TREATING CONTAMINATED STORMWATER USING VIROFLOW™ TECHNOLOGY

TECHNICAL PAPER

Stormwater runoff

virotec.com

INTRODUCTION

Contaminated (or polluted) stormwater poses a significant environmental threat in rural and urban environments. Given the sheer volume and force of some stormwater events, the environmental and health impacts of contaminated stormwater can be devastating and far-reaching. While traditionally thought of as a rather benign form of water, stormwater poses a number of dangers to the environment irrespective of whether it occurs in rural or urban areas, and is a major cause of concern to human and animal health. Left untreated (which is almost always the case) or even marginally treated (which is almost never the case), stormwater can be a substantial source of "downstream" contamination.

This Technical Data Sheet introduces the issues associated with stormwater control and management, and explains some of its common contaminants. Furthermore, the Technical Data Sheet presents a viable and successful way to treat contaminated stormwater, and details the results of six commercial applications where this has been effectively achieved using ViroFlow™ Technology.

BACKGROUND

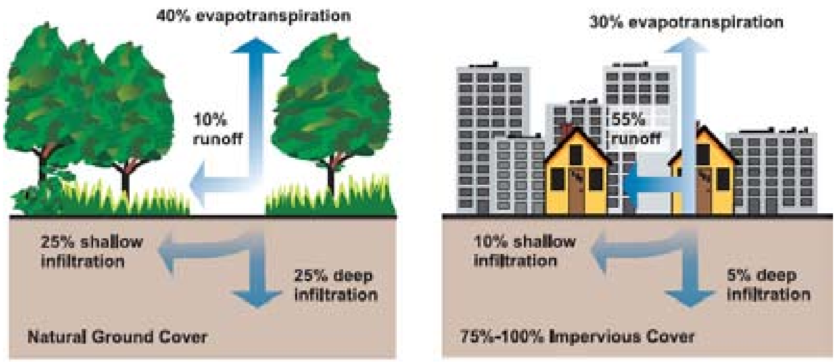
In the simplest terms, stormwater is water which originates during rain events, and includes all liquid wastes that enter the stormwater system. In addition to being the obvious water from rainfall, stormwater can in fact be a liquid waste which originates from any one or more point or diffuse sources, and may come from agricultural runoff from fields, agricultural runoff from farms such as Concentrated Animal Feedlot Operations (CAFOs), urban runoff from residential areas and industrial operations, and runoff from commercial car parks, highways and roads. These sources of potentially dangerous contaminants pose various levels of risk to the environment and to the health of humans and animals.

As shown in Figure 1, when rain falls on natural ground cover, such as grass, soil, shrubs and trees, about 40% of the water evaporates (via evapo-transpiration, which is the sum of evaporation and plant transpiration from the earth's land surface to the atmosphere), 25% infiltrates the ground as "deep infiltration", usually finding its way into the groundwater system, 25% infiltrates the ground as "shallow infiltration", migrating sideways through the soil mantle and leaching into creeks, streams, rivers and eventually oceans. Only 10% of rainwater that falls to earth becomes stormwater "runoff."

Thus, stormwater that does not soak into the ground becomes surface runoff, which either flows directly into surface waterways or is channeled into storm sewers and drainage systems, eventually discharging to surface waters. This runoff may be contaminated with pesticides, herbicides, insecticides and other man-made pollutants, such as chemicals and heavy metals, but may also be contaminated with naturally forming pollutants, such as animal and human waste, carbon-based plant matter, minerals and metals which form part of the receiving soil matrix, and other sources of organic and inorganic matter.

However, when rain falls on urban environments, such as residential areas, factories, car parks, roads and highways, and sites with compacted soils and clays (which typically have 75%-100% of the surface of the ground covered with an impervious layer), only 30% of the water evaporates (i.e., 40% minus 10% for the lack of plant transpiration), 5% and 10% infiltrate the ground as deep and shallow infiltration respectively (reductions due to impervious ground cover), with fully 55% of the rainwater that falls to earth becoming stormwater runoff.

FIGURE 1: PERCENTAGE OF STORMWATER RUNOFF IN A RURAL SETTING WITH PERMEABLE GROUND COVER (LEFT) AND IN AN URBAN SETTING WITH IMPERMEABLE GROUND COVER (RIGHT)



Stormwater is of significant concern to humans for two primary reasons: one relates to the volume and timing of runoff (such as during a flood or other significant rain event) and the other relates to the presence of potential contaminants that the stormwater might be secreting and carrying. The former cause of concern is a question of water management and control, while the latter is referred to as "water pollution". As noted above, because impervious urban surfaces do not allow rainwater to easily infiltrate the ground, more stormwater runoff is generated than in natural ground cover conditions. This additional runoff can erode watercourses (gullies, drains, streams and rivers) as well as cause flooding when the stormwater collection system is overwhelmed by the additional flow of water. Because water is flushed out of the watershed during the storm event, little rainwater infiltrates the soil, replenishes the groundwater system, or supplies streams and rivers during dry weather.

Pollutants entering stormwater during rain events produce polluted runoff. Human activities typically result in the deposition of various pollutants on roads, lawns, roofs, animal farms and fields, factory work areas, etc. When it rains, water runs off and ultimately makes its way to a creek, river, dam, lake and eventually an ocean. While some attenuation of these pollutants may occur before runoff enters receiving waters (by dilution or dissipation, for example, or by treatment in some rare cases), human activity results in large enough quantities of pollutants entering the stormwater system, thereby impairing and polluting receiving waters.

When an area is developed for industry or residential use, the extent of existing vegetation (such as grasses, trees and shrubs) is greatly reduced. This replacement of permeable, vegetated land cover with impermeable structures and surfaces such as buildings, roads, walkways and driveways, causes an increase in stormwater because less water infiltrates the ground and evapo-transpires. For example, as shown in figure 1, if a permeable surface of 1,000m^2 (10,800 square feet) receives 25mm (one inch) of rainfall, the amount of water leaving the site as runoff is approximately 250L (66 U.S. gallons). If the area is covered with an impermeable surface, this number increases to 1,375L (363 gallons) of runoff leaving the site. This represents more than a fivefold increase in stormwater management and control requirements. If the stormwater runoff is contaminated, there is potential for an exponential increase of contaminants translocating into the environment.

This example shows how five times as much runoff can be expected when a site is converted for residential or industrial development. For an urban development of 1,000 houses with 300m^2 (3,300 square feet) of roof area each, for example, this equates to about 420,000L (110,000 gallons) of runoff, which could have a significant impact on water volumes and velocities entering streams and lakes. Increased volume and velocity leads to reduced water quality due to increased soil erosion.

The addition of urban pollutants, such as car fluids, pet waste, and lawn fertilizer, which are dissolved and carried off driveways, roads and yards are delivered into drainage channels and stormwater systems. When industrial waste and agricultural pollutants are added to this brew, the resulting quality of stormwater can be both toxic and hard to treat.

An example of the problems associated with polluted stormwater can be seen in the following report. In March 2008, the Los Angeles Times and the Santa Monica Daily Press carried articles on lawsuits that have been filed by the National Resources Defense Council and other environmental groups against Los Angeles County and the city of Malibu. According to these reports, concentrations of fecal bacteria, heavy metals, and other pollutants associated with stormwater runoff from Los Angeles and Santa Monica exceed water quality guidelines. The lawsuit is designed to compel Los Angeles County and the city of Malibu to better manage and treat urban stormwater runoff to prevent violations of water quality standards in coastal waters that receive the runoff.

THE PROBLEM OF STORMWATER RUNOFF

In addition to the pollutants carried in stormwater runoff, studies conducted by Australian researchers have identified urban runoff as a cause of pollution in its own right. In natural catchments (or "watersheds"), surface stormwater runoff entering waterways is a relatively rare event, occurring a few times each year and generally only after larger rain events. Before urban development occurred most rainfall soaked into the ground and contributed to groundwater recharge or was recycled into the atmosphere by trees as a result of evapo-transpiration.

Modern drainage systems which collect runoff from impervious surfaces ensure that water is efficiently and effectively conveyed to waterways through underground pipe networks, meaning even small storm events result in increased flows in waterways. In addition to delivering higher levels of pollutants from the urban catchment, increased stormwater flow can lead to stream erosion, encourage weed invasion and can alter natural flow regimes, which native species rely on for a range of activities, including spawning, juvenile development and migration.

An example of soil erosion in agriculture is the main source of nutritent pollution in stormwater runoff

> Pesticides in Stormwater

Pollutants in stormwater can be measured in a variety of ways, including measuring the level of toxicity of pollutants in ecotoxicity bio-markers, such as small fish, worms and shrimp. For example, the January/February 2001 issue of Stormwater contained an article called "The Urban Pesticide Problem" in which its authors disclosed that "urban stormwater runoff was toxic to the zooplankton *Ceriodaphnia dubia*, as shown using a standard Environmental Protection Agency test for assessing aquatic life toxicity in fresh water" (Lee & Jones-Lee, 2005). This toxicity, the article reported, is in violation of the Clean Water Act and, in California, of the Regional Water Quality Control Board Basin Plan objective for controlling aquatic life toxicity.

Toxicity evaluations showed that urban stormwater-associated toxicity was primarily due to the presence of organophosphorus pesticides used on residential properties. The authors concluded that "it is now clear that the aquatic life toxicity problem associated with the use of organophosphorus pesticides on residential properties is a largely unrecognized national problem that needs attention" (Lee & Jones-Lee, 2005). The authors also noted that as recently as the early 1990s, many U.S. stormwaters in urban and agricultural areas contained sufficient organophosphorus pesticides to cause aquatic life toxicity.

In answer to these recognized problems with organophosphates, a number of new pesticides have been introduced. Pesticides that are marketed for home use as replacements for organophosphorus pesticides indicate several pyrethroid-based pesticides are now being used. However, these types of pesticides are as toxic, if not more toxic, to zooplankton than organophosphorus-derived pesticides, and are generally more toxic to fish (Lee & Jones-Lee, 2005). The pyrethroid-based pesticides tend to have much stronger sorption tendencies, and therefore become attached to surfaces more readily or to a greater degree than the organophosphorus-based pesticides.

Some manufactures of pyrethroid-based pesticides have claimed that these stronger tendencies eliminate the stormwater-caused aquatic life toxicity problems associated with organophosphorus pesticides. However, Lee & Jones-Lee (2005) maintain that pyrethroid-based pesticides used in agricultural areas are being found in receiving water sediments for stormwater runoffs from other areas as well, and thus this transmigration of pesticides could be occurring in urban stream sediments as well. The sediments where pyrethroid-based pesticides are being found are toxic to some benthic organisms (organisms which live on, in, or near the seabed).

> Heavy Metals in Stormwater

A variety of toxic heavy metals can be found in stormwater runoff. Depending on the source of the runoff, metals such as lead, chromium, arsenic, iron and copper are not uncommon; asbestos and other silicate minerals (from automobile brake linings) and a range of organic materials are also common.

Lead is one of the heavy metals of greatest concern in urban area and highway stormwater runoff. Its former use as an additive in gasoline has caused widespread contamination of soils near highways and streets, and is routinely found in drains used for stormwater runoff. Also of concern is the continued presence of lead in gasoline at "natural" concentrations to cause highway and street stormwater runoff from some areas to have lead at sufficient concentrations to violate U.S. EPA water-quality criteria and California Toxics Rule (CTR) guidelines for soluble lead in stormwater runoff (Lee & Jones-Lee, 2006). The particulate (or solid, insoluble) forms of lead in this type of runoff can also accumulate in receiving water sediments, such that the levels of lead in the sediments can exceed guidelines for solid waste.

A year-long study of heavy metals in stormwater runoff from ten watersheds in the Upper Newport Bay area in Orange County, CA, showed that some heavy metals exceeded CTR guidelines for soluble lead, and that the stormwater runoff was toxic to Ceriodaphnia (a freshwater zooplankton eco-toxicity marker used as a standard test organism). However, toxicity identification evaluations showed that the heavy metals were not the sole cause of this toxicity. Much of the toxicity was due to the presence of organophosphate pesticides, with likely contributions by pyrethroid-based pesticides (Lee & Jones-Lee, 2006).

> Heavy Metals in Aquatic Sediments

Since heavy metals tend to develop particulate forms (precipitates) in aquatic systems and, for many sources, are in a particulate form that does not dissolve and thus tends to accumulate in soils and sediments. For example, the Los Angeles Regional Water Quality Control Board (LARWQCB) determined that since a sample of Santa Monica Bay sediments contained lead levels above sediment-quality guidelines, the communities in the Santa Monica Bay watershed should spend $42 million controlling lead and other heavy metals in stormwater runoff to the Bay.

> Heavy Metals in Soils

Beginning in the early 1990s, as a result of the increasing recognition that even low levels of lead in the blood of children were detrimental to health, researchers became involved in assessing the public health issues associated with lead and other heavy metals in soils, many of which are deposited there as a result of stormwater infiltration. The initial involvement in the U.S. included work on the Sacramento, CA, Southern Pacific rail yard "superfund" site to evaluate the adequacy of site cleanup methods associated with lead-contaminated soil to protect children living in lowincome housing that was proposed to be constructed at the remediated site.

> Phosphorus and Nitrogen Stormwater Contamination

The development of total maximum daily loads (TMDLs) is causing a resurgence of interest in controlling the excessive fertilization (or "eutrophication") of surface runoff. Nitrogen (N), phosphorus (P) and other nutrients can stimulate the excessive growth of algae and other aquatic plants. Of particular concern are nutrients added through the widespread rural and urban application of inorganic and organic fertilizers.Those operations which fertilize land as part of crop production, fertilize urban lawns, or dispose of waste residues (biosolids, animal manure and compost) on land will be increasingly required as part of nutrient TMDLs to conduct comprehensive and reliable monitoring programs to ensure that fertilizer nutrients and the constituents in their waste do not cause pollution of ground and surface waters.

The widespread dispersal of phosphorus from sewage effluent, industrial wastewater, detergents, and stormwater runoff from urban and agricultural land has played a major part in the eutrophication of many freshwater and marine ecosystems thourghout Europe (European Environment Agency, 2000). The relationship between phosphorus and eutrophication has been known for many years (for example, Bowles & Quennell, 1971; Bressan, 1986; Cartwright et al., 1993), and the role of sewage effluent, stormwater runoff and other point and diffuse sources of phosphorus in water pollution, has been well documented (Jarvie et al., 2006).

In order to help tackle eutrophication in inland and coastal waters, more stringent measures are being applied to, for example, agricultural pollution (Environmental Data Services, 2004; 2006a) and the use of detergents (Commission of the European Communities, 2007), and stricter discharge limits on phosphate (PO_4) concentrations in effluent from wastewater treatment plants (WwTPs) are being imposed by environmental regulators. For example, phosphate consents (or licenses to discharge treated effluent into creeks or rivers) have dropped (or will drop) from between 5.0mg/L and 10mg/L to 2.0mg/L. These limits may be further tightened to 1.0mg/L in more eco-sensitive areas, as recommended by English Nature (Environmental Data Services, 1997).

The need for stricter consents was supported by studies in the United Kingdom on seven lowland river catchments, which have concluded that phosphate in sewage effluent may present an even greater eutrophication risk to the environment than agricultural runoff (for example, Jarvie et al., 2006). This study found that at all 54 monitoring sites there was a strong correlation between soluble phosphate emissions and algal growth, with sewage effluent being one of the main sources of contamination.

These and other findings have lead to a significant increase in the number of water bodies designated as "sensitive" to algal growth and toxic blooms (for example, Environmental Data Services, 2006b), with 297 sensitive areas having been declared in England alone since 1994.

The move to more tightly control phosphate concentrations in discharge water and other sources of nutrient contamination, such as stormwater runoff, have come from the Department of Environment, Food and Rural Affairs (DEFRA), the Water Services Regulation Authority (Ofwat), and the UK Technical Advisory Group (UKTAG) (Environmental Data Services, 2006c), as well as from the water framework Directives of the European Union. For example, UKTAG has advised the government that currently 65% of England's rivers fail current phosphate limits, with lakes being more sensitive to contamination; they predict that up to 70% of English lakes and up to 25% of Scottish lakes risk failure of phosphate limits.

In the UK, UKTAG has estimated that 50% of phosphate contamination originates with stormwater runoff from agricultural activities, 35% from sewage, and 7% from industry (Environmental Services Data, 2006c). The challenge for the water industry is to identify treatment options for phosphate removal which can cost-effectively achieve these newer high quality treatment standards.

The nutrients nitrogen and phosphate stimulate the growth of a variety of types of aquatic plants and cause hypoxia (low dissolved oxygen in water). When present in excessive amounts, these plants can significantly impair the beneficial uses of a water body. Eutrophication leads to the growth of plankton and attached algae, and can also, under certain conditions, lead to excessive amounts of higher aquatic plant growth, such as water weeds (e.g., water hyacinth) and others that are adverse to beneficial uses. Figure 3 presents a summary of some of the algae that are stimulated by nutrients in stormwater runoff.

Eutrophication of water bodies, such as Chesapeake Bay in the U.S., has apparently also led to the growth of certain algae (Pfiesteria) that are toxic to fish. Furthermore, in some situations, either naturally derived nutrients or those derived from agricultural sources lead to red tides, in which excessive growth of certain types of algae, some of which may be toxic, occur.

An area of the Gulf of Mexico is experiencing hypoxia, which apparently is related to algal growth in the surface waters of the gulf. According to the U.S. EPA, the observed hypoxia is strongly correlated with nutrient discharges from the mouth of the Mississippi River. This river drains 40% of the lower 48 states of the U.S. and its watershed is home to almost a third of the U.S. population. The Gulf of Mexico hypoxia has stimulated the Environmental Protection Agency and various state agencies to explore developing nutrient-control programs in the Mississippi River watershed. It has been argued that increased attention should be given to the sources of nutrients in the Chesapeake Bay and Mississippi River watersheds, i.e., the excessive fertilization of land from which stormwater runs off into the bay and the Gulf of Mexico.

FIGURE 3: ALGAE TYPES COMMONLY FOUND IN POLLUTED STORMWATER

Eutrophication of a water body can also stimulate sufficient aquatic-plant growth to impair a water body's fisheries. Although the addition of nutrients stimulates overall fish production, excessive fertilization can also adversely impact the quality of fish, changing the populations from desirable game fish to so-called rough fish, such as carp. The decomposition of excessive planktonic algae can cause de-oxygenation of the hypolimnion of a water body (the dense, bottom layer of water in a thermally-stratified lake) and, if severe, lead to significant dissolved-oxygen (DO) depletion in the surface waters as well.

POLLUTED WATER ALGAE

An example of this type of situation is occurring in the San Joaquin River Deep Water Ship Channel near Stockton, CA (Lee & Jones-Lee, 2006). There, nutrients derived primarily from agricultural sources in the San Joaquin River watershed stimulate sufficient algae to lead to depletion of oxygen to levels below water-quality standards throughout the water column, including surface waters. This situation arises from the biochemical oxygen demand (BOD) of the algae, which exerts an oxygen demand in the water column and contributes to biotic and abiotic oxygen demands in the sediments.

> Pathogen Contaminated Stormwater

Pathogens may also be present in nonpoint-source stormwater runoff, and can be a source of disease if they enter drinking water supplies. Pathogens found in contaminated runoff include: *Cryptosporidium parvum*; giardia lamblia; salmonella; novo virus and other viruses; and parasitic worms (so-called helminths).

Coliform bacteria, as opposed to pathogenic viruses, may also be detected in stormwater runoff. These bacteria are a commonly-used indicator of water pollution, but not necessarily an actual cause of disease. Pathogens may contaminate runoff due to poorly-managed livestock operations, faulty septic or urban sewerage systems, and improper handling of pet waste or medical waste.

CURRENT SOLUTIONS

There are a variety of innovative approaches for dealing with contaminated stormwater runoff. These include changing the permeable to impermeable ratios of surfaces in built-up urban areas. These initiatives can include the use of permeable walkways and car parks, which can take the form of concrete pavers (as shown in Figure 4), plantable and drivable grass products, bricks and recycled tires, as well as asphalt and "poured-in-place" permeable concrete. The goal of each of these products is to increase the permeable-to-impermeable ratio of urban surfaces in the manmade environment, thereby allowing for less than the typical 55% of stormwater runoff to infiltrate the ground as either shallow or deep infiltration.

First developed in the 1970s at the Franklin Institute in Philadelphia, porous asphalt pavement solutions consisting of standard bituminous asphalt in which the aggregate fines (particles smaller than 600 μm or the No. 30 sieve) have been screened and reduced, allow water to pass through the asphalt (as shown in Figure 5). Underneath the asphalt pavement is a bed of uniformly graded and clean-washed aggregate with a void space of 40%. Stormwater drains through the asphalt, is held in the stone bed, and infiltrates slowly into the underlying soil mantle. A layer of geotextile filter fabric separates the stone bed from the underlying soil, preventing the movement of fines into the bed. Porous pavements and asphalts are especially well suited to parking lots. Many large, successful porous pavement installations, including some that are now 20 years old, have been developed in the U.S.

These systems continue to work well as part of a well-conceived and managed parking lot and stormwater management system. Similarly, stormwater attenuation tanks, constructed using modular plastic geo-cellular units, and stormwater permeable reactive barriers (PRBs) are commonly used as part of sustainable drainage and rainwater treatment and reuse environmental management systems.

Example of permeable pavers

TREATING CONTAMINATED STORMWATER

Virotec Global Solutions has developed and implemented a number of ViroFlow™ Technology filter systems for different industrial applications during the last seven years. ViroFlow™ Technology is Figure 5: Schematic of how permeable asphalt and an underlying drainage system causes shallow and deep infiltration unique in that:

a. it provides a treatment option that does not require the handling of hazardous or unsafe chemicals;
b. is completely compatible with existing plant operations, equipment and processes;
c. is cost-effective when compared with other chemical dosing systems for stormwater treatment; and,
d. is a fully automated flow-through system which does not require constant operator supervision.

First developed in Australia in 2001, ViroFlow™ Technology has been successfully applied as a filtration or direct addition dosing system at both small and medium-sized WWTPs (Fergusson, 2004a; Wood et al, 2007) in the UK, the Royal Air Force base at Amberley (Australia), Kyogle Shire Council (Australia), Koppers Wood Products (Australia) (Fergusson, 2007), Britannia Refined Metals (UK), Lane Xang Minerals Ltd (Laos), CopperCo Mines (Australia), Hantech Ltd (Australia), among other locations. ViroFlow™ Technology has been approved for application in many countries, including the United Kingdom, South Korea, Laos, USA and Australia.

The primary focus in the application of ViroFlow™ Technology for stormwater treatment relates to its ability to reduce total phosphorus (TP) and heavy metals in discharge stormwater (Fergusson, 2004b). However, it can also play a role in reducing biological oxygen demand (BOD), total suspended solids (TSS), and improving turbidity-colour-clarity. More modest reductions in nitrogen (specifically, total nitrogen [TN], ammonia [NH3-N], and total kjeldahl nitrogen [TKN]), have also been observed.

The following six commercial applications summarise Virotec's applications in treating contaminated stormwater runoff at sites in Australia, Asia and the United Kingdom.

COMMERCIAL APPLICATION #1:

> Large Lead Smelter, London, UK

This large lead smelter in London represents a "classic" example of why stormwater attenuation and treatment is a potential problem in industrial, urban areas. The site was covered with large processing plants and factories, and the outer areas of the site were covered with vast open areas of impermeable roadways and concrete pads.

Even regular rainfall, not to mention heavy storm events, can cause a problem at the site, because the atmosphere and surfaces of the site can be laden with lead dust particles. Lead, being a potentially dangerous element to human health, was constantly monitored by the Environment Agency at the perimeter of the site.

Open areas of impermeable roadways and concrete pads

Rainwater that accumulates on the site must be captured and adequately treated to stringent limits before being discharged into the neighbouring River Thames. Rainwater (and stormwater runoff), and any collected debris and lead particulate matter, was directed via a series of gutters and channels to two large holding bays, where it was pumped to an attenuation dam.

Holding bay where stormwater is collected before being pumped into the attenuation dam (behind rear wall)

Stormwater is held in this PVC-lined holding dam prior to treatment and discharge

Influent head of the ViroFlow™ Technology filter system

Stormwater that was collected in the attenuation dam was then pumped through a gravity-fed ViroFlow™ Technology filtration system to remove heavy metals and adjust pH downward. Water was pumped to the head of the filter and allowed to feed slowly through the pelletised filter matrix, allowing enough hydraulic retention time (HRT) to remove metals and adjust pH. Water was dispersed evenly across the head of the filter via a rotating distribution arm, and was discharged at the bottom of the filter system. Results from this application shown in Table 1 indicate that ViroFlow™ Technology was effective in treating acidity and heavy metals, such as arsenic, lead, cadium and zinc, in the stormwater prior to discharge into the River Thames.

TABLE 1: PRE- AND POST-TREATMENT RESULTS OF THE VIROFLOW™ TECHNOLOGY FILTER SYSTEM IN LONDON

Parameter	Before ViroFlow™ Technology (Influent to the Filter System)	After ViroFlow™ Technology (Effluent from the Filter System)	Treatment Targets
pH	10.2	7.4	6.0 - 9.0
Antimony (mg/L)	9.26	0.49	0.5
Arsenic (mg/L)	0.34	Below Detection Limit	0.1
Cadmium (mg/L)	0.14	0.02	0.03
Cooper (mg/L)	0.18	0.02	0.1
Lead (mg/L)	4.52	0.06	1.0
Nickel (mg/L)	0.03	0.02	0.1
Zinc (mg/L)	1.5	0.16	0.5

COMMERCIAL APPLICATION #2:

> Timber Preservation Company, Brisbane, Australia

This commercial application of ViroFlow™ Technology in Australia was similar to the lead smelter in the UK in that there were vast areas of enclosed or covered impermeable surfaces at the site, and there was a potential for stormwater to be contaminated with three main elements which are a by-product of the timber preservation operation and all of which are potentially dangerous to human health, namely arsenic, chromium and copper.

ViroFlow™ Technology filter system

Stormwater holding tank (left) and two ViroFlow™ Technology filters (rear), with inlets at the bottom of the filters

Virotec was contracted to design, construct and operate a ViroFlow™ Technology filtration system, which could treat contaminated stormwater at the site. Runoff from the site was collected in two 20,000L (5,300 gallon) PVC tanks. The water was gravity fed to the bottom of two IBC's containing a combination of ElectroBind™ reagent, washed river sand and gravel, for even dispersal and treatment throughout the filter system.

Gravity-fed stormwater flowed in an upward flow from the bottom of the filters and was discharged at the top of the system into the sewer system. All treated stormwater effluent from the site met Brisbane Water discharge limits.

COMMERCIAL APPLICATION #3:

> Timber Preservation Company, Tasmania, Australia

Commercial timber preservation operations use a variety of chemicals, one of which is Copper-Chrome-Arsenate (CCA). While being phased out worldwide due to its inherent health risks, the chemical is still used quite extensively. In addition to the problems associated with the wood being impregnated with carcinogenic chemicals and their long-term threat to humans and the environment, when it rains on a CCA operation, heavy metal contaminated stormwater runs off the site and is normally collected in attenuation dams for treatment prior to discharge into the environment.

Stormwater drain, with strategically placed geotextile filter bags (right), treats runoff prior to holding in attenuation dam (centre)

Virotec is Australia's "go to company" when it comes to CCA treatment. In addition to implementing dozens of successful dam stormwater and solids treatments using ViroFlow™ Technology throughout the country, Virotec has also implemented successful drainage filtration systems as timber preservation operations. Using porous geotextile filter bags containing ElectroBind™ reagent in a pelletised form strategically placed in CCA stormwater drains, Virotec has treated contaminated runoff prior to it discharging into the stormwater attenuation dams.

Geotextile filter bags placed in CCA-contaminated stormwater drains

Discharge limits for CCA in Australia are 1.0mg/L for copper, 0.5mg/L for chromium and 0.05mg/L for arsenic. ViroFlow™ Technology reduces these heavy metal concentrations prior to discharge to 0.01mg/L for copper, 0.01mg/L for chromium and 0.02mg/L for arsenic. Therefore, it can be concluded that Virotec's solution eliminates a major environmental hazard and potential environmental incidents after rain events, treats and discharges stormwater contaminated with copper, chromium and arsenic concentrations that are well below EPA guideline limits, and is fast to mobilise and deploy.

COMMERCIAL APPLICATION #4:

> Large Copper Mine, Northern Queensland, Australia

Dam stormwater quality after treatment

Dosing Acid B™ reagent as a 10% slurry into one of the five attenuation dams (note poor pre-treatment stormwater quality)

Mine sites are not generally thought of as locations with stormwater problems; they are usually located in remote places away from urban development and, given their remoteness do not pose a significant problem to urban dwellers (i.e., the majority of the population). However, mining operations are among the most invasive human activities on earth, and they not only generate a tremendous amount of stormwater because of their vast size, but can also generate the most contaminated forms of stormwater runoff.

At a large copper mine in northern Queensland, Virotec were commissioned to apply its ViroMine™ Technology to treat a large volume of stormwater runoff in five attenuation dams (with an average capacity of 20 megalitres [five million gallons]), which had been constructed at intermittent points along the edge of a 20 kilometre (12 mile) creek. The runoff originated as overflow from a disused tailings dam, and was contaminated with acidity and copper (Cu).

As a result of applying ViroMine™ Technology to the five dams, the following representative results were recorded: pH prior to treatment was 4.3 and after treatment was 7.2; Cu was 2.2mg/L prior to treatment and after treatment was <0.001mg/L. As seen in a comparison of Figures 14 and 15, suspended solids in the treated dams were also significantly reduced.

COMMERCIAL APPLICATION #5:

> Sepon Gold Mine, Lane Xang Minerals, Laos

Rain events in high rainfall areas can be particularly problematic because of their high volume and high velocity impacts on the environment. In such cases, stormwater drainage galleries and attenuation dams are often constructed to slow the progress of stormwater runoff and to direct its flow in a manner which controls where and when the runoff discharges from site. This is especially important where the runoff must be channelled away from mining operations and can be polluted with heavy metals.

TABLE 2: HEAVY METALS AND SUSPENDED SOLIDS RESULTS OF STORMWATER DRAINAGE TREATMENT USING VIROMINE™ TECHNOLOGY

Parameter	Before ViroMine™ Technology (mg/L)	After ViroMine™ Technology (mg/L)
Total Suspended Solids (TSS)	117	1.0
Aluminium (al)	5.3	0.5
Arsenic (As)	0.2	0.08
Copper (Cu)	0.5	0.1
Lead (Pb)	0.05	<0.001
Manganese (Mn)	0.8	0.1
Zinc (Zn)	0.3	0.005

Virotec was commissioned to supply its Acid B™ reagent in pellet form to a mine site in Laos where a series of contiguous gabion baskets were constructed. These baskets were placed in a 100 metre (330 feet) drainage gallery to intercept and treat contaminated stormwater, which regularly overflowed from an attenuation dam next to the ore processing plant.

As a result of this ViroMine™ Technology application, stormwater was treated prior to discharge into the river during peak flows. The results from this application can be seen in Table 2.

Example of a drainage gallery parallel to a road (centre rear) and stormwater attenuation dam (centre)

COMMERCIAL APPLICATION #6:

> Korea Highway Construction Corporation, CheongJu City, South Korea

In 2006, Virotec with our Korean partner, Geoenevirotec Co. Ltd, implemented a stormwater treatment facility for the Korean Highway Construction Corporation in CheongJu City, South Korea. The new highway was constructed in a high rainfall area of the country (greater than 2,000mm per year), and the excavated rock and tunnel rock contained high levels of acidgenerating, pyritic material. The presence of pyrite also meant that the stormwater was contaminated with a range of heavy metals.

The treatment facility contained ElectroBind™ filter media in an "over-under" baffle tank, which was designed to increase stormwater pH and to remove heavy metals from the stormwater before it could be safely discharged into a neighbouring river.

TABLE 3: RESULTS AFTER TREATMENT WITH VIROFLOW™ TECHNOLOGY

Parameter	Influent	Effluent
pH	5.7	6.8
Cu (mg/L)	0.35	0.2
Fe (mg/L)	62.4	1.6
Mn (mg/L)	58.2	18.5
Zn (mg/L)	16.0	0.18

Stormwater runoff was channelled from the highway (top) via this drain (centre) to the ViroFlow™ Technology filter system (bottom) for treatment prior to discharge

The over-under baffle treatment system, with discharge point in distance (rear)

CONCLUSION

From this data it can be concluded that ViroFlow™ Technology is a viable and effective method for treating and managing contaminated stormwater runoff. As a result of Virotec's extensive work over many years in successfully treating contaminated stormwater throughout the world, the company has many satisfied customers who readily recommend the company's technologies.

TESTIMONIAL

"Our company commenced association with Virotec Global Solutions back in February 2002. I happened to see where Virotec had successfully treated cyanide contaminated water in Romania and upon realisation that this cyanide contaminated water also contains arsenic, I began to consider how this treatment could benefit our company. After several discussions with Virotec it became apparent that their technology, used with great success in Romania, could be applied to our site.

Our site is a Timber preservation facility and has been in operation since the late 1950's. We are continually on the look out for environmental improvements and with our commitment to adherence to the stringent limits placed on our plant as far as water emission quality goes, the opportunity to improve water quality was seen as beneficial to all parties. After several samples were extracted from our two stormwater settling ponds and sent to Virotec's laboratory for test work, Virotec visited our site and successfully treated both of the settling ponds with ViroFlow™ Technology with outstanding results. Levels of metals in these ponds were reduced dramatically and well below our licence limits. Virotec has since treated the two ponds every year since 2002.

Throughout this whole process Virotec personnel have remained diligent, totally professional and committed to the cause both whilst on site and off. I would have no hesitation in recommending Virotec to any other company either with environmental problems or a commitment to improving current practices."

Andrew Exton,
Environment Manager
Large CCA Treatment Plant

REFERENCES

Bowes, M.J, Hilton, J, Irons, G.P, and Hornby, D.D (2005) The relative contribution of sewage and diffuse phosphorus sources in the River Avon catchment, southern England: implications for nutrient management, The Science of the Total Environment, 344(1-3), 67-81.

Bressan, G (1986) General remarks on phosphorus sources in areas susceptible to eutrophication, with particular reference to the Northern Adriatic coast, The Science of the Total Environment, 55(1), 229-242.

Cartwright, N.G, Painter, H and Parr, W (1993) An assessment of the environmental quality standards for inorganic nutrients necessary to prevent eutrophication (nuisance growth of algae), WRc Report to NRA, R&D Note 230.

Commission of the European Communities (2007) Report from the Commission to the Council and the European Parliament, Brussels, 4.5.2007, COM(2007) 234.

Environmental Data Services (March, 1997) Conservation body urges action on eutrophication, ENDS Report 266, Haymarket Business Media.

Environmental Data Services (June, 2004) DEFRA to start slow on diffuse agricultural pollution, ENDS Report 353, Haymarket Business Media, 44-45.

Environmental Data Services (January, 2006a) Government moves to tackle agricultural pollution, ENDS Report 372, Haymarket Business Media, 39.

Environmental Data Services (April, 2006b) Massive increase in Scottish 'sensitive' waters, ENDS Report 375, Haymarket Business Media, 16.

European Environment Agency (2000) Environmental signals 2000, Environmental Assessment Report No. 6.

Fergusson, L (April, 2004a) ViroFlow Technology for the removal of nitrogen and phosphorus in sewage treatment, Paper presented at the Enviro04, Australian Water Association and Waste Management Association of Australia Conference, Sydney.

Fergusson, L (February, 2004b) Making light of heavy metals, Waste Management and Environment, 15(1), 29-30.

Fergusson, L (2007) The conversion and sustainable use of alumina refinery residues: global solution examples, The Minerals, Metals & Materials Society, November, 2006; and paper presented to the TMS Annual Meeting and Conference, Orlando, Florida, February 28, 2007.

Lee, G.F and Jones-Lee, A (2005) "Urban stormwater runoff aquatic life toxicity: an update", Stormwater, September-October, 2005.

Lee, G.F and Jones-Lee, A (2006) "Lead as a stormwater runoff pollutant", Stormwater, September, 2006.

Jarvie, H.P, Neal, C and Withers, P.J.A (2006) Sewage-effluent phosphorus: A greater risk to river eutrophication than agricultural phosphorus? The Science of the Total Environment, 360(1-3), 246-253.

Neal, C, Jarvie, H.P, Howarth, S.M, Whitehead, P.G, Williams, R.J, Neal, M, Harrow, M and Wickham, H (2000) The water quality of the River Kennet: initial observations on lowland chalk stream impacted by sewage inputs and phosphorus remediation, The Science of the Total Environment, 251-252, 477-495.

Wood, E, Fergusson, L, Lowe, M and Leigh, S (2007) The application of ViroFilter Technology at Yorkshire Water, Paper presented to European Water and Wastewater Management Conference, St James' Park, Newcastle Upon Tyne, UK, September 24-26, 2007.

704/MKT/11 14.10.11