DRY WEATHER SEWAGE SPILLS IMPACTS ON RIVER HEALTH

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Abstract

The Yarra River is considered to be an important environmental and recreational asset by the Melbourne community in Australia. The upper reaches of the Yarra provide water for consumptive use including drinking water for the 4.2 Million people in Melbourne and some agricultural use. The lower Yarra is mainly utilized for recreational purposes and is a focal point for tourism in Melbourne. Water quality of the Yarra River in its lower catchments is relatively poor when compared with the upper reaches due to urbanisation. Faecal coliform levels have been observed to be high in the lower sections of the Yarra River even during dry weather periods. One of the contributors to faecal contamination during dry weather has been identified as dry weather sewer spills due to structural collapses or blockages from tree roots and seepage from septic tanks.

The main aim of this study is to investigate the effect of dry weather sewer spills on river water quality and to estimate the survival rate of microbes with time on pervious and impervious surfaces after a spill. Dry weather spills are retained on the ground surface and then mobilized through surface runoff to drains and waterways following storm events. The number of faecal microbes carried to the waterways will depend on the volume of the spill, magnitude of the storm generating runoff, elapsed time after the spill and the antecedent climate conditions before the storm.

Actual spill data from 2007 were collected from archived information for two catchments in Melbourne. This research draws conclusions by discussing the potential effects on river water quality due to dry weather spills, the impact of rainfall intensity and its potential to mobilize the microbes towards a stormwater drain to be transported to a nearby water course. Overall, the objectives of this study were achieved and the transport of microbes was estimated at different elapsed times depending on the relative humidity after a dry weather spill event, providing its impact on waterways.

Keywords: River health, Dry weather spills, Microbes transported, E.coli, enterococci

1. Introduction

1.1 Impact of sewer spills on waterways

Melbourne Water and EPA Victoria, Australia (Victorian Government 2005) stated that there is significant contribution of pathogens from urban stormwater systems to the waterways. 'Our Water Our Future', (Victorian Government 2005) reported that the basic aim of the Environment Protection Agency (EPA) and Melbourne Water is to secure the sustainable water future for the community. To achieve these goals or targets maintaining public health or the waterway ecosystem, Melbourne Water and EPA Victoria monitors its waterways on a weekly basis (Yarra Watch 2007). Sewer spills and overflows cause significant impact on water bodies and potential risk to human health as this untreated sewage contains harmful pathogens (Pollard et al. 2004). Wet weather sewer spills as well as dry weather sewer spills contribute towards the total load of pollution within waterways.

A study conducted by the Brisbane City Council (Pollard et al 2004) revealed where the impact of a dry weather sewer spill is considerable, and is a higher public health hazard compared with the impact from wet weather sewer overflows. These sewer spills are known to be dominant stressors of ecological health in rivers and watercourses. The above statement highlights the importance of tracing faecal loads in stormwater systems after a spill event.

The current research concentrates on the contribution of faecal contamination from dry weather sewer spills on Yarra River water quality. Dry weather sewer spills in catchments occur due to:

- Sewer blockages due to solidified fat blocks;
- Roots searching for water finding their ways into sewer pipes; and
- Structural sewer collapses and cracks

There have been complimentary studies carried out by other researchers investigating the faecal contamination due to animal dropping wash off, illegal connections of sewer pipes into stormwater drains, poorly maintained septic tanks and wet weather overflows (Victorian Government 2005 and Wong 2006). These types of events are not considered in this research.

The sewage that overflows during a dry weather spill is retained on the land surface and will wash off to the stream during the storm event that followed the blockage. The growth of indicator organisms in water in the waterways or sediments is harmful to human health. Human pathogens contacted in waterways have significant influence as it can spread several diseases such as non-gastrointestinal illnesses, mild gastroenteritis and in some cases fatal diseases. The levels of bacterial indicators after a storm may return to background levels within a day or two, but in the absence of washout or proper amount of dilution, bacteria can stay active for longer periods. The faecal coliforms can survive up to 2 to 3 weeks on grass after sludge deposition depending on several environmental conditions and rainfall (Brown et al 1980). The above authors mentioned that municipal sludge deposition to soils is the most hazardous as it transmits pathogenic bacteria and viruses.

The amount of faecal coliform that will be carried to the stream after a dry weather sewer spill will depend on the magnitude of the storm as well as on antecedent rainfall conditions that determine surface run-off and the weather during the period between the dry weather spill and the wash off event. Minimising dry weather sewer spills is an important aspect of protecting river water quality for recreation and in general.

The primary objective of this study is to estimate the microbial inflow into stormwater drains after a dry weather sewer spill. The paper will present details of the selected of catchments for the study, the dry weather sewage spill data collected, analysis of the data, effects of rainfall intensity on the wash-off of microbes towards stormwater drains and the individual contribution of microbes from selected catchments towards the total pollutants entering waterways.

2. Yarra River Water Quality

The Yarra River in Melbourne, Australia flows across the heart of the Melbourne city and provides water for a number of purposes, including drinking water for Melbourne and its suburbs. The total length of the river is 242 Kilometres from the source. Although the water quality in the upper reaches is excellent it deteriorates as the river approaches the heavily urbanised lower section. The name "Yarra Yarra" means 'ever flowing' in the Wurundjeri Aboriginal language. In addition to water supply, the Yarra catchment supports agriculture, forestry, recreation and tourism. The catchment covers 4078 km^2, includes 24 tributaries and a population of about 2 million people live within its catchment. The lower Yarra region is mainly utilised for recreational purpose and is the focal point for tourism in Melbourne (Victorian Government 2005). The stormwater and drainage system consists of a complex network of underground pipes and pumps series of retarding basins and a number of wetlands constructed recently. According to the Yarra River Action Plan (Victorian Government 2005) and Melbourne Water (2004), the water quality in the lower reaches of the Yarra River is poor.

Unsuitable recreational water quality restricts recreational activities such as swimming, diving and water skiing, boating, fishing and wading. Yarra Watch (2007) categorises the water quality as high, medium, low and not suitable for recreational activities based on the *E.coli* levels. Water quality is defined as:

- High water quality: 200 organisms per 100 mL or lower. These sites are generally considered suitable for all forms of recreational activities.
- Medium water quality: 201 to 1000 organisms per 100 mL. Sites with water quality in this range are considered suitable for boating, but not generally suitable for swimming.
- Low water quality: 1001 to 5000 organisms per 100 mL. Sites with water quality in this range may be used for boating, but they are not suitable for swimming.

- Unsuitable for recreation: Greater than 5000 organisms per 100 mL. Sites with water quality in this range are considered unsuitable for any kind of recreational activities, with greatly increased potential risk to human health.

Haydon (2006) reported that the World Health Organisation (WHO) had identified 3.4 million deaths per year due to waterborne illnesses and diarrhoea was considered to be a prime reason (WHO 2001) with 2.2 million deaths across the world, mostly in the developing world. Recreational water consisting high pathogen concentrations is a threat to human life, as it spreads gastrointestinal diseases and skin infections.

3. Selection of Catchments

The study catchments were selected based on the *E.coli* levels in the Yarra River as well as on the basis of historical dry weather sewer spill data in the main catchment area. The main selection criteria included:

- Typical representation of urban catchments (population densities)
- Urban catchment portrays better picture of different types of wastewater systems such as sewered, unsewered, and combined systems
- Water quality issues
- Land use patterns of these selected catchments give an idea of the urban catchment. Land use pattern reflects the load of microorganisms within the catchment (McCarthy 2008 and Bannerman et al. 1993).

Based on the above criteria following two catchments were chosen for the study.

3.1 Catchment 1

Catchment 1: located 5 km south-east from the city of Melbourne and covers an area of 9.55 km^2. Population within the catchment area as per 2001 census was 54,141. This area is mainly residential and commercial where landscape mainly consists of impervious surface.

3.2 Catchment 2

Catchment 2: located 10 km south east of the City of Melbourne. This is an urban catchment and contains densely populated areas of mainly residential and commercial establishments. This catchment covers 115 km^2 of the eastern suburbs. The entire catchment has a population density of 2000-3000 persons/km^2.

4. Catchment Dry Weather Spill Data

Based on the objectives of the study actual dry weather sewage spill data were collected from archived information to determine the significance of dry weather sewer spills on stormwater quality. The dry weather sewage spill data collection was carried out at South East Water (one of the three retail water authorities in the Melbourne metropolitan area) with the assistance of an affiliated company, Utility Services. Usually, if a dry weather blockage (or sewer collapse) occurs the public will inform the water retail company. However, if the spills occur within a household property the blockages go unrecorded, as it is the responsibility of the owner to get the problem fixed. Dry weather spill data from the catchments' reticulation system were extracted from the South East Water (SEW) database.

The contribution of the two catchments is significant towards the faecal contamination in the Yarra River, as described earlier. *E.coli* levels in the river water within the two selected catchments are significant. The levels of *E.coli* organisms exceeded the primary and secondary limits (Catchment 1: 131 to 52,000 organisms/100mL and catchment 2 913 to 1984 organisms/100mL). It is necessary to check the impact of dry weather sewer spills within these catchments on the waterways. The total number of spills within these catchments throughout year 2007 will assist to isolate the faecal contribution. Actual dry weather spill data from the Catchment 1 and the catchment 2 were obtained from the South East Water's database. Further analysis was carried out to understand the contribution or significance of dry weather spills towards the Yarra River faecal contamination. The analysed actual dry weather sewer spill data is presented in Table 1 below. On the other hand, all the spills inside the household property would have not been recorded as the owner of the property would usually contact the local plumber instead of SEW services to fix the blockages and these spills will go unrecorded.

Table 1 indicates that there had been 80 dry weather sewer spills during the year 2007 in the Catchment 1. The actual spill data indicated that this catchment contributed high pollutant loads towards the Yarra River and also supports the observations from the studies on Yarra Catchment, (Yarra Watch 2007). The occurrences of spill events were more during January 2007 to April 2007 in Catchment 2.

On the other hand, the total numbers of reported dry weather sewer spills within Catchment 2 are 15 and are lower than Catchment 1. The data suggest that contribution of faecal microbes from both catchments is considerable, and they carry a considerable load towards overall microbial pollution levels in the Yarra River.

Table 1: Reported dry weather spills from two catchments during 2007

Month	*Number of spills in each sub-catchment*	
	Catchment 1	*Catchment 2*
January	*15*	*3*
February	*6*	*1*
March	*10*	*1*
April	*9*	*1*
May	*5*	*1*
June	*3*	*4*
July	*9*	*1*
August	*7*	*2*
September	*7*	*-*
October	*5*	*1*
November	*1*	*-*
December	*3*	*-*
Total	*80*	*15*

5 Computations of Microbial Concentrations at Stormwater Drain Inlets

Tavate (2009) developed a prediction model (Equation 1) to estimate microbes (*E.coli* and enterococci) retained on pervious surfaces after a dry weather spill. Microorganisms remaining at a given time on surface after a dry weather sewer spill get washed off with the surface runoff.

$$\text{Microbes} = 10^{27}\ \text{Time}^{-2.5}\ \text{RH}^{-11.5} \qquad (1)$$

where,

Microbes = Concentration of survived microbes after a spill (orgs/100mL);
Time = Elapsed time after a dry weather spill (days);
RH = Average relative humidity during the elapsed time period (%).

Estimated values for E.coli and enterococci were then used with wash-off Equation 2 developed by McCarthy (2008) to predict the amount of microbes at a stormwater drain inlet. This will eventually determine the significance of the spill on stormwater quality. Simple wash-off equation used by McCarthy (2008) was modified for the current study and rainfall was not routed for the estimation of microbes transported towards the stormwater system (Equation 2) for the current study.

$$C_s(t) = P_s(t) * RI^{0.293} \qquad (2)$$

where,

$C_s(t)$ = Concentration of microbes at the stormwater drain inlet (orgs/L)

$P_s(t)$ = Number of microbes present on surface before storm event (orgs/L)

RI = Average rainfall intensity of the storm event (mm/min)

t = Elapsed time after a spill event (days)

5.1 Application of the developed model to selected catchments

Table 2 presents the estimated concentration of E.coli at the stormwater drain inlet using the surface wash-off equation (Equation 2). E.coli values calculated from Equation 1 were used to calculate the microbial concentrations on the surface after a certain elapsed time period following a spill event. It was assumed that the spill size was equivalent to 10L. The concentration of microbes in a 10L spill was calculated and reported in Column 3 of Table 2. 60mm/hr rainfall intensity was used to calculate the concentration of microbes at the stormwater inlet using Equation 2 mimic 1 in 10 years (15 minutes duration) rainfall event over the study region. Table 2 confirms that with 60mm/hr rainfall intensity, irrespective of the antecedent time period, all the available concentrations of microbes get washed off from the location of the spill (i.e. 100% concentration).

Zhang and Farahbakhsh (2007) reported that in raw sewage, the concentration of faecal microbes couldn't exceed the limit of 10^7orgs/100 mL. Different rainfall intensities were further examined with an assumed raw sewage value of 1E+07 organisms/100mL. Average rainfall intensities for Melbourne were extracted from Intensity-Frequency- Duration curves given in Australian Bureau of Meteorology website (www.bom.gov.au).

Different storm durations for a 1 in 1 year ARI storms (different rainfall intensities) were used to calculate per cent contributed to stormwater drain after a spill event (Equation 2 and Table 3). The wash-off rate of microorganisms declines with the rainfall intensities and is equal to $RI^{0.293}$ (47mm/hr gives 93% wash-off and 5mm/hr provides with 48% wash-off). In addition, the wash-off percentage was calculated for different rainfall intensities (Table 3). Figure 1 and Table 4 depict the relationship between the storm event and the percentage of microbes transported to the drain. Above analysis demonstrates the relationship of microbes transported from the location of the sewer spill to the stormwater drain and it's variation with the rainfall intensity of the storm event.

The historical data represented 80 and 15 spills in year 2007 from the Prahran Main Drain and the Gardiners Creek catchments respectively. It was important to estimate the contribution from these spills into the Yarra River due to subsequent rain. The model (Equation 1) developed by Tavate (2009) was applied to the spill data from these catchments. The sensitivity of relative humidity, a parameter in the model, on predicting microbial survival rate was investigated. Tavate (2009) reported that the estimated values of microbial survival with elapsed time for relative humidity at 60%, 70% and 80% has an order of magnitude difference in the concentration of microbes.

Table 2: Application of surface washoff equation on the predicted E.coli values by exponential decay equation

Time (days)	*Concentration of E.coli (Orgs/100mL)*	*Concentration of E.coli organisms in a 10L spill (Orgs/10L)*	*Concentration at stormwater inlet Cs(t) Orgs/10L*	*% Contribution to the drain*
1	*5.E+06*	*5.E+08*	*5.E+08*	*100*
2	*4.E+05*	*4.E+07*	*4.E+07*	*100*
3	*9.E+04*	*9.E+06*	*9.E+06*	*100*
4	*6.E+04*	*6.E+06*	*6.E+06*	*100*
5	*3.E+04*	*3.E+06*	*3.E+06*	*100*
6	*2.E+04*	*2.E+06*	*2.E+06*	*100*
7	*1.E+04*	*1.E+06*	*1.E+06*	*100*
8	*1.E+04*	*1.E+06*	*1.E+06*	*100*
9	*9.E+03*	*9.E+05*	*9.E+05*	*100*
10	*7.E+03*	*7.E+05*	*7.E+05*	*100*
11	*5.E+03*	*5.E+05*	*5.E+05*	*100*
12	*4.E+03*	*4.E+05*	*4.E+05*	*100*
13	*3.E+03*	*3.E+05*	*3.E+05*	*100*
14	*2.E+03*	*2.E+05*	*2.E+05*	*100*
15	*2.E+03*	*2.E+05*	*2.E+05*	*100*

5.2 Estimation of faecal loads from selected catchments

As mentioned earlier, Catchment 1 and Catchment 2 in 2007 have had 80 and 15 spills respectively. Microbial contributions from these spills to the Yarra River with different elapsed times after a dry weather spill were computed. A 70% RH was used to estimate the amount of microbes for different elapsed times within 15 days in the Yarra catchment which drains both subcatchments to the sea. This RH value was selected as the average RH value based on the historical data gathered from BOM for the Melbourne region. The results obtained by applying Equation 1 to determine the microbial survival rates on each day after the spill, with a relative humidity of 70% are given in Table 5. These values together with Equation 2 were used to calculate the concentrations of microbes transported to the stormwater drain inlet. The concentrations are estimated for different ARI values and storm durations for Melbourne. A raw sewage microbial concentration of $1*10^7$ orgs/100mL was used as the base on the day of the spill to estimate the effect of the storm events on the transportation of the microbes.

Outcomes from the analysis (Figure 2) indicate that considerable amounts of microbial wash-off moved towards the stormwater drains even with storm events of smaller durations. In addition, this analysis shows that the intensity of rainfall has a significant impact on wash-off of microbes from the location of the spill. The above analysis demonstrated in a limited way, the contribution of dry weather sewer spills towards the microbial levels in the waterways for selected catchments.

Table 3: Wash-off of microbes (%) calculated with different rainfall intensities for 1 in 1 year storm (mm/hr) for Melbourne (Raw sewage value = 1E+07 orgs/100mL)

Duration	*Rainfall intensity*	*Cs(t) concentration of microbes at*	*Contribution to*
5	*47*	*9309500*	*93%*
10	*35.8*	*8595862*	*86%*
15	*29.7*	*8138031*	*81%*
20	*25.8*	*7809195*	*78%*
30	*20.8*	*7331524*	*73%*
40	*17.7*	*6992909*	*70%*
50	*15.6*	*6738872*	*67%*
60	*14*	*6528557*	*65%*
90	*10.9*	*6066911*	*61%*
120	*9.09*	*5752557*	*58%*
180	*7.01*	*5330857*	*53%*
240	*5.83*	*5050595*	*51%*
300	*5.05*	*4842460*	*48%*

Table 4: Relationship of rainfall intensity and % of microbes transported to the drain

Rainfall intensity (mm/hr)	*% Contribution of microbes*
>60	*100*
40-60	*90-100*
30-40	*80-90*
20-30	*70-80*
10-20	*60-70*
5-10	*50-60*
<5	*<50*

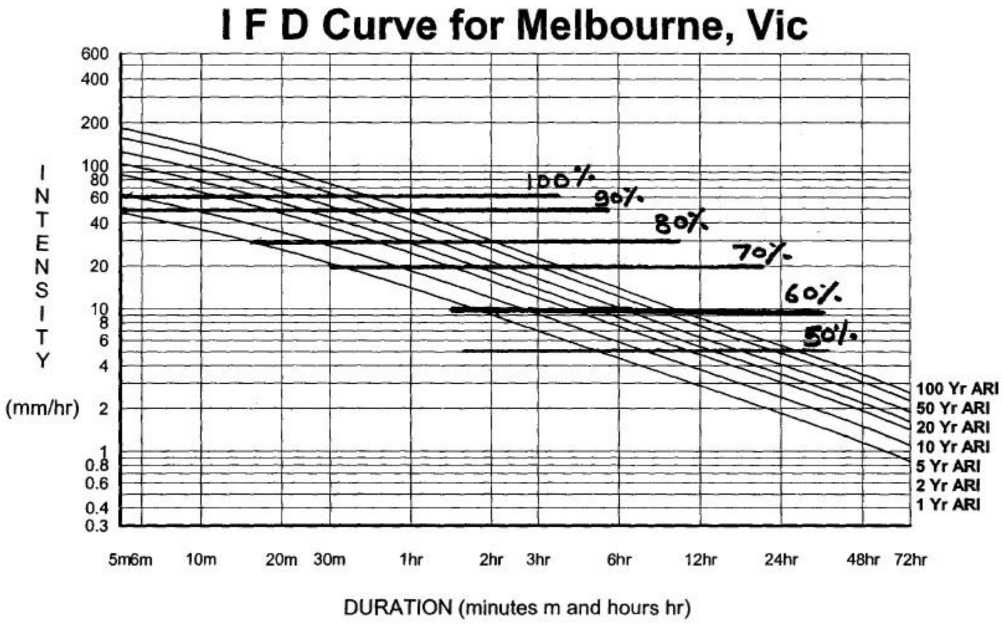
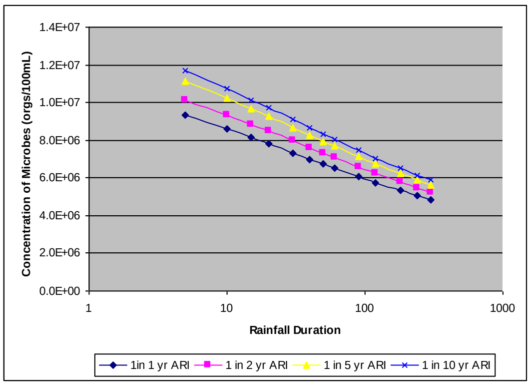
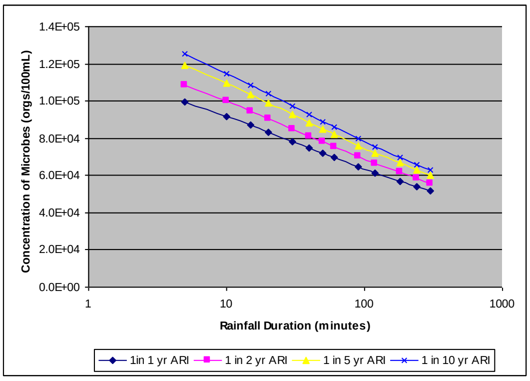


Figure 1: Relationships of storm events and per cent of microbes transported to the drain inlet



(a) Initial day of spill event



(b) Day 1 after a spill

Figure 2: Relationship between the storm event and concentrations of microbes transported towards stormwater drain for different ARI values for Yarra catchment

6. Summary and Conclusion

The research considered actual dry weather sewage spill data throughout year 2007 for the two subcatchments draining to the iconic Yarra River, estimated the % contribution of microbes after a dry weather sewage spill event and the contribution of microbes from selected catchments towards water quality in the waterways.

Table 5: The contribution of microbes at each elapsed time interval for each spill event from a catchment with a rainfall intensity of 47mm/hr and relative humidity 70% (Assume spill volume is 10L)

Time	*Microbial concentrations*	*Time*	*Microbial concentrations*
1	*1.1E+05*	*9*	*1.9E+03*
2	*3.9E+04*	*10*	*1.5E+03*
3	*1.9E+04*	*11*	*1.2E+03*
4	*1.1E+04*	*12*	*9.9E+02*
5	*6.9E+03*	*13*	*8.2E+02*
6	*4.7E+03*	*14*	*6.9E+02*
7	*3.3E+03*	*15*	*6.9E+02*
8	*2.5E+03*		

It has been noted that frequency of dry weather spills is high from catchments. Further analysis showed that these catchments contributed considerable amounts of microbial concentrations through the stormwater system to the Yarra River, polluting it. Relationships were successfully developed between rainfall intensities and wash-off rate of microbes for different storm events. Rainfall intensity above 60mm/hr will wash-off all the microbes present on the surface towards the stormwater drain. If the rainfall intensity is below 60mm/hr the wash-off rate is $RI^{0.293}$* 100%.

Data from these predictive models provide a basis for expanding the application to the full catchment and assist with developing mitigating measures to improve water quality and the ecological health of the Yarra River.

Acknowledgement

Authors would like to thank South East Water, Melbourne Water and the Victorian EPA for funding the project.

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