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Authors
Nixon, Hilary
Saphores, Jean-Daniel M

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Impacts of Motor Vehicle Operation on Water Quality: Clean-up Costs and Policies

Hilary Nixon[1] and Jean-Daniel Saphores[2]

Abstract

Environmental studies of motor vehicles typically focus on air pollution or noise, but ignore water pollution. In this paper, we investigate the costs of reversing some of the environmental impacts of motor vehicle transportation on surface waters and groundwater. Our estimates of the cost of cleaning-up leaking underground storage tanks range from \$6.5 billion to \$19.6 billion, while control costs for highway runoff from major arterials in the United States are an order of magnitude larger (from \$45.3 billion to \$249 billion, all in 2005 \$). Some causes of non-point source pollution were unintentionally created by regulations or could be addressed by changing the design of motor vehicles. Effective clean-up policies should emphasize prevention, coupled with public education, enforcement, and economic incentives. 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; environmental policy.

JEL classification: Q25, R49.

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[1] Assistant Professor, Department of Urban and Regional Planning, San Jose State University, San Jose, CA 95192 USA. E-mail: Hilary.Nixon@sjsu.edu. Phone: (408) 924 5852.

[2] Corresponding Author. Associate Professor, Civil and Environmental Engineering Department, The Henri Samueli School of Engineering, University of California, Irvine, CA 92697 USA. E-mail: saphores@uci.edu. Phone: (949) 824 7334. Fax: (949) 824 8385.

1. Introduction

Increasing concerns for the environment combined with a rising demand for transportation have motivated a number of studies of the environmental costs of motor vehicle transportation in order to inform public policy (e.g., see Delucchi 2000 and the references therein). Most of these studies focus on air pollution, the main environmental externality associated with road transportation, or noise. To date, however, the academic literature has paid relatively little attention to the impacts of motor vehicles on water quality. According to Litman (2002), there is currently no good estimate of the aggregate impact of motor vehicle transportation on water pollution, and a review of the relevant literature suggests that many estimates of water externalities resulting from motor vehicle transportation are based on educated guesses (see Delucchi 1998; 2000). While the emphasis of recent regulations lead us to surmise that these impacts are substantial, it is still very difficult to quantify them reliably because motor vehicles are but one of many causes of non-point source pollution.

Instead of trying to quantify the external costs caused by motor vehicle transportation on water quality, this paper is concerned with the costs of controlling water pollution from motor vehicles. For simplicity, we focus on two problems that have attracted considerable media attention over the last few years: leaking underground storage tanks (LUSTs) and highway runoff. Using a 7% discount rate, we estimate that the present value (PV) of the cost of cleaning-up leaking underground storage tanks range from \$6.5 billion to \$19.6 billion, while the PV of control costs for highway runoff from major arterials in the United States range from \$45.3 billion to \$249 billion (all in 2005 \$).[1] Another contribution of this paper is a discussion of

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[1] Most existing studies use vehicle miles traveled for cost estimates. This is not appropriate here as many of the costs associated with constructing highway runoff control systems are not highly sensitive to vehicle miles traveled. We estimate instead total costs, which include annual operation and maintenance costs.

policy options for dealing with the non-point source pollution generated by the operation of motor vehicles.

Substantial evidence suggests that residues from the operation of motor vehicles contribute heavily to non-point source and groundwater pollution (see, e.g. Davis et al. 2001; Kayhanian et al. 2003, among others). Pollutants from motor vehicles or from transportation infrastructure include sediments (from construction or erosion), oils 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; see Table 1), road salts, as well as fertilizers, pesticide, and herbicides (used alongside roads or on adjacent land; see Hill and Horner 2005).

< Insert Table 1 approximately here >

Indeed, the EPA (1997) estimates that up to 1/2 of suspended solids and 1/6 of hydrocarbons reaching streams originate from freeways. Vehicle-related particulates in highway runoff come mostly from tire and pavement wear (~ 1/3 each), engine and brake wear (~ 20%), and exhaust (~ 8%) (EPA 1996). Each year, approximately 185 million gallons of improperly discharged used motor oil pollute streams, lakes, and coastal areas (EPA 1999b). This should be cause for concern since one gallon of used oil can contaminate 1 million gallons of water.

Groundwater quality is also threatened. There have been more than 450,000 confirmed fuel leaks from underground storage tanks (USTs) in the U.S., including 44,000 in California (EPA 2005). Because of these leaks, many communities need to find alternative sources of freshwater. For example, Santa Monica, CA, has lost 80% of its local water supply to MTBE contamination and needs to purchase water at a cost of $3-5 million per year.

Even a comprehensive assessment of how motor vehicle transportation affects water quality is at present too complex to be feasible. We therefore focus on LUSTs, 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 important or because they lead to considering informative policy solutions.

We find that the current approach to dealing with motor vehicle externalities is typically reactive. Transaction costs are also frequently an issue because pollution often results from discharges of small amounts of pollutants in many different locations. Effective policies addressing water pollution from motor vehicles are likely to combine, in addition to best management practices (BMPs), public education campaigns, economic incentives, and enforcement.[2] Better still, they should foster the integration of environmental considerations in the design of motor vehicles and the transportation infrastructure because addressing environmental problems after-the-fact is often much more costly than preventing them.

This paper is organized as follows. In the next section, we review the relevant literature. We then give an overview of the main environmental and health impacts of used oil, used antifreeze, metal dust from brake pads, and LUSTs. Section 4 provides a preliminary quantification of the environmental costs of controlling highway runoff and groundwater pollution from leaking USTs. Section 5 discusses various options available to policy makers, and Section 6 summarizes our concluding remarks. Appendix A gives a list of acronyms and chemical symbols used in this paper. Appendix B outlines our cost assumptions.

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[2] Best management practices are the “structural, non-structural, and managerial methods considered to be the most effective and practical means of controlling non-point source pollution” (National Safety Council, Environmental Health Center Glossary, http://www.nsc.org/ehc/glossary.htm, 2007).

2. Literature Review

Interest in stormwater runoff pollution is not new: many engineering and public health papers examine pollutants in stormwater runoff, their potential health impacts, and the effectiveness of best management practices (BMPs) for removing these pollutants. A large literature also analyzes methods for removing groundwater contaminants, but space constraints prevent us from reviewing these papers here. In this section, we first summarize some key studies on stormwater runoff, before considering a few papers concerned with leaking underground storage tanks.

Stormwater Runoff

Numerous studies have examined the pollutant characteristics and sources of stormwater runoff, including Ellis et al., 1987, Davis et al., 2001, Grant et al., 2003, Han et al., 2006, Kayhanian et al., 2003, Legret and Pagotto, 1999, and Wu et al., 1998, among others. Given the extent of the U.S. highway system and the concerns associated with pollutant runoff, a number of papers have attempted to quantify the contribution from highways to non-point source pollution.

Heavy metals in stormwater 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 literature 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). Their empirical study reveals that brake wear is 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) specifically study the impact of VMT on highway runoff pollutant concentrations. As expected, pollutant concentrations are higher (two to ten times) for urban than for non-urban highways. However, non-urban highway runoff shows greater concentrations of total suspended solids, pesticides, and ammonia, which points to agriculture. The authors also caution that a simple linear relationship between annual average daily traffic and transportation-related pollutants is unlikely because of weather patterns and surrounding land use. In fact, some pollutant loadings exhibit seasonal variations: winter, for example, brings high concentrations of chlorides and sulfates from deicing salt (Legret and Pagotto 1999). In addition, irregular rainfall in many areas of the southwestern U.S. complicates runoff management. Over a long, dry season large amounts of pollutants accumulate on road surfaces and enter receiving waters during the first storm event (Han et al. 2006). Regular street sweeping can help, although there are still debates about the effectiveness of street sweeping BMPs (Tobin and Brinkmann 2002).

Stormwater runoff has also generated significant concerns for public health. Gaffield et al. (2003) examine the public health impacts from heavy metal in stormwater, which can often be traced to motor vehicle sources. Their findings suggest that the most cost-effective way to address public health concerns is to improve stormwater management. According to Van Metre et al. (2000), vehicles are a significant source of polycyclic aromatic hydrocarbons (PAHs) in water bodies. Tire wear, oil leaks, road wear, as well as car exhaust are all sources of PAH, a known carcinogen. The economic impacts of water pollution are substantial, particularly in coastal states like California. Dwight et al. (2005) estimate at $3.3 million the public health burden of illnesses from coastal water pollution at only two beaches in Orange County, CA. Their study underscores the importance of properly managing stormwater runoff.

There has also been a lot of interest in the engineering literature for stormwater best management practices (BMPs). Grant et al. (2003) conduct extensive research on stormwater runoff contaminants and their associated toxicity to inform the development of BMPs. Early work by Maestri and Lord (1987) identifies four measures for effective highway runoff management: vegetative controls (e.g. grassed swales); wet detention basins; infiltration systems; and wetlands. Shutes et al. (1999) extends their research to the effective construction, operation, and maintenance procedures of a constructed wetland, while Barbosa and Hvitved-Jacobsen (1999) examine the effectiveness of infiltration ponds under different soil conditions.

Unfortunately, inconsistencies across BMP studies have hampered the generalization of their findings (Strecker et al. 2001). In cooperation with the EPA and the American Society of Civil Engineers, Strecker et al. (2001) develop a database of stormwater BMPs to facilitate comparative analyses. Following-up on their suggestions, Barrett (2005) relies on data from the Caltrans BMP Retrofit Pilot Program to develop a methodology for comparing BMPs. His findings suggest that the degree of pollutant removal depends on the interaction between a BMP and the influent water quality, and not just on BMP characteristics.

The literature also emphasizes the importance of public education for stormwater BMPs. A 2003 Caltrans study examines the effectiveness of a two-year public education campaign that relies on a variety of outreach tools to address highway litter. The relatively short duration of this study made it difficult to ascertain if it changed people's behavior, but at least it increased people’s awareness of stormwater issues. Spray and Hoag (2004) emphasize the importance of outreach to educate people about the benefits of an effective stormwater management program, particularly for obtaining public support for raising stormwater fees.

The cost of complying with federal and state stormwater regulatory programs has been the subject of several lawsuits in California (Currier et al. 2005). As a result, Caltrans and other agencies have conducted research to better estimate stormwater management costs. Currier et al.

(2005) examine six municipalities in California that demonstrated to their Regional Water Quality Control Boards significant progress toward stormwater compliance. They report annual stormwater management costs ranging from $18 to $46 per household. Fortunately, a 2004 survey of Orange County (CA) residents by the Center for Public Policy indicates that nearly 60% of respondents would pay at least $5/month to curb urban runoff. A 2000 survey of California households by Larson and Lew (2001) is even more positive: it finds that Californians are willing to pay approximately $185 per year to remove all water quality impairments to California's water bodies.

Several studies also examine the use of market-based incentives for managing stormwater runoff (Thurston 2006; Thurston et al. 2003; Parikh et al. 2005). Parikh et al. (2005) compare hydrologic, economic, and legal approaches to stormwater management. Phase II of the EPA's National Pollution Discharge Elimination System (NPDES), signed into law in 1999, requires communities with less than 100,000 residents in urbanized areas to implement stormwater management programs. This can be a burden on smaller communities that lack the necessary infrastructure. Thurston et al. (2003) suggest that a tradable allowance system can be a cost-effective mechanism to reduce stormwater runoff.

Underground storage tanks

Leaking underground storage tanks (LUSTs) have been identified as a major source of groundwater pollution. The Energy Policy Act of 2005 targets leak prevention and expands the use of the LUST Trust Fund (EPA 2006a). Nationwide, 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 (EPA 2005). However, the large cost of addressing

LUSTs may exceed the resulting benefits; indeed, Marxsen (1999) reports that cleanup costs range from $100,000 to more than $1 million when groundwater is involved. Based on research conducted by the Lawrence Livermore National Laboratory (LLNL), Rice et al. (1995) find that LUST contamination tends to be shallow and not as likely to affect deeper public drinking water supply wells. In addition, if the source of the leak is removed, passive bioremediation processes work naturally to contain the spread of contamination. In another study, Shih et al. (2004) conclude that LUST sites are a leading cause of fuel hydrocarbon and oxygenate groundwater contamination. Their research on plume length is consistent with findings from LLNL and indicates that the extent of the contamination is relatively localized. A well-managed UST program that emphasizes leak detection can reduce the overall scope and cost of LUST damage.

In recent years, considerable attention has been paid to the potential negative impacts of methyl tertiary butyl ether (MTBE) in groundwater. MTBE is an oxygenate that was commonly used as a fuel additive in the EPA's Reformulated Gasoline and Oxygenated Fuel Programs (EPA 1999a). MTBE has been banned in California since December 2003. In their analysis of the risk associated with MTBE contamination in California, Williams et al. (2004) find that, although MTBE is present in a small percentage of the public drinking water samples, other volatile organic compounds (VOCs) are found far more often and at higher risk levels. Indeed benzene, a gasoline additive and known carcinogen, was detected at levels above the California maximum contaminant level in 58% percent of the samples examined. Interestingly, Moran et al. (2005) conclude from their national survey that MTBE is detected at or above the rate of other VOCs. As in Shih et al. (2004) and Rice et al. (1995), shallow groundwater is at greater risk for contamination. In addition, the likelihood of MTBE detection is related to the density of LUSTs surrounding the sampling well (Moran et al. 2005).

3. Environmental Impacts of Non-point Source Water Pollution from Motor Vehicles

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.[3] A number of studies link heavy metals (such as Pb, Zn, or Cu) or hydrocarbon loadings of surface water with transportation (e.g., see Ellis et al. 1987; Davis et al. 2001; Latimer et al. 1990; Bannerman et al. 1993; Walker et al. 1999, or Sutherland and Tolosa 2000). Driscoll et al. (1990) report detectable levels of zinc, lead, copper, and nitrate/nitrite in road runoff, with urban levels two to five times those of rural levels. It is important to note that 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). According to the National Oil Recyclers Association (NORA 2001), it accounts for 40% of the oil pollution of the nation's harbors and waterways. 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).[4]

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[3] Used oil can also be a point source pollutant. Indeed, mostly as a result of bad practices at processing facilities, used oil is listed as the main pollutant in 6 California Superfund sites on the National Priority List (EPA 2002); nationwide, there are 25 such sites. While used oil in itself is not a dangerous product if handled properly, it can mask many highly hazardous chemicals such as PCBs and chlorinated solvents (Arner 1996).

[4] 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.

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 (USCG 2001). 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. Natural recovery times can thus vary considerably (from a few days to over a decade), particularly if groundwater is impacted.

Another source of non-point source pollution is used coolant/antifreeze, which typically consists of 95% ethylene glycol, a clear, colorless, sweet-tasting and highly toxic liquid. Over 200 million gallons of coolant/antifreeze are sold each year in the U.S. (Arner 2000). Of the nearly 20 million gallons sold annually in California, up to 17.4 million gallons of used coolant/antifreeze find their way into the environment (CIWMB 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.[5] Improving engine design would therefore go a long way towards addressing used antifreeze leaks. Engine coolant/antifreeze can also contribute high BOD levels to stormwater (Lehner et al. 1999).

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 drum brakes, which were usually enclosed. 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 (Woodward-Clyde Consultants 1994). 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 2006 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). 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 U.S.[6] 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 xylenes. 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, the

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

[6] Small gasoline spills at gas stations or resulting from accidents can also contribute to surface water pollution.

number of still leaking registered and unregistered UST is estimated at approximately 180,000. At the same time, more than half of the U.S. population relies on groundwater for at least a portion of its drinking water and 80% of community drinking water systems are dependent on groundwater (EPA 1994). LUSTs are therefore a significant environmental problem. Table 2 summarizes key UST statistics.

< Insert Table 2 approximately here >

Until the mid-1980s, most underground storage tanks for gasoline were made of bare steel, which corroded over time, although the connectors and pipes also contributed to a great many leaks (EPA 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 (SWRCB) (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. Estimate of Clean-up Costs

To better understand the mandate of recent NPS laws, let us now quantify the costs of cleaning up LUSTs and of controlling runoff on principal arterials. Our assumptions are outlined in Appendix B. Our present value calculations use a social discount rate of 7%, as recommended by the OMB (see Circular No. A-94 Revised from the OMB). All dollar amounts are in 2005 $ and aggregate costs are rounded to the nearest billion to reflect uncertainty in these calculations.

Our estimates should of course be revised as new information becomes available.

Highway Runoff Control Costs

In general, highway runoff control costs are difficult to quantify because practical experience is still relatively scarce. 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.[7] Overall, however, it is clear that retrofitting existing roads with structural BMPs will be costly.

To capture the uncertainty surrounding BMP costs, we consider two scenarios and two levels of structural BMP implementation for which we report the present value of total (construction + O&M) costs. Tables 3 and 4 summarize key road statistics and our cost assumptions. In the low cost scenario, runoff control costs reach $45.3 billion. Considering all arterials more than doubles the mileage of rural and urban roads, but since the average number of lanes decreases to 2.60 and 3.80 respectively, total costs do not quite double to $68.3 billion. The high cost scenario provides an upper bound on the present value of construction and maintenance costs of controlling highway runoff. Nationwide costs would total $249 billion for principal arterials only, and $375 billion for all arterials.

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[7] In 2004, Caltrans completed a BMP Retrofit Pilot Program. A total of 38 sites were retrofitted with various structural BMPs including filters, detention basins, biofiltration and infiltration devices, and separators. Operation & maintenance costs were estimated to obtain total life-cycle costs based on the volume of treated runoff. Results suggest that effectiveness depends on site-specific characteristics as not all BMPs are suitable for all areas. In many cases, a large share of construction cost was directly related to the retrofit aspect of the design, so planning for runoff control during initial construction is important. Life-cycle cost estimates vary from $\$39/m^3$ for drain inlet insert (which are minimally effective for pollutant removal and require careful maintenance) to $\$2,183/m^3$ for wet basins. The latter had substantial pollutant removal but it was more difficult to find suitable sites for them; another concern was endangered species that "took over" some basins and impacted maintenance activities (Caltrans 2004).

< Insert Tables 3 and 4 approximately here >

Groundwater Cleanup Costs

Groundwater cleanup costs depend on the extent 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 groundwater remediation is necessary (see EPA 2006b). The presence of additives such as MTBE tends to substantially boost cleanup bills.[8] 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 to date is difficult because no single level of government has jurisdiction over all LUST sites, and no agency or organization seems to be tracking funds from federal, state, and private sources. Partial information suggests that cleanups already required considerable sums. For example, as of December 2006, more than $2 billion of California's UST Cleanup Fund had been spent (SWRCB 2006b).

To evaluate total cleanup costs, we also analyze two scenarios: a low cost scenario and a high cost one. Tables 2 and 4 summarize UST statistics and cost assumptions. Based on our assumptions, the present value of the total UST cleanup cost ranges between $6.5 and $19.6 billion for the U.S.

Overall Estimate

Combining the above estimates for groundwater and highway runoff pollution control gives a present value of costs ranging from $51.8 billion to $268.5 billion with BMPs for principal arterials only, and of \$74.8 billion to \$394.5 billion with BMPs along all arterials. These estimates are driven by highway runoff control costs, which dominate groundwater pollution costs almost by an order of magnitude.[9] Table 5 summarizes these results.

< Insert Table 5 approximately here >

These large costs reflect the reach of the US transportation system, but also the need to protect water quality although most of the current infrastructure was not designed to address this problem. 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. In California, for example, this issue has triggered lawsuits and delayed the implementation of BMPs (e.g., see Weikel and Hanley 2002).[10]

Since non-point source pollution is linked to the operation of motor vehicles, an increase in the gasoline tax could be considered to finance BMPs. A \$0.01 increase in the gasoline tax

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[8] Ongoing clean-up at one site in El Cajon, California has taken more than 15 years and cost over \$1.3 million (Kucher 2003).

[9] Delucchi (1998; 2000) assumes that the environmental costs of urban runoff from motor vehicles are similar to the environmental cost of groundwater pollution from leaking USTs. We estimate control costs instead, so a direct comparison is not possible.

[10] Caltrans recently came to an agreement with the Natural Resources Defense Council and Santa Monica BayKeeper in an attempt to settle a decade-long lawsuit regarding the installation of pollution controls along state highways (Weikel 2004). Caltrans originally claimed that runoff control costs (estimated for L.A. County at nearly \$5 billion) were higher than the resulting benefits. NRDC and Santa Monica BayKeeper suggest that the true figure is much lower.

provides approximately $1.5 billion in revenues, so a progressive increase in the gas tax (from 5 cents in 2007 to 14.3 cents in 2024) would provide enough funds for constructing and maintaining BMPs on principal arterials. Gasoline taxes are already being used to fund 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). Fuel taxes also overcharge urban travelers compared to rural drivers because urban roads bear most of the traffic and generate most of the tax revenues. In addition, gasoline tax revenues decrease as fuel efficiency increases.

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 (Sorensen and Taylor 2006). However, increasing their use will take time, as tolls still represent less than 5% of total revenue sources for roads (Wachs 2003), 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 (Helfand 1994).

First, it is by nature complicated to establish the relationship between sources and the pollution itself. Quantifying it, let alone identifying who should be responsible for it, is therefore difficult. Indeed, we have seen that non-point source pollution in transportation results from a very large number of actions releasing small amounts of pollutants, whether voluntarily (for used oil) or not (metal dust from brake pads). Second, non-point source pollution is not easily cleaned up (think of heavy metals such as lead). Third, there is often substantial uncertainty regarding possible environmental and health impacts of some pollutants because of random factors such as precipitation, flow conditions, temperature, or simply because there is 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 (e.g., to educate DIYs), the use of economic instruments (such as deposit refund systems for used oil), and agreements with industry to improve the environmental performance of motor vehicles. Non-structural BMPs such as street sweeping have also been recommended (e.g., see Sartor and Gaboury 1984), but their effectiveness for smaller particulates has been questioned. Walker and Wong (1999) find that street sweeping can be relatively effective for gross pollutants (>5 mm), it is ineffective for removing finer sediment.

In spite of limited success in the past, policy makers should also continue exploring the feasibility of creating water quality trading (WQT) programs including highway runoff because they 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 stirred increasing interest over the last few years (e.g., see Woodward and Kaiser 2002, or Eheart and Ng 2004). 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 empirical study (2005) shows that this approach can be successful.

Some Specific Policies

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

In the U.S., only slightly more than 50% of all used oil is recycled, however, so millions of gallons of used oil are still discharged into the environment each year (API 1997). 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 for used oil; in fact, 56% of respondents desired an incentive of $2/gallon or more, while they were only getting only $0.16 per gallon. An increase in the fees collected on the sale of lubricating oil would provide dedicated funds at a time of strained public budgets. These funds could also be used to open more collection centers, thus lowering recycling costs to the public. Public-private partnerships could be a cost-effective arrangement, as illustrated by the Canadian experience (Nixon and Saphores 2002). Extra funding could also boost public education. Finally, more funds could be useful for stepping up enforcement. The illegal disposal of used oil can be prosecuted under the California Health and Safety Code (Section 25189.5) or the California Penal Code (Section 374.8), but prosecutions are rare.[11]

Much more could be done for used oil filters. According to the Filter Manufacturers Council (FMC), only 50% of used filters used were recycled in the U.S. in 2006.[12] By contrast, three Canadian provinces (Alberta, Manitoba, and Saskatchewan) have achieved 80% recycling

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[11] E-mail from Terri Thomas, Environmental Resource Analyst II, Information Technology Division, Environmental and Energy Resources Department, Ventura County (10/21/02).

[12] See http://www.filtercouncil.org/.

rates by implementing economic incentives (Nixon and Saphores 2002). Unfortunately, the FMC does not support using economic incentives; it prefers public education campaigns and landfill bans, although bans may encourage the illegal disposal of used oil filters. A used oil filter collection pilot program conducted in 1995-1997 in California reveal some of the obstacles encountered by this type of program (CIWMB 1998). It suffered from limited public knowledge, a small number of collection facilities, and reimbursements to businesses below hauling costs. In addition, recycling was impaired by a State law that forbids used oil and oil filter reimbursement checks to be combined, so check processing costs were often higher than the amount of the filter claims. This suggests that recycling incentives should at least cover transaction costs.

Another source of non-point source pollution is used coolant/antifreeze. In spite of the potential environmental damages of used coolant/antifreeze, there are currently no programs and no economic incentives to promote coolant/antifreeze recycling, either at the federal or state levels.[13] A considerably less toxic coolant/antifreeze based on propylene glycol instead of ethylene glycol is available and popular in countries such as Austria and Switzerland, but its U.S. market share is only 10%. As with used oil, public education should help reduce the improper disposal of used antifreeze. Better information may entice manufacturers to switch to propylene glycol and to modify engine designs to limit coolant/antifreeze spills. Environmental NGOs may have a useful role to play to 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 negotiations between the parties concerned, as recommended 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, stormwater management agencies, and environmental organizations. As a result, automobile parts manufacturers have started research to reduce the use of metals in friction materials and a committee now monitors the environmental performance of brake pads. Ongoing activities of the Partnership include environmental monitoring and environmental modeling studies as well as regular stakeholder meetings (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 the problem by insuring adequate levels of enforcement and requiring effective monitoring systems. 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 annual administrative costs of compliance activities during the clean-up of a site (estimated at 5 years), not to mention the cleanup costs, which can vary between $10,000 and $1,000,000. Cleanup costs also dwarf detection and monitoring costs: the conventional test for USTs has a sensitivity of approximately 0.1 gallon/hour at a cost of $600 to $700, while enhanced tests, which are 20 times more sensitive, cost between $1500 and $1700.[14]

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

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[13] Used coolant/antifreeze is used in mining, where it is sprayed on coal to prevent coal from aggregating, in cement grinding, and to de-ice airplanes (Riverside County Health Department, http://www.rivcoeh.org/97-10.htm).

[14] Personal conversation with Scott Evans, Director of Sales and Marketing, Tracer Research Corporation, 12/11/02.

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, such as used oil or waste coolant/antifreeze, is also likely to be cost effective, although environmental benefits are difficult to quantify in this case.

6. Summary and concluding remarks

Our inquiry shows that the costs of controlling the impacts of motor vehicles on water quality are substantial. Based on currently available information, we estimate that the present value of the costs of cleaning up leaking USTs ranges from \$6.5 billion to \$19.6 billion while the cost to control runoff on principal arterials ranges between \$45.3 billion and \$249 billion.

Gasoline leaks, as well as improperly disposed used oil, waste coolant/antifreeze, and metal dust from brake pads all contribute to non-point source or groundwater pollution. Their impacts on water quality as well as other aspects of motor vehicle transportation are not yet well understood so they need to be investigated. This study also revealed 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. This is the case for MTBE, which was originally introduced to reduce harmful emissions of ozone, as well as the presence of heavy metals in brake pads.

Second, as motor vehicle pollution is often created a little bit at a time by millions of drivers, 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 (e.g. Canada, see Nixon and Saphores 2002) 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.

Third, NGOs, which are often more nimble than government agencies and can exert leverage through public information campaigns, 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 a number of environmental problems described above (e.g. UST leaks) could have been limited if environmental considerations had been incorporated at the design stage instead of being fixed later through costly regulations, the implementation of economic instruments, or re-designs. This is the purpose of design for the environment, as advocated by Graedel and Allenby (1998), among others, but implementing this approach in practice will require a mentality change.

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Appendix A

Glossary of Acronyms and Chemical Symbols

AST	Aboveground storage tank
BMP	Best management practice
BOD	Biochemical oxygen demand
Caltrans	California Department of Transportation
Cd	Cadmium
CIWMB	California Integrated Waste Management Board
Co	Cobalt
Cr	Chromium
Cu	Copper
DIY	Do-it-yourselfer
DTSC	Department of Toxic Substances Control (California)
EPA	Environmental Protection Agency
Fe	Iron
FMC	Filter Manufacturers Council
LUST	Leaking underground storage tank
Mn	Manganese
MTBE	Methyl tertiary butyl ether
Ni	Nickel
NGO	Non-governmental organization
NPDES	National Pollutant Discharge Elimination System
NPS	Non-point source
O&M	Operation and maintenance
OMB	Office of Management and Budget
Pb	Lead
PCB	Polychlorinated biphenyl
SWRCB	State Water Resources Control Board
UST	Underground storage tank
VOC	Volatile organic compound
Zn	Zinc

Appendix B

Assumptions for calculating highway runoff control costs

There has been extensive research in California on quantifying highway runoff control costs. Caltrans' Storm Water Quality Handbook (2002; see Appendix F) 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 and $90,000 per lane in rural and urban areas respectively.[15] 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.[16] In Washington State, the average 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.[17] Although $319,000 per lane mile is substantial, it represents only a small percentage of total 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 (e.g., see Stormwater 2002). A recent survey conducted for the Washington Department of Transportation (Herrera Environmental Consultants, Inc. 2001) provides some data on construction as well as of operation and maintenance (O&M) costs for stormwater BMP. Treatment and detention ponds are most common; as a percentage of construction costs, their

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[15] Personal communication with Raja Veeramachaneni, Chief of highway hydraulics for the Maryland State Highway Administration, 01/10/03.

[16] Maryland treats approximately 90% of its storm water runoff before it reaches lakes, rivers, or coastal waters (Weikel and Hanley 2002).

[17] Personal communication with George Xu, an economist with the Washington State DoT, 01/13/03.

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 extremely low. To simplify our analysis, we also suppose that necessary right-of-ways are already available but we compensate this assumption by using much more expensive costs for urban highways, thus accounting for the high opportunity costs of urban land.[18] Moreover, we assume that it will take 20 years to implement BMPs and that BMPs need to be reconstructed after 20 years.

As mentioned in the text, we consider two scenarios. In the low cost scenario, constructing BMP costs $15,000 and $90,000 per lane mile for rural and urban highways respectively, and the corresponding annual O&M costs are 1% and 4% of construction. Targeting only principal U.S. arterials still represents approximately 132,000 miles of rural roads and nearly 76,000 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 (BTS 2001). Key road statistics are summarized in Table 3.[19]

In the high cost scenario, BMPs are now respectively $60,000 and $300,000 per lane mile for rural and urban highways, and the corresponding annual O&M costs are 6% and 12% of the construction budget.

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[18] Note that, 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 01/14/03.

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

Assumptions for calculating UST cleanup costs

To evaluate total cleanup costs, we follow the EPA and assume that: 1) only half of all unregistered and abandoned USTs will be found, so 181,336 USTs need to be taken care of (item q in Table 5); 2) 20,000 tanks can be cleaned up annually, so dealing with this backlog will take approximately 9 years; and 3) there are on average 2.65 tanks per site. We then consider two scenarios.

In the low cost scenario, the cleanup cost at closure of a site is the average of the last 9 years, $82,346,[20] and it does not change over time. Moreover, we assume that the number of UST sites remains constant,[21] only 2.5% of UST leak every year, and cleaning them up costs a quarter of $82,346 per site because leaks are assumed to be detected early.

In the high cost scenario, the cleanup cost at closure in 2006 is instead the maximum annual value between 1997 and 2005 ($115,579 in 2005 $), 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 $115,579 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.

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[20] From 1997 to 2005, adjusted first to 2005 $ (Vermont DEC 2006).

[21] A total 246,650 sites nationwide. (Calculated as the number of active registered USTs (item f, Table 5) divided by 2.65 tanks per site.)

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	**U.S.**	**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: These statistics are valid as of September 30, 2005. There have been 452,041 confirmed releases nationwide and 38,753 in California. Of these, cleanups have been initiated on 421,924 releases nationally and on all 38,753 in California. Nationwide there have been 332,799 fully complete cleanups and 29,572 in California. For the calculation of the "number of leaking USTs that can be found," the EPA estimates that only 50% of abandoned, unregistered USTs will be located (EPA 2000).

Table 3

Key Road Statistics

Category	U.S.	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*[1.0067]^5)	136,443	5,260
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*[-1.0003]^5)	269,196	12.036
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*[1.0177]^5)	82,789	9,254
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*[1.0210]^5)	183,790	20,974

Notes. Data sources for California: Caltrans TABLE%204_7_00.pdf for urban roads and TABLE%204_2_00.pdf for rural ones (see http://www.dot.ca.gov/hq/tsip/TSIPPDF/). Data sources for the U.S.: 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 U.S. (Source: U.S. 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)	\$15,000/lane-mile	\$60,000/lane-mile
BMPs construction for urban roads (b)	\$90,000/lane-mile	\$300,000/lane-mile
BMPs annual O&M costs for rural roads (c)	\$150/lane-mile	\$3,600/lane-mile
BMPs annual O&M costs for urban roads (d)	\$3,600/lane-mile	\$36,000/lane-mile
Groundwater pollution		
Backlog of leaking USTs		
Cleanup costs at closure (e)	\$82,346/site	\$1115,579/site
Annual change in cleanup costs at closure (f)	0%	+10%
New UST leaks		
Cleanup costs at closure (g=e/4)	\$22,446/site	\$28,895/site
Annual rate of leakage (h)	2.5%	10%

Notes: BMPs annual O&M costs for rural roads are assumed to be 1% and 4% of construction costs for the low and high cost scenarios respectively; for urban roads, they are 6% and 12%. 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

Summary of Estimated Costs (in billion of 2005 $)

Categories	**U.S.**	**California**
<u>Highway runoff control costs</u>		
BMPs for principal arterials only (a)	$45.3 to $249	$4.7 to $25.3*
BMPs for all arterials (b)	$68.3 to $375	$8.4 to $45.9*
<u>Groundwater pollution</u>		
Backlog + ongoing leaks (c)	$6.5 to $19.6	$0.6 to $1.6
<u>Present value of total costs</u>		
(d=a+c)	$51.8 to $268.5	$5.2 to $28.9
(e=b+c)	$74.8 to $394.5	$9 to $47.5

Notes: All values have been rounded to the nearest billion dollars. 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, they could overestimate costs by ignoring already established BMPs in states like Maryland, Oregon, or Washington, which report to be already treating 90%, 30%, and 30% of their storm waters respectively. These estimates ignore the improper dumping of used oil and waste coolant/antifreeze, road salt, or the deposition of various transportation-related air pollutants (e.g., nitrogen) on water bodies. In addition, they do not account for the links between transportation, land-use and water quality, and more generally, they do not consider the water quality impacts of transportation infrastructure. The quantification of these impacts is left for future research. See Appendix B for detail of our assumptions.

* California's costs are proportionally more than its share of miles because it has proportionally more urban highways with more lanes per mile of highway than the rest of the country.