POROUS ASPHALT – MORE THAN JUST SAFETY

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ABSTRACT

Porous asphalt (PA) is commonly used on New Zealand motorways to enhance motorist safety. However, there are a number of other benefits that makes PA a sustainable option in comparison to conventional dense-graded (DG) mixes. The quality of storm water can significantly improve with PA surfacings. In this paper a review was undertaken on the role of PA surfacing to reduce the level of pollutants in storm water, such as total suspended solids and metals (lead, zinc, and copper), compared to DG overlays.

This and other sustainability benefits puts a new light on the role PA can play in the improvement of storm water quality in New Zealand, where both heavy rainfall spells and traffic volumes are important variables and where the focus on environment becoming more important. Concerns have been raised about recyclability of these millings, especially from older PA sites. The possible accumulation of toxic pollutants in road surfacing is of concern. Recently initiated research aims to characterise PA-derived RAP to quantify the level of pollutants that may leach out during storage and use. It also seeks to develop some criteria for effective recycling of these millings back to new, high value, PA mixes.

INTRODUCTION

Porous asphalt (PA), also known as an Open-Graded Porous Asphalt (OGPA), is a stone-on-stone mix, which is widely used on New Zealand (NZ) motorways. Historically, this type of a surfacing or overlay is used in NZ primary for safety reasons as it improves skid resistance at high vehicle speeds, reduces the possibility of hydroplaning, and wet skidding in rainy weather. The PA mix is designed to drain water from the surface, which helps to maintain the surface texture (anti hydroplaning), improves visibility of road markings, and reduces the reflection of light. All these benefits are important for the safety of NZ motorists. However, PA can play an important role in relation to sustainability objectives that are now getting more attention due to the climate change movement and the obligatory needs to reduce atmospheric emissions. These environmental benefits have not yet been explored in NZ, other than the noise reduction properties of PA mixes.

PA mixes provide a smooth quite surface resulting in an improved driving experience as well as in better fuel efficiency (Cooley et al. 2009). It also has the ability to reduce temperature island effects in urban environments by minimising the reflection of the sun’s energy. PA is now placed in the “cool pavement” category (Cooley et al. 2009) by the Environmental Protection Agency in the USA and considered as a one of the strategic pavement materials for combating climatic warming effects.

Another environmental benefit of PA, which is gaining increased interest internationally, is in improvement of storm water quality and retention of pollutants. Very limited scientific studies have been conducted in this area. No research has been done to date to validate and quantify these benefits for New Zealand conditions. With ever increasing traffic, especially taking into the account that this type of surfacing or overlay is typically used on high traffic volume motorways compared to other mixes in NZ (Chappell & Bennett 2015), the role of PA in reducing pollution from motorways should not be overlooked. Adding impetus to the issue is the frequent heavy rainfalls in NZ and a large number of second hand vehicles on the NZ motorways that are often leaking.

In a recent report on the current state of the NZ environment (Ministry for the Environment & Statistics New Zealand 2015), the quality of fresh water has been identified as one of the main challenges that NZ faces, alongside climate change and biodiversity. PA has the ability to minimize the concentration of pollutants in storm water and the surrounding soil close to the roadways. Pollutants include total suspended solids, lead, zinc, and copper. As a result, PA can be used as one of the tools to achieve the national objective for cleaner water in the NZ environment. Heavy metals are toxic and cumulative in the environment and in people. Total suspended solids remain in suspension in water and are a recognized water pollutant. PA can filter storm water through its pores and trap the pollutants in its structure as well as minimize spray and splash in rainy weather, which results in reduction of pollutants washed into storm water from moving vehicles.

The recently introduced “Greenroads” certification system by NZ Transportation Agency (NZTA) is designed to take a holistic approach in relation to sustainability, and rate road building projects, based on a consistent criteria. With national and local objectives towards sustainability and an increased focus on greener cities, PA itself may get extra credits for the projects where this type of surfacing or overlay is selected in preference to conventional dense-graded (DG) surfacing mix options based on the environmental benefits it can bring. In conjunction with green technologies, like warm mix asphalt, use of recycled asphalt pavement (RAP) materials and binder made with crumb rubber from old tyres, PA can be considered an even higher value product than it currently is.

In NZ, as PA has lower shear resistance compared to DG mixes due to its high air void (AV) structure and isotopic effects, it is placed mainly in low shear areas on the motorways such as mainline lanes and ramps (high strength PA mixes) – avoiding high shear stress areas such as intersections, stop-go zones, etc., that are more susceptible to shear failure. In New Mexico, Nevada, and Texas in the USA, this type of surfacing is used or overlaid on five motorway types: urban freeways, urban arterial, urban collector, rural interstate, and rural primary highways (Cooley et al. 2009). In urban areas, PA use is often restricted due to the configuration of kerbs and channels, as well as poorly drained bridge decks (Root 2009).

Auckland Motorways Alliance (AMA) is the biggest user of PA in NZ with 95% of all 800 lane kilometres being paved with PA surfacing and the other 5% consisting of Stone Mastic Asphalt (SMA) and DG mixes; the average life span of PA is 10 years (Chappell & Bennett 2015). At the end of the service life, the PA layer is typically milled off, the surface membraned, and resurfaced with a new PA layer. If PA in NZ has the ability to reduce the total suspended solids and to possibly retain heavy metals within its internal structure, similar to PA investigated in other countries (notably Netherlands, France, Germany, and USA), it is reasonable to ask what happens to these pollutants when this mix is milled off and the confinement of pollutants in the layer is no longer present.

Typically, millings from PA sites are stockpiled on various sites by contractors and then used in low value recycled applications such as drainage and fill. Recycling of PA is not standard practice by the major user of RAP in asphalt mixes in NZ. Furthermore, the NZ specifications for PA mixes don't allow inclusion of RAP of any sort. The projected volume of PA millings from Auckland motorways is expected to increase significantly in the coming years, so it is important to understand the risks (if any) these millings from old PA sites pose to the NZ environment when they are left in uncovered stockpiles and what happens when such millings are later used for drainage and fill applications. If such millings are to be recycled into new asphalt mixes, it is important to investigate what effect these pollutants may have on the asphalt mix performance properties and how these can be mitigated. Furthermore, there is also an inherent need to understand any leaching potential of such pollutants in a new asphalt mix and how can they be addressed/contained.

The recently initiated doctoral research at the University of Auckland, Faculty of Engineering, has as one of its aims, the characterisation of PA-derived RAP to quantify the level of pollutants that may leach out during storage and use. It also seeks to develop some criteria for effective recycling of these millings back to new, high value, PA mixes. To understand what possible pollutants are present in PA millings, it is essential to investigate the PA properties in relation to pollutant retention during its life cycle. The first objective of this paper is to provide an overview of a world-wide literature documentation of the impacts of PA on storm water quality in comparison to conventional DG mixes. The second objective is to investigate the applicability of these literature findings to NZ. One primary importance of studying the quality of storm water generated by different types of surface overlays is to identify mixes and materials that can have a positive impact on the environment. Additionally, the study findings may also be used as tools for the development and implementation of cleaner and more environmental sustainable practices.

POLLUTANTS AND THEIR SOURCE

There are two main sources of pollutants deposited on motorways and road pavements; firstly, is the direct deposition from polluting sources, and secondly atmospheric deposition where pollutants are initially released into the environment and then later on settle on the road surfaces (Tchounwou et al. 2012).

High traffic volume motorways are well recognized as major source of pollutants such as polycyclic aromatic hydrocarbons (PAH), heavy metals, suspended solids, and mineral oils. Vehicle exhaust fumes, although not directly impacting the road surface, it is one of the major sources of pollutants due to the use of leaded petrol (Nriagu 1990) in the past.

Pollution from zinc and cadmium are linked to the wearing of tyres and the corrosion of metal barriers; copper comes from brake linings (Muschack 1990, Hewitt & Rashed 1990, Legret & Pagotto 2003). Chromium pollution is primary related to metal processing (Tchounwou et al. 2012). Burning of fossil fuels wherever it is from vehicles or from a power station produces nitrate and nitrites. Most combustion process produces these pollutants. Nitrate and nitrites interact with metals to form soluble salts.

Mineral oil, leaking on the road surfaces from poor quality vehicles, is probably one of the serious pollutant sources in NZ, where a high level of second hand cars is imported and the vehicle fleet is relatively old.

LITERATURE REVIEW AND EXISTING RESEARCH

The impact of PA surfacing or overlays on the quality of storm water runoff compared to DG surfacing or overlays has been assessed only in a very limited number of scientific publications. With the increased focus on sustainability and quality of water in NZ, these case studies can be very helpful to understand the potential benefits of PA mixes. Research done in the Netherlands, Germany, France, and USA can be assessed with respect to NZ practice, to draw parallels and identify the potential benefits, challenges, and limitations for application to NZ conditions.

The Netherlands

Barbee at el. (1999) assessed the quality of storm water collected from two Dutch highways overlaid with PA in comparison to a DG mix. Both the road sections were standard Dutch highways with four lanes and a median crash barrier. Traffic count for the PA section was 83,000 vehicles/24h and 53,000 vehicles/24h for the DG section. Collection of storm water samples was carried out over a year with each collection lasting for a week to assess an average concentration of pollutants in the storm water runoff.

Reduction of pollutants in storm water was observed from the PA section compared to the DG section. Lead, zinc, and copper had the highest concentrations in both types of surfacing and their concentration was significantly lower in samples collected from the PA compared to the DG section (total lead by 92%, total zinc by 90%, and total copper by 67%). The majority of metals identified, had a tendency to attach to solid particles. Lead had the highest rate of bonding to particles, with median size >0.45μm compared to copper and zinc, regardless of the surfacing type. A significant reduction in the total suspended solids (≈91%) was found when PA was used (Berbee et al. 1999).

In comparison to the DG section, PAH concentrations were below the detection limits for the storm water runoff from the PA section. The highest interception rate was observed for the total suspended solids (TSS). The type of surfacing or overlay did not affect the pH of the storm water, which was found to be close to neutral (a pH of 7). Comparison of the results of storm water collected from the PA and DG sections are shown in Table 1.

Testing parameter	Units	Storm water from DG		Storm water from PA	
		Concentration range	Bonding to particles (%)	Concentration range	Bonding to particles (%)
Lead	μg/L	51 - 106	98	2 - 22	95
Copper	μg/L	91 - 163	74	14 - 107	24
Zinc	μg/L	225 - 493	76	18 - 133	30
Cadmium	μg/L	0.8 - 0.9	76	0.1	Unreliable results
Chromium	μg/L	3 - 26	85	0.4 - 2	
Nickel	μg/L	4 - 10	80	1 - 6	11
Oil	mg/L	3 - 8		<0.1 - 0.2	
Suspended solids	mg/L	153 - 354		2 - 70	
COD	mg/L	143 - 149		16 - 18	
BOD	mg/L	6		1	
PAH EPA (Note 1)	μg/L	5.2 - 5.8		<0.3	
PAH Borneff (Note 2)	μg/L	2.8 - 3.2		<0.1	
pH		6.9 – 7.5		6.9 – 7.5	

Table 1: Quality of storm water collected from Dutch highways from Berbee at al. (1999)

Abbreviations: COD - Chemical Oxygen Demand; BOD – Biochemical Oxygen Demand; PAH EPA - Polycyclic Aromatic Hydrocarbons Environmental Protection Agency.

Note1: the USA EPA defines 16 PAHs: Naphthalene, Acenaphthylene, Acenapthene, Fluorene, Anthracene, Phenanthrene, Fluoranthene, Pyrene, Benz[a]anthracene, Chrysene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo[a]pyrene, Dibenz[ah]anthracene, Indeno[123cd]pyrene, and Benzo[ghi]perylene (Wenborn et al. 1999).

Note 2: PAH Borneff lists six PAHs: Fluoranthene, Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo[a]pyrene, Indeno[123cd]pyrene, and Benzo[ghi]perylene (Wenborn et al. 1999).

Furthermore, the efficiency of water treatment methodologies, such as settling basins and filtration were evaluated in the laboratory. It was found, that such treatments are inefficient and not financially justified, especially as the concentration of pollutants from the PA runoff was already significantly lower compared to DG mixes. The cost of removing heavy metals from storm water was estimated to be 15-60 times the cost of treatment of industrial wastewater (Berbee et al. 1999).

The research suggested that particulates and some heavy metals were trapped in the PA layer and a 3 year old PA was outperforming a DG overlay in relation to storm water quality. So, by switching from DG to PA mixes result in a significant reduction of pollutants in storm water and also a reduction of pollution due to re-suspension of the build-up on roadside shoulders. The importance of PA maintenance was discussed in this work and high pressure water cleaning of PA on the hard shoulders is now recommended to be done twice a year by Dutch authorities. The sludge generated from cleaning activities is then treated as a waste.

Germany

Research done in Germany by Stotz and Krauth (1994) compared storm water collected from a PA mix laid on a two-lane highway with a traffic count of 34,675 vehicles per day. The PA was laid at a thickness of 40 mm and had air voids of 19.1% at the time of construction. Testing of storm water was done when the PA overlay was 2.5 years old.
Runoff from the PA was compared with previously published research that had covered storm water testing from DG (impervious) overlays (Stotz 1987). Pollution levels in the storm water from both types of overlays were reported and normalised to a 1 hectare surface area. This is shown in Table 2.

Testing parameter	Units	Pollution load from DG	Pollution load from PA
Lead	g/ha	52	23.13
Copper	g/ha	24.30	16.76
Zinc	g/ha	92	143.41
Filterable solids	kg/ha	34.3	13.54
Cadmium	g/ha	1.50	0.43
Chromium	g/ha	2.40	3.47
Mineral oil	g/ha	1700	73.16
COD	kg/ha	26.4	30.39
PAH (6)	mg/ha	710	25.44

Table 2: Annual pollutant loads from DG and PA overlays from Stotz and Krauth (1994)

Abbreviations: PAH (6) –six combined Polycyclic Aromatic Hydrocarbons.

The comparison in Table 2 indicates that the level of filterable solids from PA was around 60% of that from the DG overlay. It was suggested that PA acts as a filtering system, trapping particulates within its structure. The level of the total lead, total copper, and mineral oil was also reduced by 55%, 31%, and 96%, respectively. However, the zinc level was 36% higher in the storm water from the PA surfacing compared to the DG overlay.

France

Ranchet (1995) and later Pagotto et al. (2000) evaluated the differences between storm water quality from PA and DG (impervious) overlays in France. During a 2-year study period, Ranchet (1995) assessed the level of pollutants in storm water from a highway which had traffic in both directions. The section in one direction was paved with PA and the section in opposite direction was paved with a DG surfacing mix. A summary of the results from this study is shown in Table 3.

Testing parameter	Units	Strom water from DG	Storm water from PA
Lead	µg/L	<2	<1
Copper	µg/L	16	6
Zinc	µg/L	190	63
Suspended solids	mg/L	61	57
Hydrocarbons	mg/L	3.2	1.7

Table 3: Quality of storm water collected from a French highway from Ranchet (1995)

The biggest reduction of metal pollutants was observed in zinc (67%), followed by copper (63%), and hydrocarbons (47%). The level of lead concentration from both types of overlay mixes was low (< 2 µg/L).

Pagotto et al. (2000) studied runoff samples of water collected from a motorway section with three lanes (including an emergency lane) with traffic of 12,000 vehicles per day in each direction. Measurements were done firstly on the DG (impervious) overlay for a one year period and then repeated for another year after the DG overlay was replaced with a 30 mm thick PA mix.

Testing parameter	Units	Storm water from DG	Storm water from PA
Lead	µg/L	40	8.7
Copper	µg/L	30	20
Zinc	µg/L	228	77
Cadmium	µg/L	0.88	0.28
Suspended solids	mg/L	46	8.7
Hydrocarbons	mg/L	1.2	0.09

Table 4: Quality of runoff water collected from a French motorway from Pagotto et al. (2000)

The highest reduction in metal concentrations from PA was observed for lead, followed by cadmium and zinc, respectively. Copper had a moderate reduction of 32%. These metals, apart from copper, were mainly found in a particulate form. A very noticeable reduction of 92% was achieved in hydrocarbons and the total suspended solids as high as 81%. Summary of result from this study is shown in Table 4.

USA

Work done by Barrett (2006) was based on the analysis of storm water collected during a 21 months period before and after PA was paved on top of a DG overlay in Austin, Texas. A new PA overlay with voids around 18-22% was paved at 50 mm thick on top of a DG mix on a four- lane state highway with average daily traffic (ADT) of 43,000.

The concentration of metals in storm water from PA was significantly lower with the highest interception being observed for lead, followed by zinc and copper, respectively. The total suspended solids were reduced by 92% with the introduction of the PA overlay; see Table 5.

Testing parameter	Units	Storm water from DG	Storm water from PA
Lead	µg/L	12.6	<1.3
Copper	µg/L	26.8	13.1
Zinc	µg/L	167.4	43.3
Suspended solids	mg/L	117.8	9.7

Table 5: Quality of storm water collected from a highway at Texas, USA from Barrett (2006)

The author suggested that two mechanisms of retaining pollutants in PA were relevant. Firstly, washing of pollutants from the underside of vehicles may be minimized due to the ability of the PA overlay to drain water from the road surface, so pollutants do not get washed out as much as compared to driving on DG overlays in rainy weather. This by itself should reduce the level of pollutants entering the storm water. Secondly, pollutants entering the PA voids allow storm water to get trapped within the PA internal structure, thus working as a filtering mechanism. So, by using road vacuuming techniques, the void structure can be kept clean and thus, working efficiently for pollution reduction in storm water.

Later Barrett et al. (2009) evaluated a second highway site in Austin, Texas, with 48,000 vehicles per day. Results from this study are shown in Table 6. Samples of storm water were taken at the same time from PA and DG sections under the same conditions.

Testing parameter	Units	Storm water from DG	Storm water from PA
Lead	µg/L	11	1.4
Copper	µg/L	5.9	9.3
Zinc	µg/L	132	21
Suspended solids	mg/L	159	17
COD	mg/L	77	62

Table 6: Quality of storm water collected from a highway in Texas, USA from Barrett, 2009

A similar trend was observed in relation to the reduction of suspended solids and metal concentration from PA to the findings from the previous study by Barrett (2006). Due to these significant reductions in suspended solids and metals, the author suggested that PA can be used as a Best Management Practice for motorways instead of utilizing commonly used storm water treatment techniques such as ponds and filters.

The most recent research by Barrett and Sampson (2013) was consistent with previous findings. The effect of binder type on storm water quality from PA was also investigated by these authors. Two sites of PA were paved on the same highway in 2010 in Austin, Texas, using a PA mix manufactured with polymer-modified binder (PMB), reported as PG 76, and an asphalt rubber binder (AR). The paved thickness of PA was 38 mm with 40,000 to 50,000 vehicles per day. Water sampling was carried out over a two year period. Test results of this storm water from the PA were compared with results from a DG site where storm water samples were collected earlier on the same motorway. Median concentrations for both the PA and DG sites are presented in the Table 7.

Testing parameter	Units	Storm water from DG	Storm water from PMB-PA	Storm water from PMB-AR
Lead	µg/L	130	1.6	2.4
Copper	µg/L	50	12.7	13.1
Zinc	µg/L	285	37.4	85.8
Suspended solids	mg/L	152	12.0	12.0

Table 7: Quality of storm water collected from two sites on a highway in Texas, USA from Barrett and Sampson (2013).

As evident in Table 7, both PA sections were able to minimize pollutants and Total Suspended Solids (TSS) in storm water compared to the DG section. However, water samples from the AR-PA had higher concentrations of zinc compared to samples from PMB-PA (Table 7). The authors suggested that use of AR in PA contributed to the elevated level of zinc as zinc pollution is typically associated with tyres. Nevertheless, AR-PA still significantly outperformed DG in pollutant reduction. Furthermore, the use of PA itself meets the US agencies' regulations in relation to the reduction of total suspended solids for new developments. The level of reduction for TSS from both studies was 92%, which is well above the 80% reduction required by the agencies (Barrett & Sampson 2013).

Eck et al. (2012) looked at the long term performance of PA in relation to storm water quality. Storm water was collected from PA for a period of six years from three highway sites with traffic ranging from 40,000 to 50,000 vehicles per day in Austin Texas and for two years from four highway sites in North Carolina paved with 40 mm thick PA with traffic ranging from 17,000 to 20,000 vehicles per day. The majority of samples taken from the North Carolina PA sites were for PA aged 8 to 10 years old. The combined results from PA and DG sites are in the Table 8.

Testing parameter	Units	Storm water from DG	Storm water from PA
Lead	µg/L	44.3	<1
Copper	µg/L	26.9	11.2
Zinc	µg/L	159.7	21.2
Suspended solids	mg/L	141	9

Table 8: Quality of storm water collected from highways in Texas and North Carolina from Eck et al. (2012)

This research was unique as it looked at the performance of PA sites close to the end of their design life (i.e., close to 10 years). Eck et al. suggested that improvements in storm water quality lasts through the whole life of the PA and that it is highly likely that the main reason for the reduction of pollutants lays in the ability of the PA to reduce water spray and splash, resulting in less pollutants being washed into the storm water system, rather than the PA working as a filter.

DISSCUSSION AND SYNTHESIS

Even though there a limited number of research studies published in this area, the trends can already be seen between the work done in Europe and the USA for what are considered to be major pollutants in storm water such as TSS, lead, zinc, and copper.

A significant reduction in TSS was observed in all the studies reviewed, ranging from 61% to 94%, except the 7% reduction observed in France by Ranchet (1995). The summary of findings from the research reviewed is shown in Figure 1.

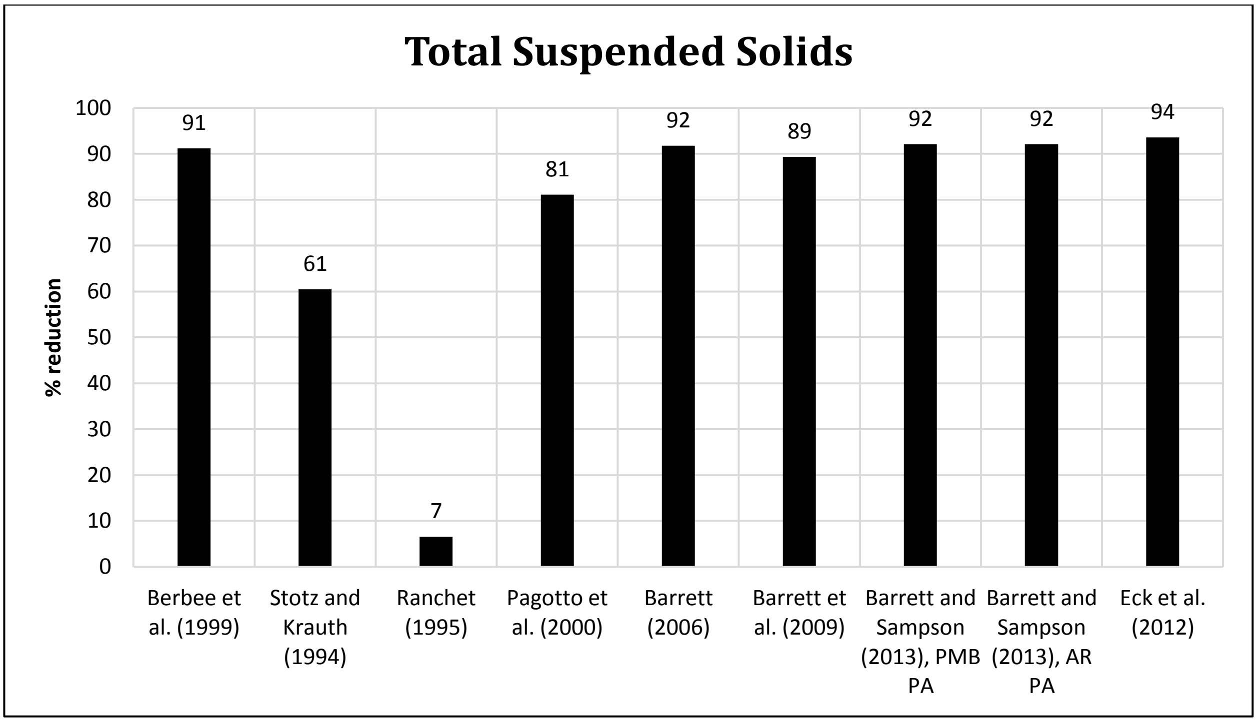

Figure 1: Reduction of suspended solids with the use of PA compared to DG

This literature data strongly supports the idea of PA have the ability to trap particulates in its internal structure unlike DG mixes. So, the importance of maintaining this structure by regular cleaning of PA as is done in Netherlands will help to retain the PA's ability to improve storm water quality. Currently cleaning of PA is not the standard practice in NZ. Also, properties like the interconnectivity of the voids of PA and stone-on-stone interlock should not be overlooked as mechanical properties that play a significant role in maintaining the internal structure of the PA mix. The selection of good stone shape for the PA mix-design contributes to the achievement of interlocking of aggregates with optimum cavities and interconnected voids in the laid mix and prevents re-orientation and resulting non optimum packing of aggregate particles occurring under traffic loading.

Furthermore, re-dispersion of particulate matter from the road surface by wind or traffic-induced movement is highly likely minimized, which can result in lower concentrations of pollutants released to the road shoulder and nearby soil.

The summary of review findings in relation to reduction of concentrations of total lead, total zin, and copper in water runoff from PA compared to DG sections is shown in Figure 2. In all the studies reviewed, the concentration of lead pollution in storm water was considerably reduced by the PA surfaces, with reductions ranging from 55% to 99%. Results from the study by Ranchet (1995) were not included in Figure 2 because the level of lead was reported to be below 2 µg/L for PA and less than 1 µg/L for DG. With the introduction of lead-free gasoline, a reduction of lead in storm water was observed. Since 1983, only lead-free petrol has been used in Western Europe, which resulted in a significant reduction of lead concentration in storm water (Berbee et al. 1999). In NZ, a free-lead gasoline was introduced 12 years later in 1996. Taking into the account that the current average life span of PA surfacings or overlays in NZ is around 10 years, paving of these mixes was done around 2005. So it is reasonable to suggest that with the introduction of lead-free gasoline in NZ, lead concentration in PA and in storm water will be significantly minimized compared to earlier years, but not fully eliminated. Most of the research done to date shows that lead is still present in storm water runoff from road pavements.

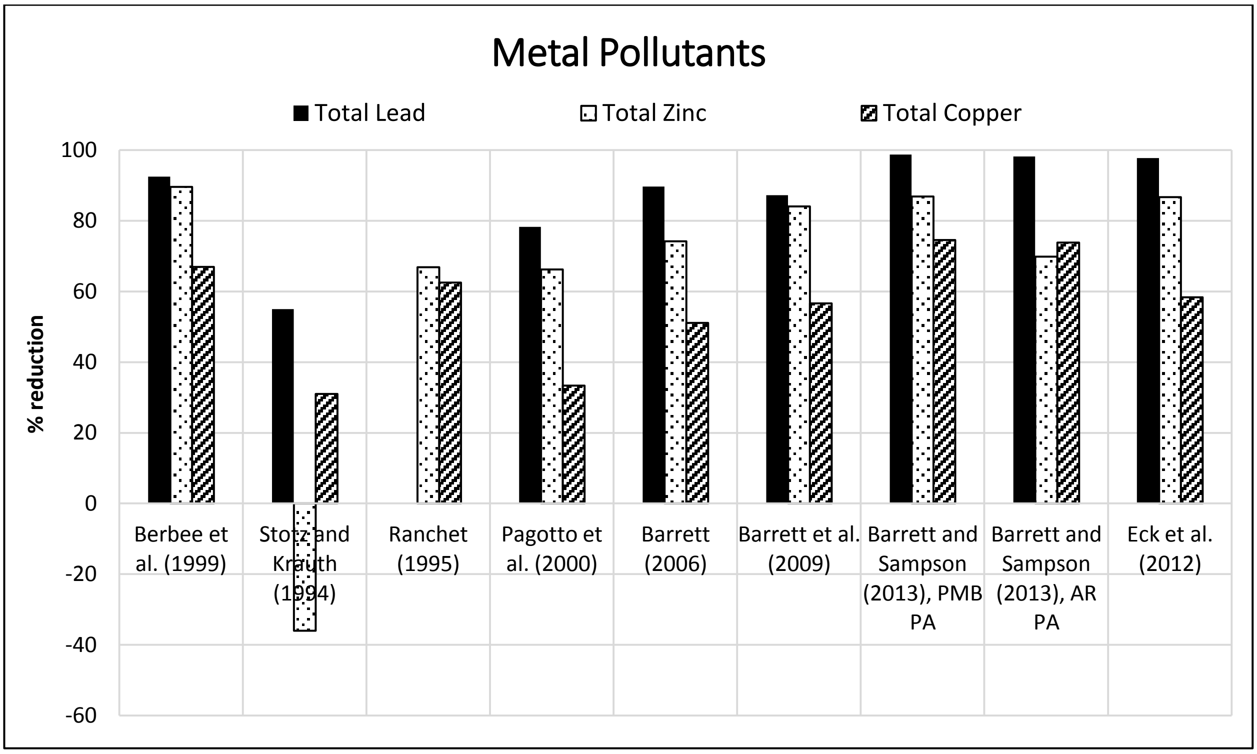

Figure 2: Reduction of metal pollutants with the use of PA compared to DG

The level of zinc pollution in storm water was consistently reduced in all the studies reviewed, except for the study done in Germany from 1990 to 1991 by Stotz and Krauth (1994). The observed 36% increase in zinc concentration in storm water from PA compared to DG is at odds with the rest of the data that was reviewed, which shows reduction of total zinc in the range of 67% to 90%. It is important to note that comparison of water runoff samples from PA and DG were done not under the same conditions in the study by Stotz and Krauth (1994). Research work on DG was done on a motorway going through a town, Pleidelsheim, several years earlier compared to the research done on PA on a highway of another town, Weinsberg. Zinc is typically linked to the wearing of tyres. It is difficult to explain why the zinc concentration was higher in the water runoff from PA compared to DG as the experimental set up was not comparing two types of the overlays under the same conditions like it was done, for example, in the USA study by Barrett et al. (2009) where PA and DG sections were analysed at the same time at the same location under similar conditions. Thus, the effects of the site location may have been significant and impacted the results.

A 31% to 75% reduction of copper concentration in water runoff from PA compared to DG sections was observed. Even though copper primarily comes in a dissolved form, the interception of total copper in the PA mix is encouraging.

APPLICABILITY TO NEW ZEALAND

An interaction between the environment, pollutants, and road pavements is a highly complex phenomenon. However, the materials and techniques employed do have significant similarities. So, the research from the above reviewed case studies is relevant to NZ conditions. The literature data shows consistent trends in relation to reduction of the major pollutants and TSS in storm water runoff when PA is used as compared to DG mixes.

The majority of the existing research was done on much thicker PA layers ranging from 40 to 55 mm; considerably greater than the thickness used in NZ. However, the work done in France by Pagotto et al. (2000) is close to the nominal thickness of 27 mm for PA10 mix (also called OGPA 10) used by the biggest user of PA in NZ, Auckland Motorway Alliance (AMA). PA10, which is made with 10 mm nominal maximum size aggregate and has 20-25% air voids, is the most commonly used PA mix on NZ motorways. The asphalt life analysis research demonstrated that PA10 mixes, along with the range of other mixes evaluated for field performance, are paved in insufficient thicknesses in NZ. The minimum of 30 mm is recommended for PA10 mixes (Chappell & Bennett 2015). Currently, it is 25mm based on the NZTA P/11 specification (NZ Transport Agency 2007).

Table 9 shows the various thicknesses and air voids used in the reviewed literature publications.

Research paper	Country	PA layer thickness (mm)	Percentage of air voids in PA
Barbee et al. (1999)	The Netherlands	50	NR
Stotz and Krauth (1994)	Germany	40	19.1
Pagotto et al. (2000)	France	30	>20
Barrett (2006)	The USA	50	18-22
Barrett and Sampson (2013)	The USA	38	NR
Eck et al. (2012)	The USA	40	NR

Table 9: PA thicknesses and percentage of air voids found in the literature on the impact of PA for storm water quality

Abbreviations: NR – Not Reported

There are two main explanations suggested in the reviewed studies as to why PA has a positive effect on storm water quality compared to impervious DG surfacings or overlays. PA works as a filter and traps pollutants in its structure, and that PA reduces water accumulation on the road surface resulting in less spray and splash; thereby reducing the washing of pollutants accumulated on the vehicles using the motorway.

It is likely that both mechanisms are important. If the internal structure of PA plays a significant role in pollution retention, as suggested in some literature work, it is reasonable to conjecture that the introduction of a double layered PA mix, paved in much greater thicknesses with higher voids structure, would provide a greater capacity for the trapping of pollutants. Also, such mixes having better drainage capabilities (due to the double layered structure), are likely to drain water from the road surface more efficiently compared to the standard PA mix, laid in one layer at 27 mm nominal thickness.

In NZ, the recent move to use an epoxy asphalt binder in PA requires an analysis of the impact on storm water quality, as this does not appear to have been studied. It is claimed that epoxy-modified PA will at least double the current life span (10 years on Auckland Motorways) by antioxidant action (Herrington 2010). If this is the case, the pollution accumulation within the PA surfacing or overlay over a long period of time may affect the recyclability of this mix at replacement and millings from such sites. It may even be considered as a hazardous waste with no future value or applications. Thus, these PA mixes should be cleaned regularly using specialized road cleaners to remove the clogged materials and pollutants. The collected sludge then needs to be treated as a hazardous waste.

The void structure and interconnectivity of voids are a function of design and manufacture and rely on the materials used and the application methodology. Based on the published research studies, all the PA mixes reviewed improved storm water quality regardless of where PA was designed and made. This includes PA mixes made with AR binders. Binders made with crumb rubber from old tires are not common in NZ, but there is a big incentive from the NZTA to incorporate this type of binders into asphalt mix manufacture. NZ faces a serious issue with a significant volume of old unutilized vehicle tires available, and use of crumb rubber in asphalt mixes is one of the valid solutions to minimize this waste while enhancing the mix performance properties. The overall results of the reviewed research are encouraging as it theoretically means that PA mixes made in NZ should have similar properties.

The challenges and limitation of the research done to date includes a lack of analysis of properties of the asphalt mixes and binders used. A lot of effort went into analysis of the water runoff, but there is hardly any literature data on the mixes themselves. PA and DG mixes can have a range of air voids including interconnected voids. The shape of aggregate particles, stone-on-stone interlock, and the interconnectivity of the voids of the asphalt mixes were not investigated, and these parameters are likely to have an effect on the pollution retention properties. However, NZ specifications also do not quantify these properties.

SUMMARY AND WAY FORWARD

PA mixes can provide a number of benefits in relation to safety, noise reduction, and environmental sustainability. Published research studies were reviewed in this study and the literature findings were comparatively evaluated to understand the impacts of PA use on the storm water quality as compared to DG surfacing or overlays.

Studies done in different countries, using the locally designed PA mixes, with locally available materials, with different binders (PMB and AR), laid at different thicknesses, on different types of highways with different traffic counts show a similar trend in relation to the PA's ability to improve storm water quality. With the use of PA mixes, a significant reduction in the major metal pollutants such as lead, zinc, and copper, as well as total suspended solids, was observed, which ultimately leads to overall improvement in the storm water quality. Theoretically, the PA in NZ should have similar properties. The requirements of local and national agencies' objectives concerning environmental sustainability and the increased traffic volume on NZ motorways, means that PA can play an important role in the reduction of pollutant concentrations, to minimize their release in storm water, road shoulders, and the surrounding soil.

Possible accumulation of pollutants in PA means that it is important to evaluate the millings of PA removed from old sites to understand the potential risk of leaching. There is expected to be a sharp increase in the level of PA millings from the Auckland Motorways in the coming years. The doctoral research initiated at Auckland University has its aims to measure and quantify the leaching potential of pollutants in PA-derived millings and develop a criteria for effective recycling of these millings back to a high value product such as new PA mixes. The ability of encapsulation by binders in finished mixes to prevent potential leaching also needs to be explored.

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