Evaporative Pavements BMPs

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Abstract

This paper describes the use of permeable paving evaporative systems as a disposal method for surface water; particularly they have potential for use where the runoff contains contaminants. The development of two systems is described and the predicted and measured performance is evaluated from data collected.

Whilst heavily contaminated fire training water from the proposed Fire Training Ground at Jersey Airport, Europe, could be discharged to the public sewer, there was no capacity for rainfall runoff. Moreover, runoff from the vehicle manoeuvring area with lower levels of non-biodegradable fire fighting foam contamination was not permitted to be discharged to watercourse. To handle the rainfall runoff a unique disposal system was developed where runoff percolates through a permeable block paved surface and is stored in a sealed geocellular structure below the pavement. Water from this cell is pumped up and jet sprayed back onto the pavement where solar radiation and wind generate evaporation. It was also realised that the stored water could be harvested for fire training.

Project feasibility was firstly determined by running a small scale evaporation model for several months; this established that significant evaporation could be achieved. Secondly, a computer model was developed to simulate the annual inputs from rainfall and losses that could be achieved by evaporation as well as investigating the use of harvested rainwater for fire training. A key model output was the volume of seasonal cell storage needed. The Penman Monteith open water evaporation equation was used to model evaporation loss. A real time computer control system was developed to match the rate of spray application to the continuously changing evaporation rate calculated from the prevailing weather conditions.

The Fire Training Ground was constructed and opened in September 2004 and the weather conditions, spray rates and stored volumes for the system have been continuously recorded. Analysis of the data has shown that the evaporative equation is valid. Spray duration has been optimised by matching the application rate with the daily pattern of solar heat gain and wind generated evaporation potential, improving performance. The improved understanding of application rates has allowed minimisation of the already small pumping energy inputs, hence enhancing the sustainability of the system.

The Fire Training Ground project has established the viability of spray on pavement evaporation as a disposal method for contaminated water on a constrained site. Collection of data relative to the systems performance has allowed for its monitoring and optimisation.

A second evaporative system under development involves the enhancement of the evaporation within a sealed storage cell below a permeable pavement by passive ventilation. The use of water retentive lamina layers within the cell increases the surface area of evaporation. A trial rig was constructed and monitored for a year and the evaporative losses compared to rainfall. The losses within the lamina system averaged 43% of incident rainfall over the trial period. The system has potential for further development for use in the management of runoff from constrained sites with a temperate climate.

Jersey Airport Fire Training Ground Redevelopment

The Island of Jersey is located in the English Channel, between the United Kingdom and France, in Europe and its Airport serves a million passengers a year. Up to 1994, Jersey Airport Fire Training Ground (FTG) was used for fire fighting training with water and foam on simulated aircraft on an unpaved and unsealed surface. As a consequence, hydrocarbons and foams contaminated the ground below. The fire fighting foam used was AFFF, like all foams it has high BOD, however AFFF also contains Perfluorooctane sulfonate (PFOS)[1] a persistent substance that bioaccumulates. PFOS is now found in the environment from the Artic to the Antarctic. European governments, including the UK, now regulate its use (Directive 2006/122/ECOF).

As a consequence of the contamination, adjoining drinking water wells became visibly contaminated with foam, leading to suspension of fire training with foam and the need to provide mains water supplies to affected properties. With the introduction of the Water Resources (Jersey) Law 2000 there was a requirement to remediate the site and a condition placed on the remediation that any replacement fire training facility would not contribute to further pollution of the site. The development of the new facility was constrained by a prohibition on the disposal of surface runoff to watercourse or to groundwater (because of the water use for public water supply and aquifer flow into a protected area of ecological value).

The disposal of fire training effluent to foul sewer (and hence to the Island's sewage treatment works and then directly to a sea outfall) was acceptable to the sewerage authority, subject to a flow limitation of 0.5l/s. This was achievable with hydraulic attenuation of the runoff generated during fire fighting practice, followed by controlled low rate discharge to sewer in order to meet the Biochemical Oxygen Demand (BOD) loading requirements of the sewage works.

The most challenging element was the disposal of surface water from the 4660m^2 of paved training area because of the large volume of surface water mildly contaminated with pollutants. Disposal to a long sea outfall by culvert was not economically viable because the site was 2km from the sea.

Figure 1. Constructing the geo-cellular runoff storage cell at Jersey Airport FTG.

The only acceptable option that was identified to meet the objectives was the use of an inventive concept of storing the rainfall runoff under the paved area in a lined geo-cellular storage cell (see Figure 1), and then disposing of it by spraying the water onto the paved surface and utilising climatic evaporation (this concept has now been patented UK Patent No. 240681, US Patent Publication No. US2007/0031192 A1) combined with the reuse of some of the water for fire training. The system would contain any contaminants, preventing release to the adjoining environment. A small trial established that evaporation from a wetted surface was a viable method for surface water disposal.

[1] The major producer of PFOS, 3M, ceased production in 2000.

Computer Modelling

Evaporation from open water has been extensively studied and modeled to develop equations that allow the prediction of evaporation under defined conditions of temperature, humidity, wind and sunshine. In particular, the Penman-Monteith Equation is developed and utilized for this purpose (FOA 1998). The relationship between evaporation from a repeatedly wetted pavement surface and open water evaporation had not been researched.

Weather on Jersey is greatly influenced by the fact it is an island situated close to the large land mass of Europe. Frosts are infrequent and despite the Island's proximity to the sea it does not have a strong maritime climate. This is reflected in its moderate annual rainfall (840 mm) and high number of warm dry sunshine days. Also the Airport sits facing the Atlantic Ocean, so there nearly always a wind. All these factors create an annual potential evaporation of 1280 mm. Annual potential evaporation is greater than the yearly rainfall, however, winter rainfall exceeds evaporation requiring storage in the system to balance rainfall and evaporation effects on the volume of water stored in the system cell (Figure 2).

A computer model was developed to simulate potential evaporation with average and extreme annual weather conditions at the site and the storage required when taking into account abstractions from the cell for water reuse. This established the viability of water management utilizing evaporative disposal and water reuse. The mathematical model was used to simulate the day to day rainfall runoff and evaporation and calculate the storage required, accounting for the highest annual rainfall record of 50 years for 2000/2001 (1430 mm). The model also considered the highest recorded monthly and three monthly rainfall values together with a contingency increas of 10% for climate change. A storage volume of 2200m^3 was recommended after allowance for harvesting and other uses described below.

The stored water is then applied to the permeable surface using water droplet sprays as opposed to fine mist sprays, to reduce the risk of drift beyond the boundaries of the site.

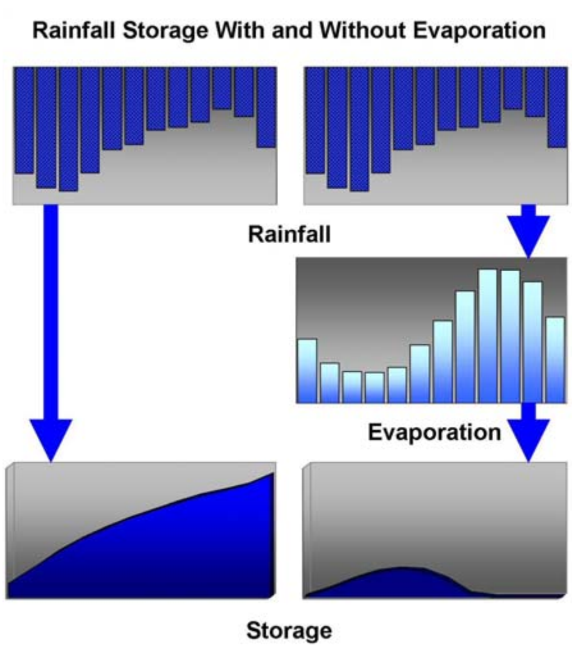


Figure 2. Annual (January to December) Water Balance in FTG Storage Cell

System Operation

A real time computer control system was developed to match the rate of spray application to the continuously changing evaporation rate calculated from the prevailing weather conditions.

Once the fire crews have washed down and left the site, all rainfall and runoff is automatically diverted to an underground storage cell. There are then four destinations for the water:

- the bulk of water is disposed of through managed evaporation;
- some of the water is used to act as a drench for the rig to keep it cool during practice;
- some of the water is used as a wash down after practice; and
- the water can also be used to top up the fire fighting tenders

Evaporation is achieved using a system of 20 water jets placed around the fire training ground (see Figure 3) that apply water from the cell to the paved surface.

They are automatically switched on once a fire practice is completed and the vehicles have left the site, and when the on-site weather station indicates that there is sufficient evaporative potential. Wind speed and direction are constantly measured so that individual jets are switched on only if their spray will fall within the site boundary.

The system of water management is unique in that it contains and manages all runoff within the site, whilst there is a limited discharge to foul for the particularly polluted fire practice runoff, the site has no discharge to local watercourse or groundwater.

Figure 3. One of the 20 controlled, evaporation sprays

A SCADA (***S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition)* system was developed for the FTG which programmes the water management of the site to operate in a predetermined way, in response to information received through monitoring.

Measured Performance of the FTG

The Fire Training Ground was constructed and opened in September 2004 and the weather conditions, spray rates and stored volumes for the system have been continuously recorded. The Penman equation that was adapted for the spray controls for FTG was derived from a Penman type equation.

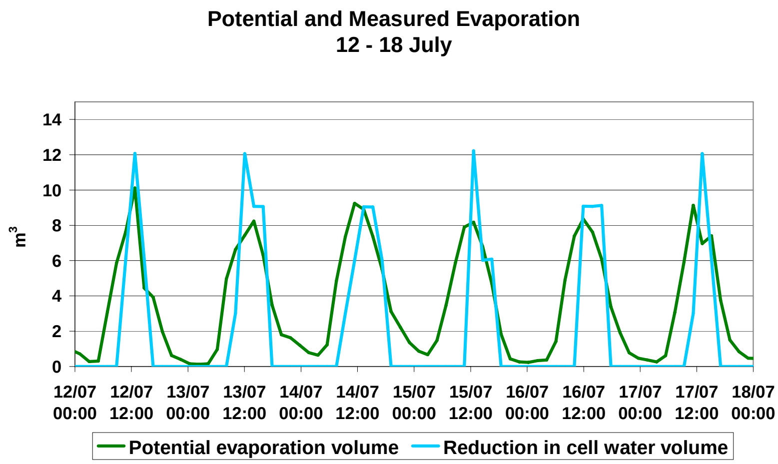
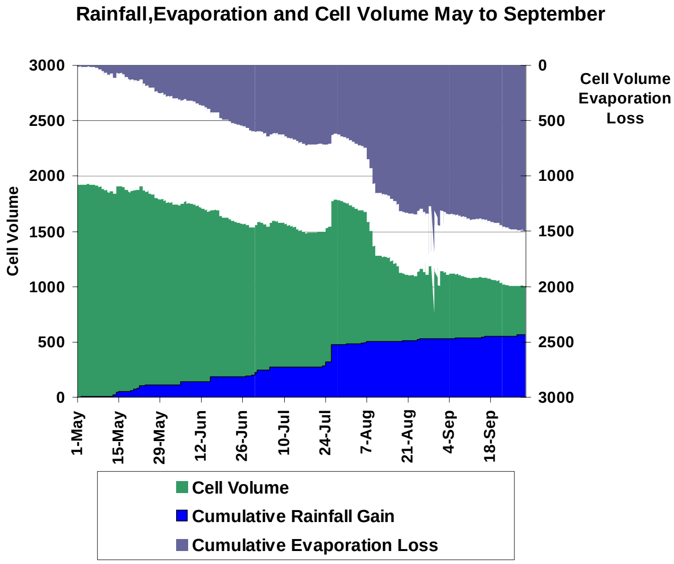


Figure 4. Comparison of potential and measured summer spray on pavement evaporation

The algorithm adopted was appropriate because:

- It calculates hourly losses; to ensure a close match of water delivery to potential evaporation, in real time, to avoid over dosing the surface (causing cooling), or under dosing (missing potential loss).
- The weather in Jersey is generally clear and sunny during the summer months; and the algorithm was developed for a climate of that type.

The accuracy of the algorithm predictions on sunny days is demonstrated in Figure 4 which shows potential and measured evaporation for a sunny 6 day period in July. Evaporation for the less common overcast conditions was less accurately predicted by the formula and this is accounted for in design. The control system was initially set to operate between 10am to 6pm when the potential water loss would be at its greatest. Figure 4 illustrate that there potential water loss available outside this period, especially in the early sunny mornings. The evaluation of the data lead to a decision to increase the period of spray operation to include these periods, to increase performance.



The evaporative losses achieved by the system are illustrated in Figure 5 which shows that the fall in stored cell water volume due to evaporation, accounting for the addition of incident rainfall, amounted to a loss from May to September of 1482m^3 of stored water, which is equivalent to evaporating 537mm of rainfall falling on the area. Due to operational and technical changes the water harvested by the fire service was far less than that envisaged at the design stage and the water loss from May to September is entirely due to evaporation.

The annual energy consumption to run the system cost is estimated as $40, which makes the system a low energy process, and the potential for power generation on site from wind or solar power could be adopted to make the process energy neutral.

Figure 5 Graph of rainfall, cell level and evaporative losses May to September

The experienced gained in the design, construction, running and performance evaluation at Jersey Airport Fire Training Ground has shown that it would be feasible to transfer this water evaporation system to other areas with a similar climate, using the computer model developed. Figure 6 highlights the parts of Britain where prospective water loss would be above 80% of annual rainfall (green) and 100% of annual rainfall (brown). Much of the south and east of the country has evaporation loss potential either approaching or exceeding the annual rainfall.

Figure 6 Map of Great Britain showing areas of high potential evaporation relative to rainfall

Development of Lamina System

Greenfield runoff rates can equate to as little as 10% of rainfall because most of the rainfall is intercepted by plants and evaporated, taken up from the soil by plants as they transpire or is transferred to groundwater. In contrast, urban developments can generate as much as 90% of rainfall as runoff because very little is evaporated to the atmosphere or transferred to groundwater prior to reaching receiving waters. Some sites where recharge to groundwater is not possible (e.g. contaminated sites or those with high water tables) pose problems for disposal where a convenient watercourse outfall is not available or the runoff is not suitable for discharge to a watercourse (CIRIA 2004). Permeable pavements with tanked cells can be used to solve the problem of collection of the surface water runoff, but disposal of the rainwater, which may be contaminated, is still a problem.

The ‘spray on pavement’ surface water disposal system is very effective for the particular application at Jersey Airport but would be unsuitable for developments such as car parks where there are continuous activities on site. The Jersey Airport system did not however take account of the potential for passive evaporation within an underground storage cell. Passive evaporation aims to use the available processes of ventilation (including natural wind energy) to provide evaporation without an artificial energy supply. Testing has shown that evaporation from within a cell is normally very limited, because cells are not usually built with through ventilation and evaporation from water in the base of the cell is limited by the exposed surface area.

A theory was developed that in-cell evaporation efficiency could be enhanced by increasing the evaporative surface area in contact with the airflow. The 'Lamina' method is the use of one or more horizontal layers of water absorbing mats below a paved surface to detain water that has percolated through the pavement. The lamina mat is dried out by evaporation in the ventilated cell and is recharged by subsequent rainfall (the concept has been patented, UK Patent No 240681, US Patent Publication No. US2007/0031192 A1).

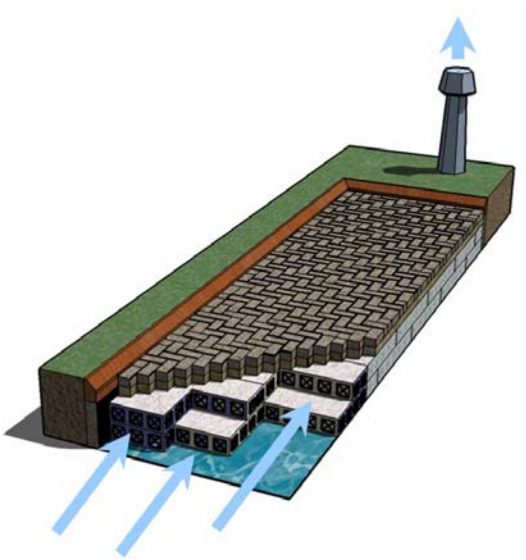


Figure 7 Model of 'Lamina' System

A model of a full-scale element of a car park with a lamina system (Figure 7), and a control without lamina (for comparison) was constructed. Natural wind flow was enhanced by a wind driven revolving cowl. The performance of these trials was monitored and the results show that the Lamina System performance exceeds the system without lamina by a factor of three, over the one year trial period, and the trials are showed that around 40% of the rainfall incident on the surface of the system was evaporated. This is loss is comparable to some vegetated sites. Whilst evaporation was higher in summer, it was strong in the spring and autumn and still significant in winter. Evaporation in the cell is increased by ventilating the cell with an air flow pathway over the cell base, linked to air intakes and flue outlets. This increases the take up of water by the usually unsaturated air throughput.

Conclusions

The Fire Training Ground project has established the viability of spray on pavement evaporation as a disposal method for contaminated water on sites with flow and quality discharge restrictions. Collection of data relative to the systems performance has allowed for its monitoring and optimisation. The low annual energy costs of the system demonstrate that it is a sustainable system.

In-cell evaporative enhancement systems have the potential to reduce disposal volume problems on sites with significant constraints for off-site discharge quality and quantity, particularly where infiltration to ground is not appropriate.

References

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