

Rainfall simulation study of the impact of unsealed roads in Cardinia Shire

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Abstract

Cardinia Shire Council, the City of Casey, and Mornington Peninsula Shire Council, with funding from the EPA Victoria as part of the Victorian Stormwater Action Program (VSAP), undertook an investigation of the impact of unsealed roads on stormwater quality. The aim of the project was to identify ways to minimise the impact of sediment runoff from the unsealed road network on the receiving waters of Western Port Bay and its tributaries by reviewing and investigating best practice road maintenance measures. Various road treatments were trialled to examine how road-surfacing techniques on unsealed roads affect sediment runoff and storm water quality. Rainfall simulation was employed as an effective method to facilitate the rapid completion of the project. This paper reports on the experimental set-up, issues involved in the experimental method, and some of the results on the effectiveness of different road treatments

Keywords: rainfall simulation, road stability, off-site impacts, hydrology, erosion, stormwater.

1 Introduction

Erosion of unsealed road surfaces is known to cause a number of problems of road surface and bank stability and off-road pollution, the latter caused by transport of contaminated sediments and the impact of the increased mass and character of sediment washed from the roads. A number of studies in urban, rural and forested areas have established the nature of the problem and developed models for predicting the likely rates of erosion [1–7].

Despite the significant investment of funds to seal rural roads, many smaller rural roads in Australia are unpaved [8] - 41.6% paved of the 810,641km of road



in Australia. There are obvious financial and environmental benefits in developing road pavement, maintenance, and erosion control strategies that reduce the off-site impact of road erosion.

Cardinia Shire Council, City of Casey and Mornington Peninsula Shire Council, with funding from the EPA Victoria as part of the Victorian Stormwater Action Program (VSAP), undertook an investigation of the impact of unsealed roads on stormwater quality. The aim of the project was to minimise the impact of sediment runoff from the unsealed road network in Cardinia, Casey and Mornington Peninsula municipalities on the receiving waters of Western Port Bay and its tributaries, by reviewing and investigating best practice road maintenance measures.

Several road treatments were trialled to examine how road-surfacing techniques on unsealed roads affect sediment runoff and storm water quality. The large-scale rainfall simulator developed by Riley and Hancock [9] was employed to facilitate the rapid completion of the project. Rainfall simulations are a well-established tool in erosion and hydrology research, although issues of spatial variability and representativeness of simulated rainfall have to be considered [10–15]. There have been many designs (e.g. [16]) and the simulator of Riley and Hancock [9], developed for large-scale studies, is a modification and uses design aspects of earlier simulators. This paper presents details of the rainfall simulation experiment and the hydrological analysis of the data collected. The focus is on the methodology and issues in running the experiment.

2 Method

The experimental site at Boes Rd, between Graydens Rd and Hodgins Rd in Hastings, Victoria, Australia (Fig. 1) involved seven road surface treatments and one control to test the effectiveness of road construction techniques to reduce sediment generation. The treatment section was constructed in series along a 1150m length of unsealed road. The proposed sampling strategy is presented in Figure 2.

The treatments included wet and dry compaction, three different stabilisers, a wearing course, and a 6% cross grade, steeper than the control site (Table 1). The Test plot was a trial to familiarise all participants with the operation of the simulator, construction of plots and collection of data, as well as to collect a reference set of data.

Within each treatment area, two experimental plots (approximately 10m along the road x 2.5m wide, from road crest to gutter) were used to compare the sediment load and water quality of stormwater runoff from each of the road sections. On each plot, three rainfall intensities were simulated. An additional 1 in 50 year storm was conducted on the control site. Water was supplied from a non-potable source and transported to the site by water cart and held in a temporary pool on site. Simulation experiments were to run for 15 minutes, and runoff was recorded in 30-second intervals. Water samples were taken at 30-second intervals.



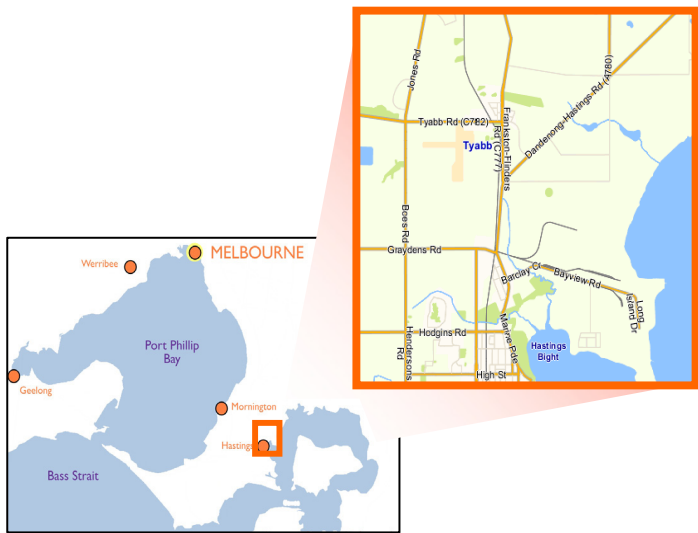


Figure 1: Location map.

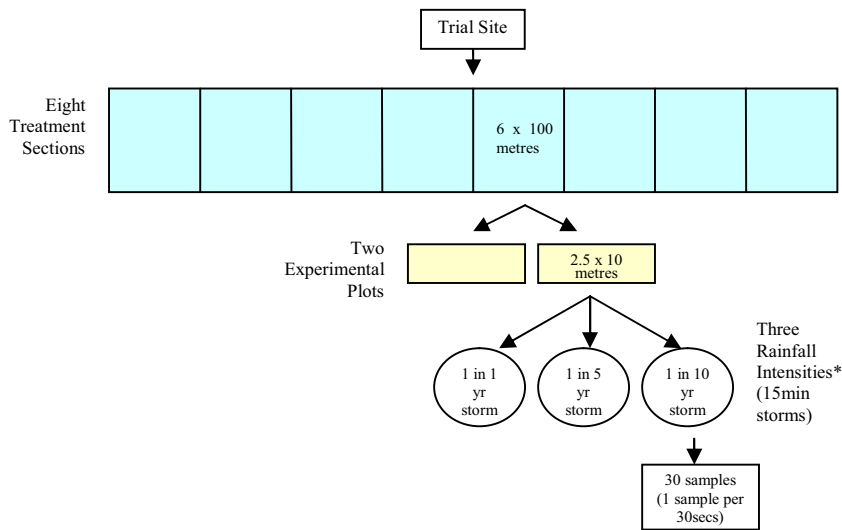


Figure 2: Proposed sampling strategy.

The targeted rainfall intensities identified from local IFD data and Bureau of Meteorology information were:

ARI (yrs)	mm/h
1	28
5	36
10	58
50 (for control)	85

Dunkerley [15] has noted that many rainfall simulation experiments choose extreme rainfall intensities and long durations. This was not the case for this study.

Sediment samples were taken from the road surface and the roadside drains. Water samples were also taken from the roadside table drains to investigate sediment production from table drains and the effect of various drain treatments on sediment production.

As a result of several difficulties in the field, including running out of time, the sampling sites were reduced to those outlined in Table 2.

3 Rainfall simulation

The rainfall simulation provided some logistical problems in the supply of water. All water had to be delivered to site in a tanker and sourced from a site that did not affect local water supplies, as the area was short of water.

Only half of the road could be used at one time, because it was still a thoroughfare. Appropriate risk management and traffic control plans were developed. Issues of working on road sites are presented in Riley and Shrestha [16].

The rainfall simulator fits into a 20-foot container, and this provided storage on site during the night. Power was supplied from a 25KVA generator. Because of the number of persons working on site toilet and catering facilities had to be supplied, along with first aid equipment. It was necessary to mount a security guard at night.

The first set of rainfall simulations were conducted on the trial site (the benchmark). Several abortive attempts were made. The test plot was the first plot constructed on the site. It was constructed in loose sand on the margin of the road. It was a learning experience for all involved. The trough was not properly sealed to the face of the cut of the plot, the depth of the medium to coarse sand deposit in which it was constructed was greater than the interception trench depth, and so considerable groundwater flow was able to escape from the plot. It was not possible to adequately seal the face. As a result the test results are considered to be of little use. However, the simulation experiment demonstrated that the substantial body of loose sand along the margins of the road had significant water storage and filtering capacity, which reduced the runoff from the plot and resulted in no runoff in the first run. Subsequent sites took account of the experience of the test site and few leaks or problems were encountered in conducting the experiments.

Simulations tended to be held early in the morning, to avoid problems with wind-drift, but this did not delay the work as the sequence of simulation runs took less than 2 hrs to complete at a site and the majority of the time was spent in preparing a site and moving equipment onto it.

The rainfall stands were placed at 5 m intervals on the equilateral triangle pattern. The layout is shown in Figure 3.

Where paired plots were used the simulations were conducted at the same time in a simulation run. The simulator easily covered the larger area. Runoff



from a plot was collected in a PVC trough running along the margin of the road, and directed into a RBC flume, at which discharge was measured and sediment samples collected. Any sediment remaining in the trough or approach to the flume at the end of a simulation run was collected for drying and weighing.

Table 1: Treatments and final sampling plan.

Treatment Number	Description	Actual
Test site	<ul style="list-style-type: none"> ▪ 100 mm local gravel base course ▪ Dry compaction ▪ 3% crossfall 	
K (Control)	Control Site: <ul style="list-style-type: none"> ▪ 100 mm local gravel base course ▪ Dry compaction ▪ 3% crossfall Road site with no treatment other than was standard for the whole of the road at time of construction and during maintenance	
A	<ul style="list-style-type: none"> ▪ 100 mm local gravel base course ▪ Wet compaction ▪ 3% crossfall 	
B	<ul style="list-style-type: none"> ▪ 100 mm local gravel base course ▪ Wet compaction ▪ 6% crossfall 	Treatments B and F were not assessed because the cross-fall was not at 6% as a result of post-construction settlement
C	<ul style="list-style-type: none"> ▪ 100 mm local gravel base course plus 70mm wearing course ▪ Wet compaction ▪ 6% crossfall 	
D	<ul style="list-style-type: none"> ▪ 100 mm local gravel base course ▪ Wet compaction ▪ 6% crossfall ▪ MgCl 	Only single plots were constructed on D and E, partly to reduce the time and cost of the experiment and also because the treatments were specific to particular stabilisers and indications of the success of the stabilisers was sufficient for the study.
E	<ul style="list-style-type: none"> ▪ 100 mm local gravel base course ▪ Wet compaction ▪ 6% crossfall ▪ lignosulfonate 	Only single plots were constructed on D and E, partly to reduce the time and cost of the experiment and also because the treatments were specific to particular stabilisers and indications of the success of the stabilisers was sufficient for the study.
F	<ul style="list-style-type: none"> ▪ 100 mm local gravel base course ▪ Wet compaction ▪ 6% crossfall ▪ Bitumen emulsion 	Treatments B and F were not assessed because the cross-fall was not at 6% as a result of post-construction settlement
G	<ul style="list-style-type: none"> ▪ 100 mm local gravel base course ▪ Dry compaction ▪ 6% crossfall 	



Table 2: Final sampling site.

Surface Treatment	Plot 1		Plot 2	
	Area (m ²)	Number of runs	Area (m ²)	Number of runs
Test plot	20.6	2	N/A	
Treatment A	25.6	2	24.8	4
Treatment C	32.2	3	33.1	3
Treatment D	32.5	3	N/A	
Treatment E	31.8	3	N/A	
Treatment K (control)	30.4	3	29.4	3



Figure 3: Rainfall simulation on site B.

Water samples were tested for conductivity, pH and suspended load. The grain size distribution was measured for some of the suspended sediment samples.

Rainfall stands for the simulator were located outside of the plots to reduce the contribution of leakage from the stands to the runoff of the plots.

Rainfall intensity for specific simulation runs often did not meet the designed intensity. These variations arose because of slight differences in pressure, variations in winds, the fact that some rain gauges were not exactly vertical, and slight differences in the nozzles on each of the rain stands. A period was set aside to conduct some calibration experiments on the simulator on site to support previous calibrations, but strong winds in the first three days and the urgency to get the simulation experiments underway meant that this work was not adequately done.

Normally the repetition of simulation experiments allows bracketing of the desired rainfall intensities if they are not achieved immediately. There was no



opportunity for repetition. The Christiansen Uniformity Coefficient for the rainfall pattern (based on a minimum of 5 rain gauges for each site, spread around the margins of the plots) was greater than 75% for most simulations. Details of the rainfall are provided in Table 3.

Table 3: Simulated rainfall characteristics.

Surface Treatment	Plot No.	Run No.	Nozzle	Pressure	Rainfall		Duration	Intensity	Target Intensity	Actual ARI
					Depth	Volume				
				kPa	(mm)	(L)	min	mm/h	mm/h	yrs
Test	1	1	1S	100	5.3	110	15	21	28	0.5
		2	2S	80	14.6	303	15	58	36	10
	1	1	1S	100	6.2	160	15	25	28	1
		2	2S	70	10.7	275	15	43	36	4
Treatment A		1	1S	100	7.6	188	15	30	28	1
		2	2S	100	10.4	257	15	42	36	3
	2	3	1L	60	19	470	15	76	58	40
		4	1L,1S	70	22.7	559	15	91	85	90
		1	1S	100	6.8	220	15	27	28	1
		2	2S	70	11.4	368	15	46	36	4
Treatment C		3	1L	60	13.8	445	12	69	58	20
		1	1S	100	7	233	15	28	28	1
	2	2	2S	70	10.7	356	15	43	36	3
		3	1L	60	12.8	421	12	64	58	17
		1	1S	100	8.4	272	15	34	28	1.8
		2	2S	70	15.3	514	15	61	36	15
Treatment D		3	1L	60	18.4	577	15	74	58	40
		1	1S	100	6.1	195	13	28	28	1
Treatment E	1	2	2S	70	13.3	418	15	53	36	10
		3	1L	60	17.1	546	15	68	58	20
		1	1S	100	5.9	178	13	27	28	1
		2	2S	70	13.7	397	15	55	36	5
		3	1L	60	18.1	549	15	72	58	30
		1	1S	100	5	146	13	23	28	0.8
Treatment K	2	2	2S	70	10.4	307	15	42	36	3
		3	1L	60	22.4	659	15	90	58	90

L – large nozzle; S – small nozzle

The 1 year ARI was achieved in most simulation runs that targeted that particular ARI intensity. The 5 year ARI was not always achieved, but the majority are within the range 3 to 5 years ARI. Much less success was obtained in achieving the 10 yr ARI rainfall intensity, and some of the simulations are in excess of 20 yrs ARI. There is no apparent reason for this variation in the 20 year target rainfall intensity. The variation among rain gauges for each simulation at each plot is acceptable, although highly variable gauges have been removed.

4 Discussion

From the rainfall and runoff data a number of relationships were developed for rainfall and runoff, time of concentration, and hydraulics of the flow. Some are shown in Figure 4.

The sediment data collected during the experiments, and not the subject of this paper, provided information on the behaviour of the different road surfaces. All of the data provided the basis for the design guidelines that were subsequently published [17].



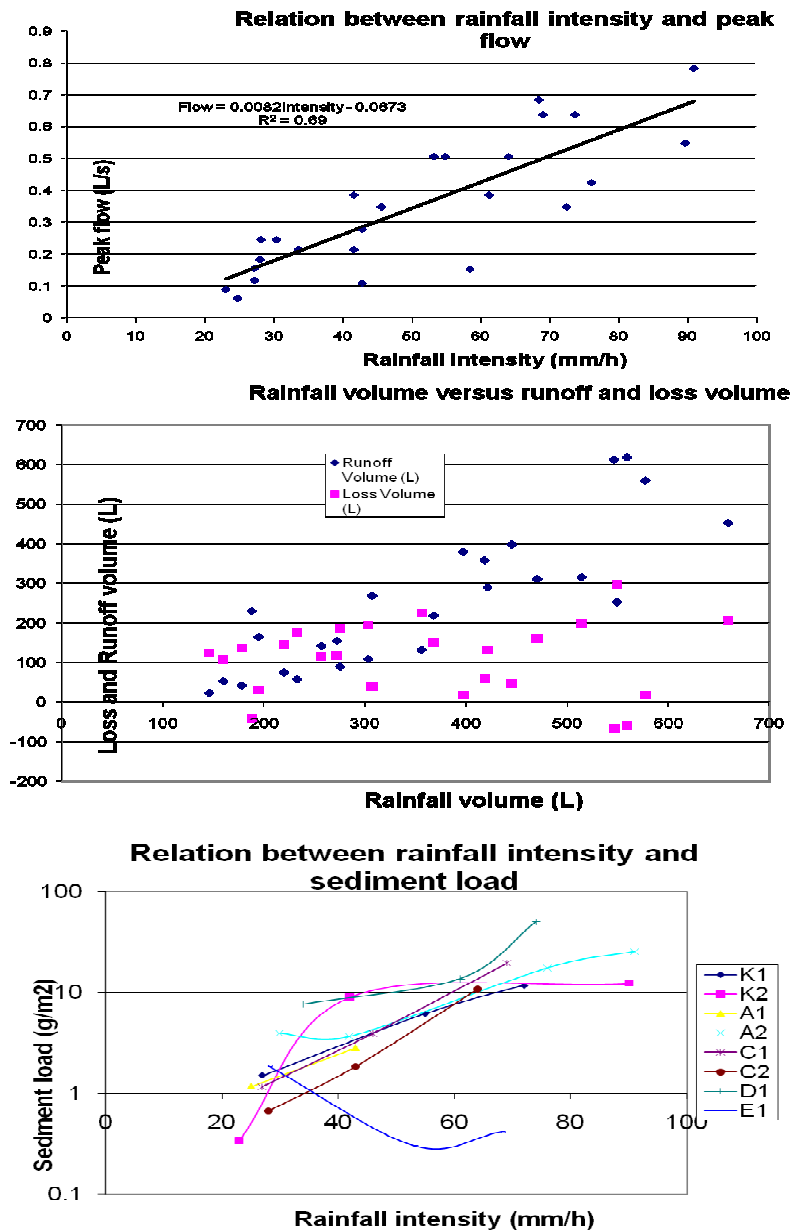


Figure 4: Relationships between rainfall intensity and volume and runoff and sediment loss.



5 Conclusion

The short period of time available for the simulation experiments did not allow collection of all the data originally intended. Nevertheless, there is sufficient hydrologic data to interpret sediment load information and compare plots on the basis of ARI and runoff.

The data suggest that there are no significant beneficial impacts of the treatments on sediment loss from the roads except for the bitumen emulsion surfacing. All the experiments were conducted after a period during which normal traffic used the road. Hence, the road surface was subject to loading and wear. Whether the bitumen surfacing would maintain its integrity in the long-term is another issue.

The last 5 minutes of runoff and sediment discharge were examined for each of the simulation run. There were no discernable relations between runoff and sediment loss in the last five minutes and the different treatments.

The results of this experiment suggest that concentrating on the roadside collection and filtering systems may better achieve reductions in the off-site impacts of road runoff. The different road stabilisation methods did not appear to significantly reduce the loss of sediment from the roads, other than when the surface was treated with a bitumen emulsion.

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