FHWA Environmental Technology Brief

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Not necessarily. Highway runoff may be a *potential* threat to receiving waters in your area, but if handled properly, it need not be a serious problem. Highway runoff is generally cleaner than runoff from buildings, farms, mines, harbors or other non-point sources. It is ironic, though, that despite the vast number of measures taken and resources invested to minimize its impact on receiving waters, highway stormwater runoff is still one of the most misunderstood and misrepresented contributors to water quality degradation.

The potential threat of highway runoff on surrounding waters is not always certain for there are highly effective active and passive means to "treat" it before it actually causes any damage. Interestingly, some of the most effective treatments are passively present even when no deliberate actions are taken for mitigation. Highway runoff that soaks into soil with or without the presence of any type of vegetation, channel, or basin is usually harmless to the environment. Nonetheless, the implementation of vegetated swales and infiltration trenches along the roadside assures that highway runoff has time to settle and is filtered through grass and soil. Retention and detention basins, among other management practices, are highly effective means for controlling excessive flows of highway runoff. These devices capture highway runoff and release it at very slow rates, allowing sufficient time for heavier particles to settle out, evaporate, infiltrate or be absorbed.[1] Given that a large number of preventive and corrective measures can and are being taken to suppress the potential of any disturbing effects of highway runoff on nearby receiving waters, it is important to recognize that highway runoff need not be and most often is not a serious problem.

What's Contaminating Our Water?

Strictly speaking, anything other than two atoms of hydrogen and one atom of oxygen is a water contaminant. Contaminants become pollutants when they interfere with the normal life cycle functions of organisms living in or dependent on the water source. Contaminants come from a variety of point and non-point sources. Among the most significant point sources are industrial waste disposal sites, municipal landfills, leaking septic tanks, and occasional accidental spills of petroleum products and industrial liquids. Non-point sources, on the other hand, include agricultural runoff, mine drainage, urban and highway runoff, and runoff from lawns and natural areas. Non-point source pollution accounts for 80 percent of the degradation of waters in the United States.[2]

If left unchecked, non-point source pollution can damage the quality of receiving surface and ground waters. **Agricultural runoff**, for example, may carry nutrients, animal wastes, sediment, salts, pesticides, fertilizers, and other ingredients that may be harmful in high concentrations.[3] High concentrations of nutrients, for example, can stimulate excessive or undesirable forms of aquatic growth such as algae and noxious weeds. These plants may consume oxygen faster than natural processes can produce it and, as a result, fish and lower species in the food chain may be destroyed.[4] Nutrient enrichment can also drive up the pH levels in water through increased photosynthetic activity. Animal wastes can accelerate the production of algae and contaminate water used for fishing, swimming, and drinking with related microorganism pathogens.

Mine drainage often contains pyrites, which are sources of sulfuric acid and hydrogen sulfide that yield a smell of rotten eggs. When disturbed, pyrites weather and react with oxygen and water to lower pH levels. Low pH may lead to high levels of aluminum, iron, and manganese, which are toxic to fish and other aquatic species.[5]

At FHWA, we have successfully:

Identified and quantified the constituents of highway runoff.

Identified the sources of these pollutants and migration paths from the highway to the receiving water.

- Analyzed the effects of these pollutants on receiving waters.

We continue to:

- Develop the necessary analytical tool and abatement/treatment criteria and guidelines to minimize the effects of objectional constituents.

Our recommendations:

- Know the quality of the runoff and then design the treatment to fit the problem

Urban runoff from roads, parking facilities, sidewalks, buildings, rooftops, and other impervious surfaces can transport trash, debris, metals, hydrocarbons, and fecal matter that pollute receiving streams with pathogenic bacteria.[6] **Lawns and natural areas** may also contaminate runoff with nutrients, fertilizers, and suspended solids. Excessive concentrations of these microorganisms can prevent receiving water from being used for certain water supply and recreational activities.

Highway runoff can also have adverse effects if no measures are taken for the removal of excessive contaminants before the runoff reaches the receiving water. The most common contaminants in highway runoff are heavy metals, inorganic salts, aromatic hydrocarbons, and suspended solids that accumulate on the road surface as a result of regular highway operation and maintenance activities. Salting and sanding practices, for example, may leave concentrations of chloride, sodium, and calcium on the roadway surface. Ordinary operations and the wear and tear of our vehicles also result in the dropping of oil, grease, rust, hydrocarbons, rubber particles, and other solid materials on the highway surface. These materials are often washed off the highway during rain or snow storm events.

Receiving surface and ground waters are both susceptible to contamination from all these sources. Surface waters (streams, rivers, ponds, and lakes) are particularly vulnerable because they are directly exposed to contaminants released into the air and to direct discharges from point or non-point sources.[7] However, they have the benefit of being easily accessible for direct measurement and application of assessment techniques. Contamination of ground waters, on the other hand, tends to occur gradually because contaminants percolate downward through the soil at slow rates, where the ground serves as mother nature's filter. However, contaminants can also reach ground waters rather quickly through drainage entering fractured rock formations or sinkholes in Karst areas.[8] (Karst usually occurs in limestone areas and is characterized by caves, openings, and sinkholes.) Ground water is more sensitive to contamination in these areas because runoff may pass directly into the subsurface with little if any infiltration through the soil. Contamination of ground waters is less visible than that of surface waters, and, given that sampling and clean up is quite difficult and expensive, prevention of contamination is the most effective way of protecting them.

The presence of undesirable contaminants in surface or ground water may interfere with the vital functions of the organisms living in it or from it. There are, as discussed, a wide variety of point and non-point sources of pollutants, but only water quality evaluations can determine their actual role in the pollution of receiving waters. Treatment of runoff, if needed, should be a function of this water quality evaluation.

Are Waste and Recycled Materials Harmful to Receiving Waters?

FHWA is currently conducting studies to determine if, and to what extent, waste and recycled materials that may be used in highway construction could have adverse impacts on receiving waters, and to develop models that describe the transformation and fate of their ingredients.

The NCHRP Project 25-9, Environmental Impacts of Construction and Repair Materials on Surface and Ground Waters, is examining highway sites where waste materials like coal-ash, scrap rubber, and municipal solid waste, among many others, were used in the construction of fills and pavements.[9] Contrary to bioassay laboratory results indicating that these materials are indeed toxic, actual field studies have shown that, so far, none of them have had toxic effects on the quality of surrounding ground waters.[10] Additional analyses and laboratory scale tests will be performed to ascertain the differences between the laboratory and field test results, and to identify the mechanisms through which most of the tested materials lose their toxicity when under field conditions.

Preliminary Results are Positive in all Studies

This project has revealed that toxic substances from waste materials can be eliminated after traveling short distances through typical roadside soils. However, research is still underway to assess the general water quality impacts from any of the materials studied by this and other research projects.

Ice & Snow Control Chemicals, for Better or for Worse?

For better. Much is written and said each winter about the effects of deicing chemicals on the environment, but little is said of their benefits to the millions of residents living in the northern portions of the United States. The truth is that deicing chemicals are essential to the safe transportation of goods and people across the nation.[11]

When applied heavily and frequently, deicing chemicals can pollute receiving waters, but the degree of their damage largely depends on the type and designated use of the receiving water, and on the drainage system used to discharge the runoff.

Surface waters are *not* as vulnerable to deicing chemicals as are ground waters because their turbulent actions blend and dilute plumes of incoming liquids almost immediately after the chemicals enter the main stream. Ground waters, on the other hand, are more susceptible to pollution since there may be no turbulent actions to dissolve the chemicals when the runoff percolates through the soil and enters the water table.[12]

Calcium Magnesium Acetate (CMA) and Potassium Acetate (KAc) are deicing chemicals most benign to the environment because they contain weak biodegradable acids.[13] Sodium Chloride (NaCl), Calcium Chloride ($CaCl_2$), and Magnesium Chloride (MgCl2), on the other hand, leave residues of chloride ions on the highway surface that may not only contaminate surrounding ground waters, but that may also corrode motor vehicles and bridge structures.

Nevertheless, the effect of deicing chemicals on receiving waters may vary with the specific use and overall ecological health of each particular water body. In some cases, water with elevated concentrations of sodium may be suitable for some uses but undesirable for certain industrial purposes. For example, high concentrations of sodium in water for human consumption are harmful to people with certain types of heart or kidney diseases, but the major objection to its use comes from the taste preference of the public. On the other hand, the effect of high salinity on fish life varies accordingly with the tolerance of individual fish species. Some fish cannot tolerate a salt level as low as 400 ppm, while others are able to live with levels higher than that of seawater (30,000 ppm.)[14>] Salt levels in highway runoff vary with the amount of chemicals applied and the intensity of subsequent rainstorm events. Highway runoff can contain salt levels as low as 10 ppm, particularly in areas where deicing chemicals are not used.

Recent studies on the migration paths of deicing chemicals have indicated that, in places where highway runoff is discharged through open-drainage systems, as is typically done in many highways, concentrations of deicing chemicals tend to be substantially higher downgradient than upgradient from the highway. A study in Massachusetts revealed that chloride loads in ground water are reduced significantly when discharged through a closed drainage system, a closed drainage system with snow berm, and a full-snow-berm drainage system. Among these, the full-snow-berm drainage system has been found to be most effective in removing chloride loads from highway runoff.[15]

Deicing chemicals are often combined with other substances to prevent caking or inhibit corrosion. These substances may be toxic to human, animal, and fish life. Sodium ferrocyanide, for instance, is often used to prevent caking, but, unfortunately, releases cyanide ions that are extremely toxic to fish. Rust inhibitors, on the other hand, may contain phosphorus compounds that, in turn, stimulate the growth of undesirable aquatic plants, weeds and algae in fresh-water lakes.[13]

It is important to note that deicing chemicals in highway runoff are neither the only nor the major source of chloride contamination of the nation's waters. Sewage discharges and runoff from industrial waste and agricultural products also contain high concentrations of chloride that may affect receiving waters as well. Rain and snow may deposit as much as 35 to 40 lb of chloride per acre annually even without the presence of deicing chemicals. Areas that are geographically located along coastal waters also experience high chloride concentrations since chloride occurs naturally in sea water, natural brines, and water which passes through salt-bearing strata. Water quality analysis is needed so that any strategies for accommodation are tailored to the degree of contamination.

Are Heavy Metals in Highway Runoff Toxic to Aquatic Organisms?

Heavy metals in highway runoff are usually not a toxicity problem. Toxicity depends largely on the physical and chemical form of the heavy metals, their availability to aquatic organisms, and the existing conditions of the receiving waters.

Highway runoff may contain higher concentrations of metals, particularly: lead, zinc, iron, chromium, cadmium, nickel, and copper, that result from the ordinary wear of brakes, tires, and other vehicle parts. Although leaded gasoline was outlawed 25 years ago, lead is still being deposited on highway surfaces, (though in dramatically smaller quantities) through such sources as paints used on the right of ways and atmospheric deposition.

Heavy metals in highway runoff generally undergo physical, chemical, and biological transformations as they reach adjacent ecosystems. Sometimes, they are taken up by plants or animals, or adsorbed on clay particles. Other times. they settle to bottom sediments, or re-dissolve back into solution. Particulate fractions settling to the bottom surface of receiving waters may develop into sediments after several years of continuous deposition. These sediments may or may not leach metals depending on the condition and sensitivity of the receiving water. For example, chloride and acetate (from deicing chemicals) trigger the movement of metals that would otherwise remain in soil-ion exchange sites usually found in the first 20cm of the soil columns in sediments.

Concrete-lined drainage channel leading to a nearby drainage basin.

Various studies have revealed that low pH levels may also trigger metal solubility and leaching, especially when pH levels drop below 7.[14] However, this may not be the case in waters under different conditions. The potential leaching of copper, iron, chromium, and nickel, for example, is very limited or even unlikely to occur in natural waters where aerobic conditions are maintained.[15]

The form of a metal and its availability to organisms determine in great part the toxicity of water. Water with high total metal concentrations may indeed be less toxic than one having lower concentrations but *different forms* of the same metal. Ionic copper, for instance, is more harmful to aquatic organisms than organically bound or elemental copper.[16] Similarly, small concentrations of ionic zinc and cadmium are more readily available and toxic to aquatic life than large concentrations of their organic or non-ionic forms. Heavy metals in highway runoff are usually not a toxicity problem, but an analysis of each situation is prudent so that treatment is provided where appropriate.

How to Treat Highway Runoff

The adverse effect of highway runoff water quality can be minimized through structural or non-structural best management practices (BMPs) or through a combination of both. Structural BMPs operate by physically trapping runoff until contaminants settle out or are filtered through the underlying soils. The basic mechanisms for constituent removal are gravity settling, infiltration of soluble nutrients through soil or filters, or biological and chemical processes. Non-structural BMPs, on the other hand, are source control practices such as street sweeping, land use planning, vegetated buffer areas, and fertilizer application controls. They are used to reduce the initial concentration and accumulation of contaminants in runoff. Non-structural BMPs may reduce the need for costly structural controls. Structural BMPs can be thought of as largely corrective measures to address existing and anticipated water quality problems.[17]

To select the most appropriate BMP, it is recommended that one takes into account the expected amount of runoff, type and amount of contaminants, availability of land, and physical characteristics of the site. Some BMPs can operate effectively regardless of weather conditions while others can't. Structural BMPs are not always suitable for areas where land space is limited, as in urban settings, while non-structural BMPs can be implemented just about anywhere, even where space is a constraint.

Structural BMPs consist of infiltration technologies, detention, retention, and vegetated practices, filtering systems, and porous pavements. **Infiltration technologies** make use of the physical, chemical, and biological interactions between soil and water to filter out sediments and other contaminants from highway runoff. As the runoff percolates into the ground, contaminant particles are trapped within the soil, and the resulting "treated" runoff makes its way to the ground water. Infiltration trenches and basins are most effective in removing total suspended solids, bacteria, and metals from highway runoff.[17] They have the advantage of being located underground but the disadvantage of being limited to areas that have adequate soil types and ground water table characteristics. They have an effective life of 10 to 15 years and require sediment/debris removal on a periodic basis. Infiltration basins, on the other hand, can operate effectively from 5 to 10 years before requiring deep tilling.[18]

Detention and retention ponds, wet or dry, provide both water quantity and water quality control since they store runoff temporarily and settle or retain suspended solids and other runoff contaminants. Detention ponds are known to be highly effective in the removal of nutrients and heavy metals.[19] **Wetland and shallow marsh systems**, on the other hand, use the nutrient uptake of vegetation to enhance constituent removal. However, wetlands are not as effective as detention ponds in the removal of metal constituents from highway runoff.[20] Ponds and wetland/pond combinations are expensive, require annual maintenance, raise liability concern, but they do have an effective life of 20 to 50 years. They are recommended for places where sufficient land and *funding* are available.[18]

Vegetated swales and filter strips are recommended for sites with limited land space. These technologies are designed to catch and filter highway runoff and to enhance the biological uptake of its constituents. Vegetated swales incur moderate capital costs and their effective life span is 5 to 20 years. Filter strips, on the other hand, are low cost technologies with a much longer effective life (20 to 50 years). Filter strips can be installed easily along roadside corridors.[21]

Filtering systems are useful in sites with limited land space. Unlike infiltration technologies, filtering systems have no soil restrictions and, even though several designs have been developed, all of them consist of a sedimentation area to retain large particles and a filter chamber that filters and removes suspended constituents.

In contrast to conventional pavements, **Porous pavements** are unique in their design. Porous pavements allow storm water to percolate through the pavement and infiltrate into the soil underneath. In the form of asphalt, concrete, or interlocking paving stones, porous pavements allow light duty roads, sidewalks, parking lots, and other impervious surfaces to keep their natural infiltrating capacity while allowing for limited vehicle and pedestrian traffic. In order for porous pavements to function effectively, they must be sited, designed, and installed correctly, and, of course, they must be cleaned on a regular basis to prevent clogging.[22] Porous pavements can remove total suspended solids, total phosphorus, and total nitrogen effectively within a life span of 15 to 20 years.[23]

Summary

Highway runoff is generally not harmful. The Federal Highway Administration encourages all jurisdictions to learn about highway runoff and its properties before implementing any strategies for its control. Given that no runoff waters are the same, a one-size-fits all approach could result in spending funds for unnecessary or inappropriate treatment. The following references will help one prepare a solution based on scientific facts and will guide one in the selection of a management practice that best suits the situation.

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