The Impacts of Motor Vehicle Operation on Water Quality: A Preliminary Assessment.[1]

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Abstract

Environmental studies of motor vehicles typically focus on air pollution or noise, but ignore water pollution. In this paper, we examine some of the impacts of motor vehicle transportation on non-point source and on groundwater pollution. Our estimates of the present value of costs for cleaning up leaking underground storage tanks and for controlling highway runoff for major arterials range from $45 billion to $235 billion, which is at least as much as noise damages. Our review of applicable measures suggests that effective policies should combine economic incentives, information campaigns, and enforcement measures, coupled with preventive environmental measures.

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

JEL classification: Q25, R49.

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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 have focused on air pollution, the main environmental externality associated with road transportation, or noise. To date, however, little attention has been paid in the transportation economics literature to the impacts of motor vehicles on water quality.[1] In this paper, we start to fill this gap for two problems that have attracted considerable media attention, at times, over the last few years: leaking underground storage tanks (LUSTs) and highway runoff. Unfortunately, estimating the benefits of cleaning up LUSTs and of preventing highway runoff (for principal arterials) is not feasible because motor vehicles are just one of several causes of non-point source pollution, a complex problem, so we estimate control costs instead. Using a 7% discount rate, we estimate that the present value of these costs ranges between $45 billion and $235 billion (in 2002 $) for the U.S. Water externalities from motor vehicles are thus a serious problem (at least as important as noise externalities), at a time of increasingly scarce water resources.

There is now substantial anecdotal evidence that residues from the operation of motor vehicles contribute heavily to non-point source and groundwater pollution. Pollutants from motor vehicles or the related 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).

Indeed, the EPA (1997a) estimates that 1/6 of hydrocarbons and up to 1/2 of suspended solids reaching streams originate from freeways. Vehicle-related particulates in highway runoff come mostly from tire and pavement wear (approximately one third each), from engine and brake wear (~ 20%), and from settleable exhaust (~ 8%) (EPA 1996). Moreover, while it is well known that one gallon of used oil can contaminate 1 million gallons of water, approximately 161 million gallons of used motor oil are improperly discharged every year in the United States, thus polluting surface waters and coastal areas (EPA 1996). Damages to aquatic ecosystems and to human health can be substantial, not to mention impacts on tourism. Indeed, coastal states generate 85% of tourism revenues in the U.S., primarily thanks to beaches, and tourism is the country's leading industry (Houston 2002). According to King (1999), beach tourism in California alone contributes $73 billion annually to the U.S. economy.

Groundwater quality is also threatened. In California alone, more than 38,000 underground storage tanks (UST) have been found to leak (EPA 2002a). As of May 31, 2002, $1.174 billion of the state UST Cleanup Fund had already been spent. Special attention has been paid to leaking USTs since MTBE, a gasoline additive, has been found in many community drinking water supplies. In southern California, Santa Monica has lost 80% of its local water supply to MTBE contamination and needs to purchase water from outside sources at a cost of $3-5 million per year (Bergeron 1997).

A comprehensive assessment of the impacts of motor vehicle transportation on water quality is at present too complex to be feasible. We thus focus on LUSTs, on highway runoff, and on the water pollution resulting from the improper disposal of used oil, oil filters, waste coolant/antifreeze, and metal dust from brake pads because these sources of pollutants are of importance and/or lead to the consideration of interesting and useful policy solutions.

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[1] Delucchi's comprehensive studies (1998, 2000) rely on educated guesses for quantifying the impacts of motor

We find that the current approach to dealing with motor vehicle externalities is typically reactive instead of proactive, which tends to be cost-ineffective. 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. Better still, they should foster the integration of environmental considerations in the design of motor vehicles and their infrastructure as recommended for example by Graedel and Allenby (1998) because addressing environmental problems after-the-fact is often more costly than preventing them.

This paper is organized as follows. In the next section, we summarize the main environmental and health impacts of used oil, used antifreeze, metal dust from brake pads, and LUSTs. In Section 3, we review briefly the relevant legal framework. 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. Section 6 summarizes our concluding remarks.

2. An Overview of some Environmental Impacts

Motor vehicles contribute mostly to non-point source pollution, as small quantities of various pollutants are emitted during vehicle use or improperly disposed of at many different locations.[2] A number of studies have linked heavy metals (such as Pb, Zn, or Cu) or hydrocarbon loadings

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vehicle transportation on water quality.

[2] 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 2002a); 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).

of surface water with transportation (e.g., see Latimer et al. 1990; Bannerman et al. 1993; Walker et al. 1999, or Sutherland and Tolosa, 2000).

Used Oil

One typical example of this type of pollution is used oil: according to the National Oil Recyclers Association (2001), it accounts for 40% of the oil pollution of the nation's harbors and waterways. Latimer et al. (1990) suggest that used oil is the main hydrocarbon source to runoff. Improperly disposed of used oil filters, which may account for 5% of the discarded used oil, have similar environmental impacts. Yet, used oil is the "single largest environmentally hazardous recyclable material" (MARRC 2001).[3]

Like crude oil slicks, used motor oil can destroy aquatic habitat, prevent the replenishment of dissolved oxygen, and impair photosynthesis. In addition, it reduces the insulating capacity of fur and the water-repellency of feathers, so animals are at risk of freezing to death or of drowning. In some species, oil vapors can damage the central nervous system, liver, and lungs, and ingested oil can seriously affect the digestive system. Oil contamination can also disrupt reproduction, particularly for birds.

In addition, 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. Common oil contaminants include trace metals like Pb and Cd (see Tables 1 and

[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.

2); chlorinated solvents; products of incomplete combustion; glycols; PCBs; and polynuclear aromatic hydrocarbons (PAH) (NORA 2001). Walker et al. (1999) show that urban runoff is a main source of PAHs, which are persistent organic pollutants, to river sediments.

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

Used Coolant/Antifreeze

Another source of non-point source pollution is used coolant/antifreeze. Over 200 million gallons of coolant/antifreeze are sold each year in the U.S. (Arner 2000). The CIWMB (2001) estimates that, 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. Used coolant/antifreeze is especially a problem for Do-It-Yourselfers (DIY) because current engine design makes it almost impossible to avoid the likelihood that some product will leak when it is changed.[4] Engine coolant/antifreeze can contribute high BOD levels to stormwater (Lehner et al. 1999).

Most brands of coolant/antifreeze consist of 95% ethylene glycol, a clear, colorless, and sweet-tasting liquid, which is highly toxic. In addition, during normal engine use, coolant/antifreeze becomes contaminated not only with traces of heavy metals such as lead from the car's radiator, but also with copper, zinc, cadmium, and chromium. If ingested by humans, ethylene glycol may cause respiratory and cardiac failure, as well as renal and brain damage

(CIWMB 2001). The ingestion of only a few ounces of pure coolant/antifreeze by children is lethal. Spilled antifreeze is also a hazard for pets, because they are attracted by its sweet taste.

Table 1 provides a qualitative overview of the metal contributions of motor vehicle transportation to water bodies. Table 2 summarizes the main health and environmental impacts of a number of metals deposited during motor vehicle operation. 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, a number of heavy metals bioaccumulate in the food chain and thus can become toxic to humans over the long run.

Metal Dusts from Brake Pads

The operation of motor vehicle disc brakes also contributes heavy metals to non-point source pollution. Until the end of the 1960s, most cars had only drum brakes, which were usually enclosed. Pads for these brakes typically included resins and asbestos but no metals. In the early 1970s, stricter braking requirements and increasing concerns for workers' health related to airborne asbestos led car manufacturers to switch progressively to cars with disc front – drum rear braking systems and to adopt semi-metallic brake pads. These pads contain no asbestos, wear out more slowly, and have good braking properties over a wide range of temperatures. The corporate average fuel efficiency (CAFE) standards reinforced the adoption of semi-metallic pads by favoring front wheel drive cars (Woodward-Clyde Consultants [WCC] 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.

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[4] Personal communication with Lee Halverson, Hazardous Waste Management Specialist, State Regulatory

Quantifying total metal loading to water bodies is a challenge because of the uncertainty involved. For example, a recent EPA study (1998) finds that brake pad dust from cars contributes approximately 35% of the total copper influx to San Francisco Bay, but WCC (1994) estimates that brake pad dust makes up approximately 52%, 3%, and 6% respectively of the total copper, lead, and zinc loadings. WCC also finds substantial variations in metals content across manufacturers and across brake pads. Extrapolating the WCC results to the whole state, we infer that the total annual motor vehicles load to storm water ranges from 59,200 to 232,000 lbs for copper, 4,000 to 13,280 lbs for lead, and 19,200 to 92,800 lbs for zinc.[5]

Leaking Underground Storage Tanks

While used oil and used coolant/antifreeze pollution mostly affects surface waters, gasoline spills from leaking underground storage tanks (or LUSTs) are a major source of groundwater pollution all over the U.S.[6] In California alone, there have been more than 38,000 confirmed releases from underground storage tanks (USTs). Cleanups have been completed on 22,695 of these as of March 2002, with another 15,469 cleanups in progress. Additionally, the EPA (2000) estimates that there are close to 175,000 unregistered tanks (10,500 in California), of which approximately 134,500 (8,100 in California) are probably leaking. Statewide, there are 42,248 active registered USTs, even after the closure of more than 112,000 tanks since the late 1980s (EPA 2002b). Nationwide, there have been 422,573 confirmed releases from USTs; cleanups have been initiated on 387,190 and completed on 277,171. More than 1.5M USTs have been closed and the

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Programs Division, California Department of Toxic Substances Control, October 4, 2001.

[5] The WCC study is based on 79% of the 953,542 vehicles registered in Santa Clara Valley in 1990 (753,298 vehicles). On this basis, the annual per vehicle contribution is 0.0037 to 0.0145 lbs for copper (mean: 0.0102), 0.00025 to 0.00083 lbs for lead (mean: 0.00058), and 0.0012 to 0.0058 lbs for zinc (mean: 0.0041). Extrapolating these ranges to the whole state, assuming a fleet of 16 million vehicles, gives the ranges provided in the text.

EPA estimates that there are currently approximately 873,000 tanks at 329,000 sites across the nation.[7] Of those, an estimated 170,000 are leaking. At the same time, more than 50% 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 thus a significant environmental problem. Table 3 summarizes key UST statistics.

Until the mid-1980s, most underground storage tanks for gasoline were made of bare steel, which corroded over time, although a great many leaks came from pipes (EPA 2001a). With increasing awareness of the costs of gasoline leaks, Congress banned the installation of unprotected steel tanks and piping in 1985. According to SWRCB (2000a), 95% of USTs now meet the California upgrade requirements and 91% have leak detection systems. However, many leaks remain undetected because monitoring is inadequate and many USTs are inactive or abandoned (Farahnak and Drewry 1998).

LUSTs contaminate the surrounding soil and groundwater (EPA 2001a). Because gasoline is lighter than water, it remains in the upper layers of aquifers, so there is a greater risk that relatively high concentrations of gasoline will enter the water supply. While severe leaks may also create fire or explosion hazards, some of the main concerns traditionally associated with gasoline releases are dissolved-phase benzene, toluene, ethylbenzene, and xylenes.

Prolonged exposure to these chemicals can seriously impair health. Benzene, for example, is carcinogenic. Short-term exposure to high levels of benzene can trigger dizziness, unconsciousness, and even death (OSHA 2001); long-term exposure can cause leukemia, alter the bone marrow, and affect blood production. Toluene is not carcinogenic but it can affect the

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[6] Small gasoline spills at gas stations or resulting from accidents can also contribute to surface water pollution.
[7] The 873,000 tanks represent 698,607 active registered tanks plus an estimated 35,000 active and 140,000 abandoned, unregistered tanks. The EPA estimates that there are approximately 2.65 tanks per site.

nervous system and damage kidneys at high levels (U.S. DHHS 2001). Ethylbenzene exposure causes similar symptoms plus eye or throat irritation, and liver damage at higher doses (U.S. DHHS 1999). Xylene can affect the brain, impair breathing, and damage the liver and the kidneys; very high concentrations can cause death (U.S. DHHS 1997). Since 1996, however, gasoline additives such as MTBE (methyl-tertiary-butyl-ether) have attracted increasing scrutiny.

MTBE was initially used as early as 1979 to replace lead as an octane enhancer in gasoline. In the early 1990s, MTBE began to be used in higher concentrations (up to 15% by volume) to fulfill oxygenate requirements established by the 1990 Clean Air Act Amendments (Johnson et al. 2000). Indeed, more oxygen enhances combustion and reduces tailpipe emissions, so MTBE has helped reduce air pollutants such as VOCs and NO_x, thus improving air quality in highly polluted cities such as Los Angeles (EPA 2001b).

Currently, there are little data on the human impacts of long-term exposure to MTBE, so the EPA has not yet set any health advisory limits (EPA 2001b). Short-term studies of the effects of MTBE inhalation are inconclusive. Some rodent-based studies suggest that MTBE may be carcinogenic and could have reproductive effects at large doses, but it is unlikely that MTBE in drinking water will cause adverse health effects at concentrations below 40 ppb (EPA 1997b).

However, even very low concentrations of MTBE impair water supplies because of its characteristic odor and taste (SWRCB 2000b). Relative to other hydrocarbons, MTBE is also highly soluble in water and slow to biodegrade (Johnson et al. 2000). The EPA (1999) estimates that 5% to 10% of drinking water supplies in high oxygenate use areas show detectable concentrations of MTBE. Of the 38,000 known LUST sites in California, more than 10,000 have been impacted by MTBE (SWRCB 2002). MTBE is to be phased out of gasoline in California by December 2003 (California Air Resources Board 2002).

3. The Legal Framework

Used Oil

A number of federal and state laws aim at limiting the environmental impacts of crude or used oil but they are typically not well suited to deal with the dumping of small quantities of used oil.

At the federal level, the Federal Water Pollution Control Act of 1972 prohibits any discharge of oil or oily waste either directly into the navigable waters of the U.S. or in a way that may affect natural resources belonging to, appertaining to, or under the exclusive management of the U.S. In addition, the 1977 Clean Water Act makes illegal the discharge of oil or hazardous substances into the waters of the U.S. within 12 miles of the coast or where natural resources such as marine sanctuaries may be affected. Finally, the Oil Pollution Act of 1990 strengthens the EPA's ability to prevent and respond to catastrophic oil spills and establishes a trust fund to clean up spills when the responsible party is incapable or unwilling to do so.[8]

In California, the Used Oil Enhancement Act of 1992 (PRC 48600-48691) created a used-oil recycling program that has been in operation since 1993. Revenues are generated by a fee of $0.16/gallon collected on the sale of lubricating oil (motor oil and transmission fluid) for use within the state. This finances the recycling incentive ($0.04/quart) paid to industrial generators, to curbside collection programs, and to certified collection centers. Recycling incentives can also paid to electric utilities that burn used lubricating oil to produce electricity.

[8] This trust fund was created to respond to large oil spills, which are typically caused by transportation accidents. It was financed by a 5-cents per barrel fee on imported and domestic oil until the end of 1994; it is now funded by interests on the fund, cost recovery from the parties responsible for a spill and penalties collected. Up to $1 billion can be paid for any oil pollution incident.

Coolant/Antifreeze

The heavy metals content of used antifreeze is high enough to make used antifreeze a regulated hazardous waste under U.S. law (DTSC 2000). In California, a water-antifreeze mixture with more than one part of antifreeze for two parts of water is considered toxic. However, waste coolant/antifreeze is rarely analyzed for its metal or water content.

To address accidental poisoning death (of humans and pets) resulting from ingesting coolant/antifreeze, a new California law (Assembly Bill 2474), signed in September 2002, requires the addition of a bittering agent, such as denatonium benzoate, to engine coolant/antifreeze containing more than 10% of ethylene glycol, and which is manufactured after July 1, 2003 and sold after Jan. 1, 2004.[9] This measure will add $0.02 to $0.03 per gallon to the cost of coolant/antifreeze (~$5 per gallon). Similar requirements exist in Oregon, Massachusetts and in several foreign countries (e.g., the United Kingdom, Japan, or Australia).

Relevant Nonpoint Source and Storm Water Legislation

A number of laws and regulations aim at controlling non-point source pollution. The four main laws are summarized below. They are currently being implemented, they involve multiple agencies or governmental entities, and their cost is still unclear.

In 1987, Congress established the Nonpoint Source Management Program under section 319 of the Clean Water Act (CWA). Its purpose is to prevent runoff from becoming polluted and to control non-point source pollution by helping states adopt and implement best management practices (BMP).[10] It provides grants for non-point source program activities.

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[9] A similar measure was first proposed in 1993 but Governor Wilson vetoed it.
[10] BMPs are physical, structural, and management practices that prevent or reduce pollution of water and attenuate peak flow and peak volume.

The 1987 amendments to the CWA and the subsequent 1990 federal regulations issued by the U.S. EPA also dealt with storm water through the National Pollutant Discharge Elimination System (NPDES). More specifically, discharges from municipal separate sewer systems serving over 100,000 persons or discharges associated with industrial activities, as well as construction sites where 5 or more acres are disturbed are considered point sources and require an NPDES permit. In California, the State Water Resources Control Board (SWRCB) received authority from the EPA to issue NPDES permits. In 1999, the SWRCB issued an NPDES statewide storm water permit to Caltrans. It requires Caltrans to control storm water and non-storm water discharges from right-of-ways during and after construction, as well as from facilities and operations. Water quality standards must be met through the implementation of BMPs and pollutants must be removed to the "maximum extent practicable." Discharges not entirely composed of storm water are prohibited. To simplify the administrative burden, Caltrans' permit applies to construction activities that disturb at least 5 acres. Starting March 2003, however, construction sites disturbing soil areas between 1 and 5 acres must also control pollutants in storm water runoff (Caltrans 2002).

Section 6217 of the Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 requires coastal states and territories to develop and implement management measures for non-point source pollution in order to restore and protect coastal waters. CZARA applies to storm water runoff from roads for cities with a separate storm sewer system serving populations of less than 100,000 and to construction sites of less than 5 acres. Management measures for roads and bridges include but are not limited to protecting erosion-prone areas, implementing approved erosion control measures as well as runoff pollution controls for existing roads. In conjunction with CZARA, Total Maximum Daily Loads (TMDLs) must be developed for watersheds identified by the state on its biennial CWA Section 303(d) list. TMDLs give a detailed interpretation of water quality standards and set the allowable pollution coming from each source. CZARA is administered nationally by the EPA and by NOAA.

Finally, the Intermodal Surface Transportation Efficiency Act (ISTEA) authorizes states to use a portion of their federal funding for financing runoff control measures and best management practices to prevent runoff from contaminating water resources (EPA 1995).

Leaking Underground Storage Tanks

In early 1984, bills were submitted to Congress to address the problem of LUSTs. At that time, existing laws, in particular CERCLA (Superfund) and the Resource Conservation and Recovery Act (RCRA) were ill suited to properly regulate USTs. The oil industry strongly objected to provisions that would have placed UST regulation under current Superfund rules because these rules allowed the assignment of liability regardless of fault, and any company that had contributed to pollution could have been assigned total liability (Cohen and Kamienicki 1991). The diversity of UST operators also complicates potential laws and regulations. “Mom and pop” operations are the most difficult group of UST owners to regulate because they are diverse, numerous, and regulations are relatively more costly for them; in addition, government crackdowns on small businesses are typically quite unpopular.

To provide funds to clean-up LUSTs, Congress amended Subtitle I of RCRA in 1986 to create the LUST Trust Fund. It is financed by a 0.l cent/gallon tax on motor fuel sold nationwide. The first purpose of this Trust Fund is to provide money for overseeing and enforcing corrective action taken by a party responsible for a leaking UST. Its second purpose is to fund cleanups at sites where the owner is unknown, unable or unwilling to respond, or which require emergency action. So far, only 4% of all identified LUST sites have been without a responsible party. In addition, 47 states have implemented their own LUST programs to fulfill a 10% matching funds federal requirement and to take care of the leaking tanks that fall under their jurisdiction.

In 1989, California established its own UST Cleanup Fund as part of the Barry Keane Underground Storage Tank Cleanup Fund Act. It currently requires UST owners to pay a fee of $0.012 per gallon of petroleum placed in USTs (CHSC 2000).[11]

4. A Preliminary Quantification of Costs

Quantifying the water externalities of motor vehicle transportation is difficult because of the nature of non-point source pollution, and because currently available information is insufficient to attempt such a task. We just note that the most recent National Water Quality Inventory reports that urban runoff is the first source of water quality impairments for estuaries and the third largest one for lakes. It is also an important contributor to beach closures.

We focus here on the costs of cleaning up LUSTs and on controlling runoff on principal arterials. 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 2002 $ and aggregate costs are rounded to the nearest billion. These estimates are preliminary; they should be updated when new information becomes available.

Highway runoff control costs

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

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[11] The fee was initially $0.006 in 1991. It increased to $0.007 in 1995, $0.009 in 1996, and $0.012 in 1997.

characteristics, traffic intensity, land availability, proximity of maintenance bases, and of course on the regulatory framework.

Retrofitting existing roads with BMPs can be costly. Based on experience accumulated in Maryland, 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.[12] In Washington State, the average weighted cost of implementing runoff BMPs was $319,000 per lane mile for 18 recent urban and rural projects dealing with 644 lane miles, admittedly a very small sample.[13] Although $319,000 per lane mile is substantial, it represents only 1.16% of total project costs on average (this percentage varies between 0.45%, for large rural projects, and 8.99%, for small urban ones). Caltrans' Storm Water Quality Handbook (2002; see Appendix F) gives comparable numbers: $100,000 per lane mile for rural highways and $250,000 per lane mile for urban ones. In general, however, it is less expensive to implement BMPs during highway construction or repair. For a new highway, for example, the dirt from a settling pond may be used as fill, thus adding little to construction costs. Implementing BMPs during road construction or retrofitting may add as little as $15,000 and $90,000 per lane in rural and urban areas respectively.[14]

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 BMPs. Treatment and detention ponds are most common; as a percentage of construction costs,

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

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

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

their annual O&M costs vary between 0.2% for the largest basins and 5% for the smallest 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.[15] Moreover, we assume that it will take 20 years to implement BMPs, and that BMPs need to be reconstructed after 20 years. We then consider two scenarios and two levels of BMP implementation for which we report the present value of total (construction + O&M) costs. These scenarios reflect the range of uncertainty currently surrounding BMPs.

In the low cost scenario, constructing BMPs 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 135,092 miles of rural roads and 76,801 miles of urban roads (at the end of 2002), with an average of 3.26 lanes for the former and 4.72 lanes for the latter (BTS 2001).[16] The corresponding costs reach $39 billion. Considering all arterials more than doubles the mileage of rural (271,040 miles) and urban roads (169,891 miles), but since the average number of lanes decreases to 2.50 and 3.20 respectively, total costs do not quite double but instead reach $60 billion. In California alone, there are approximately 5,208 miles of rural and 8,584 miles of urban principal arterial at the end of 2002,

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[15] 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.

[16] Key road statistics are summarized in Table 4. The average number of lanes per mile of principal arterial is the California average as there were insufficient data at the national level.

which gives a lower bound of $4 billion with our assumptions. Dealing with all arterials represents 12,118 miles of rural and 19,387 miles of urban roads, with an average of 2.57 and 3.78 lanes per mile respectively (see Table 4); it would require a minimum of $7 billion.

The high cost scenario provides an upper bound on the present value of construction and maintenance costs of controlling highway runoff. 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. Nationwide costs would reach $215 billion for principal arterials only, and $324 billion for all arterials. For California alone, the corresponding costs are $22 billion for principal arterials alone and $39 billion for all arterials. 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.

While dealing with runoff on arterials requires expensive structural BMPs, experience suggests that road sweeping is more appropriate (and cheaper) to reduce the transport of road sediments to storm drains for "smaller" urban roads (e.g., see Sartor and Gaboury 1984). The cost of these measures is not considered 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. The presence of additives such as MTBE tends to substantially boost cleanup bills. In addition, cleanup costs vary widely across states and over time, although they tend to increase because 1) lightly polluted sites were typically treated first and 2) pollution spreads over time. In addition, remediation technology has been quickly evolving. For the year ending June 2002, the nationwide average for total cleanup costs at closure is $77,665. State average cleanup costs per site range from $14,421 in Montana to $305,000 in Wyoming, and reach $101,000 in California (Vermont DEC 2002).

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 cleanup funds from federal, state, and private sources. Partial information suggests that considerable amounts have already been spent. For example, by 1996 approximately $17 billion had been spent on LUST sites nationwide; in California alone, between 1991 and the end of July 2001, the state UST Cleanup Fund paid out $1 billion (SWRCB 2001).

To evaluate total clean-up costs, we make a number of assumptions. Following the EPA, we suppose that: 1) only half of all unregistered and abandoned USTs will be found, so 217,010 USTs need to be taken care of (item q in Table 3); 2) 20,000 tanks can be cleaned up annually, so dealing with this backlog will take approximately 11 years; and 3) there are on average 2.65 tanks per site. For California, 19,800 LUSTs need to be cleaned up at a rate of 1,750 per year, which will require approximately 12 years. 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 (from 1994 to 2002, adjusted first to 2002 $; Vermont DEC), i.e. $76,471, and it does not change over time. Moreover, the number of UST sites remains at 263,625 sites for the US and 15,943 for California, only 2.5% of USTs leak every year, and cleaning them up costs a quarter of $76,471 per site because leaks are assumed to be detected early.

In the high cost scenario, the cleanup cost at closure in 2003 is instead the maximum annual value between 1994 and 2002 ($106,872 in 2002 $), and it increases by 10% per year thereafter. Moreover, an additional 10% of USTs begin to leak every year, and cleaning them up costs a quarter of $106,872 per site. These estimates may be conservative, however, if the current trend away from USTs in favor of above ground storage tanks (ASTs) continues.

Based on our assumptions, the present value of the total cost of cleaning up USTs is comprised between $6 and $20 billion for the U.S., and between $1 and $2 billion for California.

Overall estimate

Combining the above estimates for groundwater and highway runoff pollution control gives a present value of costs for California ranging from $5 billion to $23 billion if BMPs are installed for principal arterials only, and from $8 billion to $41 billion if all arterials are included. For the U.S., we find a range of $45 billion to $235 billion with BMPs for principal arterials only, and of $65 billion to $344 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. Cost assumptions are summarized in Table 5. Results are summarized in Table 6.

It is also important to note that these estimates do not consider a number of potentially important environmental effects that contribute to non-point source pollution. These include, for example, 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, these estimates do not account for the links between transportation, land-use (urban sprawl) and water quality, and more generally, for the water quality impacts of transportation infrastructure. The quantification of these impacts is left for future research.

To put these costs in perspective, it is interesting to compare them with other motor vehicles externalities, such as noise. According to Delucchi (2000), annual noise damages are comprised between $0.5 billion and $15 billion (in 1991 $) for the whole country. For an interest rate of 7%, the range of present values for these costs is $9 billion to $264 billion (in 2002 $ rounded to the nearest billion). External costs from transportation on water are thus at least as important as external noise damages, and they seem to have been underestimated to-date. For example, Delucchi (2000) reports an upper bound for annual water pollution damages resulting from motor vehicles of $1.5 billion (in 1991 $), which is an order of magnitude smaller than his noise damage estimates. This underscores the urgency of addressing the impacts of motor vehicle transportation on water quality in a context of increasingly scarce water resources.

5. Policy Considerations

Funding issues

Cost is understandably one of the main concerns about controlling highway runoff, especially in California; this issue has triggered lawsuits and delayed the implementation of BMPs (e.g., see Weikel and Hanley 2002). Indeed, we estimate that annual construction and O&M costs of installing BMPs for principal arterials only would cost annually (in the high cost case) from $7.5 billion in 2003 to $21.4 billion in 2022 (all in 2002 $); they would stay at this level thereafter. Taking care of all arterials would bump annual expenses from $11.3 billion in 2003 to $32.2 billion in 2022.

Since non-point source is linked to the operation of motor vehicles, an increase in the gasoline tax could be considered. Since a 1-cent increase in the gasoline tax provides approximately $1.5 billion in revenues, a progressive increase in the gas tax (from 5 cents in 2003 to 14.3 cents in 2020) would provide the necessary 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.

Finding resources for protecting water quality from the operation of motor resources thus appears feasible. Implementing BMPs much more widely (to include, for example, minor arterials) would be significantly more costly and may be politically difficult. In addition, it would not address other potential non-point sources of water pollution (see the end of the previous section). Other measures should thus be considered.

Dealing with non-point source pollution

For non-point source pollution, "standard" instruments such as the establishment of performance standards, taxes, or permit systems are typically ineffective for several reasons (Helfand 1994).

First, it is by nature difficult to establish the relationship between sources and the pollution itself. Quantifying it, and capturing it, let alone identifying who should be responsible for it is therefore difficult. Indeed, non-point source pollution in transportation often results from a very large number of actions that release small amounts of pollution each time, whether voluntarily (for used oil) or not (metal dust from brake pads). Second, non-point source 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 (this is the case for MTBE for example). Finally, when some non-point source pollutants transfer from one medium to another, they undergo chemical transformations that affect their toxicity (a good example is Chromium).

Effective policies are thus likely to combine a series of measures including public education (e.g., to educate DIY), non-structural BMPs such as street sweeping (e.g., see Sartor and Gaboury 1984), 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. Let us examine how this applies to some causes of transportation-related non-point source pollution, starting first with used oil.

Used Oil and Used Oil Filters

Used oil recycling rates in California compare favorably with the national average of 51% (API 1997): they have been steadily increasing from 55% to 63% between 1996 and 2000.[17] However, millions of gallons of used oil are still discharged into the environment each year. Improving recycling rates will take a series of measures, one of which could be to increase fees collected on the sale of lubricating oil. This would provide dedicated funds that could be used to target Do-It-Yourselfers (DIY), at a time of strained public budgets.

Indeed, DIY are responsible for most of the improperly disposed used oil: although their recycling rate improved from 14% in 1993 to 30% in 2000, it is still well below average.[18] In a recent survey of DIY conducted by Browning and Shafer (2002), 97% of respondents indicate they would be more likely to recycle if facilities paid more for used oil. Although most respondents (56%) would like an incentive of $2/gallon or more, 44% of the respondents would be happy with an incentive of $1/gallon. This compares with only $0.16 per gallon currently.

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[17] These numbers reflect that only 75% of the oil sold is recyclable because some oil is burnt or lost through leaks during use.

[18] In California, DIY consume approximately 23% of the lubricating oil sold (34 million gallons per year), so 25.5 million gallons are available for recycling.

Creating more collection centers would lower recycling costs to the public; in fact, part of the progress in the recycling rate for DIY is explained by the multiplication of certified collection centers (now over 2,600 in California). Public-private partnerships could be a cost-effective arrangement, as illustrated by the Canadian experience (see Nixon and Saphores 2002). Extra funding would also boost public education, which includes advertising the consequences of used oil pollution, giving out information about recycling centers, highlighting penalties for improperly disposing of used oil, and maintaining a web-site and a toll free number. 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.[19]

Much more could be done for used oil filters. According to the Filter Manufacturers Council (FMC), approximately 430 million used filters were used in the U.S. in 1999 but only 143 million were recycled (33%) (FMC 2000). Three Canadian provinces (Alberta, Manitoba, and Saskatchewan) have recently achieved 80% recycling rates by implementing economic incentives (Nixon and Saphores 2002). Unfortunately, the FMC opposed the use of economic incentives in the U.S. and advocates instead public education campaigns and landfill bans. A landfill ban has been adopted by five states (California, Florida, Minnesota, Rhode Island, and Texas), but such a measure may encourage the illegal disposal of used oil filters.

Results from 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). Apart from limited public knowledge about the program, poor recycling rates seemed to result primarily from excessive costs: public participation was limited by the small number of

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[19] E-mail from Terri Thomas, Environmental Resource Analyst II, Information Technology Division, Environmental

collection facilities, and businesses were deterred by reimbursements that did not even cover hauling costs. In addition, recycling was impaired by a State law that forbids used oil and oil filter reimbursement checks to be combined. As a result, the check processing cost for oil filter reimbursement was often significantly higher than the amount of the filter claim. This suggests that recycling incentives should be at least high enough to cover transaction costs.

Coolant/Antifreeze

There are currently no programs and no economic incentives to promote coolant/antifreeze recycling, either at the federal or state levels. This is regrettable given the potential environmental damages of used coolant/antifreeze and possible recycling options.[20]

It should be noted that a considerably less toxic coolant/antifreeze based on propylene glycol instead of ethylene glycol is available. It is popular in countries such as Austria and Switzerland, but its U.S. market share is only 10%.

As with used oil and oil filters, public education should be a key component to reduce the improper disposal of used antifreeze. Currently in California, public education is limited to on-line fact sheets and to a toll-free number. Information on antifreeze is often combined with information on general household hazardous waste activities.

Better information about coolant/antifreeze and available alternatives could entice manufacturers to switch to propylene glycol and give them an incentive to modify engine designs to limit coolant/antifreeze spills. Environmental NGOs may have a useful role to play to facilitate changes, as they have in the case of metal dust from brake pads.

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and Energy Resources Department, Ventura County (10/21/02).

Metal Dusts from Brake Pads

There are currently no direct regulations or economic incentives to deal with the metal content of brake pads. Instead, this problem has 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 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.

Proactive versus reactive policies

Government policies for dealing with transportation-related water pollution have been mostly reactive instead of proactive to-date. This is particularly the case for LUSTs. In retrospect, it would have been much cheaper to prevent the problem in the first place 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 only approximately $57 per tank (in 1998 $). This compares with approximately $2800 per tank per year for annual administrative costs of compliance activities during the life of a site (estimated at 5 years), not to mention the cleanup costs themselves, which can reach anywhere between $10,000 and $1,000,000. Cleanup costs also dwarf detection and monitoring costs. There are two main types of tests for USTs: conventional tests, with a detection sensitivity of approximately 0.1

[20] For example, 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 Environmental Health Department 1997).

gallon/hour at a cost of $600 to $700, and enhanced tests, which are 20 times more sensitive but cost between $1500 and $1700.[21]

A case for incorporating environmental concerns during design can also be made for highway runoff. As indicated above, 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) 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 impacts of motor vehicles on water quality have been underestimated. Indeed, they are at least as costly as noise damage: based on currently available information, we estimate that the present value of the costs of cleaning up leaking USTs and of controlling runoff on principal arterials is comprised between $45 billion and $235 billion. The corresponding costs for California are estimated to range from $5 billion to $23 billion. Moreover, highway runoff control costs are larger than leaking USTs cleanup costs by an order of magnitude.

Gasoline leaks, as well as improperly disposed of used oil, waste coolant/antifreeze, and metal dust from brake pads all contribute to non-point source or groundwater pollution. Their

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

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, or for 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 people, implementing pollution reduction programs can entail substantial transaction costs. This point is illustrated vividly 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, who are 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, it seems that 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 of 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

Glossary of Acronyms and Chemical Symbols

AST	Aboveground storage tank
BMP	Best management practice
BOD	Biochemical oxygen demand
CAFE	Corporate average fuel efficiency
Caltrans	California Department of Transportation
Cd	Cadmium
CIWMB	California Integrated Waste Management Board
Co	Cobalt
Cr	Chromium
Cu	Copper
CWA	Clean Water Act
CZARA	Coastal Zone Act Reauthorization Amendments
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
NOAA	National Oceanic and Atmospheric Administration
NO_x	Nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
O&M	Operation and maintenance
OMB	Office of Management and Budget
Pb	Lead
PCB	Polychlorinated biphenyl
RCRA	Resource Conservation and Recovery Act
SWRCB	State Water Resources Control Board
TMDL	Total maximum daily load
UST	Underground storage tank
VOC	Volatile organic compound
WCC	Woodward-Clyde Consultants
Zn	Zinc

Table 1

Sources 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

Summary of Potential Health and Environmental Impacts of Metals

Compound	Human Health Impacts	Environmental Impacts
Cadmium (Cd) *(OSHA 2002)*	Extremely toxic (especially fumes). Acute effects: fever, headache, chills, sweating and muscular pain. Chronic effects: lung and prostate cancer; kidney damage, pulmonary emphysema; bone disease; anemia; loss of smell; and teeth discoloration.	Carcinogenic for animals. Bioaccumulate.
Chromium (Cr) *Kjitrov & Jaeger (2002)*	Cr-3 is less toxic to humans than Cr-6. Cr-3 can irritate lungs and cause bronchitis or asthma. Cr-6 is carcinogenic. Chronic effects: skin inflammation, liver and kidney damage.	Cr-3 is usually benign; it is a known micronutrient in organic form. Cr-6 is toxic to plants, aquatic animals, and bacteria.
Copper (Cu) *EPA (1998)*	Acute and chronic copper poisoning rare in humans (healthy humans typically eliminate excess copper from their bodies). Chronic copper problems with rare liver diseases.	Toxic to algae and to plankton; they concentrate copper in higher-life forms such as fish and shellfish.
Lead (Pb) *ILO (2000)*	Acute effects: colics; anemia; kidney damage; encephalopathy; or death. Chronic effects: colics; paralysis of muscle groups; anemia, mood changes; retarded mental development; and irreversible nephropathy. Children are especially at risk.	Bioaccumulation takes place in plants and water organisms, especially in shellfish.
Zinc (Zn) *NIH (2002)*	Can be acutely and chronically toxic. Effects: decrease in good cholesterol; pancreas damage; muscular pain, nausea, vomiting, and anemia; decreased ability to use copper or iron.	Does not biomagnify through terrestrial food chains.

Table 3

Underground Storage Tanks (USTs) Statistics

Category	**U.S.**	**California**
Registered USTs		
Closed (a)	1,519,302	112,865
Active		
Leaking		
Clean-up in progress (b)	110,019	15,469
No clean-up initiated (c)	35,383	0
Subtotal registered active leaking USTs (d=b+c)	145,402	15,469
Non-leaking USTs (e)	553,205	26,779
Subtotal active USTs (f=d+e)	698,607	42,248
Subtotal registered USTs (g=a+f)	2,217,909	155,113
Unregistered USTs		
Abandoned (20% of (f), active registered) (h)	139,721	8,450
Leaking (90% of (h), unregistered abandoned) (j)	125,749	7,605
Non-leaking (10% of (h), unregistered abandoned) (k)	13,972	845
Active (5% of (f), active registered) (m)	34,930	2,112
Leaking (25% of (k), unregistered active) (n)	8,733	528
Non-leaking (75% of (k), unregistered active) (p)	26,197	1,584
Number of leaking USTs that can be found (q=d+50%j+n)	217,010	19,800

Notes: These statistics are valid as of March 31, 2002. There have been 422,573 confirmed releases nationwide and 38,154 in California. Of these, cleanups have been initiated on 387,190 releases nationally and on all 38,154 in California. Nationwide there have been 277,171 fully complete cleanups and 22,695 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 4

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 2002 centerline miles (d=a*[1.0118]^2)	135,092	5,208
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 2002 centerline miles (h=e*[1.0028]^2)	271,040	12,118
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 2002 centerline miles (n=j*[1.0064]^2)	76,801	8,584
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 2002 centerline miles (s=p*[1.0128]^2)	169,891	19,387

Notes. Data sources for California: Caltrans TABLE%204_7_00.pdf for urban roads and TABLE%204_2_00.pdf for rural ones, at 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 2002 centerline miles are 10-year averages (1990-2000) calculated for the U.S.

Table 5

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)	$76,471/site	$106,872/site
Annual change in cleanup costs at closure (f)	0%	+10%
New UST leaks		
Cleanup costs at closure (g=e/4)	$19,118/site	$26,718/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 6

Summary of Estimated Costs (in billion of 2002 $)

Categories	U.S.	California
Highway runoff control costs		
BMPs for principal arterials only (a)	$39 to $215	$4 to $22
BMPs for all arterials (b)	$59 to $324	$7 to $39
Groundwater pollution		
Backlog + ongoing leaks (c)	$6 to $20	$1 to $2
Present value of total costs		
(d=a+c)	$45 to $235	$5 to $23
(e=b+c)	$65 to $344	$8 to $41

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 2002, so they do not account for possible growth in the mileage of arterials, which underestimates costs. 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. The main assumptions behind our calculations can be found in Section 4.