BC Centre for Disease Control
An agency of the Provincial Health Services Authority

Rainwater Harvesting for Non-potable Use and Evidence of Risk Posed to Human Health

Sylvia Struck

Introduction

While collecting and storing rainwater for use is an ancient practice, there has been a resurgence in popularity with the promotion of green and sustainable building practices, such as Leadership in Energy and Environmental Design (LEED), and in areas where water insecurity or lack of municipal supply make it an attractive or necessary supplement or alternative. One of the features of LEED certification is assessing water efficiency, whereby points are granted; e.g., if the use of potable water is reduced or eliminated for activities such as landscape irrigation. A benefit of implementing rainwater collection is that the demand for potable water supplied from municipal sources can be reduced.

In water stressed areas, homes and commercial buildings are often outfitted with roof collection systems to capture rainfall runoff that can be diverted to storage for later use. While rainwater harvesting is used for both potable and non-potable purposes, this paper will primarily focus on potential health risks of rainwater reuse for non-potable applications, namely: spray irrigation, use in fountains, toilet and urinal flushing). Also, while rainwater can be collected from other surfaces, such as courtyards, streets, and other impermeable surfaces, the focus is on roof-collected and therefore the discussion on contaminants will concentrate on those found primarily in roof-harvested rainwater.

Initially, scholarly (peer-reviewed) journal articles with content relevant to Legionnaire's disease and rainwater reuse were searched. The search was extended to consider rainwater reuse with respect to irrigation (or associated with spray), fountains, toilet and urinal flushing, and any health risks exposure, legionnaires, *E. coli*, campylobacter, bacterial, viral. Also, the following were included: guidelines, monitoring, standards, treatment, testing information on rainwater reuse for non-potable uses.

The key search statement used to locate articles was: (legionnaire* or (*E. coli*) or camphylo* or bacterial or viral) AND (rainwater or (rain water) or spray or fountain). Additional terms and combinations were used to narrow results and obtain guidelines.

A date restriction, January 2000 to December 2011, was imposed and English-only material was included (except for two institutional reports in Dutch, from the Netherlands). Scientific literature was scoped using the Ebsco database collection and OvidSP, both available through the University of British Columbia Library (UBC). Web of Science was also used to locate miscellaneous sources not covered and to extend citation chaining and mapping where possible.

Bibliographies of retrieved articles were reviewed and authors searched forward and backward to uncover additional literature. In addition, Google and Google Scholar were used to identify relevant grey literature primarily related to guidelines, regulations and policy or additional studies that had relevance.

The primary purpose of this study was to identify health risks associated with specific non-potable uses. Therefore studies, primarily concerned with potable water, were limited (except where health risks due to ingestion were discussed), as were studies looking at different types of treatment options for roof-harvested rainwater, such as solar disinfection.

The following will briefly discuss: general hazards; the main pathogens of concern; impacts of weather on water quality; non-potable uses and identified and potential health risks; and a brief discussion on guidelines and monitoring.

Background: General hazards found in rainwater

Assessing risk posed by roof-collected rainwater, which is subsequently stored and distributed for various uses, requires consideration of whether a human health hazard is present and whether the dose of hazardous material is sufficient to cause illness. Assessing risk is particularly difficult if the rainwater is to be used for non-potable applications, where primary routes of exposure are inhalation of aerosolized rainwater (such as through spray irrigation or fountains) or dermal contact, but also potentially through unintentional ingestion.

There is difficulty in quantifying exposure. Most identified studies relate to water quality and microbiological contamination of harvested rainwater and the *potential* for health risk, mainly through ingestion, without quantifying the risk due to inherent limitations. This uncertainty increases when the routes of exposure are through accidental inhalation or ingestion of sources not intended for potable use. While studies, such as a rooftop rainwater harvesting study in Bangladesh, show that ingesting untreated rainwater can pose a significant health burden,[1] outbreaks of waterborne diseases attributed to rainwater use are frequently not reported, since tanks often serve an individual household.[2]

Rainwater is generally considered of good quality but can become contaminated if it absorbs airborne pollutants and contaminants from the catchment area, storage or distribution system. Microbial contamination in rainwater reuse systems generally originate from debris and faecal material deposited on roof surfaces by birds or small rodents. Presence of faecal indicator bacteria in rainwater suggests contamination with faeces, signifying that pathogens, such as Campylobacter, Salmonella, Vibrio, Cryptosporidium, Giardia, and enteric viruses, may also be present in the rainwater.[3-5] According to Simmons et al. (2008), roof-collected rainwater systems often provide water supplies of relatively poor physiochemical and microbiological quality.[6] However, the prevalence and level of contamination can vary widely, in terms of both indicator organisms and pathogens.[7]

Microbiological parameters are affected mainly by the cleanliness of the catchment areas, gutters, and storage tank.[5,8] Rodrigo et al. (2009) also provide information from other studies to show that tank material affects the microbial contamination of rainwater.[2] Higher counts were associated with dark coloured polyethylene tanks (which may create a warmer environment for the bacteria). Concrete tanks had a higher pH and dissolved solids which may provide nutrients that enable bacterial growth, although the higher pH may result in die-off.[2]

Microbiological and chemical parameters also show seasonal fluctuations.[8] Schets et al. (2010) found that although outside temperatures had limited effect on the temperatures and microbiological quality of water in the reservoirs, there was a correlation between rainfall intensity and faecal indicator counts.[3] Detection of pathogens increased after heavy rainfall. A study by Rodrigo et al. also noted that bacterial loads where higher (heterotrophic plate count or HPC levels) in tanks 24 and 48 hours after a rainfall event.[2]

Evans et al. (2007) also found that airborne microorganisms represented a significant contribution to bacterial load of roof water and that overall contaminant load was influenced by wind velocity.[9] Wind can also carry human viruses, as noted by Fewtrell and Kay (2007), with a theoretical risk of collected rainwater contamination from aerosols derived from wastewater treatment works.[7] Microbiological risks are likely to be similar in urban and rural settings; however, there may be significant differences in chemical contaminants between urban and rural settings.[4]

Pathogens and Contaminants found in Roof-Harvested Rainwater

Pathogens found in rainwater are likely to vary based on location and concentration and will also likely fluctuate based on temporal variations, making any prediction of occurrence difficult.[7] As mentioned, a principal source of pathogens is likely to be avian. The most frequently isolated are *Salmonella* spp. and *Campylobacter* spp. but since they are of the avian variety, they may not be generally infective to humans.[7] Of particular interest is the Legionella bacteria (which causes Legionnaires disease); it can be found in water systems and can pose a health risk, particularly when aerosolized. These pathogens can cause serious illness or fatality particularly in vulnerable groups, such as the young, elderly or immunocompromised.

A brief description of some of the main pathogens and chemicals of concern, found in harvested rainwater, are presented in this section. The initial focus of the literature search concerned Legionnaires disease but was broadened to include other identified pathogens of concern along with a brief section on chemicals, due to potential exposure.

Legionnaires/Pontiac Fever

Legionnaire's disease is an acute respiratory infection caused by Legionella bacteria; most cases caused by *Legionella pneumophila* [10] serotype 1 (Lp1).[6] This opportunistic human pathogen can be found in rainwater tanks associated with environmental contamination and can proliferate if growth conditions are in an optimum range.[11] Evidence suggests that *Legionella pneumophila* can survive between 16.5°C and up to 55°C, although at temperature extremes it will not replicate. Growth of the bacterium is generally restricted to temperatures of 25°C to 45°C, with optimal growth in the range of 35°C to 43°C.[6] Lp1 can colonize ‘cleaner’ water systems and survive under more stressful conditions, such as higher temperature and chlorine levels than other serogroups.[6]

Most infections occur in middle-aged or older and immunocompromised persons and can cause severe illness and even death. Pontiac Fever is also caused by the Legionella bacteria but is milder, causing flu-like symptoms.

E. coli

E. coli is found in the intestines of humans and warm-blooded animals; some strains of this bacterium can cause gastrointestinal illness in addition to other, more serious, health problems. *E. coli* can survive for about 4-12 weeks in water containing a moderate level of microflora at a temperature of 15-18°C.[12] The detection of *E. coli* in a water system is used as an indicator of recent faecal contamination. *E. coli* data can also be used as a benchmark, since it is available for other rainwater tank surveys.[11]

Campylobacter

Campylobacter can be transmitted through food or water contaminated with animal faeces and causes approximately 2,400 cases of enteric disease in BC a year.[13] Campylobacter has also been found in harvested rainwater samples. The most common type of campylobacter associated with human illness is *Campylobacter jejuni.*[14] According to research conducted in 2002 (Broman et al. 2002; Moore et al. 2002; Waldenstrom et al. 2002) and referenced in Schets et al. (2010), pathogens including campylobacter have been detected in the faeces of gulls (Larus spp.)[3] that can then be transferred to rooftops and catchment areas.

Giardia

Giardia can be found on surfaces or in soil, food or water that has been contaminated with faeces from infected humans or animals.[15] *Giardia lambia* which causes gastroenteritis is one of the most common human parasitic infections in Canada. People can become infected by swallowing Giardia cysts found in contaminated food or water. Symptoms of giardiasis normally begin one to two weeks after a person has been infected. Giardia has been found in roof-harvested rainwater samples, confirming the potential for this pathogen to be present.[16]

Aeromonas

Some species of aeromonas are pathogenic to animals and humans. They can cause gastroenteritis which typically occurs after the ingestion of contaminated water or food. Wound infections can also result from exposure to aeromonas contaminated water. According to an EPA report on aeromonas, households reporting gastrointestinal illness were more likely to have aeromonads in their water.[17]

Simmons et al. (2001) studied aeromonads in 125 roof-collected rainwater systems in New Zealand; 22 of the systems exceeded drinking-water regulatory levels of indicator bacteria.[18] The study found that the presence of the indicator organisms: HPC, total coliform, faecal coliform, and enterococci were all significantly correlated with one another. *Aeromonas* spp. were isolated from 20 of 125 (16%) supplies.[18]

HPC is commonly used to measure the heterotrophic microorganism population in drinking water and other media and can be used as an indicator of the overall cleanliness and nutrient level of the rainwater tank.[11] According to Chapman et al. (2008), HPC may give an indication of the amount of sediment in the tank and the turnover rate of water in the tank, with concentrations of plate count bacteria potentially being “inversely proportional to the frequency of tank cleaning or desludging the tank.”[11]

Salmonella

Salmonellosis can be spread from person-to-person or from animals-, birds- or reptiles-to-people, and by consuming food contaminated with Salmonella. Both animals and people can be carriers. Approximately 6,000 to 12,000 cases of Salmonella are reported in Canada each year.[19] Salmonella has also been found in untreated surface water and even tap water. A fatal outbreak of Salmonellosis in Gideon, Missouri in 1993 was attributed to Salmonella introduced by bird feces that had contaminated the drinking water supply storage tank (no chlorine disinfection).[20] Symptoms usually appear 12 to 72 hours after ingesting contaminated food or water and generally last up to seven days. While most people recover without treatment, infants, the elderly or people who are immunocompromised may require treatment.[21]

Cryptosporidium

Cryptosporidium may be present in animal faecal matter but are also associated with environmental contamination of the water by soil. *Cryptosporidium parvum* and *Cryptosporidium hominis* (genotype 1) are the most prevalent species causing disease in humans.[22] Cryptosporidium is a common cause of waterborne illness and have been found in rainwater tanks. The parasite is shed as an ooyst which has a hard shell and is resistant to chlorine-based disinfection.

The following table, adapted from Fewtrell and Kay (2007), presents pathogens which have been found in harvested rainwater from various studies in the UK.[7] The table presents transmission routes and general case fatality rates/100,000 cases for each of the pathogens.

Table 1 Types of pathogens that can be found in rainwater in the U.K.

Group	Pathogen	Infection	Transmission	General Case Fatality rate/100,000 cases
Bacteria	Legionella pneumophila	Legionnaire's Disease	Inhalation	10,000*
		Pontiac fever	Inhalation, Oral, Contact	0
	Bacteria Escherichia coli O157:H7	Gastroenteritis	Oral	8.3
	Campylobacter spp.	Gastroenteritis	Oral	5
	Mycobacterium avium complex (MAC)	Respiratory and GI tract infection	Oral	Fatal cases usually only associated with those having underlying infections
	Salmonella spp. (non typhoid forms)	Gastroenteritis	Oral	41
Protozoa	Cryptosporidium spp.	Gastroenteritis	Oral	22
	Protozoa Giardia spp.	Gastroenteritis	Oral	1

adapted from Fewtrell and Kay (2007) [7]
*community acquired cases

Chemicals

While pathogens are of primary concern, the quality of collected rainwater can also be influenced by roofing material, such as galvanized lead or concrete tiles, that can leach chemicals; the age of the material can influence bacterial count.[23] Rainwater is slightly acidic; therefore, relatively aggressive, and can dissolve heavy metals and other impurities from the catchment area, gutters, and storage tank.[2,5] This acidity may lead to leaching of metals in the pipes used to distribute rainwater to the household.[2] The presence of heavy metals in rainwater, for potable use, can present a health hazard depending on the level and duration of exposure.[2] Elevated levels of zinc and lead have been reported, although concentrations in rainwater are generally within acceptable limits.[5]

Chemical contaminants can also be introduced through air pollution by urban and industrial sources or bushfire smoke. Spinks et al. (2006) conducted a study to look at bushfire impact on rainwater quality after a prolonged drought and bushfire east of Victoria, Australia in 2003.[24] Forty-nine rainwater tanks were tested for organic compounds, microbiological indicators, metals, nutrients, and physio-chemical parameters. The results for cadmium (and one sample for arsenic) and microbiological indicators (coliforms, *E. Coli*, Faecal streptococci) were above levels outlined in the *Australian Drinking Water Guideline*.[24] Long-term exposure to excess levels of cadmium in drinking water can cause kidney damage and osteomalacia.[24] Agricultural pesticide residues may also be of concern in rural areas where rainwater is harvested.

Lye (2009) reviewed papers on contamination from rooftop runoff.[25] One of the studies referenced in Lye (2009), Peters et al. (2008), analysed rooftop harvested water stored in cisterns from 112 private residences.[26] They found that while the water samples exceeded standards for primary drinking water, (1% for lead, 3% for nitrate), the sediments exceeded arsenic, lead, and mercury limits by 100%, 11% and 3%, respectively.[26] Soil profiles indicated the same composition; therefore, authors concluded that soil deposits on roofs are likely to be a significant source of chemical contamination.[26]

Impacts of weather on rainwater quality

As previously mentioned, weather patterns and environmental conditions can significantly influence bacterial load and airborne microorganisms are significant contributors to bacterial load of roof-harvested rainwater.[7] Rainfall intensity and the number of dry days preceding a rainfall event can also markedly affect the quality of runoff water.[2]

Schets et al. (2010) conducted a three-year study on the microbiological quality of rainwater stored in tanks in The Netherlands and what effect environmental conditions and storage container material had on the survival of microorganisms in these reservoirs.[3] The objective of the study was to provide evidence for recommendations on safe collection and storage of rainwater.[3] The study demonstrated that rainwater stored in different reservoirs was frequently faecally contaminated and contained potential human pathogens, such as Campylobacter, Cryptosporidium, Giardia, *Aeromonas hydrophila,* and Legionella.[3]

Analysis of samples, during a period with variable weather conditions, showed a correlation between rainfall intensity and faecal indicator counts and increased detection of pathogens after heavy rainfall incidents. Outside temperature, which fluctuated quite a bit during the study period, had a limited effect on both the temperature and the microbiological quality of the water in the reservoirs.[3] The study demonstrated that the number of faecal indicator bacteria and number of pathogenic microorganisms increased with high rainfall intensity, particularly after a period of drought.[3]

Evans et al. (2007) studied the effect of wind on the microbial composition of rainwater.[9] They found both wind speed and wind direction had a strong influence on the HPC and indicated that atmospheric disposition of microorganisms played an important role in contamination of roof-collected rainwater.[9]

However, Schets et al. (2010) reported that while they did not observe a strong correlation between wind and HPC in Dutch rainwater reservoirs, there was a strong correlation between wind speed and *Clostridium perfringens*, a pathogen commonly associated with foodborne illness that can be spread via food or water.[3] Laboratory experiments conducted by Schets et al. (2010) showed that HPC increased with increasing water temperature and prolonged storage time but was constant during storage at 15 °C.[3]

Fewtrell and Kay (2007) reported an Australian study done by Gardener et al. (2004) which found that discarding the first 1 mm of runoff reduced the bacterial load entering the storage tank between 9 and 62% for individual rainfall events.[7] The stored water, however, still contained significant levels of microbial contamination with faecal coliform concentrations up to 480 cfu per 100 ml.[7]

Non-potable uses and identified risks in studies

While a number of studies were concerned with microbiological quality of rainwater for use as potable water, a few studies and case studies examined microbial quality and risk of harvested rainwater for non-potable uses. The following information presents non-potable uses that were specifically identified as being of interest, namely spray irrigation, fountains, and use in toilet or urinal flushing. Where studies did not specifically address these uses, other studies were included, showing similar uses or potential routes of exposure. Additionally, some studies did not examine uses independently but combined them as non-potable use.

Ahmed et al. (2010) conducted a study on health risk posed by the use of roof-harvested rainwater for potable and non-potable uses in Southeast Queensland, Australia.[27] This study used Polymerase Chain Reaction (PCR) for presence/absence and quantitative PCR, to detect and quantify pathogens collected from household tanks storing roof-harvested rainwater (n=82). Samples were collected from outlet taps closest to the base of the tanks. During the first phase, samples were collected after rainfall events and screened for presence/absence of pathogens. The second phase entailed taking a subset of tanks (n=19) that had tested positive for the pathogens of interest: *Camylobacter jejuni*, *Legionella pneumophila, Salmonella* spp., *Giardia lamblia* and *Cryptosporidium parvum*. Sampling during the second phase occurred over a three month period from August to June.

Of the 214 samples that were tested during the study, the following pathogens were detected: *Salmonella invA* in 23 samples (10.7%), *Giardia lamblia* in 21 (9.8%) and *L. pneumophila* in 12 (5.6%). *Campylobacter jejuni* was detected in one sample but was not quantifiable and *Cryptosporidium parvum* was not detected. An overall estimation indicated pathogens were present approximately 5% of the time. As for quantifying the risk, they assumed all the pathogens were viable and considered six scenarios for exposure to Salmonella, Giardia, and Legionella. For Salmonella and Giardia the scenarios were: liquid ingestion due to drinking rainwater (1 litre/day) on a daily basis; accidental liquid ingestion due to garden hosing twice a week (1 ml/event); aerosol ingestion due to showering (1.9 ml/event); and aerosol ingestion due to hosing twice a week (1.9 µl/event). Scenarios for Legionella were aerosol inhalation due to showering (0.84 µl/event) on a daily basis and aerosol inhalation (0.5 µl/event) due to hosing twice a week.

The calculated risk of infection per 10,000 exposed persons per event showed: aerosol inhalation infection with *Legionella pneumophila* was up to 8.8×10^{-2}; *Salmonella* spp. and *Giardia lamblia* for liquid ingestion via drinking was up to 6.8×10^{2}; liquid ingestion via hosing was up to 7.1×10^{-1}; aerosol ingestion via showering was up to 1.3×10^{0}. Low risks of infection were noted for Salmonella and Giardia, for exposure via aerosol ingestion via hosing up to 1.3×10^{-3}. The authors multiplied the proportion of the population that have a tank or use water for drinking and/or hosing; the population potentially exposed to each pathogen ranged from 0.46% to 4.76%. In this particular study, the authors note that the only likely risk was from drinking water contaminated with *Salmonella* spp. and *Giardia lamblia* and therefore advise that roof-harvested water should be disinfected before using as a potable water sources.

Spray Irrigation or spray from pressure washing

An outbreak of legionnaires was identified from a marine water blaster system (pressure washing) which may have infected or seeded roof collection rainwater systems in the area. Four people contracted legionnaire's disease; three of these cases lived within 500 meters of the water blaster.[6]

The authors note that limited conclusions can be drawn from the outbreak investigation, but it is possible that aerosols containing Legionella were discharged into the air by the marina water blaster. This may have exposed cases directly, seeded nearby roof-collected rainwater systems or exposed cases through showering. Cases tended to be male, smokers, older or have an ongoing chronic illness. The cases also tended to live closer to the marina, at a mean distance of 550 metres compared to controls (922 metres), although these differences were not statistically significant. Household supplies were less likely to return positive results for Legionella if they were situated greater than 650 metres from water blaster. The amount of time cases spent outdoors, at their home addresses, was also significantly greater as a group, when compared to controls.[6] The authors concluded that because of New Zealand's temperate climate, roof-collected rainwater systems can harbour Legionella.[6] Authors also note that collected rainwater systems need appropriate design, careful cleaning and maintenance, and hot temperatures at a minimum of 60 °C to reduce the chance of Legionella multiplying.

Fountains

A study by Palmore et al. (2009) describes a nosocomial occurrence of legionnaire's disease; identified as emanating from a hospital decorative indoor fountain, despite being equipped with a filter and ozone generator.[28] The fountain had been shut off for five months but restarted four months earlier and was routinely monitored. The water was supplied by the municipal water supply and had two levels of waterfalls, where water could be aerosolized. Patients had to pass within 1.6 metres of the fountain. The isolates from the two infected patients and the fountain were found to be identical (other water sources in the patients' rooms had also been investigated but turned up negative).

This study was included to show potential risk, since it presents a case study where water from a routinely monitored fountain aerosolized and spread Legionella. Immunocompromised patients are particularly vulnerable and when infected, have a high mortality rate. The authors note that the fountain in the hospital presents an unacceptable risk in hospitals serving immunocompromised patients.[28]

Toilet and Urinal Flushing

Schets et al. (2005) conducted a study to look at roof-harvested rainwater used for toilet flushing, cleaning, and watering plants at four sites (three commercial, one private) in the Netherlands, over four consecutive weeks.[29] They took 28 samples from the reservoirs and taps. Their findings indicate that the collected water was often faecally-contaminated, indicating potential pathogens. Faecal indicators such as total colifoms, *E. coli,* and intestinal enterococci were present in 28, 27, and 27 of the samples tested, respectively. Campylobacter and *Legionella pneumophila* were detected one time at one sampling site. Aeromonas and *Clostridium perfingens* were detected in 20 and 23 of the samples, respectively. While authors were not able to quantify the risk of infection, they did conclude that the pathogens present in untreated rainwater, used for toilet flushing, can have negative consequences for public health.[29]

In a follow-up study at the three commercial sites, Schets et al. (2007) focussed on environmental conditions that affect the microbiological quality of collected rainwater.[30] They attempt to quantify the risk of infection according to the *Ministry of Housing, Spatial Planning and the Environment*'s maximum risk of one infection per 10,000 person-years; this is used for drinking water and the only standard they currently have. Using three toilet visits per day (therefore, around 1,000 visits per year), they estimate that risk of infection is 10^{-7}. In one of the reservoirs, campylobacter measured concentrations greater than 240 cfu/l.[30] If 4 microlitres (µl) are ingested through aerosolized water, there is a chance of one infection per 10^{-4}. While the authors hypothesize that it is possible to ingest 4 µl and that there is a risk of infection, more work needs to be done to determine actual risk.[3,30]

Building on earlier work, Schets et al. (2010) conducted a three-year study using roof-harvested rainwater samples from four sites that were used for toilet flushing, cleaning floors, and watering gardens.[3] Rainwater was treated by filtration at two of the sites; one had a leaf filter and sand filter, another had a filter for large particles, and the other two had no treatment. Samples were taken to a lab and stored in various containers (polyethylene, galvanized iron, and concrete) in the dark at various temperatures of 15, 25, and 35 °C.

The study demonstrated that water was faecally contaminated and incidentally contained potential human pathogenic microorganisms, such as Campylobacter, Legionella, Cryptosporidium, and Giardia.[3] There were also very high numbers of *Aeromonas hydrophila* in some of the reservoirs, which can cause gastro-enteritis and infections of the human skin; therefore, a health concern. They note that Aeromonas colonization of reservoirs may be a reservoir-specific problem (*A. hydrophila* survived longer in PVC containers than in galvanized iron containers). The differences observed between the reservoirs suggest that roof material and roof slope may play a role in reservoir contamination, which they note has also been observed in another study, Yaziz et al. (1989).[3] The steepness of the roof and smoothness of the roof material will also impact faecal material and dirt runoff. A gentle gradient and a vegetation layer on top will retain faecal material and delay runoff during rainfall. The vegetative layer can also retain the faeces, resulting in die-off of bacteria in the faeces during drought conditions.[3]

Schets et al. (2010) also reports on a case study by Schlech et al*.* (1985) concerning an outbreak of Legionnaires' disease in the United States, caused by a hotel roof-collected rainwater supply contaminated with *L. pneumophila*. In The Netherlands, Schets et al. (2010) notes that the presence of Legionella in rainwater used for toilet flushing may pose a health risk when aerosols containing Legionella are formed during toilet flushing and then inhaled.[3]

Albrechtsen (2002) evaluated microbial quality of rainwater and graywater, in seven systems used for flushing toilets in Denmark, and compared these to reference toilets using a municipal water supply.[31] This study found that while the general microbiological quality in the rainwater and mains-supplied toilets were similar, the rainwater systems introduced pathogens not found in toilets flushed with treated water.[17,31] Almost half the samples indicated the presence of *Aeromonas sp., Pseudomonas aeruginosa, Legionella non-pneunophila, Campylobacter jejuni*, *Mycobacterium avium,* and *Cryptosporidium sp*.[31] This means that potential pathogens introduced into the household would not normally occur in water supplied by the mains. While the authors note that comparisons to Danish drinking water standards may seem irrelevant, since water in toilets is not considered drinking water, there may be potential risk of introduction of pathogens to the drinking water supply. This may happen if there is back siphonage, leakage, or incorrect installation with cross-connection to the mains used for drinking water.[31] Contamination can occur through cross-connection when two separate piping systems flow into each other, such as with the mains and rainwater systems, or through backflow issues, which can occur with poorly installed plumbing systems, or during maintenance or emergencies.[32]

In another study by Oesterholt et al. (2007), a housing estate used both drinking water and "household water" defined as non-potable water produced from surface water, groundwater, or rainwater.[33] Findings from the study show that incidents, such as cross-connections between drinking water and household water and detection of viruses and pathogenic protozoa in treated water, demonstrated the systems were microbiologically unsafe. Also, certain household water had a relatively high biofilm, leading to the potential growth of *Legionella* spp.[33] According to Oesterholt et al. (2007) and based on the results of this study, the Dutch government discouraged the production and distribution of household water on a large scale; they still allow dual water systems on a small scale when rainwater or groundwater are used as a source, when used only for toilet flushing, and complies with a 10^{-4} infection risk.[33]

Fewtrell and Kay (2007) also attempted to quantify the microbial risk with respect to Campylobacter spp. in toilets flushed with harvested rainwater.[34] They used a desk-based health impact assessment and quantitative microbial risk assessment (QMRA) to examine possible health impacts. A hypothetical case study, using a typical population of 4,000 based on data in England, along with data from literature was used to determine disability-adjusted life years (DALYs) on an annual basis. Risk of infection was through ingestion of aerosols produced as a result of toilet flushing.

Fewtrell and Kay (2007) note that in seeding experiments, conducted by Baker and Jones in 2005, microorganisms can be ejected to a height of at least 83 cm above the seat, as a result of flushing; hypothetically, that is at a height where they could be ingested.[34] Based on a number of assumptions, including volume ejected, volume ingested, frequency of exposure, and concentration and frequency of campylobacter contamination in rainwater supplies, it was estimated that over a year, there would be 0.023 cases of campylobacteriosis resulting in a mean DALY score of 6.8×10^{-5}, for the case study population.[34] Authors note that a number of assumptions were made in order to derive the estimate but, unless the exposure has been drastically underestimated, these estimates should probably be within an acceptable range.

Water Quality Guidelines

While there are guidelines for rainwater use for potable purposes (essentially drinking water guidelines), there do not seem to be consistent guidelines for non-potable use. Lye (2009) notes a lack of agreement regarding water quality guidelines and health-related standards for chemical and microbiological standards of rainwater.[26] For instance, Fewtrell and Kay (2007) write that the U.K. does not have any regulations covering the microbial quality of harvested rainwater for non-potable purposes, but a number of guidelines outline levels of faecal coliforms, *E. coli* or intestinal enterococci that may be appropriately applied for non-potable use.[7] These guidelines are shown in Table 2. The World Health Organization (WHO) has recently updated their *Guidelines for the Safe Use of Wastewater, Excreta and Greywater*.[35] The guideline specifies a methodology using health-based targets to establish appropriate guidelines at a local, regional or country level rather than specific microbial targets.[7]

Table 2 Summary of microbial quality guidelines that could be applicable to the non-potable use of rainwater

Bathing water directive (EC 1975)	WHO (1989) Reuse guidelines*	USEPA (1992) Water reuse	WRAS (1999)	WHO (2003) Recreational water Guidelines**	Bathing water Directive*** (EC 2006)
Faecal coliforms 95% <2,000/100 ml	Faecal coliforms GM ≤1,000/100 ml	E. coli <1/100 ml	Faecal coliforms <10,000/100 ml Intestinal enterococci <100/100 ml	Intestinal enterococci 95th percentile <200/100 ml	E. coli 95th percentile <1,000/100 ml Enterococci 95th percentile <400/100 ml

Adapted from Fewtrell and Kay 2007 [7]
*Category A – irrigation of crops likely to be eaten uncooked
**Marine sites to be classified as good
***Freshwaters
GM= geometric mean
All measurements per 100 ml

Fewtrell and Kay (2007) write that a more logical approach to guidelines would be to employ a health impact assessment approach, whereby specific hazards are identified and impact quantified.[7] Dose response relationships could be used to establish a maximum level of microbial contamination, based on acceptable risk.[7]

The City of Berkeley California has set guidelines for rainwater harvesting that require permits for rain catchment systems, based on volume.[36] They have determined that small-scale rainwater harvesting (less than 100 gallons) can be safely installed and utilized without oversight from the city, provided they meet guideline standards, as presented in Table 3 and below[36]:

1. Rain barrels shall be sited at grade on a sound and level surface at or near gutter downspouts.
2. Water collected shall be used for irrigation only.
3. Rain barrel openings shall be screened with a corrosion resistant metallic fine mesh (.05 inch x .05 inch) to prevent mosquitoes from entering.
4. Gutters serving rain barrels shall be screened with an approved leaf guard or maximum ½" to ¼" minimum corrosion resistant metallic hardware fabric
5. Large openings in the barrels shall be securely fastened to prevent accidental drowning.
6. No pumps, connections to domestic water or interior use are permitted.
7. Rain barrels shall be located a minimum of 3 feet from the property line.
8. Overflow or discharge from rain barrels may not discharge across the public right-of-way or onto adjacent property, or in any way create a nuisance, as per 2010 CPC Section 1101.1.or current edition of the CPC.
9. Collection vessel(s) for each existing downspout shall not exceed 100 gallons in the aggregate for each downspout.
10. Rain barrels and gutters shall be cleaned annually.
11. Rainwater from no-permit systems is not required to be treated prior to use.
12. The system shall be used and maintained in a manner that does not cause a public nuisance and may be subject to inspection and/or enforcement action as a result of a complaint.

Table 3 City of Berkeley, California Environmental Health Requirements: *Minimum Water Quality Guidelines and Treatment Options for Rainwater Reuse*

Use	Minimum Water Quality Guidelines (cfu/100 mL)*	Required treatment options
Non-potable indoor uses: toilet flushing laundry	Total coliforms < 500 Faecal coliforms < 100	Prefiltration: first flush diverter and Cartridge Filtration: 5 micron sediment filter and Disinfection – chlorination with household bleach or UV disinfection
Non-potable outdoor use: Sprinklers, HVAC, car washing	Total coliforms < 500 Faecal coliforms < 100	Prefiltration: first flush diverter and Cartridge Filtration: 5 micron sediment filter and Disinfection – chlorination with household bleach or UV disinfection
Outdoor uses: sub-surface irrigation	No treatment required	Filter as required for use per manufactures equipment specification
Rain barrels under 100 gal	No treatment required	

adapted from City of Berkeley. *Guidelines for Rainwater Harvesting* [36]
*cfu = colony forming units

The guidelines presented above are typical, in that indoor use and above ground spraying of harvested rainwater require treatment (filtration and disinfection), whereas sub-surface irrigation, with less potential for exposure, generally does not require treatment.

Monitoring

Maintenance of the rainwater harvesting catchment, storage, and distribution system can play an important role in the microbiological quality of stored rainwater.[2,3,6,37] Both Lévesque et al. (2008) and Simmons et al. (2008) observed that only a limited number of users clean their reservoirs on a regular basis.[6,37] The Lévesque et al. (2008) study also found that reservoir water quality was significantly related to the frequency at which the reservoir was emptied and cleaned.[37] Simmons et al. (2008) reported that previous studies show only 35 percent of New Zealand households had ever cleaned their water storage tanks and concluded that conditions in rainwater reservoirs, not undergoing regular cleaning, may support proliferation of Legionella in biofilms.[6] Also Schets et al. (2010) noted the potential to form biofilm in reservoirs (tanks) that protect and support pathogenic microorganisms may create public health problems.[3]

As an example of monitoring guidelines, Table 4 presents the City of Berkeley minimum guidelines on testing, inspection, and maintenance of systems used for rainwater reuse. Unless otherwise specified, responsibility is on the property owner to ensure maintenance.

Table 4 Minimum rainwater source testing, inspection, and maintenance frequency adapted from City of Berkeley, *Guidelines for Rainwater Harvesting* [36]

Description	Minimum Frequency
Inspect and clean filter and screens, and replace (if necessary)	Every 3 months
Inspect and verify that disinfection filters and water quality treatment devices and systems are operational and maintaining minimum water quality requirements as determined by Environmental Health.	In accordance with manufacturer's specifications but no less than every 3 months
Inspect and clear debris from gutters, downspouts and roof washers	Every 6 months
Inspect and clear debris from roof or other above-ground collection surface	Every 6 months
Remove tree branches and vegetation overhanging roof or other above-ground collection surfaces	As needed
Inspect pumps, valves, and pressure tanks and verify operation	After initial installation and every 12 months thereafter
Clear debris for and inspect cistern tanks, locking devises, and verify operation	After initial installation and every 12 months thereafter
Inspect caution labels, signage and pipe marking	After initial installation and every 12 months thereafter
Cross-connection test (Dual Plumbing)	After initial installation and every 12 months thereafter

EnHealth (2004), Rodrigo et al. (2008), and WHO (2011) also provide general guidance for maintenance.[2,5,38] EnHealth (2004) mentions an inspection schedule every 2-3 years and cleaning when there is a high sediment build up. Higher levels of sediments in tanks can provide nutrients for microbes to survive and proliferate.[2,38] Some guidance also calls for maintaining and inspecting the catchment area and gutters every 6 months.[39] Catchment area should also be monitored for overhanging branches over the catchment area, since they may harbour insects, decaying matter or debris and allow for small animals and birds to contaminate the surface with faecal matter; possibly affecting the quality of harvested rainwater.[38]

Conclusions and Recommendations from Literature

The type and extent of microbial contamination is dependent on local conditions and weather patterns, making it difficult to predict. Also, when looking at the microbiological quality of roof-harvested rainwater, faecal indicators can provide a poor correlation to potential pathogens.[40] The authors suggest that faecal indicators may not be adequate to assess the microbiological quality of rainwater and consequent health risk. Alternatively, culture-based methods can be laborious and costly and can underestimate bacterial number, due to injured or stressed cells.[27] Where risk information is provided in literature, particularly for non-potable use, there are usually a number of assumptions concerning exposure. More testing will need to be done to quantify actual health risk posed by using harvested rainwater for non-potable uses.[29]

In general, a risk assessment that takes into consideration the design, construction, and installation of the rainwater harvesting system is recommended by the WHO, since the quality of collected rainwater may be affected by the catchment material, piping system, and storage tank material. Also, sanitary inspections should be the focus of operational monitoring; the system should be managed and maintained in a manner that reduces levels of microorganisms, dissolved chemicals, and sediments. This should not only include checking the cleanliness of the catchment area and storage but also the physical quality of rainwater (turbidity, colour, and smell).[5]

This information is echoed in other studies. Schets et al. (2010) recommends that health risks may be reduced by regular cleaning of the collection, storage, and distribution system, but field intervention studies are required to assess efficacy.[3] Suggested measures are: prevent animals from direct access to tanks; regular cleaning of the catchment area, including gutters, and store in well isolated tanks to control temperature of the rainwater; clean and disinfect reservoirs and distribution system on a regular basis to prevent biofilm formation and growth of bacteria, such as Aeromonas and Legionella. Screens and leaf control devices have been recommended to prevent plant and other materials, insects or animals from entering the tank and to reduce the amount of debris and sediment that can provide nutrients for microorganisms.[2]

A first flush diverter is also recommended to reduce the amount of contamination. One study by Gardiner et al. (2004), on the effectiveness of rainwater first flush devices as described in Rodrigo et al. (2008), reports that use of the first flush device resulted in 9 – 62% reduction in bacterial load.[2] However, the majority (55%) of the rainwater tank samples still failed to meet the Australian drinking water guidelines for microbial contaminants.[2] Most of the guidelines reviewed dealt specifically with potable uses of rainwater, with testing and monitoring written to meet drinking water quality standards.

With an increase in popularity of rainwater harvesting, undoubtedly more testing and guidelines will be developed to ensure quality and safety for various uses. Currently, there are no consistent standards for harvested rainwater used for non-potable purposes. The case studies reviewed in this document show there is a potential for exposure to pathogens and to become infected, although quantifying risk is difficult. Standards may reflect volume of rainwater collected, use (and thus potential exposure), or both. Where there is a potential to ingest or inhale rainwater, guidelines generally require treatment via filtration and disinfection. Also, potentially exposed populations should be considered, since the elderly, young or immunocompromised may be more vulnerable and at greater risk. Lye (2009) notes that with large-scale integration of rainwater catchment systems, governmental and legal considerations need to be addressed, with users assuming more of the legal liabilities for ownership, operation, and maintenance of these systems.[26]

Acknowledgements

We would like to thank Randy Ash, Shelley Beaudet, Prabjit Barn, Tom Kosatsky, Lynn McGee, Mona Shum, Michael Wu, and Marc Zubel for their valuable input and review of the draft document and Michele Wiens for her library assistance.

References

1. Karim MR. Microbial contamination and aassociated health burden of rainwater harvesting in Bangladesh. Water Sci Technol. 2010 2010;61(8):2129-35.
2. Rodrigo S, Leder K, Sinclair M. Quality of stored rainwater used for drinking in metropolitan South Australia. Research Report. Victoria, Australia: Monash University, Dept of Epidemiology and Preventative Medicine; 2009 Oct. Report No.: 84.
3. Schets FM, Italiaander R, van den Berg HHJL, De Roda Husman AM. Rainwater harvesting:quality assessment and utilization in The Netherlands. J Water Health. 2010:224-35.
4. Sinclair M, Leder K, Chapman H. Public health aspects of rainwater tanks in urban Australia. Occational Paper Adelaide SA, Australia: Cooperative Research Centre for Water Quality and Treatment; 2005.
5. World Health Organization. Rainwater harvesting Geneva, Switzerland: WHO; 2011 [cited 2011 Aug 11]: Available from: http://www.who.int/water_sanitation_health/gdwqrevision/rainwaterharv/en/index.html.
6. Simmons G, Jury S, Thornley C, Harte D, Mohiuddin J, Taylor M. A Legionnaires' disease outbreak: a water blaster and roof-collected rainwater systems. Water Res. 2008 Mar;42(6-7):1449-58.
7. Fewtrell L, Kay D. Microbial quality of rainwater supplies in developed countries: a review. Urban Water J. 2007 Dec;4(4):253-60.
8. Sazakli E, Alexopoulos A, Leotsinidis M. Rainwater harvesting, quality assessment and utilization in Kefalonia Island, Greece. Water Res. 2007;41(9):2039-47.
9. Evans C, Coombes P, Dunstan R, Harrison T. Identifying the major influences on the microbial composition of roof harvested rainwater and the implications for water quality. Water Sci Technol. 2007;55(4):245-53.
10. Pub Med Health. Legionnaire's disease. ADAM Medical Encyclopedia [serial on the Internet]. Bethesda, MD: U.S. National Library of Medicine, National Institutes of Health, National Center for Biotechnology Information; 2010: Available from: http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0001641.
11. Chapman H, Cartwright T, Huston R, O'Toole J. Water quality and health risks from urban rainwater tanks. Salisbury SA, Australia: Cooperative Research Centre for Water Quality and Treatment; 2008. Report No.: 42. Available from: http://www.ctahr.hawaii.edu/hawaiirain/Library/papers/Non-conference%20papers/report42_WQ_health_risks_rainwater.pdf.

12. Health Canada. 4.0 Significance of E. coli in drinking water Ottawa, ON: Health Canada; 2009: Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/escherichia_coli/significance-importance-eng.php.
13. British Columbia Centre for Disease Control. Camylobacter Infection. Healthlink BC [serial on the Internet]. Vancouver, BC: CDC; 2006 [cited 2011 Mar 10]: Available from: http://www.healthlinkbc.ca/healthfiles/hfile58.stm.
14. Canadian Food Inspection Agency. Food safety facts on Campylobacter Ottawa, ON: CFIA; 2010: Available from: http://www.inspection.gc.ca/english/fssa/concen/cause/campye.shtml.
15. U.S. Centers for Disease Control and Prevention. Parasites - Giardia epidemiology & risk factors Atlanta, GA: CDC; 2011: Available from: http://www.cdc.gov/parasites/giardia/epi.html.
16. Birks R, Colbourne J, Hills S, Hobson R. Microbiological water quality in a large in-building, water recycling facility. Water Sci Technol. 2004;50(2):165-72.
17. U.S. Environmental Protection Agency. Aeromonas: Human health criteria document. Washington, DC: EPA; 2006 Mar. Available from: http://water.epa.gov/action/advisories/drinking/upload/2009_02_03_criteria_humanhealth_microbial_aeromonas-200603.pdf.
18. Simmons G, Hope V, Lewis G, Whitmore J, Gao W. Contamination of potable roof-collected rainwater in Auckland, New Zealand Water Res. 2001 Apr;35(6):1518-24.
19. Health Canada. Salmonella prevention Ottawa, ON: Health Canada; 2011 [cited 2011 Mar 17]: Available from: http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/food-aliment/salmonella-eng.php.
20. Hrudey S, Payment P, Huck PM, Gillham RW, Hrudey EJ. A fatal waterborne disease epidemic in Walkerton, Ontario: comparison with other waterborne outbreaks in the developed world. Water Sci Technol. 2003;47(3):7-14.
21. Canadian Food Inspection Agency. Salmonella food safety facts. Preventing foodborne illness Ottawa, ON: CFIA; 2009: Available from: http://www.inspection.gc.ca/english/fssa/concen/cause/salmonellae.shtml.
22. U.S. Centers for Disease Control and Prevention. Parasites - Cryptosporidium (also known as "crypto") Atllanta, GA: CDC; 2011 [cited 2011 Aug 22]: Available from: http://www.cdc.gov/parasites/crypto/.
23. Adeniyi IF, Olabanji IO. The physico-chemical and bacteriological quality of rainwater collected over different roofing materials in Ile-Ife, southwestern Nigeria. Chem Ecol. 2005;21(3):149-66.
24. Spinks J, Phillips S, Robinson P, Van Buynder P. Bushfires and tank rainwater quality: a cause for concern? J Water Health. 2006 Mar;4(1):21-8.
25. Lye D. Rooftop runoff as a source of contamination: a review. Sci Total Environ. 2009 Oct 15;407(21):5429-34.
26. Lye D. Should we be concerned about microorganisms in rainwater collected from rooftop materials? Geneva, Switzerland: International Rainwater Harvesting Alliance; 2009. Available from: http://www.irha-h2o.org/?wpfb_dl=62.
27. Ahmed W, Vieritz A, Goonetilleke A, Gardner T. Health risk from the use of roof-harvested rainwater in Southeast Queensland, Australia, as potable or nonpotable water, determined using quantitative microbial risk assessment. Appl Environ Microbiol. 2010 Nov;76(22):7382-91. Epub 2010 Sep 17.
28. Palmore TN, Stock F, White M, Bordner M, Michelin A, Bennett JE, et al. A cluster of cases of nosocomial Legionnaires disease linked to a contaminated hospital decorative water fountain. Infect Control Hosp Epidemiol. 2009;30(8):764-8.

29. Schets FM, van den Berg HHJL, Lodder WL, Docters van Leeuwen AE, in't Veld S, De Roda Husman AM. [De microbiologische kwaliteit van hemelwater toegepast voor toiletspoeling, schoonmaken en tuinsproeien]. The microbiological quality of rainwater used for toilet flushing, cleaning and watering the garden. Bilthoven, The Netherlands: RIVM, National Institute for Public Health and the Environment; 2005 Report No.: 703719009. Available from: http://rivm.nl/bibliotheek/rapporten/703719009.html.
30. Schets FM, Italiaander R, van den Berg HHJL, de Roda Husman AM. [De invloed van weersomstandigheden op de microbiologische kwaliteit van hemelwater toegepast voor toiletspoeling en schoonmaken]. Bilthoven, The Netherlands: RIVM, National Institute for Public Health and the Environment; 2007. Available from: http://www.rivm.nl/bibliotheek/rapporten/703719017.html.
31. Albrechtsen H-J. Microbiological investigations of rainwater and graywater collected for toilet flushing. Water Sci Technol. 2002;46(6-7):311-6.
32. Capital Regional District Water Services. Cross connection control FAQ. Victoria, BC: CRD; 2011; Available from: http://www.crd.bc.ca/water/crossconnection/faq.htm.
33. Oesterholt F, Martijnse G, Mederna G, van der Kooij D. Health risk assessment of non-potable domestic water supplies in the Netherlands. J Water Supply Res Technol. 2007 May 2007;56(3):171-9.
34. Fewtrell L, Kay D. Quantitative microbial risk assessment with respect to Campylobacter spp. in toilets flushed with harvested rainwater. Water Environ J. 2007;21(4):275-80.
35. World Health Organisation. Guidelines for the safe use of wastewater, excreta and greywater. Geneva, Switzerland: WHO; 2006.
36. City of Berkeley. Guidelines for rainwater harvesting. Berkeley, CA: Planning and Development Department, Energy and Sustainable Development & Building and Safety Division; 2010. Available from: http://www.ci.berkeley.ca.us/uploadedFiles/Planning_and_Development/Level_3_-_Energy_and_Sustainable_Development/rainwater.pdf.
37. Lévesque B, Pereg D, Watkinson E, Maguire JS, Bissonnette L, Gingras S, et al. Assessment of microbiological quality of drinking water from household tanks in Bermuda. Can J Microbiol. 2008;54(6):495-500.
38. EnHealth. Guidance on use of rainwater tanks. Canberra ACT, Australia: Australian Government Department of Health and Ageing; 2004. Available from: http://www.dhs.vic.gov.au/nphp/enhealth/council/pubs/pdf/rainwater_tanks.pdf.
39. State Government Victoria. Rainwater use in and around the home Melbourne, Australia: Department of Sustainability and Environment, and Department of Human Services; 2006 Dec. Available from: http://www.pic.vic.gov.au/resources/documents/DSE0603.pdf.
40. Ahmed W, Huygens F, Goonetilleke A, Gardner T. Real-time PCR detection of pathogenic microorganisms in roof-harvested rainwater in southeast Queensland, Australia. Appl Environ Microbiol. 2008 Sept;74(17):5490-6.