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Field Instrumentation for Monitoring Water-Quality Effects of Storm-Water Runoff from Highways

THOMAS V. DUPUIS AND BYRON N. LORD

Storm-water runoff from operating highways can carry considerable quantities of pollutants, especially petroleum hydrocarbons and solids and metals, into the nation's receiving waters. The Federal Highway Administration, charged with the responsibility of protecting the environment from pollution from highway sources, has approached the problem in a multiphase research effort. The objective of the first phase was to identify and quantify the constituents of highway runoff. The next phase sought to identify sources and migration paths of these pollutants from the highways to receiving waters. The third phase, currently in progress, is analyzing actual impacts of highway runoff on receiving water. A wide variety of instrumentation has been used in the field monitoring portions of the investigation. Physical, chemical, and biological characterizations have been made. A general description of the types of equipment used in all three phases of the research program is presented. Included are brief observations on the effectiveness of certain types of specialized equipment not common to most water-quality surveys. It is hoped that this information will be of assistance to the highway community in planning and conducting environmental monitoring programs.

The highway system is a potential source of many possible pollutants to surrounding surface and subsurface waters. The National Environmental Policy Act of 1969 (NEPA) mandates that, for all federal projects that affect the environment, government agencies shall use a systematic, interdisciplinary approach that will ensure integrated use of the natural and social sciences and the environmental design arts in planning and decisionmaking. The Federal Water Pollution Control Act amendments of 1972 set a national goal of restoring and maintaining the chemical, physical, and biological integrity of the nation's water resources. In addition, many states either have already enacted or are in the process of enacting legislation similar to NEPA that may be more stringent than the federal laws in controlling various point and nonpoint discharges. Thus, consideration of the effects of a highway system on the environment plays an increasingly important role in the planning, design, construction, and operation of a transportation system.

Millions of roadway miles across the country pass over or near a variety of receiving waters. Thus, large volumes of highway storm-water runoff from highway right-of-way drainage areas are eventually discharged to a variety of large and small watersheds. The roadway contaminants contained in runoff might exert significant impact on receiving waters due to both chronic and acute loadings. However, there is currently very little information in the available literature on impacts on receiving water from highway runoff. Therefore, it is necessary to develop information on these impacts in order to properly address the need to protect the quality of receiving water from degradation.

The Federal Highway Administration, charged with responsibility for protecting the environment from pollution from operating highways, has approached the problem in a multiphase research effort that has the following objectives:

1. To identify and quantify the constituents of highway runoff,
2. To identify the sources and the migration paths of these pollutants from the highways to the receiving water,
3. To analyze the effects of these pollutants on receiving waters and on specific aquatic biota, and
4. To develop the necessary abatement and treatment methodology for objectionable constituents.

To date, studies designed to fulfill the first two research objectives have been effectively completed. A study of actual impacts on receiving water (objective 3) is currently under way. It should be noted that the scope of the research program is nationwide. Six sites located in different geographic regions of the contiguous United States were monitored in the phase 1 study. Four sites are to be used for both the phase 2 and phase 3 evaluations.

The objective of this paper is to describe instrumentation requirements for conduct of such a comprehensive field monitoring program. The scope is limited to types of equipment actually used in the program but includes physical, chemical, and biological techniques. To date, only lotic (flowing water) receiving water systems have been studied in the phase 3 research and only instrumentation pertinent to these types of systems is included in this discussion.

METEOROLOGICAL MONITORING

The meteorological parameters of most importance in this type of water-quality study include precipita-

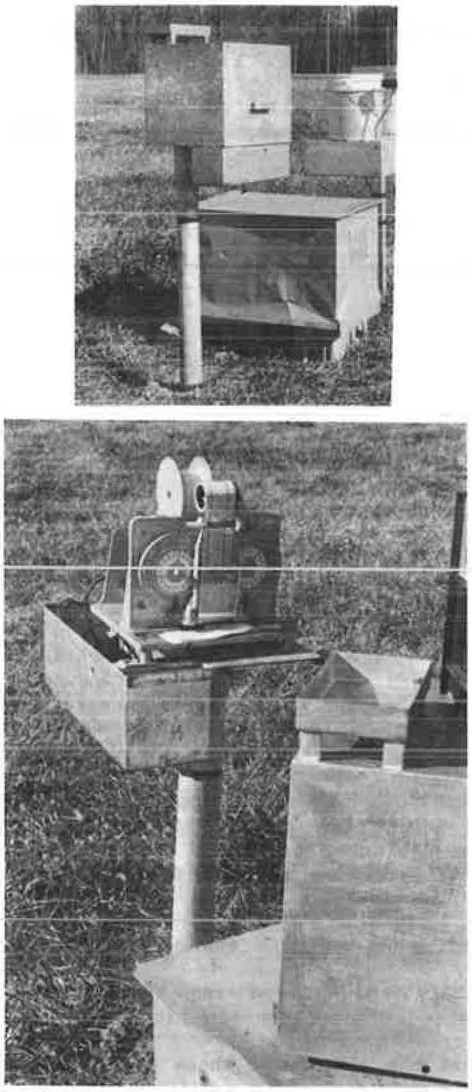


Figure 1. Precipitation measurement system.

tion (rain, sleet, hail, snow, etc.), wind speed and direction, air temperature, and atmospheric particulate deposition (dust fall).

Precipitation

The most common precipitation gage used in this program was a continuous-recording weighing gage. The major advantage of weighing gages is that continuous cumulative measurement is made so that time, quantity, and intensity can be determined for all types of precipitation. Evaporative losses for long-term charts (one week or more) can cause chart reading problems, but these losses are usually discernible.

Another system of precipitation measurement is being used by the U.S. Geological Survey (USGS) in North Carolina for one of the phase 3 sites. Rain is conducted from a collector tray to a standpipe (see Figure 1). A float and counterweight system translates the rainfall accumulation in the pipe to standard rainfall volume through the use of a Fischer-Porter automatic digital recorder. A small battery-powered pump, which is level actuated, periodically empties the standpipe of accumulated rainfall. This provides a digital punched tape recording of rainfall volume per discrete time interval and greatly reduces manpower requirements for chart reading. Diurnal thermal expansion of metallic standpipes can produce minor apparent fluctuations in precipitation volume, but these can be readily accounted for as tapes are entered into the computer file. This system would not be appropriate in northern climates unless a heating device were incorporated into the collector tray and standpipe to melt snow and ice.

Figure 2. Wet-dry collector.

Dust Fall

Dust-fall buckets were used to provide estimates of background or highway right-of-way pollutant loadings due to atmospheric deposition. American Society of Testing and Materials (ASTM) specifications on the location and size of dust-fall buckets and analytic procedures (ASTM D1739-62) were followed. A standard tapered plastic (polyethylene) bucket, 8 in (20.3 cm) in diameter and 10 in (24.4 cm) deep and equipped with bird-ring support, was used. These buckets have held up well under all climatic conditions. In addition, atmospheric deposition was separated into precipitation-related and dry dust-fall components by using wet-dry collectors (see Figure 2). These units consist of two side-by-side polyethylene buckets 11.3 in (23.6 cm) in diameter and 9.1 in (23.2 cm) deep. One bucket serves as a wet collector and the other as a dry collector, and a mechanical cover shifts from one to the other depending on climatic conditions. A heated sensor detects rainfall (or any other form of precipitation) and activates the movement of the cover from wet to dry bucket and back again.

Wind Speed and Direction and Air Temperature

Supplemental meteorological measurements such as wind speed and direction were critical for the source and migration studies. Of importance to all phases of the research program was ambient air temperature, especially with respect to snowmelt runoff. All three measurements were made with a single Meteorology Research Institute instrument set at a height of 12 ft (3.66 m). A one-month strip chart provided continuous recording of wind speed and direction and air temperature.

Quantitative Highway Runoff Monitoring

Determination of the volume and intensity of stormwater runoff was obviously of critical importance for all phases of the research program. To achieve this objective, a variety of instrumentation was used. The two basic categories of flow instrumentation are (a) primary measurement devices and (b) level-recording devices.

Primary recording devices are calibrated flow restrictions that artificially control the liquid level or energy gradient of an open-channel flow system. The most common control devices are weirs and flumes. The selection of weir or flume, or a specific type of weir or flume, depended on the hydrologic characteristics of the basin, runoff measurement sensitivity requirements, and other specific study needs. For example, weirs are generally cheaper and easier to install than flumes but promote a relatively higher head loss, are not always self-cleaning, and their accuracy can be more easily affected by excessive approach velocities (1). More detailed discussions of the selection of primary measuring devices can be found in the general literature (1,2).

Figure 3. Typical stream stilling well installation.

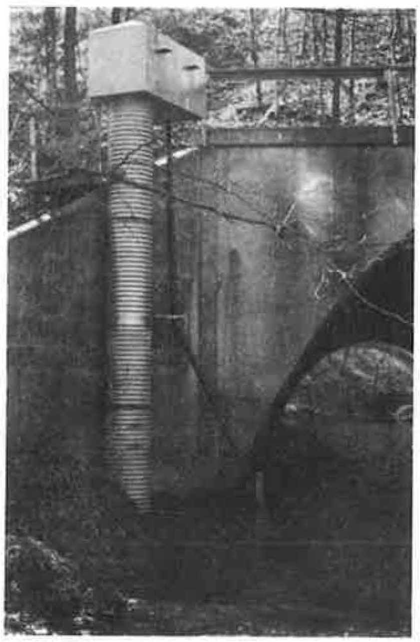
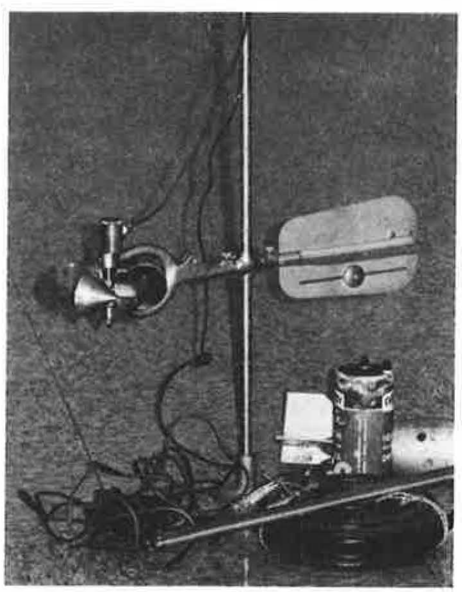


Figure 4. Gurley-type velocity meter.



The second component is the instrument for recording liquid level. The primary control devices mentioned above are simply calibrated to provide volumetric flow rates as a function of liquid level. Some secondary instruments measure and record only liquid level. Others provide direct conversion of liquid level to flow rate, which is especially useful if automatic water sampling requires flow-integrated samples (discussed later in this paper).

Two general varieties of level-sensing devices were used in this study: (a) mechanical surface floats and (b) bubbler tubes. Surface floats are attached to a cable with counterweight. The liquid level is thereby recorded in conjunction with the angular position of a shaft. Bubbler tubes discharge compressed gas (air or nitrogen) into the flow stream at a fixed depth and gas flow rate. The pressure required to maintain a constant gas flow rate is proportional to liquid level. It is preferable to enclose both surface floats and bubbler tubes in attached stilling wells to dampen out minor perturbations in liquid level caused by turbulence.

HYDROLOGIC MONITORING OF RECEIVING WATER

For both lentic (standing water) and lotic receiving water systems, the most important measurement is liquid level. For lentic systems, liquid level combined with morphological characteristics and other water sources and sinks (surface and groundwater inflows, precipitation, and evapotranspiration) provides a complete water budget. For lotic systems, liquid level combined with periodic velocity measurement provides a stage-discharge curve that covers a wide range of volumetric flow rates. Mechanical surface floats enclosed in stilling wells with accompanying continuous level recorders were used exclusively for the measurement of receiving-water level in this study. Corrugated culvert sections were used for the construction of stilling wells (see Figure 3). Staff gages were securely mounted in the stream adjacent to each stilling well to calibrate the level recorders.

Gurley-type velocity meters were used for velocity measurement (see Figure 4). As the cups are rotated by liquid flow, electrical pulses are sent to a headset worn by field personnel. The number of clicks heard per unit of time can later be accurately related to flow velocity rating tables. Due to their simplicity of design, the meters have been quite effective in terms of both operational and maintenance reliability.

WATER-QUALITY SAMPLING

Sampling for Laboratory Chemical Analysis

Both automatic and manual water-quality sampling procedures were used. Automatic discrete sampling for both highway runoff and receiving water was done with Instrument Specialties Company (ISCO) samplers. These have the capability to sample in either a time or flow-volume-integrated mode. Of course, flow integration requires input from a flow measurement device that can directly relate liquid level to flow rate. The capability to sample in a flow-integrated mode greatly reduces manpower requirements for both sample compositing and chemical analyses. Other desirable features of the ISCO sampler are as follows:

1. It has weatherproof, corrosion-resistant construction.
2. It is capable of operating with either DC or AC power source.
3. It can take twenty-eight 500-mL or seven 2-L samples or several other combinations in between, in glass or plastic bottles.
4. Sampling frequency can be anywhere from 1 to 999 min or in a flow-integrated frequency mode.
5. Sample actuation can be controlled either by a level sensor-recorder or on the basis of flow volume.
6. Sample event marking is provided on corresponding flow charts to aid in sample compositing and hydrograph quality characterization.

Manual sampling devices consisted of Kemmerer and Zobell-type (3) water-quality and bacteriological samplers, respectively. These samplers allow discrete sampling at any desired depth. Also used were standard USGS depth-integrating suspended sediment samplers; i.e., liquid intake volume is proportional to flow velocity as the sampler is moved vertically through the water column (4). These sampling devices were quite simple, and few operational problems were encountered.

In Situ Measurement of Water Quality

In situ measurement of such water-quality parameters as pH, temperature, dissolved oxygen, and specific conductivity was done with common, commercially available instrumentation. Membrane-covered polarographic sensors were used for dissolved oxygen (DO) determinations (these are generally gold-silver or platinum-lead electrodes through which a small measured voltage is applied, and chemical reduction of oxygen passing through the membrane generates an electrical current at the anode). Potentiometric determination of pH is most common (a glass and calomel reference electrode is used, and the voltage across these electrodes is a measure of hydrogen ion concentration), and thermistors are generally used for temperature measurement. Conductivity measurements are generally made with Wheatstone bridge-type recorders and conductivity cells with platinum-coated electrodes firmly enclosed in plastic or glass insulation. All instruments proved quite reliable when properly calibrated with standard solutions or field titrations. DO measurement was difficult in very cold climates due to frozen membranes. Under these conditions, field titrations had to be performed.

SEDIMENT SAMPLING

Interactions between sediment and water have come to be recognized as crucial elements in determining the overall fate and impact of pollutants in receiving waters. Sediments can serve as either a source or a sink of most pollutants, depending on such factors as oxidation and reduction potentials, pH, and turbulence.

Consolidated sediments were sampled with core tubes and dredges. Core sampling was either performed manually or, if the sediments were soft enough, with a Jenkins-type automatic corer (5). This is a spring-loaded corer that, when sunk into soft sediments and activated with a messenger, simultaneously covers both ends of the tube. This allows withdrawal of a relatively undisturbed core. Disturbed sediment samples were obtained with an Ekman dredge, especially in portions of receiving waters with substrates that prohibited core penetration.

Sediments can act as significant DO sinks due to the decomposition of deposited organic matter. To determine whether highway runoff inputs affect the rate of sediment oxygen demand or to determine background oxygen sinks, special in situ chambers were constructed to measure these rates. These chambers were designed after those of Lucas and Thomas (6) and consisted of a 4.8-gal (18-L) plexiglass chamber that gave an exposed sediment surface area of 1.8 ft^2 (0.17 m^2). A DO probe was sealed in the chamber, and internal water recirculation was provided with a submersible pump. This allowed batch measurement of oxygen depletion (or accumulation) rates per unit surface area of sediment. This instrument can only be used effectively in relatively soft sediments due to sealing problems in rocky or gravelly substrate.

BIOLOGICAL MONITORING

The biological integrity of receiving water is perhaps the best indicator of the pollutional effect of storm-water runoff. Several different methods were used to collect various types of organisms from control and highway-runoff-influenced regions of the lotic systems studied to date. These included (a) Surber samplers, (b) drift nets, and (c) artificial substrates such as glass periphyton slides and Hester-Dendy samplers.

Surber samplers (see Figure 5) are designed to collect insects, larvae (macroinvertebrates), and other forms of aquatic benthic organisms from a known surface area [1 ft^2 (0.093 m^2)] of bottom substrate in shallow streams. An attached nylon or silk net with a mesh size of roughly 1000 μm collects organisms manually dislodged from the stream bottom.

Drift nets were used to quantify migrating organisms or organisms dislodged from bottom substrates. These nets had an upstream opening of 210 in^2 (1350 cm^2) and a mesh size of 363 μm. Nets are not in actual contact with the bottom as are the Surber samplers.

Artificial substrate samplers provide sites for organisms to colonize to minimize effects of different substrates on organism distribution. Two basic types were used. Periphyton (attached primary producers) samplers consisted of a box of six standard microscope slides (plain, 25x75 mm) attached near, but not in contact with, the stream bottom. Hester-Dendy samplers (see Figure 6) consisted of 14 round, tempered hardwood plates mounted in series with variable spaces. Each plate is smooth on one side and rough on the other and has a diameter of 3 in (7.5 cm) and an effective surface area of 1.4 ft^2 (0.13 m^2). These serve as efficient substrata for sampling of benthic macroinvertebrates.

SPECIAL INSTRUMENTATION FOR SOURCE AND MIGRATION STUDIES

Saltation Catchers

Saltation catchers were designed to capture "saltating" particles (movement by a series of jumps) from roadway surfaces. Measurement of roadside saltation dust provided a good qualitative estimate of the magnitude of nonsuspended particle transport compared with suspended dust transport (i.e., dust fall).

Each saltation catcher consisted of a dust-fall bucket fitted with a polyvinyl chloride pipe measur-

Figure 1. Steel noise barrier 1 m in height atop 3.7-m-high earth berm with 3:1 slope.

Figure 2. Concrete wall 0.8 m in height atop 2.2-m-high earth berm with 2:1 slope.

a 2-m-high wall would be offset by losing the extra 3-dB(A) insertion loss associated with earth berms.

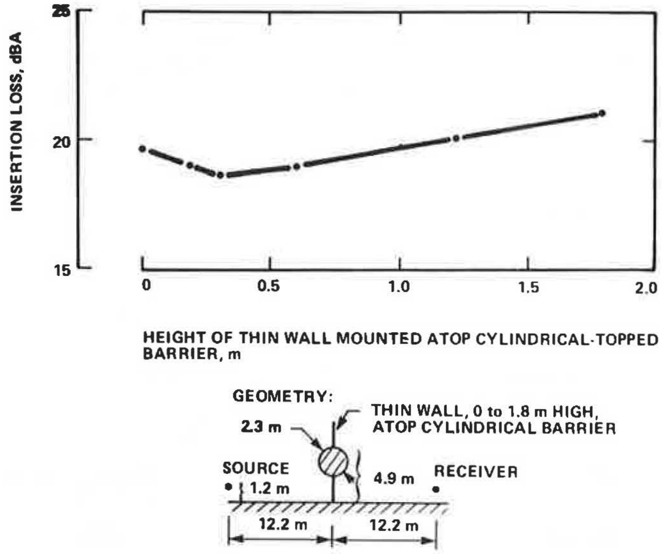
To investigate the advisability of building this wall-berm combination and to evaluate the relative acoustical performance of thin-walls and berms, a research study was undertaken that involved three phases: (a) a literature review of the effects of barrier shapes, (b) an evaluation of limited field measurements, and (c) a scale-model study. This work is part of a noise barrier research program in Ontario, the highlights of which were summarized by May (5).

REVIEW OF STUDIES CONCERNING BARRIER SHAPES

The effect of barrier shape on its performance has been studied extensively. The findings of the major studies reviewed, which compared sound attenuation by thin-walls with that achieved by wedges or berms of equal height, are summarized in Table 1 (6-19). The table does not include comparisons of thin-walls with other extraneous barrier shapes such as T-top (20) or thnadners (21) or with thin-walls that have sound-absorptive covering or sound-absorptive edges (22-24).

A review of the 13 studies listed in Table 1 does not provide an unequivocal answer to the question of whether earth berms are superior to thin-walls. Analytic investigations by several researchers concluded that thin-walls provide 1-3 dB(A) more attenuation than reflective wedges (8,17) and about the same, or slightly less, attenuation than absorptive wedges or berms (14,16). In general, scale-model studies (9,10,12,18) tend to agree with the conclu-

Figure 3. Effect of mounting thin-wall atop 4.9-m-high absorptive cylindrical-topped barrier with geometry as shown, receiver 1.2 m above ground, and grass-covered ground throughout.



sions based on analytic investigations. May and Osman (15) reported that thin-walls are less effective than wide barriers (2.4 m) with rectangular cross sections. However, the slope of the berm or wedge affects attenuation, and the vertical slope is most effective for reasons discussed later.

Only one full-scale study directly comparing thin-walls and earth berms has been identified (11). According to that study, thin-walls are less effective than earth berms and wall-berm combinations by 2.4 and 1.3 dB(A), respectively. The finding that the wall-berm combination is more effective than the wall alone is somewhat difficult to explain, since the diffraction of sound occurs over identically shaped tops. In addition, other field studies have not found any measurable differences between the insertion loss provided by reflective thin-walls and thin-walls with a sound-absorptive covering (20,24). Additional studies comparing berms and thin-walls, conducted by the Ontario Ministry of Transportation and Communications (MTC), are discussed below.

FIELD MEASUREMENTS

Field measurements evaluating the performance of earth berms were conducted at two sites. At the first site, a 1.9-km-long highway noise barrier consisting of three sections--a concrete (reflective) wall, an earth berm, and a section combining the two (see Figure 2)--was evaluated. No difference in performance could be attributed to the different barrier shapes (25).

At the second location, sound-level measurements were conducted before the construction of an earth berm, after its construction, and, finally, after erection of a steel barrier on the top (Figure 1). The addition of the thin-wall atop the berm (see Figure 3) increased insertion loss roughly as expected from the increase in the total barrier height.

It should be recognized, however, that field evaluation of noise barrier performance is influenced by several weather-related factors and by other variables. It is difficult to measure and verify statistically a change of 1 or 2 dB(A) that occurs over the span of several months (26). This

Table 1. Review of acoustical studies on effects of barrier shapes.

Reference	Publication Date	Method of Investigation	Conclusion Regarding Effect of Barrier Shape for Structures of Equal Height
Delaney, Rennie, and Collins (6)	1972	Scale modeling, 1:30, point source (pneumatic jet)	Thin-walls are 2-3 dB(A) more effective than earth berms
Jonasson (7)	1972	Analytic investigation with some full-scale measurements	Generally there is no consistent difference between thin-walls and wedges covered by densely grown grass
Pierce (8)	1974	Analytic investigation	Thin-walls are about 1-3 dB(A) more effective than 3-sided (trapezoidal) barriers[a]
Porada (9)	1975	Scale modeling, 1:100 and 1:20, line source (air-jets)	Thin-walls are about 1-3 dB(A) more effective than wedges
Cann (10)	1975	Scale modeling, 1:80, point source (electric spark)	Thin-walls and earth berms are equally effective
Simpson (11)	1976	Field testing of completed barriers	Thin-walls were less effective than earth berms and berm-wall combinations by 2.4 and 1.3 dB(A), respectively
Ringheim (12)	1976	Scale modeling, 1:20, point source (pneumatic)	Good agreement with Pierce's method in that thin-walls are better than wedges[b]
Ivey and Russell (13)	1977	Scale modeling, 1:64, point source (electric spark)	There is no direct comparison of barrier shapes; however, Pierce's solution for wide rectangular walls (8) is supported by results of this study
Hayek and others (14)	1978	Analytic investigation	Thin-walls provide about 1 dB(A) less attenuation than absorptive cylindrical-topped wedges (berms)
May and Osman (15)	1980	Scale modeling, 1:16, point source (electric spark)	Thin-walls and wedges were not compared; thin-walls were 2.5 dB(A) less effective than wide (2.4-m) barriers with rectangular cross section
Nijs (16)	1980	Analytic investigation and scale modeling (unspecified type)	Thin-walls are 3-4 dB(A) better than acoustically hard wedges; however, if wedges are perfectly absorbing, they will not differ
Seznec (17)	1980	Analytic investigation	Thin-walls are 1-3 dB(A) more effective than 3-sided (trapezoidal) barriers
Lawther and others (18)	1980	Scale modeling, 1:5, line source (tone bursts using loudspeaker array)	Thin-walls are more effective than berms unless berms are covered by an absorptive material (grass), in which case they are equally effective

Note: Comparisons are restricted mainly to reflective thin-walls ⊥, wide barriers such as wedges ∧, and berms. Thin-walls with sound-absorptive covering or sound-absorptive edges are not included.
[a]Based on Seznec's substitution (17) into Pierce's formula (8).
[b]Similar results were obtained for trapezoidal barriers by Ringheim (19).

is one of the reasons why the scale-model study was undertaken.

SCALE-MODEL STUDY

Under the aforementioned circumstances, acoustical scale modeling was an indispensable tool. A multiplicity of interacting factors made it difficult to obtain an exact analytic answer to the question posed, and full-scale experiments were too expensive. In particular, the diffraction by absorptive wedges on finite impedance ground is influenced by the interaction of the following factors:

1. Source-barrier-receiver geometry;
2. Interference (and reflections) due to ground cover that may not be uniform;
3. Scattering and absorption losses on the barrier top; and
4. Finite barrier thickness or double-edge diffraction.

Scale modeling also permitted rapid and inexpensive situational changes (barrier height and shape and ground cover) and their rapid evaluation. Because the study was conducted indoors, weather-related factors were eliminated, which enhanced repeatability and the accuracy of the results.

The scale-model study was conducted at the MTC scale-modeling facility. The equipment and materials used were described by Osman (27,28) and were used extensively before (15). Similar equipment has been used by other researchers (10,13). Briefly, the acoustical hardware consisted of a high-voltage spark as a noise source, a 0.13-in microphone receiver, filtering and processing instrumentation, and an oscilloscope.

The model scale was 1:16 and was applied to both spatial variables and the A-weighted traffic noise spectra (27). In addition, the sound-absorptive properties of the model materials (e.g., grassland, pavement, and surfaces of reflective barriers) were tested to ensure that they appropriately modeled the real-life situations on the 1:16 scale. All dimensions and frequencies quoted in this paper are full-scale equivalents. Therefore, the model dimensions were 16 times smaller and the model frequencies 16 times higher than the full-scale values.

The source-barrier-receiver geometry (see Figure 4) and materials were selected to model typical highway situations (in plan view, the line between the source and the receivers is perpendicular to the barrier alignment). The model berms had a slope of 2:1 and were 1.2 m wide across the top. The flat tops with sharp edges on the sides were rounded to reflect the shape of actual earth berms. To simulate grass cover, the model berms, constructed of plywood, were completely covered with an appropriate, acoustically soft material (fiberboard). In contrast to the acoustically soft material used on the berms, acoustically hard material (painted plywood) was used to model the surfaces of thin-walls.

For simplicity, only a single point source was used in the study. This should not limit the validity of the results, since the relative effect of barrier shape is indicated by a point source even if the absolute insertion loss values may not be (15).

The height of the point source above ground was modeled at 1.2 and 2.4 m. The source height of 2.4 m is usually associated with the source height of heavy (diesel) trucks (4); the 1.2-m height may be considered to be an equivalent source height for highway traffic flow containing about 10 percent trucks.

The basic barrier configurations evaluated are given in Table 2. Most of these barrier shapes were tested for the three basic geometries defined in Figure 4. However, for illustrative purposes, only a sample of the results is presented here.

Figure 5. Stream macroinvertebrate sampler (Surber).

Figure 6. Hester-Dendy macroinvertebrate sampler.

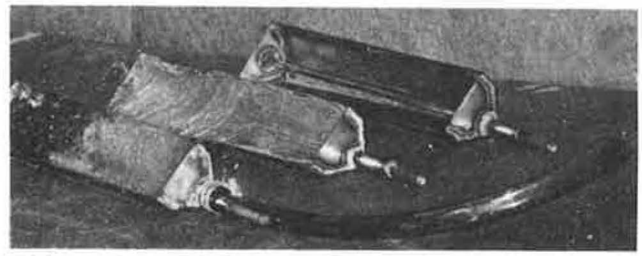
ing 28.5 in (72.4 cm) high and 6 in (15.24 cm) in diameter. This pipe has a vertical sampling slot 19 in (48.26 cm) high and 1.0 in (2.54 cm) wide that faces the roadway and captures the saltating particles, which have a height interval of 12-30 in (30-76 cm). Figure 7 shows a typical saltation catcher. The capture efficiency of this device is approximately 50 percent (7).

Zero-Tension Lysimeters

Zero-tension lysimeters measure groundwater percolation out of the major rooting zone (usually the top soil layer). They were used in the source and migration studies to estimate the loss of various chemical constituents from the highway system due to groundwater percolation. Figure 8 shows a lysimeter system. Plastic 1-gal (3.7-L) collection bottles store water that has percolated through the rooting zone into special stainless steel troughs. These troughs have a collection surface 12 in (30.5 cm) long and 2.1 in (5.4 cm) wide. Within the trough are two parallel stainless steel rods in slight contact with an overlying mesh screen, which has a thin layer of fiber wool to keep soil from clogging the screen. The rods in contact with the mesh

Figure 7. Saltation catcher.

Figure 8. Zero-tension lysimeter.



screen negate the surface tension of water percolating through the screen and provide effective capillary drainage.

Overall, lysimeters appeared to yield a high recovery efficiency provided that they were installed properly (i.e., if there was good contact between the lysimeter and the overlying soil layer) in well-drained soil. Using measured flows to convert sample percentages to areal mass loadings provided reasonable estimates of pollutant migration.

Sweeping and Flushing Studies

Sweeping and flushing studies were performed to quantify the accumulation and distribution of pollutants on the highway surface, seasonal variations in the surface pollutant load, and the particle size distribution of accumulated solids. This information was needed to establish the relations between pollutant deposition on the highway surface (including deposition from vehicles, the atmosphere, and highway maintenance activities), the highway surface load, and removal processes (including runoff, blowoff, and, where performed, highway sweeping). Test sections 50 ft in length in the distress median and travel lanes were swept and flushed to characterize the highway surface pollutant load. Test sections with visual accumulations of dust and dirt were first swept. All test sections were then wet-vacuumed with a standard carpet cleaning rinse and vacuum machines. Dry samples (swept) and liquid samples (wet-vacuumed) were analyzed separately for pollutant concentration. To date, quite good agreement has been observed between surface loads determined by sweeping and flushing and those calculated in deposition-removal mass balances. In addition, tests have shown that the rinse and vacuum machines do not add contaminants through the spraying system.

CONCLUSIONS

This paper documents instrumentation requirements for a comprehensive, multifaceted evaluation of water-quality impacts and spans several phases of investigation. The selection of instrumentation requirements obviously depends on both the required complexity of the monitoring program and available funding. As part of the research program described in this paper, separate report volumes have been, or will be, prepared concerning procedural guidelines for water-quality impact assessment and detailed monitoring guides for conduct of field programs. These manuals are designed to serve the needs of highway department personnel by providing simple and straightforward procedures in design, planning, conduct, and evaluation of proposed sampling programs and water-quality investigations.

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Are Earth Berms Acoustically Better Than Thin-Wall Barriers?

J. J. HAJEK

The two most common highway noise barrier structures are earth berms and thin-walls. Yet the relative acoustical performance of these barriers is not well understood. Previous analytic, scale-model, and full-scale studies, comparing the acoustical effectiveness of thin-walls with that of berms and wedges, are reviewed. Additional data obtained by full-scale measurements, and in particular by a 1:16 scale-model study, are presented. The source-barrier-receiver geometry and model materials used were selected to simulate typical highway situations. Preliminary results indicate that, contrary to a recommendation in the Federal Highway Administration Highway Traffic Noise Prediction Model, thin-wall barriers and earth berms of the same height are about equally effective in reducing noise. In addition, the acoustical effectiveness of combining a wall with an earth berm was found to be quite similar to that of using thin-wall barriers alone. The practice of erecting relatively low walls on top of earth berms was found to be acoustically sound.

Reflective thin-walls, earth berms, and combinations of the two, are the most common highway noise barriers. Their relative nonacoustical aspects, such as cost, maintenance, right-of-way requirements, and aesthetics, are well understood (1), but their relative acoustical performance is not so clear. Whereas some highway noise prediction methods assume that they perform equally (2,3), the widely used Federal Highway Administration (FHWA) Highway Traffic Noise Prediction Model (4) asserts that earth berms provide 3 dB(A) higher insertion loss than do thin-walls of the same height. This difference in acoustical performance has been attributed to absorption or edge effects.

The higher insertion loss assumed for earth berms could lead to an important consequence: If the shape of the earth berms (presumably the cause of the increase in the insertion loss) is changed by erecting a thin-wall on its top, the 3-dB(A) benefit provided by the berm top may be lost. Figures 1 and 2 show two wall-berm combinations. Such combinations are quite common in many states. Relatively low walls have been added to improve performance in comparison with earth berms alone. But do they?

This concern is illustrated in Figure 3, which is based on our results from scale-model testing. Details of the scale-model testing, such as instrumentation, methodology, and additional results, are discussed later in this paper. For now, Figure 3 is intended only to illustrate the effect of mounting a thin-wall atop a barrier with an absorptive top.

According to Figure 3, mounting a thin-wall atop a highly absorptive barrier can actually reduce insertion loss. Only after the thin-wall is raised to the height of 1.2 m is the reduction in the insertion loss--caused by violating the absorptive cylindrical shape--recovered by the increase in barrier height. The question arises, Can the same phenomenon occur if a thin-wall barrier is erected atop an earth berm?

This question has become acute in Ontario since a proposal was made to build a thin-wall, approximately 2 m in height, atop an existing 3-m-high earth berm. The berm is already providing some insertion loss [about 6 dB(A)], so the rate of increase in the insertion loss with additional barrier height would be about 1.5 dB(A)/m. However, the desired 3-dB(A) increase in the insertion loss expected from adding