PERMEABLE PAVING SYSTEMS WITH STORING CAPACITY

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SUMMARY

The Netherlands has a long history when it comes to water management. Dating back to the 11th century, the first democratic water boards originated from local authorities, inhabitants and landowners. The creation and draining of polders started at the 1600's. Installation of dams and dikes was of common interest and enabled different kinds of land-use such as farming and rural development.

In the following centuries much effort was spent on strengthening the coastline. Nevertheless, Holland has a rich history of storm surges, like the Saint Elisabeth flood in 1421 that not only took many lives, but also created today's National Park "de Biesbosch." Even in the 20th century the Dutch had to fight the sea. Most famous is the Great Flood of 1953, which killed 1835 people and inundated 2000 km^2 land in the southwest. To prevent future floods, the 'Deltaplan' was created and dams were built with probably the "Oosterscheldedam" as the most famous one.

Because of the position of the Netherlands, delta of European rivers like the Meuse, Rhine and Schelde, water management has become very important in everyday life. The Dutch have managed water well over the last fifty years, but times are changing. Today we are facing the threat of a global climate change. It is expected that Western Europe will face more extreme weather: more rain in shorter periods and longer periods of drought. Another aspect is the continuous growth of urban development, which brings larger areas of paved surfaces and little place for the water to go.

The Dutch Government (Rijkswaterstaat) has issued a new policy confirmed by law which states that rainwater has to be dealt with differently than in the past. In urban situations rainwater should be kept at the site, stored and released slowly. If possible it should be cleaned from oils and heavy metals as well. The new legislation allows once in 100 years only 5% of the urban infrastructure to be flooded with water. In times with more heavy and local rainfall, it is quite a challenge meet this policy. One of the preferred systems is the Aquaflow system, a road construction that can contain much water without destabilization of the sub-base and soil subgrade.

This presentation will address the following in (technical) detail:

- **Road construction stability**
- **Degradation of oils (see more detailed information Dr. Stephen Coupe)**
- **Attenuation of heavy metals**
- **Possibilities to channel and slow down water flows**
- **Storing capacity of water**

1. INTRODUCTION

Most scientists agree that the climate including that of the Netherlands will undergo dramatic changes in the coming decades. These changes will result in wetter winters, drier summers and a rising sea level. At the same time, the Netherlands is subsiding. We will have to contend with conditions of increasingly frequent and dramatic fluctuations in the water supply. The conditions in a country like the Netherlands – dominated by the sea and the mouths of four great rivers, with a high population density and an expanding economy – will more frequently result in enormous problems unless a structurally different approach is implemented to counteract these environmental changes.

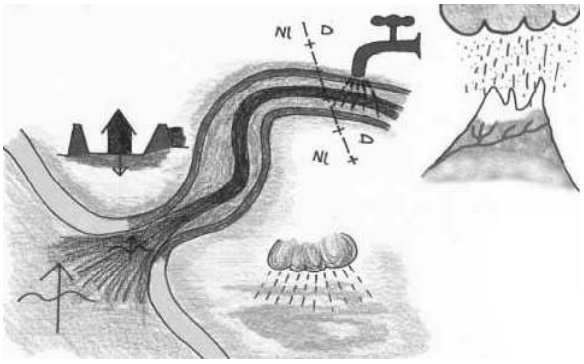


Figure 1. The Netherlands faces unique challenges from climate change.

The greatest source of concern is flooding or breaches of water-retaining structures along the coast Rhine and Maas (Meuse) rivers or in the IJsselmeer lake region. Should this occur, it would result in substantial economic loss, as well as place human lives at risk – the safety problem is undeniable. Water logging is the situation where rivers, streams and ditches, which are not diked, overflow or the water table rises to extremely high levels, however, without posing an immediate danger to people. Recent flooding in the UK, Italy and Spain offer a glimpse of the seriousness of this problem. Extreme lack of water is also a problem and can likewise result in dramatic economic loss. When the shortage persists for an extended period of time, this can lead to substantial problems with regard to the drinking water supply, shipping and dropping water tables.

Great parts of the Netherlands lie below sea level and exist on reclaimed land from the sea. In those so-called polders rainfall must pumped out, in former days that happens with the famous Dutch windmills, nowadays it is mostly done by pump installations. Ongoing urbanization, which causes great streams of water in a very short period of time, demands more and more capacity during peak flows.

The capacity is now optimized to its maximum and is roughly 14 mm rainfall in 24 hours. Frequently it is raining 100-120 mm in 2 hours regionally, which by far exceeds the pump capacity. Due the fact that a great part of the Netherlands is below the sea level (some parts -6.50 meters) the system of ditches, canals and pumps is rather complicated. In many occasions the water must be pumped from one polder into the other (occasionally 5 times) to release the water into the North Sea. Increase of pump capacity in one 'polder' causes immediately problems in the other. This is the first complication.

The Netherlands is located in the delta of the rivers Rhine, Meuse, and Schelde. During spring and times of lasting rainfall in Belgium and Germany, the water level in the rivers will increase severely due to past canalization to improve navigation. In 1990 more than one million people were evacuated from the threatened areas and borders of those rivers. Climate changes will lead to a 40% increase in river discharges in winter and 30% lower discharges in summer. This will complicate the matter in the second place.

The sea level is rising, due to the climate change, and obstructs the flow of rainwater, because of the low tide is relatively shorter than in the past. The sea level has risen 20 centimeters in the past century and will rise even further by an expected average of 60 centimeters in the next century. This will also lead to a rise in the water level of the inland IJsselmeer, which is a fresh water lake. This will complicate the problem in the third place.

Also due to the climate change, rainfall is occasionally heavier and more intense. In August 2002 the rainfall was Almost 50% of the yearly rainfall of about 900 mm That will complicate the problem in the fourth place.



Figure 2. Areas of flooding in The Netherlands if there was no flood protection.

Another complication is the fact that we face more periods of extreme warm weather. Because most of the inland dikes are made of turf covered with clay, they will shrink when the water level is to low. In some cases, seawater was let in to avoid that problem. In the low-lying parts of the Netherlands, soil subsidence will average between 2 and 60 centimeters by 2050.

The Water Management in the 21st Century Advisory Committee recommends the mandatory implementation of the three-step strategy of retaining, storing and draining water. A good mix of technological and spatial planning measures is required to counterbalance the ramifications of rising sea levels, land subsidence and climatic change. A sustainable permeable paving system with storing capacity is one of those solutions.

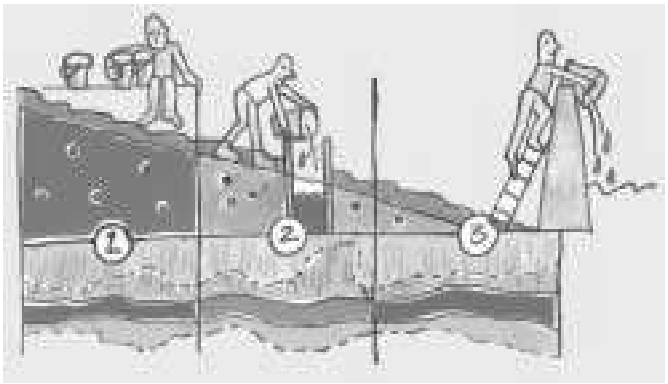


Figure 3. A three-step strategy to avoid passing on of water-related problems.

2. PERMEABLE PAVING SYSTEMS IN URBAN SITUATIONS

As a result of the new policy in new developments 10-20% of the available area should be reserved for water storing. Since land is very scare and expensive in the Netherlands this solution is very costly, particularly in urban situations. In old historic places, with an also historic lack of water storing capacity, the problems are even bigger. Solutions with the possibility of more than one function are highly preferable. The Aquaflow system with storing capacity is one of those and in most cases the most cost effective one. There are two types; the infiltration system and the tanked one, which has SC membrane at the bottom. See Figure 4.

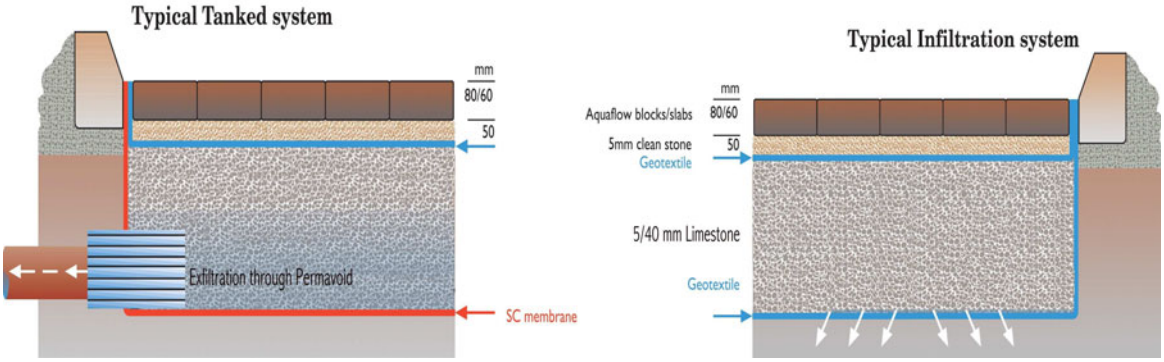


Figure 4. Permeable pavement design options: a tanked permeable pavement system (left) and an infiltration system (right).

One of these two designs is used depending on the sub-grade and the ground water level. The rainwater flows through the joints into the bedding layer, where 90-95% of the heavy metals are attenuated. Those metals mostly come from brakes and tyres (copper and zinc) and also from the gutters on the roofs. Also, bacteria lives in the bedding layer which cleans the water from oil drippings. Below the bedding layer the water is stored in the sub-base for a variable time, depending of the design. The stored water can be released by infiltration or by pipes, which leads the water to other places. Partly the water can be stored for longer time in order to use it for irrigation or other re-use.

2.1 Sub-base stability

Creating storing capacity under the pavement demands open-graded aggregate (35% voids) and those open voids affect the stability of the construction. Particles smaller than 5 mm fill the open voids and give the sub-base good stability. The lack of those could cause some severe problems which would be expressed as rutting. The foremost aspect is that the sub-base be compacted very well which means that the material should be very hard (minimum Los Angeles Abrasion value = 20). On the other hand, the material should have extremely high interlock after compaction. The material should not be too cubic so it can create a high angle of internal fraction. Due to the absence of smaller particles the sub-base doesn't exhibit good cohesion, another reason for a proper compaction.

Based on a density of 1700 kg/m^3 a Proctor density should be minimum 104%. 110% is easily obtained in combination with stable soil sub-grades. If one chooses a softer sub-base stone, compaction will suffer with crushed particles decreasing the storage capacity, less resistance against rutting due to the interlocking not taking place properly. Much research has been done to find the proper stone, the right particle shape, the right crushing resistance and optimal grading curve.

After having found the ideal sub-base stone, sub-base material was tested at the Technical University of Delft, (see presentation Dr. ir. M. Huurman,) and the Road Research Laboratory in the UK (field tests). The material had an increasing angle of internal friction as a result of increasing the axle loads, and had a good resistance against deformation/rutting when well compacted. The major threat is the lack of cohesion, which influenced the strength of the sub-base. Greater thicknesses of the sub-base could take heavier loads but the limit is about 12-13 tons.

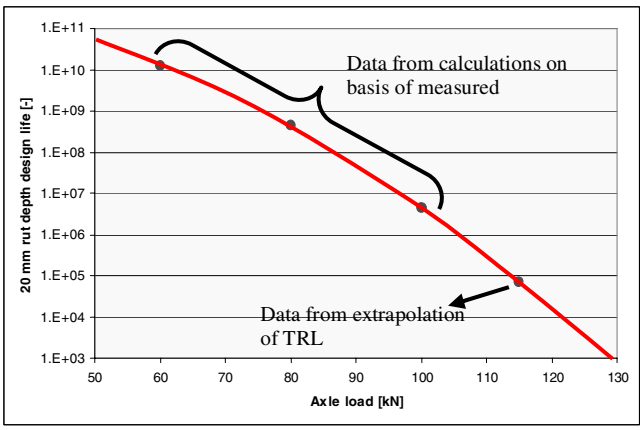


Figure 5. Load-rutting relationships of open-graded sub-base aggregate tested at the Technical University of Delft.

2.2 Degradation of oil

Under the bedding layer a special geotextile is placed. This fabric controls and slows down the water flow through the slots of the pavers and separates the bedding layer from the sub-base, it forms an ideal living area for the bacteria that degrades the oils. It also acts as a separator for the oil and water

Research has been done by Coventry University (Pratt, Coupe et al.) on how much oil per m^2 can be absorbed by the bacteria. Extensive testing has been done over more than 10 years and first was assumed that an amount of 125 mg/m^2/year was degraded but on an attempt to overload the system the conclusion was that the capacity was more than 750 mg/m^2 /year.

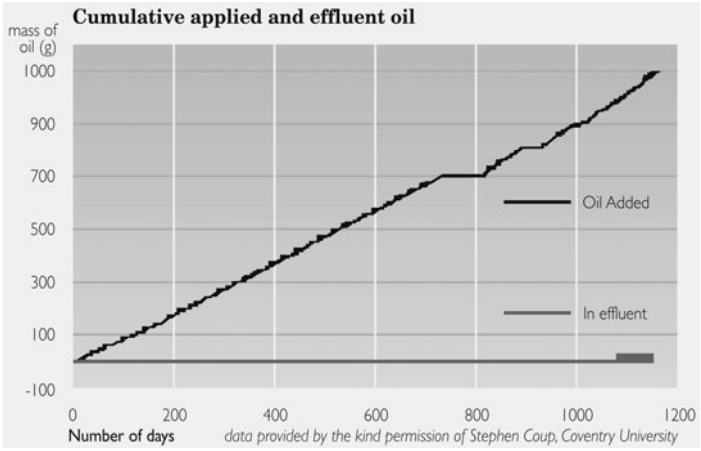


Figure 6. Applied and effluent oil from permeable Pavement research by Dr. Stephen Coupe.

One of the most important conditions was the kind of geotextile; the bacteria should be able to survive there under harsh circumstances. (See presentation by Dr. Stephen Coupe). Just a simple geotextile will not be sufficient. If the geotextile lets the water through too quickly the oil will not be separated, if it slows the flow too much the surface will flood. Another issue was how the bacteria should react in winter in combination with de-icing salt. About 80% of the first bacteria population died, with only 20% survivors, but those survivors built up a resistance against salt and created a new colony.

The bacteria were also able to handle glyphosates like Round-up, commonly used against weeds. As a result there was creation of resistant populations of bacteria in the bedding layer, just on top of the geotextile. Oil drippings from traffic were handled and runoff could be drained in the bottom or led to ditches, canals, ponds, etc. without any effect on water quality. Normally this runoff water should be treated in wastewater sewage plants.

2.3 Attenuation of heavy metals

Heavy metals in the water are a major threat in the future. In Europe is coming under law the new guideline for water, which is very severe and demands a very high quality of water in canals and lakes. Industries should improve their processes and maybe some well-known metals as Zinc and Lead will be prohibited. Alternatives must be found.

In the mean time tyres are still vulcanized with zinc and copper is used in the brakes of cars. Also gutters and roofs are made of those materials. Normally run-off water from area with more than 500 vehicles passages should be fed to the sewage plants, which have only a small spare capacity. If those heavy metals could be attenuated by the Aquaflow system, it would be a major step forward in solving the problem. Research done at the Abertay University in Scotland (Jeffries et al.) shows that most heavy metals are attenuated by the 50 mm bedding layer, directly under the pavers. The choice of geotextile in this case is also and very important, it must slow down the flow of the incoming runoff water to enable those metal ions to attach to the fine particles on the bedding grit and the biomass. A certain amount of silts on the grit helps also to a certain extent. Normal bedding material from quarries could be used, as long it is hard enough to withstand the stresses from axle-loads. In most cases we choose the same material as the sub-base, which is high quality crushed limestone. The results were good; most heavy metals were attenuated at a rate between 90-95%, in some cases even slightly better. The concentration is shown is Tables 1, 2 and 3.

Table 1. Percent copper removed

	SYSTEM A			SYSTEM B		
Date of application	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
15-Mar 2003	99	99	99	97	95	98
17-Mar	91	94	93	89	89	83
19-Mar	89	97	80	82	91	88
21-Mar	81	93	83	94	86	96
24-Mar	95	95	95	93	93	91
26-Mar	96	97	97	95	85	91
27-Mar	97	96	97	96	96	96
01-Apr	96	96	97	97	97	94
02-Apr	99	96	99	97	96	95
04-Apr	96	97	99	96	96	98

Table 2. Percent zinc removed

	SYSTEM A			SYSTEM B		
Date of application	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
15-Mar	73	73	70	84	85	88
17-Mar	66	64	70	77	88	84
19-Mar	39	61	0	2	83	67
21-Mar	0	57	37	92	92	91
24-Mar	27	32	36	73	93	91
26-Mar	2	2	45	85	67	63
27-Mar	11	37	36	75	78	85
01-Apr	50	59	79	76	85	84
02-Apr	88	75	83	95	95	92
04-Apr	65	85	84	92	92	94

Zinc is a troublesome metal, which could be soluble again when salt is used during winter de-icing. Further research should be done in this area. The other metals such as nickel, lead, cadmium show similar levels of attenuation as those obtained for copper.

Table 3. Pollutant concentrations used in Simulation 1 (from CIRIA, 1994)

Pollutant	Dose concentration (mg/l)
Cadmium	0.012
Copper	0.028
Lead	0.399
Nickel	0.144
Zinc	0.479
Sodium chloride	4

N.B. The metals concentrations used in simulation 2 were all 1 ppm.

In addition to the metals, sodium chloride and sediments were also added. Sodium chloride is the most commonly used de-icing agent on roads, and as there is some evidence that it affects the solubility and mobility of metals (CIRIA, 1994); it was decided to include it in the simulation. As with the metals, an identical dose was used for each system.

During the tests and on further research done, we assume that the environment has a background concentration of about 8 pbb. We came to that conclusion by comparing the analysis of fresh water in Scotland as well in the Netherlands. Compared to the legislation on drinking water by the World Heath Organization (WHO 1993), the water out of the system is mostly excellent, thus promising.

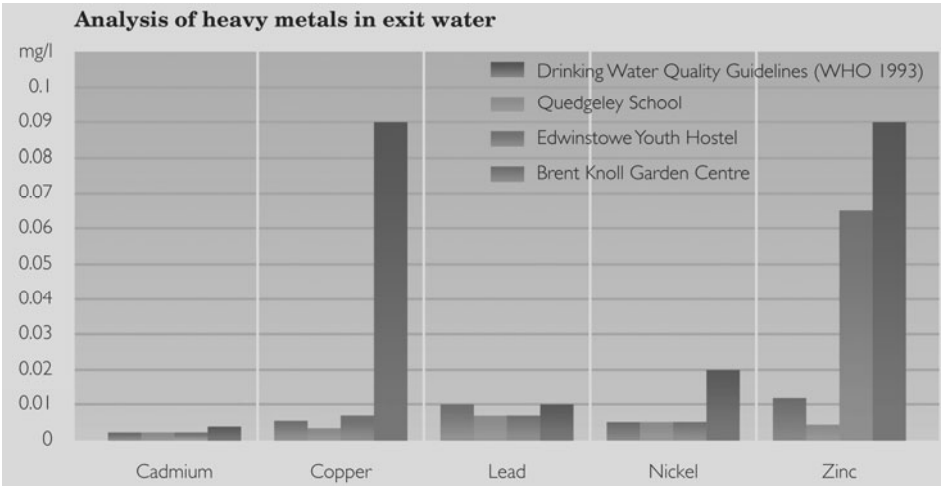


Figure 7. Comparison of WHO drinking water quality guidelines to effluent flow from permeable pavements.

2.4 Velocity of run-off water in the Aquaflow sub-base

Although the Netherlands is known as very flat, there are some hills. Retaining water in those areas is difficult because gravity forces the water downhill at uncontrolled speed. And in the case that the

amount of water exiting out the system is less than the downhill water flow, one could face flooding for a long time. Keep in mind that in some storms the rainfall by far exceeds the local pump capacity.

Therefore it is useful to know more about the speed of the flows in open granulated sub-bases. Unfortunately there was very little information in literature to fill this gap in knowledge, so field tests were executed to provide answers. The sub-base was installed in a large trailer, properly compacted and at one end of the trailer a shower was installed. During approximately 5 minutes the system was, locally under the shower, filled completely with water. Measurement over time of the outflow at the end of the truck was done at various slopes. The general feeling during the test was that there was just a little difference in speed at various slopes and the measured thickness of the water layer was only 30- 40 mm.

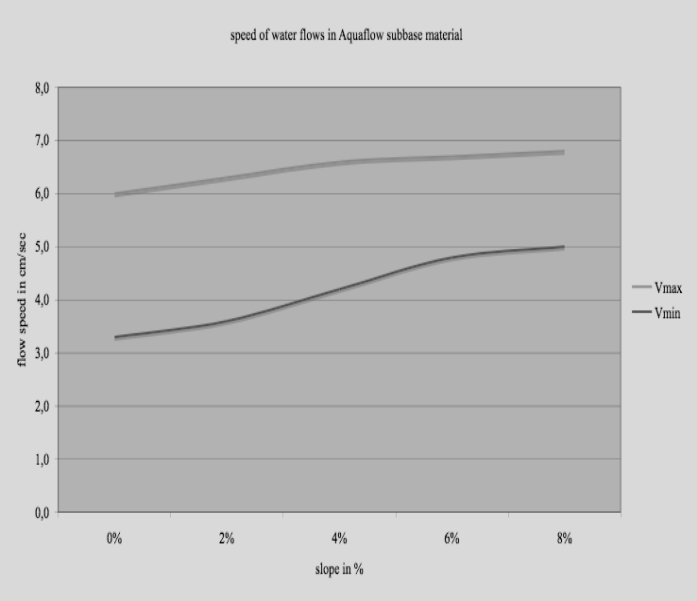


Figure 8. Relationship between flow velocity and sub-base slope in permeable pavements.

This was the first indication that the water flows at the almost maximum speed in open graded sub-bases. After gathered all the data, calculations shows that indeed the speed various only a little at various slopes (see Figure 8). Further research will be carried out at HRD Wallingford (UK)

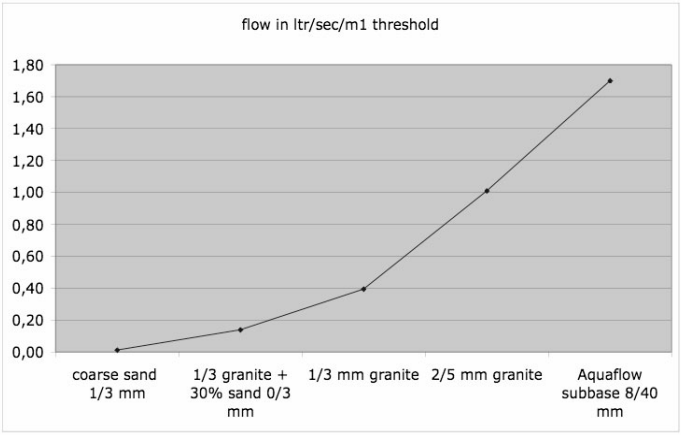


Figure 9. Flow rates for various aggregate materials.

Knowing that water flows through open graded sub-bases with the speed of about 200 m/hour led to the conclusion that in a relatively short period a lot of water is gathered at the downhill side of a 1600 m long and 5 m wide road with a 2% slope and no possible infiltration. For example, 50 mm of rain falls in one hour (very common in the Netherlands) followed with another 50 mm in the remaining 7 hours. This means an amount of 800 m^3 of water after 8 hours. The Water Board allows a release of about 10 m^3/hour (about 2.5 ltr./sec/ha), which means that during the 8 hours, 80 m^3 is released and 800 m^3 received at the downhill side. The storage capacity at 2% slope is only 37.5 m^3, and as a result the whole area downhill is flooded with 682.5 m^3 of water.

The solution is to build dams in the sub-base made of the same kind of aggregate material but having a finer grading. The water is moving through those dams with much less speed than through the

normally graded aggregate sub-base. On the one hand flows are slowed down; on the other hand temporary storage capacity is created. Using the same example, one should store 800-80 m^3 = 720 m^3 of water. By creating 20 dams, i.e. 20 retaining ponds of 37.5 m^3 the problem is solved and no flooding will take place if no water is passing through those dams. The sustained release at the lower end is still 10 m^3 an hour, which means a filtration capacity of 0.46 ltr/sec/m1. The suggestion is to make dams from 1/3mm granite or limestone with a filtration speed of 0.40 litres/sec/m1 (See Figure 9).

2.5 Storing capacity of the sub-base material

The percentage of open voids is very important for the storing capacity of storm water. The finer the sub-base, the lower the storage capacity. Finer material enables formation of capillary water. During winter this water is not released and can freeze. As a result, it will expand and de-compact the sub-base. The Aquaflow sub-base has no particles below 5 mm and measured void space is about 35%. This means that with a 400 mm thick construction (including the bedding layer) the system could contain 140-ltr water per m^2. In case of greater demand for storing capacity increasing of the thickness is an option. Every 10 cm increase of the sub-base will store 35 litres of water.

3. CONCLUSIONS

- Water management in the Netherlands changes the design of CBP roads and demands greater attention to proper compaction and insight into the entire construction of the sub-base, the soil sub-grade and the soil beneath.
- The new Dutch design method (M. Huurman, et al.) brings that insight, especially important for open-graded sub-bases.
- Oil degradation will improve the water quality and avoids the transportation to and treatment at sewage works at large costs.
- Attenuation of heavy metals in the beginning of the “water pipeline” gives better control and makes easy cleaning possible.
- Water storage and use as a road gives economical advantages.
- Flooding can be controlled if properly designed; enough insight about the behavior of the water flows is available.
- Other uses of retained water are possible, especially in other countries with different needs.

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