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IMPROVEMENT OF WATER QUALITY BY COARSE GRADED AGGREGATES IN PERMEABLE PAVEMENTS

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

1. INTRODUCTION

The Paper is split into two Investigations and considers three important factors in relation to the enhancement of water quality achieved as contaminated water passes through Coarse Graded Aggregates comprising the base of a permeable pavement. It is based upon experiments conducted on a permeable car park/sports training area at Rainey School in Northern Ireland. A feature of this work is that it is the result of collaboration between the School and a nearby major UK permeable paving manufacturer. The two school pupils who undertook the research were the winners of an essay competition on permeable paving. Their prize was to present their research findings at the 9th International Conference on Concrete Block Paving in Buenos Aires. They have been mentored by Professor Knapton throughout.

The three water quality matters considered are temperature (Investigation 1), hydrocarbons and heavy metals (both measured during Investigation 2). These properties were investigated by testing contaminated water, introducing it into the School's permeable pavement and measuring the changes at the discharge point. The contaminated water was introduced by discharging water taken from a large sump in the vehicle wash bay of Magherafelt District Council. It is representative of water commonly encountered on public highways and was applied using large slurry tanker. Data was collected between January and July 2009 in order to investigate the effect of temperature.

2. DETAILS OF TWO INVESTIGATIONS

Urban runoff is surface runoff of rainwater created by urbanisation. Urbanisation is the outward growth of urban areas at the loss of rural areas. This loss of natural drainage areas where rain soaks into the ground gives rise to an increased volume of surface water runoff to conventional drainage systems, which during extreme weather conditions become overloaded with sometimes disastrous consequences.

Many existing sewage systems have been designed without taking climate change into account. As climate change progresses with increasing extremes of weather, more intense rainfall is likely to stretch the capacity of pipe networks and cause urban flooding.

Permeable paving systems can play an important role to play in cushioning the surge of surface water drainage and thus enable the existing sewage system to cope. Instead of replacing permeable green areas with traditional impermeable surfaces to give the problems described above, the permeable paving systems allow rainwater to soak through them thereby preventing a storm surge of rainwater runoff. In addition, the aggregate below the paving acts as a trickle filter, imitating reed-beds in wetlands and removing harmful pollutants passing through. Analysis of water exiting these systems shows it to be as clean as water released from a modern sewage works.

The way in which permeable paving reduces the impact on the environment of the three factors listed below was investigated. All tests were carried out at a school car park which was surfaced with a permeable paving system without a geotextile layer, constructed by Tobermore Concrete. The aim of the experiment was to show that a SUD System without a geotextile layer is effective in bioremediation.

- Water Temperature.
- Concentration of Heavy Metals in water.
- Concentration of Hydrocarbons in water.

2.1 Investigation 1 - Temperature

"Identifying the Relationship between Subsurface Temperature of the Car Park without a Geotextile Layer and Atmospheric Temperature of the Area".

2.2 Hypothesis for Investigation 1

It is expected that the thermal properties possessed by the car park allow it to act as a buffer to changes in temperature. In extremes of atmospheric temperature, we predict that the car park will reduce this fluctuation in outlet water temperature. This will provide a more stable water temperature for the ecosystem that the water discharges into. At higher temperatures, water will contain less dissolved oxygen, with a resultant affect on biodiversity. This "buffer" effect on the water flowing through the car park will reduce the temperature of the outlet water meaning that it can contain more dissolved oxygen and therefore support more aquatic life.

2.3 Method for Investigation 1

1. The manhole covers were lifted from the surface of the car park.
2. The temperature probe was inserted to a depth of 150 cm within the car park.
3. A datalogger was used to record the temperature of each inspection point and the temperature of the outlet pipe to 1 decimal place.
4. The air temperature of the area was also recorded.
5. The results were displayed in the form of a graph, where the air temperature was plotted against the mean subsurface temperature for each session (see Figure 2).

2.4 Results for Investigation 1

This data was acquired through our primary research and shows the temperature readings taken for the experiment over an extended period of time, totalling to 39 sessions.

Table 1.

SESSION NO.	1	2	3	4	5	6	7	8	9	10
Manhole 1	11	5.7	9.7	10.6	7.2	8	8.9	6.7	4.8	2.9
Manhole 2	7.8	3.8	7.9	7.2	6.7	6.9	8.5	5.6	5.6	3.8
Manhole 3	7.7	3.9	8	7.6	7.9	6.8	8.5	5.2	6.1	3.3
Manhole 4	7.8	3.8	8.1	7.8	7	7	8.5	5.7	6.2	3
Manhole 5	7.3	5	7.8	7.7	7.1	7.1	8.3	5.4	5.6	4.2
Exit pipe	7	4.9	7.5	7.3	6.9	7	7.7	6.2	6.3	4.6
Mean	8.1	4.5	8.1	8	7.1	7.1	8.4	5.8	5.8	3.6
Air temp	9.8	2.8	9.7	9.7	9.6	9.4	8.8	4.6	4.9	0.2

Table 2.

SESSION NO.	11	12	13	14	15	16	17	18	19	20
Manhole 1	3.3	3	5.1	5.6	8.4	7.2	6.7	6.2	6.6	6.5
Manhole 2	3.6	3.5	5.3	5.6	7.6	7.2	6.5	6.1	6.6	6.7
Manhole 3	3.9	2.7	5.5	5.7	7.5	6.9	6.3	6.4	6.9	6.7
Manhole 4	4	2.8	5.6	5.7	8	7.1	6.5	6.8	7.4	7.4
Manhole 5	4.8	3.8	5.2	5.6	7.6	7.2	6.8	6.7	7.4	7.2
Exit pipe	5.1	4.8	5.9	6.2	7.3	7.1	6.9	6.1	7.3	7.1
Mean	4.1	3.4	5.4	5.7	7.7	7.1	6.6	6.4	7	6.9
Air temp	3.6	2.1	6.7	7	8.6	8.8	5.6	5.9	7.6	7.2

Table 3.

SESSION NO.	21	22	23	24	25	26	27	28	29	30
Manhole 1	6.7	9	6.1	7.2	7.9	7.8	8	8	17.5	16.8
Manhole 2	6.8	8.5	6.4	7.1	7.7	8.1	7.8	8.3	17.2	16.5
Manhole 3	6.9	8.4	6.2	7.1	7.7	7.9	8.1	8.4	16.9	16.9
Manhole 4	7.6	8.5	7.8	7.8	8	8.8	8.7	9	16.8	17.1
Manhole 5	7.3	8.4	7.7	7.5	7.7	8.2	8.4	8.8	16.9	16.9
Exit pipe	6.9	7.8	6.9	7.6	7.7	8	8.1	8.5	16.3	16.8
Mean	7	8.4	6.9	7.4	7.8	8.1	8.2	8.5	16.93	16.83
Air temp	6.6	7.3	5.2	6.7	7.7	7.7	8.2	8.9	17.1	18.2

Table 4.

SESSION NO.	31	32	33	34	35	36	37	38	39	
Manhole 1	21	20.8	19.8	18.2	20.6	17.3	18.1	20.1	18.8	
Manhole 2	20.1	20.8	20.1	18.6	20.3	17.5	18.4	19.4	18.6	
Manhole 3	18.4	19.3	19.1	18.8	20.1	18.1	17.4	19.1	18.8	
Manhole 4	18.6	19.2	18.9	17.9	19.7	17.9	17.5	19.2	18.1	
Manhole 5	17.9	18.9	19.7	17.7	18.5	17.9	17.3	18.9	17.9	
Exit pipe	16	17.6	18.2	18.1	18.7	17.5	17.3	18.8	17.6	
Mean	18.7	19.4	19.3	18.2	19.7	17.7	17.7	19.3	18.3	
Air temp	21	21.2	20.9	19.1	21.2	18.6	20.9	19.1	18.7	

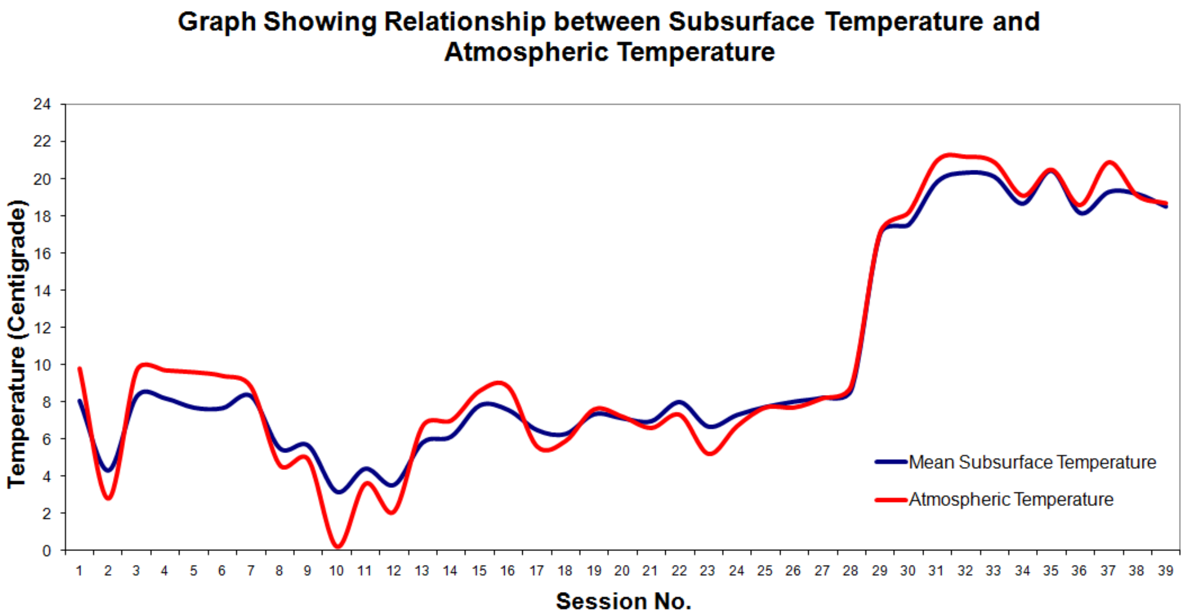

Figure 1. Difference between the mean temperature of sub-surface of the car park and the air temperature at the time of each recording.

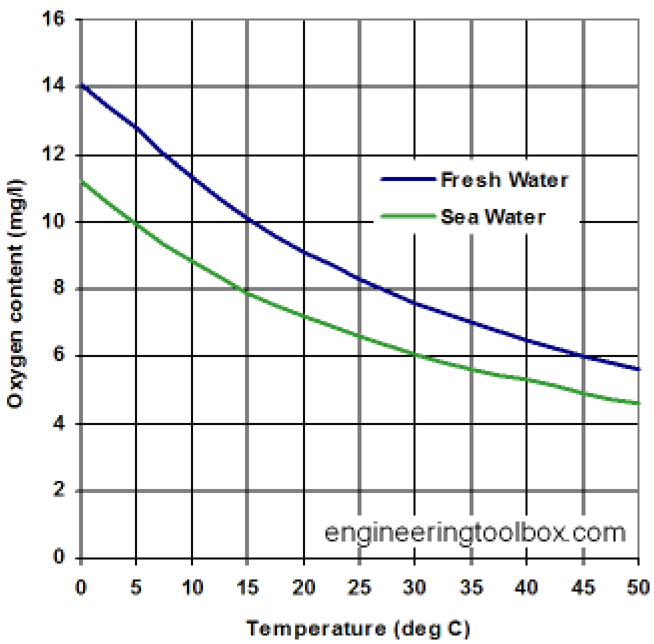

Figure 2. Relationship between Temperature and Oxygen Content.

2.5 Conclusion from Investigation 1

The results of this experiment support the hypothesis. The SUD System clearly acts as a temperature 'buffer' to smooth the sharp changes in temperature that occur in urban areas. These changes occur for a variety of reasons, for example; sunlight may only strike a surface a few hours a day, due to the positioning of taller buildings surrounding it, while precipitation can fall on it at any time. For this reason, it is important for the car park to reduce these temperature fluctuations when possible, to minimise the changes in temperature of the output water as it flows into streams and rivers.

The results can be divided into two distinct sections, where the first section (Sessions 1 – 28) had generally lower atmospheric temperatures that the second (Sessions 29 – 39). In both the system successfully buffered the atmospheric temperatures to produce a much more stable set of results. This buffering occurs because as the water passes deeper into the system, the temperature fluctuation of the ground decreases and becomes more stable. If the precipitation that reaches these depths is of a higher temperature that the ground, it will be cooled, and if the water is of a lower temperature, it will be heated.

The higher temperatures of rainfall caused by the 'Urban Heat Island Effect' will be minimised by the system to produce temperatures closer to those which would have been present in the area before the town or city was developed. As the potential dissolved oxygen content of water is directly linked to the temperature of the water, if precipitation of a higher temperature is allowed to enter the ecosystem, it will have extreme consequences for the environment. Urban runoff from traditional bitumen surfaces will be of a higher temperature than output water from a SUD System. This occurs for two reasons. Firstly, the black colour of the bitumen surface will radiate much more heat into the surface water than the lighter coloured paving stones on the surface of the SUD System. Secondly, the water from the traditional surface is immediately transferred into a storm drain and into the environment, maintaining its relatively high temperature. However, our results prove that water passing through a SUD System will be buffered to reduce these temperature changes. This means that high temperature precipitation is cooled by the system, and also that water is kept from becoming too cold at extremely low atmospheric temperatures.

Waterways containing low amounts of dissolved oxygen will have a lower biodiversity than those containing high amounts of dissolved oxygen, for the simple reason that organisms require oxygen to survive. Waterways with a low dissolved oxygen content will be home to species such as bloodworms (*Glycera dibranchiate*), whose presence is an indicator of low water quality. Water with a high dissolved oxygen content may contain stonefly nymphs (Order: Plecoptera) whose presence indicates an area of high water quality. As mentioned before, water with a high temperature will have a lower potential dissolved oxygen content that water of a low temperature. As the car park lowers higher temperatures of water, it helps the environment by ensuring that the output water to streams and rivers has the maximum potential to dissolve oxygen. For example, in session 37, the atmospheric temperature was recorded at 20.9^{o}C, and the mean subsurface temperature recorded at 17.7^{o}C, meaning that the SUD System caused a temperature reduction of 15.3%, and raised the potential oxygen content of the water by 6%. Other dissolved oxygen figures can be calculated by using the chart in Figure 2.

2.6 Evaluation of Investigation 1

The data was collected in the morning, and the car park would have undoubtedly undergone temperature fluctuations throughout the day.

If more results were collected, a deeper conclusion could have been constructed, explaining the constraints of the buffering effect of the system, but we believe that there is sufficient evidence from this experiment to ensure its reliability.

There is great potential for Sustainable Urban Drainage Systems to become mainstream in future projects, owing to the similar costs to traditional systems and the great advantages they provide for the environment, but the benefits will be limited unless this style of surface becomes widespread in existing urban areas.

3. INVESTIGATION 2 – HEAVY METALS AND HYDROCARBONS

"Comparing the Efficiency of a SUD System Containing a Geotextile Layer with a Different System without a Geotextile Layer at Removing Ecologically Damaging Heavy Metals and Hydrocarbons".

3.1 Hypothesis for Investigation 2

It is expected that a system containing a Geotextile layer will be more effective at removing certain heavy metals and hydrocarbons than a system without a Geotextile layer for the simple reason that the Geotextile layer provides a physical barrier between these substances and the outlet pipe. The heavy metals under investigation are Al, Cu, Fe, K, Mg, Pb, Ni and Zn. The hydrocarbons under investigation are C8-C35, and both aliphatic and aromatic compounds will be identified. Heavy metals and hydrocarbons can come into contact with the environment in two ways. They are either dissolved in the atmosphere and fall as contaminated rainwater, or pass directly from vehicles in the form of motor oils or solid particles. If allowed to pass into the ecosystem heavy metals and hydrocarbons will cause toxicity of water and will bioaccumulate in aquatic species, resulting is fish kill. Hydrocarbons will also reduce oxygen content in water.

Figure 3.

Figure 4.

3.2 Method for Investigation 2

1. A tanker containing contaminated water from industrial vehicles was acquired from Magherafelt District Council (see Figure 3).
2. A sample of the contaminated water was collected for analysis.
3. The car park was sprayed with the contaminated water (see Figure 4).
4. Samples of the exit water were taken after the experiment.
5. Samples were sent for chemical analysis to Queen's University Belfast.
6. From the analysis results, the percentage of hydrocarbons and heavy metals removed from the contaminated water by the car park was deduced.

3.3 Results for Investigation 2

Table 5. The amount of dangerous substances (in ppm) present in both the contaminated and exit sample of water.

SUBSTANCE	AMOUNT OF SUBSTANCE IN CONTAMINATED WATER (ppm)	AMOUNT OF SUBSTANCE IN EXIT WATER (ppm)	PERCENTAGE OF SUBSTANCE REMOVED BY PERMEABLE PAVEMENT (%)
Aluminium (Al)	45.5	1.9	95.8
Iron (Fe)	61	2.5	95.9
Zinc (Zn)	1.2	0.1	91.7
Magnesium (Mg)	40	6.4	84
Potassium (K)	14.1	3.2	77.3
Copper (Cu)	0.4	0.1	75
Nickel (Ni)	0.2	0.1	50
Lead (Pb)	0.2	0.1	50
Hydrocarbons	2.9	0.2	93.1

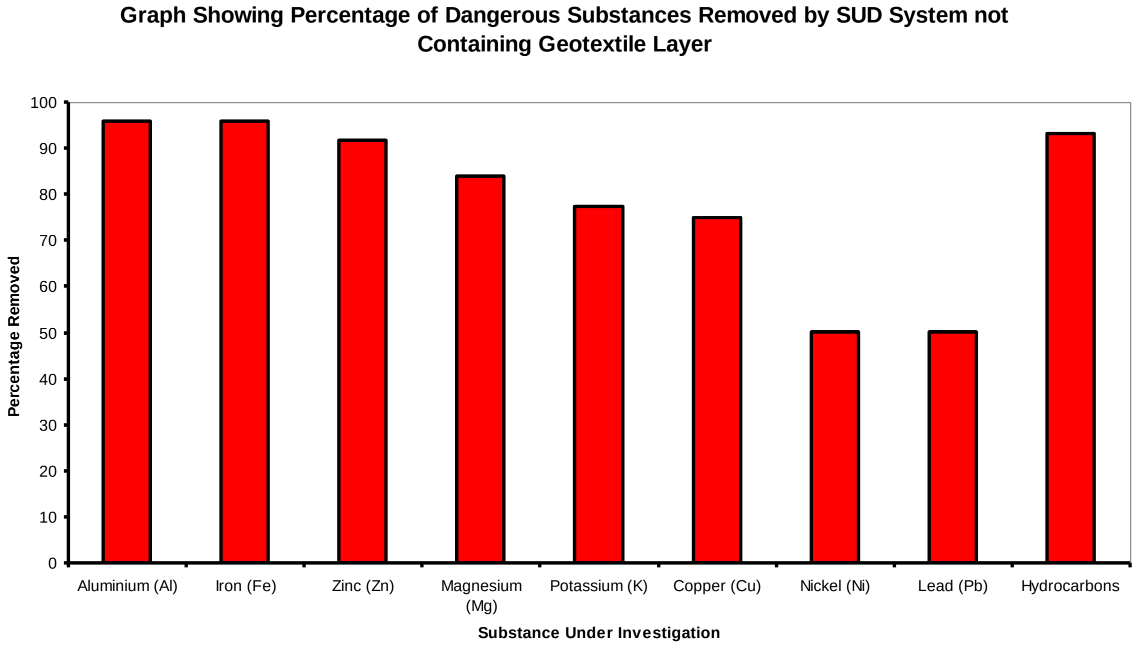

Figure 5. Percentage of removed substances under investigation.

3.4 Conclusions for Investigation 2

The results show that the Hydropave permeable paving SUDS system removed the vast majority of heavy metals and hydrocarbons from the contaminated water which was introduced into the system. The first sample of exit water was collected within an hour of the contaminated water being added. During this short period, any contaminants removed were by physical means, such as adhesion to the aggregate, as opposed to microbial action, simply because the latter take much longer to occur.

The permeable pavement removed 95.8% of the aluminium present in the contaminated water. This vast reduction is beneficial as in acidic soil aluminium will severely hinder the root function of a plant, and aluminium ions will bind to proteins found in fish gills and in the embryos of frogs. Owing to its effect on the environment, it is vital that discharged water must contain the minimum amount of aluminium possible.

The permeable pavement removed 91.7% of the Zinc present in the contaminated water. In soil, Zinc will drastically slow the activity of micro-organisms and earthworms, reducing their ability to break down organic matter. If this matter is not broken down quickly, soil may not obtain the nutrients required enough to support the organisms living in it, so biodiversity may fall.

The permeable pavement removed 84% of the Magnesium present in the contaminated water. This is beneficial to the environment since if magnesium oxide is formed, it can be detrimental to fish life.

The permeable pavement removed 77.3% of the Potassium present in the contaminated water. Although potassium is an essential macromineral for the growth of plants, in larger quantities it will damage germinating seedling and reduce crop quality.

The permeable pavement removed three quarters of copper from the test water. Copper has a similar effect to Zinc, reducing micro-organism activity, but will also cause copper poisoning. This is an example of bioaccumulation, which occurs when an organism on a higher trophic level accumulates a certain chemical after feeding off several organisms on a lower trophic level. It explains the compounded effect of copper on sheep which feed grass with high concentrations of copper.

The amount of nickel present in the test water was halved by the permeable pavement. This is important because of nickel’s effect on both plants and animals. A high nickel concentration in sandy soil is harmful to plants, and if tolerable amounts are exceeded in animals, it can cause various forms of cancer.

Half of the lead was removed from the water by the permeable pavement. Lead is a very dangerous element when introduced into the environment. Not only does it cause brain damage in humans, but will also damage water organisms such as phytoplankton, an important oxygen producer is seas. Lead will bioaccumulate as it progresses up the food chain.

The permeable pavement removed 93.1% of hydrocarbons from the contaminated water. This benefits the environment as hydrocarbons contribute to fish kill. Like lead, hydrocarbons will bioaccumulate up the food chain.

The water collected and analysed is assumed to be derived from the test water added to the permeable pavement since no precipitation fell on the car park for several days prior to the test, ensuring that the output water was not diluted in any form.

The removal of such chemicals is a key factor in sustaining and increasing the biodiversity of our streams and rivers. Overall, the research has demonstrated that permeable pavements when used as an element within a sustainable drainage system are extremely beneficial to the environment in that they have now been shown to remove the vast majority of common urban pollutants. An interesting matter is that fact that these results were achieved in a permeable pavement which did not include a filter fabric: the benefits were all achieved by the mechanical and microbial effect of the coarse graded aggregate roadbase which had been provided primarily as the pavements structural layer.

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