at this plant, the quantity of water required to cool down the cement from averages of 112 °C to 60 °C would be from 30 to 120 cubic metres per hour (personal communication). This estimate took into account the temperature of the entering water at 20 °C and exiting the cooler at 31 °C. He also indicated that the maximum flow of cement according to the design of the cement cooler was 130 tonnes per hour. Moreover, plant personnel indicated that the cement cooler also operated for an average of 70 percent of the time per year. Based on the provided information of water required (30 to 120 cubic metres per hour), it can be obtained that water usage for cement cooling ranged from 160 to 650 litres of water per tonne of cement (Equations 5.7 and 5.8).

Figure 5.5. Bottom part of the cement cooler at the Canadian plant. Water is passing between the internal and external surfaces. Photo by author.
Where:

\[ Q_{c_{\text{c, min}}} = \left( \frac{30 \text{ m}^3/\text{hour} \times 1000 \left(\frac{\text{litres}}{\text{m}^3}\right)}{130 \text{tonnes/hour}} \right) \times 70\% \text{ of year} = 160 \frac{L}{\text{tonne}} \]  

(5.7)

Where:

\[ Q_{c_{\text{c, max}}} = \left( \frac{120 \text{ m}^3/\text{hour} \times 1000 \left(\frac{\text{litres}}{\text{m}^3}\right)}{130 \text{tonnes/hour}} \right) \times 70\% \text{ of year} = 650 \frac{L}{\text{tonne}} \]  

(5.8)

Where:

\[ Q_{c_{\text{c, max}}} = \text{maximum water flow for cement cooling (litres/tonne cement), for 120 m}^3/\text{hour} \]

This researcher also estimated the water requirement at this stage based on heat transfer, taking into account available data for (a) the flow of cement being cooled down, and (b) the temperatures of cement and water arriving and leaving the cement cooler. These estimates matched those provided by plant personnel. Therefore, the estimated range of water requirements for the cement cooler was assumed to be from 160 to 650 litres per tonne of cement. There is no data available in the literature for such systems, but it is noted that the estimated water requirements at this stage are considerable at the Canadian plant, when compared to its total water intensity (2,000 L/tonne cement).
5.2.8  *Cement Dispatch at the Canadian Plant*

All trucks loaded with cement were washed before leaving the plant to avoid spread of cement powder on the roads nearby the plant. For this task, groundwater was used but not measured. This researcher attempted to estimate the quantity of water used to wash a truck per tonne of cement produced. According to the plant’s process engineer each truck transported an average mass of 35 tonnes of cement (personal communication). In previous research, this researcher found that an average of 140 litres of water was required to wash similar trucks (Bezerra et al. unpublished data). Assuming that the same volume was required to wash a truck leaving the plant with 35 tonnes of cement, then around 4 litres of water were required per tonne of cement produced. Although this flow (4 L/tonne cement) did not highly impact water intensity at this plant, it added to the total water used at that plant.

5.2.9  *Conditioning of Gaseous Emissions at the Canadian Plant*

At the plant studied in Canada, there were three conditioning towers to adjust the gaseous emissions from the preheater tower, the kiln, and the cement mill. Groundwater was sprayed inside the towers to lower the gas temperature to meet the acceptable limit of the respective filtering elements (bag filters or electrostatic precipitator), as well as to adjust the chemical characteristics for optimum conditioning of emissions, before these gases were released to the atmosphere. The flow of water sprayed inside the towers was automatically controlled in response to changes in temperature and chemical composition of gaseous emissions. The plant had its own measurement system for recording
groundwater usage inside the conditioning towers, using built-in flowmeters that were continuously measuring the instantaneous flow, although data were not totalized.

Data for water usage inside one of the towers (called the by-pass tower) were available only in 2011, from June to December. This tower had the lowest water intake when compared with the other towers, representing less than 10 percent. The water usage was added for the three towers for the total period investigated, but consideration of the total water usage for the three towers should take into account that this sum did not include the by-pass tower for the total period investigated.

Data for water usage inside the conditioning towers were provided by plant personnel. These data were available in volumetric flow rate \( Q_{CT} \) in litres of water being sprayed per minute exactly at noon and at midnight every day, from January 1, 2007 until December 31, 2011. Using the same method and assumptions described in Section 5.2.1 (Equation 5.1), the total volume of water sprayed inside the conditioning towers \( V \), for each month of each year, was then calculated (all results are included in Table A.22, Appendix A). It should be noted that the daily volumetric flow rate had some variation across the months, as a function of the characteristics of gaseous emissions, but the average figure obtained using Equation 5.1 provides a reasonable picture for the total volume of water sprayed. The monthly volume of water sprayed inside the conditioning towers was then divided by the respective monthly mass of clinker production to yield a figure that could be compared with the literature (litres of water per tonne of clinker). The complete dataset of clinker production at the plant in Canada is included in Appendix A,
Table A.19. The results for water usage inside the conditioning towers per tonne of clinker production are included in Appendix A, Table A.22. The monthly average water usage was approximately 120 litres of water sprayed inside the conditioning towers per tonne of clinker produced. This number is larger than those available in the literature, which indicate that conditioning of gaseous emissions inside conditioning towers may consume up to 75 litres of water per tonne of clinker produced (CEMBUREAU 1999). The reason for the higher number for this plant than the literature value is unknown, but it is likely related to assumptions made by this author, such as that the flows at noon and midnight were representing a realistic daily average that could be translated for the year-round operation. Moreover, at the times when equipment was under maintenance, the quality of gaseous emissions certainly had variations. Therefore, the water requirements were probably more variable than what was assumed here.

Results for water usage inside the conditioning towers were also calculated per tonne of ground cement produced (Figure 5.6 and in Appendix A, Table A.23). The monthly average water usage inside the conditioning towers was around 120 litres per tonne of cement produced. As seen in Figure 5.6, water usage was more regular between the months of April and November, following the trend of clinker and cement production, and with a few exceptions it was not highly variable across the year (average 120 L/tonne cement).

Water was also used for conditioning of gaseous emissions inside a selective non-catalytic reduction (SNCR) system. The SNCR system worked to reduce NOx from the
gaseous emissions, by injecting a solution of 25 percent ammonia in water (by volume) inside the preheater. The plant’s environmental coordinator indicated that this system was running nearly all the time and estimated the average rate being about 250 litres per hour of solution being consumed. This solution contained approximately 50 litres of ammonia and 200 litres of water (personal communication). According to these estimates, the upper limit for water usage for the SNCR system was approximately 150 thousand litres per month. The average monthly cement production was approximately 50 thousand tonnes, so this monthly volume of water used for the SNCR system represented around 3 litres of water being used per tonne of cement produced. It should be recalled that flame cooling was not performed at this plant. Therefore, adding the requirements for the conditioning towers (around 120 L/tonne cement) to those for the SNCR system (around 3 L/tonne cement), it can be assumed that the conditioning of gaseous emissions used around 123 litres of water per tonne of cement produced at this plant.

Figure 5.6. Water usage inside the conditioning towers per tonne of cement produced for the years between 2007 and 2011, at the Canadian plant.
5.2.10 Cooling of Equipment at the Canadian Plant

The equipment and bearings at the cement plant in Canada were cooled by ethylene glycol and water. There was no measurement for the quantity of water used for cooling. Some estimates for the volume of water usage at this stage, based on analysis from data obtained for all other stages, will be presented in Section 5.2.12.

5.2.11 Uses Beyond the Production Line at the Canadian Plant

As indicated before, mains water was used outside the cement production line, contributing to the overall demand for water for the cement plant. The uses investigated were for employees’ and subcontracted labourers’ needs, laboratory work, overall housekeeping, and road dust suppression. At this plant there was no sewage treatment facility for domestic effluent, but only a settling pond for process water. Therefore, there were no water requirements for effluent treatment at the plant. Domestic effluent was sent to the municipality’s plant.

5.2.11.1 Workers’ Needs at the Canadian Plant

Employees and subcontracted labourers used mains water for drinking and hygiene purposes, including showers before leaving the plant. Lunchrooms were available but there was no kitchen or restaurant for food preparation. The average number of employees and subcontracted labourers at this plant, for the years between 2007 and 2011, was around 110 workers. A daily per capita water requirement of approximately 120 litres was calculated by this author based on the average mains water intake of 400 cubic metres per month for the 110 workers (Equation 5.9).
Where:

\[ Q_w = \frac{\text{MAIN WATER INTAKE (litre/month)}}{30 \left( \frac{\text{day}}{\text{month}} \right) \times N_w} \]  

\[ Q_w = \frac{400 \times 10^3 \text{(litre/month)}}{30 \left( \frac{\text{day}}{\text{month}} \right) \times 110} = 120 \text{ L/day} \]  

This estimate is likely to be high, because mains water was also used to supply the laboratory at the plant and for housekeeping activities inside the core building. However, another study conducted in the mining, quarrying and manufacturing sectors indicated that 180 litres of water were consumed daily per employee (Undelstvedt 2006). Undelstevdt’s higher number is probably due to the likely inclusion of restaurants for food preparation in his study.

Therefore, a daily per capita water usage of 120 litres was assumed by this author to be representative of the water usage at this plant. This estimate translates into around 8 litres of water usage per tonne of cement produced (120 L/day/worker \times 110 \text{ workers} \times 30 \text{ day/month} \div 50 \text{ thousand tonnes/month}). A requirement of 8 L/tonne cement is minimal when compared to the total water intensity at this plant (2,000 litres/tonne cement), but this water has to be potable.
5.2.11.2 Laboratory Work at the Canadian Plant

Raw material and final cement quality were regularly analyzed at the laboratory inside the plant, where water was required for preparing samples and running tests. There was no measurement for water usage at this stage but the plant’s laboratory technician estimated that around 10 litres of mains water were used every hour for laboratory work (personal communication). According to his information, a regular day was around 12 hours of laboratory work, so the water usage would typically be approximately 120 litres daily. However, he also mentioned that during times of formulating new cement compositions, tests were run for 24 hours every day, so water usage in the laboratory would reach at least 240 litres daily. This volume is a lot lower than what is available in the literature, which stated in 1999 that water usage for laboratory work could reach up to 20,000 litres daily (CEMBUREAU 1999). However, this discrepancy is not surprising because current control tests are currently performed with less water than at that time.

Taking the maximum amount required daily in the laboratory, it can be calculated that around 0.1 litres of water were used for laboratory work per tonne of cement (240 L/day × 30 day/month ÷ 50 thousand tonnes/month). As happened with the amount of water usage for workers, this requirement (0.1 L/tonne cement) was very little when compared to the other stages, but this water was also required to be of drinking quality.

5.2.11.3 Overall Housekeeping and Road Dust Suppression at the Canadian Plant

The offices, washrooms and lunchrooms inside the core building were cleaned daily. In addition to sweeping, the janitorial staff also used mains water, but there was no
measurement for the quantity of water used. In the industrial area of the plant, groundwater was occasionally used for washing floors with hoses, but there was no specific frequency for performing this task and also no measurement (Figure 5.7).

Figure 5.7. Floor being washed at the Canadian plant. Photo by author.

Beyond housekeeping activities year round, water was sprayed on the surface of unpaved roads for dust suppression in the drier months, generally from May to September. Water for road dust suppression was collected from the plant’s process water discharge settling pond; thus, some effluent reuse was in place. There was no flow measurement for the volume of effluent recycled but the plant’s environmental coordinator estimated the quantity at around 16,000 litres per day, corresponding to two daily water truck loads
(each truck has a capacity of 8,000 litres). Based on this estimate, if road dust suppression were performed daily, the total water recycled for the months of May to September would reach an approximate monthly volume of 480 thousand litres (16 thousand litres/day × 30 day/month).

This volume can be converted into approximately 10 litres of water usage at this stage per tonne of cement produced (480 thousand L/month ÷ 50 thousand tonnes/month). These estimates were based on daily road dust suppression, which in fact may not have happen, but there was no specific frequency for road dust suppression. This requirement (10 L/tonne cement) was more necessary when the weather was dry because dirt is spread with the traffic of trucks.

As indicated before, at this plant there was no wastewater treatment plant (WWTP) in operation. The domestic sewage was discharged into the local sewer system and treated at the municipality’s wastewater treatment plant, and process water was discharged into a settling pond. Therefore, there was no water requirement for such operations at this plant.

5.2.12 Summary of Collected Water Usage Data at the Canadian Plant

As presented in the previous sections, two stages of cement manufacturing were continuously measured (but not totalized) at the plant studied in Canada: the raw mill stage and the conditioning tower stage. Plant personnel had some information that allowed estimates of water usage for: fuel supply preparation, cement milling, cement cooling, cement dispatch, SNCR system for lowering NO\textsubscript{x} from kiln emissions,
laboratory work and road dust suppression. For the stages not monitored, this author attempted to measure water usage by using three different procedures.

The first method was to install a portable flowmeter, but *in situ* monitoring did not yield usable data. The experiment using the portable flowmeter, and the reasons why data could not be obtained, are described and analyzed in Appendix B, in order to record this experience and help shape proper strategies for future studies. The second method was to estimate the water flow, based on the water pressure inside the pipelines, and assuming the pipes run first full of water, and then half full. This attempt proved not to be a realistic approach because the water pressure was variable throughout the day (plant personnel indicated such variability, but were not able to give a real figure because water pressure was not monitored at the plant). Moreover, not all pipes could be opened to check whether they run full or half full. Therefore, there was a lack of proper inputs to propose reasonable estimates. The third method for estimating water usage at each stage of cement manufacturing was based on information related to the existing equipment, on energy balance equations (heat transfer), and on the technical literature.

After attempting these three methods, a water usage estimate was still unavailable for the equipment-cooling stage. A reasonable estimate was then to consider water usage for cooling as the total water intensity at this plant (which was calculated in Chapter 4 at 2,000 litres of water per tonne of cement produced) minus the total water usage at the other ten stages (which was estimated to be between 365 and 875 litres per tonne). The lower value (365 L/tonne) was based on estimates of 20 litres per tonne of cement for
cement milling and 160 litres per tonne of cement for cement cooling. The larger value (875 L/tonne) was based on values for those two stages of 40 and 650 litres per tonne of cement, respectively. It should be noted that water usage for overall housekeeping included road dust suppression, which was performed only in the summer months and with recycled effluent. This amount of 10 litres per tonne of cement, used for the months from May to September but not necessarily every day, did not greatly impact water intensity, but this value was added to recognize the number for this stage. The result of this difference is that cooling of equipment required, on average, approximately 1,125 (2,000 – 875) to 1,635 (2,000 – 365) litres of water per tonne of cement. As indicated before, both water and glycol were used for cooling at this plant, but the numbers presented here are for the water requirements only. It should be noted that glycol coolant must itself be cooled in order to be recycled; the water used for this process is included in the estimate of 1,125 to 1,635 L/tonne of cement.

All collected data were combined to create a dataset of water usage per tonne of cement produced at each stage of cement manufacturing at this plant. These data are summarized in Table 5.2. As indicated before, discussion on the reliability of these data will be presented in the next chapter, along with a characterization of levels of reliability, based on method of data acquisition, for all data acquired from this research work.

For comparison, Kollar and MacAuley (1980) indicated percentages for three categories of water usage for cement manufacturing: approximately 82 percent of water usage for cooling, 17 percent for process, and 1 percent for sanitary purposes and other uses.
beyond the production line. Kollar and MacAuley did not indicate which stages were included under the category called “process and uses beyond the production line”, but their categories nonetheless provide helpful comparison. Using these percentages, when amounts are calculated for a water intensity of 2,000 L/tonne, results for the three categories are similar to the collected and estimated data presented here. The results of this comparison are included in Table 5.3.

Table 5.2. Summary of collected water usage data at each stage of cement manufacturing at the Canadian plant

<table>
<thead>
<tr>
<th>STAGE OF CEMENT MANUFACTURING</th>
<th>WATER USAGE DATA AT CANADIAN PLANT (litres/tonne cement)</th>
<th>Measured at the plant</th>
<th>Estimated by plant personnel</th>
<th>Estimated by this researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material preparation</td>
<td></td>
<td>20</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>Fuel supply preparation</td>
<td></td>
<td>N.A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning of preheater tower</td>
<td></td>
<td>N.A.</td>
<td>N.A.</td>
<td>20</td>
</tr>
<tr>
<td>Kiln gas analysis</td>
<td></td>
<td></td>
<td></td>
<td>No water usage at this stage at this plant</td>
</tr>
<tr>
<td>Clinker cooling</td>
<td></td>
<td></td>
<td></td>
<td>No water usage at this stage at this plant</td>
</tr>
<tr>
<td>Cement milling</td>
<td></td>
<td>N.A.</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Cement cooling</td>
<td></td>
<td>N.A.</td>
<td>160 to 650</td>
<td></td>
</tr>
<tr>
<td>Cement dispatch</td>
<td></td>
<td>N.A.</td>
<td>N.A.</td>
<td>4</td>
</tr>
<tr>
<td>Conditioning of gaseous emissions</td>
<td>Conditioning towers</td>
<td>120</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>Flame cooling for lowering NOx from kiln</td>
<td></td>
<td></td>
<td></td>
<td>Not applied at this plant</td>
</tr>
<tr>
<td>SNCR for lowering NOx from kiln</td>
<td></td>
<td>N.A.</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Cooling of equipment</td>
<td></td>
<td></td>
<td></td>
<td>1,125 to 1,635</td>
</tr>
<tr>
<td>Uses Beyond the Production Line</td>
<td>Workers’ needs</td>
<td>N.A.</td>
<td>N.A.</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Laboratory work</td>
<td>N.A.</td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Overall housekeeping and road dust suppression</td>
<td>N.A.</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>2,000</td>
</tr>
</tbody>
</table>

*Note: N.A. indicates that measured data was not available and there was not enough information to propose an estimate.*
Table 5.3. Comparison of water usage estimates for three categories of water usage, from the literature and from collected data at the Canadian plant

<table>
<thead>
<tr>
<th>WATER USAGE</th>
<th>ESTIMATE FOR THE CANADIAN PLANT (litres/tonne cement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Based on Kollar and MacAuley (1980)</td>
<td>Based on data obtained in this research</td>
</tr>
<tr>
<td>Cooling of equipment</td>
<td>1,640</td>
</tr>
<tr>
<td>Process</td>
<td>340</td>
</tr>
<tr>
<td>Sanitary purposes and other uses beyond the production line</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 5.8 presents all collected data for water usage at this plant, including the total water intensity figure of 2,000 litres of water per tonne of cement produced. These estimates include some uncertainties, but they provide a picture to fill the gaps of knowledge resulting from the lack of measurement routines at the plant.

For instance, plant personnel reported that the cement cooling was the stage with the highest level of water usage, followed by conditioning of gaseous emissions (water sprays inside the conditioning towers). Based on the proposed water usage diagram, their assumption did not consider water requirements for cooling of equipment, which seems to have the highest level of water usage, even knowing that glycol was also used for cooling at this plant. Installation of a flowmeter to record water usage at the cement cooler, and for cooling of equipment, could provide accurate information and confirm this finding.
In this way, Figure 5.8 also provides a schematic to identify stages with the highest generation of effluents. The installation of more flowmeters to record water usage around the plant would also allow further investigation of effluents generated in the process, and could eventually support a decision to implement a closed-loop recycling system for cooling of equipment, or at least for the cement cooler. If more recycled effluent were used at this plant, beyond the minimal amount used for road dust suppression, groundwater withdrawal would decrease, and consequently this plant’s water intensity could be lowered. Certainly the stages with high water usage and lack of data reliability are the critical ones to be measured, as discussed in the next chapter, when other water management practices will also be presented.

The next section presents the assessment of water usage at each stage of cement manufacturing at the plant studied in Brazil.
Figure 5.8. Estimated water usage for each stage of cement manufacturing at the Canadian plant.

*Note:* All numbers are for litres of water per tonne of cement produced.
5.3 Water Usage at Each Stage of Manufacturing at the Plant Studied in Brazil

The primary water sources available at the Brazilian plant were groundwater and surface water. Some effluent recycling and stormwater floor drainage accounted for a small contribution, estimated by plant personnel at around 2,000 cubic metres monthly or approximately 10 percent of the surface water intake. This recycled effluent was mixed with surface water and used only in the industrial area. Groundwater supplied two stages at the industrial area: cleaning of the preheater tower and cooling the probe of the kiln gas analysis system. Groundwater was also used outside the main production line for the overall housekeeping, as well as for restaurant, coffee rooms, washrooms, laboratory, and for preparing solutions at a wastewater treatment plant (WWTP). The water intensity at this plant was calculated in Chapter 4 to be 250 litres per tonne of cement, a much lower figure than at the Canadian plant. This difference is discussed further at the end of this chapter. Although this plant had two production lines running in parallel, all information provided by plant personnel was for both lines together. A description of water usage at each stage of cement manufacturing is presented next.

5.3.1 Raw Material Preparation at the Brazilian Plant

At the stage of raw material preparation, surface water was sometimes sprayed over the crushed limestone stockpile for dust control. Surface water was also sometimes sprayed inside the mills (one ball mill and one vertical roller mill) for improving grinding conditions. The quantity of water for raw material preparation was not measured. As indicated earlier, from 0 to 350 litres of water per tonne of clinker produced would be
typical at this stage (CEMBUREAU 1999). An attempt to estimate the volume of water usage for raw material preparation at the Brazilian plant, which operated under the dry process, will be presented in Section 5.3.12, based on estimates from the proposed water usage diagram at this plant.

5.3.2 Fuel Supply Preparation at the Brazilian Plant

The fuel supply at this plant was mainly petroleum coke. Sometimes a small quantity of coal was used. Diesel oil was mixed in the fuel supply, but only when starting up the kiln. Plant personnel indicated that there was no water usage for this stage at this plant.

5.3.3 Cleaning of Preheater Tower at the Brazilian Plant

A high-pressure water blaster was used for cleaning the bottom part of the four preheater towers at the plant in Brazil. There was no flowmeter to record the quantity of groundwater used. Plant personnel provided an estimate of around 4,000 litres of water required every day for cleaning all towers. This volume could be obtained based on the number of trucks transporting water during a period when groundwater was not available for that stage, because of a failure of the water withdrawal pumps. This daily flow rate yielded an average value of around 1 litre of water for each tonne of cement produced (4,000 L/day × 30 day/month ÷ 100 thousand tonnes cement/month). The complete dataset of cement production at this plant is included in Appendix A, Table A.14. This water requirement (1 L/tonne cement) for cleaning the preheater towers did not have a major impact on the total water intensity at this plant (250 litres of water per tonne of
cement produced), although the daily volume was a large number and this water had to be of high quality, so groundwater was used. As indicated before, water requirements at this stage differed between the Canadian plant (20 L/tonne cement) and the Brazilian plant (1 L/tonne cement), and reasons for such a difference in are discussed at the end of this chapter.

5.3.4 Kiln Gas Analysis at the Brazilian Plant

Water was continuously required for cooling the probe used for combustion gas analysis. It should be recalled that this probe was located inside the kiln at temperatures up to 1,550 °C. This water requirement was not measured at this plant but was estimated by plant personnel as a major volume of groundwater, approximately 250 litres of water per hour. Product documentation from the probe manufacturer states that the water requirement may reach 3,000 litres of water per hour, when there is no recycling in place (Enotec 2012). Thus, this estimated flow of 250 litres per hour seems a reasonable estimate because, although is much lower, it is under that limit. The estimated flow can be converted into approximately 2 litres of water per tonne of cement produced (250 L/hour × 24 hour/day × 30 day/month ÷ 100 thousand tonnes/month). This water requirement (2 L/tonne cement) was considerable when evaluating the daily usage but did not highly impact the total water intensity at this plant. However, the water used at this stage had to be of high quality and therefore groundwater was used.
5.3.5 Clinker Cooling at the Brazilian Plant

Clinker was cooled down at this plant by passing through a grate cooler where the heat exchange happens by air contact, so there was no water usage at this stage.

5.3.6 Cement Milling at the Brazilian Plant

As indicated before, the temperature rises inside the cement ball mill because of friction between the steel balls that grind the clinker. At this plant, surface water was sprayed inside the mills (there were four) to lower their internal temperature. There was no flowmeter to record the volume of water sprayed. An estimate to quantify water usage for each cement mill was made by this researcher based on heat transfer balance inside the cement mills (Equation 5.5). At this plant, clinker entered the cement mill at around 75 °C, and cement exited the mill at around 100 °C, thus $\Delta T_c = 25^\circ$C. Surface water was sprayed inside the mills at around 20 °C and was entirely converted into vapour at 100 °C, thus $\Delta T_w = 80^\circ$C. The specific parameters for each of the four mills are indicated in Table 5.4. The values for the constant characteristics of clinker and water ($c_c$, $c_w$, and $L_w$) were the same as indicated for the plant studied in Canada.

This estimate resulted in a total flow of around 3.2 litres of water sprayed inside the four mills per second, by adding the flow obtained for each mill. Clearly this volume would have been lower when not all mills were simultaneously operating. Plant personnel indicated that the mills operated for about 85 percent of the year. Thus, the estimated flow of 3.2 L/sec can be translated into a maximum volume of 7 million litres of water
used per month \((3.2 \text{ L/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hour} \times 24 \text{ hour/day} \times 30 \text{ day/month} \times 85\% \text{ of the year})\). Cement milling was continuously performed at the plant, and even when one mill was off for maintenance, the other ones were milling. Therefore, based on the estimated flow, the upper limit of water usage at this stage was around 70 litres per tonne of cement \((7 \text{ million litres/month} \div 100 \text{ thousand tonnes/month})\). This requirement is close to 30 percent of the total water intensity at this plant. The higher temperature of water sprayed inside the mill and the lower temperature of cement leaving the mill at this plant were likely influencing this larger water usage \((70 \text{ L/tonne cement})\) when compared to the estimates for the Canadian plant \((from 20 \text{ to } 40 \text{ L/tonne cement})\).

Table 5.4. Characteristics of cement mills at the Brazilian plant

<table>
<thead>
<tr>
<th>CEMENT MILL NUMBER</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P_{\text{Engine}}) (W) being 97% efficiency</td>
<td>(1.7 \times 10^6)</td>
<td>(1.7 \times 10^6)</td>
<td>(2.9 \times 10^6)</td>
<td>(3.9 \times 10^6)</td>
</tr>
<tr>
<td>(\dot{m}_c) (tonnes/hour)</td>
<td>58</td>
<td>58</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>(\dot{m}_w) (L/sec)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.9</td>
<td>1.3</td>
</tr>
</tbody>
</table>

5.3.7 Cement Cooling at the Brazilian Plant

Water was not used at this stage at the plant in Brazil. According to plant personnel the cement exited the ball mills at a temperature meeting the requirement of the Brazilian market \(\text{(personal communication)}\). It is noteworthy that this temperature was just below 100 °C and that would not be acceptable at the plant in Canada. The reason for this difference is related to seasonal effects, because in Brazil there is no long period of cement storage as there is in Canada \(\text{(mainly during the winter)}\). Since the warmer
cement leaving the mill is dispatched quickly in all seasons, its quality is not affected by being warm.

5.3.8 **Cement Dispatch at the Brazilian Plant**

Water was not used at this stage at the plant in Brazil because the trucks were not washed before they leave the plant. The internal roads were paved thus preventing dust generation.

5.3.9 **Conditioning of Gaseous Emissions at the Brazilian Plant**

At the plant studied in Brazil, there were two conditioning towers to adjust the gaseous emissions from the raw mill, the preheater tower, and the kiln. Surface water was sprayed inside the towers to lower the gas temperature to meet the acceptable limit of temperature of the respective filtering elements (bag filters or electrostatic precipitator) before the gas was released to the atmosphere. There was no flowmeter to record the volume of surface water sprayed, but plant personnel estimated based on the water pumps’ capacity that the maximum flow was around 18 cubic metres per hour for both towers together. This flow translates into approximately 13 million litres of water sprayed inside the conditioning towers every month (18 thousand L/hour × 24 hour/day × 30 day/month). This volume can also be converted into approximately 130 litres of water consumed for each tonne of cement produced (13 million L/month ÷ 100 thousand tonnes/month). This requirement (130 L/tonne cement) is close to half of the total water intensity at this plant (250 L/tonne cement), thus this is a major water requirement.
Surface water was occasionally used for conditioning of gaseous emissions, to reduce NO\textsubscript{x} emissions by flame cooling. In this case, a solution was added directly to the flame inside the kiln. There was no record of the volume of surface water used for this treatment at this plant. Plant personnel indicated that this system was rarely used, because kiln operating conditions only allowed gaseous emissions meeting regulatory limits for NO\textsubscript{x}, and no excessive amount of water would be required for this stage. The literature indicates that 3 to 20 litres may be used per tonne of clinker produced (CEMBUREAU 1999). For this plant, the lower value of 3 litres per tonne of clinker can be assumed, considering the plant personnel’s indication that this system was rarely used. Based on the average monthly clinker production at this plant, the total water usage of around 240 thousand litres per month can be estimated (80 thousand tonne clinker/month × 3 L/tonne clinker). The complete dataset of clinker production at the Brazilian plant is included in Appendix A, Table A.24. The lower flow of 3 litres per tonne of clinker represented approximately 2 litres of water usage per tonne of cement produced (240 thousand L/month ÷ 100 thousand tonnes cement/month). Therefore, the requirement for flame cooling (2 L/tonne cement) did not highly affect the water intensity at this plant.

Another available treatment for the gaseous emissions was the selective non-catalytic reduction (SNCR) system that ran with surface water. Plant personnel explained that this treatment was only implemented to provide extra safety; kiln operating conditions and the use of flame cooling (when necessary) allowed gaseous emissions low in NO\textsubscript{x}. There was no record of water being used for SNCR at this plant during the time of the study but plant personnel indicated that water usage for SNCR could be considered null. Therefore,
adding the requirements for the conditioning towers (around 130 L/tonne cement) to those for flame cooling (around 2 L/tonne cement), it can be assumed that approximately 132 litres of water were used for conditioning of gaseous emissions per tonne of cement produced at this plant.

5.3.10 Cooling of Equipment at the Brazilian Plant

According to plant personnel, surface water was used in large quantities for cooling of equipment at the plant in Brazil, but there was no measurement of this water usage. Further analysis of the volume of water usage at this stage will be presented in Section 5.3.12, based on the estimates from the proposed water usage diagram at this plant.

5.3.11 Uses Beyond the Production Line at the Brazilian Plant

As indicated earlier, groundwater was used outside the cement production line, contributing to the overall demand for water at this plant. The uses investigated were for workers’ needs, laboratory work, overall housekeeping, and for preparing solutions at the wastewater treatment plant (WWTP).

5.3.11.1 Workers’ Needs at the Brazilian Plant

Employees and subcontracted labourers used groundwater for drinking and hygiene purposes, including showers before leaving the plant. A restaurant inside the plant prepared food for all workers, also using groundwater.
The number of workers at this plant was reportedly growing since 2005, when cement production also started increasing, but the yearly number of employees could not be obtained by this researcher. However, it was indicated by plant personnel that an average number of employees and subcontracted labourers, for the years between 2005 and 2011, was around 190 workers per year. An estimate based on the withdrawal from the water source for workers could not be performed because groundwater was also used at other stages at this plant – cleaning the preheater towers, cooling the probe for the kiln gas analysis system, preparing solutions at the WWTP, and overall housekeeping – but none of these stages were measured. However, a reasonable estimate of daily water usage per worker would be about 180 litres, as reported by Undelstveldt (2006) for the mining, quarrying and manufacturing industrial sectors. A daily per capita water usage of 180 litres can then be converted into 10 litres of water usage per tonne of cement produced (180 L/day/worker × 190 workers × 30 day/month ÷ 100 thousand tonnes/month). This requirement (10 L/tonne cement) did not have a large impact on the total water usage at this plant, but it was considerable because this water had to be of potable quality.

5.3.11.2 Laboratory Work at the Brazilian Plant

Raw material and final cement quality were regularly analyzed at the laboratory inside the plant, where groundwater was required for preparing samples and running tests. There was no measurement of water usage at this stage and no estimate was available from plant personnel. Discussion of water usage at this stage, based on the analysis from the proposed water usage diagram at this plant, will be presented in Section 5.3.12.
Overall Housekeeping and a WWTP at the Brazilian Plant

The offices, washrooms, coffee rooms, and restaurant were cleaned daily. In addition to sweeping, the janitorial staff also used some groundwater, but no measurement was made of the quantity of water used. Inside the industrial area of the plant, housekeeping was only performed by sweeping and there was no water usage. It is noteworthy that road dust suppression was not performed at the Brazilian plant; because internal roads were paved, there was no water requirement for this task. However, groundwater was used for preparing solutions for the cement company’s wastewater treatment plant (WWTP). These solutions were used for correction of pH of effluents (from the quality control laboratory and from stormwater floor drainage), as well as for flocculation of their suspended solids, before all treated effluents were sent back to be reused in the industrial area. There was no measurement of the amount of water required at the WWTP and an estimate could not be calculated because there was no detailed information about the volumes of solutions used. Discussion of water usage at this stage will be presented in Section 5.3.12, based on the estimates from the proposed water usage diagram at this plant.

Summary of Collected Water Usage Data at the Brazilian Plant

As presented in the previous sections, there was no record of water usage at any stage of cement manufacturing at the plant studied in Brazil, but some estimates were available. Attempts to measure in situ data of water usage did not yield usable data, for the same reasons given in relation to the Canadian plant (please refer to Section 5.2.12). All collected data are summarized in Table 5.5, to create a dataset of water usage per tonne of
cement produced at each stage of cement manufacturing at this plant. As indicated before, further discussion on the reliability of data obtained for this case study will be presented in the next chapter.

The numbers for water usage at the Brazilian plant resulted in a total of 215 litres of water per tonne of cement produced. This figure represented approximately 85 percent of the water intensity at this plant (250 L/tonne cement). An amount of 35 litres of water per tonne of cement was left to account for the stages of raw material preparation, cooling of equipment, laboratory work, and overall housekeeping and waste water treatment. However, the water requirements for the single stage of cooling of equipment are expected to be greater than that quantity of 35 litres per tonne of cement produced. Recall that Kollar and MacAuley (1980) reported 82 percent of total water usage at cement plants being used for cooling (which was also consistent with results at the Canadian plant). Using the percentage of 82%, 205 litres of water per tonne of cement would be required for cooling (82% × 250 L/tonne).

The reason for this discrepancy may be related to the lack of measurement of the volume of effluent that was recycled and mixed with surface water. These two sources were combined before being used for cooling of equipment, raw material preparation, cement milling and conditioning of gaseous emissions. Probably the input of recycled effluent was higher than the 10 percent of surface water indicated by plant personnel. Other reasons for the discrepancy may be inaccuracy of flowmeters for measuring water
withdrawal from surface and groundwater, incorrect assumptions for estimates performed by this author, and uncertainty about data provided by plant personnel.

Table 5.5. Summary of collected water usage data at each stage of cement manufacturing at the Brazilian plant

<table>
<thead>
<tr>
<th>STAGE OF CEMENT MANUFACTURING</th>
<th>WATER USAGE DATA AT BRAZILIAN PLANT (litres/tonne cement)</th>
<th>Measured at the plant</th>
<th>Estimated by plant personnel</th>
<th>Estimated by this researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material preparation</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td></td>
</tr>
<tr>
<td>Fuel supply preparation</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td></td>
</tr>
<tr>
<td>Cleaning of preheater tower</td>
<td>No water usage at this stage at this plant</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Kiln gas analysis</td>
<td>N.A.</td>
<td>N.A.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Clinker cooling</td>
<td>N.A.</td>
<td>N.A.</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Cement kiln</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td></td>
</tr>
<tr>
<td>Cement dispatch</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
<td></td>
</tr>
<tr>
<td>Conditioning of gaseous</td>
<td>Conditioning towers</td>
<td>N.A.</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>emissions</td>
<td>Flame cooling for lowering NO(_x) from kiln</td>
<td>N.A.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SNCR for lowering NO(_x) from kiln</td>
<td>N.A.</td>
<td>Considered null</td>
<td></td>
</tr>
<tr>
<td>Cooling of equipment</td>
<td>Workers’ needs</td>
<td>N.A.</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Uses</td>
<td>Laboratory work</td>
<td>N.A.</td>
<td>N.A.</td>
<td></td>
</tr>
<tr>
<td>Beyond the Production Line</td>
<td>Overall housekeeping and a WWTP</td>
<td>N.A.</td>
<td>N.A.</td>
<td></td>
</tr>
</tbody>
</table>

*Note: N.A. indicates that data measured was not available and there was not enough information to propose an estimate.*

Because it is difficult to determine the volume of recycled water being used at this plant, no estimates could be calculated for the stages of raw material preparation, cooling of equipment, laboratory work, and overall housekeeping and wastewater treatment. It is
likely that these last three stages did not represent major volumes of water usage, but no assumption could be made by this author.

All data obtained, even incomplete data, for all stages of cement manufacturing, are presented in the estimated water usage diagram for the Brazilian plant (Figure 5.9). As with the Canadian plant, personnel reported that the conditioning tower was the most water-intensive stage of production, followed by raw material preparation (specifically for agglutinating raw material for improving milling conditions), cement milling, and cooling of equipment (personal communication). Although the proposed water usage diagram shows conditioning of gaseous emissions and cement milling as stages with the highest water usage, no conclusions can be firmly drawn because the available information was insufficient even to propose estimates for the other stages. As discussed before, implementation of flowmeters could provide more information about water usage at this plant. As with the Canadian plant, the stages with high water usage and with high uncertainty are the critical ones to be monitored, and are discussed in the next Chapter 6, when other water management practices will also be presented. Irrespective of uncertainties, the next section presents an evaluation of the outcomes from the two plants studied.
Figure 5.9. Estimated water usage for each stage of cement manufacturing at the Brazilian plant.

*Note:* All numbers are for litres of water per tonne of cement produced.
5.4 Outcomes from the Two Plants and Discussion

This chapter presented an investigation of water usage at each stage of cement manufacturing from fieldwork-based case studies performed by this author at two cement plants, one in Canada and one in Brazil. The values were obtained for regular working conditions at cement plants; these conditions normally include a number of variations, such as maintenance shut-downs and start-ups, variations in burning conditions, and changes in raw material humidity.

At the beginning of this study, it was noted that water usage in the cement industry was not considered an issue among its practitioners. It was very challenging to identify which stages of cement manufacturing had water requirements, beyond cooling of equipment, cement milling and conditioning of gaseous emissions, because such information was also scattered through the literature. Although results indicate that some stages did not require large amounts of water, this does not mean that there was no water requirement. The undertaking of fieldwork-based case studies at these two cement plants allowed the water usage at different stages to be revealed. For example, at one plant there was no indication of water usage for cleaning the preheater tower, but this requirement was mentioned by the other plant’s engineer. At that point, this researcher had to go back to the first plant and verify that such operation was also performed there. Moreover, it was learned that water for cleaning the preheater tower had to be of high quality. It should be noted that all plants’ personnel were very helpful and interested in the study. The fact that they would forget about water usage for certain stages shows how minimal the routine record-keeping was in each plant, consistent with the industry’s overall disinterest in
A summary of all results obtained from the case studies, as well as from the literature, are included in Table 5.6 and Figure 5.10. Figure 5.10 is an enhancement of Figure 3.4 (see Chapter 3), which summarized the scheme for tracking water requirements that was proposed by this author.

Table 5.6 Summary of water usage data obtained from fieldwork-based case studies at a Canadian and a Brazilian cement plant, and from the available literature

<table>
<thead>
<tr>
<th>WATER USAGE AT EACH STAGE</th>
<th>QUANTITY AND WATER SOURCE USAGE AT PLANTS</th>
<th>Data from case study</th>
<th>Data from literature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Canada</td>
<td>Brazil</td>
</tr>
<tr>
<td>Raw material preparation</td>
<td>20 L/tonne cement for vertical roller mill</td>
<td>N.A. Surface and recycled effluent</td>
<td>none to 350 L/tonne clinker (A)</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel supply preparation</td>
<td>Considered null</td>
<td>No water usage at this stage at this plant</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning of preheater tower</td>
<td>20 L/tonne cement</td>
<td>1 L/tonne cement</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td>Groundwater</td>
<td></td>
</tr>
<tr>
<td>Kiln gas analysis</td>
<td>No water usage at this stage at this plant</td>
<td>2 L/tonne cement</td>
<td>up to 3,000 L/hour (B)</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td>Groundwater</td>
<td></td>
</tr>
<tr>
<td>Clinker cooling</td>
<td>No water usage at this stage at this plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement milling</td>
<td>20 to 40 L/tonne cement for ball mill</td>
<td>70 L/tonne cement for ball mill</td>
<td>Vertical roller mill up to 20 L/tonne clinker (A)</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td>Surface and recycled effluent</td>
<td></td>
</tr>
<tr>
<td>Cement cooling</td>
<td>160 to 650 L/tonne cement</td>
<td>No water usage at this stage at this plant</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement dispatch</td>
<td>4 L/tonne cement</td>
<td>No water usage at this stage at this plant</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WATER USAGE AT EACH STAGE</td>
<td>QUANTITY AND WATER SOURCE USAGE AT PLANTS</td>
<td>Data from case study</td>
<td>Data from literature</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>--------------------------------------------------------</td>
<td>----------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Conditioning of gaseous emissions</td>
<td>Conditioning tower</td>
<td>120 L/tonne cement</td>
<td>130 L/tonne cement</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td></td>
<td>Surface and recycled</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>effluent</td>
</tr>
<tr>
<td>Flame cooling</td>
<td>No water usage at this stage at this plant</td>
<td></td>
<td>2 L/tonne cement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Surface and recycled</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>effluent</td>
</tr>
<tr>
<td>SNCR</td>
<td>3 L/tonne cement</td>
<td>Considered null</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>Groundwater</td>
<td>Surface and recycled</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>effluent</td>
<td></td>
</tr>
<tr>
<td>Conditioning of gaseous emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling of equipment</td>
<td>1,125 to 1,635 L/tonne cement</td>
<td>N.A.</td>
<td>82% of total</td>
</tr>
<tr>
<td></td>
<td>Groundwater and glycol</td>
<td></td>
<td>water usage at plant</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(C)</td>
</tr>
<tr>
<td>Uses beyond the production line</td>
<td>Workers’ needs</td>
<td>8 L/tonne cement</td>
<td>10 L/tonne cement</td>
</tr>
<tr>
<td></td>
<td>Mains water</td>
<td>Groundwater</td>
<td>Groundwater</td>
</tr>
<tr>
<td>Laboratory work</td>
<td>0.1 L/tonne cement</td>
<td>N.A.</td>
<td>up to 20,000 L/day</td>
</tr>
<tr>
<td></td>
<td>Mains water</td>
<td>Groundwater</td>
<td>(A)</td>
</tr>
<tr>
<td>Overall housekeeping, road dust suppression,</td>
<td>10 L/tonne cement</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>and WWTP</td>
<td>Mains water, groundwater and recycled effluent</td>
<td>Groundwater</td>
<td></td>
</tr>
<tr>
<td>Water intensity</td>
<td>2,000 L/tonne cement</td>
<td>250 L/tonne cement</td>
<td>147 to 1,237</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>L/tonne cement</td>
</tr>
<tr>
<td></td>
<td>Occasional in the summer months only for road dust</td>
<td>Permanently 10%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>suppression</td>
<td>for some stages, as</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>indicated in the</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>lines above</td>
<td></td>
</tr>
</tbody>
</table>

Notes: N.A. indicates that data was not available.
Sources: (A) CEMBUREAU 1999; (B) Enotec 2012; (C) Kollar and MacAuley (1980); (D) Undelstvedt 2006; (E) Current study, Chapter 3 (Table 3.3, summary of CSR report data).
Figure 5.10. Summary of all water usage data obtained in this research for the proposed scheme for tracking water requirements at eleven stages of cement manufacturing.

References are: (A) CEMBUREAU 1999; (B) European Commission 2010; (C) Enotec 2012; (D) Undestvedt 2006.
As seen in Table 5.6 and Figure 5.10, water usage for the conditioning of gaseous emissions by conditioning towers was high at both plants. Cement cooling also required a large quantity of water but only at the Canadian plant, which greatly influenced the difference in water intensity between the two plants studied. The recycling system at the Brazilian plant, although indicated by plant personnel as around 10 percent of the total freshwater withdrawal, was probably higher and contributed to lower water intensity at this plant. This table and this figure also shows large variations between the two plants regarding water usage for cleaning of the preheater tower and cement milling. Both plants had considerable water usage inside the mills per tonne of cement produced, but the numbers were different between the two plants. The available literature did not allow any firm conclusions regarding which number would be a more reasonable one. However, water usage for cement milling may also be related to operational efficiency and the power of electric motors operating the mill. The amount of water sprayed inside the mill directly affected the quality of cement being produced, thus quantity of water sprayed inside the mill was monitored continuously, but data were not totalized. This fact indicates a concern with the quality of the final product, but not necessarily with the amount of water being consumed. For both plants studied, records of flow measurement were not totalized, and data of water usage, when available for this research work, were for instantaneous or averaged values. This author made assumptions around time of operation to allow conversion into longer date ranges, generally for a month, but results could not have realistically reflected the reality at the plant. It should be recalled that variations on regular working conditions affect the operational settings of equipment, and may also interfere with their water usage.
There is considerable variation between the two plants in terms of water usage. Detailed reasons for such variation cannot be given, mainly because of the lack of measurement and monitoring at the plants, as well as the lack of related data in the literature. Nevertheless, this research developed a methodology to overcome insufficient data about water usage at plants, by systematically examining the eleven stages of cement manufacturing. The lack of proper measurement routines discussed in Chapters 4 and 5 is congruent with the lack of reliable information about water usage at cement plants found in the CSR reports evaluated in Chapter 3. This fact suggests that other cement plants may have similar realities of not routinely measuring water usage, and that pursuing knowledge of water usage is not yet a priority for plant owners in the cement industry. One reason for a lack of accurate information could be that water withdrawal from surface water and groundwater generally does not incur water costs to the cement plants, thus there is no demand for carefully monitoring water use.

It is also necessary to monitor effluent discharges for quantity, but also for quality (mainly pH, temperature, and suspended solids), in order to evaluate recycling opportunities. Industries with accurate knowledge of their water usage, and proper water management practices in place, will be better prepared for water use policies that are becoming stricter. Currently water use policies and related costs may not interfere with profits for the cement industry, but this scenario may turn into a different reality soon.

The next chapter will discuss opportunities to help overcome this unclear scenario of water usage at cement plants, by proposing a characterization of levels of reliability for
data according to method of data acquisition. Data will be categorized from a high level of reliability to a low level of reliability, with lower levels of reliability representing higher uncertainty. Furthermore, some arguments regarding the broader implication and contributions of this research will also be addressed in the next chapters, as water usage for cement manufacturing unfolds into the production of another building material, i.e. concrete, and this material is used in large quantities for buildings under construction. This understanding will provide significant insights into water usage for these major sectors of the construction industry.

This researcher proposed a methodology, based on knowledge gained from this research project, with strategies to systematically improve data reliability and to motivate action towards best water management practices. This methodology is further presented in Chapter 7 (Figure 7.2).
CHAPTER 6

ASSESSING THE RELIABILITY OF WATER USAGE DATA FOR CEMENT MANUFACTURING

So have confidence in what you do know, be humble in your ignorance, and maintain a willingness to learn.
– Christine Szymanski, “Communicating Science”, 2006

6.1 Reliability of Compiled Water Usage Data for Cement Manufacturing

Chapters 3 to 5 presented an investigation of water intensity at cement plants, and developed a framework to evaluate all water uses at cement plants, by breaking the manufacturing process into eleven stages including uses beyond the production line. Findings from this research confirmed the lack of sufficient measurement routines at cement plants. Some of the compiled water usage data were questionable because specific information about water usage during the manufacturing process and water recycling were missing. Nevertheless, as discussed in previous chapters, the results gathered in this research show results of data collection conducted within normal operating conditions at industries thus were valuable to (a) estimate an average range for the quantity of water demand at cement plants, for both water intensity and water usage at each stage of cement manufacturing, (b) show changes in water intensity through the year, due to seasonal effects, and (c) show that the year-to-year water intensity was not influenced by the rate of cement production at either plant. In this chapter results are now used to propose an approach to ensure that reported data is comparable, as well as to suggest strategies for improving reliability of data acquisition. More reliable data of water usage will provide better information to develop proper water management
practices. For this approach, research outcomes are used to characterize the reliability of various methods of data acquisition related to cement plants. This chapter ends with a discussion of how this knowledge may contribute to improved quality of water usage data collection, eventually improving data reliability. Better quality data will better enable investigation of best water management practices to increase opportunities for freshwater savings in the cement industry.

6.1.1 Challenges for Collecting Data at Cement Plants

Results presented in previous chapters point to challenges for collecting adequate data for water withdrawal and usage at cement plants. Among these challenges are minimal routine measurements and many estimates. Uncertainty around meters, mainly in terms of proper functioning and calibration, also posed a challenge. There were also several questions around published data, mainly related to a lack of information on the method of data acquisition, the manufacturing processes in place, and the specific water sources accounted for in the indicator EN8 (total water withdrawal by source).

First, the values for volumes of water withdrawal, published in some corporate social responsibility (CSR) reports, were lacking information about whether they were measured or estimated. This happened even when CSR reports were based on the standards of the Global Reporting Initiatives (GRI), specifically on indicator EN8 (total water withdrawal by source). Yet, this indication is necessary to fully evaluate the published data, because measured data tend to be more reliable than estimated values. Certainly, both the type of measurement device and proper calibration are also critical to
ensure data accuracy. In short, the majority of available CSR report information was questionable in regards to withdrawal at cement plants.

There was also evidence that water intensity data published in CSR reports did not include either the volume of all water sources used or the total water usage for all purposes at cement plants because there was a high variability from the lower to the higher range of data (a range of 147 to 1,220 litres of water used per tonne of cement produced). It should be recalled that water intensity in this research is the volume of water presented under indicator EN8 to produce one tonne of cement. Such substantial variability in the CSR reported water intensity data, combined with the lack of information on the cement manufacturing process in place, did not allow either a proper comparison between data or a definition of a reasonable range of water intensity at plants run by the dry process.

An attempt was made by the author to address questions in published data by developing two fieldwork-based case studies at cement plants. Results from the case studies revealed considerable information about water usage at these plants. Accurate numbers were not available for all eleven stages of water usage for cement manufacturing investigated in this research but the information obtained was valuable in revealing some volumes of water usage obtained within normal operating conditions. As discussed in Chapters 3 to 5, published literature does not adequately indicate which stages of cement manufacturing have water requirements, beyond cooling of equipment, cement milling and conditioning of gaseous emissions. The current study demonstrated that although
some stages did not require large amounts of water, this did not mean that there was no water requirement.

The quantity of effluent from cement plants was also investigated in the literature and in the case studies. Data for the two GRI (Global Reporting Initiative) indicators EN10 (percentage and total volume of water recycled and reused) and EN21 (total water discharge by quality and destination) were rarely reported in the CSR reports and could not be measured at the two plants studied, thus preventing correlation between volumes of recycled water used at plants and related water intensity. The recycling rate (EN10) has an impact on the reduction of freshwater withdrawal, thus this rate was needed to adequately evaluate related freshwater savings.

Among the reasons for such inconsistent reporting, one finds (a) the fact that water usage was not regularly monitored, and (b) the possibility that there were no local water regulating bodies requiring reports of water usage. Although some reports were verified by a third party, they did not provide these answers. The root of this unclear scenario of volumes of water usage for cement manufacturing could be that the financial costs associated with water withdrawal were not sufficiently high compared with other operational costs of the majority of cement companies investigated (including both CSR and case study investigations). However, it is expected that water prices and water use policies will become critical factors soon, mainly in geographic areas with increasing water scarcity. Therefore, better knowledge of water usage for cement manufacturing is
becoming of higher interest for this industry, thus further encouraging the development of best water management practices.

Clearly there is a need to strategically enhance the quality of data collection and reporting in the cement industry. The results compiled in this research will be used to create an approach for applying reliability ratings to reported data, to assist in making better comparisons between them, as well as providing strategies for improving the quality of data acquisition processes.

6.2 Proposal of Levels of Reliability for Water Usage Data

All data collected were categorized from a high level of reliability to a low reliability, with lower levels of reliability indicating higher uncertainty. Rating levels of reliability for water usage data in this work was based on the document related to uncertainty of the air emission factors (called AP-42), published by the United States Environmental Protection Agency (USEPA 1995; 2007b). The definition of categories was based on the method of data acquisition. Higher levels of reliability are related to the use of flow measurement devices, but it should be noted that accuracy is also dependent on the type and operation of flowmeter in place. Higher uncertainty is related to insufficient information about published data and to the characteristics of assumptions made to estimate the volume of water usage.

In this work, accuracy is defined as a qualitative expression of the degree to which a calculated or estimated measurement is close to its real value. Uncertainty is the quantity
of the dispersion of the measured values that could reasonably be attributed to the real value. These definitions are based on the concepts presented by The United Nations Industrial Development Organization (UNIDO 2006). According to UNIDO (2006), if the error is less than 10 percent, the measurement system is acceptable. However, an error rate between 10 and 30 percent is acceptable depending on the importance of the parameter being measured. Improvement of the measurement system is required if error is above 30 percent.

In summary, reliable data are accurate, with their degree of uncertainty provided, and collected through correct methods of measurement by appropriate instruments or from well-founded estimates. Reliable data are also precise or repeatable, meaning that similar results will be obtained by successive measurements under the same conditions. Reliability may be improved by proper calibration of instruments to ensure that they display accurate values. However, there will always be some errors, and knowing the degree of uncertainty can allow for better decision-making around best water management practices. A description of the rationale behind the characteristics of levels of reliability is discussed next and also is summarized in Table 6.1.
Table 6.1. Description of theoretical levels of reliability for water usage data based on method of data acquisition

<table>
<thead>
<tr>
<th>LEVEL OF DATA RELIABILITY</th>
<th>UNCERTAINTY</th>
<th>TYPICAL METHOD OF DATA ACQUISITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Reliability (2)</td>
<td>A⁺ ± 5%</td>
<td>Use of a high accuracy flow measurement device continuously for providing totalized water usage data. Information on proper installation, operation and calibration is provided.</td>
</tr>
<tr>
<td></td>
<td>A⁻ ± 10%</td>
<td>Use of a high accuracy flow measurement device continuously for providing total or instantaneous water usage data. Device properly installed, operated but not periodically calibrated.</td>
</tr>
<tr>
<td>Moderate Reliability (3)</td>
<td>B⁻ ± 20%</td>
<td>Estimated either by personnel with over 10 years of related work experience or by researcher based on combination of equipment characteristics and energy balance equation (heat transfer).</td>
</tr>
<tr>
<td></td>
<td>B⁻ ± 30%</td>
<td>Estimated by researcher based solely on equipment characteristics, technical literature, or water balance diagram (total water intake minus other stages).</td>
</tr>
<tr>
<td>Low Reliability (3)</td>
<td>C⁻ Unknown</td>
<td>Data published in the literature with indication that data was measured but no information about type and calibration of measuring device.</td>
</tr>
<tr>
<td></td>
<td>C⁻ Unknown</td>
<td>Data published in the literature with no indication whether data were measured or estimated.</td>
</tr>
</tbody>
</table>

Notes: (1) Percentage indicated is an approximate level of uncertainty based on empirical investigation of available equipment. (2) The estimated margin of uncertainty may increase or decrease depending on the accuracy and operating conditions of the measurement device. (3) Reliability of estimated and published data may improve if information is provided on well-founded assumptions or on device used.
The first level of reliability is called A, and is highly reliable, representing fairly accurate measurement and recording procedures. The A level is further split into A+ and A– grades, according to the quality of instruments used and the frequency of calibration. Data categorized under level A+ are obtained from flow measurement devices of good quality that are in place to continuously measure and register the total volume of water usage during a specified time period, for instance by providing totalized water usage data in litres per day or in litres per month. It should be noted that water usage data totalized in litres per day would account for variability. Such records, covering an extended period of time, account for changes in water requirements due to regular operations throughout the day or seasons of the year. The range of accuracy of the flowmeter will relate to precision, but it is reasonable to state that such equipment tend to present uncertainty within ± 5 percent, based on investigation of available equipment. The level A– represents data acquired by instruments that are of high quality but are not regularly calibrated, or by a flow measurement device recording the instantaneous flow of water. In the latter case, one may access the volume of water being used at a particular time, for instance the quantity of litres of water used exactly at twelve noon. Therefore, data are not totalized by the equipment and readings are related to records of water usage at a particular time; some assumptions are required in order to totalize the volume of water usage for extended periods of time. One assumption, for instance, could be that the instantaneous reading in litres per minute is representative of the average volume of water used for the day, by multiplying the obtained data for the 1,440 minutes per day. However, possible changes of water requirements along operating conditions may not be represented. It is possible to account for a reasonable average of water usage for some period, but the
results have lower reliability (uncertainty within ± 10 percent) than those obtained using an A\(^+\) level method.

The B level of reliability also represents a reliable source. The major difference between level B and level A is that available data are not measured, but estimated. Assumptions made to allow estimates of water usage will influence the accuracy of data, thus there may be reasons to question whether data are representative of actual operations. However, there is moderate reliability in this level because assumptions are based on reasonable evidence. Personnel with several years of related work experience may be able to reasonably state an estimated figure of water usage at certain stages of manufacturing, and such data are characterized as level B\(^+\), with uncertainty around +/− 20 percent. Data estimated by researchers, based on characteristics of equipment in place combined with related energy and material balance equations, such as heat transfer inside the equipment, may also allow for a reasonable estimate, and are also categorized as grade B\(^+\). However, if estimated numbers are based solely on equipment characteristics, technical literature, or a related water balance calculations (please see Chapter 5, Figures 5.8 and 5.9 for examples of such diagrams), then they are categorized as less reliable, at level B\(^−\), uncertainty around +/− 30 percent. Further information on manufacturing process and on type of equipment used are required in order to achieve higher reliability.

Data categorized under level C have the lowest reliability and therefore unknown uncertainty. The difficulty with these data is that they are published in the literature, but not supplemented by specific details on their method of acquisition. Errors in the
reporting of GRI’s indicators of water usage in CSR reports, or in any other type of literature, would interfere with data quality. For that reason, if the published data have at least the indication of being measured, even without information about the type and calibration of measuring device, then they are categorized as level C\(^+\). As discussed before, measured data tend to be more reliable, although their precision and accuracy also depend on measuring device characteristics. On the other hand, if available data in the literature have no indication as to whether data were measured or estimated, then they are categorized under level C\(^-\). In general, the reasons for low reliability of published data are related to potential errors associated with data collection and reporting, as well as the lack of information on the method of data acquisition.

It should be noted that the proposed percentage is an approximate expected level of uncertainty. The level of reliability of measured data also depends on operating conditions of measurement device. Furthermore, reliability of estimated and published data may improve if there is information provided on well-founded assumptions or on the measurement device used.

This approach of categorizing data according to levels of reliability is useful not only for the two plants studied, but also for other cement plants, and even other industries. It is noteworthy that this approach, when combined with related quantity of water usage, also helps to identify areas to prioritize water savings, or to implement strategies to improve water management practices. Figure 6.1 illustrates interactions between quantity of water usage and level of data reliability.
Areas of critical relevance are the ones with higher water usage and lower data reliability, thus the uncertainty of such data is of concern (indicated in Fig. 6.1 in red). Focus on improving the quality of data should be pursued at these critical areas, before moving into decisions on implementing best water management practices. In other words, pursuing higher reliability for data where water usage is high is suggested to better evaluate whether water savings could be achieved. On the other hand, stages where water usage is lower and reliability of related data is higher may not deserve much attention, because this condition indicates that the potential for water savings is not likely to be considerable (indicated in Fig. 6.1 in green). Areas indicated in orange in Fig. 6.1 also deserve attention for better planning decisions around water savings strategies, because of existing uncertainties or high water usage.

Any proposed strategy to increase data reliability, for instance installing flowmeters at certain stages to move from level B or C to level A, will require financial investment. In some regions, the need to reduce water usage may eventually justify such investment.
However, a higher reliability of measured data at A level may be achieved in some plants by simply keeping measurement devices properly calibrated without incurring considerable additional costs.

All values obtained from this research are next categorized and evaluated according to the proposed framework of levels of reliability. As indicated before, this approach may be developed for use beyond the cement manufacturing, for example in any one of many other industries with similar questionable data. This approach has the potential to enable the evaluation of the quality of available data, and contribute to decisions about increasing data quality and developing appropriate water management practices.

6.3 Reliability of Water Usage Data at Cement Plants

This section provides a categorization of water usage data compiled in Chapter 3 to 5, based on the proposed levels of reliability indicated in Table 6.1. It includes data from the literature, consisting of CSR reports and other technical literature, as well as data collected from the two case studies. Data are indicated in Table 6.2 and show values for water used at each stage of cement manufacturing per tonne of cement produced. Data of total water intensity at cement plants are also included. Although water intensity at the Canadian plant was eight times higher than at the Brazilian plant, they can both be rated at level A, because of lack of information on accuracy of flowmeters. Reasons for such difference were discussed in Chapters 4 and 5.
Table 6.2. Levels of reliability of available water usage data from cement plants

<table>
<thead>
<tr>
<th>STAGE OF CEMENT MANUFACTURING</th>
<th>QUANTITY OF WATER USAGE</th>
<th>LEVEL OF DATA RELIABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material preparation (dry and semi-dry processes)</td>
<td>20 L/tonne cement, Canadian plant(^{(1)})</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>None to 350 L/tonne clinker(^{(2)})</td>
<td>C</td>
</tr>
<tr>
<td>Fuel supply preparation</td>
<td>Considered null, Canadian plant (^{(1)})</td>
<td>B(^{+})</td>
</tr>
<tr>
<td>Cleaning of preheater tower</td>
<td>1 L/tonne cement, Brazilian plant (^{(1)})</td>
<td>B(^{+})</td>
</tr>
<tr>
<td></td>
<td>20 L/tonne cement, Canadian plant (^{(1)})</td>
<td>B</td>
</tr>
<tr>
<td>Kiln gas analysis</td>
<td>2 L/tonne cement, Brazilian plant (^{(1)})</td>
<td>B(^{+})</td>
</tr>
<tr>
<td></td>
<td>Up to 3,000 L/tonne cement (^{(3)})</td>
<td>C</td>
</tr>
<tr>
<td>Clinker cooling (no water usage at both plants studied)</td>
<td>Rotary cooler up to 5,000 L/hour (^{(3)}) or up to 60 L/tonne clinker (^{(2,4)})</td>
<td>C</td>
</tr>
<tr>
<td>Cement milling</td>
<td>20 to 40 L/tonne cement for ball mill, Canadian plant (^{(1)})</td>
<td>B(^{+})</td>
</tr>
<tr>
<td></td>
<td>70 L/tonne cement for ball mill, Brazilian plant (^{(1)})</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Vertical roller mill = up to 20 L/tonne clinker (^{(2)})</td>
<td>C</td>
</tr>
<tr>
<td>Cement cooling</td>
<td>160 to 650 L/tonne cement, Canadian plant (^{(1)})</td>
<td>B(^{+})</td>
</tr>
<tr>
<td>Cement dispatch</td>
<td>4 L/tonne cement, Canadian plant (^{(1)})</td>
<td>B</td>
</tr>
<tr>
<td>Conditioning of gaseous emissions</td>
<td>Conditioning tower</td>
<td></td>
</tr>
<tr>
<td></td>
<td>120 L/tonne cement, Canadian plant (^{(1)})</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>130 L/tonne cement, Brazilian plant (^{(1)})</td>
<td>B(^{+})</td>
</tr>
<tr>
<td></td>
<td>Up to 75 L/tonne clinker (^{(2)})</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>Flame cooling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 L/tonne cement, Brazilian plant (^{(1)})</td>
<td>B(^{+})</td>
</tr>
<tr>
<td></td>
<td>3 to 20 L/tonne clinker (^{(2)})</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>SNCR</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 L/tonne cement, Canadian plant (^{(1)})</td>
<td>B(^{+})</td>
</tr>
<tr>
<td>Cooling of equipment</td>
<td>1,125 to 1,635 L/tonne cement (of water and glycol), Canadian plant (^{(1,5)})</td>
<td>B(^{+})</td>
</tr>
<tr>
<td></td>
<td>82% of total water usage at plant (^{(6)})</td>
<td>C</td>
</tr>
<tr>
<td>STAGE OF CEMENT MANUFACTURING</td>
<td>QUANTITY OF WATER USAGE</td>
<td>LEVEL OF DATA RELIABILITY</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Uses beyond the production line</td>
<td>Workers’ needs</td>
<td>8 L/tonne cement, Canadian plant (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 L/tonne cement, Brazilian plant (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>180 L/day (7)</td>
</tr>
<tr>
<td></td>
<td>Laboratory work</td>
<td>0.1 L/tonne cement, Canadian plant (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Up to 20,000 L/day (2)</td>
</tr>
<tr>
<td></td>
<td>Overall housekeeping, road dust suppression, and WWTP</td>
<td>10 L/tonne cement, Canadian plant (1)</td>
</tr>
<tr>
<td>Total water intensity for cement manufacturing</td>
<td></td>
<td>250 L/tonne cement, Brazilian plant (8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2,000 L/tonne cement, Canadian plant (8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>147 to 3,500 L/tonne cement (5,9,10)</td>
</tr>
</tbody>
</table>

Notes: (1) Current study, Chapter 5 (Table 5.6, summary of data); (2) CEMBUREAU 1999; (3) Enotec 2012; (4) European Commission 2010; (5) Range obtained allowed increased reliability of estimated data; (6) Kollar and MacAuley (1980); (7) Undelstvedt 2006; (8) Current study, Chapter 4 (Table 4.4, comparison between plants studied); (9) Current study, Chapter 3 (Table 3.3, summary of CSR report data); (10) CEMBUREAU 2008.

Some contradictions may be noted in the data presented in Table 6.2. For instance, there is a large difference between the volumes of water used for cleaning of the preheater towers at the two plants studied (1 and 20 L/tonne cement), and there are no available data in the literature to allow further comparison. Data for both cases were estimated, so they are categorized under the reliability level B. The Brazilian plant personnel offered information on the daily volume of water to supply the high-pressure water blaster used to clean the preheater tower. This volume could be obtained based on the number of trucks transporting water during a period when groundwater was not available for that stage, because of a failure of the water withdrawal pumps. The quantity of water used per tonne of cement produced was estimated by this researcher, based on the volume of water...
provided by plant personnel and the average monthly cement production. This estimate resulted in one litre per tonne of cement and was considered level B⁺, as described in Table 6.1. At the Canadian plant, the average water usage at this stage (20 L/tonne cement) was estimated by this researcher based on equipment characteristics and average monthly cement production. There was no other information available from plant personnel; thus, more assumptions were necessary to estimate water usage for this stage. For this reason, this number is categorized under level B⁻. Cleaning of preheater towers posed occupational health and safety risks so this researcher was not allowed to perform any in situ observation of this operation at either of the plants studied. Therefore, in order to increase reliability of data for cleaning of preheater towers, it would be helpful to gather more information about this operation, to improve reliability of estimates, or to install flow measurement devices on the inlet of the water blaster.

As seen in Table 6.2, another stage with considerable difference in water usage between the two plants was the cement milling. Data were estimated and assumptions were made for both plants, so they are categorized under level B. The lower value for the Canadian plant (20 L/tonne cement, categorized as B⁺) was estimated by the plant engineer, based on his assumptions about the time required to fill a water tank that fed the cement mill. However, the plant engineer expressed doubts about his own assumptions (personal communication). The higher value (40 L/tonne cement, also categorized as B⁺) was estimated by this author, based on heat transfer calculations in the cement mill. Please see Chapter 5 (Section 5.2.6) for details of these estimates. There was no further information available to allow any decision about which value was the best estimate. However, there
was a monitoring system measuring the mill’s internal temperature used to control the quantity of water sprayed inside the mill. It is likely that some adjustment on this system would enable logging of the totalized volume of water, for a set period of time, which could subsequently provide data with higher reliability. The same condition was found at the Brazilian plant, but only estimates made by this author were utilized. The estimated value (70 L/tonne cement, categorized as B+) is higher than that at the Canadian plant. The literature offers data for comparison, but only for the vertical roller mill, thus not allowing comparison of water usage inside ball mills (the type used at the plants studied).

It is also noted in Table 6.2 that the stage of cement cooling, used only at the Canadian plant, presented a high volume of water usage (160 to 650 L/tonne cement), or around 8 to 33 percent of total water intensity at that plant (2,000 L/tonne cement). However, these values were estimated based on a combination of equipment characteristics and heat transfer calculations inside the cement mill (using an energy balance equation), so they are only moderately reliable (level B). Such scenarios would fall into an area of high water usage and moderately reliable data as indicated in Figure 6.1. Therefore, it will be valuable to invest in improving the reliability of these values in order to better characterize potential water savings at this stage. A plan for using recycled process water instead of groundwater for the cement cooler has been pursued by the plant environmental coordinator since 2012. A better level of reliability for this stage would help develop an appropriate strategy for freshwater savings. Installing flow meters would allow reaching a level of reliability A+, depending on the type of and operating conditions of measurement device used. Beyond improving data reliability, flowmeters would also
allow for proper monitoring of potential water savings and other real savings achieved through process modification.

At both plants studied, the only cost for water withdrawal was the associated energy consumption for pumping. However, this may change when water use policies are enforced, for example by limiting the volume of freshwater withdrawal, or by charging for it. Under that scenario, water usage would become a higher concern at these plants. At that point, the stages with higher water usage and lower data reliability shall deserve further attention and eventually improved water measurement systems. Currently, as seen in Table 6.2 these stages are cement milling, cement cooling (only at Canadian plant), and conditioning of gaseous emissions (by conditioning towers).

As seen in this chapter, available water usage data for cement manufacturing falls mainly into levels of moderate to low reliability. Decision-makers could benefit from categorizing available data using this proposed approach, thereby allowing them to better evaluate options for improving data reliability and to determine proper water management practices, as well as monitor the outcomes of implemented water savings strategies. This approach was developed and tested for the cement industry but in the next chapter it will be applied to two other important sectors of the construction industry: ready-mixed concrete production and buildings under construction and after occupation. The industry’s driver of cost-benefit assessment of implementing best water management practices requires an understanding of the reliability of data to enable better decisions and increase opportunities for freshwater savings in these sectors of the construction industry.
CHAPTER 7

RELIABILITY OF WATER USAGE DATA IN OTHER SECTORS OF THE CONSTRUCTION INDUSTRY

Water is everybody’s business.

7.1 Reliability of Water Usage Data in the Construction Industry

Based on the investigation of water usage in cement manufacturing, an approach was developed for categorizing the reliability of water usage data according to the method of data acquisition. As described in Chapter 6 (Section 6.2), there are three proposed levels of reliability called A, B and C. A summary of the types of data acquisition methods is also presented in the previous chapter (Table 6.1). According to the proposed levels of reliability, data are classified as level A, highly reliable, when mainly acquired by the use of flow measurement devices. Data classified as level B are moderately reliable because they are generally based on assumptions. However, level C data have low reliability because there is a lack of information on method of data acquisition. As discussed before, the level of reliability of measured data also depends on operating conditions of the measurement device, and the reliability of estimated and published data may improve if there is information provided on well-founded assumptions or on the device used. The approach presented in the previous chapter makes it possible to categorize the reliability of available data of water usage, based on their methods of data acquisition, allowing an indication of higher or lower levels of data accuracy.
In this chapter, that approach is applied to two other sectors of the construction industry: ready-mixed concrete production, and buildings under construction and after occupation. Selection of these sectors was based on the rationale that cement is a basic component for making concrete, and the majority of construction projects worldwide rely on concrete as their structural building material (Mehta and Monteiro 2006).

This chapter discusses the levels of reliability of data of water usage at ready-mixed concrete plants obtained from the literature, as well as from a fieldwork-based case study at a Brazilian plant, including measured and estimated data. Data of water usage for buildings under construction are also discussed in terms of their reliability and were obtained by the same methods above. Data of water usage in buildings after occupation exclusively available from the literature are also evaluated. The chapter ends with a discussion on opportunities for improving the reliability of available data.

7.2 Water Usage at Ready-Mixed Concrete Plants

Ready-mixed concrete plants, also called batching plants, produce concrete that is immediately dispatched to construction sites by concrete mixer trucks. Concrete is a building material comprised of water, cement (binding medium), and aggregates. Aggregates for concrete may be natural minerals such as stone and sand, or alternative ones such as fly ash from coal combustion, crushed blast-furnace slag, or construction and demolition wastes. Admixtures may also be used to help meet certain criteria, for instance to control strength development and enhance the durability of concrete exposed to aggressive environmental conditions. Concrete is fluid and has plasticity when fresh,
but after a certain period, known as “setting time”, it dries and hardens (a process called curing). Concrete for different structures can be plain or reinforced (meaning that there are strengthening members such as steel bars embedded in it). As indicated before, concrete has been the most widely used structural building material in the world. Some reasons for the preference of concrete as a building material are its strong resistance to water (compared to the resistance of wood and ordinary steel), and its facility to make elements in a variety of shapes and sizes (Mehta and Monteiro 2006).

Water is used at ready-mixed concrete plants for mixing water in the production of concrete, for preparing samples in the quality control laboratory, for washing concrete mixer trucks, for dust control, and for workers’ needs. Volumes of mixing water have been reported in the literature as ranging from 100 to 243 litres of water per cubic metre of concrete (Blake 1989; Mehta and Monteiro 2006; Oliveira 2007). The quantity of mixing water in the production of concrete influences the target compressive strength and the slump (a measure of plasticity while fresh), so although the data comes from the literature, there is a known, accurate measurement system for the volume of water added to prepare concrete at ready-mixed concrete plants. Therefore, the reported data of volumes of mixing water could be categorized as being at the A level, according to proposed levels of reliability, because these data are continuously measured by accurate devices to ensure the expected quality of the concrete.

The quantities of total water usage at ready-mixed concrete plants, for other uses beyond mixing water, such as preparing samples for laboratory work, washing concrete trucks,
and workers’ needs, have not been available in the literature. However, concrete production is growing worldwide (Mehta and Monteiro 2006; Meyer 2009), thus suggesting a growing demand for water at ready-mixed concrete plants. For this reason, data for the total quantity of water used at ready-mixed concrete plants needs to be reassessed by related stakeholders, to better evaluate options for implementing water savings programs.

7.3 Water Usage for Buildings Under Construction and After Occupation

The construction of buildings encompasses all methods for assembling various building materials into a designed architecture, using a number of systems and subsystems that must be integrated with each other (Ching 2008). Techniques of construction vary widely according to the choice of building materials and the construction type. When the construction phase is complete, the building is ready for occupation. As mentioned in Chapter 2, buildings under construction and after occupation account for approximately 12 to 20 percent of the world’s freshwater withdrawals (McCormack et al. 2007; Retzlaff 2009; Roodman and Lenseen 1995).

Water at the construction site may be used for preparing concrete and mortar (a mixture of water, sand and cement, but without aggregates); soil compaction; dust control; cleaning tools and equipment; workers’ needs; and for commissioning and tests. It should be noted that when ready-mixed concrete is brought from a batching plant, water is required on site for watering the structure while it hardens (a process called curing). It is also noteworthy that potable water usage for workers’ needs is constant during all phases
of a construction project. When a building is ready, water is used for commissioning and tests. Furthermore, water usage follows permanently after building occupation to meet all the needs of building inhabitants, including drinking, food preparation, hygiene and overall cleaning purposes.

### 7.3.1 Buildings Under Construction

Overall, there are few published data of water usage at construction sites. A recent study conducted in the United Kingdom suggests that there is also little consistency on water management at construction sites, despite water savings opportunities that ranged from 13 to 24 percent of total water usage, and as high as 40 to 83 percent when major leaks were observed (McNab, Lynch and Young 2012). Results from these reported case studies include one-day water audits at nine construction sites, and six-month water audits at three other construction sites. Data for the total volume of water usage at the construction site per square metre of floor space built were not indicated. According to their findings, the stages of dust suppression, cleaning, commissioning and tests were considered the main opportunities for reduction of water usage. In addition, demand for potable water for workers’ needs accounted for a considerable portion of a site’s total water consumption, with estimates ranging from 59 to 85 percent of total water usage for buildings under construction (McNab, Lynch and Young 2012). It is indicated in their report that some sites had metered supplies and paid for their water regularly, but other sites were not even registered with the local water provider, thus were not paying for water. Their data may be categorized under level B because of assumptions made to address the lack of meters on sites.
Another study of water usage for buildings under construction, conducted in Brazil, reported that from 370 to 680 litres of water were used at construction sites per square metre of floor space built (Pessarello 2008). These data can also be categorized under B level, following the proposed approach for categorizing levels of data reliability, because of assumptions made to cover lack of measurements, as with the previous study.

This author also participated in fieldwork-based case studies at two construction sites in the city of Curitiba, in the South of Brazil, to quantify water usage at construction sites for buildings based on structural units made of concrete and walls comprised of bricks and mortar (Brown et al. 2012a, *Estimativa do Consumo de Água Potável na Construção de Edificações*, translated in Appendix C). These two building types are frequently used in Brazil. Details on methodology and the complete set of results and discussion are included in an abbreviated translated paper by this author in Appendix C. The findings revealed that water monitoring for sources other than mains water was not routine at the two construction sites (Brown et al. 2012a), consistent with results in other studies (McNab, Lynch and Young 2012). Results indicated that mains water usage at the two construction sites ranged from 80 to 160 litres of water per square metre of floor space built (Brown et al. 2012a). One particular challenge was to estimate the number of workers to determine the demand of potable water for workers’ needs. There was no accurate information on the changing number of subcontracted labourers at the construction site at different stages of construction, as was also noted in other studies (Chan and Chan 2004; McNab, Lynch and Young 2012). Hence, an average number of workers and related water usage were estimated for the entire period of construction at
each building studied, which resulted in around 53 percent of total water usage at the construction site for workers’ needs (Brown et al. 2012a). Another challenge encountered by this author was that there were alternative sources of water (i.e. groundwater and rainwater) used at the construction sites but not measured, thus the total quantity of water usage measured represented the low end of volume of water intake to the site (Brown et al. 2012a). According to the proposed approach, these data could be categorized under low reliability, or C level, because many assumptions were made and the results did not include all water sources used due to lack of measurement.

Further investigation on quantity of water usage at construction sites is still required for developing proper water management practices, and eventually meet the potential for water savings for buildings under construction. Water use then continues after buildings are occupied. Some elements to advance this knowledge are investigated in the next section.

7.3.2 Buildings After Occupation

One way of measuring water usage in buildings after occupation is based on the per capita water usage. *Per capita* quantities can be expressed in litres of water used per person per day and are dependent on regional patterns including climate, culture and economy; thus specific surveys should be pursued for defining local individual demands (Wong and Mui 2008). Wong and Mui indicated that a range from 65 to 365 litres of water per person per day (L/person day) has been reported worldwide, with an average of 164 L/person day. The variation reported from 65 to 365 L/person day is related to local
habits and these data can be categorized under the A level of reliability, because they were based on in-house metering figures, or from the metering records of water authorities. Although there was no information provided by the authors about type and calibration of measurement devices, for issuing bills they tend to be highly reliable.

7.4 Potential for Potable Water Savings: Fieldwork-Based Case Studies

Water and energy have been described as "the two major pillars that support human activities" inside a building (Bardhan 2011). However, only energy consumption in buildings has been receiving attention; information on water usage is still scarce. The following sections present several case studies that investigate the potential for water savings for the manufacturing of ready-mixed concrete and buildings under construction and after occupation.

7.4.1 Ready-Mixed Concrete Plants

Many ready-mixed concrete plants located in urban areas are supplied with mains water systems (Irbaris 2009), but groundwater is also used. However, rainwater and effluent recycling are also often used for mixing water, a practice which has been found to be acceptable as long as the recycled water is tested for meeting local standards for the physical, chemical and microbiological qualities of mixing water (Bezerra et al. 2008; Mehta 2002; Sandrolini and Franzoni 2001, Tsimas and Zervaki 2011; Wasserman 2012). Considerable freshwater savings may be achieved by using alternative water sources, not only for mixing water, but also for other uses at ready-mixed concrete plants. Furthermore, the large amounts of water used for washing concrete mixer trucks in many
places cannot be discharged into any local water course or sewer without first allowing the cement and aggregates to settle out to meet local policies, thus motivating the recycling of effluent in many plants worldwide. Researchers suggest that in most ready-mixed concrete plants, the incentive to use a system of settling tanks to recirculate truck washing water is mainly related to meeting local water use policies, instead of aspects related exclusively to freshwater savings (Meyer 2009; Sandrolini and Franzoni 2001; Tsimas and Zervaki 2011).

This author conducted fieldwork-based case studies at two ready-mixed concrete plants in Brazil, specifically in the city of Curitiba, state of Paraná, in the south of Brazil (Bezerra et al. 2008). The main objectives were to evaluate the total water usage at that plant, beyond the quantity for mixing water, as well as the local characteristics of effluent recycling and the potential for rainwater harvesting to be used as mixing water. An abbreviated abstract of a conference paper (Bezerra et al. 2008), translated from Portuguese to English, is included in Appendix D. A first attempt to have some estimates of water usage beyond mixing water at the two plants studied could not be undertaken because of a lack of water measurement systems for uses beyond concrete production. As for the evaluation of quality, the findings confirmed that concrete prepared with alternative water sources such as rainwater was similar in compressive strength to samples prepared with potable water, as also shown in the literature for plants located in other regions (Mehta 2002; Sandrolini and Franzoni 2001, Tsimas and Zervaki 2011; Wasserman 2012). The results encouraged plant personnel at one of the plants to expand both effluent recycling and the rainwater harvesting systems, consequently increasing the
volume of these alternative water sources available for mixing water. An evaluation of the resultant potable water savings at this plant is currently under investigation by this author (Bezzerra et al. unpublished data).

7.4.2 Buildings Under Construction and After Occupation

The use of alternative water sources also deserves attention at construction sites, where potable water is not necessary. This author conducted an investigation into the quality of local rainwater for attending to water requirements at construction sites in the city of Curitiba (Brazil), with the intention to evaluate the potential for mains water savings at the construction sites (Brown et al. 2012b, *Qualidade da Água de Chuva em Curitiba-PR para ser Usada na Construção de Edificações*). Appendix E provides an abbreviated paper (translated from Portuguese to English) that describes the methodology, results, and discussion on rainwater quality for uses at construction sites in that Brazilian city. Results showed that implementing a rainwater harvesting system at construction sites would certainly allow mains water savings. Studies of local rainfall rates were performed and showed that the average annual precipitation of around 1,500 millimetres and its monthly distribution were favorable for investing into rainwater harvesting systems (Akishino, Bezerra and Farahbakhsh 2009, 2010).

Beyond the use of rainwater, some effluents from construction sites may be recycled for use as another alternative source of water. One example is that effluent from washing hand tools and larger volumes of effluent from concrete curing processes could be applied at least for dust control. In addition, as indicated in Chapter 2 (Section 2.1.2), a
range of erosion and sediment control measures and pollution prevention practices may be required to deal with stormwater discharges from construction sites, as well as effluent discharge from activities such as dewatering, soil stabilization, and concrete washout (the effluent from washing the drums and chutes of ready-mixed concrete trucks, hoppers of concrete pump trucks, and hand tools used at sites). Therefore, further investigation of effluent recycling at construction sites is also an important area to expand both the availability and quality of information, eventually supporting better decision-making about whether substantial potable water savings could be achieved.

Efforts to promote potable water savings for buildings after occupation, also called the built environment, are also gaining attention. In that sense, the use of alternative sources of water, such as rainwater harvesting systems, are being pursued in many cities. This author investigated a 2003 governmental policy for water conservation and rational use of water, which is mandatory for all new buildings in the city of Curitiba (state of Paraná), in the South of Brazil (Christian and Bezerra 2007; Christian, Bezerra and Teixeira 2008; Bezerra et al. 2009, 2010, 2010a). The program is called PURAE, for its acronym in Portuguese (Programa de Conservação e Uso Racional da Água nas Edificações), and it mandates that harvested rainwater should be used for non-potable needs in buildings. Some of the findings indicated that the launch of PURAE in 2003 was an important action taken by the municipality, but the policy’s effectiveness for promoting potable water savings could be improved. One critical need was to promote broad discussion between stakeholders, in order to mitigate some of the technical difficulties that building professionals were encountering, mainly around the sizing harvested-rainwater storage
tanks. To address this need, this author also performed an investigation comparing national methods of sizing tanks to the municipal decree. Results showed that equations in both methods should incorporate the information of local rainfall rates to improve their effectiveness (Bezerra et al. 2010). As indicated before, the city of Curitiba has rainfall rates and distribution patterns that are beneficial for investments in rainwater harvesting systems that contribute to potable water savings (Akishino, Bezerra and Farahbakhsh 2009, 2010).

The program PURAE also does not address the issue of monitoring the quality of rainwater harvested in the storage tanks in buildings. Stakeholders such as design professionals, building occupants and employees continue to ask questions on how to maintain proper quality for harvested rainwater and whether there are health risks associated with this water, even for non-potable needs. To address these concerns, this author participated in preliminary research to investigate the quality of rainwater in storage tanks between 2006 and 2008 (Decker and Ferreira 2008). Samples of rainwater were collected from roofs at three residential buildings in the city of Curitiba to evaluate physical, chemical, and microbiological characteristics. Results indicated that the rainwater harvested was not posing health risks for non-potable uses but that there were some samples that tested positive for coliforms, thus requiring some care during use. Currently, this author is developing a new investigation into the quality of harvested rainwater for those same storage tanks (Bezerra, Buzeti and Farahbakhsh unpublished data). The main objective is to compare the quality of current harvested rainwater with the initial results in 2008, to evaluate proper strategies for maintaining adequate quality.
This author also conducted an investigation to compare the quality of rainwater harvested in the city of Curitiba (Brazil) from a conventional roof made of concrete and from a green roof system (the roof was covered with vegetation). Results showed that the quality of both types of harvested rainwater was safe for non-potable uses (Budel et al. 2012). These studies confirmed that the use of rainwater for non-potable uses allows for considerable potable water savings in buildings after occupation. Appendix F presents a list of all publications from 2007 to 2013 this author has produced regarding water usage in the construction industry.

7.5  Reliability of Water Usage Data Compiled in this Research

The research completed in Chapters 3 to 6, as well as the discussion in this chapter, allow for a characterization of levels of reliability for important sectors of the construction industry. Figure 7.1 presents a schematic of the estimated reliability of available data for cement manufacturing, ready-mixed concrete production and buildings under construction and after occupation, as well as ranges for water usage through this chain. This figure shows that water usage for cement manufacturing adds to water usage for ready-mixed concrete production, and eventually to buildings under construction and after occupation. The highest levels of data reliability are available for volumes of mixing water for concrete production and for buildings after occupation, but the other sectors present lower levels of data reliability.
Figure 7.1. Levels of reliability of available water usage data at three sectors of the construction industry. (1) Case studies, Chapter 4 (Table 4.4). (2) CSR reports, Chapter 3 (Table 3.3); Kollar and MacAuley (1980). (3) Blake (1989); Mehta and Monteiro (2006); Oliveira (2007). (4) Brown et al. (2012a). (5) Pessarello (2008). (6) Wong and Mui (2008).

Data of water usage for cement manufacturing are generally indicated in litres of water per tonne of cement produced (L/tonne cement). However, data of water usage for concrete production are usually presented in litres of water per cubic metre of concrete produced (L/m³ concrete). When it comes to buildings under construction, data of water usage is mostly published in litres of water per square metre of floor space built (L/m² floor). In the built environment, water usage is indicated in the daily per capita unit, meaning litres of water used per person per day (L/person day).

In order to calculate the embodied water in buildings after occupation, also coming from embodied water for buildings under construction, and related water usage for building materials manufacturing, conversion of the units to the same standard is necessary. The literature indicates that the average percentage of mixing water in concrete is around 8 percent of total mass; around 12 percent of the total mass of concrete is cement and 80 percent is aggregates (Mehta and Monteiro 2006). Thus, the water intensity of cement
can be converted into an added amount of approximately 8 percent of total mass of concrete produced; mass can then be converted into volume. However, information on the total volume of water used at ready-mixed concrete plants was not available, so the complete evaluation of water usage for cement manufacturing translating into water usage for concrete production could not be obtained yet. As indicated before, this author is currently pursuing further research in this area. Furthermore, the total volume of concrete used in buildings under construction can be translated into embodied water in buildings after occupation. This researcher has attempted to obtain the volume of concrete used in the two buildings under construction that were investigated for this research, but such information was not available, so the volume of concrete per square metre of floor space could not be calculated to allow investigation of incorporated water from concrete to buildings. Although it seems logical that the total volume of concrete would be recorded by the building company, in reality these data are not always kept after the construction period, and this is what happened with the case studies evaluated in this work.

The lack of such information negatively impacts the proper evaluation of water usage through this chain, from cement manufacturing to concrete production and to buildings under construction and after occupation. Beyond the difficulties in gathering such data, the level of reliability of water usage data in these three sectors of the construction industry varied from high reliability, at level A, to low reliability, at level C.
7.6 Improving Water Management Practices in the Construction Industry

This chapter has presented an approach for evaluating the reliability of available water usage data in the construction industry based on the method of data acquisition, and has shed light on the need for improved methods of data collection. As indicated in Chapter 2, businesses are seeking standards, guidance and tools to enable changes to more sustainable water management practices (WBCSD-IUCN 2010). Based on the outcomes of this research, decision-makers can categorize available water usage data from their processes using the proposed approach (please refer to Table 6.1, Chapter 6), and then identify areas of critical concern, mainly where water usage is high but data reliability is low.

The total water usage at ready-mixed concrete plants is one area of critical concern, thus an important field to be investigated. It was shown that rainwater can be substitute for potable water when preparing batches of concrete but water usage for other activities at ready-mixed concrete plants can also be reduced. In any case, a higher level of data reliability is necessary to adequately investigate the potential for water savings.

At construction sites, the water usage for some activities is expected to be high and continuous during the construction phase, for instance for dust suppression. For this activity the quality of water does not need to be potable, therefore there is potential for substituting for alternative sources, such as rainwater or recycled effluent. However, the few available data are not highly reliable thus cannot confirm where water is used in large quantities. Certainly the stage of dust suppression is not the only activity indicated
as high concern but there are other areas of large water usage at construction sites that
deserve further investigation in order to be better understood.

Water usage is ongoing for buildings after occupation and better knowledge of where
water is used and where water is wasted, both in terms of quantity and quality, will also
allow better decision-making around best water management practices in the built
environment.

This author has shown that it is difficult to find reliable water usage data for some sectors
of the construction industry, but there is a growing need for such information. However,
more reliable data, beyond allowing for better decisions on water management practices,
may also allow for developing water use policies and determining water prices where
appropriate. The interest in constructing buildings that have characteristics aligned with
principles of sustainable development, such as social, environmental and economic
benefits is increasing in this industry. Therefore, concerted efforts should be made by
construction industry practitioners, such as cement and ready-mixed concrete plant
managers, engineers, architects, contractors, builders, and local authorities, to promote
water conservation in this industry.

Figure 7.2 shows a methodology to systematically improve data reliability and encourage
best water management practices. This methodology was proposed based on knowledge
gained from this project, with the intention to inform water conservation planning in this
industry.
Figure 7.2. Strategies to improve water conservation planning.
Phase 1 of the methodology in Figure 7.2 involves running a full diagnostic of water intensity and water usage at each stage of manufacturing, to allow development of a water flow diagram. Phase 2 entails identifying stages with highest water usage and applying the approach described in Chapter 6, Section 6.2, to categorize levels of data reliability (please see Table 6.1). Actions to minimize data uncertainty can also be initiated in Phase 2, for example by properly calibrating existing flowmeters, installing new flowmeters at stages with high water usage but low data reliability, and providing estimates based on well-founded assumptions. In Phase 3, a strategic plan for water conservation is developed, using comparisons of observed water use data (based on the water flow diagram developed in Phase 1 with benchmarks drawn from available datasets in the literature). Phase 3 should encompass the following three steps: (1) set up a water line maintenance program to regularly inspect water leaks; (2) identify potential fixture and equipment changes to reduce water usage, implementing changes when cost-effective; and (3) evaluate the quality of effluent from various stages to identify recycling opportunities, and implementing recycling either plant-wide or at certain stages when cost-effective. Phase 4 should include revision, at least once a year, of the water flow diagram, followed by an update of the strategic plan. Industries following these strategies will be better prepared to meet increasingly stringent local water use and pricing policies.

Currently, water withdrawal is underpriced in many countries, including Canada and Brazil (where case studies for this research were developed), and thus does not pose a financial risk to this industry, especially when compared to costs associated with energy consumption. It seems that there is little incentive for the industry for effective water
measurement and reporting, and that air emissions policies are more strict than water use policies. This apparent lack of effective water use and pricing policies is not driving investments in water conservation in the cement industry and related construction sectors investigated in this work. However, this is changing as concern around water scarcity and conservation is gaining momentum.

The next chapter will present the overall conclusions, recommendations and conclusions from this research work.
The water crisis is a bad thing; but more attention and effort focused on solving it is good.


8.1 Research Context and Methodology

This research examined water usage for cement manufacturing, ready-mixed concrete production, and buildings under construction and after occupation. The motivation for this study arose from the lack of benchmarks of water usage data, particularly in the cement industry. Cement is the main component in making concrete, which is the most widely used structural building material in the world. Cement production is growing worldwide and water is required throughout its manufacturing processes. However, this research has demonstrated that monitoring and reporting of water usage in the cement industry are not diligently pursued. This inattention will have to change as water becomes more highly valued due to scarcity and policies become more strongly enforced in terms of limiting volume for withdrawal and imposing related costs. In addition to economic and environmental issues, concern around social factors is gaining attention from the construction industry as a whole, because of a potential controversy around this industry’s need for water in its various manufacturing processes. This may be in competition with the rights of human populations to adequate housing, infrastructure and safe water. Thus, enhanced knowledge of water usage in the construction industry is
timely because this industry may be driven to invest more significantly into best water management practices in the near future.

Data of water usage for cement manufacturing, concrete production, and buildings under construction and after occupation were collected from the literature and from case studies. It is noteworthy that data collection from case studies was done within the industry’s context of regular operating conditions; thus the data obtained were valuable to represent real existing scenarios.

For cement manufacturing, the performance metric of water usage applied to this research was water intensity, defined as the volume of water in litres used to produce one tonne of cement. Water intensity data were mainly obtained or calculated from the information in corporate sustainability reports (CSR reports). Reports included in the analysis were limited to those published by members of the Cement Sustainability Initiative (CSI), and further limited by selecting only reports that followed the Global Reporting Initiative (GRI) guidelines. Data were also collected from case studies developed at two cement plants, one in Brazil and one in Canada. Data analysis accounted for the variety of cement manufacturing processes and created a new scheme to understand the water requirements at cement plants by dividing these manufacturing processes into eleven stages, from raw material preparation through to overall cooling of equipment. This scheme also included uses beyond the production line, namely employees’ and subcontracted labourers’ needs, laboratory work, overall housekeeping and road dust suppression. Data obtained from the case studies and literature revealed
considerable information about water usage at these plants, as well as some uncertainties around compiled data. A proposal for categorizing levels of data reliability according to methods of data acquisition was presented to indicate the extent of uncertainty. This approach proved valuable to classify data, as well as to suggest strategies for improving data reliability.

Moving beyond cement manufacturing, data of water usage at ready-mixed concrete plants were collected from the literature and from a case study performed at a plant in Brazil. Water intensity was also selected as a performance metric\textsuperscript{13}. Findings revealed that water usage for the production of concrete, namely mixing water, was under strict control but the other uses for water at the plant were not monitored. Thus, the total water usage at plants could not be assessed. Furthermore, local rainwater and recycled effluent were tested for mixing water. Data obtained also had uncertainties and were classified according to the proposed levels of reliability, revealing areas to be further investigated.

Available data of water usage for buildings under construction and after occupation were also investigated in the literature and from case studies in Brazil. For buildings under construction water intensity was also used as a performance metric. Water usage in buildings after occupation was investigated in terms of total water usage in litres per person per day. The potential for substituting groundwater and mains water with rainwater was also evaluated and it was concluded that potential water savings exist for

\textsuperscript{13}See broader definition of water intensity in Chapter 2, Section 2.3.7. For ready-mixed concrete, water intensity represents the total volume of water in litres used to produce one cubic metre of concrete. For buildings under construction, it represents the total volume of water in litres used to produce one square metre of floor space built.
buildings both during construction and after occupation. Similar to the other investigated areas, the few available data revealed considerable information about water usage data but also showed uncertainties and were classified according to the proposed levels of reliability, helping identifying areas of future work.

This research supports global efforts to improve water usage policies and water conservation. For example, it supports the United Nations “Eight Millennium Development Goals” (MDGs) by investigating and promoting strategies to save freshwater and drinking water, here with a particular focus on the construction industry. These strategies may help address Goal 7, “Ensure Environmental Sustainability”, and its first target of integrating the principles of sustainable development into country policies and programs and reversing loss of environmental resources. Results from this research are expected to support construction industry decision-makers who are investing in improvements of their economic, environmental and social performance in relation to water usage.

Table 8.1 presents an overview of other potential stakeholders who are likely to benefit from this research. This researcher has already provided preliminary results to some of the stakeholders, who have expressed strong interest in those findings. Example of stakeholders’ comments are presented below.

“I’d use the most relevant parts to my plant and since it seems that our plant, thanks to you, has the most advanced water balance available from which to make reduction decisions, I would evaluate how best to share ideas with other plants (and possibly divisions) in the company.” (Cement plant manager)
“Other projects were not as easy to identify because I was working with a poor data set at the time... once we understand the process better, I’m sure we can work at slowly removing areas of concern smartly.” (Cement plant manager)

“We have not as yet done any research regarding water consumption but are considering this in our future work plan... We expect to make a survey of water use practices within the companies involved in the CSI, but the timing of this has not been settled at this time... Perhaps you would be interested in helping with the survey as part of your thesis?” (CSI board member)

Table 8.1. Potential stakeholders who may benefit from this research

<table>
<thead>
<tr>
<th>STAKEHOLDER</th>
<th>USE OF INFORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction industry decision-makers (plant managers, engineers, architects, and builders)</td>
<td>Identifying better water measurement practices and opportunities Providing strategies for best water management practices</td>
</tr>
<tr>
<td>Regulatory agencies, policy-makers</td>
<td>Raising awareness of the special challenges in water monitoring and measurement in this industry. This will provide better information for applicable policy frameworks, for example those related to guidelines, programs, legislation, incentives, water use and pricing policies and effluent discharge policies</td>
</tr>
<tr>
<td>Members of the Cement Sustainability Initiative (CSI), under the World Business Council for Sustainable Development (WBCSD)</td>
<td>Evaluating best water measurement, reporting and management practices Providing information about water intensity as a performance metric for water usage for cement manufacturing Providing a dataset of water usage for cement manufacturing for combined analysis with the Global Water Tool for the Cement Sector</td>
</tr>
</tbody>
</table>
The Global Reporting Initiative – GRI

Offering an approach for categorizing levels of data reliability for GRI indicators
Raising awareness about the need for more reliable data
Providing information to support creation of an indicator based on water intensity exclusively for freshwater withdrawal
Raising awareness of the need to understand water usage at each stage of manufacturing

Organizations for rating sustainable buildings (also called green buildings)

Raising awareness of water usage in the manufacture of building materials and in building construction

Investors

Raising awareness for parties investigating and evaluating water-efficient industries

8.2 Main Findings

Approximately half of the cement companies that are members of the CSI, as well as nearly half of the CSR reports selected for this research, did not publish values of water usage at cement plants, although in some of those reports there is discussion of water issues. This fact indicates that water usage disclosure is not a regular practice in the cement industry. Moreover, since these reports were written to follow GRI guidelines and yet did not include the GRI-required value for water usage, one can infer that water usage may not be frequently monitored, or even measured at all, at a large number of cement plants worldwide.

Published water intensity data available in CSR reports varied widely from 147 up to 1,220 litres/tonne of cement. Part of this variability may be due to the difference between wet and dry manufacturing processes. However, information about the process in place was not available in the majority of CSR reports. More specifically, out of the 35 data
points obtained, only 6 had an indication of the cement manufacturing process. Even for those 6 data points that indicated the type of kiln, there were two companies that combined their data from plants with both wet and dry processes. Moreover, the variability in reported water intensity may indicate that some published data did not include either the volume of all water sources used or the total water usage for all purposes at cement plants. Such substantial variability in the CSR-reported water intensity data, combined with the lack of information on the cement manufacturing process in place, did not allow either a proper comparison between data or determination of a reasonable range of water intensity at plants run by the dry or wet process.

Another common gap in CSR reports was a lack of information about whether the reported Global Reporting Initiative’s indicator of water withdrawal (GRI-EN8) was measured or estimated, despite the fact that this information is required by GRI guidelines. Moreover, the term water “consumption”, published sometimes along with indicator EN8, raised questions as to whether the reported data could be representing water withdrawal minus effluent discharge.

The author addressed this uncertainty in published data by developing fieldwork-based case studies at two cement plants. The water intensity figures obtained from the two case studies showed a large difference. The water intensity for cement manufacturing at the plant in Canada (2,000 litres/tonne cement) was about eight times higher than that at the plant in Brazil (250 litres/tonne cement). A possible partial explanation for this difference is that the recycling system in place at the Brazilian plant contributed to a lower water
intensity for cement manufacturing. Another difference is the water used for cement cooling, which was used only at the plant in Canada, and required a large volume of water per tonne of cement produced.

It is interesting to note that two similarities between the plants studied were (a) lack of identification of routine for flowmeter calibration to measure water withdrawal and (b) lack of systematic measuring of effluent discharge or recycling. It is likely that other cement plants may have similar practices of not routinely measuring water usage, and that determination of water usage is not yet a priority for plant owners in the cement industry. One reason for a lack of accurate information could be that water withdrawal from surface water and groundwater generally does not incur water costs to the cement plants, thus there is no incentive to carefully monitor water use. Mains water was used and charged only at the Canadian plant studied, for uses beyond the production line, and it represented less than 1 percent of the total water intake. Monthly mains water billing was under CAD$1,000 (approximately US$900), which is relatively low for a cement plant. At both plants studied there were no local regulatory limits for water withdrawal.

Results from the case studies revealed considerable information about water usage at these plants. Accurate numbers could not be developed for all eleven stages of water usage for cement manufacturing investigated in this research but the information obtained was valuable in revealing some volumes of water usage. In any case, the results from this research were valuable to (a) estimate an average range for the quantity of water demand at cement plants, for both water intensity and water usage at each stage of cement
manufacturing, (b) help identifying stages of manufacturing with highest water usage, (c) show changes in water intensity through the year, due to seasonal effects, and (d) show that the year-to-year water intensity was not influenced by the rate of cement production at either plant. Results presented also pointed to challenges for collecting adequate data for water withdrawal and usage at cement plants. Among these challenges are minimal routine measurements and a lack of the information necessary to create reliable estimates. Questions around the accuracy of meters, mainly in terms of proper functioning and calibration, also posed a challenge.

The quantity of effluent from cement plants was also investigated in the literature and in the case studies. Data for the two GRI (Global Reporting Initiative) indicators EN10 (percentage and total volume of water recycled and reused) and EN21 (total water discharge by quality and destination) were rarely reported in the CSR reports and could not be measured at the two plants studied, thus preventing correlation between volumes of recycled water used at plants and related water intensity.

In terms of reporting of water usage data, it should be recalled that indicator EN8 (total water withdrawal by source) reflects the extraction of water from freshwater sources, the use of harvested rainwater, and effluent recycling when wastewater is brought in from an external facility. However, rainwater harvesting is included under two GRI indicators: EN8 and EN10 (percentage and total volume of water recycled and reused). Since not all CSR reports reviewed by this author included information about what their specific water sources were, it would be better to make these indicators more distinct to achieve
improved clarity in the reporting of water usage. If harvested rainwater and recycled wastewater brought in from another facility were included only in the indicator EN10, then water accounted for in EN8 would exclusively represent withdrawal from rivers, lakes or groundwater sources. This way, the indicator EN10 would represent exclusively the use of alternative water sources and recycling practices. Moreover, it would avoid the risk of having harvested rainwater accounted for in both indicators. Clearer indicators make it possible to evaluate whether freshwater usage could be reduced or substituted by alternative water sources, such as effluent recycling or rainwater harvesting.

Irrespective of limitations, research outcomes were used to characterize the reliability of various methods of data acquisition related to cement plants, thus allowing comparisons between data and assessment of opportunities for improving data reliability. For this approach, data were classified as level A, highly reliable, when mainly acquired by the use of flowmeter devices. Data classified as level B were moderately reliable because they are generally based on assumptions. However, level C data have low reliability because there is a lack of information on method of data acquisition. Certainly these levels of reliability of measured data also depend on the operating conditions of any measurement devices. The reliability of estimated and published data may improve if there is information provided on well-founded assumptions or on the type of device used. This approach provided an improved method for assessing stages of cement manufacturing where water usage was of concern (for instance where the rate of water usage was high but data reliability was low), thus facilitating investigation of
opportunities for water savings, as well as decisions for improving methods of data collection.

The approach also allowed the identification of opportunities for improving data reliability in other sectors of the construction industry: ready-mixed concrete production and buildings under construction and after occupation. Beyond the call for more reliable data, results showed that both ready-mixed concrete plants and buildings under construction and after occupation have potential for using alternative water sources, such as harvested rainwater and recycled effluent.

The reliability rating approach can also be applied to broader initiatives. For example, this approach may help improve data reliability for reporting initiatives such as the GRI and their guidelines. The levels of data reliability could be indicated with GRI indicators of water usage, mainly indicators EN8 (total water withdrawal by source), EN10 (percentage and total volume of water recycled and reused), and EN21 (total water by quality and destination). Furthermore, this approach may also help inform regulatory agencies about levels of data reliability, facilitating implementation of appropriate regulatory frameworks around water usage and pricing.

Findings from this research reinforce the need for improving data reliability, sometimes by regular calibration of existing flowmeters. It is also recommended that flowmeters should be set up to provide totalized data to account for variation in water demands resulting from regular operating conditions. Water savings strategies, based on some data
from this research, are already being assessed at the Canadian cement plant and the Brazilian ready-mixed concrete plant. This research has already had a significant impact on water management at these plants. However, the industry’s driver of cost-benefit assessment for implementing more costly strategies may still require data of higher reliability for the areas of concern. Data classified in this work are already helping these industries to identify areas where investments into more expensive methods of data acquisition may be valuable.

8.3 Recommendations for Future Work

Future research to expand on these findings about water usage at cement plants should include more case studies to allow a broader dataset. Such future work could be conducted in cooperation with international organizations interested in improving this knowledge, such as the Cement Sustainability Initiative (CSI). This cooperation would allow the establishment of a central database of water usage for the cement industry. The availability of a central database would promote knowledge sharing among stakeholders, allowing broader access to information for benchmarking water intensity at plants, as well as developing best water management practices. Another recommendation for future work is to collect data on the quality of effluent to better evaluate recycling opportunities.

Further studies are also needed to investigate the total water usage at ready-mixed concrete plants, beyond knowledge of mixing water. It is recommended to develop more case studies at plants where all water sources can be measured. Knowledge about total water usage at ready-mixed concrete plants is still scarce but is required for development
of water balance diagrams at each plant. These diagrams, combined with data collection on the quality of effluent and rainwater, will allow analysis of the costs and benefits of existing and planned systems for using recycled effluent and harvested rainwater.

Water usage for different activities at the construction site must also be further investigated. Case studies should be developed at sites where all water sources can be measured and the number of workers on site is regularly monitored. Although construction projects differ from each other, some activities at construction sites are similar and can be analyzed to evaluate commonly shared opportunities for water savings. Further studies should include analysis of the quality of effluent and rainwater to help identify the potential for use of alternative water sources.

8.4 Contributions to the Field

This research is a novel investigation of water usage at cement plants and started by revealing the lack of previous knowledge on this topic. The methodology adopted to fill this gap of knowledge included data collection and estimates within two cement plants, thus incorporating real world operating conditions. Such data contain uncertainties but are valuable to represent the real scenario of water usage in these industries, as well as to show limitations around lack of measurement devices and doubts about available data reliability. This research is timely because of the growing interest in addressing such limitations. For example, the recent launch on October 10th of 2013 of the ‘Global Water Tool for the Cement Sector’ shows that the industry is shifting from no measurement to an interest in better managing its water use. Recalling that the ‘Global Water Tool for the
Cement Sector’ is a customized version of the Global Water Tool launched by The World Business Council for Sustainable Development, briefly described in Chapter 2.

This research is the first comprehensive analysis of water usage in the cement industry and the results are significant because of special challenges faced by this sector compared to others. Moreover, this research demonstrates techniques for collecting and evaluating data where there is little available and proposes an approach for improving reliability of water usage data. These findings form a dataset as a foundation to build further knowledge.

Data of water usage collected from the Canadian plant has had a positive impact as it seems to represent the most advanced water balance available, as a result of this research work, in various plants operating under this company worldwide (personal communication). This outcome was indicated by the plant’s environmental coordinator, after he attended a meeting with their worldwide environmental team, including a representative of the Cement Sustainability Initiative (CSI). Results from this research are already being used at that plant to evaluate implementation of water savings strategies. This knowledge transfer to the Canadian cement plant will help advance best practices and improve sustainability of that plant’s water usage.

Findings from this research on the use of an alternative water source at the Brazilian ready-mixed concrete plant were also used by plant decision-makers. Based on preliminary data from this research, they have implemented a larger rainwater storage
tank, thus increasing their rainwater harvesting system. Evaluation of this system will follow. Such feedback from the facilities where case studies were developed demonstrates a strong interest in enhancing knowledge about water usage at their plants, thus showing practical contributions from this research.

Although there are uncertainties around some data compiled for this research, resulting from the lack of monitoring of water usage in the cement manufacturing and related industries, all data could be categorized in terms of their reliability. The resultant classification of data is valuable in identifying areas where higher levels of data reliability should be pursued. In addition, the approach proposed in this work may contribute to increasing the overall reliability of water usage data in these industries, if method of data acquisition is improved according to the proposed reliability levels. Eventually, more reliable data could be compiled into an enhanced database that could serve as input for other tools associated with water management practices, such as life cycle assessment (LCA), water footprint calculations and the global water tool (GWT). The need to increase data quantity and reliability in LCA inventories is being widely recognized; this work can help address that need. The proposed levels of reliability could also be applied to other industries outside of cement, concrete, and buildings under construction and occupation, providing a consistent framework for evaluating water usage data.

Academic research needs to be made available to professionals in the field, in addition to published papers and dissertations. More real water savings will be achieved if more
researchers, construction professionals and government authorities work together, fostering new understanding and raising awareness among stakeholders. Findings from this research were proven valuable in that sense, as resultant data were shared with plant personnel through periodic discussion and evaluation of water savings opportunities. Further knowledge transfer will benefit other stakeholders as indicated in Table 8.1.

In summary, this work is a significant contribution to the field of water management in shedding light on the lack of water usage data availability and reliability in the cement industry, thus calling for improved measurement and reporting. Some of the data obtained from this research has already been put to use by the Canadian cement plant and by the Brazilian ready-mixed concrete plant, where findings from this research are being applied to their feasibility studies of water reduction, and use of alternative water sources. The approach created for rating data according to method of measurement and reliability of water usage data in this industry will help decision-makers identify areas of concern, for example where water usage is high but data reliability is low. In addition, policy-makers can also use this approach to rate available data in the process of developing regulatory frameworks around water usage and pricing. Furthermore, results from this work offer an initial data set that will help build benchmarks of water usage in the globally important sectors of cement manufacturing, concrete production, and buildings under construction and after occupation.
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<tr>
<th>Description</th>
<th>Chemical formula</th>
<th>Short notation</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tricalcium silicate (alite)</td>
<td>3CaO·SiO₂</td>
<td>C₃S</td>
<td>50 to 55%</td>
</tr>
<tr>
<td>Dicalcium silicate (belite)</td>
<td>2CaO·SiO₂</td>
<td>C₂S</td>
<td>19 to 24%</td>
</tr>
<tr>
<td>Tricalcium aluminate (aluminate)</td>
<td>3CaO·Al₂O₃</td>
<td>C₃A</td>
<td>6 to 10%</td>
</tr>
<tr>
<td>Tetracalcium aluminoferrite (ferrite)</td>
<td>4CaO·Al₂O₃·Fe₂O₅</td>
<td>C₄AF</td>
<td>7 to 11%</td>
</tr>
<tr>
<td>Calcium sulfate dihydrate (gypsum)</td>
<td>CaSO₄·2H₂O</td>
<td>CSH₂</td>
<td>3 to 7%</td>
</tr>
</tbody>
</table>

Source: CEMBUREAU 1999; van Oss and Padovani 2002

### TABLE A.2. MEMBERS OF THE CEMENT SUSTAINABILITY INITIATIVE (CSI) AS OF JUNE 12, 2012

<table>
<thead>
<tr>
<th>CEMENT COMPANY</th>
<th>COUNTRY OF ORIGIN</th>
<th>WEBSITE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(24 in total)</td>
<td>(14 in total)</td>
<td>(in English when available)</td>
</tr>
<tr>
<td>Cementos Argos</td>
<td>Colombia</td>
<td><a href="http://www.argos.co">www.argos.co</a></td>
</tr>
<tr>
<td>Cemex</td>
<td>Mexico</td>
<td><a href="http://www.cemex.com">www.cemex.com</a></td>
</tr>
<tr>
<td>Cimentos Liz</td>
<td>Brazil</td>
<td>vr06.pytown.com</td>
</tr>
<tr>
<td>Cimpor</td>
<td>Portugal</td>
<td><a href="http://www.cimpor.com">www.cimpor.com</a></td>
</tr>
<tr>
<td>CNBM</td>
<td>China</td>
<td><a href="http://www.cnbmengineering.com/cement-engineering/index.htm">www.cnbmengineering.com/cement-engineering/index.htm</a></td>
</tr>
<tr>
<td>CRH</td>
<td>Ireland</td>
<td><a href="http://www.crh.ie">www.crh.ie</a></td>
</tr>
<tr>
<td>Dalmia Cement</td>
<td>India</td>
<td><a href="http://www.dalmiacement.com">www.dalmiacement.com</a></td>
</tr>
<tr>
<td>GCC - Grupo Cementos de Chihuahua</td>
<td>Mexico</td>
<td><a href="http://www.gcc.com">www.gcc.com</a></td>
</tr>
<tr>
<td>Holcim</td>
<td>Switzerland</td>
<td><a href="http://www.holcim.com">www.holcim.com</a></td>
</tr>
<tr>
<td>InterCement (formerly Camargo Corrêa Cimentos)</td>
<td>Brazil</td>
<td><a href="http://www.intercement.com">www.intercement.com</a> (formerly <a href="http://www.camargocorrea.com.br">www.camargocorrea.com.br</a>)</td>
</tr>
<tr>
<td>Italcementi Group</td>
<td>Italy</td>
<td><a href="http://www.italcementigroup.com/ENG">www.italcementigroup.com/ENG</a></td>
</tr>
<tr>
<td>Lafarge</td>
<td>France</td>
<td><a href="http://www.lafarge.com">www.lafarge.com</a></td>
</tr>
<tr>
<td>Secil</td>
<td>Portugal</td>
<td><a href="http://www.secil.pt/default_en.asp">www.secil.pt/default_en.asp</a></td>
</tr>
<tr>
<td>Shree Cement</td>
<td>India</td>
<td><a href="http://www.shreecement.in">www.shreecement.in</a></td>
</tr>
</tbody>
</table>

265
<table>
<thead>
<tr>
<th>CEMENT COMPANY (24 in total)</th>
<th>COUNTRY OF ORIGIN (14 in total)</th>
<th>WEBSITE (in English when available)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinoma</td>
<td>China</td>
<td>en.sinoma.cn/Index.html</td>
</tr>
<tr>
<td>Taiheiyo Cement</td>
<td>Japan</td>
<td><a href="http://www.taiheiyo-cement.co.jp/english/index.html">www.taiheiyo-cement.co.jp/english/index.html</a></td>
</tr>
<tr>
<td>Tianrui Group</td>
<td>China</td>
<td><a href="http://www.trcement.com/doce/home/about.asp">www.trcement.com/doce/home/about.asp</a></td>
</tr>
<tr>
<td>Titan Cement</td>
<td>Greece</td>
<td><a href="http://www.titan.gr/en/">www.titan.gr/en/</a></td>
</tr>
<tr>
<td>UltraTech Cement (same group for Aditya Birla and Grasim)</td>
<td>India</td>
<td><a href="http://www.ultratechcement.com">www.ultratechcement.com</a></td>
</tr>
<tr>
<td>Votorantim Cimentos</td>
<td>Brazil</td>
<td><a href="http://www.votorantimcimentos.com.br/htms-enu">www.votorantimcimentos.com.br/htms-enu</a></td>
</tr>
<tr>
<td>Yatai Group</td>
<td>China</td>
<td><a href="http://www.yatai.com">www.yatai.com</a></td>
</tr>
</tbody>
</table>

Source: WBCSD-CSI 2012

### TABLE A.3. MONTHLY CEMENT PRODUCTION FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th>MONTHLY CEMENT PRODUCTION (tonnes)</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>20963</td>
<td>0</td>
<td>30764</td>
<td>27528</td>
<td>42459</td>
</tr>
<tr>
<td>February</td>
<td>4985</td>
<td>2269</td>
<td>26951</td>
<td>48265</td>
<td>22994</td>
</tr>
<tr>
<td>March</td>
<td>17582</td>
<td>37926</td>
<td>13250</td>
<td>30332</td>
<td>11714</td>
</tr>
<tr>
<td>April</td>
<td>53977</td>
<td>41823</td>
<td>43868</td>
<td>45557</td>
<td>47480</td>
</tr>
<tr>
<td>May</td>
<td>63131</td>
<td>56914</td>
<td>62855</td>
<td>45370</td>
<td>58838</td>
</tr>
<tr>
<td>June</td>
<td>68919</td>
<td>61349</td>
<td>46181</td>
<td>69821</td>
<td>57405</td>
</tr>
<tr>
<td>July</td>
<td>73182</td>
<td>58875</td>
<td>49870</td>
<td>59995</td>
<td>56618</td>
</tr>
<tr>
<td>August</td>
<td>67347</td>
<td>52591</td>
<td>62254</td>
<td>56287</td>
<td>55374</td>
</tr>
<tr>
<td>September</td>
<td>80250</td>
<td>56384</td>
<td>76888</td>
<td>58970</td>
<td>49486</td>
</tr>
<tr>
<td>October</td>
<td>78973</td>
<td>51043</td>
<td>64563</td>
<td>53827</td>
<td>54734</td>
</tr>
<tr>
<td>November</td>
<td>71740</td>
<td>58656</td>
<td>34584</td>
<td>52709</td>
<td>42905</td>
</tr>
<tr>
<td>December</td>
<td>61698</td>
<td>9909</td>
<td>0</td>
<td>55062</td>
<td>45697</td>
</tr>
<tr>
<td>TOTAL (tonnes/year)</td>
<td>662748</td>
<td>487739</td>
<td>512028</td>
<td>603723</td>
<td>545704</td>
</tr>
<tr>
<td>AVERAGE (tonnes/month)</td>
<td>55229</td>
<td>40645</td>
<td>42669</td>
<td>50310</td>
<td>45475</td>
</tr>
<tr>
<td>AVERAGE APRIL TO NOVEMBER (tonnes/month)</td>
<td>69690</td>
<td>54704</td>
<td>55133</td>
<td>55317</td>
<td>52855</td>
</tr>
</tbody>
</table>
### TABLE A.4. MONTHLY GROUNDWATER INTAKE FROM WELL “A” FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th>MONTHLY GROUNDWATER INTAKE FROM WELL “A” (m³)</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>99297</td>
<td>10306</td>
<td>56125</td>
<td>23389</td>
<td>-</td>
</tr>
<tr>
<td>February</td>
<td>40629</td>
<td>20722</td>
<td>50376</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>March</td>
<td>37040</td>
<td>51747</td>
<td>38336</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>April</td>
<td>97341</td>
<td>52676</td>
<td>11465</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>May</td>
<td>47633</td>
<td>58695</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>June</td>
<td>67629</td>
<td>56287</td>
<td>22971</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>July</td>
<td>56095</td>
<td>58201</td>
<td>32041</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>August</td>
<td>59808</td>
<td>60870</td>
<td>29869</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>September</td>
<td>56605</td>
<td>59734</td>
<td>40395</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>October</td>
<td>57121</td>
<td>59075</td>
<td>34215</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>November</td>
<td>53888</td>
<td>56904</td>
<td>25693</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>December</td>
<td>55416</td>
<td>55333</td>
<td>20268</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL (m³/year)</td>
<td>728501</td>
<td>600550</td>
<td>361752</td>
<td>23389</td>
<td>-</td>
</tr>
<tr>
<td>AVERAGE (m³/month)</td>
<td>60708</td>
<td>50046</td>
<td>32887</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>AVERAGE APRIL TO NOVEMBER (m³/month)</td>
<td>62015</td>
<td>57805</td>
<td>28093</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note: A dash (-) indicates that data was not measured.*

### TABLE A.5. MONTHLY GROUNDWATER INTAKE FROM WELL “B” FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th>MONTHLY GROUNDWATER INTAKE FROM WELL “B” (m³)</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>71488</td>
<td>23047</td>
<td>31168</td>
<td>-</td>
<td>88284</td>
</tr>
<tr>
<td>February</td>
<td>61602</td>
<td>13057</td>
<td>25965</td>
<td>75336</td>
<td>79289</td>
</tr>
<tr>
<td>March</td>
<td>44549</td>
<td>46904</td>
<td>19680</td>
<td>53680</td>
<td>81003</td>
</tr>
<tr>
<td>April</td>
<td>68545</td>
<td>51747</td>
<td>79410</td>
<td>73495</td>
<td>90239</td>
</tr>
<tr>
<td>May</td>
<td>80447</td>
<td>62238</td>
<td>91682</td>
<td>73525</td>
<td>92116</td>
</tr>
<tr>
<td>June</td>
<td>72617</td>
<td>58510</td>
<td>82374</td>
<td>71052</td>
<td>87505</td>
</tr>
<tr>
<td>July</td>
<td>76808</td>
<td>59747</td>
<td>86541</td>
<td>85415</td>
<td>90489</td>
</tr>
<tr>
<td>August</td>
<td>74618</td>
<td>44639</td>
<td>92330</td>
<td>93506</td>
<td>89929</td>
</tr>
<tr>
<td>September</td>
<td>69808</td>
<td>34526</td>
<td>91609</td>
<td>90749</td>
<td>83807</td>
</tr>
<tr>
<td>October</td>
<td>71622</td>
<td>32836</td>
<td>85649</td>
<td>90656</td>
<td>89441</td>
</tr>
<tr>
<td>November</td>
<td>69415</td>
<td>38484</td>
<td>58087</td>
<td>86345</td>
<td>85522</td>
</tr>
<tr>
<td>December</td>
<td>72685</td>
<td>23713</td>
<td>-</td>
<td>88099</td>
<td>91012</td>
</tr>
<tr>
<td>TOTAL (m³/year)</td>
<td>834204</td>
<td>489445</td>
<td>744492</td>
<td>897859</td>
<td>1048637</td>
</tr>
<tr>
<td>AVERAGE (m³/month)</td>
<td>69517</td>
<td>40787</td>
<td>67681</td>
<td>81624</td>
<td>87386</td>
</tr>
<tr>
<td>AVERAGE APRIL TO NOVEMBER (m³/month)</td>
<td>72985</td>
<td>47841</td>
<td>83460</td>
<td>85093</td>
<td>88631</td>
</tr>
</tbody>
</table>

*Note: A dash (-) indicates that data was not measured.*
### TABLE A.6. MONTHLY GROUNDWATER INTAKE FROM BOTH WELLS FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th>Month</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>170785</td>
<td>33353</td>
<td>87293</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>February</td>
<td>102231</td>
<td>33779</td>
<td>76340</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>March</td>
<td>81590</td>
<td>98650</td>
<td>58016</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>April</td>
<td>165886</td>
<td>104423</td>
<td>90874</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>May</td>
<td>128080</td>
<td>120933</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>June</td>
<td>140246</td>
<td>114797</td>
<td>105345</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>July</td>
<td>132903</td>
<td>117947</td>
<td>118582</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>August</td>
<td>134426</td>
<td>105509</td>
<td>122199</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>September</td>
<td>126412</td>
<td>94261</td>
<td>132003</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>October</td>
<td>128743</td>
<td>91910</td>
<td>119864</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>November</td>
<td>123302</td>
<td>95388</td>
<td>83779</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>December</td>
<td>128101</td>
<td>79046</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1562705</strong></td>
<td><strong>1089996</strong></td>
<td><strong>994295</strong></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>AVERAGE</strong></td>
<td><strong>130225</strong></td>
<td><strong>90833</strong></td>
<td><strong>99430</strong></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>AVERAGE APRIL TO NOVEMBER</strong></td>
<td><strong>135000</strong></td>
<td><strong>105646</strong></td>
<td><strong>110378</strong></td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note: A dash (-) indicates that data was not measured simultaneously for the two wells.*

### TABLE A.7. MONTHLY MAINS WATER INTAKE FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th>Month</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>302</td>
<td>290</td>
<td>560</td>
<td>235</td>
<td>302</td>
</tr>
<tr>
<td>February</td>
<td>303</td>
<td>290</td>
<td>560</td>
<td>235</td>
<td>303</td>
</tr>
<tr>
<td>March</td>
<td>310</td>
<td>325</td>
<td>672</td>
<td>237</td>
<td>285</td>
</tr>
<tr>
<td>April</td>
<td>310</td>
<td>325</td>
<td>673</td>
<td>238</td>
<td>285</td>
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<tr>
<td>May</td>
<td>577</td>
<td>395</td>
<td>552</td>
<td>305</td>
<td>330</td>
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<tr>
<td>June</td>
<td>578</td>
<td>395</td>
<td>553</td>
<td>305</td>
<td>330</td>
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<tr>
<td>July</td>
<td>800</td>
<td>530</td>
<td>517</td>
<td>620</td>
<td>387</td>
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<tr>
<td>August</td>
<td>800</td>
<td>530</td>
<td>518</td>
<td>620</td>
<td>388</td>
</tr>
<tr>
<td>September</td>
<td>572</td>
<td>605</td>
<td>487</td>
<td>627</td>
<td>287</td>
</tr>
<tr>
<td>October</td>
<td>573</td>
<td>605</td>
<td>488</td>
<td>628</td>
<td>288</td>
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<tr>
<td>November</td>
<td>397</td>
<td>505</td>
<td>295</td>
<td>340</td>
<td>302</td>
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<tr>
<td>December</td>
<td>398</td>
<td>505</td>
<td>295</td>
<td>340</td>
<td>303</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>5920</strong></td>
<td><strong>5300</strong></td>
<td><strong>6170</strong></td>
<td><strong>4730</strong></td>
<td><strong>3790</strong></td>
</tr>
<tr>
<td><strong>AVERAGE</strong></td>
<td><strong>493</strong></td>
<td><strong>442</strong></td>
<td><strong>514</strong></td>
<td><strong>394</strong></td>
<td><strong>316</strong></td>
</tr>
<tr>
<td><strong>AVERAGE APRIL TO NOVEMBER</strong></td>
<td><strong>576</strong></td>
<td><strong>486</strong></td>
<td><strong>510</strong></td>
<td><strong>460</strong></td>
<td><strong>325</strong></td>
</tr>
</tbody>
</table>
### TABLE A.8. MONTHLY TOTAL WATER WITHDRAWAL FROM ALL SOURCES (EN8) FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th>Monthly Water Withdrawal (EN8)</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>171087</td>
<td>33643</td>
<td>87853</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>February</td>
<td>102534</td>
<td>34069</td>
<td>76900</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>March</td>
<td>81900</td>
<td>98975</td>
<td>58688</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>April</td>
<td>166196</td>
<td>104748</td>
<td>91547</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>May</td>
<td>128657</td>
<td>121328</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>June</td>
<td>140824</td>
<td>115192</td>
<td>105898</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>July</td>
<td>133703</td>
<td>118477</td>
<td>119099</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>August</td>
<td>135226</td>
<td>106039</td>
<td>122717</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>September</td>
<td>126984</td>
<td>94866</td>
<td>132490</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>October</td>
<td>129316</td>
<td>92515</td>
<td>120352</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>November</td>
<td>123699</td>
<td>95893</td>
<td>84074</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>December</td>
<td>128499</td>
<td>79551</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TOTAL (m³/year)</strong></td>
<td>1568625</td>
<td>1095296</td>
<td>999618</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**AVERAGE (m³/month)**

- January: 130719
- February: 91275
- March: 99962
- April: 135576
- May: 106132
- June: 110882

Note: A dash (-) indicates that data was not measured simultaneously for all sources.


<table>
<thead>
<tr>
<th>Monthly Clarified Effluent Discharge (EN8)</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>N.A.</td>
<td>124140</td>
<td>113316</td>
<td>0</td>
<td>84175</td>
</tr>
<tr>
<td>February</td>
<td>N.A.</td>
<td>60270</td>
<td>131126</td>
<td>77988</td>
<td>140304</td>
</tr>
<tr>
<td>March</td>
<td>N.A.</td>
<td>124016</td>
<td>113221</td>
<td>101900</td>
<td>185032</td>
</tr>
<tr>
<td>April</td>
<td>N.A.</td>
<td>166651</td>
<td>119015</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>May</td>
<td>N.A.</td>
<td>118218</td>
<td>94053</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>June</td>
<td>N.A.</td>
<td>93983</td>
<td>140584</td>
<td>123893</td>
<td>-</td>
</tr>
<tr>
<td>July</td>
<td>N.A.</td>
<td>91903</td>
<td>134957</td>
<td>108123</td>
<td>-</td>
</tr>
<tr>
<td>August</td>
<td>N.A.</td>
<td>93991</td>
<td>127725</td>
<td>107551</td>
<td>-</td>
</tr>
<tr>
<td>September</td>
<td>N.A.</td>
<td>93991</td>
<td>11739</td>
<td>109459</td>
<td>34243</td>
</tr>
<tr>
<td>October</td>
<td>N.A.</td>
<td>86687</td>
<td>138750</td>
<td>122843</td>
<td>43751</td>
</tr>
<tr>
<td>November</td>
<td>N.A.</td>
<td>95022</td>
<td>80910</td>
<td>98595</td>
<td>34691</td>
</tr>
<tr>
<td>December</td>
<td>N.A.</td>
<td>119841</td>
<td>138647</td>
<td>0</td>
<td>144341</td>
</tr>
<tr>
<td><strong>TOTAL (m³/year)</strong></td>
<td>614866</td>
<td>1270125</td>
<td>1305396</td>
<td>1195509</td>
<td>895262</td>
</tr>
</tbody>
</table>

**AVERAGE (m³/month)**

- January: 102478
- February: 105844
- March: 108783
- April: 99626
- May: 99474
- June: 102881
- July: 118467
- August: 108910
- September: 85584

Note: A dash (-) indicates that data was not measured and N.A. indicates that data was not available.
### TABLE A.10. ESTIMATED MONTHLY DOMESTIC EFFLUENT FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th>Month</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>257</td>
<td>247</td>
<td>476</td>
<td>200</td>
<td>257</td>
</tr>
<tr>
<td>February</td>
<td>258</td>
<td>247</td>
<td>476</td>
<td>200</td>
<td>258</td>
</tr>
<tr>
<td>March</td>
<td>264</td>
<td>276</td>
<td>571</td>
<td>201</td>
<td>242</td>
</tr>
<tr>
<td>April</td>
<td>264</td>
<td>276</td>
<td>572</td>
<td>202</td>
<td>242</td>
</tr>
<tr>
<td>May</td>
<td>490</td>
<td>336</td>
<td>469</td>
<td>259</td>
<td>281</td>
</tr>
<tr>
<td>June</td>
<td>491</td>
<td>336</td>
<td>470</td>
<td>259</td>
<td>281</td>
</tr>
<tr>
<td>July</td>
<td>680</td>
<td>451</td>
<td>439</td>
<td>527</td>
<td>329</td>
</tr>
<tr>
<td>August</td>
<td>680</td>
<td>451</td>
<td>440</td>
<td>527</td>
<td>330</td>
</tr>
<tr>
<td>September</td>
<td>486</td>
<td>514</td>
<td>414</td>
<td>533</td>
<td>244</td>
</tr>
<tr>
<td>October</td>
<td>487</td>
<td>514</td>
<td>415</td>
<td>534</td>
<td>245</td>
</tr>
<tr>
<td>November</td>
<td>337</td>
<td>429</td>
<td>251</td>
<td>289</td>
<td>257</td>
</tr>
<tr>
<td>December</td>
<td>338</td>
<td>429</td>
<td>251</td>
<td>289</td>
<td>258</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>5032</td>
<td>4505</td>
<td>5245</td>
<td>4021</td>
<td>3222</td>
</tr>
</tbody>
</table>

**ESTIMATED MONTHLY DOMESTIC EFFLUENT (m³)**

**AVERAGE (m³/month)**

<table>
<thead>
<tr>
<th>Month</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL</strong></td>
<td>5032</td>
<td>4505</td>
<td>5245</td>
<td>4021</td>
<td>3222</td>
</tr>
<tr>
<td><strong>AVG (m³/month)</strong></td>
<td>419</td>
<td>375</td>
<td>437</td>
<td>335</td>
<td>268</td>
</tr>
</tbody>
</table>

**AVG APRIL TO NOVEMBER (m³/month)**

### TABLE A.11. ESTIMATED TOTAL EFFLUENT DISCHARGE (EN21) FOR THE YEARS BETWEEN 2008 AND 2010, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th>Month</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>124387</td>
<td>113792</td>
<td>200</td>
</tr>
<tr>
<td>February</td>
<td>60517</td>
<td>131602</td>
<td>78187</td>
</tr>
<tr>
<td>March</td>
<td>124293</td>
<td>113792</td>
<td>102101</td>
</tr>
<tr>
<td>April</td>
<td>166927</td>
<td>119587</td>
<td>111291</td>
</tr>
<tr>
<td>May</td>
<td>118553</td>
<td>94523</td>
<td>89988</td>
</tr>
<tr>
<td>June</td>
<td>94319</td>
<td>141054</td>
<td>124152</td>
</tr>
<tr>
<td>July</td>
<td>81559</td>
<td>135396</td>
<td>108650</td>
</tr>
<tr>
<td>August</td>
<td>83367</td>
<td>128165</td>
<td>108078</td>
</tr>
<tr>
<td>September</td>
<td>91845</td>
<td>112153</td>
<td>109992</td>
</tr>
<tr>
<td>October</td>
<td>73868</td>
<td>139165</td>
<td>123377</td>
</tr>
<tr>
<td>November</td>
<td>115921</td>
<td>81160</td>
<td>98884</td>
</tr>
<tr>
<td>December</td>
<td>139076</td>
<td>251</td>
<td>144630</td>
</tr>
</tbody>
</table>

**ESTIMATED TOTAL EFFLUENT DISCHARGE - EN21 (m³)**

**TOTAL (m³/year)**

<table>
<thead>
<tr>
<th>Month</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1274630</td>
<td>1310640</td>
<td>1199530</td>
</tr>
<tr>
<td>February</td>
<td>106219</td>
<td>109220</td>
<td>99961</td>
</tr>
<tr>
<td>March</td>
<td>103295</td>
<td>118900</td>
<td>109301</td>
</tr>
</tbody>
</table>

**AVG (m³/month)**
### TABLE A.12. ESTIMATED WATER CONSUMPTION, EN8 MINUS EN21 FOR THE YEARS 2008 AND 2009, AT THE CANADIAN PLANT

**ESTIMATED MONTHLY WATER CONSUMPTION = EN8-EN21 (m³)**

<table>
<thead>
<tr>
<th></th>
<th>EN8</th>
<th>EN21</th>
<th>EN8-EN21</th>
<th>EN8</th>
<th>EN21</th>
<th>EN8-EN21</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>33643</td>
<td>124387</td>
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<td>-25940</td>
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<td>60517</td>
<td>-26448</td>
<td>76900</td>
<td>131602</td>
<td>-54701</td>
</tr>
<tr>
<td>March</td>
<td>98975</td>
<td>124293</td>
<td>-25317</td>
<td>58688</td>
<td>113792</td>
<td>-55104</td>
</tr>
<tr>
<td>April</td>
<td>104748</td>
<td>166927</td>
<td>-62180</td>
<td>91547</td>
<td>119587</td>
<td>-28040</td>
</tr>
<tr>
<td>May</td>
<td>121328</td>
<td>118553</td>
<td>2774</td>
<td>-</td>
<td>94523</td>
<td>N.C.</td>
</tr>
<tr>
<td>June</td>
<td>115192</td>
<td>94319</td>
<td>20873</td>
<td>105898</td>
<td>141054</td>
<td>-35156</td>
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<tr>
<td>July</td>
<td>118477</td>
<td>81559</td>
<td>36919</td>
<td>119099</td>
<td>135396</td>
<td>-16297</td>
</tr>
<tr>
<td>August</td>
<td>106039</td>
<td>83367</td>
<td>22672</td>
<td>122717</td>
<td>128165</td>
<td>-5449</td>
</tr>
<tr>
<td>September</td>
<td>94866</td>
<td>91845</td>
<td>3021</td>
<td>132490</td>
<td>112153</td>
<td>20337</td>
</tr>
<tr>
<td>October</td>
<td>92515</td>
<td>73868</td>
<td>18648</td>
<td>120352</td>
<td>139165</td>
<td>-18814</td>
</tr>
<tr>
<td>November</td>
<td>95893</td>
<td>115921</td>
<td>-20027</td>
<td>84074</td>
<td>81160</td>
<td>2914</td>
</tr>
<tr>
<td>December</td>
<td>79551</td>
<td>139076</td>
<td>-59525</td>
<td>-</td>
<td>251</td>
<td>N.C.</td>
</tr>
<tr>
<td><strong>TOTAL (m³/year)</strong></td>
<td>1095296</td>
<td>1274630</td>
<td>-179334</td>
<td>999618</td>
<td>1310640</td>
<td>-216249</td>
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</tbody>
</table>

**AVERAGE (m³/month)**

<table>
<thead>
<tr>
<th></th>
<th>EN8</th>
<th>EN21</th>
<th>EN8-EN21</th>
</tr>
</thead>
<tbody>
<tr>
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<td>91275</td>
<td>106219</td>
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<td>February</td>
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<td>-21625</td>
</tr>
<tr>
<td>March</td>
<td>106132</td>
<td>103295</td>
<td>2837</td>
</tr>
<tr>
<td>April</td>
<td>110882</td>
<td>118900</td>
<td>-11501</td>
</tr>
</tbody>
</table>

**Note:** A dash (-) indicates that data was not measured and N.C. indicates that data was not calculated because the flowmeter was not working.
### TABLE A.13. WATER INTENSITY BASED ON ESTIMATED WATER CONSUMPTION FOR THE YEARS 2008 AND 2009, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th></th>
<th>WATER INTENSITY BASED ON CONSUMPTION (L/tonne)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ESTIMATED CEMENT WATER PRODUCTION CP EN8 - EN21 (L)</td>
<td>WATER INTENSITY CONSUMPTION (tonnes)</td>
<td>ESTIMATED CEMENT WATER PRODUCTION CP EN8 - EN21 (L)</td>
<td>WATER INTENSITY CONSUMPTION (tonnes)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wc (L/tonne)</td>
<td></td>
<td>Wc (L/tonne)</td>
</tr>
<tr>
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<td>N.C.</td>
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<tr>
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<td>-26447803</td>
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<td>-11656</td>
<td>-54701212</td>
</tr>
<tr>
<td>March</td>
<td>-25317221</td>
<td>37926</td>
<td>-668</td>
<td>-55103701</td>
</tr>
<tr>
<td>April</td>
<td>-62179712</td>
<td>41823</td>
<td>-1487</td>
<td>-28040009</td>
</tr>
<tr>
<td>May</td>
<td>2774312</td>
<td>56914</td>
<td>49</td>
<td>N.C.</td>
</tr>
<tr>
<td>June</td>
<td>20873292</td>
<td>61349</td>
<td>340</td>
<td>-35156287</td>
</tr>
<tr>
<td>July</td>
<td>36918561</td>
<td>58875</td>
<td>627</td>
<td>-16296789</td>
</tr>
<tr>
<td>August</td>
<td>22671906</td>
<td>52591</td>
<td>431</td>
<td>-5448710</td>
</tr>
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<td>September</td>
<td>3020785</td>
<td>56384</td>
<td>54</td>
<td>20337464</td>
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<tr>
<td>October</td>
<td>18647578</td>
<td>51043</td>
<td>365</td>
<td>-18813553</td>
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<tr>
<td>November</td>
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<td>-341</td>
<td>2913697</td>
</tr>
<tr>
<td>December</td>
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<td>9909</td>
<td>-6007</td>
<td>N.C.</td>
</tr>
<tr>
<td>AVERAGE YEAR (L/tonne)</td>
<td>-1663</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVERAGE APRIL TO NOVEMBER (L/tonne)</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: N.C. indicates that data was not calculated because the plant was not producing cement or the flowmeter was not working.*
### TABLE A.14. MONTHLY CEMENT PRODUCTION FOR THE YEARS BETWEEN 2005 AND 2011, AT THE BRAZILIAN PLANT

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
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<td><strong>January</strong></td>
<td>57888</td>
<td>76593</td>
<td>62677</td>
<td>72894</td>
<td>97775</td>
<td>95320</td>
<td>115444</td>
</tr>
<tr>
<td><strong>February</strong></td>
<td>63397</td>
<td>73614</td>
<td>71349</td>
<td>95952</td>
<td>96059</td>
<td>105302</td>
<td>117096</td>
</tr>
<tr>
<td><strong>March</strong></td>
<td>71141</td>
<td>78755</td>
<td>78839</td>
<td>94608</td>
<td>113143</td>
<td>127481</td>
<td>137069</td>
</tr>
<tr>
<td><strong>April</strong></td>
<td>69117</td>
<td>73600</td>
<td>70106</td>
<td>88271</td>
<td>108215</td>
<td>108624</td>
<td>120956</td>
</tr>
<tr>
<td><strong>May</strong></td>
<td>66178</td>
<td>73280</td>
<td>67073</td>
<td>99090</td>
<td>111272</td>
<td>122786</td>
<td>126883</td>
</tr>
<tr>
<td><strong>June</strong></td>
<td>72858</td>
<td>72474</td>
<td>78062</td>
<td>98425</td>
<td>103539</td>
<td>115656</td>
<td>133095</td>
</tr>
<tr>
<td><strong>July</strong></td>
<td>76884</td>
<td>69958</td>
<td>77639</td>
<td>115027</td>
<td>102527</td>
<td>111969</td>
<td>128083</td>
</tr>
<tr>
<td><strong>August</strong></td>
<td>71560</td>
<td>67168</td>
<td>81382</td>
<td>111323</td>
<td>113770</td>
<td>121704</td>
<td>127771</td>
</tr>
<tr>
<td><strong>September</strong></td>
<td>63191</td>
<td>60758</td>
<td>82426</td>
<td>117365</td>
<td>106122</td>
<td>134121</td>
<td>135595</td>
</tr>
<tr>
<td><strong>October</strong></td>
<td>62684</td>
<td>64973</td>
<td>88484</td>
<td>123852</td>
<td>108277</td>
<td>136378</td>
<td>157692</td>
</tr>
<tr>
<td><strong>November</strong></td>
<td>70302</td>
<td>63540</td>
<td>91045</td>
<td>111185</td>
<td>115033</td>
<td>133020</td>
<td>150702</td>
</tr>
<tr>
<td><strong>December</strong></td>
<td>83857</td>
<td>63487</td>
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<td>111871</td>
<td>103511</td>
<td>120088</td>
<td>140830</td>
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<td><strong>TOTAL</strong></td>
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<td>838200</td>
<td>938030</td>
<td>1239862</td>
<td>1279241</td>
<td>1432449</td>
<td>1591217</td>
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<td></td>
<td><strong>AVERAGE</strong></td>
<td><strong>(tonne/year)</strong></td>
<td></td>
<td><strong>(tonne/month)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td><strong>January</strong></td>
<td>69088</td>
<td>69850</td>
<td>78169</td>
<td>103322</td>
<td>106603</td>
<td>119371</td>
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### TABLE A.15. MONTHLY GROUNDWATER INTAKE FOR THE YEARS BETWEEN 2005 AND 2011, AT THE BRAZILIAN PLANT

<table>
<thead>
<tr>
<th>MONTHLY GROUNDWATER INTAKE (m$^3$)</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>2565</td>
<td>4589</td>
<td>3130</td>
<td>3499</td>
<td>2999</td>
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<td>4741</td>
</tr>
<tr>
<td>February</td>
<td>2412</td>
<td>4614</td>
<td>2729</td>
<td>3163</td>
<td>4251</td>
<td>4288</td>
<td>4565</td>
</tr>
<tr>
<td>March</td>
<td>3199</td>
<td>5823</td>
<td>2791</td>
<td>2566</td>
<td>3931</td>
<td>4743</td>
<td>3233</td>
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<tr>
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<td>2540</td>
<td>3567</td>
<td>3870</td>
<td>5304</td>
<td>4288</td>
<td>4900</td>
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<td>May</td>
<td>3146</td>
<td>2574</td>
<td>2480</td>
<td>3513</td>
<td>3649</td>
<td>3842</td>
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<td>3016</td>
<td>-</td>
<td>3225</td>
<td>3561</td>
<td>5797</td>
<td>4176</td>
<td>4760</td>
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<tr>
<td>July</td>
<td>2510</td>
<td>-</td>
<td>3313</td>
<td>3596</td>
<td>2883</td>
<td>5377</td>
<td>4664</td>
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<td>-</td>
<td>4237</td>
<td>5409</td>
<td>4518</td>
<td>3422</td>
<td>4800</td>
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<tr>
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<td>2596</td>
<td>3606</td>
<td>5413</td>
<td>5337</td>
<td>4085</td>
<td>4500</td>
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<td>2700</td>
<td>2714</td>
<td>4101</td>
<td>4593</td>
<td>4866</td>
<td>3959</td>
<td>4400</td>
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<td>3588</td>
<td>3466</td>
<td>3719</td>
<td>4060</td>
<td>4788</td>
<td>4745</td>
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<tr>
<td>December</td>
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<td>2457</td>
<td>3438</td>
<td>5322</td>
<td>5134</td>
<td>5143</td>
<td>4261</td>
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<tr>
<td>TOTAL (m$^3$/year)</td>
<td>35328</td>
<td>32522</td>
<td>40386</td>
<td>47858</td>
<td>51913</td>
<td>53043</td>
<td>53054</td>
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<tr>
<td>AVERAGE (m$^3$/month)</td>
<td>2944</td>
<td>3614</td>
<td>3366</td>
<td>3988</td>
<td>4326</td>
<td>4420</td>
<td>4421</td>
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*Note: A dash (-) indicates that data was not measured because the flowmeter was being calibrated.*
### TABLE A.16. MONTHLY SURFACE WATER INTAKE FOR THE YEARS BETWEEN 2005 AND 2011, AT THE BRAZILIAN PLANT

<table>
<thead>
<tr>
<th>MONTHLY SURFACE WATER INTAKE (m$^3$)</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
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<td>21958</td>
<td>14525</td>
<td>15700</td>
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<td>17636</td>
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<tr>
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<td>17040</td>
<td>18253</td>
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<td>-</td>
<td>22593</td>
<td>19952</td>
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<td>20661</td>
<td>9081</td>
<td>5722</td>
<td>26320</td>
<td>-</td>
<td>21602</td>
<td>25191</td>
</tr>
<tr>
<td>April</td>
<td>4859</td>
<td>18689</td>
<td>22718</td>
<td>21599</td>
<td>-</td>
<td>21277</td>
<td>23414</td>
</tr>
<tr>
<td>May</td>
<td>18586</td>
<td>14823</td>
<td>19612</td>
<td>24708</td>
<td>21365</td>
<td>25550</td>
<td>24239</td>
</tr>
<tr>
<td>June</td>
<td>16420</td>
<td>-</td>
<td>17156</td>
<td>22436</td>
<td>23490</td>
<td>15929</td>
<td>23688</td>
</tr>
<tr>
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<td>-</td>
<td>16336</td>
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<td>-</td>
<td>17804</td>
<td>19040</td>
<td>21048</td>
<td>20844</td>
<td>19058</td>
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<tr>
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<td>5931</td>
<td>11665</td>
<td>13981</td>
<td>21703</td>
<td>21709</td>
<td>29697</td>
<td>22636</td>
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<tr>
<td>October</td>
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<td>6862</td>
<td>12166</td>
<td>22719</td>
<td>15769</td>
<td>21911</td>
<td>17677</td>
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<tr>
<td>November</td>
<td>21679</td>
<td>15635</td>
<td>16406</td>
<td>22145</td>
<td>19808</td>
<td>28385</td>
<td>25538</td>
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<td>December</td>
<td>19889</td>
<td>10024</td>
<td>16801</td>
<td>26656</td>
<td>22383</td>
<td>24781</td>
<td>22363</td>
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<tr>
<td><strong>TOTAL (m$^3$/year)</strong></td>
<td>184722</td>
<td>126990</td>
<td>186366</td>
<td>266550</td>
<td>188048</td>
<td>269629</td>
<td>272174</td>
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<tr>
<td><strong>AVERAGE (m$^3$/month)</strong></td>
<td>15394</td>
<td>14110</td>
<td>15531</td>
<td>22213</td>
<td>20894</td>
<td>22469</td>
<td>22681</td>
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</table>

*Note:* A dash (-) indicates that data was not measured because the flowmeter was being calibrated.
### TABLE A.17. MONTHLY TOTAL WATER WITHDRAWAL FROM ALL SOURCES (EN8) FOR THE YEARS BETWEEN 2005 AND 2011, AT THE BRAZILIAN PLANT

<table>
<thead>
<tr>
<th>MONTHLY TOTAL WATER WITHDRAWAL - EN8 (m$^3$)</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
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</thead>
<tbody>
<tr>
<td>January</td>
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<td>26547</td>
<td>17655</td>
<td>19199</td>
<td>25926</td>
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<tr>
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<td>22867</td>
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<td>-</td>
<td>26881</td>
<td>24517</td>
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<td>-</td>
<td>26177</td>
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<td>17397</td>
<td>22092</td>
<td>28221</td>
<td>25014</td>
<td>29392</td>
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<td>-</td>
<td>20381</td>
<td>25997</td>
<td>29287</td>
<td>20105</td>
<td>28448</td>
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<td>July</td>
<td>18935</td>
<td>-</td>
<td>19649</td>
<td>30037</td>
<td>22432</td>
<td>24801</td>
<td>25190</td>
</tr>
<tr>
<td>August</td>
<td>20611</td>
<td>-</td>
<td>22041</td>
<td>24449</td>
<td>25566</td>
<td>24266</td>
<td>23858</td>
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<td>14261</td>
<td>17587</td>
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<td>27046</td>
<td>33782</td>
<td>27136</td>
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<td>27312</td>
<td>20635</td>
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<td>12481</td>
<td>20239</td>
<td>30178</td>
<td>27717</td>
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<td>26624</td>
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<td>TOTAL (m$^3$/year)</td>
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<td>226752</td>
<td>314408</td>
<td>227491</td>
<td>322672</td>
<td>325228</td>
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<tr>
<td>AVERAGE (m$^3$/month)</td>
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<td>17724</td>
<td>18896</td>
<td>26201</td>
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<td>26889</td>
<td>27102</td>
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</table>

*Note: A dash (-) indicates that data was not measured simultaneously for both sources, because the flowmeter was being calibrated.*
### TABLE A.18. SUMMARY OF WATER WITHDRAWAL, CEMENT PRODUCTION AND WATER INTENSITY FOR THE YEARS BETWEEN 2005 AND 2011, AT THE BRAZILIAN PLANT

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th></th>
<th>2006</th>
<th></th>
<th>2007</th>
<th></th>
<th>2008</th>
<th></th>
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</thead>
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<td>CEMENT</td>
<td>PRODUCTION</td>
<td>INTENSITY</td>
<td>TOTAL WATER</td>
<td>CEMENT</td>
<td>PRODUCTION</td>
<td>INTENSITY</td>
</tr>
<tr>
<td></td>
<td>ENS (Litres)</td>
<td>CP (Tons)</td>
<td></td>
<td>(L/Tone)</td>
<td>ENS (Litres)</td>
<td>CP (Tons)</td>
<td></td>
<td>(L/Tone)</td>
</tr>
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<td>57035</td>
<td>201</td>
<td>26547000</td>
<td>76593</td>
<td>347</td>
<td>17455800</td>
<td>61977</td>
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<td>22867000</td>
<td>73614</td>
<td>311</td>
<td>15858000</td>
<td>71349</td>
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<tr>
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<td>71411</td>
<td>335</td>
<td>14964000</td>
<td>78775</td>
<td>379</td>
<td>25139000</td>
<td>73439</td>
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<td>69117</td>
<td>107</td>
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<td>73600</td>
<td>302</td>
<td>26585000</td>
<td>70106</td>
</tr>
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<td>21732000</td>
<td>66173</td>
<td>328</td>
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<td>22992600</td>
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<td>301</td>
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<td>-</td>
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<td>-</td>
<td>67160</td>
<td>292</td>
<td>22841000</td>
<td>81692</td>
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<td>61654</td>
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<td>19728000</td>
<td>91945</td>
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<td>63487</td>
<td>197</td>
<td>20839000</td>
<td>81949</td>
</tr>
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</table>

#### AVERAGE YEAR (Litres)

|          | 2005   |      | 2006   |      | 2007   |      | 2008   |      |
|          |        |      |        |      |        |      |        |      |
| TOTAL WATER | 265 |      | 254 |      | 262 |      | 254 |      |

Note: A dash (-) indicates that data was not measured and N.C. indicates that data was not calculated because water intake was not measured.
TABLE A.19. MONTHLY CLINKER PRODUCTION FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th>MONTHLY CLINKER PRODUCTION (tonnes)</th>
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<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
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<td>0</td>
<td>47162</td>
<td>22450</td>
<td>68923</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>40621</td>
<td>56173</td>
<td>55224</td>
</tr>
<tr>
<td>March</td>
<td>0</td>
<td>42977</td>
<td>15248</td>
<td>63551</td>
<td>10951</td>
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<td>46460</td>
<td>65194</td>
<td>39906</td>
<td>68227</td>
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<td>67117</td>
<td>60371</td>
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<td>30541</td>
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<td>54092</td>
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<td>63823</td>
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<td>53224</td>
<td>62065</td>
<td>65434</td>
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<td>61185</td>
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<td>59086</td>
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<td>60946</td>
<td>36920</td>
<td>61117</td>
<td>46595</td>
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<tr>
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<td>63099</td>
<td>10776</td>
<td>0</td>
<td>70956</td>
<td>58357</td>
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<td>TOTAL (tonnes/year)</td>
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<td>506050</td>
<td>550684</td>
<td>650495</td>
<td>634726</td>
</tr>
</tbody>
</table>

| AVERAGE (tonnes/month)              | 44479| 42171| 45890| 54208| 52894|

| AVERAGE APRIL TO NOVEMBER (tonnes/month) | 58831| 56537| 55957| 54671| 55159|
### TABLE A.20. WATER USAGE INSIDE THE RAW MATERIAL MILL PER TONNE OF CLINKER PRODUCED FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th>2009</th>
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<th>2010</th>
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<th>2011</th>
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</thead>
<tbody>
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<td></td>
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<td>CLinker</td>
<td>WATER</td>
<td>CLinker</td>
<td>WATER</td>
<td>CLinker</td>
<td>WATER</td>
<td>CLinker</td>
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<tr>
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<td>SPRAY</td>
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<td>PRODUCTION</td>
<td>SPRAY</td>
<td>PRODUCTION</td>
<td>SPRAY</td>
<td>PRODUCTION</td>
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<td>PRODUCTION</td>
<td>SPRAY</td>
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</tr>
<tr>
<td></td>
<td>(litres)</td>
<td>(tonnes)</td>
<td>(litres)</td>
<td>(tonnes)</td>
<td>(litres)</td>
<td>(tonnes)</td>
<td>(litres)</td>
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<td>(litres)</td>
<td>(tonnes)</td>
<td>(litres)</td>
<td>(tonnes)</td>
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</tr>
<tr>
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<td>-</td>
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**Note:** A dash (-) indicates that data was not measured for the full month and N.C. indicates that data was not calculated because there was no clinker production or the volume of water sprayed was not available.

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**AVERAGE YEAR (L/tonne)**

| 2007 | 19 | 19 | 25 | 20 | 9 |

| 2008 | 18 | 20 | 20 | 18 | 8 |

**Note:** A dash (-) indicates that data was not measured for the full month and N.C. indicates that data was not calculated because there was no cement production or the volume of water sprayed was not available.
### TABLE A.22. WATER USAGE INSIDE THE CONDITIONING TOWERS PER TONNE OF CLINKER PRODUCED FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

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**Average Year (L/tonne)**: 144 124 115 118 102

**Average April to November (L/tonne)**: 149 123 118 128 111

*Note: N.C. indicates that data was not calculated because there was no clinker production.*
TABLE A.23. WATER USAGE INSIDE THE CONDITIONING TOWERS PER TONNE OF CEMENT PRODUCED FOR THE YEARS BETWEEN 2007 AND 2011, AT THE CANADIAN PLANT

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AVERAGE YEAR (L/tonne) | 116 | 129 | 123 | 127 | 119
AVERAGE APRIL TO NOVEMBER (L/tonne) | 126 | 127 | 119 | 127 | 116

Note: N.C. indicates that data was not calculated because there was no cement production.
### TABLE A.24. MONTHLY CLINKER PRODUCTION FOR THE YEARS BETWEEN 2007 AND 2011, AT THE BRAZILIAN PLANT

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<td>52970</td>
<td>66581</td>
<td>88493</td>
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<td>99912</td>
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<tr>
<td>AVERAGE APRIL TO NOVEMBER</td>
<td>(tonnes/month)</td>
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<td>90131</td>
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APPENDIX B

SUMMARY OF PORTABLE FLOWMETER PROCEDURE AT THE CANADIAN PLANT

The flowmeter used by this researcher was a portable transit time ultrasonic device, with clamp-on transducers — also called sensors — for non-invasive liquid measurement. The available clamp-on transducers were suitable for pipes with diameters from 15 mm to 6,000 mm (1/2" to 240"). The flowmeter used has an internal data logger to record the following parameters of interest for this research: flow rate, date, total flow and signal condition. A portable ultrasonic thickness gauge was also used, to measure the pipe wall thickness where the flowmeter was to be installed.

The optimum positioning of the transducers had to meet requirements such as being positioned on a certain length of straight pipe and being located at a certain distance from tube fittings and adaptors. These requirements were dependent on pipe characteristics: diameter, wall thickness and material. Moreover, the pipe needed to be completely full of liquid at all times. Furthermore, the pipe surface had to be clean and some coupling compound had to be applied to the spots where transducers were to be installed. The cable for upstream and downstream sensors had to be correctly connected according to the flow direction. When properly installed, and if the battery had more than 3.9 Volts, the device would indicate in its display a signal strength higher than the number 50.
The types of installation selected for this research, based on the equipment’s manual and the existing pipe diameters, were the V-method or the Z-method. In the V-method, also called reflective mode, the transducers are located on the same side of the pipeline and are aligned. The distance between them is a function of the characteristics of the pipelines. In the Z-method, the sensors are installed on opposite sides of the pipe, also at a certain distance determined as a function of pipe characteristics.

The first procedure was to calibrate the equipment. The flowmeter was then positioned near a built-in flowmeter in order to calibrate its measurements. For this test, the portable flowmeter was positioned on the pipe connected to one of the pumps for withdrawing groundwater because it was the easiest to access. That pipe is made of cast iron, with a wall thickness of 4.2 mm and outer diameter of 100 mm. The installation followed the “V-method”. After following the procedures to ensure a proper installation, there was one condition that could not be met: necessary distance between the sensors and tube fittings and adaptors. The reason was that the accessible length of the pipe was too short. The flowmeter was started, but the signal obtained was indicated as “poor” in the equipment display. An initial troubleshooting procedure was then started to evaluate whether the portable flowmeter was being used incorrectly, beyond the lack of distance between sensors and tube connections. The flowmeter was removed, the pipe surface was cleaned one more time with sandpaper, and transducers were relocated on top of more coupling compound. The coupling compound was added under the transducers to improve the signal transmission. The amount of coupling compound was then increased to make sure there were no air-gaps between the transducers and the pipe, but the signal obtained did
not improve. The upstream and downstream cables of the sensors were all checked for proper assembly, but the signal was not appropriate. Under those conditions, the portable flowmeter read about 48 litres per hour of water being withdrawn. However, this figure was almost three times lower than the flow rate measured at the plant’s meter at that time, which was 133 litres per hour. Many questions arose around this issue but data from the built-in flowmeter were expected to be correct, as that device had been calibrated recently at that time. Contacts with the portable flowmeter manufacturer were initiated and some potential errors were evaluated. The trouble appeared to be that the distance between the transducers and tube connections was shorter than required. According to the manufacturer’s information, insufficient straight-pipe may lead to turbulent flow, which can interfere with signal. This situation could not be fixed because at that locale there was no other accessible spot with a longer piece of pipeline. Another potential source of error is related to the condition of the old pipes that may not be allowing proper frequency output, because of either the rusty outside or potential internal fouling. No pictures could be taken at that spot.

The portable flowmeter was then moved to another area of the plant, also with a built-in flowmeter installed, to perform a second calibration test. For this trial the straight length of the pipe met the requirements. The pipe used was the pipe for the effluent discharge from the settling pond to the river. That pipe is made of carbon steel; it has a wall thickness of 8.8 mm, and outer diameter of 200 mm (Figure B.1). The installation followed the “V-method” and the sensors were about 190 mm apart (Figure B.2). However, the data acquisition was even worse than the first trial as no signal strength
could be obtained. Once again, a troubleshooting procedure was performed but did not result in any improvement of the signal strength. The reason for having no signal at this point was probably that the pipe was not permanently full of liquid, which interferes with signal strength, according to the manufacturer’s information.

Figure B.1. Installation of portable flowmeter at effluent discharge pipe at plant studied in Canada. Photo by plant’s environmental coordinator.
Therefore, a third place for testing the flowmeter was selected, where there is also a built-in flowmeter. This time, the portable flowmeter was installed at the quarry, on the pipe for water withdrawal from the limestone quarry to the river. This point is outside of the boundaries for investigating water usage for this research, but the trial was performed anyway to check whether any data could be obtained with the available flowmeter. The quarry pipe is made of carbon steel, with a wall thickness of 12.5 mm and an outer diameter of 323 mm. The installation followed the “Z-method” and the sensors were about 180 mm apart (Figure B.3 and Figure B.4). Once again, no signal could be obtained. The reason is likely to be again that the pipe was not permanently full of water, or that the conditions of the old and rusty pipes were not allowing proper frequency output, because of either the rusty outside or potential internal fouling.
Figure B.3. Installation of portable flowmeter at water withdrawal pipeline from limestone quarry to the river at plant studied in Canada. Photo by author.

Figure B.4. Z-method of installation for transducers at water withdrawal pipeline from limestone quarry to the river at plant studied in Canada. Photo by author.
It was learned from the tests described that the available flowmeter was inappropriate to collect data under the existing conditions of pipelines at the Canadian cement plant. One main reason is the insufficient straight pipe length, because of the many pipe fittings and pipe adaptors around the areas where it was possible to access pipelines. One example is of the water tank for the cement mill, which had no place to install the portable flowmeter because of existing tube connections (please see Figure 5.3, Chapter 5). This scenario also exists in other areas of the plant where pipes have many tube connections (Figure B.5).

Another potential reason that the flowmeter could not work properly is the fact that the outside shells of pipes where the transducers are to be attached should be clean. At the plant being studied, pipes were rusted. Even with the attempt to use sandpaper to clean
the surface, probably that condition did not allow the pair of transducers to properly send signals between themselves. Moreover, internal fouling may also have affected the frequency between transducers.

Another aspect that probably led to failure of measurement with the available flowmeter was that the pipes should be permanently full of water to obtain a proper signal. The water flow is variable under regular operational conditions at the plant and consequently the pipes would not have been full of water at all times.

Further discussion was initiated with the manufacturer of the portable flowmeter to try to solve the problems described; however, this discussion resulted in the conclusion that the available equipment was not suitable for measuring water flow under the typical scenario at cement plants.
APPENDIX C

ESTIMATED CONSUMPTION OF POTABLE WATER IN BUILDING CONSTRUCTION

(Abbreviated version of paper from Brown et al. 2012a, in Portuguese: “Estimativa do Consumo de Água Potável na Construção de Edificações”)

Brown, Elisabeth P. S.; Müeller, J.; Bezerra, S. M.C.; Farahbakhsh, Khosrow

Conference paper presented at: XV Symposium Luso-Brazilian of Sanitary and Environmental Engineering (XV SILUBESA), March 18-22, 2012, Belo Horizonte, Brazil

Abstract: This abbreviated version of the paper presents the main results of a study that evaluated mains water usage during the construction of two residential buildings called “Building A” and “Building B”, in the city of Curitiba (state of Paraná), in the South of Brazil. The initial objective was to investigate total water usage at the two construction sites but only mains water withdrawal was measured in both of them. Moreover, for Building A, the first 15 months of construction did not have any record of quantity of water withdrawal. Therefore, the final objectives were to investigate: (1) mains water withdrawal per constructed area (cubic metre of water per square metre of floor space built), (2) mains water usage per stage of construction, and (3) mains water usage for workers’ needs. Results show that mains water withdrawal per constructed area was 0.08 m³/m² (Building A) and 0.16 m³/m² (Building B). It should be noted that for Building A the total mains water withdrawal was available for 28 out of the 43 months of construction, thus this should be the reason for the lower rate of water per constructed area. The investigation of water usage per stage of construction was not conclusive due to overlap of activities at the construction site. The investigation of water usage for workers was also not conclusive due to a lack of precise information about the number of labourers at the sites, although it pointed to considerable demand for potable water for workers’ needs. In summary this study suggests that for proper investigation of water usage at construction sites, it is essential to measure all sources of water withdrawn to the construction site from the start of construction activities. Results also suggest that to investigate water usage for labourers’ needs, it is necessary to track the daily number of workers at the construction site. Moreover, this investigation points to the need for implementing best water management practices to reduce mains water usage at construction sites.
1. **Introduction**

Water is used at the construction site for preparing and curing of concrete and mortar; soil compaction; dust control; cleaning tools and equipment; workers’ needs; and for commissioning and tests. Despite the importance of water to construction projects, water is generally not treated as a construction material, probably because it represents a small percentage of the project’s cost. This has been noted in the budgets of engineering projects, in which the cost of water is generally not included, even considering, for instance, the quantity of water used in soil compaction that may reach up to 300 litres of water per cubic metre of soil compacted) (Filho Neto 2008). In addition, water wastage is common at construction sites (Dantas Neto 2008; Pessarello 2008; Souza and Müller 2009). Therefore, the quantification of water usage at construction sites is necessary to identify the construction stages that require more water, and to evaluate opportunities for water savings. Furthermore, an estimation of water usage may serve as a benchmark for establishing best water management practices. Based on that need, the objectives of this study were to investigate: (1) mains water usage per constructed area (cubic metre of water per square metre of floor space built), (2) water usage per stage of construction, and (3) water usage for workers’ needs.

2. **Characteristics of Buildings**

Two recently constructed residential buildings were selected for this study. These buildings were located in the city of Curitiba, in the state of Paraná, in the South of Brazil. For this study they are called “Building A” and “Building B”. Some characteristics of these buildings are included in Table C.1. For Building A, data of mains water withdrawal were obtained from the municipal water supply company, but were not available for the entire period of construction. For Building B, data of mains water withdrawal were provided by the construction company based on their water bills. The total area indicated in the construction project and the related mains water withdrawal were used to calculate water usage per constructed area.

<table>
<thead>
<tr>
<th>BUILDING</th>
<th>CONSTRUCTED AREA (m²)</th>
<th>CONSTRUCTION PERIOD (months)</th>
<th>MAINS WATER WITHDRAWAL (m³)</th>
<th>MONTHLY MAINS WATER USAGE (m³/month)</th>
<th>MAINS WATER USAGE PER CONSTRUCTED AREA (m³/m²)</th>
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<tr>
<td>A</td>
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<td>43</td>
<td>1,094 (between month 16 and 43)</td>
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<tr>
<td>B</td>
<td>3,547</td>
<td>12</td>
<td>554</td>
<td>46</td>
<td>0.16</td>
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</table>
3. Mains Water Usage at the Construction Sites

It should be noted that in addition to mains water, other sources of water were also used but not measured. For Building A, the water from a well was also used in nearly 20 of the 43 months of the construction period. For Building B, rainwater harvested was also used in 3 of the 12 months of its construction period. Due to the lack of measurement of these alternative water sources, the estimates of water usage per constructed area include only mains water (Table C.1), thus they represent the consumption of potable water. The monthly mains water withdrawal are included in Figure C.1 (Building A) and in Figure C.2 (Building B).

![Figure C.1 Available monthly mains water withdrawal for Building A.](image)

For Building A (Figure C.1), only mains water withdrawal from the 16th month of construction was considered for calculating water usage, because data from the previous months were not available. The total mains water measured at the construction site between months 16 and 43 resulted in 0.08 m³/m² (cubic metres of mains water per square metre of floor space). For Building B (Figure C.2), data about mains water withdrawal was available for the entire period of construction and resulted in 0.16 m³/m² (cubic metres of mains water per square metre of floor space). However, it should be recalled that these figures did not represent the total volume of water used for the execution of the construction project, because of the use of alternative water sources that were not measured.
These authors attempted to evaluate the quantity of water usage per stage of construction but results were not conclusive\textsuperscript{14}.

4. **Water Usage for Workers’ Needs at the Construction Sites**

The number of workers at the construction site was provided only by Building B’s construction company. The construction company for Building A did not have these data available. Therefore, the estimate of water usage for workers’ needs was calculated only for Building B. The number of workers at that construction site varied from 17 to 33 according to estimates made by the trainee engineer at the site. He mentioned that these numbers were not tracked properly because the practice of hiring subcontracted labourers meant that these numbers were monitored only by the subcontracted company, which did not provide any data. This fact represented a challenge to estimating proper numbers of water usage for workers’ needs. However, the monthly volume of mains water usage was calculated assuming that each worker consumed 45 litres of water daily, and accounting for the days of work per month, as indicated in previous studies (Silva 2006). Results showed that the total water usage for workers’ needs (around 300 m\textsuperscript{3}) reached approximately 54 percent of total mains water withdrawal (554 m\textsuperscript{3}), thus the demand for potable water was considerable at that construction site. Once again it should be recalled that harvested rainwater was also used but not measured at that construction site, so the percentage here indicated is accounting exclusively for mains water. In any case, these

\textsuperscript{14} In the original paper in Portuguese there is some speculation but they are not included here due to insufficient scientific value. The reason for doubtful evaluation was lack of measurement of alternative water sources and overlap of activities at the two construction sites studied.
are preliminary data for water usage at construction sites but, as indicated before, they lack accuracy\textsuperscript{15}.

5. Conclusion

The results indicate that the mains water withdrawal per constructed area was 0.08 m\textsuperscript{3}/m\textsuperscript{2} (Building A) and 0.16 m\textsuperscript{3}/m\textsuperscript{2} (Building B). The difference between these figures may be attributed to the fact that in Building A data was only available from the 16\textsuperscript{th} month of construction. Therefore, if mains water withdrawal from the previous months were accounted for, water usage per constructed area for Building A would probably be greater. The relationship between water usage and specific construction stages could not be calculated due to the lack of measurement of all water sources used and the overlap between several activities in the construction of the buildings. It is estimated that water usage for workers’ needs contributed to the considerable demand for potable water, but accurate numbers of workers at the site were not available. This study pointed out that for the proper evaluation of water usage at construction sites, it is critical to have accurate measurement of water withdrawal, including all sources used, from the beginning of construction. Despite the considerable demand for potable water for workers’ needs, some alternative water sources can be used for other activities at construction sites, thus reducing potable water usage for buildings under construction. Moreover, using water-saving devices such as low flow toilets and raising awareness among workers would also contribute to water savings at construction sites. Further studies should be based on construction sites where all water sources are measured and a proper monitoring of number of workers is in place, not to mention the need of recording for construction stages through the entire period of construction.

6. References


Pessarello, Regiane G. 2008. Estudo Exploratório Quanto Ao Consumo De Água Na Produção De Obras De Edifícios: Avaliação e Fatores Influenciadores [Investigative study of water consumption in the production of buildings’ projects: evaluation and influential factors]. Edited by Especialização em

\textsuperscript{15} Some other speculation and details of this study were presented in a monograph (only published in Portuguese) that was resultant from a research project conducted by this author and two undergraduate students (Souza and Müeller 2009).
Tecnologia e Gestão na Produção de Edifícios. São Paulo, Brazil: Escola Politécnica da Universidade de São Paulo.


APPENDIX D

WATER CONSUMPTION AND REUSE AT A READY-MIXED CONCRETE PLANT IN CURITIBA-PR

(Abstract from Bezerra et al. 2008, in Portuguese: “Consumo de água e reúso em uma indústria de concreto dosado em central fixa em Curitiba-PR”)

Bezerra, Stella M.C.; Kirsch, Gabriela; Irume, Carynne A; Davidovicz, Sérgio; Farahbakhsh, Khosrow

Conference paper presented at: IV Workshop on Water Management and Reuse in Industry, November 20-22, 2008, Florianópolis, Brazil

Abstract: Ready-mixed concrete production requires large volumes of water as input for mixing water and also for concrete mixer truck washing. The objectives of this study were to evaluate water usage at one ready-mixed concrete plant. Three sources of mixing water were investigated, including recycled effluent (truck washing effluent), rainwater and mains water. A case study was developed at a plant called Concrebras, located in Curitiba, Paraná. The results indicated that the water consumption from mains water could be reduced with the implementation of rainwater storage tanks. Some of the physical, chemical and microbiological parameters for the recycled effluent and rainwater did not meet the local standards for mixing water. However, simple treatment would provide adequate safety characteristics; as well, all sources of mixing water produced samples with similar compressive strength. Further research is necessary to propose more efficient systems for effluent recycling and rainwater harvesting at that plant.

Paper not translated due to copyright issues.
APPENDIX E

QUALITY OF RAINWATER IN THE CITY OF CURITIBA, BRAZIL FOR USE IN BUILDING CONSTRUCTION

(Abbreviated version of paper from Brown et al. 2012b, in Portuguese: “Qualidade da Água de Chuva para ser Utilizada na Construção de Edificações”)

Brown, Elisabeth P. S.; Müller, J.; Bezerra, S. M.C.; Farahbakhsh, Khosrow

Conference paper presented at: XV Symposium Luso-Brazilian of Sanitary and Environmental Engineering (XV SILUBESA), March 18-22, 2012, Belo Horizonte, Brazil

Abstract: This translated paper presents the main results of a study that evaluated the feasibility of using harvested rainwater in the construction of buildings. In addition, some evaluation was also performed regarding non-potable uses for harvested rainwater in buildings after occupation. Samples of rainwater were collected in four locations in the city of Curitiba (state of Paraná), in the South of Brazil. The quality of harvested rainwater in Curitiba was compared to several national and international standards of water quality for use in buildings under construction and after occupation. Results showed that the harvested rainwater was suitable for use in several activities at construction sites, such as the preparing and curing of concrete and mortar, soil compaction, washing of aggregates, and dust control. Disinfection of harvested rainwater may be necessary for non-potable uses in buildings after occupation. The substitution of rainwater for potable water is feasible for many non-potable uses and may represent around fifty percent of the total water usage at construction sites. Saving potable water is in accordance with best water management practices for the construction industry.

1. Introduction

A portion of the water used for activities at construction sites does not need to be potable, but can be replaced with some types of recycled effluent or rainwater. Potable water demand for workers’ needs may represent around 50 percent of the total water usage at construction sites (Souza and Müller 2009), and there is no substitute for this purpose. However, the use of alternative sources of water during the construction of a project is applicable for many other activities, although is not yet a common practice. This translated paper presents a short summary of an investigation of the quality of rainwater in the city of Curitiba (state of Paraná), in the South of Brazil, for non-potable uses at two construction sites of residential buildings. Such knowledge is needed to allow the broader use of rainwater for buildings under construction.
2. **Materials and Methods**

Samples of rainwater were collected directly from the sky (called atmospheric rainwater) and from gutters after flowing on roof surfaces (called roof rainwater). These samples were collected in four different neighborhoods in the city of Curitiba called: Água Verde, Centro, Novo Mundo, and Rebouças. The plastic containers used for sampling were previously sterilized with alcohol and rinsed with rainwater, and all samples were tested through physical, chemical and microbiological analyses. These analyses used the parameters outlined in the procedures of the Standard Methods for Examination of Water and Wastewater (APHA 2005) and included the following: pH, color, total solids, total suspended solids, total dissolved solids, biochemical oxygen demand, turbidity, chlorides, nitrates, lead, zinc, total and fecal coliforms. The choice of these parameters was made to compare to the selected standards of water quality for use in buildings under construction and after occupation that were:

- NM 137:1997 (NM 1997) and BS EN 1008:2002 (BS EN 2002) from the European Union, both for testing water for preparing and curing of concrete and mortar;
- a Brazilian reference translated as “Conservation and Reuse of Water in Buildings” (ANA 2006), which indicated parameters of water quality for several activities at construction sites and for other non-potable water uses; and
- NBR 15527:2007 (ABNT 2007) that is a Brazilian standard specifically for monitoring the quality of rainwater collected from roofs in urban areas, for non-potable uses.

3. **Results and Discussion**

Results suggested that rainwater harvested in Curitiba was suitable for use at construction sites, including preparing and curing of concrete and mortar, soil compaction, washing of aggregates, and dust control, without the need for any treatment. The results for total solids were below 79 mg/L. The results for total suspended solids were below 25 mg/L and for total dissolved solids were below 54 mg/L. The average pH of the samples of atmospheric rainwater collected were 6.04 (Novo Mundo), 6.30 (Água Verde), and 6.51 (Rebouças). The average pH of roof rainwater were 6.68 (Novo Mundo) and 6.66 (Centro). It was expected that the pH of samples of roof rainwater were slightly higher than the pH of the atmospheric rainwater samples, due to the contact between rainwater and sediments on roofs that tends to increase their pH (Despins et al. 2009; Jaques 2005).

16 A complete description of the methodology is presented in a monograph (only published in Portuguese) that resulted from a research project conducted by this author and two undergraduate students (Souza and Müller 2009).
Irrespective of being atmospheric or roof rainwater, all samples were in accordance with the limits for pH established by the standards adopted, which vary between 4.0 and 9.0. The other physical and chemical parameters presented concentrations considerably below the limits established in the selected standards for use at construction sites. Total and fecal coliforms in the samples were below 79CFU/100 mL (MPN = most probable number). Thus, results pointed to the potential for using rainwater at construction sites in Curitiba.

Moreover, the quality of rainwater in Curitiba is also adequate for non-potable uses in buildings after occupation, provided disinfection is performed. The reason is that only around 33 percent of samples were in conformity with the Brazilian standard (ABNT 2007), which recommends absence of fecal coliforms in a 100 mL sample. However, most samples (approximately 94%) were in conformity with the maximum limit for turbidity of 5.0 NTU (nephelometric turbidity unit), for non-potable needs in buildings after occupation, according to the Brazilian standard NBR 15527:2007 (ABNT 2007). All samples presented color below 2.5 uH (except one), and were lower than the maximum limit of 15 uH (Hazen unit), also in accordance with that Brazilian standard. Therefore, the quality of rainwater in Curitiba is also adequate, after disinfection, for non-potable uses in buildings after occupation.

4. Conclusion

The quality of rainwater in the city of Curitiba (state of Paraná), in the South of Brazil, is adequate for use at construction sites, for example in the following activities: producing and curing of concrete and mortar, washing aggregates, soil compaction, and dust control. Moreover, rainwater harvesting for non-potable uses in buildings after occupation is also feasible, provided disinfection. The substitution of potable water for rainwater should be encouraged in the construction industry.

5. References


APHA (American Public Health Association), AWWA (American Water Works Association), and WEF (Water Environment Federation). 2005. Standard Methods for the Examination of Water and


APPENDIX F

PUBLICATIONS DOCUMENTING RESEARCH BY THIS AUTHOR INTO WATER USAGE IN THE CONSTRUCTION INDUSTRY


Abstract: This paper presents an investigation of the rainfall data available from three different governmental meteorological stations in the city of Curitiba, state of Paraná, in the south of Brazil. They were called: INMET (National Meteorology Institute), SUDERHSA (The Superintendency for the Development of Hydric Resources and Environmental Sanitation) and SIMEPAR (Technology Institute of Paraná). Ultimately only INMET data was used, because INMET was the oldest meteorological office in the city and consequently had more sets of data available. The results showed that from the years 1924 to 2008, the average annual urban rainfall was 1428.5 mm. The highest rates occurred in the months of January (average 191.5 mm) and February (average 160.0 mm). The lowest rates occurred from April to August (monthly average 86.7 mm). As this study was based solely on data from one local office, the conclusions presented should not be used for designing urban storm management systems. This study showed that the total annual rainfall, and its distribution over a period of 12 months, were favorable for implementing rainwater harvesting systems for non-potable uses in the City of Curitiba.
INVESTIGAÇÃO DO ÍNDICE PLUVIOMÉTRICO EM CURITIBA-PR, ENTRE 1924 E 2008

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Resumo – Este estudo realizou um levantamento de dados de pluviometria na cidade de Curitiba, estado do Paraná, em três estações meteorológicas diferentes, operadas por órgãos distintos. A estação mais antiga, e consequentemente com maior número de dados, é a do INMET e, portanto, a análise foi realizada a partir desses dados. Ao avaliar os dados das precipitações diárias dos anos de 1924 a 2008, encontrou-se uma média da precipitação total anual de 1428,5 mm. Ao considerar as médias por períodos de 10 anos, na década de 1990 houve um pico, que foi de 1646,8 mm, em relação à média das demais décadas. Ainda não é possível concluir se esta década atual (a partir de 2000), será confirmada a tendência de aumento da média da precipitação total anual, pois faltam os dados de 2009. Apenas os dados futuros poderão confirmar se a aumenta da precipitação a partir de 1990 será mantida, e se este fato está associado às recentes mudanças climáticas. Vale ressaltar que esta análise foi realizada com dados de apenas uma estação meteorológica e que as conclusiones encontradas não são apropriadas para dimensionamento de obras de drenagem urbana. Com os dados obtidos foi comprovado que o índice pluviométrico em Curitiba, bem como a distribuição do regime de chuvas ao longo do ano, favorece o investimento em sistemas de captação de água de chuva para fins não-potáveis.

Palavras-chave: água de chuva, Curitiba, pluviômetro.

Abstract - This paper presents an investigation on the rainfall data available from three different governmental sources in the City of Curitiba, state of Paraná, south of Brazil. The oldest meteorological office in the city, and consequently with more sets of data available, is named INMET. The evaluation on the urban rainfall over the years was based solely on their data. Results showed that from the year of 1924 to 2008 the average annual urban rainfall is 1428.5 mm. When considering periods of 10 years, in the 1990’s there was a higher average annual rainfall of 1646.8 mm. It is not possible to indicate if the current decade, from the year 2000, will follow the increasing trend of annual rainfall, as data from 2009 is not complete. Future research will show if the annual rainfall is increasing and so reflecting climate changing. This study was based solely on data from one local office and the conclusions presented shall not be used for designing urban storm management systems. From this study, it has been shown that the annual rainfalls, and its distribution over the months, indicate a considerable potential for rainwater harvesting systems for non-potable uses, in the City of Curitiba.

Keywords: rainwater, Curitiba, rainfall data.

INTRODUÇÃO

A precipitação é um dos fatores que afetam vários setores da sociedade, como: o abastecimento de água doméstico e industrial, a produção agrícola, o planejamento urbano, entre outros. Isso é devido a sua grande variabilidade, tanto em quantidade, quanto em duração e tempo de ocorrência. Nos estudos climatológicos, a temperatura do ar e as precipitações têm recebido destaque para avaliar a ocorrência de mudanças climáticas, visando identificar fatores naturais e antropogênicos responsáveis por tais alterações. Aliado a isto, o aproveitamento de água de chuva para fins não-potáveis vem ganhando destaque como alternativa para economia de água potável. Na cidade de Curitiba, capital do Paraná, é obrigatória a instalação de sistemas de captação de águas de chuva para aproveitamento em
fins não-potáveis, em todas as novas edificações, que solicitaram alvará de construção desde março de 2007[1],[2],[3].

**Objetivo.** Por essas razões, este trabalho teve como objetivo caracterizar o índice pluviométrico da cidade de Curitiba – PR, para posterior investigação do potencial de aproveitamento da água de chuva para fins não-potáveis.

**Curitiba-PR.** A cidade de Curitiba está situada na região sul do Brasil, e apresenta clima temperado (ou subtropical) umido, mesotérmico, sem estação seca, com verões frescos e invernos com geadas frequentes [4].

**Estações meteorológicas.** Para monitorar, informar e realizar previsões de natureza meteorológica, hidrológica e ambiental há alguns órgãos como o Instituto Nacional de Meteorologia (INMET), ligado ao Ministério da Agricultura, Pecuária e Abastecimento; que mantém uma rede de observação em nível nacional. A rede de estações meteorológicas do INMET é constituída por [5]: estação de observação de altitude ou de radiossonda; estação meteorológica de observação de superfície automática e estação meteorológica de observação de superfície convencional. Na cidade de Curitiba estão localizadas as duas últimas estações, localizadas atualmente no Centro Politécnico da UFPR (Universidade Federal do Paraná), operando desde 1911 e 2003 respectivamente. Nas são analisados parâmetros meteorológicos como: pressão atmosférica, temperatura e umidade relativa do ar, precipitação, radiação solar, direção e velocidade do vento [6]. A estação convencional disponibiliza dados de precipitações diários desde o ano de 1924. As estações se diferem no método de coleta dos dados. A estação automática utiliza-se de pluviômetro automático que envia os dados automaticamente a cada hora. A estação convencional utiliza pluviômetros manuais, que são lidos por um observador a cada intervalo de seis horas e os envia a um centro coletor por um meio de comunicação via telefone [7]. No Paraná, os dados meteorológicos também são coletados pelo órgão estadual do Instituto Tecnológico SIMEPAR. A estação de Curitiba situa-se também dentro do Centro Politécnico, dividindo o espaço com as estações meteorológicas do INMET. Os dados de precipitação são medidos com auxílio de pluviógrafo, instalado desde 1997. Outro órgão estadual que coleta os dados pluviométricos de Curitiba é a SUDERHSA (Superintendência de Desenvolvimento de Recursos Hídricos e Saneamento Ambiental). Sua estação está localizada na PUCPR (Pontifícia Universidade Católica do Paraná) do campus do Prado Velho. A análise é feita por meio de pluviômetro manual. A estação possui registros desde 1981 [8]. Existem outros pluviômetros instalados em Curitiba, mas esta pesquisa foi embasada nos dados obtidos a partir dos três órgãos descritos acima: INMET, SIMEPAR e SUDERHSA.

**METODOLOGIA**

Foram identificados os principais pontos de coleta de dados pluviométricos existentes em Curitiba, e os respectivos responsáveis pela disponibilização dos dados. Contatos foram feitos para solicitação dos valores dos índices pluviométricos diários em cada estação, para todos os dados disponíveis. Em seguida, iniciaram-se as visitas às estações, para acompanhamento dos procedimentos de rotina de coleta dos dados meteorológicos. Por fim, foi escolhido como objeto de estudo os dados de precipitação obtidos pela estação meteorológica convencional do INMET, por apresentar número de dados registrados. Estes dados foram utilizados para totalizar (em períodos de 10 anos) as precipitações mensais e anuais, assim como avaliar as respectivas médias, para investigar se ocorreram variações nos índices pluviométricos anuais, ao longo das últimas décadas.
RESULTADOS E DISCUSSÕES

Analisando as Figuras 1 e 2, verifica-se que ao longo dos anos a média das precipitações totais anuais não apresentou grandes variações, mantendo uma média de 1428,5 mm com desvio padrão de 93,7; desde 1924 até 2008, exceto pela década de 1990 que resultou uma média maior (1646,8 mm). A Figura 2 mostra a precipitação total anual por ano entre 1924 a 2008. Os anos que apresentaram os menores valores para precipitação total anual foram 1933 e 1985 com 795,2 mm e 765,5 mm respectivamente. Em contrapartida, os anos de maior abundância de chuvas foram 1957, 1983 e 1998, apresentando 2165,2 mm; 1992,7 mm e 2071,2 mm respectivamente.

Quanto à distribuição de precipitação ao longo dos meses, podemos observar, conforme nos mostra a Figura 3, que em geral o comportamento entre épocas mais chuvosas e secas não tem se alterado. As precipitações mais abundantes ocorrem nos meses de janeiro (em média 191,5 mm) e fevereiro (em média 160,0 mm) e vão diminuindo até o mês de abril (em média 80,6). Os meses entre abril e agosto apresentam as menores precipitações do ano (média dos cinco meses: 86,7 mm), e tornam a aumentar entre o mês de setembro até o mês de dezembro (média de dezembro: 144,6 mm). Alguns casos que se distanciaram desse padrão, como o período de 1924 a 1930 e 1961 a 1970 que apresentaram um pico de precipitação no mês de junho (128,6 mm e 128,2 mm respectivamente), e o período de 1991 a 2000 que se constatou uma elevada precipitação no mês de janeiro (241,7 mm), fevereiro (221,8 mm) e setembro (185,6 mm), acima da média dos demais períodos.
Estudos anteriores indicam que a média da precipitação pluviométrica anual em Curitiba, no período entre 1921 e 1963, era de 1394 mm. Os dados obtidos no presente trabalho, com dados entre 1924 e 2008, indicam um pequeno aumento, sendo a média 1428,5 mm.

**Figura 3. Médias das precipitações acumuladas mensais.**

**CONCLUSÕES**

A média da precipitação total anual entre 1924 e 2008 é 1428,5 mm. Ao considerar as médias por períodos de 10 anos, a década de 1990 foi 1646,8 mm, portanto maior em relação à média das demais décadas. Ainda não é possível concluir se nesta década atual (a partir de 2000), será confirmada a tendência de aumento, pois faltam dados de 2009. Apenas os dados futuros poderão confirmar se o aumento da precipitação a partir de 1990 será mantido, e se este fato está associado às recentes mudanças climáticas. A análise realizada neste trabalho utilizou dados de apenas uma estação meteorológica e não se recomenda utilizar estas conclusões para dimensionamento de obras de drenagem urbana. Para isto seriam necessários dados de outras estações meteorológicas próximas de Curitiba, a fim de efetuar tratamento estatístico de validação dos dados e de variáveis hidrológicas como: período de recorrência, intensidade das chuvas, entre outros. Com os dados obtidos fica comprovado que o índice pluviométrico em Curitiba, bem como a distribuição do regime de chuvas ao longo do ano, favorece o investimento em sistemas de captação de água de chuva para fins não-potáveis.

**REFERÊNCIAS**


Abstract: This paper presents the results of a preliminary investigation study of the influence of climate change on the behavior of rainfall rates in the city of Curitiba, state of Paraná, in the south of Brazil. Data were collected at the oldest meteorological station in the city with information from the years 1924 to 2008, when this research was being carried out. The parameter investigated was simple averages of monthly and annual precipitation. Results showed that the average annual urban rainfall was 1428.5 mm. The years from 1980 to 1990 had a higher than average annual rainfall of 1646.8 mm. As this study was based solely on data from one local office, the conclusions presented here should not be used for designing urban storm management systems. Future research should statistically validate the data and include other hydrological variables such as the period of recurrence and intensity of rains, in order to evaluate whether average annual rainfall is varying and so reflecting climate change.

Paper not included due to copyright issues.

Abstract: Ready-mixed concrete production requires large volumes of water as input for mixing water and also for concrete mixer truck washing. The objectives of this study were to evaluate water usage at one ready-mixed concrete plant. Three sources of mixing water were investigated, including recycled effluent (truck washing effluent), rainwater and mains water. A case study was developed at a plant called Concrebras, located in Curitiba, Paraná. The results indicated that the water consumption from mains water could be reduced with the implementation of rainwater storage tanks. Some of the physical, chemical and microbiological parameters for the recycled effluent and rainwater did not meet the local standards for mixing water. However, simple treatment would provide adequate safety characteristics; as well, all sources of mixing water produced samples with similar compressive strength. Further research is necessary to propose more efficient systems for effluent recycling and rainwater harvesting.

Paper not included due to copyright issues.

Abstract: This paper presents an investigation of the Program for Water Conservation and its Rational Use in Buildings (also known as PURAE), in the city of Curitiba, state of Paraná, south of Brazil. PURAE was first proposed in 2003, following amendments by municipal decrees in 2006 and 2007. This program required all new buildings to have rainwater harvesting systems, water-saving devices, and effluent recycling. In addition, flowmeters should be installed at each residential unit inside condominiums. The assessment of PURAE was based on a review of similar programs existing in Brazil and on interviews with stakeholders. Results indicated that PURAE was an important tool for allowing water savings in the city but should be improved to incorporate information on instrumenting its implementation. Future amendments to PURAE should include information on proper cleaning of rainwater storage tanks, parameters for monitoring rainwater quality and recycled effluent, obligation to include proper identification of these installations, as well as definition of a permanent advisory committee. This committee should have stakeholders from regulatory agencies, users and researchers.

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RESUMO

Este trabalho apresenta um estudo das exigências impostas pelo Programa de Conservação e Uso Racional da Água nas Edificações – PURAE, da cidade de Curitiba-PR. Dentro das suas exigências estão a captação e o aproveitamento da água de chuva, o uso de dispositivos hidráulicos redutores do consumo de água, o uso de hidrômetros individuais em condomínios, e o reuso da água servida. O PURAE foi criado pela Lei Municipal Nº10.785/2003 e regulamentado pelos Decretos Municipais Nº293/2006 e 212/2007. Para avaliar a opinião dos profissionais sobre o PURAE, foram entrevistados funcionários da prefeitura, responsáveis técnicos por obras em andamento e projetistas hidráulicos. As respostas mostraram que existem dúvidas sobre o PURAE e que seu funcionamento está aquém do objetivo do programa. Foi feito um levantamento de legislações semelhantes ao PURAE existentes em outras cidades brasileiras, para traçar propostas de aprimoramento para o programa, e a realização de estudos de caso em edificações residenciais localizados em Curitiba-PR. Conclui-se que o PURAE é um programa importante para a cidade, mas não contém todas as informações para o seu funcionamento adequado. Para otimizar este programa recomenda-se incluir na legislação: os indicadores de qualidade da água de chuva e da água servida, para garantir seus usos sem o comprometimento da saúde pública; a obrigatoriedade de sinalização deste sistema ou da utilização de sistemas de acesso restrito, para evitar usos indevidos destas águas; a orientação sobre a manutenção e limpeza dos reservatórios destas águas não potáveis e a implantação de um grupo gestor deste programa, composto por pessoal de órgãos governamentais e não governamentais, sociedade civil e universidades.

PALAVRAS-CHAVE: PURAE, Curitiba-PR, água, edificações

INTRODUÇÃO

A busca de fontes alternativas de captação de água, a conservação e o uso racional dos recursos hídricos são estratégias de gestão ambiental indispensáveis para combater o problema da escassez da água causado pelo aumento excessivo do consumo deste recurso natural, decorrente do crescimento demográfico, do desenvolvimento industrial e da expansão do cultivo irrigado. Uma das alternativas para a conservação dos recursos hídricos é projetar edificações visando à redução do consumo de água potável, quando esta não é necessária.

A Lei Nº10.785, de 18 de setembro de 2003, criou no Município de Curitiba o Programa de Conservação e Uso Racional da Água nas Edificações – PURAE. Essa lei previa para as novas edificações a utilização de fontes alternativas para a captação de água, que compreendem a captação das águas pluviais e a reutilização das águas servidas para a descarga dos vasos sanitários. Nas ações de conservação e uso racional da água, a lei abordava a utilização de dispositivos hidráulicos redutores do consumo de água, como: bocas sanitárias de

Surgiu então a importância em avaliar como está o funcionamento deste Programa junto à Prefeitura Municipal de Curitiba, para averiguar se todas as partes envolvidas, sejam os construtores, os funcionários da prefeitura e os moradores, estão atingindo as metas de uso sustentável da água estabelecidas neste programa. O objetivo principal deste estudo foi avaliar as exigências estabelecidas pelo PURAE em Curitiba e propor medidas para sua otimização.

MATERIAIS E MÉTODOS

Para a elaboração do trabalho foram realizadas as seguintes etapas: (1) levantamento do histórico da legislação que criou o PURAE em Curitiba, através da pesquisa da Lei Nº 10.785 e dos Decretos Municipais 293/2006 e 212/2007; (2) verificação do funcionamento do PURAE, pela realização de entrevistas na Secretaria Municipal de Urbanismo, da Prefeitura Municipal de Curitiba, para investigações sobre o programa; (3) levantamento de legislações existentes em outras cidades do Brasil para fazer um comparativo com o PURAE, trazendo propostas para o aprimoramento do programa em Curitiba; (4) realização de três estudos de casos em edificações residenciais localizadas em Curitiba que já estão utilizando alguma medida que reduza o consumo de água potável, com visita técnica nas áreas selecionadas, para conhecimento das medidas, registro de imagens e para a coleta dos dados e (5) análise crítica do PURAE e proposta de medidas para a otimização do programa.

RESULTADOS

Através da metodologia acima citada foram coletados e analisados dados que estão aqui apresentados per etapa da investigação.

Levantamento do histórico da lei e dos decretos que regulamentaram o PURAE em Curitiba-PR

O PURAE foi criado no Município de Curitiba-PR, pela Lei Nº 10.785, de 18 de setembro de 2003. Esse programa tem como principal objetivo estabelecer medidas que induzam a conservação, uso racional e utilização de fontes alternativas para captação de água nas novas edificações (CURITIBA, 2003).

Após a criação da Lei Municipal Nº 10.785/2003 foi necessário aproximadamente 2,5 anos para ser instituído em Curitiba o Decreto Nº 293, em 22 de março de 2006 (CURITIBA, 2006), que regulamentou o PURAE no município. Dentre as exigências do Decreto Nº 293 estão:

- utilização de dispositivos hidráulicos reduutores do consumo de água, tais como: bacias sanitárias de volume reduzido de descarga e torneiras dotadas de aceladores;
- instalação de hidrômetros para a medição individualizada do volume de água nos edifícios de habitação coletiva cuja área total construída por unidade seja igual ou superior a 250 m²; em todas as construções de habitações unifamiliares em série e nos conjuntos habitacionais independentes da área construída;
- implantação de um sistema de captação de águas de chuva nas coberturas das edificações, sendo esta água direcionada e armazenada em reservatório próprio para posterior utilização em atividades que não exigem o uso da água potável e
- instalação de um sistema de coleta e tratamento de águas servidas nas edificações comerciais e industriais com área compatível construída igual ou superior a 5.000 m², para ser reutilizada em atividades onde não é necessário o uso da água potável.

Somente em 2007, quando entrou em vigor o Decreto Municipal Nº 212, trazendo o novo Regulamento de Edificações do Município de Curitiba que o PURAE efetivamente passou a ser implantado para os novos pedidos de árvore de construção. A Tabela 1 relaciona os tipos de edificações com as respectivas exigências do PURAE.
### Tabela 1 - Exigências do PURAE para as edificações

<table>
<thead>
<tr>
<th>Tipos de Edificações</th>
<th>Exigências</th>
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<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Habitação unifamiliar</td>
<td>x</td>
</tr>
<tr>
<td>Habitação de uso institucional</td>
<td>x</td>
</tr>
<tr>
<td>Habitação transitéria 1 (apartamento, hotel e pensão)</td>
<td>x</td>
</tr>
<tr>
<td>Habitação transitéria 2 (hotel)</td>
<td>x</td>
</tr>
<tr>
<td>Habitação transitéria 3 (molte)</td>
<td>x</td>
</tr>
<tr>
<td>Comunitário 1 - ensino, assistência social e biblioteca</td>
<td>x</td>
</tr>
<tr>
<td>Comunitário 2 - lazer, cultura, ensino, saúde e culto religiosos</td>
<td>x</td>
</tr>
<tr>
<td>Comunitário 3 - lazer e ensino</td>
<td>x</td>
</tr>
<tr>
<td>Comércio e serviço até 400 m²</td>
<td>x</td>
</tr>
<tr>
<td>Posto de abastecimento</td>
<td>x</td>
</tr>
<tr>
<td>Habitação coletiva e ou conjunto residencial (edifícios com área total construída por unidade igual ou superior a 250 m² e nas residências isoladas)</td>
<td>x</td>
</tr>
<tr>
<td>Habitação unifamiliar em série</td>
<td>x</td>
</tr>
<tr>
<td>Casas populares em série</td>
<td>x</td>
</tr>
<tr>
<td>Comércio e serviço acima de 400 m²</td>
<td>x</td>
</tr>
<tr>
<td>Edifício de escritórios</td>
<td>x</td>
</tr>
<tr>
<td>Estacionamento comercial</td>
<td>x</td>
</tr>
<tr>
<td>Centro comercial</td>
<td>x</td>
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<tr>
<td>Super e hipermercado</td>
<td>x</td>
</tr>
<tr>
<td>Lava rápido</td>
<td>x</td>
</tr>
<tr>
<td>Clínica e ambulatório</td>
<td>x</td>
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<tr>
<td>Indústria</td>
<td>x</td>
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Fonte: (Elaborado a partir de CURITIBA, 2007).
Observações: 1 captação e aproveitamento da água de chuva; 2 dispositivos hidráulicos redutores do consumo de água; 3 hidrômetros individuais e 4 sistema de coleta e tratamento das águas servidas.

x* é apenas para as edificações com área computável construída igual ou superior a 5.000 m²

Algumas edificações concluídas entre 2006 e 2007 já vinham adotando medidas como a captação de água de chuva, a instalação de hidrômetros individualizados e o uso de vaso sanitários com caixa acoplada, mesmo sem a exigência da legislação. Três destas edificações serviram como estudo de caso para esta avaliação do PURAE.

### Verificação do funcionamento do PURAE

Desde março de 2007, no pedido do alvará de construção, o responsável técnico pela obra e o proprietário assinaram um termo de compromisso declarando que o projeto de instalações hidráulicas e a construção atenderão integralmente às exigências do Decreto Municipal N° 293/2006, sendo apresentado à devida ART (anotação de responsabilidade técnica) do projeto. Ao final da construção, quando os técnicos da prefeitura efetuam a fiscalização da obra para a expedição do certificado de vistoria, é verificado se a edificação está de acordo com todas as exigências do PURAE, e a liberação do certificado está condicionada ao seu atendimento.

Foram entrevistados vinte e três funcionários dos setores de pedido de alvará de construção da Prefeitura Municipal de Curitiba – PMC, e com as respostas obtidas conclui-se principalmente que:

- 57% das dúvidas mais frequentes dos profissionais que dão entrada com o pedido de alvará de construção na PMC dizem respeito aos requisitos que devem ser implantados na edificação e 17% sobre o sistema de captação de água de chuva;
- a reação dos profissionais perante o PURAE é cerca de 40% discordam, 30% concordam e 30% indecisos;
- cerca de 43% dos funcionários da Prefeitura que são responsáveis pelo atendimento aos profissionais que vão fazer o pedido do alvará de construção ainda têm dúvidas sobre o PURAE.
Foram entrevistados dez profissionais que deram entrada no pedido de alvace de construção após a exigência de cumprimento do PURAE e com as respostas obtidas conclui-se que:
- 70% dos profissionais entrevistados foram solicitados para o atendimento do PURAE e 30% obtiveram o alvace de construção sem nenhuma solicitação para atendimento ao programa;
- 80% destes profissionais possuem dúvidas sobre o PURAE e
dentre os dez entrevistados 80% acreditam que o PURAE é viável técnica e economicamente.

Novas entrevistas estão sendo realizadas para aumentar a amostragem.

**Levantamento de legislações semelhantes em outras cidades do Brasil**

No Brasil existem em diversos municípios leis que regulamentam programas relacionados ao uso sustentável da água nas edificações e algumas destas serviram de base para a avaliação do PURAE de Curitiba estão indicados na Tabela 2.

<table>
<thead>
<tr>
<th>Município</th>
<th>Estado</th>
<th>Legislação (mês – ano)</th>
</tr>
</thead>
<tbody>
<tr>
<td>São José</td>
<td>SC</td>
<td>Lei Nº 4.682 (Dezembro/2003)</td>
</tr>
<tr>
<td>São Paulo</td>
<td>SP</td>
<td>Lei Nº 14.018 (Junho/2005)</td>
</tr>
<tr>
<td>Campinas</td>
<td>SP</td>
<td>Decreto Nº 47.731 (Setembro/2006)</td>
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<td>Catas do Sul</td>
<td>RS</td>
<td>Lei Nº 12.474 (Janeiro/2006)</td>
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<td>Amparo</td>
<td>SP</td>
<td>Lei Nº 3.286 (Junho/2007)</td>
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<td>Cascavel</td>
<td>PR</td>
<td>Lei Nº 4.631 (Agosto/2007)</td>
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a) **Município do Rio de Janeiro**

Em 30 de janeiro de 2004 foi criado o Decreto Nº 23.940 que tornou obrigatória para as edificações que tenham área superior a 500 m², a construção de reservatórios para a detenção temporária das águas pluviais, prevenindo assim possíveis inundações. Além disso, reservatório para a detenção das águas pluviais é obrigatório para novas edificações industriais, comerciais e residenciais multifamiliares de 50 ou mais unidades, que apresentem área do pavimento de telhado superior a 500 m², a implantação de um outro reservatório de retenção para o aproveitamento da água de chuva em atividades que não exigem o uso da água potável (RIO DE JANEIRO, 2004).

Sempre que houver o aproveitamento das águas de chuva é necessário atender as normas sanitárias vigentes e as condições técnicas específicas estabelecidas pelo órgão municipal como: evitar o consumo indevido, definindo sinalização de alerta padronizada a ser colocada em local visível e junto ao ponto de consumo da água de chuva, determinando os tipos de utilização admitidos para esta água, alertando que a água não é potável, garantir padrões de qualidade de água apropriados ao tipo de utilização previsto, definindo os dispositivos, processos e tratamentos necessários para a manutenção desta qualidade e impedir qualquer tipo de contaminação no sistema predial destinado à água potável proveniente da rede pública de abastecimento, lembrando que o sistema de captação de água de chuva deve ser totalmente independente do sistema de água potável.

Para o pedido do certificado de conclusão da obra deve ser apresentada uma declaração, assinada pelo profissional responsável da obra e pelo proprietário, de que a edificação atende aos requisitos do Decreto Municipal Nº 23.940 (Rio de Janeiro), com uma breve descrição do sistema instalado, e que os reservatórios e as instalações destinadas a captação da água de chuva para o aproveitamento estão de acordo com as normas vigentes e as condições técnicas específicas estabelecidas pelo órgão municipal responsável pela Vigilância Sanitária e também pelo órgão responsável pela drenagem urbana.
b) Município de São Paulo

Em 28 de junho de 2005, foi criada a Lei N° 14.018 que abrange as novas edificações, os bens imóveis do Município de São Paulo e também as novas edificações de interesse social. Para as edificações já existentes são estudadas soluções técnicas e medidas de incentivo para a adaptação (SÃO PAULO, 2005).

Dentro as ações da Lei Municipal N° 14.018 (São Paulo) estão: o uso de dispositivos hidráulicos economizadores de água, como, bacias sanitárias de volume reduzido de descarga, torneiras dotadas de arejadores, chuveiros e lavatórios com volume fixo de descarga e a instalação de hidrômetros individualizados; captação e aproveitamento de águas de chuva e o reúso das águas servidas (SÃO PAULO, 2005).

Para a regulamentação da Lei N° 14.168 foi instituído o Decreto N° 47.731, em 28 de setembro de 2006 (SÃO PAULO, 2006), o qual visou a implementação do 'Grupo Gestor do Programa'. Este grupo, composto por diversos representantes dos órgãos municipais e estaduais, possui as seguintes atribuições: pesquisar, coibir, divulgar e incentivar a implantação de soluções técnicas aplicáveis aos projetos de novas edificações, bem como à adaptação das já existentes; recomendar a utilização de fontes alternativas para a captação de água e o seu reúso nas novas edificações, e práticas que proporcionem a economia e o combate ao desperdício da água; promover eventos sobre temas ligados à água na cidade de São Paulo, em parceria com instituições públicas; analisar a viabilidade de aplicação de propostas ofertadas pelas instituições públicas e privadas, organizações não-governamentais, comunidades científicas e população e informar à Secretaria Municipal de Gestão das novas soluções técnicas e ações recomendadas, além de propor para a Prefeitura de São Paulo a elaboração e alteração da legislação municipal vigente, com o fim de estabelecer a obrigatoriedade da adoção dos novos soluções técnicas.

c) Campinas – SP

Em 16 de janeiro de 2006, foi criada a Lei Municipal N° 12.474 que abrange as novas edificações de interesse social, de propriedade do Estado, da União ou do Município, assim como a adaptação dos bens imóveis do município, ao prazo de 10 anos (CAMPINAS, 2006).

Dentro as ações da Lei N°12.474 (Campinas) estão: o uso racional de água com um eficiente combate ao desperdício quantitativo e a redução das perdas de vazamento; o aproveitamento de água de chuva, que deverá ser entendido como o conjunto de ações que possibilitem a captação, tratamento e monitoramento da qualidade e distribuição para o uso em atividades menos nobres: irrigação, lavagem de pisos, etc; o reúso das águas servidas, que deve ser entendido como as que já foram utilizadas primeiramente em tanques, máquinas de lavar, chuveiros e banheiras, para utilização em atividades menos nobres e o uso de dispositivos hidráulicos como: bacias sanitárias com volume de descarga reduzido, chuveiros e lavatórios com volumes fixos de saída de água, torneiras e válvulas de fechamento automático, arejadores e bacias sanitárias de volume reduzido de descarga e a instalação de hidrômetro para medição individualizada em edifícios residenciais e comerciais.

Nesta lei é alertado que os hidrômetros que forem usados para os edifícios residenciais, e comerciais devem estar de acordo com as exigências do INMETRO, ou outra que a substituir, além de serem submetidos a ensaios devidamente comprovados por laudos técnicos de órgãos competentes, atestando que o referido equipamento está de acordo com as Normas Brasileiras (CAMPINAS, 2006).

São desenvolvidos estudos para a efetiva aplicação dos sistemas redutores do consumo de água nos projetos das novas edificações, além de soluções técnicas e um programa de estímulo à adaptação das edificações já existentes. Instituições públicas, privadas e a comunidade científica são convidadas a participar das discussões e apresentar sugestões eficientes para o programa. Conforme a lei, o Poder Executivo cria uma comissão de estudos, controle e gestão da conservação e uso racional da água, composta por diversos representantes de várias instituições, que tem a função de definir as ações de implantação do programa (CAMPINAS, 2006).
Estudos de casos em três edifícios residenciais localizados em Curitiba

As três edificações residenciais selecionadas para os estudos de casos foram concluídas antes da obrigatoriedade do PURAE, mas por decisões voluntárias dos construtores foram contemplados nas obras os dispositivos hidráulicos redutores do consumo de água, hidrômetros individualizados e a captação e o aproveitamento da água de chuva.

a) Edifício A

O edifício A (figura 1) possui 46 apartamentos e 2 coberturas duplex, totalizando 48 unidades habitacionais. As áreas dos apartamentos variam entre 288 e 535 m², e o número de quartos por apartamento é 3 ou 4, dependendo da planta. A água da chuva é captada na cobertura do edifício, com uma área de aproximadamente 300 m², e conduzida através de caixas e condutores verticais para um reservatório de PVC localizado no subsolo do jardim frontal do prédio. Este reservatório é exclusivo para o aproveitamento de água de chuva, com capacidade de armazenamento de 5000 litros. O tratamento desta água coletada é feito passando por um filtro na entrada do reservatório, conforme mostra a Figura 2.

Figura 1: Edifício A

Figura 2: Filtro

A água captada fica disponível para o uso em seis torneiras de acionamento restrito, localizadas no pavimento térreo (figura 3). O objetivo desta restrição é evitar o uso indevido da água destas torneiras pelos moradores, uma vez que esta água não é potável. Esta água é utilizada para a lavagem de pisos e rega de jardins (figura 4). As torneiras de acesso restrito funcionam somente com uma chave destacável que fica com o pessoal responsável pela manutenção do prédio.

Figura 3: Torneira de acesso restrito

Figura 4: Uso da água de chuva coletada
b) Edifício B

O edifício B (figura 5) é construído em duas torres, totalizando 45 unidades habitacionais, sendo 14 apartamentos de 3 quartos e 31 com 2 quartos, e a área dessas unidades variam de 126 a 350 m². Esta obra foi entregue em abril de 2007, sendo que a solicitação do alvará de construção foi feita antes da obrigatoriedade do PURAE, mas também por opção da construtora o edifício contempla um sistema de captação de águas de chuva, o uso de hádrometros individualizados e de vasos sanitários com caixa acoplada de volume reduzido.

O sistema de aproveitamento da água de chuva capta a água do pavimento térreo, através de ralos (figura 6), e a água da cobertura, utilizando caixas e condutores verticais, a área de captação é de aproximadamente 400 m². A água coletada é levada a um reservatório de concreto armado exclusivo para o aproveitamento das águas de chuva, com capacidade de armazenamento de 10.000 litros, localizado no subsolo do prédio. Além do reservatório para o aproveitamento da água de chuva, o edifício também possui um reservatório de concreto armado para a detenção de cheias, com capacidade de 21.350 litros, localizada no subsolo do prédio.

Figura 5: Edifício B
Figura 6: Ralos localizados no pavimento térreo

O tratamento da água de chuva coletada é feito por um sistema de grades metálicas, para reter as partículas maiores como folhas (figura 7). A água coletada fica disponível para o uso em sete torneiras convencionais (figura 8) localizadas no pavimento térreo, sendo bombeada após passar pelas grades. Esta água é utilizada para a lavagem de pisos e rega de jardins. Durante a visita ao edifício, foi sugerido ao engenheiro da obra a substituição das torneiras abastecidas por águas pluviais, por torneiras de acionamento restrito, considerando que esta água não é potável, evitando assim possíveis usos indevidos.

Figura 7: Sistema de grades metálicas
Figura 8: Torneiras convencionais
b) Edifício C

O edifício C (figura 9) é construído em duas torres com 7 andares cada, sendo um apartamento por andar, totalizando 14 unidades habitacionais, com 639 m² e 4 quartos. A água de chuva é captada da cobertura do edifício, através de calhas e condutores verticais, e conduzida até um reservatório de concreto armado, localizado no subsolo do prédio, com capacidade de armazenamento de 38.000 litros, exclusivo para o aproveitamento da água de chuva. (figura 10).

O tratamento da água de chuva coletada é feito através de um filtro composto por telas, no qual a água passa antes de ser armazenada no reservatório. Esse filtro retém apenas partículas maiores (figura 11).

![Figura 9: Edifício C](image1)

![Figura 10: Reservatório](image2)

![Figura 11: Sistema de grades](image3)

![Figura 12: Bombas usadas para o sistema de captação de água de chuva](image4)

A água coletada é bombada até a cobertura do edifício (figura 13) para quatro reservatórios de concreto armado, com volume de 8.600 litros cada, de uso exclusivo para o armazenamento da água de chuva, sendo dois reservatórios em cada torre do edifício. Estes reservatórios armazenam a água que será utilizada para abastecer a descarga de todos os vasos sanitários do prédio. Além do abastecimento dos vasos sanitários a água de chuva também é utilizada para a irrigação dos jardins e para a lavagem dos pisos. Esta água fica disponível somente aos funcionários do prédio, com o uso de torneiras de acesso restrito (figura 14). Para garantir a segurança dos moradores e dos funcionários, todos foram alertados que é utilizado a água de chuva na descarga dos vasos sanitários.
Análise crítica do PURAE e proposição de medidas para o aprimoramento do programa

Através da realização deste estudo, até este momento, foram constatados alguns aspectos positivos, entre eles:

a) é um instrumento que pode ser utilizado para a sensibilização da população sobre a importância da conservação dos recursos hídricos;

b) as exigências são obrigatórias apenas para as novas edificações, não exigindo adaptação nas obras antigas, o que pode gerar custos elevados;

c) a obrigatoriedade da utilização de dispositivos hidráulicos economizadores de água resulta em economia no consumo de água;

d) a obrigatoriedade da instalação de higrômetros individualizados possibilita o controlo do volume consumido de água por unidade;

e) a implantação de um sistema de captação de água de chuva nas edificações proporciona benefícios como a redução do consumo de água potável, a contribuição para a redução das enchentes, a redução dos custos para manutenção e ampliação dos redes de drenagem urbana, e da mesma forma, a redução dos custos para manutenção e ampliação das redes de distribuição de água potável;

f) o reuso de águas servidas para fins não potáveis reduz o consumo de água proveniente da rede pública de abastecimento. O fato desta exigência ser obrigatória somente para as edificações comerciais e industriais, com área igual ou superior a 5.000 m² facilita a implantação do sistema.

Entre os aspectos que merecem revisão neste programa temos:

a) falta a criação de um grupo gestor do PURAE, assim como foi implantado no Decreto Nº 47.731/06 (Município de São Paulo). Este grupo poderia contribuir para a permanente avaliação do programa e colaborar para o debate de soluções técnicas específicas;

b) falta especificar aos usuários as normas sanitárias vigentes para estes reservatórios de água não potável, assim como foi apresentado no Decreto Nº 23.940/04 (Municipio do Rio de Janeiro). Essas condições são necessárias para garantir a eficiência do sistema e a segurança para o consumidor, portanto deveriam ser consideradas para o PURAE em Curitiba;

c) falta a detecção de indicadores da qualidade das águas de chuva armazenadas para aproveitamento em fins não potáveis e das águas servidas para reúso, com seus respectivos usos para não oferecer riscos à saúde dos usuários;

d) no PURAE não está indicada a exigência de que as instalações de águas não potáveis sejam sinalizadas para evitar o consumo indevido pelos usuários, e que sejam totalmente independentes dos outros sistemas de água potável.

Portanto, até esta etapa de avaliação são propostas as seguintes medidas para otimização do PURAE:

a) a criação de um grupo gestor do programa ou de uma comissão de estudos, assim como foi implantado no Decreto Nº 47.731/06 (Município de São Paulo) e na Lei Nº 12.474/06 (Campinas). Este grupo poderia colaborar para esclarecer as dúvidas dos profissionais, para sugestir soluções técnicas e estudar medidas mais eficientes para serem implantadas nas edificações;
b) a divulgação e sensibilização da população sobre a importância do PURAE, através de campanhas publicitárias, palestras, congressos, seminários e debates sobre os benefícios trazidos pelo programa ao meio ambiente e a população e
c) a implantação de normas sanitárias para sistemas de aproveitamento de água de chuva.

CONCLUSÕES

No presente estudo verificou-se que o programa de conservação e uso racional da água nas edificações PURAE, existente em Curitiba-PR não apresenta todas as informações necessárias para o seu funcionamento adequado. Conclui-se também que o programa carece de maior divulgação acerca de seus objetivos e requisitos junto aos profissionais da construção civil e da população em geral. Outro aspecto muito importante é que sejam determinados os indicadores relacionando os parâmetros de qualidade da água de chuva e das águas servidas com seus potenciais usos. O aproveitamento de água de chuva é uma ação importante e que deve ser estimulada, portanto este programa deve ser revisado e permanentemente monitorado para que sua implantação seja mais eficaz e para que seus benefícios sejam maximizados.

REFERÊNCIAS BIBLIOGRÁFICAS

Abstract: This paper presents an investigation of the Program for Water Conservation and its Rational Use in New Buildings (also known as PURAE), in the city of Curitiba, state of Parana, south of Brazil. The program, launched under Municipal Bylaw Nº 10.785/2003 and the Municipal Decrees Nº 293/2006 and 212/2007, mandates that all new buildings in the city of Curitiba include rainwater harvesting systems for non-potable uses, as well as for water-saving devices. For commercial and industrial buildings with floor areas over 5000 m², wastewater should be collected, treated and reused. In order to evaluate the effectiveness of PURAE, the history of its implementation since 2003 was reviewed, and interviews were conducted in 2008 and 2010 with the city hall employees responsible for delivering the permits for new construction. The results indicate that the program is important to the city but improvement is needed in order to meet its goals. To optimize PURAE, more discussion is needed between the private and public sectors, as well as within academia, in order to clarify the program’s objectives and to mitigate some of the technical difficulties that building professionals are finding. With permanent monitoring and disclosure of its performance, the program will have a better chance of achieving its targets of motivating and implementing water conservation strategies.
POLÍTICAS PÚBLICAS PARA CONSERVAÇÃO E USO RACIONAL DE ÁGUA: ESTUDO DE CASO DO MUNICÍPIO DE CURITIBA – BRASIL

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Keywords: buildings, Curitiba, legislation, policies, PURAE, rainwater, reuse, water

Summary
This paper presents an investigation of the program for water conservation and its rational use in new buildings (also known as PURAE), in the city of Curitiba, state of Parana, southern Brazil. The program, launched under municipal bylaw No. 10.785/2003 and the municipal decrees No. 293/2006 and 212/2007, mandates that all new buildings in the city of Curitiba include rainwater harvesting systems for non-potable uses, as well as water-saving devices. For commercial and industrial buildings of over 5000 m2 of floor area, wastewater should be collected, treated and reused. In order to evaluate the effectiveness of PURAE, the history of its implementation since 2003 was researched, and interviews were conducted in 2008 and 2010 with the city hall employees responsible for delivering the permits for new constructions. The results indicated that the program is important to the city but improvement is needed in order to meet its goals. To optimize PURAE more discussion is needed between the private and public sectors, as well as with academia, in order to clarify the program’s objectives and to mitigate some of the technical difficulties the professionals are finding. With permanent monitoring and disclosure of its performance, the program will have a better chance of achieving its targets of motivating and implementing water conservation strategies in the city of Curitiba.

1. Introdução
A água doce recebe, no Brasil, tutela específica através da Lei Federal n.º 9.433/1997 que estabelece os fundamentos da Política Nacional de Recursos Hídricos (PNRH), a qual no art. 1º indica que a água é um recurso natural limitado, dotado de valor econômico, que deve ser conservado. Mesmo em regiões onde a água ainda não é percebida como recurso limitado, além da adoção de tecnologias para sua conservação e uso racional, é fundamental a implementação de programas para conscientização acerca da disponibilidade presente e futura desse recurso (Gomes e Silva, 2005). Cabe ressaltar que em diversas cidades no Brasil a água já está se tornando escassa, mas a população ainda não percebe este fato. Entre alguns exemplos de ações para a conservação dos recursos hídricos tem-se: a redução da poluição; a diminuição de perdas quantitativas nos sistemas de distribuição municipais e nas instalações prediais; a medição eficiente do consumo; e o uso de fontes alternativas para água potável, quando esta não é necessária. Não somente a utilização de tecnologias para redução do consumo, mas é fundamental implantar um eficiente sistema de gestão entre a oferta e a demanda de água, considerando ambos os aspectos quantitativos e qualitativos.

Por esta razão, nota-se que o poder público em diversas cidades vem instituindo legislações municipais para implementar programas relacionados à conservação e ao uso racional da água nas edificações. Esta base apresentada em políticas públicas deve ser coerente e eficiente, pois oferece o arcabouço legal para dar incentivo e apoio às necessárias inovações tecnológicas a serem adotadas. Para tanto, a elaboração de políticas públicas deve ser um esforço conjunto entre poder público, cidadãos, instituições de pesquisa e setor privado. Gomes et al. (2008) indicam que a indústria da construção no Brasil carece de uma rede de políticas governamentais e mecanismos regulatórios, para alavancar o estabelecimento efetivo da construção sustentável no país. Para tanto, os mesmos autores ressaltam a importância do envolvimento do poder público para a implementação de políticas públicas, através da coordenação de esforços visando à divulgação do conhecimento técnico disponível na academia, para a adoção de inovações tecnológicas pelo setor privado, e para as liberações dos financiamentos necessários para a implementação destas ações. Diante do exposto, este trabalho investigou as ações para conservação e uso racional de água, propostas no Programa de Conservação e Uso Racional da Água nas Edificações (PURAE), existente no município de Curitiba, no estado do Paraná,

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situado no Sul do Brasil.

2. Procedimentos metodológicos
Para a elaboração deste estudo foram realizadas as seguintes etapas:
1) levantamento do histórico da legislação que criou o PURAE em Curitiba, através de pesquisa da Lei Municipal Nº 10.785/2003 e dos Decretos Municipais Nºs 293/2006 e 212/2007;
2) levantamento de legislações existentes em outras cidades do Brasil, para fazer um comparativo com o PURAE, na tentativa de formular propostas para o aprimoramento deste;
3) verificação do funcionamento do PURAE, por realização de entrevistas com os técnicos responsáveis pelo setor de recepção dos pedidos de alvará de construção, na Secretaria Municipal de Urbanismo da Prefeitura Municipal de Curitiba, e com alguns profissionais que deram entrada no pedido de alvará de construção, após a efetiva implantação do PURAE em 2007 e
4) análise crítica do andamento dos três primeiros anos da implantação do PURAE (2007 a 2010) e proposição de medidas para a oprimização do programa.

O foco desta avaliação foi verificar se todas as partes envolvidas estão participando no atendimento das exigências legais do PURAE e colaborando para a conscientização quanto a conservação e uso racional da água, nas novas construções em Curitiba. A partir dessa investigação, os mecanismos legais do PURAE foram revistos e comparados com outras legislações, para a elaboração de propostas para oprimização do programa. Para analisar especificamente se a conscientização está efetivamente acontecendo outras investigações serão realizadas, no sentido de detectar se os usuários dos sistemas de fonte alternativa de água também o fazem com parcimônia.

3. PURAE em Curitiba-PR: regulamentação e exigências legais
A Lei Municipal Nº 10.785, de 18 de setembro de 2003, criou o Município de Curitiba o Programa de Conservação e Uso Racional da Água nas Edificações - PURAE. Esse programa tem como objetivo estabelecer medidas que induzam à conservação, uso racional e utilização de fontes alternativas para captação de água nas novas edificações, inclusive nas habitações de interesse social, bem como a conscientização dos usuários sobre a importância da conservação da água. O não cumprimento das exigências dessa lei implica na negativa da concessão do alvará de construção. No texto da lei está indicado que as instalações hidráulico-sanitárias devem ser projetadas para visar o conforto e segurança dos usuários, mas também a sustentabilidade dos recursos hídricos e, para tanto, os projetos devem contemplar a utilização de equipamentos hidráulicos reduutores do consumo de água, como: bacias sanitárias de volume reduzido de descarga, chuveiros e lavatórios de volumes fixos de descarga, e torneiras dotadas de arejadores. Para os condomínios, além dos equipamentos citados anteriormente, é também necessária a instalação de hidrômetros para a medição individualizada do consumo de água gasto em cada unidade. Quando a utilização de fontes alternativas para a captação de água, os projetos devem contemplar um sistema para aproveitamento de água da chuva proveniente da cobertura das edificações, para posterior utilização em fins não potáveis, e outro sistema para a reutilização das águas servidas.

Em se tratando da conscientização dos usuários, o programa enfoca o desenvolvimento de campanhas educativas nas escolas da rede pública municipal, para apresentar métodos de combate ao desperdício quantitativo de água. Ao final do texto da lei, está a indicação de que a sua regulamentação, bem como a indicação dos critérios para seu atendimento, será feita na sequência. De fato, após a publicação desta lei em 2003, seguiram-se dois decretos para regulamentar o PURAE, Decretos Municipais Nºs 293/2006 e 212/2007, onde alguns destes requisitos foram revisados e especificados apenas para algumas tipologias de edificações. No Decreto Municipal Nº 293/2006, foram especificadas as seguintes exigências:

- a implantação do sistema de captação de águas de chuva é de responsabilidade do proprietário e do profissional responsável pela execução da obra, e deve ser concluída antes de ocorrer a habitação da edificação. No ato do pedido do alvará de construção, o proprietário e o responsável técnico entregam um ‘Termo de Responsabilidade’, quanto ao atendimento do decreto;
- o dimensionamento do reservatório para aproveitamento de água de chuva é feito conforme fórmula indicada no decreto, em função da tipologia da edificação (residencial, comercial, industrial), e sempre estabelecendo um volume mínimo de 500 litros;
- a instalação de hidrômetros para a medição individualizada do volume de água será obrigatória nos edifícios de habitação coletiva, apenas quando a área total construída por unidade for igual ou superior a 250 m², porém em todas as construções de habitações unifamiliares em série, e nos conjuntos habitacionais independentes da área construída;
- no ‘Termo de Responsabilidade’ assinado pelo proprietário e pelo profissional responsável pela execução da obra, também fica implicita a ciência quanto à utilização de dispositivos hidráulicos reduutores do consumo de água, os quais foram reduzidos nas edificações habitacionais para bacias sanitárias de volume reduzido de descarga e torneiras dotadas de arejadores;
- apenas nas edificações comerciais e industriais também são exigidos equipamentos para controle de volume fixo de descarga nos pontos de consumo, por exemplo os chuveiros e lavatórios de volumes fixos de descarga, como anteriormente citado na lei e
- a instalação de um sistema de coleta e tratamento de águas servidas passou a ser obrigatório apenas
nas edificações comerciais e industriais com área computável construída igual ou superior a 5000 m², sendo estas águas servidas reutilizadas em atividades onde não é necessário o uso da água potável.

Entre as principais alterações apresentadas no decreto regulamentador (293/2006), em relação ao texto da lei inicial do PURAE, está a exigência da eliminação de reúso de águas servidas em qualquer tipologia de edificação, pois passou a ser exigido apenas para edificações comerciais e industriais de grande porte (acima de 5.000 m² de área construída).

As exigências do PURAE tornaram-se obrigatórias às novas construções somente a partir da publicação do Decreto Municipal Nº 212/2007, trazendo o novo Regulamento de Edificações do Município de Curitiba. Neste decreto (212/2007), as principais alterações em relação à lei e ao decreto anterior (293/2006) tratam da eliminação no seu texto da obrigatoriedade da utilização de chuvarões e lavatórios de volumes fixos de descarga nas edificações comerciais e industriais. Além disso, foi incluída a obrigatoriedade de atendimento às normas vigentes estaduais com relação à concepção do projeto, em função do tipo da indústria e do número de funcionários. Portanto, não estão indicados parâmetros de qualidade para monitoramento do reúso das águas servidas. É importante ressaltar que no texto do decreto 212/2007, o reúso de águas servidas em indústrias está indicado para qualquer área, mas, segundo informação obtida junto a prefeitura, isso foi por um lapso na elaboração do decreto, e de fato é apenas exigido para indústrias com área total construída acima de 5000 m². A Tabela 1 relaciona as tipologias das edificações com as respectivas exigências legais do PURAE.

Então, somente a partir de março de 2007, que efetivamente ao dar entrada no pedido de alvará de construção, o responsável técnico pela execução da obra e o proprietário assinam um termo de compromisso declarando que o projeto das instalações hidráulicas e a construção atenderão integralmente às exigências do PURAE. Ao final da construção, quando os técnicos da Prefeitura efetuam a fiscalização para a expedição do certificado de vistoria de conclusão de obra (CVCO), é verificado se a edificação está de acordo com todas as exigências do PURAE, e a liberação do CVCO é condicionada ao seu atendimento.

Tabela 1: Exigências legais do PURAE para as tipologias de edificações.

<table>
<thead>
<tr>
<th>Tipologia</th>
<th>Exigência 1</th>
<th>Exigência 2</th>
<th>Exigência 3</th>
<th>Exigência 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitação unifamiliar</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitação de uso institucional</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitação transitória</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edificação de uso comunitário (ensaio, assistência social, saúde, biblioteca, lazer, cultura e culto religioso)</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitação coletiva (mais de duas unidades autônomas agrupadas verticalmente), cuja área total construída por unidade seja menor do que 250 m²</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitação coletiva (mais de duas unidades autônomas agrupadas verticalmente), cuja área total construída por unidade seja igual ou superior a 250 m²</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Conjunto habitacional (mais de vinte unidades e/ou mais de dois edifícios no mesmo terreno), para área total construída por unidade de apartamento menor que 250 m²</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conjunto habitacional (mais de vinte residências e/ou mais de dois edifícios no mesmo terreno), para residências isoladas e para área total construída por unidade de apartamento igual ou superior a 250 m²</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Habitação unifamiliar em série (entre três e vinte unidades isoladas, agrupadas horizontalmente)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Casas populares em série (entre três e vinte unidades isoladas, agrupadas horizontalmente, cuja área total dividida pelo número de lote seja menor que 10, conforme indicação no Decreto 212/2007)</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posto de abastecimento</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comércio e serviço com área menor do que 5000 m²</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comércio e serviço com área maior do que 5000 m²</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Edifício de escritórios, Sede administrativa, Serviço público, Estacionamento comercial, Centro comercial, Shopping Center, Super e Hipermarchado, Lava rápido, Clínica e Ambulatório com área menor do que 5000 m²</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edifício de escritórios, Sede administrativa, Serviço público, Estacionamento comercial, Centro comercial, Shopping Center, Super e Hipermarchado, Lava rápido, Clínica e Ambulatório com área maior do que 5000 m²</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Indústria com área menor do que 5000 m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indústria com área maior do que 5000 m²</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Exigências: 1 = captação e aproveitamento da água da chuva das coberturas; 2 = hidrômetro para medição individualizada do consumo; e 3 = sistema de coleta e tratamento das águas servidas.

Fonte: Adaptado do Decreto Municipal Nº 212/2007 de Curitiba-PR.
4. Outras legislações municipais brasileiras que regulamentam programas de uso racional da água nas edificações

Existem em diversos municípios brasileiros legislações que regulamentam programas relacionados ao uso racional da água nas edificações. Algumas destas, que serviram de base para a avaliação do PURAE de Curitiba, são apresentadas na Tabela 2. Na sequência estão descritos alguns requisitos que constam nas legislações dos municípios do Rio de Janeiro, São Paulo e Campinas, por terem sido selecionados entre boas práticas de implementação de programas semelhantes ao PURAE. Cabe ressaltar que as informações apresentadas na Tabela 2 e as descritas nos itens 3.1 a 3.3 foram obtidas apenas por pesquisa bibliográfica. Houve diversas tentativas de obter confirmação destas informações, por telefone, direto com as respectivas prefeituras, mas não foram bem sucedidas, em função da dificuldade em encontrar os funcionários responsáveis e interessados sobre o assunto. Portanto, a descrição aqui indicada é passível de diferenças em relação ao que está efetivamente ocorrendo nos municípios.

Tabela 2 – Exemplos de outras legislações municipais sobre uso racional da água no Brasil.

<table>
<thead>
<tr>
<th>Município - Estado</th>
<th>Legislação</th>
<th>Linhas gerais</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitória – ES</td>
<td>Lei Municipal n° 7.079/2007</td>
<td>Institui o Programa de Conservação, Redução e Rationalização do Uso de Água nas Edificações Públicas</td>
</tr>
<tr>
<td>Campinas – SP</td>
<td>Lei Municipal n° 12.474/2006</td>
<td>Cria o Programa Municipal de Conservação, Uso Racional e Reutilização de Água em Edificações</td>
</tr>
<tr>
<td>Matão – SP</td>
<td>Projeto de Lei Municipal n° 042/2006</td>
<td>Cria o sistema de aproveitamento de água de chuva para usos não potáveis</td>
</tr>
<tr>
<td>Americana – SP</td>
<td>Projeto de Lei Municipal n° 093/2006</td>
<td>Cria o “Programa Uso Racional da Água”</td>
</tr>
<tr>
<td>Cascavel – PR</td>
<td>Lei Municipal n° 4.831/2007</td>
<td>Institui o programa de conservação e uso racional de água e reuso em edificações</td>
</tr>
<tr>
<td>Rio de Janeiro - RJ</td>
<td>Decreto Municipal n° 23.940/2004</td>
<td>Torna obrigatória para alguns casos, a adoção de reservatórios para o reacondicionamento da água pluvial na rede de drenagem e o aproveitamento de água de chuva para usos não potáveis</td>
</tr>
<tr>
<td>São Paulo – SP</td>
<td>Decreto Municipal n° 47.731/2006</td>
<td>Regulamenta a lei que institui o Programa Municipal de Conservação e Uso Racional da Água em Edificações</td>
</tr>
<tr>
<td>Campinas – SP</td>
<td>Lei Municipal n° 12.474/2006</td>
<td>Cria o Programa Municipal de Conservação, Uso Racional e Reutilização de Água em Edificações</td>
</tr>
<tr>
<td>Matão – SP</td>
<td>Projeto de Lei Municipal n° 042/2006</td>
<td>Cria o sistema de aproveitamento de água de chuva para usos não potáveis</td>
</tr>
<tr>
<td>Americana – SP</td>
<td>Projeto de Lei Municipal n° 093/2006</td>
<td>Cria o “Programa Uso Racional da Água”</td>
</tr>
<tr>
<td>Cascavel – PR</td>
<td>Lei Municipal n° 4.831/2007</td>
<td>Institui o programa de conservação e uso racional de água e reuso em edificações</td>
</tr>
<tr>
<td>Vitória – ES</td>
<td>Lei Municipal n° 7.079/2007</td>
<td>Institui o Programa de Conservação, Redução e Rationalização do Uso de Água nas Edificações Públicas</td>
</tr>
</tbody>
</table>

4.1. Município do Rio de Janeiro (RJ)

No Rio de Janeiro foi instituído o Decreto Municipal Nº 23.940/2004 que tornou obrigatória para as novas edificações industriais, comerciais e residenciais multifamiliares de 50 ou mais unidades, que apresentem área do pavimento de telhado superior a 500 m², a implantação de sistema de captação e aproveitamento de água de chuva para fins não potáveis. Para tanto é necessário atender as normas sanitárias vigentes e as condições técnicas estabelecidas pelo órgão municipal de vigilância sanitária. Entre as indicações desta lei encontram-se requisitos como colocar sinalização de alerta junto ao ponto de consumo da água de chuva, indicando os usos admitidos, e alertando que a água não é potável, garantir padrões de qualidade de água apropriados aos usos previstos, definindo os dispositivos, processos e tratamentos para a manutenção da qualidade, e ainda impedir contaminação no sistema predial destinado à água potável proveniente da rede pública de abastecimento, lembrando que o sistema de captação de água de chuva deve ser independente do sistema de água potável (art. 4º). Para o pedido do certificado de conclusão da obra deve ser apresentada uma declaração, assinada pelo profissional responsável, a obra e pelo proprietário, de que a edificação atende aos requisitos do Decreto Municipal N° 23.940/2004. Nesta declaração consta uma breve descrição do sistema instalado, e de que os reservatórios e as instalações de água de chuva estão de acordo com as normas vigentes e condições estabelecidas pelos órgãos municipais de vigilância sanitária e drenagem urbana (art. 7º).
4.2. Município de São Paulo (SP)

Em São Paulo foi instituída a Lei Municipal Nº 14.018/2005 e entre suas exigências legais está o uso de dispositivos hidráulicos economizadores de água como: bacias sanitárias de volume reduzido de descarga, torneiras dotadas de aeradores, chuveiros e lavatórios com volume fixo de descarga; a instalação de hidrômetros individualizados; a captação e aproveitamento de águas de chuva, e o reúso das águas servidas. Esta legislação é aplicada para as novas edificações particulares, os bens imóveis públicos do município e também as novas edificações de interesse social. Para as edificações já existentes são estudadas soluções técnicas de 57% das perguntas mais frequentes feitas pelos residentes no prazo de 10 anos. Para a regulamentação dessa lei foi instituído o Decreto Municipal Nº 47.731/2006, o qual criou o “Grupo Gestor do Programa”, composto por diversos representantes dos órgãos municipais e estaduais, que entre outras, contempla as seguintes atribuições: pesquisar, conhecer, divulgar e incentivar a implantação de soluções técnicas aplicáveis aos projetos de novas edificações, bem como à adaptação das já existentes; recomendar a utilização de fontes alternativas para a captação do água e o seu reúso nas novas edificações; promover encontros sobre o tema água no município; analisar a viabilidade de aplicação das propostas ofertadas pelas instituições públicas e privadas, organizações não-governamentais, comunidades científicas e populações; e informar à Secretaria Municipal de Gestão das novas soluções técnicas, além de propor a Prefeitura de São Paulo a elaboração/alteração da legislação municipal visando a rendição de efetivo estabelecer a obrigatoriedade dessas novas soluções técnicas.

Cabe mencionar que em 1995 foi criado no Estado de São Paulo o Programa de Uso Racional da Água (PURU), através de convênio entre a Escola Politécnica da Universidade de São Paulo (EPUSP), a Companhia de Saneamento Básico do Estado de São Paulo (Sabesp) e o Instituto de Pesquisas Tecnológicas (IPT). O PURU contempla ações para a conscientização e a utilização de tecnologias para o uso racional da água, tendo sido inicialmente desenvolvido nas universidades, e depois foi sendo expandido para outras edificações do poder público, para todo o estado de São Paulo (PURU, 2010).

4.3. Município de Campinas (SP)

Em Campinas foi instituída a Lei Municipal Nº 12.474/2006 para implementar o uso racional de água, com um eficiente combate ao desperdício quantitativo e a redução das perdas por vazamento. Para tanto, é obrigatório o aproveitamento de águas das chuvas, que deverá ser entendido como o coletor de águas; e a instalação de hidrômetros para a captação, tratamento e monitoramento da qualidade e distribuição do uso em fins não potáveis. Além disso, é obrigatório o reúso das águas servidas, que deve ser entendido como as que já foram utilizadas em tanques, máquinas de lavar, chuveiros e banheiras, sendo reutilizadas para fins não potáveis. Aliado a isso, é obrigatório o uso de dispositivos hidráulicos para a adaptação de edificações, como: bacias sanitárias com volume de descarga reduzido, chuveiros e lavatórios com volumes fixos de saída de água, torneiras e válvulas de fechamento automático com aeradores e a instalação de hidrômetros para medição individualizada em edificações residenciais e comerciais. Esta legislação é aplicada às novas edificações de interesse social, de propriedade do Estado, da União ou do Município, assim como indica que deve ser feita adaptação dos bens imóveis já existentes no município, no prazo de 10 anos. O Poder Executivo ficou encarregado de criar uma comissão de estudos, controle e gestão desse programa, composta por diversos representantes de várias instituições, e com a função de definir as ações de implantação do programa. As instituições públicas, privadas e a comunidade científica são convidadas a participar de discussões e apresentar sugestões eficientes para o programa.

5. Resultados do processo de avaliação do PURAE em Curitiba

5.1. Resultados das entrevistados com os técnicos da Secretaria Municipal de Urbanismo

Em 2008 foram entrevistados vinte e três técnicos dos setores de recepção de pedido de alvarás de construção, e a partir das respostas obtidas concluiu-se principalmente que (Christian, 2008):

- 57% das perguntas mais frequentes feitas pelos responsáveis técnicos da execução da obra, quando dadas entradas no pedido de alvarás de construção, diziam respeito aos equipamentos hidráulicos economizadores que seriam “cobrados” quando da vitória da conclusão da obra;
- 17% das perguntas dos responsáveis técnicos pela execução da obra eram relacionadas ao sistema de captação de água de chuva como um todo, incluindo o seu dimensionamento;
- 40% dos responsáveis técnicos pela execução da obra discordavam da obrigatoriedade do PURAE;
- 30% discordavam e 30% não tinha opinião definida e
- 43% dos funcionários da prefeitura entrevistados, responsáveis pela liberação do alvarás de construção, tinham dúvidas sobre o PURAE, e assim não podiam colaborar no esclarecimento das dúvidas dos requerentes de alvarás.

Comparativamente, em 2010 foram entrevistados treze funcionários dos setores de recepção de pedido de alvarás de construção, e com os resultados obtidos foi possível concluir que:

- 100% dos funcionários da prefeitura entrevistados, responsáveis pela liberação do alvarás de construção, afirmaram que não têm mais dúvidas quanto às exigências legais impostas pelo PURAE;
- 86% das perguntas mais frequentes feitas pelos responsáveis técnicos da execução da obra dizem respeito ao dimensionamento do volume do reservatório de água de chuva;
- 47% dos responsáveis técnicos pela execução do alvará concordam parcialmente com a obrigatoriedade do PURAE; 39% concordam totalmente e 14% discordam, inferindo que deveria haver um incentivo a
adoção do programa e não uma imposição legal;
- 62% dos funcionários da prefeitura entrevistados avaliam que os objetivos do PURAE - de conscientização, conservação e uso racional das águas - são alcançados na maioria dos casos.

Em 2008 também, foram entrevistados dez responsáveis técnicos por execução de obras, que foram encontrados no pedido de alvará de construção após a implanção do PURAE, e com as respostas obtidas concluiu-se que (Christian, 2008):
- 70% dos profissionais entrevistados eram alertados em 2007 para o atendimento às exigências do PURAE, mas, na mesma época, 30% obtiveram o alvará de construção sem nenhuma solicitação para atendimento ao programa;
- 80% dos responsáveis técnicos pelas obras possuíam dúvidas sobre o PURAE e
- 80% afirmavam que o PURAE é viável técnica e economicamente.

A partir dos resultados destas entrevistas, verificou-se que de 2008 a 2010 houve um avanço quanto ao conhecimento das exigências legais impostas pelo PURAE, por parte dos funcionários dos setores de recepção de pedido de alvará de construção da prefeitura. No entanto, houve um aumento significativo das dúvidas dos profissionais que dão entrada com o pedido de alvará de construção na prefeitura, no que se refere ao dimensionamento do reservatório de água de chuva.

5.2. Análise do processo de implementação do PURAE e recomendações para sua otimização

A Lei Municipal Nº 10.785/2003 criou o PURAE em 2003, mas o programa só entrou em vigor em 2007, após a instituição de dois decretos municipais. Neste período de quatro anos, entre a instituição da lei e sua efetiva aplicação, vários requisitos descritos no texto da lei inicial foram alterados no conteúdo dos decretos que se seguiriam (Decreto Municipal N.º 293/2006 e Decreto Municipal N.º 213/2007). Portanto, o PURAE que está atualmente em vigor, ou seja, a partir de 2007, não é igual ao programa que está descrito na lei que o instituiu. A fim de analisar a situação real do PURAE, foi necessário agrupar as mudanças descritas nos dois decretos regulamentadores, pois não existem nenhuma publicação com uma revisão no texto da lei inicial que descreva o programa como está efetivamente funcionando. Diante do exposto, para facilitar a adoção do programa pelos municípios, recomenda-se uma publicação, por parte da Prefeitura Municipal de Curitiba, de um mecanismo legal, ou manual, descrevendo os requisitos do PURAE, na forma de seu atual funcionamento, e com linguagem técnica simples e objetiva. Além de auxiliar os profissionais envolvidos com projetos de execução de novas obras, esta material pode auxiliar na divulgação do programa junto a população, e no processo de conscientização sobre o assunto.

Um aspecto relato pelos técnicos responsáveis pela fiscalização da conclusão de obras diz respeito ao fato de que alguns sistemas de captação de água de chuva, existentes nas obras vistoriadas, não estavam instalados corretamente, além de indicarem forte suspeita de que seriam removidos logo após a vistoria. Este fato também foi relatado, de forma anômica, por alguns profissionais responsáveis pela execução técnica da obra, dizendo que eles tiveram um sistema de aproveitamento de água de chuva provisório na edificação, somente para a vistoria da conclusão da obra, e depois é removido e colocado em outra obra, e assim sucessivamente. Este fato encontrado em algumas obras é indicativo da falta de conscientização sobre a importância da conservação e uso racional da água. É possível concluir a partir desta observação, que não se está atingindo em 100% o objetivo principal do PURAE.

Ao refletir sobre a obrigatoriedade do atendimento a uma exigência legal, em relação ao seu atendimento consciente e voluntário, fica evidente a importância do processo educacional para os necessários esclarecimentos dos princípios de uma política pública. Em conjunto com esse processo de educação ambiental, podem ser adotadas pelo poder público medidas de cunho econômico que incentivem o setor envolvido, seja também público ou privado, a dar o passo para a mudança de hábito solicitada. Diante disto, poderiam ser estudados incentivos fiscais aos projetos que comprovadamente resultem em concretização das ações propostas no PURAE e talvez uma reavaliação da obrigatoriedade do seu atendimento. Diante do que foi observado na implantação do PURAE e embasado no exposto em Hernandez e Amorim (2005), recomenda-se que, diferente do que ocorreu com o PURAE em Curitiba, o período inicial de implementação de uma política pública seja isento de obrigatoriedade. Seria mais adequado estipular um período de dois ou três anos, para uma permanente discussão e avaliação da efetividade da política e, se necessário, para a definição de ajustes no programa. Após esse período inicial de adoção voluntária e adequação do programa à realidade da região, ele poderia passar a ser obrigatório. De fato, segundo Hernandez e Amorim (2005), no cenário internacional é comum não se exigir a obrigatoriedade e, em alguns casos, o poder público até amparar com subsídios financeiros, além de tecnológicos, o desenvolvimento de sistemas de uso racional de água. Um exemplo disto ocorre na cidade de Austin (Texas), nos Estados Unidos (Hernandez e Amorim, 2005).

Com base nos resultados das entrevistas e na avaliação de programas semelhantes em outras cidades brasileiras os seguintes aspectos poderiam ser incluídos no PURAE para a sua otimização:
- a determinação da responsabilidade pela manutenção e controle da qualidade da água de chuva armazenada para aproveitamento em fins não potáveis, e da água servida para reuso, com seus respectivos parâmetros indicadores dos usos, para não oferecer riscos à saúde dos seus usuários;
- a indicação de que as instalações de águas não potáveis sejam bem sinalizadas, para evitar o consumo indevido pelos usuários, e que estas instalações sejam totalmente independentes dos outros sistemas de água potável, para evitar a contaminação cruzada;
a criação de um grupo gestor do programa ou de uma comissão de estudos, que ficaria responsável por realizar permanentemente avaliações do programa, colaborando para esclarecer as dúvidas dos profissionais responsáveis técnicos pelas obras, sugerindo soluções técnicas, e estudando medidas mais eficientes para serem implantadas nas edificações e

* a permanente divulgação e sensibilização da população sobre a importância do PURAE, através de campanhas publicitárias, palestras, congressos, seminários e debates sobre os benefícios trazidos pelo programa ao meio ambiente e para a população, favorecendo as necessárias mudanças de atitude que efetivamente contribuam para uma sociedade sustentável ambientalmente.

5.3. Recomendações gerais para a instituição de programas semelhantes

No município de Curitiba a lei do PURAE foi instituída em 2003, mas o programa só entrou em vigor em 2007, após a instituição de dois decretos municipais. Portanto, observou-se que neste período de quatro anos, entre a instituição da lei e sua efetiva aplicação, são encontrados na literatura alguns trabalhos descrevendo o PURAE como se já estivesse funcionando em Curitiba, quando, de fato, o que existia era uma lei que não estava em vigor (Lei Municipal N°. 10.785/2003). Aliado a isso, vários requisitos descritos no texto da lei inicial foram alterados no conteúdo dos decretos que se seguiram, os quais raramente são citados na bibliografia (Decreto Municipal N°. 293/2006 e Decreto Municipal N°. 212/2007). Portanto, o PURAE que está atualmente em vigor, ou seja, a partir de 2007, não é igual ao programa que está descrito na lei que o instituiu. Desta forma, antes de embasar uma nova legislação em um estudo de legislações existentes, deve ser verificado se a proposta da lei está sendo efetiva na prática.

No período anterior a obrigatoriedade do PURAE, foi constatada que algumas construtoras estavam adotando parcialmente em seus projetos alguns dos requisitos da lei inicial. Exemplos destas edificações e dos requisitos adotados são encontrados em Bezerra et al. (2009).

Um aspecto que não foi contemplado no PURAE, mas que é fundamental para a conscientização efetiva para a economia da água, é quanto à inclusão de questões não somente referentes à economia quantitativa, mas também qualitativa do recurso. Ou seja, não basta usar água de chuva sem parcimônia, por esta não ser potável, e com isso considerar que sua quota de economia de água está resolvida. O fundamental é usar menos água nas atividades, mesmo que seja água de qualidade não potável.

6. Conclusões

Através deste estudo verificou-se que o Programa de Conservação e Uso Racional da Água nas Edificações – PURAE, existente em Curitiba-PR, é relevante à cidade, mas não apresenta todas as informações necessárias para o seu funcionamento efetivo. O processo de implantação ainda carrega de maior debates entre os profissionais dos setores públicos e privados, com a participação da comunidade científica e da população em geral, para serem esclarecidas as dúvidas existentes, dirimidos os conflitos e, então, contribuir para a conscientização sobre a importância da conservação e uso racional da água.

Infere-se que esta conscientização da necessidade de preservação e uso racional da água é um processo educacional e, como tal, é lento e contínuo. Este processo deve contar com a participação de toda a sociedade – Poder Público e coletividade. Para se atingir o desafio de garantir o permanente funcionamento do PURAE, assim como a melhoria contínua do programa, é fundamental que se estabeleçam mecanismos para o permanente monitoramento e divulgação das ações do programa.

Assim, para otimização do PURAE, recomenda-se incluir no programa: normas de vigilância sanitária quanto ao aproveitamento da água de chuva e para o reúso da água servida; a obrigatoriedade de sinalização da instalação hidráulica de água não potável e da utilização de torneiras de acesso restrito, para evitar usos indevidos destas águas; a implantação de grupo gestor, composto por pessoal de órgãos governamentais e não governamentais, sociedade civil e universidades; e o desenvolvimento permanente de campanhas de divulgação e conscientização para preservação e uso racional da água.

Referências


Abstract: This paper compares methods for sizing harvested-rainwater storage tanks for non-potable uses: the methods provided by the Brazilian Standard NBR 15527/2007 and the method provided by Municipal Decree 293/2006 in the city of Curitiba, state of Parana (PR), in the south of Brazil. Five rainwater harvesting systems located in buildings in the city of Curitiba were studied. The results obtained from the two guidelines varied significantly. In order to obtain volumes that are consistent with the efficient harvesting of rainwater, the Municipal Decree equations should be revised to include rainfall data, roof size and rainwater demands. For the methods described in NBR 15527/2007, ambiguities in the name of variables may lead to misunderstandings. The names of the variables used should be standardized and more information should be provided about how to use the NBR 15527/2007 equations. When sizing reservoirs for rainwater-harvesting systems, it is recommended that both methods be used for initial calculations. The results can then be compared and evaluated in relation to cost considerations and the space available for the construction of the reservoir.
Dimensionamento de reservatório para aproveitamento de água de chuva: comparação entre métodos da ABNT NBR 15527:2007 e Decreto Municipal 293/2006 de Curitiba, PR

Sizing rainwater harvesting reservoirs: a comparison between methods of ABNT NBR 15527:2007 and of Municipal Decree 293/2006 from the city of Curitiba, PR

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Priscila de Christian
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Khosrow Farahbaksh

Resumo
Este trabalho apresenta uma comparação entre os métodos de dimensionamento de reservatório de água de chuva propostos na NBR 15527:007 e no Decreto Municipal 293/2006, de Curitiba, PR. Para esta análise foram selecionadas cinco edificações que possuem sistema de captação e aproveitamento de água de chuva em funcionamento. Os resultados obtidos através dos dois métodos foram discrepantes. A fim de resumirem volumes coerentes com o aproveitamento de água de chuva, as equações do Decreto Municipal 293/2006 merecem uma revisão, para serem incluídas as considerações sobre índice pluviométrico, área de captação e demanda para a água de chuva armazenada. A utilização dos métodos apresentados na NBR 15527:007 seria facilitada com ajustes de nomenclatura e inclusão de mais informações na apresentação das equações, em função da ambigüidade de denominação das variáveis. A decisão final sobre qual método mais indicado pode ser baseada na comparação dos volumes obtidos e na viabilidade em termos de área disponível e custo de construção do reservatório.


Abstract
This paper compares the methods for sizing rainwater reservoirs for non-potable uses provided by the Brazilian Standard NBR 15527:2007 and the Municipal Decree 293/2006 in the city of Curitiba, state of Parana (PR), in the south of Brazil. To pursue that objective, five rainwater harvesting systems located in buildings in the city of Curitiba were studied. The results obtained from those two methods varied significantly. In order to obtain volumes that are consistent with the harvesting of rainwater, the Municipal Decree equations should be revised in order to include rainfall data, roof size and the rainwater demands in their formulation. Standardization of the names of the variables is suggested for the methods described in NBR 15527:2007, as well as the inclusion of more information about its equations, since the existing ambiguities may lead to misunderstandings. In order to decide on the best method one should compare the different results and evaluate the available area for the construction of the reservoir, as well as its cost.

Keywords: Curitiba. Municipal Decree 293/2006. NBR 15527:2007. PURAE. Rainwater. Sizing.
Introdução

Em um sistema de captação e aproveitamento de água de chuva para fins não potáveis, o reservatório de armazenamento é geralmente o componente mais oneroso do sistema (AMORIM, PEREIRA, 2008; COHIM et al., 2008; COHIM, OLIVEIRA, 2009). Por esse motivo recomenda-se avaliar os diversos métodos de dimensionamento existentes, para então projetar a solução técnica e economicamente mais adequada para cada caso. Independentemente do método selecionado, o sistema para aproveitamento de água de chuva pode não suprir totalmente a demanda e necessitar de maior ou menor complementação com água da rede de abastecimento municipal. Por esse motivo, o projeto do reservatório deve incluir mecanismos para evitar a contaminação cruzada entre as fontes de abastecimento. Ou seja, a utilização de um sistema de captação de água de chuva deve ser baseada em análise da demanda a que será destinada, dos possíveis riscos sanitários, da adequação dos sistemas prediais e do correcto dimensionamento do reservatório, para se evitar a implantação de projetos inadequados, que comprometam os aspectos positivos dessa fonte alternativa de água (COHIM et al., 2007). O índice pluviométrico da região, a área de captação de água de chuva e a previsão da demanda são parâmetros fundamentais nessa avaliação.


Aproveitamento de água de chuva

O aproveitamento de água de chuva pode colaborar para economizar os recursos hídricos de qualidade superior e para prevenir a escassez da água potável nos sistemas de distribuição municipais. A água de chuva nos centros urbanos pode ser aproveitada em atividades que não necessitam água potável, como, por exemplo, na descarga de bacias sanitárias, na irrigação de jardins e na limpeza de pisos, equipamentos e carros. Outros usos também podem ser propostos, desde que atendam aos requisitos de qualidade e segurança sanitária, para os diversos fins e usuários. A necessidade do tratamento depende da qualidade da água de chuva armazenada e da finalidade a que se destina. A água de chuva também é aproveitada para fins potáveis em regiões onde se justifica essa necessidade.

Um projeto de captação, tratamento e uso de água de chuva é constituído de vários componentes, conforme bem detalhado em ANA (2006), não necessariamente sendo todos obrigatórios. Basicamente, o sistema é formado por área de captação ou área de contribuição, componentes de transporte constituídos de condutores horizontais, condutores verticais, cais e reservatório (AMORIM; PEREIRA, 2008). Os componentes de transporte podem ser projetados conforme a NBR 10844:1989, intitulada "Instalações prediais de água pluviais" (ABNT, 1989). Essa norma fixa as exigências e critérios necessários ao projeto do sistema predial de água pluvial em coberturas e demais áreas associadas ao edifício, como terraços, pátios, quintais, entre outras áreas impermeáveis.

Norma Brasileira ABNT NBR 15527:2007

A NBR 15527 foi publicada pela ABNT em 2007 e é intitulada “Água de chuva – aproveitamento de cobertura em áreas urbanas para fins não potáveis – requisitos”. Esta norma apresenta em seu anexo seis métodos para o dimensionamento do volume do reservatório de armazenamento da água de chuva: Método de Rippl, Método da Simulação, Método Azvedo Neto, Método Prático Alemão, Método Prático Inglês e Método Prático Australiano. De acordo com essa norma, fica a critério do projetista a decisão do método a ser utilizado, ou mesmo a utilização de algum outro procedimento de cálculo não apresentado na norma, desde que atendidos critérios técnicos, econômicos e ambientais.

Entre os métodos não incluídos no anexo da NBR 15527:2007 tem-se o método do máximo aproveitamento (MIERZWA et al., 2007; MORUZZI et al., 2008). Neste método o objetivo principal é possibilitar a redução da demanda de água potável, sem depender de alta confiabilidade de fornecimento de água de chuva, porém potencializando o uso desta durante o período.
chuvoso. Cohim et al. (2007) também apresentam um método para dimensionamento de reservatório, tendo como resposta verificar a taxa de atendimento à demanda anual para diferentes volumes de reservatórios, podendo acompanhar o balanço hídrico diário, com diferentes faixas de consumo e regimes pluviométricos. Outra avaliação interessante é feita pelo programa computacional Netuno, que determina o percentual de economia de água potável pelo aproveitamento de água de chuva, além da possibilidade de determinar o volume ideal do reservatório interior (GHISI et al., 2009).

Decreto municipal 293/2006 de Curitiba, PR


Método de pesquisa

A partir do objetivo de apresentar uma comparação entre os métodos de dimensionamento de reservatório de água de chuva propostos na norma NBR 15527 (ABNT, 2007) e no Decreto Municipal 293/2006, foram selecionadas cinco edificações localizadas em Curitiba, PR, as quais possuem em funcionamento um sistema de captação e aproveitamento de água de chuva, para aproveitamento em fins não potáveis. As edificações selecionadas são três edifícios residenciais (Edifício A, Edifício B e Edifício C), uma edificação comercial (estacionamento e lavagem de veículos) e uma habitação unifamiliar. Cabe ressaltar que os reservatórios para armazenamento de água de chuva nessas edificações já estavam construídos, portanto o dimensionamento apresentado neste artigo é apenas investigativo.

Edifício A

O Edifício A possui quarenta e seis apartamentos e duas coberturas duplex, totalizando quarenta e oito unidades habitacionais. As áreas dos apartamentos variam entre 288 e 535 m², com três ou quatro quartos por apartamento. A água da chuva é captada na cobertura do edifício, com área de contribuição de 300 m², e conduzida através de calhas e condutores verticais para um reservatório de PVC (5.000 litros), que fica enterrado no jardim frontal do prédio. A água de chuva coletada é filtrada na entrada do reservatório e fica disponível para o uso em torneiras de acionamento restrito, dispostas no pavimento térreo, sendo o uso destinado a lavagem de pisos e a rega de jardins. Na ausência de chuva, esse reservatório recebe água potável do sistema municipal de abastecimento. As entradas de chuva e água potável foram projetadas de forma a evitar a contaminação cruzada.

Edifício B

O Edifício B é composto de duas torres com quarenta e cinco unidades habitacionais, sendo quatorze apartamentos com três quartos, e trinta e um apartamentos com dois quartos. A área dessas unidades varia de 126 a 350 m². O sistema de captação coleta água de chuva da cobertura, mas também do piso no pavimento térreo através de ralos, totalizando uma área de contribuição de 400 m². A água de chuva coletada é armazenada em um reservatório de concreto armado, com capacidade de armazenamento de 10.000 litros, localizado no subsolo do prédio. Na entrada do reservatório existem grades metálicas para retenção de folhais ou de outros resíduos de maior dimensão. A água armazenada fica disponível para o uso em torneiras convencionais localizadas no pavimento térreo, sendo o uso destinado para a lavagem de pisos e rega de jardins. Na ausência de chuva esse reservatório também recebe água potável do sistema municipal de abastecimento, e as entradas de chuva e água potável foram projetadas de forma a evitar a contaminação cruzada.

Dimensionamento de reservatório para aproveitamento de água de chuva: comparação entre métodos da ABNT NBR 15527:2007 e decreto municipal 293/2006 de Curitiba, PR
Edifício C

O Edifício C é composto de duas torres com sete andares. Cada torre possui um apartamento por andar, totalizando quatorze unidades habitacionais com quatro quartos e 639 m² de área. A água de chuva é captada parcialmente da cobertura das duas torres, com uma área de contribuição de 500 m². Depois segue através de calhas e condutores verticais até um único reservatório de concreto armado, localizado no subsolo de uma das torres, com capacidade de 38.600 litros. A água de chuva coletada é filtrada na entrada do reservatório inferior e então é bombeada para dois reservatórios superiores em cada torre, cada um com 8.600 litros. Estes reservatórios armazenam a água de chuva que é destinada para a descarga de bacias sanitárias dos apartamentos e para torneiras de acesso restrito no pavimento térreo, para a irrigação dos jardins e lavagem dos pisos. Da mesma forma que os demais edifícios, na ausência de chuva o reservatório recebe água potável do sistema municipal de abastecimento, e as entradas de chuva e água potável foram projetadas de forma a evitar a contaminação cruzada.

Edificação comercial

Na edificação comercial, que é um estacionamento e lavagem de veículos, a captação da água de chuva é feita na cobertura com área de contribuição de 125 m². O reservatório de armazenamento é de PVC com capacidade de 5.000 litros. O tratamento dessa água é feito por filtração, apenas para retenção das partículas maiores. A água de chuva é destinada para a lavagem dos veículos.

Habitação unifamiliar

Na habitação unifamiliar a água de chuva é coletada da cobertura da edificação, com uma área de contribuição de 100 m², e armazenada em um reservatório de PVC de 200 litros. A água coletada fica disponível através de uma torneira convencional localizada no próprio reservatório e é destinada para a lavagem de pisos e a rega de jardins. Essa água não sofre nenhum tipo de tratamento antes de ser utilizada.

Constantes utilizadas nos estudos de caso

Para a obtenção dos dados necessários nas equações para dimensionamentos apresentadas na NBR 15527 (ABNT, 2007) e no Decreto Municipal 293/2006, além da revisão bibliográfica, foram realizadas visitas técnicas nas edificações em questão e entrevistadas com os respectivos responsáveis técnicos pelos projetos.

Neste artigo, para a apresentação dessas constantes e dos detalhes das metodologias de dimensionamento investigadas, selecionou-se o Edifício B, pois suas características atendem às condições apresentadas nos métodos do anexo da NBR 15527 (ABNT, 2007). No caso do Edifício C, não foi possível a utilização dos métodos de Rippl, Simulação e Prático Australiano, porque o valor da demanda é maior que o volume de água de chuva aproveitável. Todos os demais detalhes e resultados para as outras edificações avaliadas estão descritos em Christian (2008).

Definição da demanda de água de chuva

Em edificações comerciais, públicas ou residenciais é possível a utilização de água não potável em diversas atividades, desde que atendidas condições que garantam a segurança sanitária dos usuários e a qualidade necessária para as diversas finalidades. O Quadro 1 apresenta alguns exemplos de usos internos e externos da água, com base em residência norte-americana, para finalidades que poderiam ser abastecidas com água de chuva.

<table>
<thead>
<tr>
<th>Usos internos</th>
<th>Usos Externos</th>
</tr>
</thead>
<tbody>
<tr>
<td>A bacia sanitária é utilizada por uma pessoa, em média, 4 a 6 vezes por dia.</td>
<td>Em média um carro é lavado uma ou duas vezes por semana, sendo gastos aproximadamente 150 litros de água em cada lavagem.</td>
</tr>
<tr>
<td>A bacia sanitária consome, em média, 6,8 a 18 litros de água por descarga.</td>
<td>Na irrigação de gramados ou na limpeza dos pisos, gastam-se aproximadamente 2 litros/dia/m² de água.</td>
</tr>
</tbody>
</table>

Fonte: Tomaz (2003)

Quadro 1 - Alguns exemplos de usos internos e externos da água em residência norte-americana
A partir dos dados do consumo potencial para água de chuva por equipamento e/ou atividade indicados no Quadro 1, foram feitas as seguintes considerações para o Edifício B:

(a) lavagem de 300 m² de pisos diariamente, sendo 2 litros/dia/m², que resultam em 600 litros/dia, ou 18 m³/mês;

(b) rega de 100 m² de jardins diariamente, sendo 2 litros/dia/m², que resultam em 200 litros/dia, ou 6 m³/mês; e

(c) somando essas demandas, o volume necessário de água de chuva é de 24 m³/mês.

Foram consideradas a lavagem de pisos e rega de jardins realizadas diariamente para resultar em demanda máxima. Neste artigo, conforme exposto acima, a demanda D = 24 m³/mês ou Danual = 288 m³/ano.

**Determinação da área de captação de água de chuva ou área de contribuição**

A determinação da área total de captação é uma etapa importante no desenvolvimento de um projeto para aproveitamento de água de chuva, pois irá influenciar no volume total coletado, assim como na qualidade da água a ser armazenada. Portanto, na área total deve ser considerado o somatório de todas as áreas de contribuição que serão direcionadas ao reservatório de armazenamento de água de chuva. O cálculo dessas áreas pode seguir os métodos indicados na NBR 10844 (ABNT, 1989). A norma brasileira para aproveitamento de água de chuva, NBR 15527 (ABNT, 2007), dispõe sobre os requisitos de captação apenas de coberturas, sendo estas situadas em áreas urbanas, mas vale ressalta que em alguns casos a água de chuva pode também ser coletada de outras áreas, incluindo pisos impermeáveis. Para qualquer situação deve ser analisada a influência das características da área de coleta sobre a qualidade da água de chuva armazenada. No Edifício B a área de contribuição do sistema existente é parte da cobertura da edificação e do piso da área externa do pavimento térreo, com 400 m². Assim, a área de captação A = 400 m².

**Dados pluviométricos em Curitiba-PR**

Os índices pluviométricos do município de Curitiba para este estudo foram obtidos a partir da estação meteorológica da Superintendência de Desenvolvimento de Recursos Hídricos e Saneamento Ambiental (SUDERHSA), que é um órgão público do estado do Paraná. Os dados foram coletados para os anos de 1982 até 2007 e referem-se à Bacia do Rio Iguaçu, na estação denominada Prado Velho – PUC. Com base nesses dados, foram utilizadas as médias mensais e média anual histórica para o período de 1982 a 2007. Assim, Panual = 1.487,50 mm (média anual) e Pt (de janeiro a dezembro, em mm): 225,50; 186,60; 69,20; 100,00; 106,20; 25,60; 41,60; 104,20; 179,20; 116,60; 170,40 e 162,10 (médias mensais).

**Coeficiente de aproveitamento do escoamento superficial**

A partir de Tarum (2005, 2010) pode-se dizer que o coeficiente de aproveitamento do escoamento superficial (indicado neste artigo pela variável $C_{AE}$) é referente à perda da água precipitada por interceptação, seja por evaporação, vazamentos ou lavagem do telhado, em função do material da superfície de escoamento, e da eficiência do sistema de captação de água de chuva. Esse coeficiente de aproveitamento do escoamento superficial é obtido pelo produto entre o coeficiente de escoamento superficial específico do material da área de captação ($C_{t}$), multiplicado por um fator de eficiência do sistema existente ($\eta_{tendeo de captação}$). Dessa forma, o volume de água de chuva aproveitável é sempre menor do que o volume precipitado. O Método Prático Australiano para dimensionamento de reservatório de água de chuva, o qual está apresentado no anexo da NBR 15527 (ABNT, 2007), recomenda adotar o coeficiente de aproveitamento de escoamento superficial igual a 0,8. Neste artigo também é adotado $C_{AE} = 0,8$ para os demais métodos.

**Volume do reservatório existente**

Para o estudo de caso do Edifício B, detalhado neste artigo, o volume do reservatório que está construído naquele edificação foi estabelecido pelo projetista hidráulico em 10.000 litros. Esse volume é adotado como volume fixado inicial nos métodos por tentativa e denominado neste artigo $V_{e} = 10$ m³.

**Volume de água de chuva aproveitável de acordo com a NBR 15527:2007**

A norma indica que o volume de água de chuva aproveitável depende dos fatores apresentados na Equação 1, em que a precipitação da chuva ($P$) pode ser considerada a média anual, mensal ou diária.

$$V_{AE} = P_{t} \times A \times C \times \eta_{tendeo de captação}$$  \hspace{1cm} \text{Eq. 1}

Onde:

---

Dimensionamento de reservatório para aproveitamento de água de chuva: comparação entre métodos da ABNT NBR 15527:2007 e decreto municipal 293/2006 de Curitiba, PR 223
\[ V_{AP} = \text{volume de águas de chuva aproveitáveis, podendo ser anual, mensal ou diária, em função da precipitação utilizada (litros);} \]
\[ P_t = \text{precipitação média da chuva no tempo} \ t \ (\text{anual, mensal ou diária}) \ (\text{mm});} \]
\[ A = \text{área de captação} \ (m^2);} \]
\[ C = \text{coeficiente de escoamento superficial do material da cobertura (neste artigo adotado como 0,95 para o telhado de fibrocimento do Edifício B);} \]
\[ \eta_{\text{captação}} = \text{eficiência do sistema de captação, levando em conta a existência ou não de dispositivo de descarte de sólidos e desvio de escoamento inicial, que, segundo Tomaz (2010), é estabelecida na prática em 0,85.} \]

Dessa forma, e considerando a precipitação média anual, temos:
\[ V_{AP(\text{anual})} = 1.487,5 \ mm \times 400 \ m^2 \times 0,95 \times 0,85 = 480.463 \text{litros.} \]
Assim, \( V_{AP(\text{anual})} = 481 \text{ m}^3 \).

**Resultados e discussões**

Seguem os passos dos dimensionamentos pelos métodos que estão sendo investigados, ressaltando novamente que neste artigo são apresentados os detalhes apenas para o Edifício B, por atender a todas as condições de utilização dos diferentes métodos. Para os demais estudos de caso são indicados apenas os resultados para o comparativo entre os métodos. Os respectivos dados são encontrados em Christan (2008).

A NBR 15527 (ABNT, 2007) contém seis métodos para dimensionamento de reservatórios de água de chuva, apresentados em seu anexo e descritos a seguir. Para facilitar o entendimento das fórmulas e a comparação dos resultados, algumas variáveis usadas na norma tiveram a nomenclatura alterada neste artigo, mas sem modificar nenhum cálculo.

**Método de Rippl**

Neste método podem ser usadas as séries históricas mensais ou diárias de precipitação. No desenvolvimento desta pesquisa são utilizados os totais mensais. Seguem as equações para o Método de Rippl, utilizando a nomenclatura adaptada para este trabalho (Eq. 2 a Eq. 4).

\[ S_t = D_t - Q_t \quad \text{Eq. 2} \]

Onde:

\[ S_t = \text{volume de água de chuva armazenado no reservatório no tempo} \ t \ (m^3);} \]
\[ D_t = \text{demanda de água de chuva no tempo} \ t \ (m^3), \text{sendo nesta pesquisa o volume da demanda constante, portanto na apresentação dos resultados é adotada a nomenclatura} \ D; \]
\[ Q_t = \text{volume de água de chuva aproveitável no tempo} \ t \ (m^3), \text{conforme a Equação 3, em que foi incluída a divisão por 1.000 para ajustar a unidade de volume.} \]

Na norma aparece a indicação de demanda ou consumo no tempo \( t \) (\( D_t \)), mas foi considerado aqui apenas como sendo a demanda, pois se entende que o consumo para a água de chuva não é medido no local.

\[ Q_t = C_{AP} \times P_t \times A / 1.000 \quad \text{Eq. 3} \]

Onde:

\[ C_{AP} = \text{coeficiente de aproveitamento do escoamento superficial (adoptado 0,8 neste artigo);} \]
\[ P_t = \text{precipitação da chuva no tempo} \ t \ (\text{mm});} \]
\[ A = \text{área de captação} \ (m^2).} \]

A condição para a utilização desse método é que o somatório das demandas no tempo \( t \) deve ser menor do que o somatório do volume de água de chuva aproveitável no tempo \( t \) (\( \Sigma D_t \times \Sigma Q_t \)). Para o Edifício B essa condição foi atendida, pois \( \Sigma D_t = 288 \text{ m}^3/\text{ano} \) e \( \Sigma Q_t = 476 \text{ m}^3/\text{ano} \). O volume do reservatório de água de chuva receberá a nomenclatura \( V_R \), onde:

\[ V_R = \Sigma S_t, \text{ somente para valores} \ S_t > 0. \quad \text{Eq. 4} \]

O procedimento de cálculo foi realizado conforme indicado na Tabela 1.

Com base nessa metodologia, o volume dimensionado para o reservatório de água de chuva resultou em: \( V_R = 28 \text{ m}^3 \) (Rippl).

**Método da simulação**

Neste método a norma NBR 15527 (ABNT, 2007) indica que duas hipóteses devem ser feitas:

(a) o reservatório está cheio no início da contagem do tempo \( t \); e
(b) os dados históricos são representativos para as condições futuras.

Neste artigo a primeira hipótese não foi considerada e, ao contrário, fixou-se que o reservatório estava vazio no início da contagem do tempo \( t \), para simular a situação de um reservatório recém-construído e, portanto, sem nenhuma quantidade de água de chuva armazenada. Assim, em janeiro, \( S_{ho} = 0 \). Seguem as equações para o Método da Simulação:

\[ S_t = Q_t + S_{ho} - D_t \quad \text{Eq. 5} \]
<table>
<thead>
<tr>
<th>Meses</th>
<th>Precipitação da chuva no tempo t (P&lt;sub&gt;t&lt;/sub&gt; (mm))</th>
<th>Volume de água de chuva aproveitável no tempo t (m&lt;sup&gt;3&lt;/sup&gt;) (Eq. 3)</th>
<th>Volume de chuva armazenada no reservatório no tempo t menos 1 (S&lt;sub&gt;t-1&lt;/sub&gt; (m&lt;sup&gt;3&lt;/sup&gt;))</th>
<th>Volume de chuva armazenada no reservatório no tempo t (S&lt;sub&gt;t&lt;/sub&gt; (m&lt;sup&gt;3&lt;/sup&gt;))</th>
<th>Volume do reservatório V&lt;sub&gt;R&lt;/sub&gt; (m&lt;sup&gt;3&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Janeiro</td>
<td>225,8</td>
<td>72,26</td>
<td>0,00</td>
<td>25,00</td>
<td>28</td>
</tr>
<tr>
<td>Fevereiro</td>
<td>186,6</td>
<td>59,71</td>
<td>25,00</td>
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<td>28</td>
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<tr>
<td>Março</td>
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<td>28</td>
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<tr>
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<td>25,00</td>
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</tr>
<tr>
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<td>33,98</td>
<td>25,00</td>
<td>25,00</td>
<td>25</td>
</tr>
<tr>
<td>Junho</td>
<td>25,6</td>
<td>8,19</td>
<td>0,00</td>
<td>9,19</td>
<td>12</td>
</tr>
<tr>
<td>Julho</td>
<td>41,6</td>
<td>13,31</td>
<td>9,19</td>
<td>0,00</td>
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<tr>
<td>Agosto</td>
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<tr>
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<td>25,00</td>
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<td>25</td>
</tr>
<tr>
<td>Dezembro</td>
<td>162,1</td>
<td>51,87</td>
<td>25,00</td>
<td>25,00</td>
<td>25</td>
</tr>
</tbody>
</table>

Volume do reservatório V<sub>R</sub> (m<sup>3</sup>) = 28

Tabela 1 - Dimensionamento do reservatório pelo Método de Rippl - Edifício B

<table>
<thead>
<tr>
<th>Meses</th>
<th>Precipitação da chuva no tempo t (P&lt;sub&gt;t&lt;/sub&gt; (mm))</th>
<th>Volume de água de chuva aproveitável no tempo t (m&lt;sup&gt;3&lt;/sup&gt;) (Eq. 3)</th>
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<td>25</td>
</tr>
</tbody>
</table>

Volume do reservatório V<sub>R</sub> (m<sup>3</sup>) = 25

Obs.: *S<sub>t</sub>*, é considerado zero quando o reservatório está vazio ou quando S<sub>t</sub> é negativo no mês anterior.

Tabela 2 - Dimensionamento do reservatório pelo Método da Simulação - Edifício B

Onde:

V<sub>R</sub> = volume de água de chuva armazenada no reservatório no tempo t (m<sup>3</sup>);

Q<sub>t</sub> = volume de água de chuva aproveitável no tempo t (m<sup>3</sup>), conforme já apresentado na Eq. 3;

S<sub>t-1</sub> = volume de água de chuva armazenada no reservatório no tempo t menos 1 (m<sup>3</sup>);

d<sub>t</sub> = demanda de água de chuva no tempo t (m<sup>3</sup>), sendo esta pesquisa o volume da demanda constante, portanto na apresentação dos resultados é adotada a nomenclatura D.

Para a utilização deste método adota-se um volume fixo para o reservatório no início da contagem do tempo t. Esse volume fixado é denominado neste artigo V<sub>F</sub> e deve atender à condição apresentada na Equação 6.

0 ≤ S<sub>t</sub> ≤ V<sub>F</sub>  

Eq. 6

Não está indicado na norma como definir o volume do reservatório (V<sub>R</sub>) a partir das equações apresentadas. Neste artigo considera-se que o volume do reservatório (V<sub>R</sub>) a ser escolhido será o que apresentar a maior confiança entre os volumes fixados nas tentativas (aqui indicado como V<sub>F</sub>). A primeira tentativa foi realizada com V<sub>F</sub> = 10 m<sup>3</sup>, por ser o volume do reservatório existente. A partir desse valor, outros valores menores e maiores também foram testados. A confiança é estabelecida como a relação entre o período em que o reservatório atende à demanda (não precisa ser abastecido com outra fonte de água) e o período total investigado, que são 12 meses para este estudo de caso. Além da confiança verificou-se a eficiência do sistema, como sendo a relação entre o volume de chuva captada e o volume de chuva realmente utilizado, ou seja, o volume que não transbordou.

O procedimento de cálculo para o volume selecionado foi realizado conforme indicado na Tabela 2.
Além do volume indicado na Tabela 2 (\( V_R = 25 \) m³), foram também efetuadas tentativas conforme apresentado na Tabela 3.

Com base nesta metodologia, utilizando valores de confiança de 90% e considerando que a variação na eficiência não aumentou significantemente, o volume dimensionado para o reservatório de água de chuva ficou em: \( V_R = 25 \) m³ (Simulação).

### Método Azevedo Neto

Neste método, também intitulado Método Prático Brasileiro (AMORM; PEREIRA, 2008; COHIM et al., 2008), a NBR 15527 (ABNT, 2007) indica três definições para a variável \( V_p \), que são o volume de chuva, o volume de chuva aproveitável e o volume de água de chuva do reservatório. Neste artigo é feita uma diferenciação na nomenclatura da seguinte forma: o volume de chuva aproveitável é indicado por \( V_{AP} \); e o volume do reservatório de água de chuva é indicado por \( V_R \).

A partir da equação apresentada para esse método entende-se que aquela resulta no volume a ser projetado para o reservatório \( (V_R) \), quando considerado apenas 1 mês de seca \((T = 1)\) no período de 1 ano (Eq. 7). Para o município de Curitiba, situado na Bacia do Paraná (ou Bacia do Alto Iguaçu, na divisão estadual), não estão historicamente registrados números significativos de eventos de estiagem (ANA, 2009). Além disso, na Região Sul do Brasil as chuvas são bem distribuídas durante o ano (ANA, 2007). Dessa forma, a consideração para \( T = 1 \) é coerente.

\[
V_R = 0,042 \times P_{anual} \times A \times T \tag{Eq. 7}
\]

Onde:
- \( V_R \) = volume do reservatório de água de chuva (litros);
- \( P_{anual} \) = precipitação da chuva média anual (mm);
- \( A \) = área de captação (m²);
- \( T \) = número de meses de pouca chuva ou seco.

Então, \( V_R = 0,042 \times 1.487,5 \times 400 \times 1 = 24.990 \) litros. Dessa forma, determinou-se o seguinte volume para o reservatório de água de chuva: \( V_R = 25 \) m³ (Azevedo Neto).

### Método Prático Alemão

A NBR 15527 (ABNT, 2007) indica que esse método considera o volume do reservatório de água de chuva como sendo 6% do menor valor entre:

(a) o volume anual do consumo, que aqui se considera como volume anual da demanda de água de chuva e indicado neste artigo como \( V_{D} \), e

(b) o volume anual de chuva aproveitável, indicado neste artigo como \( V_{AP(ano)} \), a partir da fórmula da Eq. 1.

A condição desse método é expressa pela Equação 8.

\[
V_R = \min (V_D; V_{AP}) \times 0,06 \text{ (litros)} \tag{Eq. 8}
\]

A demanda mensal \((D)\) foi estimada em 24 m³/mês \((24.000 \text{ litros/mês})\), a qual, multiplicada pelos 12 meses do ano, resultou em \( V_D = 288.000 \) litros/ano. O volume anual de chuva aproveitável, \( V_{AP(ano)} \), foi obtido a partir da Equação 1 = 481.000 litros. Com esses dados e usando a Equação 8, encontra-se:

\[
V_R = \min (288.000; 481.000) \times 0,06 = 17.280 \text{ litros}
\]

Dessa forma, determinou-se o seguinte volume para o reservatório de água de chuva: \( V_R = 17 \) m³ (Prático Alemão).

### Método Prático Inglês

Este método é semelhante ao de Azevedo Neto e apresenta a seguinte equação:

\[
V_R = 0,05 \times P_{anual} \times A \tag{Eq. 9}
\]

Onde:
- \( V_R \) = volume do reservatório de água de chuva (litros);
- \( P_{anual} \) = precipitação da chuva média anual (mm); e
- \( A \) = área de captação (m²).

Então, \( V_R = 0,05 \times 1.487,5 \times 400 = 29.750 \) litros. Dessa forma, foi determinado o seguinte volume para o reservatório de água de chuva: \( V_R = 30 \) m³ (Prático Inglês).
Método Prático Australiano

Neste método o volume do reservatório (V_R) é determinado por tentativas, para atender à demanda com confiança do sistema entre 90% e 99%, conforme recomendação na NBR 15527 (ABNT, 2007). De acordo com as equações indicadas na norma, e considerando o período de 1 ano, que foi investigado nesses estudos de caso, o reservatório deve atender à demanda por no mínimo 11 meses ao ano, para obter confiança de 91% (Equações 10 e 11).

\[ \text{Confiança do sistema} = (1 - P_t) \quad \text{Eq. 10} \]

Onde:

\[ P_t = \text{falha do sistema (Eq. 11).} \]

\[ P_t = \frac{N_f}{N} \quad \text{Eq. 11} \]

Onde:

\[ N_f = \text{número de meses em que o reservatório não atende à demanda, ou seja, quando o reservatório está vazio no fim do mês} \quad (V_{t1} = 0), \quad \text{sendo} \quad V_t (\text{Eq. 12}); \]

\[ N = \text{número de meses considerado no cálculo, sendo indicado na NBR 15527 (ABNT, 2007) como geralmente 12 meses, portanto é o valor adotado neste artigo} \quad (N = 12). \]

\[ V_t = V_{t1} + Q_e - D_t \quad \text{Eq. 12} \]

Onde:

\[ V_t = \text{volume de água de chuva que está no reservatório no fim do mês;} \]

\[ V_{t1} = \text{volume de água de chuva que está no reservatório no início do mês;} \]

\[ Q_e = \text{volume de água de chuva aproveitável no mês} \quad (m^3), \quad \text{conforme a Eq. 13}, \quad \text{onde foi incluída a divisão por 1.000 para ajustar a unidade de volume;} \]

\[ D_t = \text{demanda mensal para água de chuva} \quad (m^3), \quad \text{sendo nesta pesquisa o volume da demanda constante, portanto na apresentação dos resultados é adotada a nomenclatura} \quad D. \]

Para o primeiro mês, considera-se o reservatório vazio (ou seja, \( V_{t1} = 0 \)). Além disso, quando \( (V_{t1} + Q_e - D_t) < 0 \), então \( V_t = 0 \).

\[ Q_e = A \times C_{AP} \times \left( \frac{P_t - 1}{1.000} \right) \quad \text{Eq. 13} \]

Onde:

\[ Q_e = \text{volume de água de chuva aproveitável no mês, considerando intercepção} \quad (m^3); \]

\[ A = \text{área de captação} \quad (m^2); \]

\[ C_{AP} = \text{coeficiente de aproveitamento do escoamento superficial} \quad \text{(neste artigo adotado 0,8)} \]

\[ P_t = \text{precipitação da chuva média mensal (mm);} \]

\[ I = \text{intercepção da água que mola as superfícies e perdas por evaporação, adotando-se 2 mm, conforme indicado na NBR 15527 (ABNT, 2007).} \]

O procedimento de cálculo foi realizado conforme indicado na Tabela 4.

Além do volume indicado na Tabela 4 (\( VF = 17 \) m³), foram também efetuadas tentativas, conforme apresentado na Tabela 5.

Com base nesta metodologia, utilizando valores de confiança de 90% e considerando que a variação na eficiência não aumentou significativamente, e volume dimensionado para o reservatório de água de chuva ficou em: \( VR = 17 \) m³ (Prático Australiano).

<table>
<thead>
<tr>
<th>Meses</th>
<th>Precipitação da chuva no tempo t (mm)</th>
<th>Volume de água de chuva aproveitável no tempo t (Eq. 13)</th>
<th>Volume de chuva armazenada no reservatório no início do mês (Eq. 12)</th>
<th>Volume de chuva armazenada no reservatório no fim do mês (Eq. 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Janeiro</td>
<td>225,8</td>
<td>71,62</td>
<td>0,00</td>
<td>17,00</td>
</tr>
<tr>
<td>Fevereiro</td>
<td>186,6</td>
<td>59,07</td>
<td>17,00</td>
<td>17,00</td>
</tr>
<tr>
<td>Marco</td>
<td>69,2</td>
<td>21,50</td>
<td>17,00</td>
<td>14,50</td>
</tr>
<tr>
<td>Abril</td>
<td>100</td>
<td>31,36</td>
<td>14,50</td>
<td>17,00</td>
</tr>
<tr>
<td>Maio</td>
<td>106,2</td>
<td>33,34</td>
<td>17,00</td>
<td>17,00</td>
</tr>
<tr>
<td>Junho</td>
<td>25,6</td>
<td>7,55</td>
<td>17,00</td>
<td>0,55</td>
</tr>
<tr>
<td>Julho</td>
<td>41,6</td>
<td>12,67</td>
<td>0,55</td>
<td>0,00</td>
</tr>
<tr>
<td>Agosto</td>
<td>104,2</td>
<td>32,70</td>
<td>0,00</td>
<td>8,70</td>
</tr>
<tr>
<td>Setembro</td>
<td>179,2</td>
<td>56,70</td>
<td>8,70</td>
<td>17,00</td>
</tr>
<tr>
<td>Outubro</td>
<td>116,6</td>
<td>36,67</td>
<td>17,00</td>
<td>17,00</td>
</tr>
<tr>
<td>Novembro</td>
<td>170,4</td>
<td>53,89</td>
<td>17,00</td>
<td>17,00</td>
</tr>
<tr>
<td>Dezembro</td>
<td>162,1</td>
<td>51,23</td>
<td>17,00</td>
<td>17,00</td>
</tr>
</tbody>
</table>

Volume do reservatório: \( V_R \) (m³)

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Obs.: \( V_{t1} \) é considerado zero quando o reservatório está vazio ou quando \( V_t \) é negativo no mês anterior.

Tabela 4 - Dimensionamento do reservatório pelo Método Prático Australiano - Edifício B

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Dimensionamento de reservatório para aproveitamento de água de chuva: comparação entre métodos da ABNT NBR 15527:2007 e decreto municipal 293/2006 de Curitiba, PR

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### Tabela 5 - Demais volumes testados no Método Prático Australiano - Edifício B

<table>
<thead>
<tr>
<th>Volume do reservatório (m³)</th>
<th>Confiança do sistema (%)</th>
<th>Eficiência do sistema (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>83</td>
<td>60</td>
</tr>
<tr>
<td>17</td>
<td>91</td>
<td>63</td>
</tr>
<tr>
<td>25</td>
<td>92</td>
<td>66</td>
</tr>
<tr>
<td>30</td>
<td>100</td>
<td>68</td>
</tr>
</tbody>
</table>

Fonte: Curitiba (2006)

### Tabela 6 - Consumo diário de água de chuva por quarto (litros/dia)

<table>
<thead>
<tr>
<th>Quantidade de quartos</th>
<th>Consumo (litros/dia)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (um)</td>
<td>400</td>
</tr>
<tr>
<td>2 (dois)</td>
<td>600</td>
</tr>
<tr>
<td>3 (três)</td>
<td>800</td>
</tr>
<tr>
<td>4 (quatro) ou mais</td>
<td>1,000</td>
</tr>
</tbody>
</table>

### Método do decreto municipal 293/2006 para edificações habitacionais

No Decreto Municipal 293/2006, de Curitiba-PR, são indicadas duas equações para o dimensionamento do volume do reservatório, uma destinada a edificações habitacionais e outra para comerciais. Em todos os casos fica estabelecido um volume mínimo de 300 litros.

O dimensionamento do reservatório de água de chuva nas edificações habitacionais é indicado a partir da Equação 14, em que a nomenclatura V foi substituída por $V_R$.

\[
V_R = N_e \times C_d \times d_r \times 0,25 \quad \text{Eq. 14}
\]

Onde:
- $V_R$ = volume do reservatório de água de chuva (litros);
- $N_e$ = número de unidades habitacionais (quando edifícios de habitação coletiva);
- $C_d$ = consumo diário de água de chuva (litros/dia), conforme a Tabela 6; e
- $d_r$ = número de dias de reserva = 2 (estabelecido no Decreto Municipal 293/2006).

Então, $V = (14 \text{ unidades de 3 quartos x 800} + 31 \text{ unidades de 2 quartos x 600}) \times 2 \times 0,25 = 14,900$ litros. Dessa forma, determinou-se o seguinte volume para o reservatório de água de chuva: $V_R = 15 \text{ m}^3$ (Decreto Municipal Curitiba, para edificação residencial).

### Método do decreto municipal 293/2006 para edificações comerciais

O dimensionamento do reservatório de água de chuva nas edificações comerciais é indicado a partir da Equação 15.

\[
V = A_e \times 0,75
\]

Onde:
- $V$ = volume do reservatório de água de chuva (litros);
- $A_e$ = área total computável da edificação (m²).

Lembra-se que neste artigo estão apresentados os cálculos apenas para o Edifício B, que é residencial; portanto, o método do decreto para edificação comercial não se aplica. Vale destacar que os resultados do estudo de caso da edificação comercial, bem como para os demais residenciais, estão descritos em Christan (2008).

### Resumo dos resultados e considerações finais

A Tabela 7 mostra os volumes dos reservatórios obtidos através dos diferentes métodos, para todos os estudos de caso.

De forma geral, os resultados foram discrepantes entre os diferentes métodos. A melhor aproximação ocorreu para o Edifício B, onde o maior volume obtido (30 m³), pelo Método Prático Inglês, foi da ordem de duas vezes o menor volume obtido (15 m³), pelo Método do Decreto Municipal 293/2006. O caso mais extremo ocorreu para a edificação comercial, onde a diferença foi da ordem de 100 vezes, pois o Método de Rippl resultou em aproximadamente 20 m³, e o Método do Decreto Municipal 293/2006 resultou em apenas 0,2 m³.
<table>
<thead>
<tr>
<th>Métodos</th>
<th>Volume dos reservatórios (m³)</th>
<th>Edificações</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Edifício A</td>
<td>Edifício B</td>
</tr>
<tr>
<td>Rippl</td>
<td>55</td>
<td>28</td>
</tr>
<tr>
<td>Simulação</td>
<td>36</td>
<td>25</td>
</tr>
<tr>
<td>Azevedo Neto</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>Prático Alemão</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>Prático Inglês</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>Prático Australiano</td>
<td>38</td>
<td>25</td>
</tr>
<tr>
<td>Decreto 293/2006 –</td>
<td>24</td>
<td>15</td>
</tr>
<tr>
<td>Edificação residencial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreto 293/2006 –</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Edificação comercial</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legenda:
1 = a condição \(2D_{1+2Q_{1}}\) não foi atendida para a aplicação desse método no estudo de caso;
2 = em função da alta demanda, a melhor confiança obtida foi de 16%; e
NA quando não se aplica.

Tabela 7 - Resumo do dimensionamento dos reservatórios

Campos et al. (2007), Mierzwa et al. (2007) e Amorim e Pereira (2008) comentam que Ripl é o método mais utilizado, portanto, por ter sido desenvolvido inicialmente para a regularização de vazão, geralmente resulta em grandes reservatórios. Neste estudo isso não foi constatado. Por outro lado, para o edifício com maior demanda de água de chuva, onde está utilizada em descarga de bacias sanitárias (Edifício C), os Métodos de Rippl, Simulação e Prático Australiano não puderam ser testados, pois as condições impostas naqueles métodos não tiveram como ser atendidas. Para os demais estudos de caso, os resultados foram próximos para o Método de Simulação e Prático Australiano, pois a metodologia de cálculo é semelhante. No Método de Azevedo Neto e no Método Prático Alemão os resultados se enquadraram nos menores volumes entre os métodos apresentados na NBR 15527 (ABNT, 2007). Em quatro dos cinco estudos de caso, na comparação entre todos os métodos avaliados neste artigo, os menores volumes foram obtidos pelo Método do Decreto Municipal 293/2006, tanto para edificações residenciais quanto comerciais.

Comentários sobre o decreto municipal 293/2006

Em relação ao Método do Decreto Municipal 293/2006 para edificação comercial, a equação considera o volume do reservatório como sendo 75% da área total computável da edificação, mas nenhum parâmetro relacionado ao índice de precipitação pluviométrica, nem a demanda para a água de chuva, nem a área de captação. Da mesma forma, para edificações residenciais a equação é formulada a partir do número de quartos da unidade residencial, levando em consideração valores de consumo *per capita* de água potável e não considerando parâmetros relacionados à demanda para água de chuva. Comparando os resultados das equações do Decreto Municipal 293/2006 com os dos métodos da NBR 15527 (ABNT, 2007), fica evidente a necessidade de mais investigações acerca das fórmulas do decreto e provavelmente sua revisão, a fim de serem incluídas considerações sobre o índice pluviométrico, a área de captação e a demanda para a água de chuva armazenada.

Comentários sobre a NBR 15527:2007

Os métodos apresentados na NBR 15527 (ABNT, 2007), bem como em seu anexo, possuem diferenças na indicação das mesmas variáveis, o que compromete o entendimento das fórmulas. Por exemplo, a variável “V” em alguns métodos é o volume do reservatório e, em outros, é o “volume de água aproveitável”, ou “volume de água do reservatório”, ou “volume de água da cisterna”. Seria mais apropriado utilizar variáveis exclusivas para cada parâmetro, e a utilização de índices em algumas das variáveis, para diferenciar alguma característica específica. Um exemplo disso é o volume de água de chuva aproveitável, que poderia ser indicado como “\(V_{AP}\)” em vez de simplesmente “\(V\)”, pois este pode ser confundido com um método de dimensionamento em função do uso da nomenclatura “\(V\)” para os dimensionamentos no anexo da norma. Outra indicação de variável que pode provocar equívoco é o coeficiente de aproveitamento do escoamento superficial (indicado na norma como \(C_{es}\), porém denominado neste artigo \(C_{as}\)), o qual é resultante da multiplicação do coeficiente de escoamento...
superficial do material da área de captação (também indicado na norma como C), multiplicado por um fator de captação em função da eficiência do sistema existente. Talvez a indicação de “coeficiente de aproveitamento do escoamento superficial (C_{AP})” em vez de “coeficiente de escoamento superficial (C)” seria mais apropriada.

Até mesmo a definição do volume do reservatório de água de chuva, que é a finalidade do anexo, fica comprometida quando, por exemplo, não aparece a indicação de seu cálculo no Método da Simulação e também quando no Método Prático Australiano está indicado que o volume do “tanque” escolhido será “T”, mas também não está indicado como calcular esse “T”. Além disso, apenas nesse método existe denominação como tanque (T), que se entende ser o volume do reservatório de água de chuva, mas que nos demais métodos aparece como “V”. Esses ajustes de nomenclatura e apresentação das equações são aqui sugeridos, pois facilitariam consideravelmente a utilização dos métodos apresentados na NBR 15527 (ABNT, 2007).

Analisar a apresentação das variáveis nos métodos da NBR 15527 (ABNT, 2007) e seu anexo não foi o objetivo principal deste trabalho, mas conclui-se que uma revisão da norma para padronizar os termos e as variáveis seria conveniente, pois o entendimento dos métodos é prejudicado pela ambiguidade na nomenclatura de variáveis. Uma definição de nomenclatura específica aos sistemas de aproveitamento de água de chuva certamente é de valia para a comunidade técnica e científica, no sentido de evitar as associações dessas variáveis aos métodos de dimensionamento de sistemas de drenagem urbana ou outras obras hidráulicas.

Tanto na NBR 15527 (ABNT, 2007) como no Decreto Municipal 293/2006 existem outras considerações passíveis de melhorias, mas este artigo enfoca apenas os critérios relacionados especificamente ao dimensionamento de reservatórios. Vale ressaltar a importância da publicação daqueles documentos, que certamente iniciaram um processo importante para contribuir com a disseminação do uso de água de chuva em finais não potáveis e agora, após estes primeiros anos em circulação, podem ser objeto de melhorias.

Conclusões

Este estudo não foi conclusivo quanto à definição de qual seria o melhor método entre os avaliados neste artigo, pois os resultados não indicaram nenhum padrão constante e provavelmente cada caso terá seu método mais apropriado. Assim, salienta-se a importância de efetuar esse tipo de investigação comparativa, antes de optar por um ou outro método de dimensionamento. Os métodos que resultam em volumes maiores em geral, mas não necessariamente, atendem à condição de suprir a demanda por mais tempo ao longo do ano. Por outro lado, os métodos que resultam em menor volume apresentam menor custo do reservatório.

Dessa forma, a decisão final pelo método mais adequado pode ser baseada na comparação dos volumes obtidos, em sua viabilidade em termos de área disponível no local onde será construído o reservatório, e também no custo da construção do reservatório, o qual pode representar uma fração significativa do valor final do sistema. Aliado ao aspecto econômico, o aproveitamento de água de chuva para fins não potáveis, ao contribuir para a diminuição do consumo de água potável, resulta em ganho ambiental muito importante, e por isso deve ser estimulado. A qualidade da água de chuva coletada deve ser adequada ao atendimento das demandas, garantindo sempre a segurança sanitária dos usuários.

Referências

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AGÊNCIA NACIONAL DE ÁGUAS.

AGÊNCIA NACIONAL DE ÁGUAS.


TOMAZ, P. Dúvida NBR 15527 [mensagem pessoal]. Mensagem recebida por <sbezerra@utfpr.edu.br>, em 28 mar. 2010.

Agradecimentos

Os autores agradecem sinceramente os comentários dos revisores, pois foram de extrema valia para a melhoria deste artigo.

Abstract: This paper presents the main results of a study that evaluated the feasibility of using harvested rainwater in the construction of buildings. In addition, some evaluation was also performed regarding non-potable uses for harvested rainwater in buildings after occupation. Samples of rainwater were collected in four locations in the city of Curitiba (state of Paraná), in the South of Brazil. The quality of harvested rainwater in Curitiba was compared to several national and international standards of water quality for use in buildings under construction and after occupation. Results showed that the harvested rainwater was suitable for use in several activities at construction sites, such as the preparation and curing of concrete and mortar, soil compaction, washing of aggregates, and dust control. Disinfection of harvested rainwater may be necessary for non-potable uses in buildings after occupation. The substitution of rainwater for potable water is feasible for many non-potable uses and may represent around fifty percent of the total water usage at construction sites. Saving potable water is in accordance with best water management practices for the construction industry.
IV-109 – ESTIMATIVA DO CONSUMO DE ÁGUA POTÁVEL NA CONSTRUÇÃO DE EDIFICAÇÕES

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RESUMO
Este estudo avaliou o consumo de água potável durante a construção de dois edifícios em Curitiba, estado do Paraná, no sul do Brasil. Com dados obtidos nas construtoras envolvidas, e na concessionária dos serviços de abastecimento municipal, foram investigados: (1) o consumo de água potável por área construída, (2) as etapas construtivas que requerem mais água para serem concluídas e (3) o volume total de água potável para consumo humano. Os resultados indicaram que o consumo de água potável por área construída foi 0,08 m³/m² (edição A) e 0,16 m³/m² (edição B). A avaliação da relação entre consumo de água e as respectivas etapas construtivas não foi conclusiva, em função do sondreamento entre as diversas atividades durante o processo construtivo, e pelo fato de não ter sido estabelecido um padrão na construção dos dois edifícios avaliados. A estimativa do volume de água para consumo humano não resultou em valor coerente e, com volume total de água potável consumado na obra, provavelmente em função da ausência de dados precisos do número de pessoal no canteiro de obras. Este estudo indica que para a determinação do consumo de água na construção de edifícios é fundamental a correta medição do consumo de água no canteiro de obras, incluindo todas as fontes utilizadas, desde o início da implantação da obra. Com relação à estimativa do consumo humano ao canteiro de obras, é necessário o controle do número de pessoal em cada período da construção da obra. Os resultados obtidos indicam que o consumo de água potável na construção de edificações é significativo e poderia ser reduzido com medidas de conservação e uso racional deste recurso.

PALAVRAS-CHAVE: Consumo de água, Construção de edifícios, Estimativa.

INTRODUÇÃO
Na construção de edifícios, água é um elemento imprescindível. Seu uso está relacionado tanto ao consumo humano pelo pessoal que trabalha na obra, quanto à execução de diversos serviços, tais como: fabricação e cura de concreto, fabricação de argamassa, testes de impermeabilização e limpeza da obra, entre outros.

Apesar da importância da água na construção de edificações, provavelmente por representar uma parcela pequena do custo do empreendimento, o consumo de água no canteiro muitas vezes é negligenciado. De maneira geral, a água não é vista e nem tratada como material de construção. Este é notado em diversas composições de custos dos serviços de engenharia, quando o valor para o consumo de água não está incluído, mesmo considerando os elevados volumes de água utilizados na confecção do concreto (até 200 litros/m³), ou na compactação de areia (até 300 litros/m³) (FILHO NETO, 2008). Aliado a isso, vazamentos e pouca
preocupação com o uso racional da água são comuns na fase de execução da obra (DANTAS NETO, 2008). Até o momento existem poucos estudos sobre o consumo de água durante a fase de construção (PESSARELLO, 2008; SOUZA & MÜLLER, 2009).

Por isso, a quantificação do consumo de água durante a fase de construção de uma obra torna-se importante para identificar quais etapas construtivas requerem mais água, e definir medidas de redução do uso desse recurso. Além disso, a estimativa do consumo de água pode servir como parâmetro comparativo para outros estudos (SOUZA & MÜLLER, 2009).

Nesse estudo avaliou-se o consumo de água potável durante a construção de dois edifícios residenciais. Os objetivos da pesquisa foram: (1) determinar o consumo de água potável proveniente da rede de abastecimento municipal por área construída, (2) determinar o consumo de água potável por etapa dos serviços de construção, avaliando quais etapas da construção demandam mais água para serem executadas, e (3) estimar o consumo de água potável para consumo humano durante o período de construção.

MATERIAIS E MÉTODOS

Dois edifícios recentemente construídos foram escolhidos para participar do trabalho, pelo fato de apresentarem cronogramas bem definidos, e da disponibilização do registro dos dados de consumo de água potável durante toda a construção. Os edifícios estão localizados no município de Curitiba, estado do Paraná, no sul do Brasil, e estão denominados como "edifício A" e "edifício B". As áreas totais de cada edifício e os respectivos períodos de execução estão indicados na Tabela 1.

Os dados de consumo de água na construção do edifício A foram obtidos na concessionária dos serviços de operação da rede de abastecimento municipal e para o edifício B foram fornecidos pela construtora do mesmo, através das contas de água arquivadas na empresa. Os cronogramas físicos foram fornecidos pelas construtoras envolvidas no estudo. O número de pessoa no canteiro de obras foi fornecido pela construtora, mas somente para o edifício B, pois a construtora do edifício A não disponibilizou esses dados, em função de falta no seu arquivamento. Os cronogramas físicos e os dados de consumo de água foram utilizados para determinar o consumo de água potável por área construída. Os dados também foram utilizados para realizar uma tentativa de identificar as etapas da construção de maior utilização de água. Ao final foi estimado o volume de água destinado ao consumo humano e avaliado em termos de percentual em relação ao consumo total na obra. Para tanto foi utilizada a quantidade de pessoas que trabalharam na obra e adotado um valor para o consumo de água por capitalidade (Equação 1).

RESULTADOS DO CONSUMO DE ÁGUA POTÁVEL NO CANTEIRO DE OBRAS

Durante o processo de coleta dos dados do consumo de água, foi constatado que na construção dos edifícios A e B, além do uso da água proveniente da rede de abastecimento municipal, houve utilização de água de outras fontes. No caso do edifício A foi utilizada água de poço em aproximadamente 20 dos 43 meses do período construtivo, e na construção do edifício B foi utilizada água de chuva em 36 dos 12 meses de execução da obra. Por falta de medição da quantidade de água utilizada dessas fontes, as estimativas do consumo de água apresentadas neste trabalho contêm apenas a água proveniente da rede de abastecimento municipal e, portanto, são referentes apenas ao consumo de água potável. Desta forma, as estimativas do consumo total de água para a construção (m³), do consumo médio mensal durante a construção (m³/mês), e do consumo total por área total construída (m³/m²) estão indicadas na Tabela 1. Os resultados do consumo de água confrontados com as etapas construtivas encontram-se na Figura 1 (edifício A) e na Figura 2 (edifício B).

Para o edifício A, foi considerado apenas o consumo de água potável a partir do décimo sexto mês de construção, pois os dados anteriores não foram fornecidos no decorrer desta pesquisa. Desta forma, o resultado que foi calculado em 0,68 m³/m² (edifício A) não representa o volume real do consumo de água potável na execução da obra. Para o período avaliado, os picos máximos de consumo de água potável ocorreram nos meses 24 e 25 e corresponderam, respectivamente, a 150 e 130 m³ de água por mês. Conforme o cronograma da obra, esses consumos máximos estão relacionados aos serviços de estrutura impermeabilização,
revestimentos e instalações hidráulicas. Em função do semelhamento das atividades, não foi possível identificar qual dessas etapas é a principal consumidora de água na obra. Vale salientar que Pessaruolo (2008, p.96-113) observou aumento no consumo de água nas etapas de estrutura e revestimento. No período entre os meses 27 e 36, o consumo de água ocorreu sem muitas variações, com um valor médio mensal de 11,20 m³. No mês 37, aliado as etapas de revestimentos e instalações hidráulicas, foi iniciado o serviço de pintura. Naquele mês o consumo duplicou em relação ao anterior, e pode estar relacionado ao consumo de água potável utilizada para a diluição de tintas. No mês 41 (pintura e limpeza da obra) ocorreu um decréscimo gradativo na quantidade de água consumida no canteiro de obras. Este fato é contrário ao esperado, pois os serviços de limpeza consumem um volume significativo de água. É importante destacar que a partir do mês 24 foi adicionado o uso da água do poço existente no canteiro de obras, mas seus volumes não foram mensurados. Portanto, os serviços realizados após a inclusão desta fonte alternativa de água, incluindo a limpeza final da obra, a avaliação da quantidade de água por etapa construtiva ficou prejudicada, considerando que o volume de água potável provavelmente não supria toda a demanda para a execução dos serviços indicados no cronograma.

Para o edifício B, os dados do consumo de água potável são referentes ao período completo da construção e resultaram em 0,16 m³/mês. A partir do quinto mês ocorreu um aumento no consumo de água quando estavam sendo realizados os serviços de estrutura, revestimentos e instalações hidráulicas, e também foi iniciada a impermeabilização. No mesmo mês ocorreu um aumento de 84% no consumo de água, comparado com o mês anterior, totalizando 90 m³. Este consumo elevado, assim como no edifício A, pode estar relacionado ao consumo de água potável utilizada para a diluição de tintas, pois naquele período foram iniciados os serviços de pintura. Nos meses 11 e 12 (conclusão das instalações hidráulicas, correção da pintura e início da limpeza), ocorreu redução do consumo de água. Novamente essa diminuição pode ser atribuída ao uso de fonte alternativa de água, no caso da água de chuva armazenada no reservatório construído para a edificação, que começou a ser captada no décimo mês de construção. Da mesma forma, nos serviços realizados após a adição desta fonte alternativa de água, a avaliação da quantidade de água potável por etapa construtiva ficou prejudicada, considerando que o volume de água mensurado provavelmente não supria toda a demanda para a execução dos serviços indicados no cronograma.

O volume total de água potável para a construção dos edifícios estudados foi 1094 m³ para o “edifício A” e 554 m³ para o “edifício B”. O consumo médio mensal de água potável também foi calculado, sendo 39 m³/mês para o “edifício A” e 46 m³/mês para o “edifício B” (Tabela 1).

<table>
<thead>
<tr>
<th>Edifício</th>
<th>Área total construída (m²)</th>
<th>Período de execução (meses)</th>
<th>Consumo total (m³)</th>
<th>Consumo médio mensal (m³/mês)</th>
<th>Consumo total/área total construída (m³/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edifício A</td>
<td>13572,7</td>
<td>43</td>
<td>1094</td>
<td>39</td>
<td>0,08</td>
</tr>
<tr>
<td>Edifício B</td>
<td>3547</td>
<td>12</td>
<td>554</td>
<td>46</td>
<td>0,16</td>
</tr>
</tbody>
</table>

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Figura 1: Consumo mensal de água confrontado com as etapas construtivas do edifício A.

Figura 2: Consumo mensal de água confrontado com as etapas construtivas do edifício B.

RESULTADOS DO CONSUMO HUMANO DE ÁGUA NO CANTEIRO DE OBRAS

Nessa etapa foi realizada a estimativa do consumo de água para uso humano do edifício B, pois, conforme mencionado anteriormente, a quantidade de trabalhadores na construção do edifício A não foi disponibilizada pela construtora.
O consumo de água para uso humano na construção da obra está relacionado ao número de operários no canteiro, e a frequência e uso das instalações hidrossanitárias, tais como bebedouros, bacias sanitárias e chuvas. No canteiro de obras do edifício B haviam instalados quatro chuvas e seis bacias sanitárias.

A estimativa do consumo de água para uso humano foi obtida considerando-se um valor per capita de consumo de água no canteiro e a estimativa da quantidade média mensal de trabalhadores no canteiro, e a quantidade de horas trabalhadas por dia. O valor adotado para o per capita diário do pessoal no canteiro foi 4,5 litros, considerando operário com idade a jovem (SILVA, 2006). A partir desses dados, a quantidade mensal de água destinada ao consumo humano foi calculada através da seguinte equação (Equação 1):

\[
\text{Consumo humano mensal (L/mês)} = \frac{45 \, \text{L/pessoa x dia}}{(\text{dias de trabalho no mês}) \times (\text{média de trabalhadores no mês})
\]

Equação 1

O somatório dos consumos mensais de água potável resultou em 296,81 m³. Comparado este volume com o total consumido na obra (554 m³) verifica-se que o consumo humano representou 53,4% de toda a água utilizada na construção do edifício A. Porém, estes valores contemplam apenas o consumo de água obtido pela concessionária dos serviços de abastecimento municipal e, portanto, o total de água para os serviços da construção pode ser maior, pois também foi utilizada água de chuva armazenada em reservatório no canteiro de obras.

A Figura 3 representa o consumo estimado para o uso humano e o consumo total mensurado de água potável durante a construção do edifício B. Nos meses 1, 2, 3, e 4, o consumo de água estimado para uso humano excede o valor do consumo total de água. Tal incidência pode estar relacionada a erros na adoção do valor de consumo per capita por trabalhador e/ou nos dados da quantidade mensal de trabalhadores no canteiro de obras.

Figura 3: Consumo de água para uso humano e consumo total na construção do edifício B.

A relação entre o consumo total mensurado de água potável, e a quantidade média mensal de pessoal no canteiro, foi avaliada a fim de verificar se a variação na quantidade de trabalhadores no canteiro influencia a quantidade total de água (Figura 4). Este fato não pode ser observado no presente estudo, mas em Pessarillo...
(2008, p.89-92) tinha sido constatado que a quantidade de operários trabalhando na obra e o consumo de água crescem em conjunto, com raras exceções.

![Gráfico de consumo de água e número de pessoas trabalhando]

Figura 4: Consumo de água e média de pessoas trabalhando durante a construção do edifício B.

CONCLUSÃO

Os resultados indicam que o consumo de água potável por área construída foi 0,08 m³/m² (edifício A) e 0,16 m³/m² (edifício B). A diferença entre os valores pode ser atribuída ao fato de que no edifício A, os dados somente foram computados a partir do décimo sexto mês da obra, portanto se fosse considerado desde o início, provavelmente o valor seria maior. A avaliação da relação entre consumo de água e as respectivas etapas construtivas não foi possível, em função do bombeamento entre as diversas atividades durante o processo construtivo, e pelo fato de não ter sido estabelecido nenhum padrão na construção dos dois edifícios avaliados.

A estimativa de volume de água para consumo humano não resultou em volume coerente com volume total de água consumida na obra, provavelmente em função da ausência de dados precisos de número de pessoal no canteiro de obras e/ou da adoção de valor inadequado para o consumo per capita diário de água por pessoal no canteiro de obras. Este estudo indica que para a determinação do consumo de água na construção de edificações é fundamental a correta medição do consumo de água no canteiro de obras, incluindo todas as fontes utilizadas, desde o início da construção. Os resultados obtidos indicam que o consumo de água potável na construção de edificações é significativo e poderia ser reduzido com medidas de conservação e uso racional deste recurso.

Considerando o consumo significativo de água potável durante a obra, diversas medidas de conservação e uso racional poderiam ser implantadas. Para o consumo humano sugere-se adotar no canteiro de obras a utilização de torneiras com acionamento e desligamento automático, a instalação de temporizadores nos chuveiros, e a utilização de água da chuva para descargas em bacias sanitárias. Quanto aos serviços de construção, várias atividades poderiam usar água não potável, por exemplo: água de chuva, água de poço e reúso de esgoto tratado, entre eles para a preparação de concreto e serviços de limpeza da obra. Aliado a isso, pode-se investir em campanhas educativas para o uso racional de água junto aos profissionais que atuam na obra.
REFERÊNCIAS BIBLIOGRÁFICAS


Abstract: This paper presents the main results of a study that evaluated the feasibility of using harvested rainwater in the construction of buildings. In addition, some evaluation was also performed regarding non-potable uses for harvested rainwater in buildings after occupation. Samples of rainwater were collected in four locations in the city of Curitiba (state of Paraná), in the South of Brazil. The quality of harvested rainwater in Curitiba was compared to several national and international standards of water quality for use in buildings under construction and after occupation. Results showed that the harvested rainwater was suitable for use in several activities at construction sites, such as the preparation and curing of concrete and mortar, soil compaction, washing of aggregates, and dust control. Disinfection of harvested rainwater may be necessary for non-potable uses in buildings after occupation. The substitution of rainwater for potable water is feasible for many non-potable uses and may represent around fifty percent of the total water usage at construction sites. Saving potable water is in accordance with best water management practices for the construction industry.
IV-108 – QUALIDADE DA ÁGUA DA CHUVA EM CURITIBA – PARANÁ - PARA SER UTILIZADA NA CONSTRUÇÃO DE EDIFICAÇÕES

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RESUMO
Este trabalho verifica a qualidade da água da chuva em quatro bairros da cidade de Curitiba, estado do Paraná, no sul do Brasil, através de ensaios microbiológicos e físico-químicos, e propõe o aproveitamento desta água durante a construção de edificações. Os resultados dos parâmetros avaliados foram comparados com diversas normas e padrões nacionais e internacionais. Verificou-se que a qualidade da água da chuva das amostras analisadas é compatível com sua utilização em diversos serviços na construção de edificações, mas pode ser necessário algum tratamento preliminar, em função dos limites indicados nas normas dotadas. A substituição de água potável por água de chuva é uma medida que pode ser adotada para a conservação e uso racional nas edificações, desde a etapa de construção, e deve ser estimulada.

PALAVRAS-CHAVE: Água de chuva, Aproveitamento, Convolução civil, Edificações, Qualidade.

INTRODUÇÃO
A adoção de práticas que substituam o uso de água potável por águas de menor qualidade, sempre que possível, é de suma importância nos dias atuais, visto os problemas de escassez de água que vem ocorrendo em todo o mundo. O problema da falta de água tende a se agravar por diversos fatores, como a ausência de uso sustentável, o uso inadequado, o aumento da demanda em função do crescimento demográfico.

A construção civil é um setor no qual práticas conservacionistas de água são possíveis, pois a água utilizada nos serviços de construção não necessita ser potável, podendo ser substituída por água com qualidade inferior, como a água de chuva, por exemplo. A viabilidade dessa prática baseia-se na consequência da água, bem como na economia financeira obtida no custo final da obra.

Em edificações já construídas, sistemas de aproveitamento da água da chuva para fins não potáveis já são empregados para a descarga em bacias sanitárias, a lavagem de calçadas e a irrigação de jardins. Por outro lado, a utilização desse recurso durante a construção de uma obra ainda é pouca difundida entre profissionais da construção civil (SOUZA & MÜLLER, 2009).

Neste estudo analisou-se a viabilidade da utilização de água de chuva para finalidades não potáveis na construção de duas edificações em Curitiba, estado do Paraná, no sul do Brasil.
MATERIAIS E MÉTODOS

A qualidade da água de chuva no município de Curitiba foi avaliada através de análises físico-químicas e microbiológicas, de amostras coletadas em quatro bairros distintos da cidade: Água Verde, Centro, Novo Mundo e Reboças. As coletas aconteceram nos meses de agosto, setembro e outubro de 2009. Foram coletadas amostras de chuva atmosférica e de chuva após escoamento por telhado da seguinte forma:

1. Amostra de chuva atmosférica - coletada diretamente em um recipiente plástico exposto à chuva e elevado a uma altura de aproximadamente 70 centímetros em relação ao solo para evitar respingos e
2. Amostra de chuva após escoamento por telhado - coletada em um recipiente plástico, após o escoamento da chuva por telhado. Também houve elevação do recipiente para evitar respingos. Os tipos de telha referentes a cada ponto de coleta estão descritos na Tabela 1.

Os recipientes plásticos utilizados nas coletas foram previamente esterilizados com álcool e enaguados com a própria água da chuva. As amostras de chuva nem sempre foram coletadas logo no início da chuva, em função da disponibilidade para a coleta dos pesquisadores envolvidos no trabalho.

Os parâmetros analisados foram: pH, cor, sólidos totais, sólidos suspensos totais, sólidos dissolvidos totais, DBO, turbidez, cloretos solúveis, nitratos, chumbo, zinco, coliformes totais e coliformes fecais, de acordo com os procedimentos do Standard Methods for Examination of Water and Wastewater (APHA, 2005).

A análise dos resultados dos parâmetros físico-químicos e microbiológicos foi realizada por meio da comparação dos mesmos com os limites de duas normas internacionais: Marcsoul CMN NM 137 (CMN, 1997) e da União Européia BS EN 1008 (BS; 2002). Estas normas apresentam padrões de qualidade para água utilizada na produção de concreto e cura de argamassa e concreto. Os resultados também foram comparados com os limites estabelecidos no manual “Conservação e Reuso da Água em Edificações” (ANA, 2005), que indica parâmetros de qualidade da água para diversos serviços de construção de edificações, entre outras aplicações para fins não potáveis, e com a norma da Associação Brasileira de Normas Técnicas - ABNT NBR 15527/2007 (ABNT, 2007), que trata do aproveitamento de água de chuva captada em coberturas em áreas urbanas para fins não potáveis. A partir da comparação dos resultados com os parâmetros indicados nas normas investigadas, foi possível verificar a possibilidade de empregar a água de chuva para fins não potáveis na construção de edifícios. A Tabela 2 apresenta a relação dos parâmetros avaliados no estudo e seus respectivos limites estabelecidos nas normas.

Tabela 1: Localização dos pontos de coleta e formas de captação das amostras de chuva

<table>
<thead>
<tr>
<th>Ponto de Coleta</th>
<th>Formas de captação</th>
<th>Tipo de telha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Água Verde</td>
<td>Atmosférica</td>
<td>-</td>
</tr>
<tr>
<td>Centro</td>
<td>Atmosférica e após escoamento por telhado</td>
<td>Fibrocimento</td>
</tr>
<tr>
<td>Novo Mundo</td>
<td>Atmosférica e após escoamento por telhado</td>
<td>Barro seguido de telha de fibra transparente</td>
</tr>
<tr>
<td>Reboças</td>
<td>Atmosférica</td>
<td>-</td>
</tr>
</tbody>
</table>
Tabela 2: Parâmetros avaliados nas análises da água de chuva e respectivos limites

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>5.5-9</td>
<td>&gt;4</td>
<td>6.0-9.0</td>
<td>6.0 a 8.0</td>
</tr>
<tr>
<td><strong>Sólidos totais (ST)</strong></td>
<td>5000 mg/L</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sólidos suspensos totais (SST)</strong></td>
<td>-</td>
<td>-</td>
<td>30 mg/L</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sólidos dissolvidos totais (SDT)</strong></td>
<td>-</td>
<td>&lt;100 mg/L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>DBO</strong></td>
<td>-</td>
<td>-</td>
<td>≤ 30 mg/L</td>
<td>&lt; 2,0 UNT 5,0 UNT (Usos restritivos)</td>
</tr>
<tr>
<td><strong>Turbidez</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Cor</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>&lt; 15 uH</td>
</tr>
<tr>
<td><strong>Cloro</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Concreto simples</strong></td>
<td>2000 mg/L</td>
<td>4500 mg/L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Concreto armado</strong></td>
<td>700 mg/L</td>
<td>1000 mg/L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Concreto protendido</strong></td>
<td>500 mg/L</td>
<td>500 mg/L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Fosfatos</strong></td>
<td>-</td>
<td>&lt;100 mg/L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Nitratos</strong></td>
<td>-</td>
<td>&lt;500 mg/L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Chumbo</strong></td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Zinco</strong></td>
<td>-</td>
<td>&lt;100 mg/L</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Coliformes Totais</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>ausência em 100 mL</td>
</tr>
<tr>
<td><strong>Coliformes fecais</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>≤ 1000/mL ausência em 100 mL</td>
</tr>
</tbody>
</table>

Obs.: Requisitos de qualidade da água para: 1° arranque do concreto; 2° cura de argamassa e concreto de cimento portland; 3° serviços de construção de edificação tais como lavagem de agregados, preparação de concreto, compactação do solo e controle da poeira; 4° aproveitamento de água de chuva captada em coberturas em áreas urbanas para fins não potáveis. Os traços (-) indicam que o limite do respectivo parâmetro não está disponível.

RESULTADOS E DISCUSSÃO: ANÁLISES FÍSICO-QUÍMICAS

Os resultados obtidos nas análises físico-químicas nos diferentes pontos de coleta encontram-se na Tabela 3. Em relação ao pH das amostras coletadas nos bairros Novo Mundo e Centro, observou-se que os valores de pH da chuva coletada após passagem por telhado, com exceção de uma amostra, foram mais baixos do que os da chuva atmosférica (Tabela 3). Esses valores corroboram que o pH da chuva atmosférica normalmente é levemente ácido (DESPINS et al., 2009), e o pH da chuva captada após escoamento por telhado é mais básico (JAQUES, 2005).

Os valores de pH médio das amostras de chuva atmosférica do bairro Novo Mundo (6,04), Centro (6,03), Água Verde (6,30), e Rebouças (6,51) e das amostras de chuva após passagem por telhado do Novo Mundo (6,68) e do Centro (6,66) estão de acordo com os limites das normas utilizadas nesse estudo, os quais variam entre 4,0 e 9,0 (CMN, 1997; BS, 2002; ANA, 2006 e ABNT, 2007). Verificando o pH de cada amostra, observa-se que 100% das amostras analisadas atendeu à BS EN 1008 (BS, 2002), 99% atendeu à CMN NM 137 (CMN, 1997), e 70% atendeu aos limites da ABNT NBR 15527/2007 (ABNT, 2007) e do manual "Conservação e Reuso da Água em Edificações" (ANA, 2006). Em geral, 70% das amostras analisadas atendeu aos limites superior e inferior de pH de todas as normas utilizadas nesse estudo. Portanto, em relação ao pH, conclui-se que a água da chuva analisada poderia ser utilizada para a produção de concreto conforme as normas BS EN
1068 (BS, 2002) e CMN NM 137 (CMN, 1997), e cura de argamassa conforme a BS EN 1008 (BS, 2002). Para outros usos seria necessário o ajuste do pH.

Na análise da turbidez, os resultados foram comparados com os dois limites indicados pela norma ABNT NBR 15527/2007 (ABNT, 2008). Verificou-se que a maioria das amostras, 30 de 32 amostras ou aproximadamente 94%, atendia ao limite máximo de 5,0 UNT para usos menos restritivos. Portanto, em relação a esse parâmetro, é mais adequado que a água de chuva seja utilizada para finalidades não potáveis menos restritivas. Ressalta-se que a norma brasileira não define o que são usos menos e mais restritivos (ABNT, 2007). Nas demais normas selecionadas para este trabalho, o limite para turbidez não está indicado.

Para o parâmetro cor, todas as amostras analisadas apresentaram resultados dentro do limite indicado na norma ABNT NBR 15527/2007 (ABNT, 2007), menor do que 15 uH. Nas demais normas e no manual selecionados na presente pesquisa, o limite para cor não está indicado.

A concentração de cloretos das amostras encontra-se dentro dos limites indicados pelas normas internacionais analisadas, variando entre 500 mg/L e 4500 mg/L, em função do tipo de concreto a ser produzido (CMN, 1997; BS, 2002). Nas normas e manual brasileiros selecionados para este trabalho, o limite para cloretos não está indicado.

Em relação aos parâmetros fosfato, nitrato, zinco e chumbo, analisados somente para chuva atmosférica, verificou-se que estes estão dentro dos limites estabelecidos pela norma europeia BS EN 1008 (BS, 2002), os quais são: concentração inferior a 100 mg/L para fosfatos, chumbo e zinco, e inferior a 500 mg/L para nitratos. Nas demais normas e no manual selecionados para este trabalho, o limite para os parâmetros acima indicados não estão indicados.

A DBO para chuva atmosférica permaneceu abaixo do limite de 30 mg/L indicado no manual “Conservação e Reúso da Água em Edificações” (ANA, 2006). Da mesma forma que para o parâmetro cor, o limite para DBO não está indicado nas demais normas analisadas neste trabalho.

Dos parâmetros para sólidos encontrados nas normas e no manual selecionado no trabalho, os resultados para sólidos totais da chuva atmosférica permaneceram de acordo com o valor estabelecido na CMN NM 137 (CMN, 1997). Os resultados para sólidos suspensos totais atenderam o limite de 30 mg/L estabelecido no manual “Conservação e Reúso da Água em Edificações” (ANA, 2006) e os resultados de sólidos dissolvidos totais atenderam o limite da BS EN 1008 (BS, 2002) que estabelece concentração inferior a 100 mg/L. Portanto, conforme os resultados dos parâmetros físico-químicos cor, cloretos, fosfato, nitrato, zinco, chumbo, DBO, ST, SDT, SST, a água de chuva poderia ser utilizada sem tratamento para a produção de concreto (CMN, 1997; BS, 2002; ANA, 2006); para cura de argamassa (BS, 2002); e para lavagem de agregados, compactação de solo e controle da poeira (ANA, 2005). As restrições relacionadas aos parâmetros microbiológicos são discutidas a seguir.

RESULTADOS E DISCUSSÃO: ANÁLISES MICROBiológICAS

A análise microbiológica foi feita apenas para as amostras de chuva atmosférica dos pontos de coleta nos bairros Água Verde e Rebouças (Tabela 4). Em relação aos resultados da análise microbiológica, o valor estabelecido como < 1,1 NMP/100mL está sendo considerado como ausência do microorganismo em 100mL de amostra. Os resultados obtidos para coliformes fecais nas amostras de chuva atmosférica analisadas atenderam ao limite estabelecido pelo manual “Conservação e Reúso da Água em Edificações” (ANA, 2006), que recomenda concentração menor ou igual a 1000 NMP/100mL. No entanto, apenas duas das seis amostras analisadas ou aproximadamente 33%, atenderam à norma brasileira ABNT NBR 15527/2007 (ABNT, 2007), que recomenda a ausência de coliformes totais e fecais em 100 mL de amostra. Em relação aos coliformes totais, a água de chuva atendeu ao limite estabelecido pela norma brasileira (ABNT, 2007) de ausência em 100 mL de amostra. As normas internacionais adotadas neste trabalho não indicam os limites para os parâmetros microbiológicos.
A concentração mais elevada de coliformes totais nas amostras do Rebouçais, em relação às amostras da Água Verde, pode estar relacionada com diversos fatores tais como intensidade da chuva e o período de amostragem. A amostra do Rebouçais do dia 28/09/09, a qual apresentou a concentração mais elevada de coliformes totais, foi coletada em apenas 5 minutos durante uma chuva intensa e sem descarte dos milímetros iniciais de chuva. De acordo com Marinossi (2007) e Gonçalves (2009), quando a coleta nos instantes iniciais da chuva é descartada, a qualidade da chuva armazenada é superior.


**Tabela 3: Resultados das análises físico-químicas da chuva atmosférica e da chuva captada após passagem por telhado**

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<th>SST (mg/L)</th>
<th>SDT (mg/L)</th>
<th>DO (mg/L)</th>
<th>PO4 (mg/L)</th>
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Obs.: AV- Água Verde; R- Rebouçais; NM- Novo Mundo; C- Centro; (A) - Chuva atmosférica; (T) - Chuva após passagem por telhado; Apar. - Aparelho; Turb. - Turbidez; P O4 - Fosfato; NO3 - Nitrito; Pb - Chumbo; Zn- Zinco; Cl- - Cloreto.
CONCLUSÕES

Conclui-se que a qualidade físico-química da água de chuva na cidade de Curitiba, estado do Paraná, no sul do Brasil, quando comparada ao que está estabelecido nas normas BS EN 1008 (BS, 2002), CMN NM 137 (CMN, 1997), ABNT NBR 15527/2007 (ABNT, 2007) e no manual “Conservação e Reuso da Água em Edificações” (ANA, 2006), com algum tratamento preliminar, em função das normas adotadas, poderia ser utilizada na fabricação de concreto e em serviços como lavagem de agregados, compactação do solo, controle da poeira e para finalidades não potáveis em geral. Quanto à qualidade microbiológica, especificamente coliforme total e fecal, a norma brasileira ABNT NBR 15527/2007, indica a necessidade de desinfecção da água de chuva antes de sua utilização (ABNT, 2007).

Desta forma, o monitoramento e, se necessário, algum tratamento preliminar da água de chuva em Curitiba, em função dos usos previstos e das normas adotadas, podem ser necessários para que a água de chuva seja utilizada na construção de edificações. Recomenda-se também que sejam tomadas medidas para melhorar a qualidade de água de chuva coletada, por exemplo, a coloação de algum filtro para retenção de sólidos na entrada dos reservatórios, e o descarte da água dos instantes iniciais da chuva.

A substituição de água potável por água de chuva nas construções, sempre que possível, é um prático muito importante nos dias de hoje e deve ser estimulada, devido à necessidade de conservação da água mais nobre para uso humano, já que este recurso encontra-se ameaçado.

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Abstract: The study described in this paper consisted of a comparison between samples of rainwater collected in two different forms: a system composed of an inclined roof with concrete tiles and another composed of a flat green roof. The study was conducted at two residences in the Santa Felicidade neighborhood, in the city of Curitiba, state of Paraná, South of Brazil. Three samples of rainwater were collected: one at the output of each roof studied, and one from atmospheric rain. The latter was collected without interference from other surfaces, in order to characterize the rainwater in its natural state. The samples collected from the roofs were analyzed for pH, color, turbidity and coliforms. The results obtained met the quality standards for rainwater harvested in urban areas for non-potable uses, set by the Brazilian guidelines in ABNT NBR 15527:2007. The study also showed that the green roof had the potential to function as a substitute for the filters available in the market for rainwater harvesting systems.
IV-068 – ESTUDO COMPARATIVO DA QUALIDADE DA ÁGUA DE CHUVA COLETADA EM COBERTURA CONVENCIONAL E EM TELHADO VERDE

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RESUMO
Este estudo consiste em uma comparação da qualidade da água da chuva coletada em duas formas distintas de captação: um sistema composto por um telhado inclinado com telhas de concreto e o outro composto por uma cobertura plana com telhado verde. O objetivo consistiu em caracterizar os sistemas utilizados nas duas formas de cobertura e analisar a qualidade da água da chuva captada nos dois sistemas. O presente estudo foi realizado em duas residências no bairro de Santa Felicidade, região noroeste da cidade de Curitiba, capital do Paraná. Para a comparação da qualidade da água da chuva armazenada foram coletadas três amostras: uma proveniente do telhado de cada casa em estudo e uma amostra da chuva atmosférica. Esta última foi coletada sem a interferência de outras superfícies, com o objetivo de caracterizar a água da chuva em seu estado natural. As amostras coletadas nas coberturas, devidamente acondicionadas, foram levadas ao laboratório no qual foram analisadas para determinação de: pH, cor, turbidez e coliformes. Os resultados obtidos atenderam aos padrões de qualidade dispostos no norma ABNT NBR 15527:2007 e apresentaram informações relevantes para comparação entre os sistemas. Para estes dois casos avaliados concluiu-se que a utilização da água da chuva, para fins não potáveis, possui qualidade satisfatória para o local e a forma de captação demonstrada no estado. Este estudo também mostrou que o telhado verde tem potencial de funcionar em substituição aos filtros disponíveis no mercado para sistemas de captação de água da chuva.

PALAVRAS-CHAVE: Água da chuva, aproveitamento, qualidade, telhado verde, estudo de caso.
INTRODUÇÃO

A sustentabilidade nos últimos anos vem sendo discutida e cada vez mais se torna um tema conhecido entre a população. A preocupação com o meio ambiente e com impactos ambientais deixou a grande escala para entrar nos lares, escolas e escritórios. Porém se engana quem pensa que são necessários grandes projetos e tecnologia de ponta para contribuir com essa nova realidade. Neste trabalho são apresentadas medidas simples e aplicáveis em qualquer empreendimento, mas que muito auxiliam na busca por melhores condições. Os temas de captação e utilização de água da chuva e utilização de vegetação nas coberturas são abordados e analisados.

A escassez de água, os fenômenos de ilhas de calor, as enchentes, dentre muitos outros eventos comuns nas grandes metrópoles, podem ser minimizados por sistemas de retenção e uso da água da chuva, reuso de água cinza e aumento de áreas permeáveis. Essas ações podem contribuir para a sustentabilidade ambiental nas cidades, ao deixarem de ser atos isolados para tornarem-se medidas públicas por meio da legislação e incentivos governamentais.

O objetivo geral deste trabalho é comparar dois sistemas de cobertura e captação de água da chuva, sendo um o sistema convencional e outro o sistema composto de telhado verde, ambos no Município de Curitiba, Estado do Paraná.

Os objetivos específicos são:
1- caracterizar os sistemas utilizados nas duas formas de cobertura: plana vegetada e telhado convencional;
2- analisar a qualidade da água da chuva captada nas duas formas de cobertura;
3- comparar os resultados referentes à qualidade da água nas duas formas de cobertura.

CARACTERÍSTICAS DA ÁGUA DA CHUVA

Segundo Carvalho (2004) a formação da atmosfera se dá pela aglomeração ou mistura de diversos gases e partículas em suspensão. Estas partículas podem ser sólidas ou líquidas e a chuva resulta, então, das partículas suspensas e principalmente da água em suspensão, as quais formam as nuvens.

De acordo com a região geográfica e suas características meteorológicas, considerando-se, por exemplo, vegetação profusa ou falta desta, zonas urbanas ou rurais, efluentes gasosos emitidos e outros fatores, as chuvas podem variar tanto em sua composição como em intensidade (TOMAZ, 2005). Emissões atmosféricas podem alterar o pH das chuvas, fazendo com que em alguns lugares ocorram precipitações da chamada "chuva ácida". Na ausência de poluentes, o pH das chuvas se apresentam em torno de 5,7, o que é o nível de acidez normal devido à formação de H₂CO₃ – ácido carbônico, derivado do CO₂ – dióxido de carbono, cuja presença é normal na atmosfera (JAQUES, 2005).

A excesiva utilização de combustíveis fósseis também contribui para que se solubilizem os gases que estão na atmosfera, resultando na geração de ácidos mais fortes, chegando a formar, por exemplo, ácido nítrico – HNO₃ e ácido sulfúrico - H₂SO₄ os quais geram chuvas com pH inferiores a 5,0. Chuvas ácidas podem ser prejudiciais tanto para os seres humanos, diretamente e indiretamente, atingindo edificações, veículos, e o próprio solo, assim como as plantas (OLIVEIRA, 2005).

Pelo seu grau de pureza, Zlot (2005) classifica a água nos graus de A à D, representando respectivamente água de melhor para pior qualidade (Tabela 1).
<table>
<thead>
<tr>
<th>GRAU DE PUREZA</th>
<th>ÁREA DE COLETA</th>
<th>UTILIZAÇÃO</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Tellados (lugares não ocupados, porém frequentados por animais de sangue quente).</td>
<td>Bacia Sanitária, rega de plantas e outros usos. Se purificadas por tratamento simples, são potáveis ao consumo.</td>
</tr>
<tr>
<td>B</td>
<td>Coberturas, sacadas (lugares frequentados por pessoas e animais).</td>
<td>Bacia Sanitária, rega de plantas e outros usos não potáveis. São impropriados para consumo. Tratamento necessário.</td>
</tr>
<tr>
<td>C</td>
<td>Estacionamentos, jardins artificiais.</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Vias elevadas, estradas de ferro, rodovias.</td>
<td></td>
</tr>
</tbody>
</table>

Fonte: modificação de FENDRICH (2002).

Conforme indicado na Tabela 1, a água captada da chuva ainda não é apropriada para o consumo humano, necessitando tratamento para que se torne potável. Porém, pode ser utilizada para fins não potáveis diversos como limpeza em geral e em descargas de bacias sanitárias.

Naturalmente a coleta de águas da chuva por telhados faz com que esta água contenha microorganismos diversos, procedendo, por exemplo, de fezes de pássaros além de outros elementos como restos de plantas, folhas e galhos, muitos destes em decomposição. Desta forma, para o consumo humano, a água coletada da chuva deve ser devidamente tratada, para que se torne potável (TORDO, 2004). A Associação Brasileira de Normas Técnicas (ABNT) através da norma NBR 15527/2007 especifica parâmetros de qualidade para água de chuva ser utilizada para usos em fins não-potáveis (Tabela 2).

<table>
<thead>
<tr>
<th>PARÂMETRO</th>
<th>ANÁLISE</th>
<th>VALOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coliformes totais</td>
<td>Semestral</td>
<td>Ausência em 100mL</td>
</tr>
<tr>
<td>Coliformes termotolerantes</td>
<td>Semestral</td>
<td>Ausência em 100mL</td>
</tr>
<tr>
<td>Cloro residual livre¹</td>
<td>Mensal</td>
<td>0,5 ± 3,0 mg/L</td>
</tr>
<tr>
<td>Turbidez</td>
<td>Mensal</td>
<td>&lt; 2,0 uT², para usos menos restritos &lt; 5,0 uT³</td>
</tr>
<tr>
<td>Cor aparente (caso não seja utilizado nenhum corante)</td>
<td>Mensal</td>
<td>&lt; 15 uH²</td>
</tr>
<tr>
<td>pH (Deve prever ajuste para proteção das redes de distribuição, caso necessário)</td>
<td>Mensal</td>
<td>pH de 6,0 a 8,0 no caso de tabulação de aço carbono ou galvanizado</td>
</tr>
</tbody>
</table>

NOTA: Podem ser utilizados outros processos de desinfeção além do cloro, como a aplicação de raio ultravioleta e aplicação de ozônio.

¹ No caso de serem utilizados compostos de cloro para desinfeção.
² uT é a unidade de turbidez.
³ uH é a unidade Hazen

Fonte: modificado de ABNT (2007)

MEDIDAS E CUIDADOS NO ARMAZENAMENTO DA ÁGUA DE CHUVA COLETADA

Quando do projeto e execução de um sistema de captação e armazenamento de águas pluviais, deve-se prever medidas que garantam a segurança sanitária da água após tratamento adequado. (SIQUEIRA CAMPOS, 2004). Entre as medidas que devem ser adotadas, destaca-se o descarte inicial das chuvas preconizadas pela ABNT NBR 15527/07 objetivando eliminar os primeiros milímetros de chuva, as águas seguitas tendem a ser de melhor qualidade já que as anteriores carregaram consigo muito das impurezas indesejáveis, tornando mais fácil o tratamento das águas então aproveitadas (Zolet 2005). As primeiras águas limpam, até certo ponto, o telhado onde a água é captada, e ao serem descartadas melhoram a condição no armazenamento da água de chuva que segue o descarte.

A norma ABNT NBR 15527/2007 estabelece o que é necessário para que seja dimensionado o volume de descarte da precipitação pluviométrica inicial e que, no caso da impossibilidade de se dimensionar tal volume,
este seja estabelecido em um mínimo de 2mm (ABNT, 2007). Além disso, a mesma norma indica uma rotina de manutenção das partes do sistema (Tabela 3).

É de suma importância que seja planejado, de forma adequada, um sistema que aproveite ao máximo a água da chuva estabelecendo-se qual a quantidade desta água que poderá, efetivamente, ser aproveitada. Também as necessidades de tratamento devem ser estabelecidas, considerando-se a utilização que se pretende de tal água (JAQUES, 2005).

Dentre alguns fatores importantes quanto à captação, transporte e armazenamento das águas de chuva, salienta-se que os dutos de águas captadas das chuvas não devem ser ligados a dutos da rede pública de abastecimento de água potável, pois há alto risco de contaminação cruzada. Um tratamento prévio da água de chuva coletada pode ser necessário para retirar possíveis agentes contaminantes de maior porte, como galhos, folhas, e outros materiais que possam produzir impurezas. Este tratamento pode ser feito com a utilização de telas e redes de tal forma que os materiais passem em função de uma esponja com filtros que possam remover certos elementos que poderiam prejudicar a qualidade da água (ZOLET, 2005).

Na Tabela 3 é apresentada uma rotina de manutenção da águas de chuva, listando os componentes envolvidos e a periodicidade da limpeza de cada um.

**Tabela 3 – Frequência de manutenção de alguns componentes do sistema de aproveitamento de água de chuva**

<table>
<thead>
<tr>
<th>COMPONENTE</th>
<th>FREQUÊNCIA DE MANUTENÇÃO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispositivo de descarte de dejetos</td>
<td>Inspeção mensal</td>
</tr>
<tr>
<td></td>
<td>Limpeza trimestral</td>
</tr>
<tr>
<td>Dispositivo de descarte do escoamento inicial</td>
<td>Limpeza mensal</td>
</tr>
<tr>
<td>Calhas, condutores verticais e horizontais</td>
<td>Semestral</td>
</tr>
<tr>
<td>Dispositivos de desinfecção</td>
<td>Mensal</td>
</tr>
<tr>
<td>Bombas</td>
<td>Mensal</td>
</tr>
<tr>
<td>Reservatório</td>
<td>Limpeza e desinfecção anual</td>
</tr>
</tbody>
</table>

Fonte: ABNT (2007)

**MATERIAIS E MÉTODOS**

O presente estudo foi realizado em duas residências localizadas a aproximadamente mil metros uma da outra, no bairro de Santa Felicidade, região noroeste da cidade de Curitiba, capital do Paraná. Consiste em um estudo de caso elaborado pela comparação através de análises laboratoriais da qualidade da água de chuva captada pelas coberturas das duas residências, conforme descrito na sequência.

**DESCRIÇÃO DO SISTEMA: CASA-1_TELHADO CONVENCIONAL**

A casa 1 possui como cobertura um telhado inclinado com 50% com telhas de concreto planas e uma área de captação de 65m² que corresponde a uma das duas águas do telhado.

A água da chuva que escoa pelo telhado é primeiramente coletada por uma calha, seguindo por um duto vertical de alumínio até o nível do solo, no qual se encontra um filtro do tipo 3F Tecnik_VF1, responsável pela retirada de partículas maiores, como folhas e galhos. Após passar pelo filtro a água segue para uma cisterna de 2.800 litros de PEAD (polietileno de alta densidade - pré-fabricada) na qual fica armazenada para uso.

O sistema de distribuição conta com uma eletrobomba com pressostato que aciona o funcionamento da bomba quando verifica variação de pressão ao abrir uma das torneiras. A utilização da água da chuva nesta residência é para limpeza de áreas externas e rega de jardim.

**DESCRIÇÃO DO SISTEMA: CASA-2_TELHADO VERDE**

A casa 2 tem cobertura composta por uma laje plana, com 77m² de área de captação, recoberta por vegetação, ou seja, um telhado verde.
A água da chuva após passar pelo telhado verde é conduzida para dutos verticais de PVC até a cisterna de concreto de 1.500 litros no nível do solo. O sistema contempla uma eletrobomba responsável por bombear a água até um reservatório de 1.000 litros da PEAD (polietileno de alta densidade - pré-fabricada) localizado na cobertura acima do nível do telhado verde, na qual fica armazenada até sua utilização. O uso destinado à água da chuva nesta residência, além de limpeza externa e rega de jardim, é fornecer água para a descarga nas bacias sanitárias.

**COLETA DAS AMOSTRAS DE ÁGUA DE CHUVA**

Para a comparação da qualidade da água foram coletadas três amostras, nomeadas como:

`Amostra 1_Casa-1_Telhado Convencional`: coletada diretamente da torneira com abastecimento de água da chuva.

`Amostra 2_Casa-2_Telhado Verde`: coletada diretamente da torneira com abastecimento de água da chuva.

`Amostra 3_Atmosférica`: coletada diretamente da chuva, sem interferência de outras superfícies.

As coletas, `Amostra 1_Casa-1_Telhado Convencional` e `Amostra 2_Casa-2_Telhado Verde`, foram realizadas no dia 18 de maio de 2011 entre 9 e 10:30 horas e a `Amostra 3_Atmosférica` foi realizada em dia diferente, dia 16 de maio de 2011, último dia de chuva mais intensa anterior às análises.

Para que a amostragem da água da chuva representasse um mesmo período de chuvas foi feito o esvaziamento de ambas as cisternas no dia 12 de maio de 2011, sendo que o período de armazenamento das chuvas comprime os dias 14, 15, 16 e 17 de maio de 2011. O último registro anterior de chuva foi no dia 04 de maio, assim sendo o período entre esse dia, 4 de maio e o primeiro dia da chuva, dia 14 de maio, são os dias nos quais foram depositados nas coberturas partículas como poeira, dejetos de animais, resíduos orgânicos, folhas galhos, etc.

Depois de coletadas, as amostras foram acondicionadas de forma adequada, seguindo os requisitos estabelecidos pelo laboratório contratado para realizar as análises, e foram imediatamente encaminhadas ao laboratório para determinação de: pH, cor, turbidez e coliformes. As análises seguiram a metodologia indicada no Standard Methods for Examination of Water and Wastewater, 21ª edição, publicado em 2005.

**RESULTADO DAS ANÁLISES: COR APARENTE**

<table>
<thead>
<tr>
<th>Amostra</th>
<th>Método</th>
<th>LQ(*)</th>
<th>Resultado</th>
<th>Expressão</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosférica</td>
<td>SM 2:20 B</td>
<td>2,5</td>
<td>&lt; 2,5</td>
<td>un PI Co</td>
</tr>
<tr>
<td>Casa-1_Telhado Convencional</td>
<td>SM 2:20 B</td>
<td>2,5</td>
<td>&lt; 2,5</td>
<td>un PI Co</td>
</tr>
<tr>
<td>Casa-2_Telhado Verde</td>
<td>SM 2:20 B</td>
<td>2,5</td>
<td>&lt; 2,5</td>
<td>un PI Co</td>
</tr>
</tbody>
</table>

(*)L.Q.: Limite de Quantificação do Método Analítico Utilizado

No parâmetro cor aparente (Tabela 4) as três amostras indicaram resultados inferiores ao limite de quantificação estabelecido pelo método analítico utilizado no laboratório. Sendo a análise de cor aparente (Escala Platina-Cobalto) uma escala indicada para detectar tons de amarelo e os resultados se apresentarem inferiores ao limite de quantificação, isso indica que não há matéria orgânica suficiente para interferir na cor da água.

**RESULTADO DAS ANÁLISES: TURBIDEZ**

<table>
<thead>
<tr>
<th>Amostra</th>
<th>Método</th>
<th>LQ(*)</th>
<th>Resultado</th>
<th>Expressão</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosférica</td>
<td>SM 2:30 B</td>
<td>0,01</td>
<td>0,72</td>
<td>NTU</td>
</tr>
<tr>
<td>Casa-1_Telhado Convencional</td>
<td>SM 2:30 B</td>
<td>0,01</td>
<td>0,64</td>
<td>NTU</td>
</tr>
<tr>
<td>Casa-2_Telhado Verde</td>
<td>SM 2:30 B</td>
<td>0,01</td>
<td>0,50</td>
<td>NTU</td>
</tr>
</tbody>
</table>

(*)L.Q.: Limite de Quantificação do Método Analítico Utilizado
A turbidez é um parâmetro que caracteriza a existência de partículas finamente divididas dispersas em água podendo deixar as águas com aparência turva, sem transparência. No parâmetro turbidez (Tabela 5) foi verificada diferença entre as amostras. A ‘Amostra_3_Atomosférica’ apresentou o maior valor. Isso provavelmente indica que os sistemas de filtragem funcionam de forma eficiente melhorando a qualidade da água. A ‘Amostra_2_Casa-2_Telhado Verde’ apresentou o menor valor de turbidez indicando que esse sistema, telhado verde, foi a esperada, funcionando como um filtro e acabou por obter melhor resultado que o filtro da Casa_1_Telhado Convencional, no parâmetro turbidez.

RESULTADO DAS ANÁLISES: pH

<table>
<thead>
<tr>
<th>Amostra</th>
<th>Método</th>
<th>LQ(1)</th>
<th>Resultado</th>
<th>Expressão</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosférica</td>
<td>SM 4500-B</td>
<td>0,01</td>
<td>6,00</td>
<td>-</td>
</tr>
<tr>
<td>Casa-1_Telhado Convencional</td>
<td>SM 4500-B</td>
<td>0,01</td>
<td>6,18</td>
<td>-</td>
</tr>
<tr>
<td>Casa-2_Telhado Verde</td>
<td>SM 4500-B</td>
<td>0,01</td>
<td>7,22</td>
<td>-</td>
</tr>
</tbody>
</table>

(1)LQ: Limite de Quantificação do Método Analítico Utilizado

O pH é um parâmetro físico-químico que indica a acidez, neutralidade ou alcalinidade de uma solução. Com relação à captura e ao armazenamento, este parâmetro é importante para que os sistemas e tubulações não sejam danificados. Na utilização para rega de plantas o pH da água utilizada é um fator determinante no crescimento e bem desenvolvimento das mesmas.

Todas as amostras coletadas se apresentaram dentro da faixa ideal - com pH de 6,0 a 8,0 - conforme estabelecido pela ABNT NBR 15527:2007 (Tabela 2).

A ‘Amostra_1_Casa-1_Telhado Convencional’, com pH 6,18 mostrou-se muito semelhante a ‘Amostra_3_Atomosférica’ com pH 6,00 levemente acida e condizente com o pH natural da chuva, já a ‘Amostra_2_Casa-2_Telhado Verde’ apresenta uma variação considerável se mostrando levemente alcalina, possivelmente pelo fato do sistema ser novo e ter passado por um processo de limpeza recente que utiliza hipoclorito de sódio, de natureza alcalina, desta forma resíduos dessa limpeza podem ter alterado os resultados. Porém somente outras análises poderiam assegurar isso, já que não temos informações suficientes também para descartar o efeito do telhado verde no pH da água por ele captada.

RESULTADO DAS ANÁLISES: COLIFORMES TERMOTOLERANTES E TOTAIS

<table>
<thead>
<tr>
<th>Amostra</th>
<th>Método</th>
<th>LQ(1)</th>
<th>Resultado</th>
<th>Expressão</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casa-1_Telhado Convencional</td>
<td>SM 9221</td>
<td>18,0</td>
<td>&lt; 18,0</td>
<td>NMP/100mL</td>
</tr>
<tr>
<td>Casa-2_Telhado Verde</td>
<td>SM 9221</td>
<td>18,0</td>
<td>&lt; 18,0</td>
<td>NMP/100mL</td>
</tr>
</tbody>
</table>

(1)LQ: Limite de Quantificação do Método Analítico Utilizado

A análise de coliformes é um importante parâmetro microbiológico utilizado como indicador da existência de microorganismos patogênicos, responsáveis pela transmissão de doenças de veiculação hídrica, tais como febre tifoide, febre paratióide, dengue, bacilar e cólica.

As amostras Casa_1_Telhado Convencional e Casa_2_Telhado Verde apresentaram valores inferiores ao limite de quantificação da análise (Tabela 7), porém somente análises mais precisas poderiam indicar a ausência de coliformes e desta forma assegurar o que regula a ABNT NBR 15527:2007 (Tabela 2).

COMPARATIVO DE DESEMPENHO ENTRE AS COBERTURAS

Na figura 1 são indicados comparativamente os parâmetros que apresentaram diferenças nos resultados das amostras: que foram pH e turbidez. Cor e coliformes não são apresentados nos gráficos por não possuírem valores significativos, estando estes com os valores mínimos decorrentes do limite quantitativo das análises.
O telhado verde funcionou como um filtro tendo inclusive o melhor resultado no parâmetro turbidez (0,5 NTU). A amostra coletada do telhado convencional ( lembrando que possui um filtro acoplado) apresentou o valor de turbidez em 0,64 NTU. Para a amostra coletada diretamente da chuva atmosférica a turbidez foi 0,72 NTU. Estes dados nos fornecem uma importante informação, visto que na casa com telhado verde a água captada da chuva é também utilizada nas descargas das bacias sanitárias, portanto, a qualidade superior no parâmetro turbidez é uma vantagem e um incentivo na utilização conjunta do telhado verde com a captação de água da chuva.

No parâmetro cor aparente todas as amostras apresentaram valores inferiores ao limite quantitativo da análise indicando que não há matéria orgânica suficiente para alterar a coloração da água e que os sistemas funcionam de forma adequada já que não permitem a entrada deste material, que em sua decomposição poderia piorar a qualidade da água. Com relação ao pH a ‘Amostra 1_Casa-1_Telhado Convencional’ ficou muito próxima à ‘Amostra 3_Atmosférica’, porém levemente mais alcalina, provavelmente por se tratar de uma cobertura de telhas de concreto, o que influenciaria no pH tendendo a ficar mais básico (TORDO, 2004).

Já a ‘Amostra 2_Casa-2_Telhado Verde’ indicou um pH mais alcalino 7,22 em comparação ao pH 6,60 da ‘Amostra 3_Atmosférica’, essa variação possivelmente ocorreu devido ao fato do sistema ser novo e o reservatório ter sido higienizado com hipoclorito de sódio, de caráter alcalino. O resíduo desta limpeza pode ter afetado o resultado da análise, porém não é descartada a possibilidade de o telhado verde ser responsável pela alteração do pH, já que não se sabe o pH do solo utilizado. Na análise de coliformes, tanto totais quanto termotolerantes as duas amostras, Casa-1_Telhado Convencional e Casa-2_Telhado Verde, apresentaram valores inferiores ao limite quantitativo indicando uma possível ausência, contudo seria necessária uma nova análise mais precisa para assegurar este fato.

CONCLUSÕES

A partir dos resultados obtidos é possível concluir que tanto o sistema composto por telhado convencional e filtro, quanto o telhado verde conseguem atender aos critérios de qualidade da água da chuva para usos não potáveis, estando dentro das normas estabelecidas pela ABNT NBR 15527:2007 e ainda apresentando uma melhoria em comparação à qualidade da água da chuva atmosférica in natura.

Os resultados também indicam que a utilização da água da chuva para fins não potáveis possui boa qualidade para o local e a forma de captação demonstrada no estudo. Aliado a isso, mostra que telhados verdes podem funcionar satisfatoriamente em substituição aos filtros disponíveis no mercado para esse fim.

Ao longo do estudo novas dúvidas surgiram, as quais serão investigadas na continuidade desta pesquisa. Entre os questionamentos resultantes estão: (1) qual seria a relação do pH da água da chuva captada, com o telhado verde?, (2) como seria o comportamento do telhado verde com o passar do tempo e a estabilização do substrato? e (3) o pH do solo é alterado após a captação da água chuva?
Vale salientar que este estudo continua em desenvolvimento com o objetivo de responder as questões apresentadas acima.

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Abstract: This paper presents an investigation of rainwater harvesting in two residential buildings recently built in the city of Curitiba, state of Paraná, South of Brazil. Rainwater harvesting is suitable for uses where there is no need for high quality water and, for that reason, is effective to reduce the consumption of potable water. These two buildings had rainwater harvesting systems to meet a municipal bylaw approved in 2003 (also known as PURAE), which brought a program for water conservation and rational use in buildings. Based on this bylaw, it is mandatory to implement rainwater harvesting for non-potable uses, for all new buildings. The bylaw took effect in 2007, after the approval of two other municipal regulations. The impact of this program and its contribution towards potable water savings can only be evaluated in a few years. The present work describes the initial stages of implementation of PURAE in Curitiba and will help future investigations to bring contributions for optimization of the program.
APROVEITAMENTO DE ÁGUAS PLUVIAIS EM EDIFÍCIOS RESIDENCIAIS NA CIDADE DE CURITIBA-PARANÁ

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Resumo - Este artigo apresenta uma investigação sobre captação de águas pluviais em dois edifícios residenciais, recentemente construídos na cidade de Curitiba, estado do Paraná. O aproveitamento da água da chuva, para atividades onde não é necessário o uso de água com qualidade superior, é uma medida eficiente para reduzir o consumo de água potável. Em 18/09/2003 foi aprovada a Lei Nº 10.785 criando o Programa de Conservação e Uso Racional da Água nas Edificações - PURAE, que, entre outras medidas, torna obrigatória a construção de uma cisterna para o armazenamento de águas pluviais nas novas construções. Esta legislação ainda dependeu da aprovação de dois decretos municipais, para efetivamente entrar em vigor em 29/03/2007. O impacto deste programa, e sua contribuição para a economia no consumo de água potável, poderá ser quantificado em poucos anos, quando as novas construções em Curitiba já estiverem adequadas ao PURAE. O presente estudo servirá de base para investigações futuras e confirmar a eficiência e/ou trazer contribuições para a otimização do PURAE.

Palavras-chave: águas pluviais, PURAE, edificações, Curitiba.

Abstract - This paper shows an investigation about rainwater harvesting in two residential buildings recently done in the city of Curitiba, state of Paraná. Rainwater harvesting is suitable for uses where there is no need for high quality water and, for that reason, is effective to reduce the consumption of potable water. In 18/09/2003 it was approved a bylaw Nº 10.785, stating a program for conservation and rational use of water in the buildings, also know as PURAE, where between its procedures to attend the program, it includes the obligation for a rainwater tank for all new buildings. That bylaw took effect in 29/03/2007, after the approval of other two municipal regulations. The impact of this program and its contribution towards the potable water savings will be evaluated in a few years, when the new buildings would be adapted to PURAE. This study will help future investigations in order to confirm and/or bring contributions for optimization of PURAE.

Key-words: rainwater, PURAE, buildings, Curitiba.

INTRODUÇÃO

Atualmente é crescente a escassez de fontes de água com qualidade satisfatória para serem selecionadas como mananciais de abastecimento, em função da contaminação pela poluição doméstica e industrial, além dos desequilíbrios ambientais resultantes do desmatamento e do mau uso do solo [1].

O setor da construção civil está entre as indústrias que mais geram impactos ambientais, pois utiliza 40% dos recursos naturais extraídos, é responsável por 50% dos resíduos sólidos urbanos (provenientes de construções e demolições) e consome 50% da energia elétrica gerada [2]. Diante deste cenário é urgente buscar a sustentabilidade das construções, através de ações, desde a concepção do projeto, seguindo durante a execução da obra e na pos-ocupação, como, por exemplo, adotando a captação de águas pluviais para fins não potáveis.

A utilização de sistemas de coleta e aproveitamento de águas pluviais pode trazer benefícios como a redução do consumo de água potável, diminuindo os gastos para o consumidor e para a concessionária dos serviços de abastecimento municipal da água potável,
além da redução do escoamento superficial das águas de chuva, o que contribui para a diminuição de alagamentos e enchentes e, consequentemente, a potencial redução dos custos com a manutenção e ampliação das redes de drenagem urbana. Entre os usos possíveis para esta água estão a descarga em vasos sanitários, a irrigação de jardins e a lavagem de pisos, equipamentos e carros. A coleta de águas pluviais pode ser realizada em qualquer edificação, urbana ou rural; seja residencial, comercial ou industrial. A captação é feita em áreas impermeáveis, por exemplo: telhados, pátios e áreas de estacionamento. Após a captação, esta água é levada para reservatórios e poderá passar por um sistema de tratamento, dependendo da qualidade da água coletada e do seu uso previsto [3]. Para a instalação do sistema de captação de águas pluviais é necessário um projeto de acordo com as exigências da NBR 10844 da ABNT (Associação Brasileira de Normas Técnicas), contendo uma rede hidráulica específica para esta água não entrar em contato com a tubulação de água potável [4].

METODOLOGIA

Este projeto de pesquisa foi conduzido da seguinte forma: revisão bibliográfica sobre aproveitamento de águas pluviais; levantamentos de informações sobre as edificações recentemente construídas em Curitiba que adotaram a captação de águas pluviais; seleção de dois edifícios residenciais para visitas de investigação sobre o funcionamento do sistema de captação de águas pluviais e estudo da legislação local pertinente ao assunto, através de visitas e entrevistas na Prefeitura Municipal de Curitiba.

RESULTADOS

Na cidade de Curitiba, capital do estado do Paraná, a Lei Nº 10.785, de 18/09/2003, criou o Programa de Conservação e Uso Racional da Água nas Edificações – PURAE. Esse programa tem como principal objetivo estabelecer medidas que induzam a conservação e o uso racional da água, além da utilização de fontes alternativas para a captação de água. Entre as medidas do PURAE é obrigatória a construção de sistema para armazenamento de águas pluviais em todas as novas construções. Essa água será utilizada em atividades que não necessitam de água potável, como limpezas em geral, lavagem de carros e rega de jardins e hortas [5]. Apenas 2,5 anos depois da criação do PURAE foi criado o Decreto Nº 293, em 22/03/2003, para sua regulamentação [6]. Depois deste decreto regulamentador, foi necessário mais 1 ano de espera e o PURAE efetivamente foi implantado a partir do dia 29/03/2007, quando entrou em vigor o Decreto Nº 212 trazendo o novo Regulamento de Edificações do Município de Curitiba. Neste novo regulamento estão relacionadas as exigências do PURAE para cada tipo de edificação [7]. Portanto, apenas desde março de 2007 a liberação dos alvarás de construção está sendo condicionada ao atendimento do PURAE. Até a presente data, setembro de 2007, nenhuma obra foi concluída atendendo todos os requisitos do PURAE, mas algumas obras recentes já vinham adotando medidas de captação de águas pluviais, mesmo sem a cobrança da legislação (informação verbal)1.

A operacionalização do PURAE, efetivada a partir de março de 2007, inicia na entrada do pedido do alvará de construção. Nesta ocasião, o responsável técnico pelo projeto hidráulico preenche um termo de compromisso declarando estar ciente das exigências do Decreto Nº 293. Ao final da construção, quando os técnicos da prefeitura efetuam a fiscalização da obra para a expedição do certificado de vistoria, é verificado se a edificação está de acordo com todas as exigências do PURAE e a liberação do certificado está condicionada ao seu atendimento.

O primeiro edifício selecionado para o estudo foi o Residencial Tibet, da Laguna Construtora e Incorporadora Ltda., localizado em Curitiba, no bairro do Batel. A obra foi iniciada em junho de 2004 e concluída em dezembro de 2006. Portanto, não havia a exigência de atendimento ao PURAE. Em função da política de uso de fontes alternativas de água, que já estava em vigor na citada construtora, o projeto hidráulico deste edifício foi contemplado a captação de águas pluviais. A água é captada na cobertura do edifício e conduzida, através de calhas e condutores verticais, para uma cisterna exclusiva para águas pluviais (volume de 5000 litros). Na saída da cisterna esta água passa por um filtro (figura 1) e depois segue para torneiras de acionamento restrito, localizadas no pavimento térreo (figura 2). Esta água é utilizada para a lavagem de pisos e rega de jardins. As torneiras de acesso restrito funcionam somente com uma chave destacável que fica com o pessoal responsável pela manutenção do prédio. O objetivo desta restrição é evitar o uso indevido da água destas torneiras pelos moradores, uma vez que esta água não é potável (informação verbal)\(^2\).

![Figura 1. Filtro.](image1)

![Figura 2. Torneira acesso restrito.](image2)

O outro estudo foi realizado no Edifício Arbos, da Monarca Empreendimento Imobiliário Ltda., localizado no centro de Curitiba. Esta obra foi concluída antes da obrigatoriedade do PURAE, mas também contempla um sistema de captação de águas pluviais. Neste sistema a água da chuva é captada no pavimento térreo, através de ralos, e também é captada na cobertura, utilizando calhas e condutores verticais, sendo então armazenada em cisterna exclusiva para águas pluviais, com capacidade de 10.000 litros\(^3\). Na saída da cisterna esta água passa por grades metálicas, para reter as partículas maiores como folhas e plásticos (figura 3), seguindo para um tanque de decantação, e depois seguindo para torneiras convencionais, localizadas no pavimento térreo (figura 4). Esta água é utilizada para a lavagem de pisos e rega de jardins. Durante a visita ao edifício, foi sugerido por esta pesquisadora ao engenheiro da obra que substitua o modelo das torneiras abastecidas por águas pluviais, por torneiras de acionamento restrito, considerando que esta água não é potável.

![Figura 3. Grade.](image3)

![Figura 4. Torneira.](image4)

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\(^2\) Informação fornecida pelo Eng. de Produção Civil Cristian Coelho, responsável técnico da obra do edifício Residencial Tibet, no dia 16 de Agosto de 2007.

\(^3\) Informação fornecida pelo Eng. Civil Fabiano Meier, responsável técnico da obra do edifício Arbos, no dia 23 de Agosto de 2007.
DISCUSSÃO E CONCLUSÕES

Utilizar fontes alternativas para abastecimento de água, como os exemplos apresentados nesta pesquisa, são práticas que contribuem para prevenir, ou minimizar, a escassez de água potável. O aproveitamento da água de chuva nas edificações, ao reduzir o consumo da água potável, também resulta na diminuição do valor das taxas pagas para a concessionária de distribuição de água potável.

Nesta etapa foi realizado um diagnóstico do aproveitamento de águas pluviais existentes em dois edifícios residenciais em Curitiba. Foi observado que mesmo antes da obrigatoriedade em atender aos requisitos do Programa de Conservação e Uso Racional da Água nas Edificações - PURAE, recém implantado na cidade de Curitiba, algumas construtoras já estavam adotando medidas para contribuir para a sustentabilidade ambiental das construções. Outra contribuição deste trabalho é o intercâmbio de experiências que trazem benefícios para a eficiência dos sistemas de captação de águas pluviais.

Este trabalho servirá de base para investigações futuras, a fim de confirmar a eficiência do PURAE e/ou sugerir propostas para a otimização deste programa, a partir da quantificação do volume de utilização de águas pluviais e seu impacto sobre a redução no volume do consumo de água potável.

AGRADECIMENTOS


REFERÊNCIAS


Abstract: This paper presents an investigation of the Program for Water Conservation and its Rational Use in Buildings (also known as PURAE), in the city of Curitiba, state of Paraná, south of Brazil. PURAE was first proposed in 2003. This program required all new buildings to have rainwater harvesting systems, water-saving devices, and effluent recycling. In addition, flowmeters should be installed at each residential unit inside condominiums. A municipal decree was published in 2006 excluding the obligation of effluent recycling for residential buildings. However, it was only in 2007 that PURAE and its changes were effectively implemented. The assessment of PURAE was based on a review of similar programs existing in Brazil and on interviews with stakeholders. At the stage this investigation was concluded PURAE was confirmed as an important tool for allowing water savings in the city but it should be improved to incorporate information on instrumenting its implementation. Future amendments to PURAE should include information on proper cleaning of rainwater storage tanks, parameters of monitoring rainwater quality and recycled effluent, obligation to include proper identification of these installations, as well as definition of a permanent advisory committee.
Estudo do programa de conservação e uso racional da água nas edificações – PURAE, de Curitiba – Paraná

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Resumo: Este trabalho apresenta um estudo do Programa de Conservação e Uso Racional da Água nas Edificações – PURAE, de Curitiba-PR. Dentre as exigências deste programa estão a captação e aproveitamento da água de chuva, o uso de dispositivos hidráulicos vedutores do consumo de água, o uso de hidrômetros individuais e o reuso da água servida. O PURAE foi criado em 2003 e regulamentado em 2006, mas apenas passou a ser solicitado para as novas edificações em março de 2007, quando entrou em vigor o Decreto Nº 212. Para a avaliação do PURAE foram analisadas legislações existentes em outras cidades brasileiras, além de observações do funcionamento do programa junto aos profissionais da construção civil e aos funcionários da Prefeitura Municipal de Curitiba. Concluiu-se que o PURAE é um programa importante para a cidade, mas não contém todas as informações para o seu funcionamento adequado. Para otimizar este programa recomenda-se incluir na legislação: os indicadores de qualidade da água de chuva e da água servida, para garantir seus usos sem o comprometimento da saúde pública; a obrigatoriedade de sinalização deste sistema, para evitar usos indevidos destas águas; a orientação sobre a manutenção e limpeza dos reservatórios destas águas não potáveis; e a implantação de um grupo gestor deste programa.

Palavras-Chave: PURAE, Curitiba, água de chuva, reuso, edificações

1. Introdução

A busca de fontes alternativas de captação de água, a conservação e o uso racional dos recursos hídricos são os principais objetivos do Programa de Conservação e Uso Racional da Água nas Edificações – PURAE, existente em Curitiba-PR. Essas estratégias de gestão ambiental são indispensáveis para combater o problema da escassez da água causado pelo aumento excessivo do consumo deste recurso natural, decorrente do crescimento demográfico, do desenvolvimento industrial e da expansão do cultivo irrigado.

Uma das alternativas para a conservação dos recursos hídricos é projetar edificações visando a redução do consumo de água potável, quando esta não é necessária. Surge então a importância de avaliar as exigências impostas pelo PURAE e o seu funcionamento junto à Prefeitura Municipal de Curitiba, para averiguar se todas as partes envolvidas, sejam os construtores, a prefeitura e os moradores, estão atingindo as metas de uso sustentável da água estabelecidas neste programa.

O objetivo principal deste estudo foi avaliar as exigências estabelecidas pelo PURAE em Curitiba e propor medidas para sua otimização.

2. Materiais e métodos

Para a elaboração do trabalho foram realizadas as seguintes etapas: (1) levantamento do histórico da lei e dos decretos que regulamentaram o PURAE em Curitiba; (2) verificação do funcionamento do PURAE, com a realização de entrevistas aos funcionários da Secretaria Municipal de Urbanismo da Prefeitura Municipal de Curitiba e junto aos profissionais da construção civil na cidade; (3) levantamento de legislações semelhantes em outras cidades do Brasil; (4) avaliação do PURAE; e (5) proposição de medidas para otimização do programa.

3. Resultados e discussões

3.1. Levantamento do histórico da lei e dos decretos que regulamentaram o PURAE em Curitiba

Após a criação da Lei Nº 10.785 foi necessário aproximadamente 2,5 anos para ser instituído em Curitiba o Decreto Nº 293, em 22 de março de 2006 (CURITIBA, 2006), que regulamentou o PURAE no município. Dentre as exigências do Decreto Nº 293 estão:

- utilização de dispositivos hidráulicos redutores de consumo de água, tais como: bacias sanitárias de volume reduzido de descarga e torneiras dotadas de arejadores;
- instalação de hidrômetros para a medição individualizada do volume de água nos edifícios de habitação coletiva cuja área total construída por unidade seja igual ou superior a 250 m²; em todas as construções de habitações unifamiliares em série e nos conjuntos habitacionais independentes da área construída;
- implantação de um sistema de captação de águas pluviais nas coberturas das edificações, sendo esta água direcionada e armazenada em reservatório próprio para posterior utilização em atividades que não exigem o uso da água potável e
- instalação de um sistema de coleta e tratamento de águas servidas nas edificações comerciais e industriais com área construída igual ou superior a 5.000 m², para ser reutilizada em atividades onde não é necessário o uso da água potável.

Foi somente a partir do dia 29 de março de 2007, quando entrou em vigor o Decreto Nº 212, trazendo o novo Regulamento de Edificações do Município de Curitiba que o PURAE entrou em vigor.

A Tabela 1 relaciona os tipos de edificações com as respectivas exigências do PURAE: 1 – captação e aproveitamento da água de chuva; 2 – dispositivos hidráulicos redutores do consumo de água; 3 – hidrômetros individuais e 4 – sistema de coleta e tratamento das águas servidas.

Tabela 1 - Exigências do PURAE para as edificações

<table>
<thead>
<tr>
<th>Tipos de edificações</th>
<th>Exigências</th>
</tr>
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<tr>
<td></td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>Habitação unifamiliar</td>
<td>x x</td>
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<tr>
<td>Habitação de uso institucional</td>
<td>x x</td>
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Fonte: (Elaborado a partir de CURITIBA, 2007). Observação: x* é apenas para as edificações com área construída igual ou superior a 5.000 m².

No PURAE em Curitiba são considerados como dispositivos redutores do consumo de água as bacias sanitárias de volume reduzido de descarga e as torneiras dotadas de arejadores.

Portanto, apenas desde março de 2007 a liberação dos alvarás de construção está sendo condicionada ao compromisso de atendimento do PURAE. Algumas edificações concluídas recentemente já vinham adotando medidas como a captação de água de chuva, a instalação de hidrômetros individualizados e o uso de vasos sanitários com caixa acoplada, mesmo sem a cobrança da legislação (informação verbal).³

3.2. Verificação do funcionamento do PURAE

Desde março de 2007, no pedido do alvará de construção, o responsável técnico pela obra e o proprietário assinam um termo de compromisso declarando que o projeto de instalações hidráulicas e a construção atenderão integralmente às exigências do Decreto Nº 293, sendo apresentado à Devida ART (anotação de responsabilidade técnica) do projeto.

Ao final da construção, quando os técnicos da prefeitura efetuam a fiscalização da obra para a expedição do certificado de vistoria, é verificado

se a edificação está de acordo com todas as exigências do PURAE, e a liberação do certificado está condicionada ao seu atendimento. Além disso, a averiguação está sendo exigido um memorial descritivo relata todos os dispositivos que foram adotados na obra (informação verbal)².

Foram entrevistados vinte e três funcionários dos setores de pedido de alvará de construção da Prefeitura Municipal de Curitiba – PMC, e com as respostas obtidas conclui-se principalmente que:

- 57% das dúvidas mais frequentes dos profissionais que dizem entrar com o pedido de alvará de construção na PMC dia respeito aos requisitos que devem ser implantados na edificação e 17% sobre o sistema de captação de águas pluviais;
- a reação dos profissionais perante o PURAE é cerca de 40% negativa, 30% positiva e 30% indecisos e
- cerca de 43% dos funcionários da PMC que são responsáveis pelo atendimento aos profissionais que vão fazer o pedido de alvará de construção ainda têm dúvidas sobre o PURAE.

Foram entrevistados dez profissionais que deram entrada no pedido de alvará de construção recentemente e com as respostas obtidas conclui-se que:

- 70% dos profissionais entrevistados foram solicitados para o atendimento do PURAE quando deram entrada com o pedido de alvará de construção e 30% obtiveram o alvará de construção sem nenhuma solicitação para atendimento ao programa;
- 80% destes profissionais, ou seja, oito dos dez entrevistados possuem dúvidas sobre o PURAE e
dentre os dez entrevistados 80% acreditam que o PURAE é viável técnica e economicamente.

### 3.3. Levantamento de legislações semelhantes em outras cidades do Brasil

No Brasil existem várias legislações que regulamentam programas relacionados ao uso sustentável da água nas edificações e algumas estão indicadas na Tabel 2. Algumas destas legislações serviram de base para a proposição de medidas de otimização do PURAE de Curitiba.

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### Tabela 2 – Exemplos de outras legislações sobre uso racional da água no Brasil

<table>
<thead>
<tr>
<th>Município - Estado</th>
<th>Legislação (mês - ano)</th>
</tr>
</thead>
<tbody>
<tr>
<td>São José – SC</td>
<td>Lei Nº 4.082 (Dezembro/2003)</td>
</tr>
<tr>
<td>São Paulo – SP</td>
<td>Lei Nº 14.018 (Julho/2005)</td>
</tr>
<tr>
<td></td>
<td>Decreto Nº 47.701 (Setembro/2006)</td>
</tr>
<tr>
<td>Campinas – SP</td>
<td>Lei Nº 12.474 (Janeiro/2006)</td>
</tr>
<tr>
<td>Caxias do Sul – RS</td>
<td>Lei Nº 6.615 (Dezembro/2006)</td>
</tr>
<tr>
<td>Amparo – SP</td>
<td>Lei Nº 5.286 (Junho/2007)</td>
</tr>
<tr>
<td>Cascavel – PR</td>
<td>Lei Nº 4.631 (Agosto/2007)</td>
</tr>
</tbody>
</table>

### 3.3.1. Município do Rio de Janeiro

Em 30 de janeiro de 2004 foi criado o Decreto Nº 23.940 que tornou obrigatória para as edificações que tenham área superior a 500 m², a construção de reservatórios para a retenção temporária das águas pluviais, prevenindo assim possíveis inundações. Além disso, o reservatório para a contenção da água é obrigatório para novas edificações industriais, comerciais e residenciais multifamiliares de 50 ou mais unidades, que apresentem área do pavimento de telhado superior a 500 m², a implantação de um outro reservatório para o aproveitamento da água pluvial em atividades que não exijam o uso da água potável (RIO DE JANEIRO, 2004).

Sempre que houver o aproveitamento das águas pluviais é necessário atender as normas sanitárias vigentes e as condições técnicas específicas estabelecidas pelo órgão municipal como:

- evitar o consumo indevido, definindo sinalização de alerta padronizada a ser colocada em local visível e junto ao ponto de consumo da água de chuva, determinando os tipos de utilização admitidos para esta água, alertando que a água não é potável;
- garantir padrões de qualidade de água apropriados ao tipo de utilização previsto, definindo os dispositivos, processos e tratamentos necessários para a manutenção desta qualidade e
- impedir qualquer tipo de contaminação no sistema predial destinado à água potável proveniente da rede pública de abastecimento, lembrando que o sistema de captação de água de chuva deve ser totalmente independente do sistema de água potável.

Para o pedido do certificado de conclusão da obra deve ser apresentada uma declaração, assinada pelo profissional responsável da obra e
pelo proprietário, de que a edificação atende aos requisitos do Decreto Nº 23.940, com uma breve descrição do sistema instalado, e de que os reservatórios e as instalações destinadas à captação da água de chuva para o aproveitamento estão de acordo com as normas vigentes e as condições técnicas específicas estabelecidas pelo órgão municipal responsável pela Vigilância Sanitária e também pelo órgão responsável pela drenagem urbana.

3.3.2. Município de São Paulo

Em 28 de junho de 2005, foi criada a Lei Nº 14.018 que abrange as novas edificações, os bens imóveis do Município de São Paulo e também as novas edificações de interesse social. Para as edificações já existentes são estudadas soluções técnicas e medidas de incentivo para a adaptação (SÃO PAULO, 2005).

Dentre as ações da Lei Nº 14.018 estão: o uso de dispositivos hidráulicos como, bacias sanitárias de volume reduzido de descarga, torneiras dotadas de arejadores, chuveiros e lavatórios com volume fixo de descarga e a instalação de hidrômetros individualizados; captação e aproveitamento de águas pluviais e o reuso das águas servidas (SÃO PAULO, 2005).

Para a regulamentação da Lei Nº 14.108 foi instituído o Decreto Nº 47.731, em 28 de setembro de 2006 (SÃO PAULO, 2006). Visando a efetiva implementação das diretrizes da Lei Nº 14.018, foi criado neste decreto o ‘Grupo Gestor do Programa’. Este grupo, composto por diversos representantes dos órgãos municipais e estaduais, possui as seguintes atribuições:

- pesquisar, conhecer, divulgar e incentivar a implantação de soluções técnicas aplicáveis aos projetos de novas edificações bem como à adaptação das já existentes;
- recomendar a utilização de fontes alternativas para a captação de água e o seu reuso nas novas edificações, e práticas que proporcionem a economia e o combate ao desperdício da água;
- promover eventos sobre temas ligados à água na cidade de São Paulo, em parceria com instituições públicas;
- analisar a viabilidade de aplicação das propostas ofertadas pelas instituições públicas e privadas, organizações não-governamentais, comunidades científicas e população e;
- informar à Secretaria Municipal de Gestão das novas soluções técnicas e ações recomendadas, além de propor ao prefeito de São Paulo a elaboração e alteração da legislação municipal vigente, com o fim de estabelecer a obrigatoriedade da adoção das novas soluções técnicas.

3.3.3. Campinas – SP

Em 16 de janeiro de 2006, foi criada a Lei Nº 12.474 que abrange as novas edificações de interesse social, de propriedade do Estado, da União ou do Município, assim como a adaptação dos bens imóveis do município, ao proposto na lei, no prazo de 10 anos (CAMPINAS, 2006).

Dentre as ações da Lei Nº12.474 estão:

- o uso racional de água com um eficiente combate ao desperdício quantitativo e a redução das perdas de vazamento;
- o aproveitamento de água de chuva, que deverá ser entendido como o conjunto de ações que possibilitem a captação, tratamento e monitoramento da qualidade e distribuição para o uso em atividades menos nobres: irrigação, lavagem de pisos, etc.
- o reuso das águas servidas, que deve ser entendido como as que já foram utilizadas primeiramente em tanques, máquinas de lavar, chuveiros e banheiras, para utilização em atividades menos nobres,
- o uso de dispositivos hidráulicos como: bacias sanitárias com volume de descarga reduzido, chuveiros e lavatórios com volumes fixos de saída de água, torneiras e válvulas de fechamento automático, arejadores e bacias sanitárias de volume reduzido de descarga e a instalação de hidrômetro para medição individualizada em edifícios residenciais e comerciais.

Nesta lei é alertado que os hidrômetros que forem usados para os edifícios residenciais, e comerciais devem estar de acordo com as exigências do INMETRO, ou outra que a substituir, além de serem submetidos a ensaios devidamente comprovados por laudos técnicos de órgãos competentes, atestando que o referido equipamento está de acordo com as Normas Brasileiras (CAMPINAS, 2006).

São desenvolvidos estudos para a efetiva aplicação dos sistemas redutores do consumo de água nos projetos das novas edificações, além de soluções técnicas e um programa de estímulo à adaptação das edificações já existentes. Instituições públicas, privadas e a comunidade científica são convidadas a participar das discussões e apresentar sugestões eficientes para o programa. Conforme a lei, o Poder Executivo
criou uma comissão de estudos, controle e gestão da conservação e uso racional da água, composta por diversos representantes de várias instituições, que tem a função de definir as ações de implantação do programa (CAMPINAS, 2006).

3.4. Avaliação do PURAE

O PURAE em funcionamento em Curitiba-PR é resultante da Lei Nº 10.785 e dos Decretos Nº 293 e Nº 212. A avaliação apresentada neste artigo refere-se aos requisitos que realmente ficaram obrigatórios após toda a regulamentação.

3.4.1. Aspectos positivos

a) É um instrumento para a sensibilização da população sobre a importância da conservação dos recursos hídricos.

b) As exigências são obrigatórias apenas para as novas edificações.

c) A obrigatoriedade da utilização de dispositivos hidráulicos economizadores de água resulta em economia no consumo de água.

d) A obrigatoriedade da instalação de hidrômetros individualizados possibilita o controle do volume consumido de água por unidade.

e) A implantação de um sistema de captação de água de chuva nas edificações proporciona benefícios como a redução do consumo de água potável, a contribuição para a redução das enchentes, a redução dos custos para manutenção e ampliação das redes de drenagem urbana, e da mesma forma, a redução dos custos para manutenção e ampliação das redes de distribuição de água potável.

f) O reúso de águas servidas para fins não potáveis reduz o consumo de água proveniente da rede pública de abastecimento. O fato desta exigência ser obrigatória somente para as edificações comerciais e industriais, com área igual ou superior a 5.000 m² viabiliza a implantação do sistema.

3.4.2. Aspectos negativos

a) Falta a criação de um grupo gestor do PURAE, assim como foi implantado no Decreto Nº 47.731/2006 (Município de São Paulo). Este grupo pode contribuir para a permanente avaliação do programa e colaborar para o debate de soluções técnicas específicas.

b) Falta especificar aos usuários as normas sanitárias vigentes para estes reservatórios de água não potável, assim como foi apresentado no Decreto Nº 23.940/2004 criado no Município do Rio de Janeiro. Essas condições são necessárias para garantir a eficiência do sistema e a segurança para o consumidor, portanto deveriam ser consideradas para o PURAE em Curitiba.

c) Falta a determinação de indicadores da qualidade das águas de chuva armazenadas para aproveitamento em fins não potáveis e das águas servidas para reúso, com seus respectivos usos, sem oferecer riscos à saúde dos usuários. Também não foram definidos os dispositivos, processos e tratamentos necessários para a manutenção desta qualidade.

d) O PURAE não exige que as instalações de águas não potáveis sejam sinalizadas para evitar o consumo indevido pelos usuários, e sejam totalmente independentes dos outros sistemas de água potável.

3.5. Propostas de medidas para a otimização do PURAE

a) Criação de um grupo gestor do programa ou de uma comissão de estudos, assim como foi implantado no Decreto Nº 47.731/2006 do Município de São Paulo e na Lei Nº 12.474, de Campinas – SP, respectivamente. Este grupo poderia atender as dúvidas dos profissionais, sugerir soluções técnicas e estudar medidas mais eficientes para serem implantadas nas edificações.

b) Alertar aos usuários, de que sempre quando houver um sistema de captação e aproveitamento de água de chuva e/ou reúso das águas servidas, é necessário atender as normas sanitárias vigentes, como foi apresentado no Decreto Nº 23.940/2004 criado no Município do Rio de Janeiro.

c) Divulgação e sensibilização da população sobre a importância das edificações que enquadrarem às exigências do PURAE, através de campanhas publicitárias, palestras, congressos, seminários e abordagem do tema nas aulas ministradas nas escolas integrantes da Rede Pública Municipal, debitando sobre os benefícios trazidos pelo programa ao meio ambiente e a população.

d) Alertar a população sobre a importância da manutenção do sistema de captação de água de chuva.

4. Conclusões

No presente estudo verificou-se que o programa de conservação e uso racional da água nas edificações – PURAE, existente em Curitiba-PR não apresenta todas as informações necessárias para o seu funcionamento adequado.
Conclui-se que o programa pode ser otimizado e também que o PURAE carece de maior divulgação acerca de seus objetivos e requisitos junto aos profissionais da construção civil e da população em geral.

Outro aspecto muito importante para as futuras investigações é a determinação de indicadores relacionando os parâmetros de qualidade da água de chuva e das águas servidas com seus potenciais usos. Além disto é importante indicar a obrigatoriedade de sinalização das instalações de água não potáveis e a orientação sobre a manutenção e limpeza destes reservatórios, para que esta água seja utilizada sem oferecer risco à saúde dos usuários.

A criação do PURAE foi um passo muito importante, mas para garantir sua otimização é indicada a implantação de um grupo gestor do programa.

Outras considerações sobre a viabilidade deste programa no sentido de garantir a segurança e a viabilidade econômica para o usuário são objetos de estudos em andamento.

5. Referências


Responsabilidade de autoria

As informações contidas neste artigo são de inteira responsabilidade de suas autoras. As opiniões nele emitidas não representam, necessariamente, pontos de vista da Instituição e/ou do Conselho Editorial.

Abstract: This study consisted of comparison between samples of rainwater collected in two different forms: a system composed of an inclined roof with concrete tiles and another composed of a flat green roof. The study was conducted at two residences in the Santa Felicidade neighborhood, in the city of Curitiba, state of Paraná, South of Brazil. Three samples of rainwater were collected: one at the output of each roof studied, and one from atmospheric rain. The latter was collected without interference from other surfaces, in order to characterize the rainwater in its natural state. The samples collected from the roofs were analyzed for pH, color, turbidity and coliforms. The results obtained met the quality standards for rainwater harvested in urban areas for non-potable uses, set by the Brazilian guidelines in ABNT NBR 15527:2007. The study also showed that the green roof had the potential to function as a substitute for the filters available in the market for rainwater harvesting systems.
CAPÍTULO 6

ESTUDO COMPARATIVO DA QUALIDADE DA ÁGUA DE CHUVA COLETADA EM COBERTURA CONVENCIONAL E EM TELHADO VERDE

Cellimar Azambuja Teixeira
Marcel Atamis Budel
Stella Maris da Cruz Bezerra
Khosrow Farahbakhsh
Margarine Giacchini
Resumo

Este estudo consiste em uma comparação da qualidade da água da chuva coletada em duas formas distintas de captação: um sistema composto por um telhado inclinado com telhas de concreto e o outro composto por uma cobertura plana com telhado verde. O objetivo consistiu em caracterizar os sistemas utilizados nas duas formas de cobertura e analisar a qualidade da água da chuva captada nos dois sistemas. O presente estudo foi realizado em duas residências no bairro de Santa Felicidade, região noroeste da cidade de Curitiba, capital do Paraná. Para a comparação da qualidade da água da chuva armazenada foram coletadas três amostras: duas provenientes dos telhados das casas em estudo e uma amostra da chuva atmosférica. Essa última foi coletada sem a interferência de outras superfícies, com o objetivo de caracterizar a água da chuva em seu estado natural. As amostras coletadas nas coberturas, devidamente acondicionadas, foram levadas ao laboratório no qual foram analisadas para determinação de: pH, cor, turbidez e coliformes. Os resultados obtidos atenderam aos padrões de qualidade dispostos na norma ABNT NBR 15527:2007 e apresentaram informações relevantes para comparação entre os sistemas. Para esses dois casos avaliados conclui-se que a utilização da água da chuva, para fins não potáveis, possui qualidade satisfatória para o local e a forma de captação demonstrada no estudo. Este estudo
PROSPECTOS CONTEMPORâNEOS EM ENGENHARIA CIVIL

também mostrou que o telhado verde tem potencial de funcionar em substituição aos filtros disponíveis no mercado para sistemas de captação de água da chuva.

Palavras-chave: Água da Chuva; Aproveitamento; Qualidade; Telhado Verde; Estudo de Caso.

INTRODUÇÃO

A sustentabilidade nos últimos anos vem sendo discutida e cada vez mais se torna um tema conhecido entre a população. A preocupação com o meio ambiente e com impactos ambientais deixou a grande escala para entrar nos lares, escolas e escritórios. Porém, se engana quem pensa que são necessários grandes projetos e tecnologia de ponta para contribuir com essa nova realidade. Neste trabalho são apresentadas medidas simples e aplicáveis em qualquer empreendimento, mas que muito auxiliam na busca por melhores condições. Os temas de captação e utilização de água da chuva e utilização de vegetação nas coberturas são abordados e analisados.

A escassez de água, os fenômenos de ilhas de calor, as enchentes, dentre muitos outros eventos comuns nas grandes metrópoles, podem ser minimizados por sistemas de retenção e uso da água da chuva, reuso de água cinza e aumento de áreas permeáveis. Essas ações podem contribuir para a sustentabilidade ambiental nas cidades, ao deixarem de ser atos isolados para tornarem-se medidas públicas por meio de legislação e incentivos governamentais.

O objetivo geral deste trabalho é comparar dois sistemas de cobertura e captação de águas da chuva, sendo um, o sistema convencional, e outro, o sistema composto de telhado verde, ambos no município de Curitiba, estado do Paraná.
Os objetivos específicos são:

- caracterizar os sistemas utilizados nas duas formas de cobertura: plana vegetada e telhado convencional;
- analisar a qualidade da água da chuva captada nas duas formas de cobertura;
- comparar os resultados referentes à qualidade da água nas duas formas de cobertura.

**CARACTERÍSTICAS DA ÁGUA DA CHUVA**

Segundo Carvalho (2004), a formação da atmosfera se dá pela aglomeração ou mistura de diversos gases e partículas em suspensão. Essas partículas podem ser sólidas ou líquidas e a chuva resulta, então, das partículas suspensas e principalmente da água em suspensão, as quais formam as nuvens.

De acordo com a região geográfica e suas características meteorológicas, considerando-se, por exemplo, vegetação profusa ou falta dessa, zonas urbanas ou rurais, efluentes gasosos emitidos e outros tantos fatores, as chuvas podem variar tanto em sua composição como em intensidade (TOMAZ, 2005). Emissões atmosféricas podem alterar o pH das chuvas, fazendo com que em alguns lugares ocorram precipitações da chamada “chuva ácida”. Na ausência de poluentes, o pH das chuvas se apresentam em torno de 5,7, o que é o nível de acidez normal devido à formação de $\text{H}_2\text{CO}_3$ – ácido carbônico –, derivado do $\text{CO}_2$ – dióxido de carbono –, cuja presença é normal na atmosfera (JAQUES, 2005).

A excessiva utilização de combustíveis fósseis também contribui para que se solubilizem os gases que estão na atmosfera, resultando na geração de ácidos mais fortes, chegando a formar, por exemplo, ácido nítrico – $\text{HNO}_3$ – e ácido sulfúrico – $\text{H}_2\text{SO}_4$ – os quais geram chuvas com pH inferiores a 5,0. Chuvas ácidas podem ser prejudiciais tanto para os seres humanos, diretamente e indiretamente, atingindo edificações, veículos, e o próprio solo, assim como para as plantas (OLIVEIRA, 2005).

Pelo seu grau de pureza, Zolet (2005) classifica a água nos graus de A a D, representando sucessivamente água de melhor para pior qualidade (Tabela 6.1).

Tabela 6.1 – Variação da qualidade da água da chuva de acordo com seu local de coleta

<table>
<thead>
<tr>
<th>GRAU DE PUREZA</th>
<th>ÁREA DE COLETA</th>
<th>UTILIZAÇÃO</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Telhados (lugares não ocupados, porém frequentados por animais de sangue quente).</td>
<td>Bacia-sanitária, rega de plantas, outros usos. Se purificadas por tratamento simples, são potáveis ao consumo.</td>
</tr>
<tr>
<td>B</td>
<td>Coberturas, sacadas (lugares frequentados por pessoas e animais).</td>
<td>Bacia sanitária, rega de plantas, outros usos não potáveis. São impróprias para consumo.</td>
</tr>
<tr>
<td>C</td>
<td>Estacionamentos, jardins artificiais.</td>
<td>Tratamento necessário.</td>
</tr>
<tr>
<td>D</td>
<td>Vias elevadas, estradas de ferro, rodovias.</td>
<td></td>
</tr>
</tbody>
</table>

Fonte: Adaptada de FENDRICH (2002)
Conforme indicado na Tabela 6.1, a água captada da chuva ainda não é apropriada para o consumo humano, necessitando tratamento para que se torne potável. Porém, pode ser utilizada para fins não potáveis diversos, como limpeza em geral e em descargas de bacias sanitárias.

Tabela 6.2 – Parâmetros de qualidade da água da chuva para usos restritivos não potáveis

<table>
<thead>
<tr>
<th>PARÂMETRO</th>
<th>ANÁLISE</th>
<th>VALOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coliformes totais</td>
<td>Semestral</td>
<td>Ausência em 100 mL</td>
</tr>
<tr>
<td>Coliformes termotolerantes</td>
<td>Semestral</td>
<td>Ausência em 100 mL</td>
</tr>
<tr>
<td>Cloro residual livre(1)</td>
<td>Mensal</td>
<td>0,5 a 3,0 mg/L</td>
</tr>
<tr>
<td>Turbidez</td>
<td>Mensal</td>
<td>&lt; 2,0 uT(3), para usos menos restritivos &lt; 5,0 uT</td>
</tr>
<tr>
<td>Cor aparente (caso não seja utilizado nenhum corante)</td>
<td>Mensal</td>
<td>&lt; 15 uT(3)</td>
</tr>
<tr>
<td>pH (Deve previr ajuste para proteção das redes de distribuição, caso necessário)</td>
<td>Mensal</td>
<td>pH de 6,0 a 8,0 no caso de tubulação de aço carbono ou galvanizado</td>
</tr>
</tbody>
</table>

NOTA: Podem ser utilizados outros processos de desinfecção além do cloro, como a aplicação de raio ultravioleta e aplicação de ozônio.

\(1\) No caso de serem utilizados compostos de cloro para desinfecção.

\(3\) uT é a unidade de turbidez.

\(4\) uT é a unidade Hazen

Fonte: Adaptada da ABNT (2007)

Naturalmente, a coleta de águas da chuva por telhados faz com que essa água contenha microorga-
nismos diversos procedentes, por exemplo, de fezes de pássaros além de outros elementos, como restos de plantas, folhas e galhos, muitos desses em decomposição. Desta forma, para o consumo humano, a água coletada da chuva deve ser devidamente tratada, para que se torne potável (TORDO, 2004). A Associação Brasileira de Normas Técnicas (ABNT) através da norma NBR 15527/2007 especifica parâmetros de qualidade para a água de chuva ser utilizada para usos em fins não potáveis (Tabela 6.2).

**MEDIDAS E CUIDADOS NO ARMAZENAMENTO DA ÁGUA DE CHUVA COLETADA**

Quando do projeto e execução de um sistema de captação e armazenamento de águas pluviais deve-se prever medidas que garantam a segurança sanitária da água após tratamento adequado (SIQUEIRA CAMPOS, 2004). Entre as medidas que devem ser adotadas, destaca-se o descarte inicial das chuvas preconizado pela NBR 15527/07 objetivando eliminar os primeiros milímetros de chuva, as águas seguintes tendem a ser de melhor qualidade já que as anteriores carregaram consigo muito das impurezas indesejáveis, tornando mais fácil o tratamento das águas então aproveitadas (ZOLET, 2005). As primeiras águas limpas, até certo ponto, o te-
Ihado onde a água é captada, e ao serem descartadas melhoram a condição no armazenamento da água de chuva que segue o descarte.

A norma ABNT NBR 15527:2007 estabelece o que é necessário para que seja dimensionado o volume de descarte da precipitação pluviométrica inicial e que, no caso da impossibilidade de se dimensionar tal volume, este seja estabelecido em um mínimo de 2 mm (ABNT, 2007). Além disso, a mesma norma indica uma rotina de manutenção das partes do sistema (Tabela 6.3).

É de suma importância que seja planejado, de forma adequada, um sistema que aproveite ao máximo a água da chuva estabelecendo-se qual a quantidade dessa água que poderá, efetivamente, ser aproveitada. Também as necessidades de tratamento devem ser estabelecidas, considerando-se a utilização que se pretende de tal água (JAQUES, 2005).

Dentre alguns fatores importantes quanto à captação, transporte e armazenamento das águas de chuva, salienta-se que os dutos de águas captadas das chuvas não devem ser ligados a dutos da rede pública de abastecimento de água potável, pois há alto risco de contaminação cruzada. Um tratamento prévio da água de chuva coletada pode ser necessário para retirar possíveis agentes contaminantes de maior porte, como galhos, folhas e outros materiais que possam produzir impurezas. Esse tratamento pode ser feito com a utilização de telas e redes estratégicamente distribuídas em pontos dos condutores da água (ZOLET, 2005).

Na Tabela 6.3 pode-se ver uma rotina de manutenção da água coletada, listando os componentes envolvidos e a periodicidade da limpeza de cada um.

Tabela 6.3 – Frequência de manutenção de alguns componentes do sistema de aproveitamento de água de chuva

<table>
<thead>
<tr>
<th>COMPONENTE</th>
<th>FREQUÊNCIA DE MANUTENÇÃO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispositivo de descarte de detritos</td>
<td>Inspeção mensal, Limpeza trimestral</td>
</tr>
<tr>
<td>Dispositivo de descarte do escoamento inicial</td>
<td>Limpeza mensal</td>
</tr>
<tr>
<td>Calhas, condutores verticais e horizontais</td>
<td>Semestral</td>
</tr>
<tr>
<td>Dispositivos de desinfecção</td>
<td>Mensal</td>
</tr>
<tr>
<td>Bombas</td>
<td></td>
</tr>
<tr>
<td>Reservatório</td>
<td>Limpeza e desinfecção anual</td>
</tr>
</tbody>
</table>

Fonte: ABNT (2007)

**METODOLOGIA**

Descrição do sistema: CASA-1 – TELHADO CONVENCIONAL

A casa 1 possui como cobertura um telhado inclinado em 50% com telhas de concreto planas e uma área de captação de 65m² que corresponde a uma das duas águas do telhado.

A água da chuva que escoa pelo telhado é primeiramente coletada por uma calha, seguindo por um duto vertical de alumínio até o nível do solo, no qual se encontra um filtro do tipo 3P Tecnik_VF1 responsável pela retirada de partículas maiores como folhas e galhos. Após passar pelo filtro, a água segue para uma cisterna de 2.800 litros de PEAD (polietileno de alta densidade – pré-fabricada) na qual fica armazenada para uso.

O sistema de distribuição conta com uma eletrobomba com pressostato que aciona o funcionamento da bomba quando verifica variação de pressão ao abrir uma das duas torneiras. A utilização da água da chuva nessa residência é para limpeza de áreas externas e rega de jardim.

Descrição do sistema: CASA-2 – TELHADO VERDE

A casa 2 tem cobertura composta por uma laje plana, com 77m² de área de captação, recoberta por vegetação, ou seja, um telhado verde.

A água da chuva após passar pelo telhado verde é conduzida para dutos verticais de PVC até a cisterna de concreto de 1.500 litros no nível do solo. O sistema contempla uma eletrobomba responsável por bombear a água até um reservatório de 1.000 litros localizado na cobertura acima do nível do telhado verde, no qual fica armazenada até sua utilização. O uso destinado à água da chuva nessa residência, além de limpeza externa e rega de jardim, é fornecer água para a descarga nas bacias sanitárias.

Coleta das amostras de água de chuva

Para a comparação da qualidade da água foram coletadas três amostras, nomeadas como:

- Amostra 3 – Coleta Atmosférica: coletada diretamente da chuva, sem interferência de outras superfícies.

As coletas Amostra 1 – Casa-1 – Telhado Convencional e Amostra 2 – Casa-2 – Telhado Verde foram realizadas no dia 18 de maio de 2011 entre 9h e 10h30min e a coleta
atmosférica foi realizada em dia diferente, dia 16 de maio de 2011, último dia de chuva mais intensa anterior às análises. Para que a amostragem da água da chuva representasse um mesmo período de chuvas foi feito o esvaziamento de ambas as cisternas no dia 12 de maio de 2011, sendo que o período de armazenamento das chuvas compreende os dias 14, 15, 16 e 17 de maio de 2011. O último registro anterior de chuva foi no dia 4 de maio, assim sendo, o período entre esse dia, 4 de maio e o primeiro dia da chuva, dia 14 de maio, são os dias nos quais foram depositados nas coberturas particuladas como poeira, dejetos de animais, resíduos orgânicos, folhas, galhos etc.

Depois de coletadas, as amostras foram acondicionadas de forma adequada, seguindo os requisitos estabelecidos pelo laboratório e após serem imediatamente encaminhadas ao laboratório particular situado em Curitiba, as amostras foram examinadas para determinação de: pH, cor, turbidez e coliformes.

RESULTADO DAS ANÁLISES: COR APARENTE

Tabela 6.4 – Resultados para cor aparente

<table>
<thead>
<tr>
<th>Amostra</th>
<th>Método</th>
<th>LQ (1)</th>
<th>Resultado</th>
<th>Expressão</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosférica</td>
<td>SM 2130 B</td>
<td>2,5</td>
<td>&lt; 2,5</td>
<td>un PtCo</td>
</tr>
<tr>
<td>Casa-1 – Telhado Convencional</td>
<td>SM 2130 B</td>
<td>2,5</td>
<td>&lt; 2,5</td>
<td>un PtCo</td>
</tr>
<tr>
<td>Casa-2 – Telhado Verde</td>
<td>SM 2130 B</td>
<td>2,5</td>
<td>&lt; 2,5</td>
<td>un PtCo</td>
</tr>
</tbody>
</table>

(1)LQ: Limite de Quantificação do Método Analítico Utilizado

Fonte: Elaborada pelos autores

No parâmetro cor aparente (Tabela 6.4) as três amostras indicaram resultados inferiores ao limite de quantificação estabelecido pelo método analítico utilizado no laboratório. O método utilizado para análise de cor aparente foi a Escala Platina-Cobalto, que é uma escala indicada para detectar tons de amarelo. E quando os resultados se apresentam inferiores ao limite de quantificação, isso indica que não há matéria orgânica suficiente para interferir na cor da água.

RESULTADO DAS ANÁLISES: TURBIDEZ

Tabela 6.5 – Resultados para turbidez

<table>
<thead>
<tr>
<th>Amostra</th>
<th>Método</th>
<th>LQ (1)</th>
<th>Resultado</th>
<th>Expressão</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosférica</td>
<td>SM 2130 B</td>
<td>0,01</td>
<td>0,72</td>
<td>NTU</td>
</tr>
<tr>
<td>Casa-1 – Telhado Convencional</td>
<td>SM 2130 B</td>
<td>0,01</td>
<td>0,64</td>
<td>NTU</td>
</tr>
<tr>
<td>Casa-2 – Telhado Verde</td>
<td>SM 2130 B</td>
<td>0,01</td>
<td>0,50</td>
<td>NTU</td>
</tr>
</tbody>
</table>

(1)LQ: Limite de Quantificação do Método Analítico Utilizado

Fonte: Elaborada pelos autores

A turbidez é um parâmetro que caracteriza a existência de partículas finamente divididas dispersas em água podendo deixá-la com aparência turva, sem transparência. No parâmetro turbidez (Tabela 6.5) foi verificada diferença entre as amostras. A amostra da chuva atmosférica apresentou o maior valor. Isso provavelmente indica que os sistemas de filtragem funcionam de forma eficiente melhorando a qualidade da água. A amostra Casa-2 – Telha-
do Verde apresentou o menor valor de turbidez indicando que esse sistema, telhado verde, como havia expectativa, funciona como um filtro e acabou por obter melhor resultado que o filtro da Casa-1 – Telhado Convencional, no parametro turbidez.

RESULTADO DAS ANÁLISES: pH

Tabela 6.6 – Resultados para pH

<table>
<thead>
<tr>
<th>Amostra</th>
<th>Método</th>
<th>LQ (')</th>
<th>Resultado</th>
<th>Expressão</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosférica</td>
<td>SM 4500-H+ B</td>
<td>0,01</td>
<td>6,00</td>
<td></td>
</tr>
<tr>
<td>Casa-1 – Telhado Convencional</td>
<td>SM 4500-H+ B</td>
<td>0,01</td>
<td>6,18</td>
<td></td>
</tr>
<tr>
<td>Casa-2 – Telhado Verde</td>
<td>SM 4500-H+ B</td>
<td>0,01</td>
<td>7,22</td>
<td></td>
</tr>
</tbody>
</table>

(’) LQ: Limite de Quantificação do Método Analítico Utilizado

Fonte: Elaborada pelos autores

O pH é uma grandeza físico-química que indica a acidez, neutralidade ou alcalinidade de uma solução. Com relação à captação e ao armazenamento, esse parâmetro é importante para que os sistemas e tubulações não sejam danificados. Na utilização para rega de plantas, o pH da água utilizada é um fator determinante no crescimento e bom desenvolvimento das mesmas.

Todas as amostras coletadas se apresentaram dentro da faixa ideal, com pH de 6,0 a 8,0, conforme estabelecido pela ABNT NBR 15527:2007 (Tabela 6.2).

A amostra Casa-1 – Telhado Convencional, com pH 6,18 mostra-se muito semelhante à amostra Atmosférica com pH 6,00 levemente ácida e condizente com o pH natural da chuva. Já a Casa-2 – Telhado Verde, apresenta uma variação considerável se mostrando levemente alcalina, possivelmente pelo fato do sistema ser novo e ter passado por um processo de limpeza recente que utiliza hipoclorito de sódio, de natureza alcalina, desta forma, resíduos dessa limpeza podem ter alterado os resultados. Porém, somente outras análises poderiam assegurar isso, já que não temos informações suficientes também para descartar o efeito do telhado verde no pH da água por ele captada.

RESULTADO DAS ANÁLISES: COLIFORMES TERMOTOLERANTES E TOTAIS

Tabela 6.7 – Resultados para coliformes termotolerantes e totais

<table>
<thead>
<tr>
<th>Amostra</th>
<th>Método</th>
<th>LQ (')</th>
<th>Resultado</th>
<th>Expressão</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casa-1 – Telhado Convencional</td>
<td>SM 9221 B/C e E</td>
<td>18,0</td>
<td>&lt; 18,0</td>
<td>NMP/100 mL</td>
</tr>
<tr>
<td>Casa-2 – Telhado Verde</td>
<td>SM 9221 B/C e E</td>
<td>18,0</td>
<td>&lt; 18,0</td>
<td>NMP/100 mL</td>
</tr>
</tbody>
</table>

(’) LQ: Limite de Quantificação do Método Analítico Utilizado

Fonte: Elaborada pelos autores

A análise de coliformes é um importante parâmetro microbiológico utilizado como indicador da existência de microorganismos patogênicos, responsáveis pela transmissão de doenças de veiculação hídrica, tais como febre tifoide, febre paratifóide, desistiria bacilar e cólera.
As amostras Casa-1 – Telhado Convencional e Casa-2 – Telhado Verde apresentaram valores inferiores ao limite de quantificação da análise (Tabela 6.7), porém somente análises mais precisas poderiam indicar a ausência de coliformes e desta forma assegurar o que regula a ABNT NBR 15527:2007 (Tabela 6.2).

**COMPARATIVO DE DESEMPENHO ENTRE AS COBERTURAS**

No Gráfico 6.1 são indicados, comparativamente, os parâmetros que apresentaram diferenças nos resultados das amostras: que foram pH e turbidez. Cor e coliformes não são apresentados nos gráficos por não possuírem valores significativos, estando estes com os valores mínimos decorrentes do limite quantitativo das análises.

Gráfico 6.1 – Comparativo da qualidade da água da chuva coletada nas coberturas

O telhado verde funcionou como um filtro tendo inclusive o melhor resultado no parâmetro turbidez, (0,5). A amostra coletada do telhado convencional e filtro apresentou o valor 0,64 e a amostra atmosférica 0,72. Esses dados nos fornecem uma importante informação, visto que, na casa com telhado verde, a água captada da chuva é também utilizada nas descargas das bacias sanitárias, portanto, a qualidade superior no parâmetro turbidez é uma vantagem e um incentivo na utilização conjunta do telhado verde com a captação de água da chuva.

No parâmetro cor aparente todas as amostras apresentaram valores inferiores ao limite quantitativo da análise indicando que não há matéria orgânica suficiente para alterar a coloração da água e que os sistemas funcionam de forma adequada já que não permitem a entrada desse material, que em sua decomposição poderia piorar a qualidade da água.

Com relação ao pH, a amostra Casa-1 – Telhado Convencional ficou muito próxima à Atmosférica, porém, levemente mais alcalina, provavelmente por se tratar de uma cobertura de telhas de concreto, o que influenciaria no pH tendendo a ficar mais básico (TORDO, 2004).

Já a amostra Casa-2 – Telhado Verde indicou um pH mais alcalino (7,22) em comparação ao pH 6,00 da amostra atmosférica. Essa variação possivelmente ocorreu devido ao fato do sistema ser novo e o reservatório ter sido higienizado com hipoclorito de sódio, de caráter alcalino. O resíduo dessa limpeza pode ter afetado o resultado da aná-
lise, porém não é descartada a possibilidade de o telhado verde ser responsável pela alteração do pH, já que não se sabe o pH do solo utilizado. Na análise de coliformes, tanto totais quanto termotolerantes, as duas amostras, Casa-1 - Telhado Convencional e Casa-2 - Telhado Verde, apresentaram valores inferiores ao limite quantitativo indicando uma possível ausência, contudo seria necessária uma nova análise, mais precisa, para assegurar esse fato.

CONCLUSÕES

A partir dos resultados obtidos é possível concluir que tanto o sistema composto por telhado convencional e filtro, quanto o telhado verde conseguem atender às expectativas quanto à qualidade da água da chuva para usos não potáveis, estando dentro das normas estabelecidas pela ABNT NBR 15527:2007 e ainda apresentando uma melhora em comparação à qualidade da água da chuva atmosférica in natura.

Os resultados nos indicam que a utilização da água da chuva para fins não potáveis possui boa qualidade para o local, e a forma de captação demonstrada no estudo mostra ainda que telhados verdes podem funcionar satisfatoriamente em substituição aos filtros disponíveis no mercado para esse fim. Ademais, ao longo do estudo, novas dúvidas surgiram, as quais se espera responder com a continuidade deste estudo e com novas pesquisas.

Questionamentos

- Qual seria a relação do pH da água da chuva captada com o telhado verde?
- Como seria o comportamento do telhado verde com o passar do tempo e a estabilização do substrato?
- O pH do solo é alterado após a captação da água da chuva?

O estudo encontra-se em fase de monitoramento e avaliação, novas análises e um acompanhamento mais prolongado. Além de responder às questões apresentadas acima, fornecem esclarecimentos mais precisos acerca da presença de coliformes e de minerai, e o comportamento dos mesmos ao passar pelo telhado verde, desta forma, tendo mais dados de referência, seria possível agregar maior certeza e confiabilidade aos resultados obtidos neste estudo.
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