IMPROVING THE COST EFFECTIVENESS OF WATER SENSITIVE ROAD DESIGN

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ABSTRACT

Treating stormwater at the roadside is currently not proving cost effective for the Victorian state road authority on major greenfields road projects, however other smaller more urbanised sites such as road duplication projects are proving to be cost effective. VicRoads are currently undertaking research and development programs to ensure treating stormwater at the roadside (know within the industry as Water Sensitive Road Design, WSRD) is cost effective across all situations.

The construction of exotic grass swales (with limited sections of planted bio-retention system where required for advanced treatment) is proving the preferred and least costly application of WSRD for VicRoads. Grass swales are the most ‘practicable’ in their application to the linear form of road reservations, require the least amount of ongoing maintenance, and require maintenance practices in line with current roadside landscape practices. Wetlands, sedimentation ponds, sand filters and gross pollutant traps by contrast, prove to have very high construction and ongoing maintenance costs, require specialised maintenance practices, provide no greater pollutant removal capacity, and could pose a greater risk to receiving waters if not properly maintained in the future.

INTRODUCTION

Ongoing studies by Melbourne Water and the Co-operative Research Centre for Catchment Hydrology in Victoria demonstrate that a distributed treatment approach of Water Sensitive Urban Design (incorporating both stormwater treatment at the source and downstream catchment based treatment) will exceed best practice targets for nitrogen discharge levels into Port Phillip Bay by 2030 and provide cost savings to the community of 17% (Lloyd, Francey & Skinner 2004). When implemented in isolation each method will only meet the best practice targets, resulting in a net increase in nitrogen levels in Port Phillip Bay and a greater overall cost to the community (Lloyd, Francey & Skinner 2004). However these studies focus on the urban environment, with few studies having been undertaken specifically for Water Sensitive Urban Design applied in the road environment, or as it is now more specifically termed Water Sensitive Road Design (WSRD).

VicRoads has been implementing WSRD at the roadside on major urban road projects such as the Hallam Bypass and Craigieburn Bypass over the past 10 years, and significantly higher installation and maintenance costs have been experienced than currently promoted within the industry. The costs associated with implementation and maintenance of extensive wetlands in addition to the cost of conventional road drainage systems was greatly increasing costs for the community, not reducing them. Additional parcels of land were also required to be purchased outside of the road reservation for the placement of large wetlands, adding further significant cost considerations during the planning stages. Ongoing management of the natural resources created by constructing wetlands was also high as they fall outside the core business of a road authority. As experience was gained within VicRoads on completed projects it became apparent current best practice in Water Sensitive Urban Design did not equate to current best practice in Water Sensitive Road Design, but Victorian water authorities were not providing a framework for differentiation.

CURRENT RESEARCH PROGRAMS

Over the past three years VicRoads has undertaken specific studies to improve the cost effectiveness and maintenance practices associated with Water Sensitive Road Design, working closely with research organisations and water authorities to improve practices, policies, guidelines and our understanding of Water Sensitive Road Design.

Flow weighted automatic composite water quality sampling programs are currently implemented on the Hallam Bypass Project in Melbourne, Australia with results due to be completed in September 2006 (yet to be concluded). Monitoring and research programs have been implemented and run for the past two years by the construction contractors (forming part of their post construction monitoring contractual agreements), with consultation, peer review and support provided by VicRoads and Melbourne Water's Stormwater Quality Team. The aim of the water quality analysis is to establish whether the wetlands, bio-retention swales and vegetated swales (WSRD) are actually achieving the design objectives set out for reductions in nitrogen, phosphorus, suspended solids, litter, oils and heavy metals.

Sediment sampling programs (including a field based microcosm method) have been implemented on the Hallam Bypass Project, Monash Freeway and the Western Ring Road in Melbourne, Australia over the past 12 months (results completed in August 2006). The research program is being run by Melbourne Water and the Centre for Environmental Stress and Adaptation at Melbourne University under the management of VicRoads Design. The aim of the sediment sampling is to establish whether wetlands, bio-retention swales and vegetated swales (WSRD) are achieving the design objectives set for reductions in heavy metals, if heavy metals are accumulating in the sediments at the roadside, the rate of heavy metal accumulation, and the level of toxicity to living organisms.

Two research reports have also been prepared by VicRoads Design for the development of WSRD within the organisation and broader industry. 'R & D 890 Maintenance Implications of Water Sensitive Road Design' was completed and released in June 2004, and 'R & D 891 Cost Effectiveness of Water Sensitive Road Design' was completed and released in August 2005 (due for review in September 2006). The reports incorporated desk top analysis of existing sources of literature and previous research, which included approximately 250 journals and papers. Sources of the literature included Web-based resources, Austroads documents, VicRoads Library resources, CRC for Catchment Hydrology and Freshwater Ecology, VicRoads Environment Section Resources, Caltrans USA (California Highway research papers) and Melbourne Water research programs and papers.

Many experiences of VicRoads staff also provided a significant amount of research related to local case studies within these reports. Interviews with VicRoads staff were undertaken to include a broad range of road construction design and contract management issues over many VicRoads projects, including technical engineering and landscape organisational perspectives. VicRoads Environmental Services team similarly contributed a broad range of project experiences and input into the planning and policy based aspects. The reports were peer reviewed by local water authorities and industry experts.

RESULTS AND DISCUSSION

Current VicRoads research supports the implementation of exotic grass swales (Figure 1) with small sections of vegetated bio-retention systems (Figure 2) as the most cost effective method of meeting WSRD obligations at the source. This method requires the lowest installation costs, and the lowest ongoing maintenance costs; satisfies the rates for heavy metal and sediment removal and is proving the most practical for management by a road authority (refer to Appendix 1 for a table of construction and maintenance costs, and Appendix 2 for a summary of sediment and heavy metals removal capacity). Their linear forms fit best into narrow road reservations; they can almost eliminate the need for additional conventional drainage pipe systems and require the least technical design and maintenance expertise as they form essentially a landscape rather than engineering element. Current research is proving that grass swales alone in many roadside situations will meet the State Environment Protection Policy guidelines for reductions in road based pollution (WBM Oceanics Australia 2004, Engineers Australia 2003). Discouraging the implementation of constructed wetlands (Figure 3), sedimentation ponds (Figure 4), gross pollutant traps (Figure 5) or sand filters will help to greatly improve the cost effectiveness of WSRD (exclusive of the implementation of wetlands for balancing other environmental objectives).

Figure 1. Grass swale, Melbourne 2004

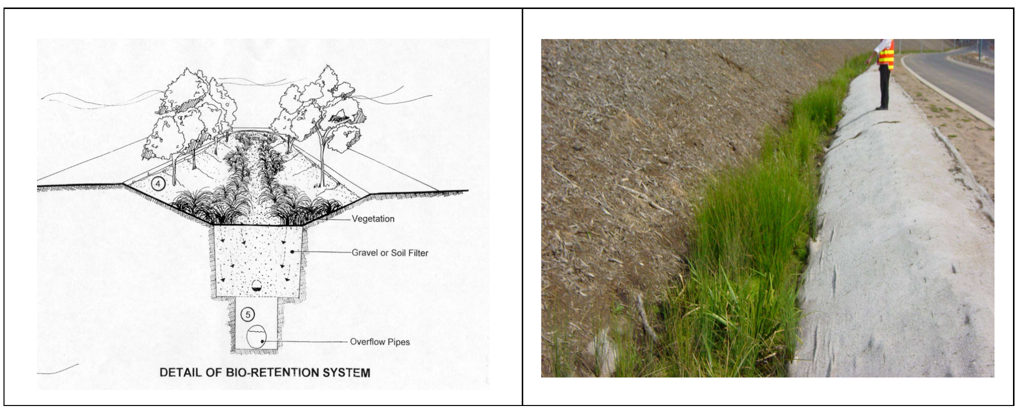

Figure 2. Vegetated Bio-retention swale on Hallam Bypass, Melbourne 2005

Figure 3. Constructed Wetlands on the Hallam Bypass, Melbourne 2005

Figure 4.Sedimentation Pond on Calder Freeway, Victoria 2004

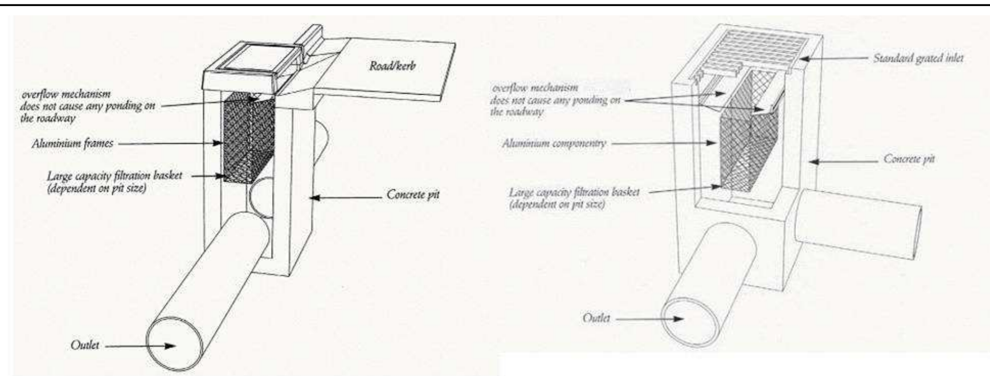

Figure 5. Gross pollutant trap (Victorian Stormwater Committee 1999)

Wetlands and sedimentation ponds are effective in the treatment of road runoff and can also meet the State Environment Protection Policy target objectives They have been the most commonly implemented WSRD devices on large VicRoads projects over the last 10 years, as they have been simultaneously advocated and promoted by research and industry. However, the maintenance costs associated with wetlands are very high when comparing the cost effectiveness of various types of WSRD, and they also require specialised maintenance practices that are outside the current standard skill-set and budget available to VicRoads. Installation costs are also high, without considering the cost of additional land required to be purchased outside of the road reservation to accommodate large wetland footprints. There is little information to date regarding the efficacy of constructed wetlands in the greater Melbourne area in treating common urban toxicants. Current VicRoads research programs suggest wetlands may not provide permanent removal of heavy metals, where potential reactions may occur when contaminated waters stagnate, enhancing and releasing toxic forms of some chemicals. The current nine years of drought experienced in Victoria have also greatly altered the effectiveness of wetlands, as wetland function relies on permanent water storage. Permanent water storages on the roadside also introduce a new public roadside hazard to be managed. The design of ephemeral wetlands with drought tolerant plants would appear to be a way forward to addressing some of the current problems experienced by VicRoads; however, the current industry design tools such as MUSIC (Model for Urban Stormwater Improvement Conceptualisation) do not provide design parameters specific to dry basin wetlands, making their use and application more experimental.

The principles of WSUD and WSRD have essentially been driven by an engineering industry with water authorities and Co-operative Research Centres advocating highly technological responses to stormwater pollution. These are now proving to be over-engineered by comparison to the simplicity of traditional roadside table drains that can be seen as equally effective in terms of water treatment on the roadside. Extensive areas of rock beaching have been incorporated in treatment trains to reduce the velocity of stormwater flows, resulting in large rock weirs and rock piled outlet risers that are so dominant they remain visible to the motorist and increase public health and safety risk long after vegetation has established. Melbourne Water has now set design guidelines and high safety standards for the engineered components of WSUD that would not be applicable to wetlands as biological or landscape elements, so the design of wetlands and vegetated swales has become very rigid in the approval process so that variations (such as shallow ephemeral wetlands, or outlets stabilised by vegetation alone) are generally not considered or catered for. WSRD forms a significant part of the natural landscape, as much as the engineered roadside, potentially leading to new conflicts between technical disciplines as we attempt to balance landscape amenity, ecology and long term ease of maintenance with the engineered elements of WSRD.

The benefits of natural wetlands in terms of environmental biodiversity and the preservation of natural habitat need to be differentiated from the use of wetlands as an element of Water Sensitive Road Design. Road runoff should not be directed into natural wetland ecosystems which may have unintended ecological impacts / consequences. WSRD should primarily be considered as road infrastructure and hence utilised to treat road runoff before it enters receiving waters, not as an adjunct to natural ecosystems. Constructed wetlands attract fauna and subsequently should be considered a possible toxic sink for heavy metals in the future. Current research suggests that sediment ponds utilised during the construction of the Western Ring Road may produce significant ecological impairment of invertebrate communities (Marshall et al, 2006).

Wetlands or other alternative WSRD elements potentially provide opportunities for recreation and landscape enhancement. The road environment often isolates, detaches or adjoins existing public open space or recreational facilities, creates new 'pocket parks' or larger parcels of open space that make ideal locations for wetlands or vegetated swales that could be considered a public recreational asset. Wetlands can also form a component of the overall landscape or architectural strategy, be expressed as entry statements in critical locations, or used for artistic expression or sculptural enhancement. These multiple uses for WSRD elements cannot be overlooked as an integral feature of the road environment

Monitoring WSRD elements is currently intensive, costly and not well understood. Storm event 'flow weighted composite sampling' is the current industry standard and post construction monitoring is required for many VicRoads projects. In order to assess the effectiveness of monitoring techniques VicRoads has research programs currently comparing sediment quality sampling(field based microcosm methods) to the industry standard of water quality sampling (flow weighted composite sampling). Sediment sampling utilises random manual sample collection techniques that is not storm event dependent, so the method of sample collection is greatly simplified and the costs are greatly reduced. The results of sediment sampling so far have been more quantifiable, quicker to obtain, more accurate and far less expensive than any water quality sampling obtained on VicRoads projects. Sediment sampling will provide an excellent low cost long term analysis option for WSRD. Monitoring data will build up over time and will help road authorities refine State Environment Protection Policy target objectives specific to roads.

Improving the process of obtaining Melbourne Water or other CMA (Catchment Management Authority) advice on Victorian WSRD will also improve the cost effectiveness of water treatment at the source. The first step has been establishing high level policy agreements between Melbourne Water and VicRoads that acknowledge swales and bio-retention systems are generally the preferred form of WSRD on road projects. Where swales and bio-retention systems cannot be implemented due to site constraints and WSRD is considered 'not practicable' for that project, a developer contribution for the stormwater quality offset is a reasonable alternative, such as has been demonstrated on the Canterbury Road Duplication project recently in Melbourne.

RECOMMENDATIONS

Current recommendations under consideration by VicRoads organisation wide to improve the cost effectiveness of WSRD are as follows:

1. Differentiation between the target objectives of Water Sensitive Urban Design and Water Sensitive Road Design shall be explored and promoted throughout water authorities and the broader industry. Greater emphasis shall be placed on exceeding best practice environmental management targets for sediments and associated heavy metals, hydrocarbons, oils and toxicants in road runoff, and less emphasis placed on exceeding removal targets of nitrogen and phosphorus.
2. Standardise the use of grassed swales and bio-retention systems as the most cost effective and preferred method of best practice WSRD. The use of wetlands, gross pollutant traps and sand filters shall be discouraged within VicRoads as they are less cost effective at the roadside (exclusive of wetlands beneficial for balancing environmental objectives).
3. Develop water quality monitoring standards for WSRD post-construction on all major VicRoads projects through the development of VicRoads WSRD Guidelines, with consideration given for sediment versus water quality sampling.
4. Establish computer modelling input parameters specific to Victorian roads, to be applied to VicRoads design projects. Parameters shall be based on actual collected data from VicRoads monitoring programs.
5. Review standard specification clauses to clearly articulate the approval process with Melbourne Water and other CMAs.
6. Develop a simple design and handover checklist for VicRoads project engineers to utilise when assessing proposed WSRD schemes (or modified from Melbourne Water 'WSUD Engineering Procedures')
7. Provide adequate training in WSRD for project engineers and the consulting industry.
8. Develop standard VicRoads design drawings for bio-retention systems and grassed swales. Obtain Melbourne Water signoff/agreement on these standard designs.
9. Implement a central VicRoads system for collation and analysis of all water and sediment quality results to contribute towards planning future maintenance and upgrade works.

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AUTHOR BIOGRAPHY

Brooke Ryan is a Senior Landscape Architect for VicRoads Design in Melbourne. Her role as a specialist in Water Sensitive Road Design has included over the last 5 years participating in the design and construction supervision of major urban road projects, such as the Craigieburn Bypass and the Pakenham Bypass, and the initiation and implementation of research and development programs such as “The cost effectiveness of WSRD” 2005, “Maintenance implications of WSRD” 2004 and “WSRD on existing arterial roads” 2004.

In 2002 Brooke received a ‘Winston Churchill Memorial Trust Research Fellowship’ to study Landscape Architecture and Water Sensitive Urban Design in the Netherlands, France, Stockholm and Germany.

APPENDIX 1

WSRD Cost effectivness - Life Cycle Cost Analysis	CAPITAL / CONSTRUCTION COSTS				MAINTENANCE COSTS		
	AUS Capital Costs - per hectare of catchment	*AUS Capital Cost excluding costs for equivalent conventional drainage(per hectare of catchment)	AUS Capital Costs - per per m2 of device construction	Caltrans USA 2004 Retrofit construction costsper hectare of catchment in US$	AUS Maintenance Costs (per m2 of device per annum)	AUS Maintenance Cost (per hectare of catchment, per year)	Caltrans USA 2004 Maintenance Costs per annum per ha of catchment in US$
Sedimentation Ponds					**or 6% of construction costs**		
	Included in wetland costs	Included in wetland costs				<$100 - $250 per hectare per annum	
Swales							
Grass Swales	$10,000	-$20,000					
Long grass with indig seed/regeneration	$10,000	-$20,000	$15.00 per m2		$0.10 per m2/year		
Swales planted with indigenous vegetation - (Hallam Bypass) Section 1	$27,778	-$2,222	$30.00 per m2		$1.50 per m2/year		
Infiltration trenches/basin				**$130,000.00**	**$ 2.50 per m2/year**		$2,000.00
Mown exotic grass swale with sub-surface drainage	$130 per m2		$130 per m2		or 5% Capital Costs		
Extended detention basins	**n/a**	**n/a**	**$1,500**	**$150,000.00**		**$100 - >$250 per hectare per annum**	$1,500.00
Bio-retention systems				**$230,000.00**	**$1.50 per m2/year**		$10,000.00
Grass swales with vegetated bio-retention(Fitzgerald Road)	$57,143	$27,143	$13.20 per m2		$ 0.50 per m2/year	$1,824	
(Costs projected from MUSIC, not actual costs)					$0.20 per m/year		
Grass swales with vegetated bio-retention(Fitzgerald Road)	$17,143	-$12,857					
(Actual contractor construction costs)							
Vegetated swales with vegetated bio-retention(Fitzgerald Road)	$91,429	$61,429				$4,765	
(Costs projected from MUSIC, not actual costs)							
Constructed Wetlands				**$260,000.00**		**$100 - $250 per hectare per annum**	$10,300.00
Wetlands, Barnes Rd Bridge (1265m2 pavement area) 0.1265 ha #	$197,628	$227,628				or 2% of Capital Costs for first 2 years	
Wetlands, Section 1 (Hallam Bypass) 27 ha. #	$33,333	$63,333				then 1% of Capital Costs for next years	
Vegetated swales and wetlands (Hallam Bypass) 33.33 ha. Overall costs	$45,005	$15,005				$330-$660 per hectare per annum	
Gross Pollution Traps					**$600 per unit/clean (2-4 cleans per year)**	**$200-$2000**	
GPT's with Sand filters(Fitzgerald Road) #	$113,714	$143,714			or 7.6% of total acquisition costs per annum	$8,706	
Large In-ground			$20,000-$200,000 p/unit		$20,000 per annum		
					or 10% of construction costs		
GPT's only (Fitzgerald Road)	$136,000	conventional drainage required	$136,000			$6,353	
Side Entry Pit Trap			approx. $200		$180 per annum (12 cleans @ $15)		
CDS			approx. $10,000 - $50,000		$4000 per annum (4 cleans @ $1000)		
Sand Filter			**$5,000 - $50,000 p/unit**	**$250,000.00**	**$1000 per clean**		$2,000.00
						or 13% of construction costs	
						$1000 - $5000 per annum	
Equivalent Melbourne Water 'Water Quality" Developer Contribution		**$7,300**					

* conventional underground road drainage, pits and kerb and channel is estimated to cost $30,000 per hectare of catchment. It has been included or excluded from the cost of each system as required.
# cost of conventional drainage required and included in this treatment system cost

The Australian values found in this table have been obtained from actual VicRoads project costs or where listed, have been provided by **MUSIC** (Model for Urban Stormwater Improvement Conceptualisation) the stormwater design program developed by the Co-operative Research Centre for Catchment Hydrology in Victoria (based on actual survey information obtained from government agencies across Victoria). Values have also been provided by Caltrans (California Department of Transportation, USA) to provide a global comparison from the extensive research programs Caltrans have undertaken in 2004 to test the cost effectiveness of similar treatment devices used in Californian roadsides in the USA.

The Melbourne Water 'Water Quality' Developer Contribution is the current applicable rate as supplied by Melbourne Water (Lloyd, Francey & Skinner 2004).

APPENDIX 2

Water Sensitive Road Design

– Summary of the effectiveness of each device in the removal of road related pollutants (predominantly sediment and associated heavy metals)	**Sediment removal effectiveness (%)**	**Construction Costs**	**Ongoing Maintenance Costs**
Sedimentation Ponds	50-60%	Medium	High
Swales	> 80%	Low	Low
Infiltration trenches/basin	70-80%	Medium	Low -Medium
Extended detention basins	40-60%	Low	Low
Bio-retention systems	> 90%	Medium	Low - Medium
Constructed Wetlands	70-80%	High - Very high	Very High
Gross Pollution Traps	<50%	High	Very High
Sand Filter	70-80%	Very High	High

The values found in this table have been summarised by the author from numerous desktop research studies.