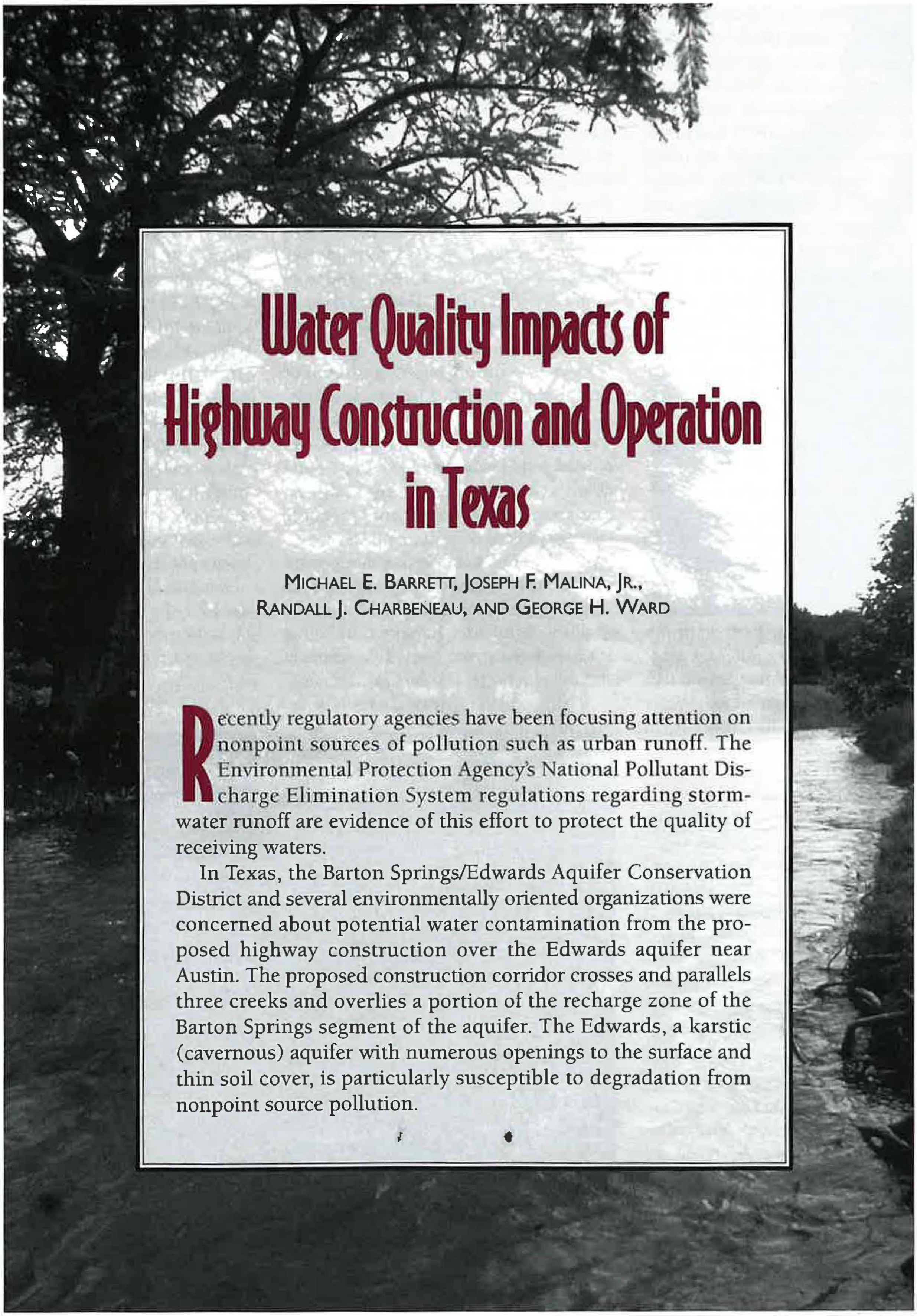

# Water Quality Impacts of Highway Construction and Operation in Texas

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Recently regulatory agencies have been focusing attention on nonpoint sources of pollution such as urban runoff. The Environmental Protection Agency's National Pollutant Discharge Elimination System regulations regarding stormwater runoff are evidence of this effort to protect the quality of receiving waters.

In Texas, the Barton Springs/Edwards Aquifer Conservation District and several environmentally oriented organizations were concerned about potential water contamination from the proposed highway construction over the Edwards aquifer near Austin. The proposed construction corridor crosses and parallels three creeks and overlies a portion of the recharge zone of the Barton Springs segment of the aquifer. The Edwards, a karstic (cavernous) aquifer with numerous openings to the surface and thin soil cover, is particularly susceptible to degradation from nonpoint source pollution.

The concern over the Edwards aquifer led to litigation involving the Texas Department of Transportation and the Federal Highway Administration, which temporarily halted construction on the project site. The district and TxDOT had previously negotiated a settlement approved by the U. S. District Court. The district removed itself from the litigation and TxDOT took specific actions to address the concerns of the district. The cooperation of the two agencies has been effective in reducing water pollution from both point and nonpoint sources during roadway construction. In fact the agencies' improvements in engineered and nonengineered best-management practices—such as the design of permanent runoff control devices and the use of native vegetation on highway rights-of-way, respectively—have earned local, state, and national recognition.

The agreed-to consent decree between TxDOT and the district also ordered a study of the water quality and quantity of highway runoff and the effects of highway construction and operation on the quality of receiving waters in the Barton Springs segment of the Edwards aquifer recharge zone. TxDOT and the district agreed that the Center for Research in Water Resources (CRWR) at The University of Texas at Austin would conduct the study.

## Highway Construction Impacts

Highway construction and the associated grading activities typically are initiated with a clearing and grubbing phase in which vegetation and other natural soil stabilizers are removed from the construction site. The surface areas and slopes created by excavation or embankments are exposed to the erosive forces of wind, snowmelt, and rain until the earthwork is completed and the grassy vegetation is restored or the surface is artificially stabilized.

Soil losses from such construction may inflict damage if transported into surface waterways. Fish-spawning areas and river-bottom habitats may be destroyed or damaged when sediment accumulates in streams and rivers. Suspended solids reduce the transmission of light, which limits in-stream photosynthesis and diminishes aquatic food supply and habitat. Suspended solids also may coat and abrade aquatic organisms, reduce surface water quality and suitability for various uses such as fishing and recreation, and lead to diminished capacities in downstream reservoirs or other conveyance systems when sediments settle there. The eroded solids may further disrupt water quality by transporting phosphorus, nitrogen, and toxic compounds into local waterways.

Sediment that reaches surface streams in the recharge zone of the Edwards aquifer may be carried into the aquifer itself through faults, fractures, and other features in the streambeds. This sediment will be deposited in the aquifer and will reduce the water storage and transmission capacity necessary to maintain spring flow during droughts. The threat to endangered species in this area associated with diminished spring flow has already been the subject of several lawsuits.

The CRWR study used field sampling to assess the effects of highway construction on water quantity and quality in creeks near highway construction in the aquifer district. Samples were taken from a creek downstream from an intensive construction site. Flow rate in the creek increased significantly below the construction site as a result of increased impermeable cover on the highway surface and concentration of flow in the highway storm sewer system. Downstream concentrations of total suspended solids below the right-of-way during the final stages of construction were observed to be approximately 10 times greater than before construction began.

Among the most common methods used for the control of sediment during highway construction in the Austin region is the silt fence. These geotextile fabric

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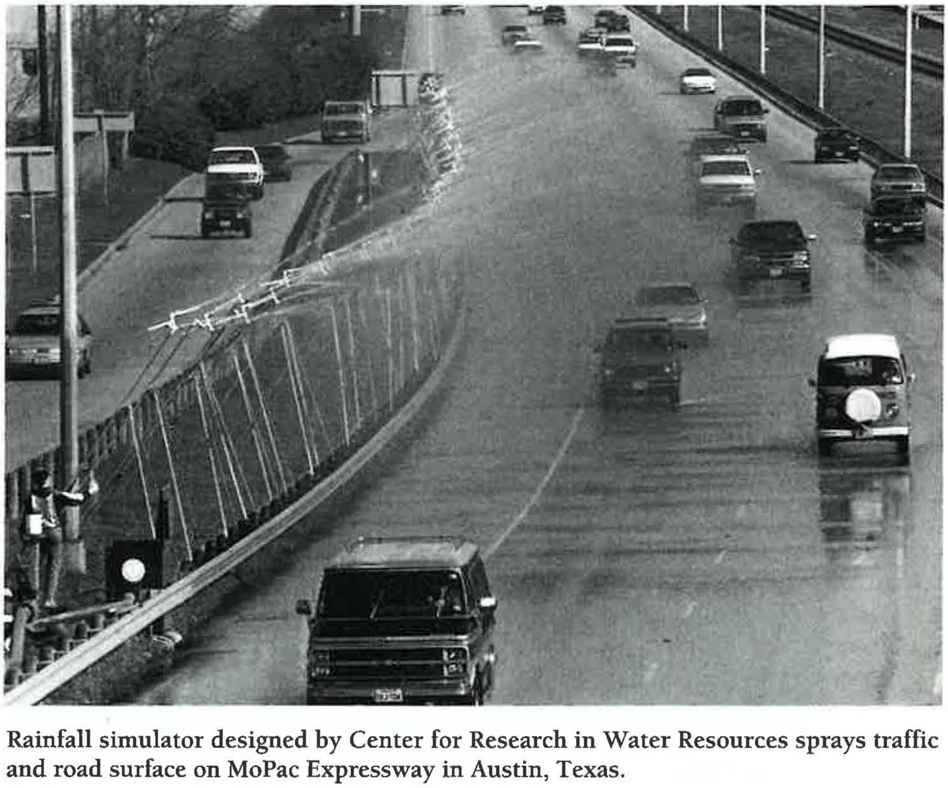
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**Rainfall simulator designed by Center for Research in Water Resources sprays traffic and road surface on MoPac Expressway in Austin, Texas.**

fences are about 0.9 meters (3 feet) high and are used to impound water during storms, allowing the sediment particles to settle out. The water seeps through the fabric to discharge to the nearest water course. Despite their widespread use, little is known about the sediment removal effectiveness of these devices or their hydraulic behavior. As part of the CRWR study, silt fences were monitored in the field and in a controlled laboratory setting.

The field sites were uncontrolled in the sense that normal construction processes governed installation and maintenance, rather than experimental design. The concentration of total suspended solids (TSS) was determined for samples from six specific silt fence applications within the study area, using both woven and nonwoven fabric. There was essentially no reduction in the concentrations of these paired samples across the fence, indicating that straining and filtration are not important mechanisms for sediment removal. Grain size analysis of the samples indicates that only silt and clay-size particles remained in suspension at the upstream face of the fence. The diameter of these particles is significantly less than the apparent opening size of the fabrics monitored.

Failures caused by exceeding the water storage and detention capacities were common. Deficiencies in the level of performance because of improper installation and maintenance were also noted. These include ruptured fabric splices, failure to correct fence damage resulting from water spilling over the top of the fencing, holes in the fabric, water running under the fence, and fences damaged and partially covered by temporary stockpiles of materials.

CRWR researchers conducted laboratory tests of four types of silt fences and a rock berm to quantify their efficiency at sediment removal. The tests were designed to measure the reduction caused by ponding the runoff to allow sediment to settle and filtration of the runoff as it passes through the barrier. A sediment slurry was prepared with the local topsoil and with a TSS concentration similar to stormwater runoff from construction sites. This work showed that sediment removal cannot be estimated from the properties normally used to characterize geotextile fabrics. Removal efficiency is instead controlled by the ponding and detention time associated with the individual control devices.[1]

## Highway Runoff Impacts

Water quality effects of highway runoff are extremely site-specific. Different types of water bodies react differently to the loading of pollutants. The processes controlling the transport and fate of pollutants in lakes and reservoirs differ from those in rivers, streams, and aquifers. Lakes respond to cumulative pollutant loads delivered over an extended period and are usually analyzed on an annual or seasonal basis. Because the most common environmental issue in lakes is the overstimulation of aquatic life, nutrients such as nitrogen compounds and phosphorus are the pollutant types of greatest significance.

Streams respond more immediately to individual events, because runoff produces a pulse of contaminant that moves downstream and is well removed by the time the next storm occurs. The most common concern in streams is the suppression of aquatic life by the toxic effects of heavy metals. The relative size of the receiving water determines the amount of dilution of highway runoff and related pollutants. In addition, the type of water body and its designated beneficial use determine which sets of pollutants will have the most significance.

To estimate the potential effects of highway runoff on the water quality of surface streams, the CRWR team equipped

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**Field researcher collects data on effectiveness of geotextile fences in retaining sediment and debris at construction sites.**

highway sites at three locations with automatic sampling equipment for runoff. The three sites were located on MoPac Expressway, an urban highway in the Austin area. The sites differed primarily in traffic count, amount of impervious cover, and drainage systems.

During runoff events, flow rates were measured and water samples were collected automatically. Temperature, pH, specific conductance, and dissolved oxygen were recorded in the field immediately after sample collection. Water quality parameters analyzed in the laboratory included turbidity, total and volatile suspended solids, biochemical oxygen demand, chemical oxygen demand, total organic carbon, oil and grease, nutrients, and heavy metals. The data indicate that the type of drainage system is a more important factor in determining pollutant concentration and load than traffic volume.

[1] In theory, detention time could be calculated from the physical properties of the fabrics; however, observed flow rates were several orders of magnitude less than rates predicted from fabric permeability. This difference was the result of two factors: first, the parameters used to characterize the fabric are not valid because of turbulent flow at the water depths geotextile fabrics experience as sediment control devices; second, clogging of the fabric by the sediment-laden water further reduced the flow rates.

## Monitoring of Highway Runoff under Controlled Conditions

To estimate the impacts of future highways on the water quality of the Edwards aquifer, TxDOT and the conservation district requested the creation of a computer model to predict the quality of runoff. Because many variables might affect runoff quality, a method to create runoff under controlled conditions was needed to help determine which variables were significant. CRWR developed, installed, and operated a rainfall simulation system for one year at a site on the MoPac Expressway.

The advantages of using the simulator to produce highway runoff included the ability to control variables such as application rates, type of pavement maintenance (street sweeping versus no sweeping), duration of preceding dry periods, and vehicular load (no traffic and selected traffic rates). Scheduling the simulations allowed a precise start-to-finish sampling scheme for the runoff. In addition, the simulator allowed the collection and analysis of about three times as many samples as would have been possible from natural events alone.

A sprinkler-type rainfall simulator was installed along 230 meters (750 feet) of highway that drained into a single curb inlet. The spray from the simulator covered approximately the entire natural watershed of the curb inlet, which allowed direct comparisons of natural and simulated rainfall events at the site. The average daily volume of traffic at this site is approximately 60,000 vehicles, ranging from a minimum of about 100 vehicles per hour to a maximum of 6,000 vehicles per hour. Induction coils installed in each traffic lane recorded vehicle counts for each simulation. A high-speed off/on ramp provided a convenient bypass for motorists who chose not to drive through the artificial rain.

Samples were collected during 32 synthetic rainstorms under traffic conditions and 3 synthetic rainstorms without traffic. The water quality characteristics of the runoff samples collected during simulations were adjusted for the original quality of the water applied in the simulation. Pollutants observed when there was no traffic flow indicated the presence of constituents that accumulated during the previous dry period and were washed from the pavement by the sprinkler. The concentrations observed under traffic conditions were the result of pollutants contributed by the vehicle surfaces, removed from the pavement by rainfall, and mobilized by the action of the tires on the road surface. The data collected demonstrated that most of the variation observed in highway stormwater loading in the Austin area could be explained by causal variables measured during the rainstorm, the preceding dry period, and the previous storm.

One of the surprising findings of this research is that the volume of traffic does not play a large role in contributing solids to highway runoff. Conditions during the preceding dry period, such as dustfall and maintenance of pavement and rights-of-way, and the intensity of the runoff during the previous storm have a greater influence on the solids loadings from highways in the Austin region than does the input of solids from vehicles and rainfall during the storm itself.

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**Through controlled experiments researchers can determine optimum designs for runoff control systems.**

## Evaluation of Permanent Pollution Control Structures

Several permanent runoff controls were constructed along new highways in the Austin area, and their performance has been monitored since the highways opened. These controls are intended to improve the quality of the water discharged from the highway surface during storms. The control systems consist of a 38-cubic-meter (10,000-gallon hazardous material trap, a sedimentation basin designed to capture the first 1.3 centimeters (0.5 inches) of runoff, and a vertical sand filter. The hazardous material trap is designed to capture accidental spills of materials such as petroleum products or pesticides. The purpose of the sedimentation basin is to create a pond where the heavier solids and attached pollutants can settle to the bottom for later removal. The filter, which is constructed as part of the basin wall, should remove the smaller particles that remain in suspension.

Although the runoff control systems cost approximately $200,000 each and account for as much as 20 percent of the overall cost of highway construction in the Edwards aquifer recharge zone, they were built without an adequate design basis. CRWR researchers have observed numerous problems with the systems, mostly in conjunction with the performance of the vertical sand filter. Most of these systems were constructed at the same time and by the same contractor, but the hydraulic performance of the filters varies widely. Channeling of the runoff through the filter may wash out the sand, resulting in inadequate detention times and no filtration. In other systems the filters clogged almost immediately and all subsequent runoff bypassed the control. Because of these hydraulic problems the systems have not performed as desired and it has been impossible to accurately determine their pollutant removal effectiveness. These problems demonstrate that design of a functioning passive pollution control structure is not a trivial matter.

One question addressed by the study is the necessary characteristics of the filter medium. Laboratory, bench-scale filtration columns using various media have been operated to evaluate performance of filtration media and adsorptive media for removing pollutants from highway runoff. The bench-scale, vertical-flow filtration systems were dosed with stormwater runoff collected from an area highway.

Media selected for these experiments include a well-sorted, medium-grain-size sand, a fine aggregate, Grade 5 gravel, compost, and zeolites (a clay mineral). The well-sorted sand is typical of that used in sand filtration systems in the Austin area. The compost was obtained from a company in Oregon that has used it successfully in runoff controls. The zeolites were obtained locally and were tested because of their adsorption capability. They were tested in combination with the fine sand.

These experiments demonstrated that compost is a very effective medium, outperforming the other media for the removal of TSS, oil and grease, and metals. The medium sand performed well for the removal of TSS and most of the metals. The column with the medium sand media outperformed the column with the fine sand plus zeolites, showing that the zeolites are not a promising medium for enhancing removal via adsorption.

A prototype scale physical model of a runoff control has been constructed at CRWR. This model will allow researchers to determine the pollutant removal efficiency and hydraulic performance of proposed runoff control designs. Studies are under way to establish a design basis and configuration that will improve the performance of the runoff control systems constructed along the new highways in the Austin region.

## Conclusions

The negative impact of highway construction on the quality of surface waters is often significant despite improvements in the technologies used for erosion and sediment control. Monitoring of water quality in one of the creeks below a highway construction site in the Austin region indicates that even an extensive system of temporary controls is inadequate to prevent large amounts of suspended sediment from entering receiving waters. Deterioration in water quality has certainly been less than would have occurred in the past, but the performance of even the best controls is often compromised by inadequate installation and maintenance.

The development of adequate guidelines for the placement of temporary sediment controls has been hampered by the lack of knowledge about the performance of silt fences and other controls in a field setting. Parameters commonly used to characterize geotextile fabrics were also found to have little relevance for estimating their sediment removal abilities or hydraulic characteristics under field conditions. Accurate prediction of the hydraulic properties of these fabrics would allow the estimation of appropriate drainage areas to minimize overflowing of these temporary controls.

Once construction of a new highway segment is completed the stormwater runoff may need to be treated to protect environmentally sensitive areas. The use of the rainfall simulator in the CRWR experiments allowed researchers to collect sufficient data to formulate a computer model that will predict the quality of runoff from operating highways in the Austin, Texas, region. This model allows the prediction of the potential impacts of new highways and provides a screening tool to identify existing highway segments that may threaten nearby receiving waters.

Permanent water controls may be required if stormwater runoff from a highway is identified as a threat to environmental quality. Unfortunately structural controls built on the new highway segments to protect the Edwards aquifer have not performed effectively. The hydraulic performance of the vertical sand filters has been uneven, resulting in little apparent improvement in runoff quality. Testing of new filter configurations is continuing with the goal of improving the performance of these systems.

The search for cost-effective treatment of highway stormwater runoff is an active research area. The cost, maintenance requirements, and performance of many engineered controls provide the impetus for developing simpler approaches to treating stormwater. An example of such a method for reducing runoff concentrations and volumes is the grassy swale, which has been demonstrated to lower pollutant concentrations and quantities of runoff. Any strategy chosen to reduce the impacts of stormwater runoff must be relatively low maintenance, affordable, effective, and appropriate for the site.