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Wind, rain and bacteria: The effect of weather on the microbial composition of roof-harvested rainwater

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ABSTRACT

The microbiological and chemical quality of tank-stored rainwater is impacted directly by roof catchment and subsequent run-off contamination, via direct depositions by birds and small mammals, decay of accumulated organic debris, and atmospheric deposition of airborne micro-organisms and chemical pollutants. Previous literature reports on roof water quality have given little consideration to the relative significance of airborne micro-organisms. This study involved analyses of direct roof run-off at an urban housing development in Newcastle, on the east coast of Australia. A total of 77 samples were collected during 11 separate rainfall events, and microbial counts and mean concentrations of several ionic contaminants were matched to climatic data corresponding to each of the monitored events. Conditions both antecedent to, and those prevailing during each event, were examined to investigate the influence of certain meteorological parameters on the bacterial composition of the roof water and indirectly assess the relative contribution of airborne micro-organisms to the total bacterial load. Results indicated that airborne micro-organisms represented a significant contribution to the bacterial load of roof water at this site, and that the overall contaminant load was influenced by wind velocities, while the profile (composition) of the load varied with wind direction. The implications of these findings to the issues of tank water quality and health risk analysis, appropriate usage and system design are discussed.

1. Introduction

In Australia, ongoing drought conditions in catchment areas and the escalating demand of growing populations have led to the imposition of restrictions on domestic water use in many urban centres. As a potential solution, the implementation of rainwater storage tanks on domestic allotments as a supplement to mains water offers a number of benefits including reductions in: demand on municipal water supplies, the cost of infrastructure, and the environmental impact of stormwater discharge. Nonetheless, it is apparent that due to limited understanding, and the existence of conflicting reports within the literature, the widespread application of rainwater tanks is somewhat impeded by the issues of water quality and perceived health risk.

A number of studies reviewed by Gould (1999) and Lye (2002) have identified various pathogens including *Salmonella*, *Shigella*, *Vibrio*, *Clostridium*, *Legionella*, *Campylobacter*, *Cryptosporidium* and *Giardia* spp. in samples taken from rainwater tanks, while others have reported that roof-harvested and tank-stored rainwater was of acceptable quality for drinking and cooking purposes (Dillaha and Zolan, 1985), and presented no increased risk of gastro-intestinal illness on consumption when compared with chlorinated and filtered public mains water (Heyworth, 2001). In general, a clear consensus on the quality and health risk associated with roof-collected rainwater has not been reached.

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Recently, evidence of the operation of a 'treatment train' has emerged (Coombes et al., 2000), whereby improvements in the water quality were observed to occur throughout the collection system. Spinks et al. (2003) examined the components of rainwater harvesting systems and the factors contributing to the water quality, highlighting gaps in our process understanding, particularly those occurring within the tank. Since processes within the tank would be affected by the nature and amount of contamination entering the tank, it is appropriate that this understanding begin with the composition of roof run-off and the factors influencing this composition.

From a microbiological perspective, two separate modes of contamination of the roof catchment are likely: either via the direct activities of insects, birds and small mammals, or by atmospheric deposition of environmental organisms. Major emphasis has been focussed on the former, and the possible introduction of pathogenic organisms to the storage system through faecal contamination of the catchment surface, insect breeding, or the decay of dead organisms and other organic debris. Conversely, reports on roof water quality have given little direct consideration to airborne micro-organisms.

Numerous studies of the chemical composition of urban rainwater and roof run-off (Bridgman, 1992; Bucheli et al., 1998; Forster, 1998, 1999; Garnaud et al., 1999; Loye-Pilot and Morelli, 1988; Willey et al., 1988; Zhong et al., 2001) have demonstrated relationships between concentrations of chemical contaminants and proximity to contaminant sources (emissions), weather patterns, and atmospheric transport and deposition. Aerobiological studies, reviewed by Lighthart (2000) and Jones and Harrison (2004), have repeatedly demonstrated seasonal and meteorological influences on atmospheric concentrations of bacteria and fungal spores, which have been correlated for certain species, with the incidence of allergic and infectious outbreak (Brouqui et al., 2004; Corden and Millington, 2001; Hawker et al., 1998; Tissot-Dupont et al., 2004). Nonetheless, the potential significance of similar processes to the bacterial composition of roof run-off has not been widely explored in the published literature.

In this context, the relative contributions of the two modes of contamination to the bacterial load of roof water should be considered. If atmospheric deposition is significant, variations in the composition from one rain event to the next would likely reflect the influence of weather. If the direct activity of animals is the major contributor, the influence of weather should be less apparent. Previous studies of the bacterial quality of roof run-off have focussed primarily on comparison of roof types and/or site environments (Uba and Aghogho, 2000; Yaziz et al., 1989). Yaziz et al. (1989) reported a positive relationship between heterotrophic plate counts (HPCs) and duration of the antecedent dry period, and Dillaha and Zolan (1985) alluded to seasonal improvements in the bacteriological quality of roof water, related to the volume and frequency of precipitation. Beyond these examples, little analytical consideration has been given to associations between the bacterial composition of roof run-off and specific climatic variables.

The report presented here examines data derived from 11 separate rainfall events, collected as part of the 'Figtree place' water sensitive urban re-development project (Coombes, 2002), conducted in the city of Newcastle, on the east coast of Australia. Multiple sequential roof run-off samples were analysed, and climatic data for the corresponding period matched with microbial counts and measured concentrations of ionic pollutants. In the context of the issues outlined above, the objectives were: to provide a preliminary examination of the influence of weather patterns on the bacterial loading of roof-harvested rainwater in an urban setting; to investigate whether analysis of roof run-off can reveal fluctuations in the bacterial composition, correlated with specific meteorological parameters; and indirectly assess the relative contribution of airborne micro-organisms to the total bacterial load.

2. Materials and methods

2.1. *Site location and roof catchment details*

The 'Figtree Place' housing re-development is located in an inner city suburb of Newcastle, on the east coast of Australia, approximately 160 km north of Sydney. The site, 3 km from the coast, is positioned 100 m from a major arterial road and is adjacent to a city bus depot. Two busy commercial centres are located within close proximity to the North and East, while Newcastle's major industrial precinct and shipping port are found NE of the site. The catchment surface of the multi-unit allotment comprises a Colourbond^{TM} roof and gutter system with combined area of 340 m^2, consisting of both north and south facing panels. The roof area is free of overhanging trees.

2.2. *Sample collection and storage*

Samples were harvested directly from the roof catchment down-pipe system, using an automated refrigerated water quality sampler, with run-off collected continuously throughout 11 separate storm events from March 1999 to January 2001. The auto-sampler temperature was set at 4 °C, and all samples were maintained in storage at this temperature prior to analysis. Elemental analyses were carried out in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 1995), and conducted within 14 days of sample collection. Microbial analyses were commenced within 24 h of each rain event.

2.3. *Chemical analysis*

All samples were analysed for the inorganic ions Cl^-, NO_3^-, SO_4^{2-}, Ca^{2+} and Na^+, all of which are significant to water quality, with guideline values assigned in the Australian Drinking Water Guidelines (ADWG). From a source perspective Ca^{2+} is prominent in soil and construction materials, while Cl^-, Na^+ and SO_4^{2-} are principle components of sea salt. SO_4^{2-} and NO_3^- together represent the major ionic derivatives of industrial and traffic emissions. Ion concentrations were determined using an ion chromatograph.

2.4. Microbial analysis

All samples were examined for HPC, total coliform, thermotolerant (faecal) coliform, and *Pseudomonas* spp. counts, using the Millipore filtration system. Sample aliquots were filtered and plated onto either HPC, Pseudomonas selective, or m-coli media as appropriate, and incubated as per the manufacturer's instructions. Coliform counts provide a measure of possible faecal contamination, and HPC a measure of overall bacterial load while the inclusion of *Pseudomonas*, a genus of widespread environmental organisms, was designed to allow fluctuations in a single group of organisms to be monitored in comparison to both climatic variables and overall bacterial load.

2.5. Climatic data

The auto-sampler recorded both time and cumulative rainfall depth details for successive samples collected throughout the course of each rain event, and from this data both average and peak rainfall intensities were calculated and recorded along with the wind speed and direction. For the dry period antecedent to each monitored rain event, the duration; average, maximum and minimum temperatures; average relative humidity; average wind speed; and predominant wind direction, were all determined.

3. Results

In total, 11 separate rainfall events were monitored. The wind directions varied between events with the antecedent winds characterized as either north-westerly (sector A) or south-easterly (sector B) and winds prevailing during rain events as either northerly (sector C) or southerly (sector D), as summarized in Fig. 1. The winds antecedent to each rain event are characterized by direction and average velocities in Table 1, together with their corresponding rainfall data. Six of the 11 antecedent dry intervals were found to be dominated by wind regimes from sector A, while the remaining five were dominated by winds from sector B. In the case of storm winds (those prevailing during the rainfall events), five were found to be from sector C and six from sector D. Dry interval winds from sector A were found to be stronger on average (3.52 m/s) than those from sector B (2.01 m/s), while prevailing storm wind velocities were greater on average for sector D (3.47 m/s) compared with 2.16 m/s for sector C. Overall mean wind velocities were 2.83 m/s for antecedent dry intervals and 2.87 m/s for prevailing storm winds.

Average rainfall intensities ranged from 0.93 to 15 mm/h with four of the five highest values belonging to storms from sector C. The largest fall recorded was 44.9 mm (event #2) while all other events fell within the range 0.93–8.29 mm.

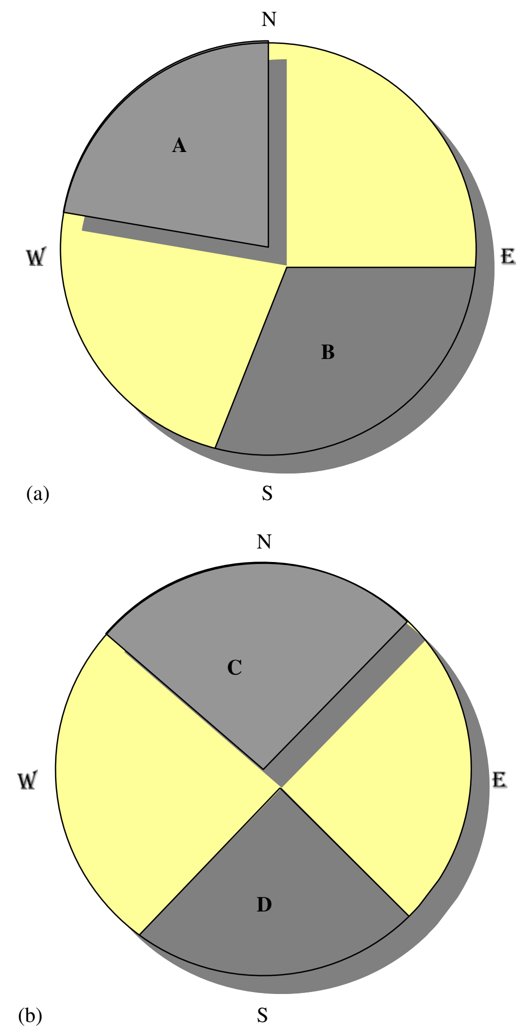

Figure 1 – The sector classification used to categorize the rain events according to: (a) the predominant wind regime during the dry interval antecedent to each event, and (b) the direction of the storm winds prevailing during each event.

3.1. Microbial composition

From the monitored events, a total of 77 samples were collected and analysed. Mean microbial counts for the complete sample set were heterotrophs, 1362 ± 194 cfu/mL; *Pseudomonas* spp. 596 ± 132 cfu/mL; total coliforms $<4 \pm 0.76$ cfu/mL; and faecal coliforms $<2 \pm 0.42$ cfu/mL, indicating that coliforms represent less than 0.3% of the total bacterial count of the collected roof run-off. A zero coliform count was recorded in 17.5% of samples.

Regression analysis of the mean counts for each event revealed a correlation between faecal and total coliforms ($r = 0.86$, $p = 0.0007$), and between HPC and *Pseudomonas* spp. ($r = 0.67$, $p = 0.02$). However, no correlations were observed between coliforms and either HPC or *Pseudomonas* spp., suggesting that throughout the sampling period coliform numbers were under influences independent of those determining other microbial parameters.

Analysis of HPC against meteorological parameters suggested an inverse relationship to average dry interval humidity ($r = -0.61$, $p = 0.04$) and a positive relationship with wind speed, especially during storm events ($r = 0.62$, $p = 0.04$). A similar, albeit weaker trend with these parameters was observed for *Pseudomonas* spp., although dry interval, rather

Table 1 – Summary of wind and rainfall parameters for each of the monitored events, along with mean run-off concentrations of ionic components

Event #	Anteced. dry days	Dry int. wind dir. (sector)[a]	Avge velocity (m/s)	Storm wind dir. (sector)[a]	Velocity (m/s)	Rainfall depth (mm)	Avge intensity (mm/h)	Chloride (mg/L)	Sulphate (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Nitrate (mg/L)
1	1	A[b]	3.5	C[b]	2.2	0.95	5.73	10.3	8.02	6.7	5.4	1.68
2	9	A[b]	2.4	C[b]	1.4	44.9	12.76	5.73	3.57	0	0	0.31
3	8	A	3	C	4.4	7.4	1.7	17.43	10.42	14.62	3.68	2.2
4	0.17	A	6.1	D	6.1	1	15	24.48	4.5	15.12	1.52	0.56
5	4.5	A[b]	2.1	D[b]	3.9	8.29	1.25	7.72	4.34	5.47	1.88	1.06
6	2.37	B[b]	2.6	D[b]	2.5	3.27	4.91	12.53	19.7	5	7.27	2.2
7	1	B	0.8	D	1.4	2.78	0.93	7.62	5.88	5.34	1.78	4.63
8	2	B	1.9	C[b]	1.7	3.38	9.39	40.5	11.72	27.90	4.17	5.73
9	2.17	A[b]	4	D	3.6	4.95	2.52	8.58	3.7	6.02	0.87	1.54
10	2	B	2.9	C	1.1	0.93	5.1	8.9	3.7	6.25	0.92	2.15
11	11	B	1.84	D	3.3	7.05	2.07	29.41	7.94	24.63	3.27	2.56

[a] The wind sector categories refer to the directional origin of predominating dry interval winds and prevailing storm winds as illustrated in Fig. 1.
[b] Indicates winds with a westerly component used to categorize events for total coliform analysis (refer Fig. 5).

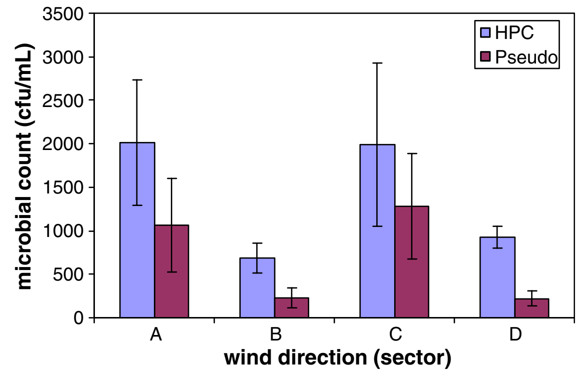

Figure 2 – Mean heterotrophic plate (HPC) and *Pseudomonas* counts for events grouped according to wind direction, as detailed in Fig. 1 and Table 1.

than storm event wind speed, appeared more significant in this case. No such association with any meteorological parameter was apparent for coliform counts.

For examination of the influence of wind direction on bacterial counts, mean counts were compared firstly for events categorized according to the predominant dry interval wind regime (either sector A or B), and secondly according to prevailing storm wind direction (either sector C or D)(refer to Fig. 1). The results are presented in Fig. 2. Mean heterotrophic counts were found to be more than threefold greater, and *Pseudomonas* counts more than fourfold greater, for events where dry interval winds from sector A predominate than for those with sector B regimes. A similar trend emerged for storm winds, where the northerly bias was further strengthened for *Pseudomonas* with a mean count more than 5 times greater for storms from sector C, than for those from sector D. This influence was found to be weaker for heterotrophic counts, where the mean count for northerly storms is less than double that recorded for storms from the south, and variance is significant.

To further investigate the relationship between microbial counts and wind speed, events were separated, irrespective of direction, into those above and those below overall mean wind speed, resulting in five higher velocity and six lower velocity events in both the dry interval and storm wind categories. Calculation of mean heterotrophic and *Pseudomonas* counts for these groupings (Fig. 3) revealed a heterotrophic count almost 2.5 times, and a *Pseudomonas* count more than 3.5 times greater, for events with higher velocity dry interval winds than for those of lower average wind speed. For prevailing storm winds, a similar result was observed for the HPC. However, the influence of wind speed was not apparent for *Pseudomonas* counts, where the mean was found to be $\approx$65% greater for the lower velocity events compared to the higher velocity events, with substantial variance evident in both cases.

The strength of the relationship between HPC and storm wind velocities is graphically illustrated in Figs. 4(a) and (b), where linear regression of HPC versus velocity for sectors C and D reveal r values >0.99 and 0.85, and $p \leqslant 0.0005$ and 0.03, respectively. By contrast, the relationship of wind velocity to

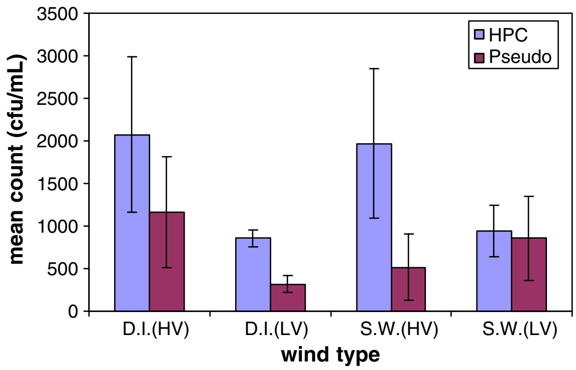

Figure 3 – Mean heterotrophic plate and *Pseudomonas* counts for events grouped as either high velocity (HV = $\geqslant$2.9 m/s) or low velocity (LV$<$2.9 m/s) according to both average dry interval (D.I.) wind velocity and storm wind (S.W.) velocity.

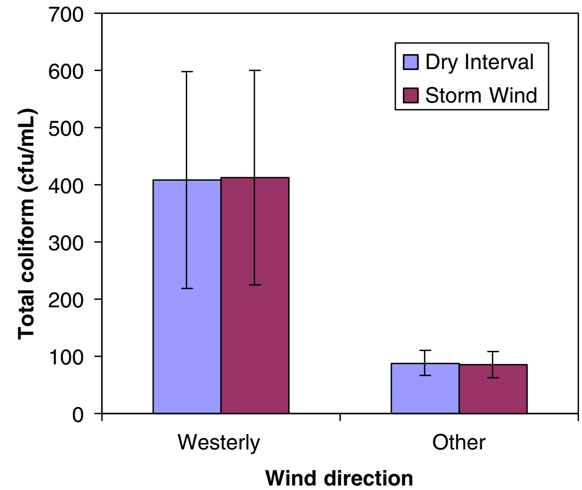

Figure 5 – The impact of both dry interval wind regimes and prevailing storm winds of westerly orientation on total coliform counts. (Events involving winds with a westerly component are identified by (+), in the wind sector columns of Table 1.)

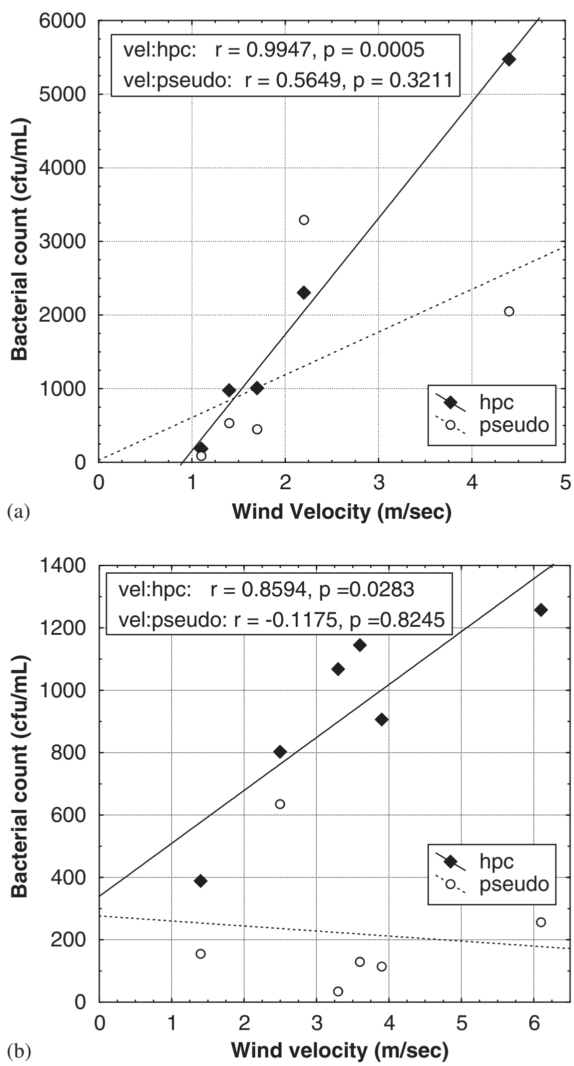

Figure 4 – Correlation of heterotrophic (HPC) and *Pseudomonas* plate counts to storm wind velocity for: (a) Northerly storms (sector C), and (b) southerly storms (sector D).

Pseudomonas count is poor. No strong correlation with velocity was evident for any of the microbial parameters and dry interval winds of either sector A or B.

As noted, no relationship was evident between wind speed and total coliform counts. However, close inspection of mean values in relation to wind direction suggested the existence of a westerly influence on total coliform counts. For both the dry interval, and storm wind cases, winds with a westerly component were found to prevail in five of the 11 rain events (refer Table 1, note b). Whether considering dry interval or storm winds, separation of events on this basis provided a similar result (Fig. 5), with the mean total coliform count for westerly events in both cases, almost fourfold greater than the mean count for all other events.

3.2. *Chemical composition*

Examination of intra-storm variations for each rain event indicated a general trend of declining concentration with increasing rainfall depth for all ionic components monitored. Consequently, all ionic species correlated consistently with one another, although the weakest associations were those between NO_3^- and other species, and the strongest correlation between Na^+ and Cl^-. The average molar ratio of Na^+ to Cl^- was found to be 1.04 ± 0.06, closely approximating the ratio of 1.00 expected where sea salt is the dominant source for both ions. However, based on the formula of Willey et al. (1996), calculations of the sea salt derived SO_4^{2-} (SS-SO_4^{2-}) in each sample indicate that the majority of SO_4^{2-} found in the samples was of non-sea salt (NSS) origin.

Given the observed Na^+ to Cl^- ratio, it was presumed that the bulk of the Cl^- found in the samples was derived from sea salt, and therefore anticipated that Cl^- concentrations would be highest for events where either predominant dry interval winds, or prevailing storm winds, originated from the SE

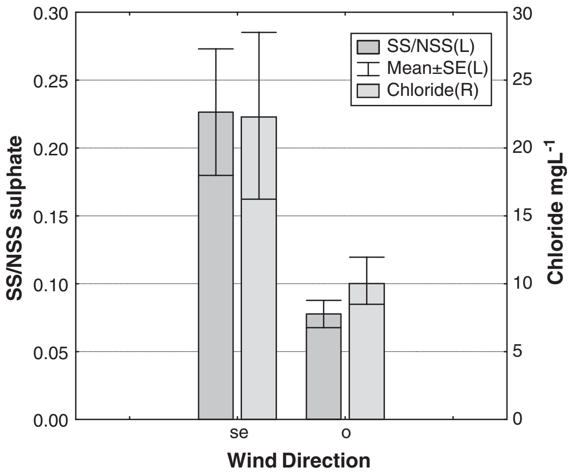

Figure 6 – Comparison of mean chloride concentration, and sea salt:non-sea salt sulphate ratio, for events involving winds of SE origin (se), to those involving winds from other quadrants (o).

quadrant. This criterion was met in five events, for which the mean Cl^- concentration was found to be more than double the mean of all other events (Fig. 6). The same figure reveals that the mean ratio of SS-SO_4^{2-}:NSS-SO_4^{2-} was also threefold greater for these events than for all others, indicating that the relative contribution of sea salt is greatest for events characterized by winds from the SE, and minimal for other wind regimes.

4. Discussion

Clearly, the dominant feature of the Figtree results is the influence of wind on the bacterial load, with trends apparent in relation to both direction and speed. Most importantly, the four bacterial parameters monitored, exhibited differing patterns of response in relation to these two factors or the combined effect of them. This is best illustrated by closer examination of the HPC and *Pseudomonas* results.

Figure 3 indicates that HPCs were determined largely by wind speed irrespective of direction, a conclusion strongly supported by the close correlations to storm wind velocities observed in Figs. 4(a) and (b). Importantly however, the same close correlation with velocity was not observed within the dry interval wind categories. During the monitored dry intervals, most winds of high velocity were from the N-NW (sector A), and these winds appear to be influential on bacterial counts. Thus, differences in counts between sectors A and B events may be more indicative of relative source density than of transport processes. Certainly, *Pseudomonas* counts bear no direct correlation to either dry interval or storm wind velocities, and appear to be under much stronger influence of wind direction. *Pseudomonas* counts were found to be $>60\%$ of HPC on average for events under N-NW wind influence, yet for strong SE storm winds where significant HPCs were also recorded, *Pseudomonas* counts were comparatively low (typically $<10\%$ of HPC). This northerly bias for *Pseudomonas* (clearly evident in Fig. 2) suggests that *Pseudomonas* and other organisms similarly derived from sources N-NW of the site probably contribute significantly to the total bacterial load for winds of this origin while winds from other directions evidently contribute a different mix of organisms to the catchment surface.

The close correlation of HPC to storm wind velocities may also indicate something of the relative significance of wet deposition to the bacterial load of roof water, or that much of the load is uplifted, carried and deposited by storm winds immediately prior to the onset of rain. While high velocity winds throughout the dry intervals would presumably uplift and deliver organisms in the same manner, any correlation to velocity may be confounded by die-off on the catchment surface due to UV exposure or desiccation before the next run-off event. Hence, factors such as site characteristics, interval duration, and UV intensity would all impact on the survival of micro-organisms on the catchment surface and their viability in the run-off.

A similar rationale applies to assessment of the total coliform results (Fig. 5) where a strong westerly wind influence is evident. Again this result probably reflects source location relative to the sampling site. Although coliforms are widely recognized and used as indicators of faecal contamination in water samples, the coliform group of bacteria includes many environmental organisms not necessarily common to the mammalian or avian digestive tract (Prescott et al., 2002). The influence of wind direction on coliform counts may therefore indicate that non-enteric environmental organisms account for much of the observed total coliform count in the 'Figtree Place' roof water.

Although no direct correlation between coliform counts and wind speed emerged for westerly wind events, it should be remembered that inert release and airborne transport of micro-organisms from environmental sources/surfaces is dependent upon a number of variables, including bonding forces, wind shear forces and mechanical disturbances (Jones and Harrison, 2004). As a result, the minimum threshold wind speed required for uplift may vary over time, depending on surface conditions such as moisture content. It is therefore likely that in this study, too few events have been sampled to reveal the nature of any relationship between variable source conditions and wind speed thresholds for airborne transport of soil coliforms. The implication here is that threshold wind speeds are not only important when considering abundance of particular organisms in roof water samples, but also in predicting the likely contributions of different contaminant sources to the microbial profile at a specific location and time.

It is pertinent at this point to put the microbial data into context by considering the overall level of bacterial contamination found in the Figtree place roof water. In general, the mean microbial counts are comparable with contaminant levels found previously in roof water studies (Thomas and Greene, 1993; Uba and Aghogho, 2000; Yaziz et al., 1989) encompassing a range of roof materials including concrete tile, galvanized iron, aluminium and zinc sheeting, and are also consistent with those found in samples taken from roof-fed rainwater tanks (Albrechtsen, 2002; Dillaha and Zolan, 1985; Simmons et al., 2001). Essentially, Figtree place does not represent an abnormal case in terms of run-off quality.

The observed dilution of ionic components of the run-off during the course of each event no doubt reflects the combined effects of both atmospheric 'washout' of aerosols, and the removal of dry deposited material from the catchment surface by the precipitation. Previous studies of temporal variations in the chemical composition of urban rainwater (Kins, 1982; Poissant and Beron, 1994) and roof run-off (Bucheli et al., 1998; Zobrist et al., 2000) during individual events have reported similar patterns of high initial concentrations, declining rapidly to near constant levels in later fractions.

It is possible that the small variations observed in the degree of correlation between ionic components result from differences in the manner in which the total atmospheric concentration of each ionic species is partitioned across the particulate size range, and hence for each, the relative significance of dry versus wet deposition. According to Muller (1982), short-range dry deposition is most significant for particulates $>2.0\,\mu M$ diameter, while wet deposition is more significant for particulates $<2.0\,\mu M$ which, due to extended residence time in the atmosphere, may be subject to longer distance transport from point source emissions. Therefore, the pattern of deposition of each ion in relation to weather may be subject to both the location of sources relative to the collection site, and the mode of deposition.

While wet deposition is likely to be more significant for sulphate, for which the majority of anthropogenic emissions are in the fine particulate range, chloride is known to have a more even distribution of its total atmospheric mass across the particulate size range (Muller, 1982). Thus, both dry and wet depositions are likely to be important under the appropriate circumstances, and the grouping of both dry interval and storm winds when assessing the influence of direction on chloride concentrations in the run-off appears justified in this case by the consistency of the sodium:chloride ratio, and the balance of SS:NSS sulphate, for such a categorization.

It is important to recognize that in the context of this paper, the significance of the chloride data, relative to sodium and sulphate, lay not in the assessment of run-off quality per se, but rather in its implications for our interpretation of the microbiological data. Certainly, manipulation of the data set in the manner applied here lends itself to a degree of subjectivity, and we might therefore question whether apparent variations in microbial counts based on meteorological parameters are not merely analytical or statistical artefacts. However, application of an identical approach to the chemical composition of the run-off has yielded a pattern of ionic concentrations relative to sources and wind directions that satisfy logical expectations, thus validating the observed relationships between microbial counts and weather patterns as real and meaningful.

Clearly, several key findings with significant implications emerged from this study. The negligible coliform counts relative to total bacterial load indicate that faecal contamination represented an extremely minor component of total run-off contamination, and the importance of this to the issues of quality monitoring and health risk analysis, are twofold.

Firstly, if domestically harvested rainwater is used as a supplement to mains water (e.g. for hot water, laundry and toilet flushing), and excluded from use for drinking and cooking purposes, then traditional indicators of enteric pathogens (whose primary threat arises through ingestion) may be of little relevance in assessing tank water quality and health risk. Furthermore, such indicators reveal nothing of the possible presence of environmental organisms of non-faecal origin (the vast majority of the bacterial load), with potential to pose a health risk via other pathways, e.g. external irritation of eyes, ears and skin, or through respiratory ailments arising from aerosols, especially in the bathroom environment. This is not to suggest that the likely health risk due to environmental organisms is substantial, or that the potential risk due to enteric pathogens should be ignored, simply that the full diversity of the bacterial contamination may need to be recognized for thorough assessment of tank water quality.

Secondly, evidence that the bulk of the bacterial contamination of roof water was not due to the random activity of animals, but rather determined largely by weather patterns, points to a future potential for predicting bacterial tank water quality at a given site. Knowledge of the site environment and regional weather patterns may be incorporated into assessment of health risk and determination of appropriate usage at any given locality.

Finally, if airborne environmental organisms are prominent in roof water they are likely to be important to processes occurring within the tank. Such processes may include competitive exclusion of pathogens, biofilm formation, nutrient cycling, and sequestering of trace metals and organic contaminants. In this respect environmental micro-organisms may have beneficial rather than adverse impacts, and their potential role in regulating tank water quality is worthy of further exploration.

5. Conclusions

Several key microbiological conclusions may be drawn from this study:

1. Weather patterns, in conjunction with other factors such as relative source location, can significantly influence the bacterial load of roof run-off.
2. The total bacterial load of roof run-off at this site was largely a function of wind speed, probably due to greater uplift of organisms from sources and arrival of more organisms at the catchment surface per unit time.
3. The profile or composition of the load was source dependent and therefore influenced by wind direction.
4. Sources of faecal coliform had little impact on overall bacterial load at the 'Figtree' site.

In terms of the study objectives, demonstration of the influence of weather patterns on bacterial composition indicates that airborne micro-organisms are significant contributors to the bacterial load of roof, and therefore tank water. Furthermore, this phenomenon has potential future utility and widespread application in prediction and monitoring of bacterial contamination of tank water at any given location.

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