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Impacts of Motor Vehicle Operation on Water Quality in the United States - Clean-up Costs and Policies

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Abstract

This paper investigates the costs of controlling some of the environmental impacts of motor vehicle transportation on groundwater and on surface waters. We estimate that annualized costs of cleaning-up leaking underground storage tanks range from $0.8 billion to $2.1 billion per year over ten years. Annualized costs of controlling highway runoff from principal arterials in the US are much larger: they range from $2.9 billion to $15.6 billion per year over 20 years (1.6% to 8.3% of annualized highway transportation expenditures.) Some causes of non-point source pollution were unintentionally created by regulations or could be addressed by simple design changes of motor vehicles. A review of applicable measures suggests that effective policies should combine economic incentives, information campaigns, and enforcement, coupled with preventive environmental measures. In general, preventing water pollution from motor vehicles would be much cheaper than cleaning it up.

Key Words: non-point source pollution; groundwater pollution; motor-vehicle transportation; economic incentives.

1. Introduction

Most studies of the environmental impacts of transportation focus on air pollution, the main environmental externality associated with road transportation, or noise (Delucchi 2000). Currently, there is no good estimate of the aggregate impact of motor vehicle transportation on water pollution (Litman 2002), and a review of the relevant literature suggests that many estimates of water externalities resulting from motor vehicle transportation are based on educated guesses. While the emphasis of recent regulations leads us to surmise that these impacts are substantial, it is still very difficult to quantify them reliably because motor vehicles are just one of several causes of non-point source pollution.

This paper is concerned with the costs of controlling water pollution from motor vehicles. It focuses on two problems that have attracted considerable media attention over the last few years in the US, and particularly in California: leaking underground storage tanks (LUSTs) and highway runoff.

There is evidence that residues from the operation of motor vehicles contribute heavily to non-point source and groundwater pollution. Pollutants from motor vehicles or from transportation infrastructure include sediments (from construction or erosion), oils

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and grease (from leaks or improperly discarded used oil), heavy metals (from car exhaust, worn tires and engine parts, brake pads, rust, or used antifreeze; Table 1), road salts, as well as fertilizers, pesticide, and herbicides (used alongside roads or on adjacent land).

< Insert Table 1 approximately here >

The US Environmental Protection Agency (EPA) (1996) estimates that up to half of suspended solids and a sixth of hydrocarbons reaching streams originate from freeways. Vehicle-related particulates in highway runoff come mostly from tire and pavement wear (about a third each), engine and brake wear (about 20%), and exhaust (about 8%). Each year, millions of gallons of improperly discharged used motor oil pollute streams, lakes, and coastal areas. This should be cause for concern since one gallon of used oil can contaminate one million gallons of water. Not all pollutants found in highway runoff, however, come from transportation activities. Roads collect pollutants from many other sources, including agricultural runoff or wind-blown contaminants from manufacturing and energy production.

Groundwater quality is also threatened. There have been more than 450,000 confirmed fuel leaks from underground storage tanks (USTs) in the US, including 44,000 in California (US Environmental Protection Agency 2005a). Because of these, many communities need to find alternative sources of freshwater. For example, Santa Monica, California, has lost 80% of its local water supply to MTBE contamination and since 2005 oil companies responsible for this pollution have had to purchase replacement water at a cost in excess of \$3 million per year (US Environmental Protection Agency 2005b).

A comprehensive assessment of how motor vehicle transportation affects water quality is too complex to be feasible, so the focus here is on leaking USTs, on highway runoff, and on water pollution resulting from the improper disposal of used oil, waste coolant/antifreeze, and metal dust from brake pads either because these sources of pollution are generally important or because they lead to the consideration of informative policy solutions.

2. Literature Review

Interest in storm-water runoff pollution in the US is not new: many engineering and public health papers examine pollutants in storm-water runoff, their potential health impacts, and the effectiveness of best management practices (BMPs) for removing them.

Storm-water Runoff

Heavy metals in storm-water runoff are of particular concern because of their toxicity, pervasiveness, and persistence. In an early study, Ellis et al. (1987) find that heavy metals can make highway runoff chronically toxic to receiving waters. In their review, Davis et al. (2001) report that pollutant loads typically follow the pattern: Zn (20-5,000 μg/l) > Cu ≈ Pb (5-200 μg/l) > Cd (< 12 μg/l)[1] and their empirical study reveals that brake wear is

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[1] The notation used for pollutants throughout this paper is: Cd – Cadmium; Co – Cobalt; Cr– Chromium; Cu – Copper; Fe – Iron; Mn – Manganese; MTBE – Methyl tertiary butyl ether; Ni – Nickel; Pb – Lead; PCB – Polychlorinated biphenyl; VOC – Volatile organic compound; and Zn – Zinc.

the largest contributor to copper loading (47%) in urban runoff while tire wear contribute 25% of zinc loading, the second largest after buildings.

Kayhanian et al. (2003) study the impact of VMT on highway runoff pollutant concentrations. Concentrations are two to ten times higher for urban than for non-urban highways but non-urban highway runoff shows greater concentrations of total suspended solids, pesticides, and ammonia, which points to agricultural sources. They also caution that a simple linear relationship between annual average daily traffic and pollutants is unlikely because of weather patterns and land use. Many pollutant loadings exhibit seasonal variations: winter brings high concentrations of chlorides and sulfates from deicing salt (Legret and Pagotto 1999) while irregular rainfall complicates runoff management. Over a long, dry season pollutants accumulate on road surfaces and enter receiving waters during the first storm event (Han et al. 2006). Regular street sweeping can help, although its effectiveness is still debated (Tobin and Brinkmann 2002).

Storm-water runoff has also generated significant public health concerns. Gaffield et al. (2003) examine impacts from heavy metals in storm-water, which can often be traced to motor vehicle sources. According to Van Metre et al. (2000), vehicles (through tire wear, oil leaks, or car exhaust) are a significant source of polycyclic aromatic hydrocarbons, a known carcinogen, in water bodies.

There has also been considerable interest in the US in storm-water BMPs. Maestri and Lord (1987) identified vegetative controls (e.g. grassed swales); wet detention basins; infiltration systems; and wetlands as measures for run-off-control. Shutes et al. (1999) extend their work to the effective construction, operation, and maintenance procedures of constructed wetlands. Inconsistencies across these US BMP studies, however, have limited their usefulness. Barrett (2005) relies on the California Department of Transportation's (Caltrans) BMP Retrofit Pilot Program to develop a methodology for comparing BMPs. He finds that the degree of pollutant removal depends on interactions between a BMP and the influent water quality, not just on BMP characteristics.

The cost of complying with US federal and state storm-water regulations has been the subject of lawsuits in California. As a result, state agencies have conducted research to better estimate storm-water management costs. Currier et al. (2005) examine six California municipalities that made good progress toward storm-water compliance; they report annual storm-water management costs ranging from $18 to $46 per household. By comparison, a 2004 survey of Orange County (CA) residents found that nearly 60% of respondents would pay at least $5 per month to curb urban runoff (Center for Public Policy 2004).

Underground storage tanks

The US Energy Policy Act of 2005 targets leak prevention and expands the use of the leaking underground storage tanks (LUST) Trust Fund. In the US, there were more than 450,000 confirmed releases at underground storage tanks as of September 2005 and cleanups had been initiated on more than 421,000 of these (US Environmental Protection Agency, 2005a). Marxsen (1999), however, claims that the cost of addressing LUSTs may exceed benefits; he reports that cleanup costs range from $100,000 to more than $1 million when groundwater is involved. Rice et al. (1995) find that LUST contamination tends to be shallow so it may not affect deeper public drinking water wells. In addition, if the source of the leak is removed, passive bioremediation processes may naturally contain the spread of contamination. A well-managed UST program that emphasizes leak detection can reduce the overall cost of LUST damage.

Considerable attention has been paid in the US to groundwater pollution caused by methyl tertiary butyl ether (MTBE). Until recently, it was widely used as a fuel additive in the US EPA's Reformulated Gasoline and Oxygenated Fuel Programs. In their risk analysis of MTBE contamination in California, Williams et al. (2004) find, however, that volatile organic compounds (VOCs) other than MTBE are detected more often and at higher risk levels. In contrast, Moran et al. (2005) conclude from a national survey that MTBE is detected at or above the rate of other VOCs.

3. Environmental Impacts of Non-point Source Water Pollution

Motor vehicles are a major contributor to non-point source (NPS) pollution, as small quantities of various pollutants are emitted during vehicle use or improperly disposed of at many different locations. A number of studies link heavy metals (e.g. Pb, Zn, or Cu) or hydrocarbon loadings of surface water with transportation. Heavy metals in highway runoff are not necessarily toxic because toxicity depends on chemical form and availability to aquatic organisms. However, some heavy metals bioaccumulate in the food chain and can become toxic to humans over the long run.

Sources of Surface Water Pollution

We consider three sources of NPS pollution for surface waters. Of these, used oil is likely the main hydrocarbon source to runoff (Latimer et al. 1990).[2] According to the US Environmental Protection Agency (1996), road runoff carries hundreds of thousands of tons of oil. Additionally, improperly disposed used oil filters may account for 5% of used oil discarded into the environment. Yet, used oil is the “single largest environmentally hazardous recyclable material” (MARRC 2001).[3]

Like crude oil slicks, used oil can have devastative impacts on aquatic life. However, refined products such as motor oil and gasoline are more toxic than crude oils. First, they disperse more readily into water. Second, soft tissues absorb them more easily. Third, used motor oil often contains contaminants, such as chemicals added to boost engine performance, compounds produced during engine operation, or wastes mixed-in during disposal.

The severity of the environmental impacts of used oil depends on weather, water temperature, geographic features, and characteristics of the oil itself. Whereas wave action can quickly disperse an oil spill in open waters, oil contamination in calm waters can persist for years, so natural recovery times can vary considerably.

Another source of non-point source pollution is used coolant/antifreeze, which

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[2] Used oil can also be a point source pollutant. Indeed, used oil is listed as the main pollutant at 25 Superfund sites. While used oil in itself is not dangerous if handled properly, it can mask many highly hazardous chemicals such as PCBs and chlorinated solvents (US Environmental Protection Agency, 1996).

[3] Used oil can be refined again (at one third the energy cost), but it can also be used for producing asphalt, or burned for energy (MARRC 2001). In addition, metal in used oil filters can be recycled to manufacture rebars, nails, and wire. Finally, used oil plastic containers can be processed to produce plastic products such as pipes and posts.

typically consists of 95% ethylene glycol, a clear, sweet-tasting and highly toxic liquid. Millions of gallons of coolant/antifreeze are sold each year in the US yet only 12% is recycled (Department of Toxic Substances Control 2001). Used coolant/antifreeze is especially a problem for Do-It-Yourselfers (DIY) because current engine design makes it almost impossible to avoid spilling some product when it is changed.[4] Engine coolant/antifreeze can also contribute high biochemical oxygen demand (BOD) levels to storm-water.

In addition, operating motor vehicle disc brakes contributes heavy metals to non-point source pollution. Interestingly, this source of pollution resulted from technological change and new regulations. Indeed, until the end of the 1960s, most cars had enclosed drum brakes. Pads for these brakes typically contained asbestos but no metals.

In the early 1970s, stricter braking requirements and concerns for workers' health related to airborne asbestos led manufacturers to adopt disc front – drum rear braking systems with semi-metallic brake pads. These pads contain no asbestos, wear out more slowly, and have good braking properties. Corporate average fuel efficiency standards reinforced the adoption of semi-metallic pads by favoring front wheel drive cars. Disc brakes, however, are open to the environment, so each time semi-metallic brake pads squeeze against the wheels' rotors, tiny amounts of metal dust, often copper but sometimes also zinc and lead, are deposited along the roadway and washed to water bodies by rain or snow.

Releases from brake lining wear add up: a recent study estimates that they contributed 53.8 metric tons of copper in 2003 (95% confidence interval: [31.9, 75.7]) to the San Francisco Bay watershed for all motor vehicle classes (Sinclair Rosselot 2006). Unfortunately, national estimates are not available.

Sources of Groundwater Pollution

While used oil and used coolant/antifreeze pollution mostly affects surface waters, gasoline spills from leaking underground storage tanks (LUSTs) are a major source of groundwater pollution all over the US. Although severe leaks can create fire or explosion hazards, the primary environmental concerns associated with gasoline releases are volatile organic compounds such as dissolved-phase benzene, toluene, ethylbenzene, and xylene. More than 1.6 million USTs have been permanently closed since the LUST problem first surfaced and the number of confirmed releases exceeds 450,000. Although cleanups have been completed on nearly 75% of these, there are still more than 150,000 leaking registered and unregistered UST where clean-up has not started (items c + j + n in Table 2).

At the same time, more than half of the US population relies on groundwater for at least a portion of its drinking water and 80% of community drinking water systems are dependent on groundwater (US Environmental Protection Agency 1994). LUSTs are therefore a significant environmental problem. Table 2 summarizes key UST statistics.

< Insert Table 2 approximately here >

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[4] Personal communication with Lee Halverson, Hazardous Waste Management Specialist, State Regulatory Programs Division, California Department of Toxic Substances Control, October 4, 2001.

Until the mid-1980s, most gasoline USTs were made of bare steel, which corroded over time, although connectors and pipes also caused many leaks (US Environmental Protection Agency 2001). With increasing awareness of the costs of gasoline leaks, Congress banned the installation of unprotected steel tanks and piping in 1985. According to the State Water Resources Control Board (2006a), 80% of USTs now meet California regulations for both release detection and prevention requirements. However, many leaks remain undetected because monitoring is inadequate and many USTs are inactive or abandoned (Farahnak and Drewry 1997).

4. Clean-up Costs Estimates

To quantify the costs of cleaning up LUSTs and of controlling highway runoff, we use a social discount rate of 7% (nominal annual), as recommended by the Office of Management and Budget (OMB Circular No. A-94 Revised), and a real social discount rate of 4%. Unless specified otherwise, amounts are in 2005 dollars.

Highway Runoff Control Costs

In general, highway runoff control costs are difficult to quantify because practical experience is still relatively limited. For a given site, these costs depend on precipitation, soil and vegetation characteristics, traffic intensity, land availability, proximity of maintenance bases, and of course on the regulatory framework.[5] To capture the uncertainty surrounding BMP costs, we consider two scenarios and two levels of BMP implementation for which we report construction as well as operation and maintenance (O&M) costs. Costs are annualized over twenty years to limit the burden on limited public resources.

There has been extensive research in California on quantifying highway runoff control costs. Caltrans' Storm Water Quality Handbook (2002) estimates costs at $100,000 per lane mile for rural highways and $250,000 per lane mile for urban ones. Implementing BMP during initial construction may add as little as $15,000 per lane (2002 dollars) in rural areas ($90,000 in urban areas). By contrast, experience accumulated in Maryland suggests that BMP costs range from $45,000 to $60,000 per lane mile for rural roads and from $150,000 to $300,000 per lane mile for urban roads, which is comparable to California data (in 2002 $).[6] In Washington State, the average

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[5] In 2004, Caltrans completed a BMP Pilot Program where 38 sites were retrofitted with BMPs such as filters, detention basins, biofiltration and infiltration devices, as well as separators. Life-cycle costs were estimated based on the volume of treated runoff. Results suggest that effectiveness depends on site-specific characteristics. In many cases, retrofitting absorbed a large share of construction costs, which highlights the importance of planning for runoff control during initial construction. Estimated life-cycle costs varied from $\$39/m^3$ for drain inlet inserts (which are not very effective for removing pollutants and require careful maintenance) to $\$2,183/m^3$ for wet basins. The latter removed a substantial fraction of pollutants but they were not suitable for all sites; another concern was endangered species that "took over" some basins and disturbed maintenance (Caltrans 2004).

[6] Personal communication with Raja Veeramachaneni, chief of highway hydraulics for the Maryland State Highway Administration, January 10 2003.

weighted cost of implementing runoff BMP was $319,000 per lane mile for 18 recent urban and rural projects dealing with 644 lane miles, admittedly a very small sample.[7] Although $319,000 per lane mile is substantial, it represents only a small percentage of project costs (from 0.45% for large rural projects to 8.99%, for small urban ones).

Maintenance costs also need to be accounted for, as it is essential to insure that BMPs function properly. A 2001 survey conducted for the Washington Department of Transportation by Herrera Environmental Consultants provides some data on construction as well as O&M costs for storm-water BMPs. Treatment and detention ponds are most common; as a percentage of construction costs, their annual O&M costs vary between 0.2% for larger basins and 5% for smaller ones. Infiltration basins are slightly more expensive (from 4 to 7%), but not as much as infiltration trenches (from 9 to 12%). A wider range is observed for swales (from 3.7 to 11.5%) and even much more so for vegetated filter strips (from 0.9 to 200%) because their construction costs can be very low. To simplify our analysis, we suppose that necessary right-of-ways are already available but we compensate for this assumption by using much more expensive maintenance and operations costs for urban highways.[8] Moreover, we assume that it will take 20 years to implement BMPs and that BMPs need to be reconstructed after 20 years.

We consider two scenarios. In the low cost scenario, constructing BMP respectively costs $16,230 and $97,380 per lane mile for rural and urban highways, and the corresponding annual O&M costs are 1% and 3% of construction. Targeting only principal US arterials still represents approximately 126,000 miles of rural roads and 88,000 miles of urban roads (at the end of 2005), with an average of 3.26 lanes for the former and 4.72 lanes for the latter. Key road statistics are summarized in Table 3.[9]

In the high cost scenario, BMPs are now, respectively, $64,920 and $324,599 per lane mile for rural and urban highways, and the corresponding annual O&M costs are 3% and 9% of the construction budget. Moreover, costs increase by 1% per year in real terms. Indeed, the composite index for federal aid highway construction increased by 3.34% on average between 1993 and 2004 in nominal terms, while inflation during that period was approximately 3% before Hurricane Katrina (US Department of Transportation 2006).

To better grasp the magnitude of control costs on public finances, we compare them to highway transportation expenditures. For the country as a whole, highway transportation expenditures reached $121.6 billion in 2001, the last year for which this statistic is currently available. To extrapolate these expenditures into the future, we assume they grow at a rate of 3.2% per year in real terms (the average between 1990 and 2001). For California, highway transportation expenditures reached $10.6 billion in 2000 and are assumed to grow by 4% annually in real terms.

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[7] Personal communication with George Xu, an economist with the Washington State Washington State Department of Transportation, January 13 2003.

[8] Although the Federal Highway Administration (FHWA) tracks how federal funds are spent on right-of-way acquisitions, it does not record the corresponding areas (just the number of "parcels"). Personal communication with David Waltershied from the FHWA on January 14 2003.

[9] The average number of lanes per mile of principal arterials is the California average as there were insufficient data at the national level.

Our results are thus driven by several assumptions. First, BMP construction costs for rural roads are only one fifth or less of the value for urban roads partly to reflect differential land costs; likewise, O&M costs are three times cheaper in rural areas than in urban areas. Second, in our low cost scenario, we suppose that costs are constant in real terms thanks to technological improvements; in our high cost scenario, they increase by 1% per year in real terms. Third, when we compare control costs to future highway transportation expenditures, we assume these grow annually by 3.2% in real terms (the 1990-2001 average) at the federal level and by 4% in California. Tables 3 and 4 summarize key road statistics and our cost assumptions.

Key results are presented in Table 5. If runoff is controlled only on principal arterials, annualized costs range from $2.9 billion to $15.6 billion, or 1.6% to 8.3% of annualized transportation expenditures on highways. Extending control to all arterials increases these percentages, respectively, to 2.3% and 12.3% of annualized highway transportation expenditures. The difference between these estimates is mostly explained by much higher O&M costs.

We also see that annualized control costs for California represent a larger percentage of the state's annual expenditures on highways because California has been under-spending on highways, it has a higher proportion of urban arterials compared to the country as a whole, and controlling runoff from urban arterials is much more expensive than from rural arterials.

< Insert Tables 3 and 4 approximately here >

Groundwater Cleanup Costs

Groundwater cleanup costs depend on the level of contamination and on cleanup standards. If only small volumes of soil need to be treated, cleanup costs can be as low as $10,000, but they can quickly exceed $1 million if extensive remediation is necessary. The presence of additives such as MTBE tends to substantially boost cleanup bills. Although costs vary widely across states and over time, they tend to increase because lightly polluted sites were typically treated first and pollution spreads over time.

Getting a reliable estimate of cleanup expenses is difficult because no single level of government has jurisdiction over all LUST sites, and nobody seems to be tracking funds from federal, state, and private sources. Partial information suggests that completed and on-going cleanups already required considerable sums. For example, as of December 2006, more than $2 billion of California's UST Cleanup Fund had been spent (State Water Resources Control Board, 2006b).

To evaluate cleanup costs, we assume that only half of all unregistered and abandoned USTs will be found (a US EPA assumption), so 181,336 USTs need to be taken care of (item q in Table 2); dealing with this backlog will take approximately 10 years so 18,130 USTs are cleaned up every year, in addition to new leaking USTs; and there are on average 2.61 tanks per site. To evaluate cleanup costs, we then consider two scenarios.

In the low cost scenario, the cleanup cost at closure of a site is the 1997-2005 average or $90,050, and it does not change over time.[10] Moreover, we assume that the number of UST sites remains constant,[11] only 2.5% of UST leak every year, and cleaning them up costs a quarter of $90,050 per site because leaks are detected early. In the high cost scenario, the cleanup cost at closure in 2006 is instead the maximum annual value between 1997 and 2005 ($115,345), and it increases by 10% per year thereafter. Moreover, an additional 10% of UST begin to leak every year, and cleaning them up costs a quarter of $115,345 per site. These estimates may be over-conservative, however, if the current trend away from UST in favor of above ground storage tanks (AST) continues.

Tables 2 and 4 summarize UST statistics and cost assumptions. The annualized cost of cleaning-up LUSTs in the US is between $0.8 billion and $2.1 billion per year, or between 0.5% and 1.3% of annualized highway expenditures. The corresponding percentages for California are slightly higher because California has been spending proportionately less on highways per capita than the country as a whole.

Overall Estimate

As shown in Table 5, when we combine groundwater and highway runoff pollution control costs, we obtain annualized values ranging from $3.7 billion to $17.7 billion if BMPs are installed only on principal arterials; this corresponds to a range of 2.0% to 9.6% of annualized highway transportation expenditures. If BMPs are installed and maintained on all arterials, this range jumps to between 2.8% and 13.6%. California estimates are substantially higher still for two reasons: under-investment in highways and a larger percentage of urban arterials.

These estimates are driven by highway runoff control costs, which dominate groundwater pollution costs almost by an order of magnitude even though they are annualized over a longer period. The share of highway runoff control costs is even larger after the backlog of leaking USTs has been cleaned up.

< Insert Table 5 approximately here >

These large costs reflect the reach of the US transportation system, and they result from the inadequate design of most of the current transportation infrastructure for protecting water quality. Under our scenarios, these estimated control costs would represent a large drag on public budgets over many years, but cleanups are mandated by law and they are consistent with the "polluters pay" principle. It is therefore essential to carefully weigh policy options.

5. Policy Considerations

Cost is understandably one of the main concerns about controlling highway runoff. Since non-point source pollution is linked to the operation of motor vehicles, an increase in the

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[10] Cost data for LUST cleanup is collected by the Vermont Department of Environmental Conservation (*Summary of State Fund Survey Results, Waste Management Division, Underground Storage Tank Section.*)

[11] Some 246,650 sites nationally.

gasoline tax could be considered to finance BMPs. A $0.01 increase in the gasoline tax provides approximately $1.5 billion in additional annual revenues, so a $0.118 gas tax raise would provide enough funds for cleaning up the backlog of leaking USTs as well as constructing and maintaining BMPs on principal arterials for the high cost scenario. Gasoline taxes are already financing the federal LUST trust fund, although at a much more modest level.

Unfortunately, raising gasoline taxes has been very unpopular with legislators for many years: indeed, fuel taxes would have to increase by 11 cents per gallon on average just to go back to their 1957 purchasing power (Wachs 2003).

An alternative would be to rely on use fees, which are more efficient and more equitable than other financing mechanisms such as bonds or general sales taxes. Electronic tolls, which have benefited from recent technological advances, appear especially promising. However, increasing their use will take time, and their public acceptance is not guaranteed.

While financing issues are being discussed, it appears wise to adopt policies designed to reduce the contribution of motor vehicles to non-point source pollution.

Dealing with Non-Point Source Pollution

For non-point source pollution, “standard” instruments such as the establishment of performance standards or taxes may not be effective for several reasons.

First, it is by nature complicated to establish the relationship between sources and pollutants. Indeed, non-point source pollution results from a very large number of actions releasing small amounts of pollutants, whether voluntarily (used oil) or not (metal dust from brake pads). Second, non-point source pollution is not easily cleaned up. Third, there is often substantial uncertainty regarding the environmental and health impacts of some pollutants because of random factors such as precipitation, flow conditions, temperature, or insufficient toxicity data. Finally, when some non-point source pollutants transfer from one medium to another, they undergo chemical transformations that affect their toxicity (e.g., Chromium).

Effective policies are thus likely to combine a series of measures including public education, economic instruments (such as deposit refund systems for used oil), and partnerships with industry. Non-structural BMPs such as street sweeping have also been recommended, but their effectiveness for smaller particulates has been questioned (Tobin and Brinkmann 2002).

In spite of limited success in the past, policy makers should also continue exploring the feasibility of water quality trading (WQT) programs including highway runoff. Such programs could greatly lower the costs of preserving water quality if transaction costs can be reduced thanks to better hydrologic models combined with geographic information systems, and well-designed institutions. This approach has attracted increasing interest over the last few years. Recently, Farrow et al. (2005) proposed criteria to address common WQT implementation problems, and Obropta and Rusciano (2006) presented an approach for evaluating the suitability of WQT trading in a watershed. Fang, Easter and Brezonik’s study (2005) suggests that this approach can be successful.

Some Specific Policies

Let us examine how this applies to some aspects of transportation-related non-point source pollution, starting with used oil.

In the US, only half of all used oil is recycled, so millions of gallons of used oil are still discharged into the environment each year (US Environmental Protection Agency 1996). One way to increase recycling rates would be to target Do-It-Yourselfers (DIY), who are responsible for most of the improperly disposed used oil. In a 2002 survey of California DIY conducted by Browning and Shafer, 97% of respondents indicated they would be more likely to recycle if facilities paid more than $0.16 per gallon of used oil; in fact, 56% of respondents asked for at least $2/gallon. Increasing fees on lubricating oil would provide dedicated funds to help open more recycling centers, boost public education, and step up enforcement. Indeed, although dumping used oil in the environment is illegal, prosecutions are rare. Public-private partnerships could also be cost-effective, as illustrated by the Canadian experience (Nixon and Saphores 2002).

Much more could be done for used oil filters. According to the Filter Manufacturers Council (FMC), only 50% of used filters were recycled in the US in 2006. By contrast, three Canadian provinces (Alberta, Manitoba, and Saskatchewan) have achieved 80% recycling rates by implementing economic incentives (Nixon and Saphores 2002). Unfortunately, the FMC rejects economic incentives in favor of public education and landfill bans, even though bans may encourage illegal disposal.

A used oil filter collection pilot program conducted in 1995-1997 in California revealed some of the obstacles encountered by this type of program (California Integrated Waste Management Board 1998). It suffered from limited public knowledge, a small number of collection facilities, and reimbursements to businesses below hauling costs. Recycling was also impaired by a State law that forbids combining used oil and oil filter reimbursement checks, so check processing costs often exceeded their face value.

Another source of non-point source pollution is used coolant/antifreeze. In spite of its toxicity, there are currently no programs to promote its recycling. A considerably less toxic coolant/antifreeze based on propylene glycol (instead of ethylene glycol) is popular in some European countries, but its US market share is only 10%. Better public information may entice manufacturers to switch to propylene glycol and to modify engine designs to limit spills. Environmental NGOs could also facilitate changes, as they have for metal dust from brake pads.

In the absence of direct regulations or economic incentives, environmental problems associated with the metal content of brake pads have been addressed by negotiation, as discussed by Coase (1960). Along with the Stanford Law School, Sustainable Conservation (a Northern California NGO) created the Brake Pad Partnership in 1996 to bring together businesses, government regulators, storm-water management agencies, and environmental organizations. As a result, automobile parts manufacturers are conducting research to reduce metal use in friction materials. Apart from regular stakeholder meetings, ongoing activities of the Partnership include environmental monitoring and modeling studies (Brake Pad Partnership 2006).

Proactive versus Reactive Policies

To date, government policies for dealing with transportation-related water pollution have been mostly reactive instead of proactive. This is particularly the case for LUSTs. In retrospect, it would have been much cheaper to prevent leaks through enforcement and monitoring. Indeed, according to Sausville et al. (1998), in the late 1990s, annual administrative costs for compliance activities were less than \$60 per tank (in 1998 \$). This compares with approximately \$2800 per tank per year for administrative costs of compliance activities during a site clean-up (for 5 years on average), not to mention cleanup costs. By contrast, detection and monitoring costs are small: the conventional test for USTs (which detects ~0.1 gallon/hour) costs \$600 to \$700, while enhanced tests, which are 20 times more sensitive, cost between \$1500 and \$1700.[12]

A case for incorporating environmental concerns during design can also be made for highway runoff. Experience accumulated in Maryland and other states shows that designing and implementing BMPs is much cheaper for new roads (often by a factor of 3 or more) or during repair than it is for retrofitting existing roads if special construction projects are required. Reducing the large costs of implementing BMPs for highway runoff may thus require altering the design of new infrastructure (incorporating the principles of design for the environment, as recommended in Graedel and Allenby 1998) and waiting for road repair to install BMPs.

A similar proactive approach for dealing with transportation related pollutants contributing to nonpoint source pollution is also likely to be cost effective, although environmental benefits are difficult to quantify in this case.

6. Conclusions

Our inquiry shows that the costs of controlling the impacts of motor vehicles on water quality are substantial; we estimate that annualized costs of controlling runoff from principal arterials only could cost between 1.6% and 8.3% of annualized highway transportation expenditures, while the annualized cost of cleaning up leaking USTs would cost an additional 0.5% to 1.4% per year for 10 years. Gasoline leaks, as well as improperly disposed used oil, waste coolant/antifreeze, and metal dust from brake pads all contribute to non-point source water pollution. Their impacts on water quality as well as other aspects of motor vehicle transportation are not yet well understood. This study, however, reveals several interesting stories.

First, a number of current environmental problems caused by the operation of motor vehicles are due, at least indirectly, to regulations designed to address other problems (so-called “intervention failures”). This is the case for MTBE, which was originally introduced to reduce harmful emissions of ozone, or for heavy metals in brake pads after asbestos was abandoned because of health concerns.

Second, as motor vehicle pollution is often released in tiny amounts at a time by millions of people, implementing pollution reduction programs can entail substantial transaction costs, as illustrated by the difficulties encountered by the California oil filter collection pilot program. Experiences in other countries such as Canada, or in other industries (e.g., aluminum containers), indicate, however, that it is possible to successfully implement deposit refund programs to collect and recycle items such as used oil or oil filters.

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[12] Personal conversation with Scott Evans, Director of Sales and Marketing, Tracer Research Corporation, December 11 2002.

Third, NGO could have an important role to play in negotiating with industry in order to make motor vehicle transportation more environmentally friendly, as illustrated by the Brake Pad Partnership.

Finally, the severity of several environmental problems (e.g. UST leaks) could have been limited if environmental considerations had been incorporated at the design stage instead of fixing problems later through costly regulations, economic instruments, or re-designs.

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Table 1. *Source of Heavy Metals from Transportation*

Source	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Gasoline	●			●				●	●
Exhaust							●	●	
Motor Oil & Grease	●	●			●		●	●	●
Antifreeze	●		●	●	●			●	●
Undercoating								●	●
Brake Linings				●	●		●	●	●
Rubber	●			●				●	●
Asphalt				●			●		●
Concrete				●			●		●
Diesel Oil	●								
Engine Wear					●	●	●	●	●

Source: Local Ordinances: A Users Guide, Terrene Institute and EPA, Region 5, 1995.

Table 2. *Underground Storage Tanks (USTs) Statistics*

Category	US	California
Registered USTs		
Closed (a)	1,618,920	121,352
Active		
Leaking		
Clean-up in progress (b)	89,125	14,618
No clean-up initiated (c)	30,117	0
Subtotal registered active leaking USTs (d=b+c)	119,242	14,618
Non-leaking USTs (e)	534,379	24,135
Subtotal active USTs (f=d+e)	653,621	38,753
Subtotal registered USTs (g=a+f)	2,272,541	160,105
Unregistered USTs		
Abandoned (20% of (f), active registered) (h)	130,724	7,751
Leaking (90% of (h), unregistered abandoned) (j)	117,652	6,976
Non-leaking (10% of (h), unregistered abandoned) (k)	13,072	775
Active (5% of (f), active registered) (m)	32,681	1,938
Leaking (25% of (k), unregistered active) (n)	3,268	194
Non-leaking (75% of (k), unregistered active) (p)	9,804	581
Number of leaking USTs that can be found (q=d+50%j+n)	181,336	18,300

Notes: Statistics are valid as of September 30, 2005. There have been 452,041 confirmed releases nationwide and 44,190 in California. Of these, cleanups have been initiated on 421,924 releases nationally and on all 44,190 releases in California. Nationwide there have been 332,799 fully complete cleanups and 29,572 in California. For calculating the "number of leaking USTs that can be found," the US EPA estimates that only 50% of abandoned, unregistered USTs will be located (US Environmental Protection Agency 2000 *Liquid Assets*).

Table 3. *Key Road Statistics*

Category	US	California
Rural roads		
Principal arterials		
Year 2000 centerline miles (a)	131,959	5,087
Year 2000 lane miles (b)	N/A	16,562
Average number of lanes/mile (c=b/a)	N/A	3.26
Estimated 2005 centerline miles (d=a*[-1.0045]^5)	126,061	4,849
All arterials		
Year 2000 centerline miles (e)	269,533	12,051
Year 2000 lane miles (f)	674,505	30,937
Average number of lanes/mile (g=f/e)	2.50	2.57
Estimated 2005 centerline miles (h=e*[-1.0062]^5)	261,469	11,679
Urban roads		
Principal arterials		
Year 2000 centerline miles (j)	75,831	8,476
Year 2000 lane miles (k)	N/A	40,009
Average number of lanes/mile (m=k/j)	N/A	4.72
Estimated 2005 centerline miles (n=j*[1.0264]^5)	88,066	9,654
All arterials		
Year 2000 centerline miles (p)	165,620	18,900
Year 2000 lane miles (q)	529,772	71,529
Average number of lanes/mile (r=q/p)	3.20	3.78
Estimated 2005 centerline miles (s=p*[1.0242]^5)	189,739	21,303

Notes. Data sources for California: Caltrans TABLE%204_7_00.pdf for urban roads and TABLE%204_2_00.pdf for rural roads (see http://www.dot.ca.gov/hq/tsip/TSIPPDF/). Data sources for the US: Bureau of Transportation Statistics table_01_05.html (mileage) and table_01_06.html (centerline miles), at http://www.bts.gov/publications/nts/html/. Growth rates for estimating 2005 centerline miles are 15-year averages (1990-2000) calculated for the US (Source: US Department of Transportation, Federal Highway Administration, *Highway Statistics Summary to 1995* table HM-220 and *Highway Statistics (Annual issues)* table HM-20).

Table 4. *Summary of Costs Assumptions*

Categories	**Low cost scenario**	**High cost scenario**
Highway runoff control		
BMPs construction for rural roads (a)	$16,230/lane-mile	$64,920/lane-mile
BMPs construction for urban roads (b)	$97,380/lane-mile	$324,599/lane-mile
BMPs annual O&M costs for rural roads (c)	$162/lane-mile	$1,948/lane-mile
BMPs annual O&M costs for urban roads (d)	$2,921/lane-mile	$29,214/lane-mile
Groundwater pollution		
Backlog of leaking USTs		
Cleanup costs at closure (e)	$90,050/site	$115,345/site
Annual change in cleanup costs at closure (f)	0%	+10%
New UST leaks		
Cleanup costs at closure (g=e/4)	$22,512/site	$28,836/site
Annual rate of leakage (h)	2.5%	10%

Notes: BMPs annual O&M costs for rural roads are assumed to be 1% and 3% of construction costs for the low and high cost scenarios respectively; for urban roads, they are 3% and 9%. For groundwater pollution, cleanup costs at closure for new UST leaks are assumed to be 25% of cleanup cost at closure for the backlog of leaking USTs because leaks are detected earlier.

Table 5. *Estimated Annualized Costs in $ billions (2005 prices) and percent of annualized highway transportation expenditure*

Groundwater	Backlog		Recurring leaks		Total costs	
(annualized over 10 years)	Low	High	Low	High	Low	High
US	0.6	1.4	0.1	0.7	0.8	2.1
	(0.4%)	(0.8%)	(0.1%)	(0.4%)	(0.5%)	(1.3%)
California*	0.06	0.14	0.01	0.04	0.07	0.18
	(0.5%)	(1.0%)	(0.1%)	(0.3%)	(0.5%)	(1.4%)

Highway runoff	Construction costs		O&M		Total costs	
(annualized over 20 years)	Low	High	Low	High	Low	High
Principal arterials only						
US	2.4	8.9	0.6	6.8	2.9	15.6
	(1.3%)	(4.7%)	(0.3%)	(3.6%)	(1.6%)	(8.3%)
California	0.2	0.9	0.1	0.7	0.3	1.6
	(1.5%)	(5.5%)	(0.4%)	(4.6%)	(1.9%)	(10.1%)
All arterials						
US	3.5	13.1	0.9	9.9	4.4	23.1
	(1.9%)	(7.0%)	(0.5%)	(5.3%)	(2.3%)	(12.3%)
California	0.4	1.5	0.1	1.3	0.5	2.8
	(2.7%)	(9.9%)	(0.7%)	(8.1%)	(3.4%)	(17.9%)

Groundwater and highway runoff (first 10 years)[#]	*Groundwater + principal arterials*				*Groundwater + all arterials*	
	High	Low			High	Low
US	3.7	17.7			5.1	25.2
	(2.0%)	(9.6%)			(2.8%)	(13.6%)
California	0.4	1.8			0.6	3.0
	(2.4%)	(11.5%)			(3.9%)	(19.3%)

Notes:

* Except for groundwater costs in California, all costs estimates are rounded to the nearest $0.1 billion and % are rounded to the nearest 0.1%; some aggregates may appear to be slightly off because of rounding. Highway runoff control costs are based on the length of the road network at the end of 2005, so costs may be slightly underestimated. On the other hand, costs could be slightly overestimated because we ignored already established BMPs in states like Maryland, Oregon, or Washington, which are already treating 90%, 30%, and 30% of their storm-water runoff respectively.

[#] Between years 11 and 20, annualized values would only combine the costs of dealing with recurring groundwater contamination with highway runoff control costs.