**RECLAIMED POROUS ASPHALT AND CONTAMINANT LEACHATE**

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# ABSTRACT

Reclaimed Asphalt Pavements (RAP) refers to any material containing asphalt and aggregate taken from asphalt pavements. RAP can be derived from any existing asphalt surface, such as Porous Asphalt (PA) or Dense Graded (DG). In New Zealand, PA is the most used asphalt mix on Auckland motorways primarily for safety reasons (surface texture and skid resistance). PA surfacing can also improve stormwater quality. It has been reported that the internal void structure of PA can act as a filter, trapping the pollutants in the bound pavement surface. The combination of various pollutants being retained in PA layers is beneficial in treating stormwater, whilst pollutants are bound in the pavement. However, with little research investigating what pathways pollutants take once the porous layer is milled, it is uncertain whether the material is safe for reuse applications.

The primary objective of this research was to determine if pollutants such as heavy metals (HMs) leach from PA derived RAP. As there are limited studies on RAP derived from PA in New Zealand, a methodology for column leaching testing of HMs was adapted from existing column methodology to investigate the leaching potential from PA of HMs. These tests showed leaching of HMs can occur at significant concentrations, and as a result, it is recommended that further research is undertaken to determine the extent of leaching, and the safety of PA derived RAP.

# ****Introduction****

Porous Asphalt (PA) pavement surfacing have commonly been used in New Zealand (NZ) for safety, to improve skid resistance and to reduce splash and spray. The widespread use of PA, especially in Auckland means that there is a great potential to recycle and reuse these pavement materials, at the end of their design life. Current emphasis on sustainable practices has meant that Reclaimed Asphalt Pavement (RAP) is widely being used and provides economic and environmental benefits. Research has been undertaken about leaching from RAP samples from Dense Graded (DG) mixtures, but there has been limited research conducted into the leaching of PA derived RAP. Due to the significant differences in mix structure for PA and DG, specific research needs to be undertaken on the potential leaching of PA derived RAP.

# ****Literature Re********view****

PA is currently the most commonly used asphalt surfacing material on Auckland highways, with Auckland Motorway Alliance (AMA) using PA for 95% of its 800 lane kilometres, with the remaining percentage made up of Stone Mastic Asphalt (SMA) and DG mixes (Holleran et al. 2016). PA is an open graded pavement mix, with a void content usually within the range of 20-25% in New Zealand (Holleran et al. 2016). PA surfacings have a lifespan of approximately 10 years (Chappell & Bennett, 2015), and as a result, PA surfacings need more frequent maintenance. The use of PA in RAP would have many benefits to NZ such as minimising and optimising the use and reuse of natural resources, as well as a potential cost savings. Research needs to be undertaken to identify the impact and mitigation required for risks to the NZ environment.

PA is commonly used for safety, such as to optimise surface property skid resistance performance (Holleran et al. 2016), however, existing research has suggested that additionally this high-quality material can also be used to improve surrounding storm water quality. Researchers have suggested that the interconnected voids in PA act as an at source contaminant filter for pavement surface runoff, filtering out common pollutants deposited on the pavement surface by vehicles, and thereby reducing pollutants in neighbouring storm water, and locking these into the pavement surface layer (Barret et al. 2009).

Barret (2008) observed a reduction in pollutants in storm water when conducting a 2-year-long study in America comparing a PA, Porous Friction Course (PFC) in North American terminology, to traditional pavements. It was observed that PFC had a reduction in concentrations of Total Suspended Solids (TSS) (92%), total Lead (91%) total Copper (47%) and total Zinc (75%). In France, Pagotto et al, (2000) also conducted a similar experiment and found that HMs present in runoff water are reduced by 20% for Copper and up to 74% for Lead, and hydrocarbons present are reduced by 90%, when compared to a DG asphalt surface.

The combination of various pollutants being retained in PA is beneficial in treating storm water quality when bound in the pavement (Barret 2008). However, it does raise concerns over the pathways these pollutants will take once the porous layer is milled, and the pollutants are no longer entrained in the matrices of these layers. Whilst there are various pollutants identified in current literature that are deposited on the pavement surface, such as Volatile Organic Compounds, and TSS such as particulates in the water, the scope of this research is limited to measurement of the presence of HMs in PA derived RAP. HMs were chosen to be analysed in this research as they pose a serious risk to humans and the environment even in low concentrations when present in runoff.

HMs are commonly found in vehicle emissions, tyre wear and from galvanised steel crash barriers (Legret et al. 2005). HMs can enter the human’s system through ingestion, inhalation or absorption through the skin. For example, Lead at small levels of exposure can cause headaches, abdominal pain or fatigue, while high levels of exposure can have serious effects such as muscular weakness, organ damage or paralysis (Ministry of Health, revised 2008). HMs can also be toxic to animals and the environment as the runoff from pavement surfacings can wash into drains, streams and rivers. HMs within the runoff has the ability to bioaccumulate within living organisms, and are also non-degradative, which makes them persistent and able to result in long terms effects on the ecosystem. Even at low concentrations, HMs pose a serious risk to humans, animals and the environment.

**2.1 Current Tests on RAP**

Pollutant leaching from RAP has been studied overseas, however, the characterisation of the RAP itself is lacking. There are three common types of asphalt that could be the source of RAP; DG, SMA and PA. Legret et al. (2005) and Brantley and Townsend (1999) both looked at leaching of pollutants from RAP, however they did not specify what type of asphalt mix the RAP was derived from. In NZ, Herrington, Kvatch and O'Halloran (2006) have provided proposed guidelines on how to test and work with RAP in NZ, however the study did not specify the material the RAP could be derived from. With each material having significantly different properties, it is important that procedures for RAP are not generalised.

**2.2 Leaching Tests**

Research on generalised RAP identified batch and column as common leaching tests. In some instances, pollutant concentrations from column experiments were higher in solution than batch testing and then decreased rapidly (Legret et al. 2005). In other experiments, leachate collected during column tests did not contain levels of selected HMs, and pollutants (Brantley & Townsend, 1999). Townsend (1998) undertook column leaching tests to simulate a more realistic environment, as it simulates rainfall falling on the stockpiles more realistically then batch testing.

**2.3 Column Leaching Tests**

**2.3.1 Sampling**

Nemeth et al (2010) prepared their samples homogenising and screening for material passing through a 19.0mm sieve. These sampling preparations were similar to all experiments reviewed, with Legret et al. (2005) preparing samples at a particle size of 19.5 mm.

**2.3.2 Apparatus**

The apparatus and materials used in these column tests differed between experiments. Townsend (1998) undertook column leaching tests in stainless steel leaching columns, whilst Kang et al. (2011) used long clear PVC tubes. It is interesting that PVC was used in this experiment as stainless-steel columns are most commonly used as they are inert to most pollutants, whilst PVC is inert to HMs. Townsend (1998) placed 3 inches of fine sand on top of the RAP sample within the columns. This could have been done to evenly distribute leachate flow. The addition of sand may introduce new contaminants, which is not desirable.

# ****Objectives****

After detailed review of current literature, it was identified that, to the authors’ knowledge, there is no existing published research on leaching in PA derived RAP in New Zealand. Without this research, there is little information available on the environmental effects of PA derived RAP. To fill this identified gap in research, this research aims to investigate the potential leachate from PA derived RAP by satisfying the following objectives:

* To determine if HMs are present in Porous Asphalt derived RAP from the samples gathered
* To determine if HMs leach from PA derived RAP. Specifically, the HMs analysed were: Cadmium(Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Lead (Pb), Nickel (Ni) and Zinc (Zn),
* To adapt / develop an effective methodology to undertake column leaching procedures

# ****Methodology****

As no methodology currently exists in NZ for testing leachability of PA derived RAP, the methodology followed for this research was developed by adapting methodology for DG Asphalt and adhering to relevant standards for testing waste in New Zealand. In order to simulate a realistic environment, column leaching tests were utilised. The samples used for this investigation were obtained from 17 pavement samples from various milled RAP from Auckland motorway surfaces. Of these, the following two greywacke aggregate PA samples detailed in Table 1 below were selected for comparative purposes.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sample | Age | Aggregate Material | Location | Land Use |
| SUR 216  AADT – 50,000 vehicles/ day | 8 years | Greywacke | State Highway 1, North bound.  Between Oteha Valley Road and Silverdale, Auckland, New Zealand | Rural area |
| PAV 133  AADT – 100,000 Vehicles/ day | 4 years | Greywacke | State Highway 20, North bound.  Between Puhinui and Portage, Auckland, New Zealand | Industrial area |

Table 1: Pavement sample details

These samples were selected as they were both made from greywacke aggregate and represented rural and heavy industrial areas respectively. Both pavements were full depth milled at 25mm, the typical depth of PA Surfacing layers in New Zealand.

**4.1 Sample Preparation**

Samples were sieved at 19mm and split from 20 kg bags to 1 kg airtight bags for ease of use, using a riffle box. Moisture content (MC) tests were undertaken on randomly selected samples as per ASTM C566-13 to ensure that samples were split effectively. Two kgs of sample were placed in metals trays lined with paper and weighed. Samples were then heated at 110°C for 24 hours. After allowing samples too cool, the weight of the tray plus the sample was recorded. The difference in initial and final weight was used to find MC. MC tests are shown in Tables 2 and 3 below.

|  |  |  |  |
| --- | --- | --- | --- |
| Tray Number | Weight of undried material (g) | Weight of Dried material (g) | Moisture Content (%) |
| 1 | 2013 | 1998 | 0.75 |
| 2 | 2089 | 2072 | 0.81 |
| 3 | 2030 | 2014 | 0.78 |

Table 2: Summary of moisture content results for pavement sample SUR 216

|  |  |  |  |
| --- | --- | --- | --- |
| Tray Number | Weight of undried material (g) | Weight of Dried material (g) | Moisture Content (%) |
| 1 | 2709 | 2644 | 2.4 |
| 2 | 2711 | 2649 | 2.3 |
| 3 | 2625 | 2561.5 | 2.4 |

Table 3: Summary of moisture content results for pavement sample PAV 133

Consistent MC tests suggest that the volume of fines between samples were similar, suggesting the quartering process was effective.

**4.2 Solution Preparation**

To simulate realistic conditions, the influence of pH on leaching was tested as rainfall can have a variety of pH values. Three pH solutions were chosen, a pH of 4.2, 5.6 and a control of tap water, which had a pH of 8.2.

The following laboratory equipment was required for solution preparation:

* 2L glass beakers
* 6.5% diluted Nitric acid
* Pipette
* pH meter

The pH values of 4.2 and 5.6 were chosen to reflect acidic rainfall and clean rainfall as per the EPA guidelines for pH (EPA, 2017). To attain these pH values, 2000mL of tap water was measured out in a glass beaker; 1.5ml and 2ml of dilute 6.5% Nitric acid was then added using a 10ml plastic pipette to change the pH to 5.6 and 4.2 respectively.

The pH of a solution is due to the dissociation of hydrogen ions (H+) which form hydroxide ions (OH-) with water, so an acid in which H+ readily dissociates was needed to change pH. Nitric acid was chosen to change the pH due its ability to readily dissociate and as it occurs naturally. In nature, lightning creates Nitric Oxide, this then leads to Nitric Acid reacting with water causing acidic rain.

**4.3 Column Leaching Equipment**

**4.3.1 Material List**

Column leaching equipment was developed for the column leaching tests completed. The following equipment is needed to develop the columns:

* Six PVC pipes of Diameter = 0.1m and Length = 0.5m
* Six PVC end caps
* Stainless steel ball valve taps
* 1.5L of pH solution
* Rubber hose
* Temperature controlled room
* Drainage cloth (filter material)

**4.3.2 Apparatus construction**

Columns were made from PVC pipes with stainless steel valves to control flow, the setup is shown in Figure 1. PVC was used as it was cost effective and had minimal reactions with HMs as PVC is fairly inert with minimal plasticizer. A sediment filter was placed on top of the ball valve to ensure fines did not enter the collected leachate.

PVC Pipe Dimension:

0.1m by 0.5m

Specimen Dimensions:

100 mm by 375 mm

Coarse sediment filter

Tap/ valve to be screwed into PVC end cap, with tubing into collection jar. Leak resistant

PVC end cap

Borosilicate glass jars

Figure 1: Column Apparatus

**4.4 Column leaching test**

Six columns were made to test six samples simultaneously. The respective quartered pavement samples (PAV 133 and SUR 216) were added to the columns. The total weight of the samples ranged from 2.7 kg to 3.3 kg.

Approximately 1600ml of pH solution was then added to the sample. These columns were then drained for 1 hour, representing the first flush. The tap was then closed, and another aliquot of solutions was added. They were then allowed to soak for 1 day, when the tap was opened and allowed to drain for 1 hour, representing a soaking time of 1 day. This process was repeated for 2 days, and 4 days soakage times. The overall diagrammatic representation of the setup of the tests is shown in Figure 2.

Pavement Samples

pH 4.2

pH 8.2

pH 5.6

PAV 133

pH 4.2

pH 5.6

pH 8.2

SUR 216

Figure 2: Diagrammatic representation of column leaching test

The leachate was then collected in borosilicate glass jars as per ASTM D3987 “Shake Extraction of Solid Waste with Water”, a standard specifically for Batch testing. This allows for effective comparisons between column leaching tests and batch tests in the future. The pH of each sample was then tested with a pH meter. This process was repeated three times for each pavement sample and their respective pH solution.

**4.5 Chemical Analysis**

Firstly, the pH was tested, then the samples were vacuum filtered using a 0.45 μm filter in accordance with ASTM D3987. 100 ml of the filtered sample was then added to PVC bottles, and 2ml of 65% nitric acid was added to preserve the sample in accordance with ASTM standard D3370. The solution chosen to preserve the samples was Nitric acid, as is commonly used to preserve HM samples (Coffey, 2006)

These samples were stored in a refrigerator at 4°C. Inductively coupled mass spectrometry, using the Agilent 7700 ICP-MS was carried out by the Chemistry Department of the University of Auckland to test for HM. Blank samples of tap water were also chemically tested for HM content, and showed no HM content. This testing confirmed that all HM observed were from the RAP samples tested and were not present in the water prior to the leaching process.

# ****Analysis of Results****

All HMs investigated were present in each leachate sample. Depending on the pH solution, each concentration of HM varied in the collected leachate, suggesting that the pH of rainfall could affect the leaching potential of RAP.

As there was uncertainty regarding the presence of HM in the control solution of tap water, blank samples of each pH solution were also sent for analysis, to determine if any HM concentrations were present. Nickel and Zinc were present, and had concentrations of 0.0001 and 0.0063, respectively in the 5.6 blank sample. This concentration was subtracted from the respective leachate concentrations. The remaining metals returned concentrations less than zero, therefore they were not present in the tap water.

All HM concentrations were compared to drinking water standards or irrigated water standards, whichever was the lower value. Irrigated water trigger values were obtained from Australia and New Zealand Guidelines of Fresh and Marine Water Quality (2000). Drinking water trigger values were obtained from The New Zealand Ministry of Health, Drinking Water Standards (revised 2008). All HMs were compared to the lowest trigger values of either standard, in Table 4.

|  |  |  |
| --- | --- | --- |
| Heavy Metal | Irrigated water trigger values (mg/L) | Drinking water trigger values (mg/L) |
| Lead (Pb) | 2 | 0.01 |
| Cadmium (Cd) | 0.01 | 0.004 |
| Zinc (Zn) | 2 | - |
| Copper (Cu) | 0.2 | 2 |
| Nickel (Ni) | 0.2 | 0.08 |
| Cobalt (Co) | 0.05 | - |
| Chromium (Cr) | 0.1 | 0.05 |

Table 4: Heavy metal trigger values used to compare against heavy metals concentrations from leachate

Whilst all HMs were present Cadmium, Chromium, Cobalt, and Zinc were present in very low levels for both samples when compared to the associated trigger values as shown in Table 4.

**5.1 Presence of Copper**

Copper was found in significant levels in both pavement samples as shown in Figure 3 and 4. In Figure 3, a first flush curve can be observed from the HM Copper, within pavement sample SUR 216. A decline in the graph is observed between 1 and 2 days of soakage before there is a slight increase after 4 days of soakage. The SUR 216 sample in comparison to PAV 133 sample had lower Copper concentrations in leachate samples for the acidic solution. The concentration of Copper in leachate samples is the highest after one day of soakage, then the concentration of Copper in these leachate solutions decreases.

For pavement sample PAV 133, the concentration of Copper increased as soakage time increased. The acidic pH of 4.2 consistently had higher concentrations of Copper in leachate samples throughout the test period.

Figure 3: Average Cu Conc. vs Cu Irrigated water trigger value vs Soakage time for SUR 216

Figure 4: Average Cu Conc. vs Cu Irrigated water trigger value vs Soakage time for PAV 133

**5.2 Presence of Lead**

Lead was found in significant concentrations, and the concentration of Lead was consistently higher in PAV 133 when compared to SUR 216.

In SUR 216 (Figure 5), there was an absence of a consistent trend between the concentration of Lead and the pH of solutions in SUR 216 concentrations of Lead in leachate samples stayed consistent with increasing soakage for the acidic solution.

The PAV 133 sample shown in Figure 6, shows a slightly different relationship between the concentration of Lead and soakage time. For pH 4.2 solution, the first hour of soakage had the highest concentration of Lead present and then it slightly deceases as soakage time increases. However, for the other two solutions, it peaks at one day of soakage and then decreases at a similar rate as pH 4.2 solution.

Figure 5: Average Pb Conc. vs Pb Drinking water trigger value vs Soakage time for SUR 216

Figure 6: Average Pb Conc. vs Pb Drinking water trigger value vs Soakage time for PAV 133

**5.3 Presence of Nickel**

Nickel was present in significant concentrations in both pavement samples as shown in Figure 7 and 8 below.

The results showed the concentration of Nickel in some leachate samples were higher than the associated drinking water limit in sample PAV 133, however this was not true of sample Sur 216. The concentration of Nickel in leachate samples from PAV 133 were consistently higher with more acidic solutions, which showed an increasing trend with an increase in soakage times. However, in SUR 216, the acidic solution of pH 4.2, consistently showed lower concentrations of Nickel and the pH solution of 8.2 showed a higher concentration of Nickel in leachate samples. The concentration of Nickel in leachate samples increased with increasing soakage times in SUR 216.

Figure 7: Average Ni Conc. vs Ni Drinking water trigger value vs Soakage time for SUR 216

Figure 8: Average Ni Conc. vs Ni Drinking water trigger value vs Soakage time for PAV 133

# ****Discussion****

**6.1 Discussion of results**

While all HMs were present in the leachate, HMs such as Cadmium, Chromium, Cobalt, and Zinc were present in very low levels in all samples, when compared to their associated trigger values. Although the four mentioned HMs reported at low levels, these HMs should not be disregarded as longer soakage time may increase leaching potential.

Although Nickel was present in significant quantities when compared to its respective trigger value, the results should be disregarded. It is suspected that the higher concentrations of Nickel are present due to the use of stainless steel ball valves in the test equipment apparatus. The valves were attached at the bottom of the column to allow control over the drainage of the columns. Due to time and budget constraints, the valves were kept consistent throughout the testing process. For future research, the use of polymer-based valves is recommended in the columns as an alternative, to isolate any HM presence from the testing apparatus.

This investigation identified four key factors that affected the leaching of HM’s. These are:

* pH
* Soakage time
* Surrounding land use
* Chemical makeup of samples

**6.1.1 pH of Solutions**

From the limited data set, the results indicate that the pH of solutions may influence the concentration of pollutants that leach out from RAP material. In the PAV 133 sample, the more acidic solutions, pH 4.2 and pH 5.6 showed higher concentrations of all three HMs in leachate samples. However, this trend was not repeated in SUR216. In this sample, there was a difference between the concentrations of HMs in leachate samples, however there was no consistent trend. In some instances, the pH 8.2 sample leached higher concentration of HMs, whilst at times the pH 4.2 solutions leached higher concentrations. Without further testing, the effect of pH on the leaching of HMs cannot be fully conclusive, however it would be expected that the pH of rainfall will significantly influence the leaching of HMs.

**6.1.2 Soakage time of samples**

In the PAV 133 sample, generally an increase in soakage times indicated an increase in the concentration of pollutants present in leachate. Depending on the pH of the solution used, there was a difference in the concentration of HMs in the leachate.

In SUR 216, it was observed that a soakage time of one day commonly had the highest concentration of pollutants. The concentration of pollutants then decreased with increased soakage times. However, a contrary trend was observed for the release of Nickel from Pav 133.

Some of these trends could be explained by the reactions that are occurring within each sample. This trend could also be accounted for through some metals requiring a longer reaction time. Longer soakage times are required to ascertain a definite relationship between soakage times and pollutant release. From the results observed, it is not conclusive if soakage time influences the concentration of pollutants found in leachate, further testing is required.

**6.1.3 Road Use and Surrounding Land Use**

There were vast differences in the results observed between the two samples PAV 133 and SUR 216. PAV 133 is a younger pavement surfacing, so it was expected that the concentration of pollutants would be lower when compared to SUR 216. However, PAV 133 was from a more industrial area, with a higher AADT, which could explain the higher concentration of pollutants. SUR 216 was an older pavement which was in an area surrounded by farmland, so as a result had a lower concentration of pollutants in leachate. These observed differences in results highlight that surrounding land and the AADT has a great influence on the quantity of pollutants deposited on the road surface.

Another factor that could contribute to these differences is the level of traffic congestion and potentially lower vehicle speeds experienced by the pavements. PAV 133 experienced high congestion when compared to the SUR 216 site which had free flowing traffic. The stop-start nature of congested traffic on PAV 133 might have contributed to the higher concentration of pollutants, as brake fluid, and pollutants from tires are more likely to be deposited in this environment when compared to a free-flowing traffic environment.

**6.1.4 Initial makeup of sample**

It was ensured that the initial make of both pavements was constant. This was undertaken by ensuring both pavements were made up of greywacke (Hunua aggregates) and had no presence of artificial aggregates containing HMs (e.g. melter slag). The binder was assumed to be bitumen. Some samples however, had the presence of surface marking materials such as road paint and raised reflective pavement markers (RRPM or cats-eyes). These materials may have contributed to the levels of Lead leached from the material. This could suggest that the presence of certain pollutants could be due to the surfacing materials instead of the pavement itself. However, it is important to assess the pavement in its entirety as the construction processes to produce RAP does not separate out surface markings from the pavement.

It was also observed that sample PAV 133 had a significantly higher moisture content than SUR 216. This could affect the amount of water in contact with the HMs, and as a result affect the amount of HMs found in the leachate. Whilst the liquid/solid ratio was approximately 20, this ratio did not consider initial moisture conditions, which could mean that PAV 133 had a higher liquid to solid ratio. Further testing needs to be undertaken to investigate this potential relationship between liquid to solid ratio and leaching of HMs. The drying of samples was investigated in order to address this issue; however due to the content of bitumen, which changes states when heated, drying was deemed inappropriate.

**6.1.5 Observations**

During the column leaching test and filtration, the following observations were made:

* As the leachate was filtered, it would foam in the filtration flask
* Some leachate collected would have a tinted yellow colour showing turbidity
* Small black spots were visible on the glass beakers used for sample collection
* Change in initial pH of the solution after collection

Foaming could indicate reactions with alkaline substances such as brake fluid. Another possible theory could be that acidic solutions are reacting with calcium carbonate or, as a product of the reaction, carbon dioxide is being released.

The yellow colour and turbidity could indicate the presence of iron nitrates and insoluble particles. HMs commonly have low reactivity; however, they could react readily with Nitric acid, which is known to be a strong oxidising agent. The reaction between HMs and dilute nitric acid is likely to produce nitrate ions (NO2), which will contribute to the turbidity observed. The yellow colour could also indicate the presence of chlorine, that may have been present in the tap water used for testing.

The small black spots visible on the glass beakers, is highly likely to be the particulate matter drained from the columns. These spots could also indicate the presence of carbon. A full chemical analysis is needed to quantify the presence of these materials.

As leachate was collected from the columns, pH was measured and a change from the initial pH of the column was observed. Acidic pH solutions 4.2 and 5.6 would increase after each soakage times, while the basic pH solution 8.2 decreased after each soakage time. All solutions showed an average final pH within the range of 7-8. The change in pH suggests that reactions are taking place within the sample. As pH is a measure of OH- and H+ ions, an increase or decrease in pH suggests reactions involving the dissociations and association of H+ ions. This could be due to reactions with HMs, or reactions with other substances such as calcium or chloride in the tap water. A full chemical analysis of the substances present in leachate samples is needed to conclusively show the reactions causing this change in pH.

Whilst physical observations suggest these reactions, without further testing to fully chemically analyse all particles present in the leachate samples, no conclusion can be made on the source of these observed characteristics.

**6.2 Impact on RAP use**

The findings outlined in this report have substantial consequences for current practises surrounding PA RAP use and handling. There are three main aspects identified that could impact RAP use.

**6.2.1 Environment and human health and safety**

Certain HM concentrations are known to have determinantal effects on the environment and humans, even at low concentrations. In the environment, HM are non-degradative, which makes them persistent and can exert long term effects on the ecosystem. Concentrations of HM can also affect the natural population of bacteria in soils and in some instances, accumulate in aquatic life, which means HM can contaminant food supplies (Ministry of Health., 2016). HM can enter the human system through inhalation, absorbing through the skin and through ingestion. Low to moderate effects can make humans feel light headed, have skin reactions or heavy breathing. While extreme cases can cause people to have carcinogenic effects, organ failure or adverse effects to the nervous system (Ministry of Health, 2016). To avoid this, it would be required of people handling this material to wear correct PPE to avoid any illness caused by being exposed to HM in the runoff.

**6.2.2 Clean fill**

The Auckland Unitary Plan (Auckland Council, 2013) defines clean fill material as an inert material that has no leachable components. However, with the two pavement samples tested, all seven HM were identified within the leachate with some level of concentration. As HM were identified, within the leachate, this could deem the material hazardous and would not qualify for clean fill applications. PA derived RAP would need to be used in bound applications, where water cannot infiltrate and filter the pollutants away. These materials should be tested for the levels of pollutants before they can be used in drainage applications.

**6.2.3 PA derived RAP stockpiles**

Currently stockpiles are left outside and are left uncovered from rainfall. With each rainfall event, rainfall drains through the stockpiles and pollutants could leach out. There is nothing containing the stockpiles, so they could leach into the surrounding soil. With time, HM present in the drained leachate would bio-accumulate in the soil and surrounding environment due to repeated rainfall. To avoid this, stockpiles would need to be transported to a contractor’s yard, where a water collected treatment system is present. The water treatment systems would collect the leachate, so it can be treated, instead of it draining and contaminating the environment.

# ****Conclusion****

In this research three objectives have been investigated and satisfied. It was found that HMs are present in PA derived RAP samples and do leach. The methodology outlined in this report can also be used for further column leaching testing on PA derived RAP materials.

Several factors such as land use and pavement traffic were identified to influence the concentrations of pollutants observed in the leachate. Factors such as acidity of rainfall and soakage time of RAP have indicated an influence of the leachability of HM metals, however a definite trend was not observed.

As a result of this research, current practises surrounding RAP handling and storage may need to be reviewed. RAP is usually stored in stockpiles without any cover or treatment of the runoff produced. However, this research has identified the presence of HMs suggesting that treatment is needed before RAP is kept in a stockpile; or a new means of storage that doesn’t produce leachate is required. This is to ensure that HMs found in RAP is not released into the environment in the form of runoff. As PA derived RAP has shown to leach HMs, it should also no longer be used as clean fill, or should be treated prior to use.

# ****Limitations and Recommendati********ons****

This research has identified the presence of HMs in leachate from PA derived RAP, however, there were limitations during the testing process. For example, there were limited total soakage duration times to seven days and only testing of two PA derived RAP samples was undertaken. The first flush curve used for analysis only consists of data for a short period of time, whilst past literature has data ranging from two weeks to two years. Existing literature also conducted different leaching methods on the same pavement samples to represent different scenarios. However, due to research project constraints, this research focused on column leaching tests, which simulates more realistic environments.

Therefore, it is recommended that future research is extended into the following areas:

* The column leaching test methodology should be re-examined to produce a more repeatable testing procedure, that can be compared to batch testing or other leaching tests;
* Column leaching tests be repeated, with soakage times increased to find a consistent relationship between soakage time and concentration of HMs leached
* Undertake other known leaching tests like batch leaching tests (which submerges the full sample in solution, usually having a liquid to solid ratio of 20:1), compacted granular leach tests or observing in-field RAP stockpiles and analysing the collected leachates;
* Research to determine safe storage and applications of PA derived RAP; and
* Test other known pollutants such as, volatile organic compounds, polyaromatic hydrocarbons and total suspended solids

**Acknowledgements**

The investigators would like to thank Bernard Jacobsen, Jeff Melster, Stuart Morrow and Marieke Ramsbottom for their assistance and advice in laboratory work.

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