5.15   Water Pollution and Hydrologic Impacts

This chapter describes water pollution and hydrologic impacts caused by transport facilities and vehicle use.

5.15.1 Chapter Index

5.15.2 Definitions
Water pollution refers to harmful substances released into surface or ground water, either directly or indirectly. *Hydrologic impacts* refers to changes in surface (streams and rivers) and groundwater flows.

5.15.3 Discussion
Motor vehicles, roads and parking facilities are a major source of water pollution and hydrologic disruptions.[1] These include:

Water Pollution	**Hydrologic Impacts**
• Crankcase oil drips and disposal.	• Increased impervious surfaces.
• Road de-icing (salt) damage.	• Concentrated runoff, increased flooding.
• Roadside herbicides.	• Loss of wetlands.
• Leaking underground storage tanks.	• Shoreline modifications.
• Air pollution settlement.	• Construction activities along shorelines.

These impacts impose various costs including polluted surface and ground water, contaminated drinking water, increased flooding and flood control costs, wildlife habitat damage, reduced fish stocks, loss of unique natural features, and aesthetic losses.

---

[1] Chester Arnold and James Gibbons (1996), "Impervious Surface Coverage: The Emergence of a Key Environmental Indicator," *American Planning Association Journal*, Vol. 62, No. 2, (www.planning.org), Spring, pp. 243-258; EPA (1999), *Indicators of the Environmental Impacts of Transportation*, Center for Transportation and the Environment (www.itre.ncsu.edu/cte); Richard Forman, et al (2003), *Road Ecology: Science and Solutions*, Island Press (www.islandpress.com).

An estimated 46% of US vehicles leak hazardous fluids, including crankcase oil, transmission, hydraulic, and brake fluid, and antifreeze, as indicated by oil spots on roads and parking lots, and rainbow sheens of oil in puddles and roadside drainage ditches. An estimated 30-40% of the 1.4 billion gallons of lubricating oils used in automobiles are either burned in the engine or lost in drips and leaks, and another 180 million gallons are disposed of improperly onto the ground or into sewers.[2] Runoff from roads and parking lots has a high concentration of toxic metals, suspended solids, and hydrocarbons, which originate largely from automobiles.[3] Highway runoff is toxic to many aquatic species.[4] Table 5.15.3-1 shows pollution measured in roadway runoff.

Table 5.15.3-1 **Pollution Levels in Road Runoff Waters** (micrograms per litre)[5]

Pollutant	Urban	Rural	Pollutant	Urban	Rural
Total suspended solids	142.0	41.0	Nitrate + Nitrite	0.76	0.46
Volatile suspended solids	39.0	12.0	Total copper	0.054	0.022
Total organic carbon	25.0	8.0	Total lead	0.400	0.080
Chemical oxygen demand	114.0	49.0	Total zinc	0.329	0.080

Large quantities of petroleum are released from leaks and spills during extraction, processing, and distribution.[6] Road de-icing salts cause significant environmental and material damages.[7] Roadside vegetation control is a major source of herbicide dispersal.

Roads and parking facilities have major hydrologic impacts.[8] They concentrate stormwater, causing increased flooding, scouring and siltation, reduce surface and groundwater recharge which lowers dry season flows, and create physical barriers to fish. One survey found that 36% of 726 Washington State highway culverts interfere with fish passage, of which 17% were total blockages.[9] Reduced flows and plant canopy along

---

[2] Helen Pressley (1991), "Effects of Transportation on Stormwater Runoff and Receiving Water Quality," internal agency memo, Washington State Department of Ecology (www.ecy.wa.gov).

[3] R.T. Bannerman, et al (1993), "Sources of Pollutants in Wisconsin Stormwater," *Water Science Tech*. Vol. 28; No 3-5; pp. 247-259; Lennart Folkeson (1994), *Highway Runoff Literature Survey*, VTI (www.vti.se), #391; John Sansalone, Steven Buchberger and Margarete Koechling (1995), "Correlations Between Heavy Metals and Suspended Solids in Highway Runoff," *Transportation Research Record 1483*, TRB (www.trb.org), pp. 112-119.

[4] Ivan Lorant (1992), *Highway Runoff Water Quality, Literature Review*, Ontario Ministry of Transportation, Research and Development Branch, (www.mto.gov.on.ca/english), MAT-92-13.

[5] Eugene Driscoll, et al (1990), *Pollution Loadings and Impacts from Highway Stormwater Runoff*, Publication Number FHWA-RD-88-007, FHWA (www.fhwa.dot.gov). Also see Forman, et al, 2003.

[6] Peter Miller and John Moffet (1993), *The Price of Mobility,* NRDC (www.nrdc.org), p. 50.

[7] R. Field and M. O'Shea (1992), *Environmental Impacts of Highway Deicing Salt Pollution*, EPA/600/A-92/092; Gregory Granato, Peter Church & Victoria Stone (1996), "Mobilization of Major and Trance Constituents of Highway Runoff in Groundwater Potentially Caused by Deicing Chemical Migration," *Transportation Research Record 1483*, TRB (www.trb.org), pp. 92.

[8] OPW (1995), *Impervious Surface Reduction Study* (1995), Olympia Public Works (www.ci.olympia.wa.us).

[9] Tom Burns, Greg Johnson, Tanja Lehr (1992), *Fish Passage Program; Progress Performance Report for the Biennium 1991-1993*, Washington Dept. of Fisheries, WSDOT (www.wdfw.wa.gov).

roads can increase water temperatures. These impacts reduce wetlands and other wildlife habitat, degrade surface water quality, and contaminate drinking water. Hydrologic impacts can be as harmful to natural environments as toxic pollutants.[10] Ebrahimian, Gulliver and Wilson, develop a method for measuring "effective" impervious area (EIA), which refers to the portion of total impervious area that is hydraulically connected to the storm sewer system, as opposed to areas where stormwater runoff flows into local ground or surface water.[11]

Quantifying these costs is challenging. It is difficult to determine how much motor vehicles and roads contribute to water pollution problems since impacts are diffuse and cumulative. Roadway runoff usually meets water quality standards, but some pollutants concentrate in sediments or through the food chain. Even if we know the quantity of pollutants originating from roads and motor vehicles, and their environmental effects, we face the problem of monetizing impacts such as loss of wildlife, reduced wild fish reproduction, and contaminated groundwater. New policies designed to reduce pollution, prevent fuel tank leaks, and internalize cleanup expenses may reduce some of these externalities. Consumers and industry are more aware of water pollution problems and so tend to reduce some emissions However, growing public value placed on water quality and increased vehicle use may increase total costs even if impacts per vehicle-mile decrease.

---

[10] Waste Management Group (1992), *Urban Runoff Quality Control Guidelines for the Province of British Columbia*, BC Ministry of Environment (www.gov.bc.ca/env), June 1992.

[11] Ali Ebrahimian, John S. Gulliver and Bruce N. Wilson (2015), *Determination of Effective Impervious Area in Urban Watersheds*, Center for Transportation Studies at the University of Minnesota (www.cts.umn.edu); at http://bit.ly/1V7BNDo.

5.15.4 Estimates:
Note: all monetary units in U.S. dollars unless indicated otherwise.

Summary Table
Table   5.15.4-1 **Water Costs Summary Table – Selected Studies**

Publication	Costs	Cost Value	2007 USD
Bray & Tisato (1998)	Pollution	$0.002 Aust. (1996)	$0.003/mile
Peter Bein (1997)	Pollution & Hydrologic	$0.02 Canadian/km*	$0.03/mile
Delucchi (2000)	Oil Pollution – US/yr.	0.4 to 1.5 billion (1991)	$0.06 – 2.3 billion
Chernick & Caverhill (1989)	Tanker spills	$0.10- 0.47per gallon of imported crude oil*	$0.17 – 0.79 per gallon
Douglass Lee (1995)	Oil Spills	$2 billion/yr*	$2.7 billion/yr
Murray and Ulrich (1976)	US road salt impacts	$4.7 billion/yr (1993)	$6.7 billion/yr
Nixon & Saphores (2007)	Leaking Tank Clean up in US	$0.8 - $2.1 billion/yr over 10 years	$0.8 - $2.1 billion/yr
	Highway runoff control in US	$2.9 to $15.6 billion/yr over 20 years	$2.9 to $15.6 billion/yr
Project Clean Water (2002)	US stormwater management fees	$3.13 - $76.78 per 1000 sq ft/yr*	$3.60 – 88.30 per 1000 sq ft/yr
Washington DOT (1992)	Stormwater quality and flood control	$75 to $220 million/yr*	$111 to 326 million/yr
Environment Canada (2006)	Compensation for road salt contamination.	$10,000 Canadian per well per year*	$9083 per well per year

*More detailed descriptions of these studies are found below, along with summaries of other studies. 2007 Values have been adjusted for inflation by Consumer Price Index. * Indicates that the currency year is assumed to be the same as the publication year.*

Water Pollution & Combined Estimates

- The California Energy Commission estimates major petroleum oil spill (such as the Exxon Valdez) costs at 0.4¢ per gallon of gasoline, or about 0.02¢ per mile.[12]

- Australian researchers estimate motor vehicle water pollution averages 0.2¢ 1996 AUS. (0.12¢ U.S.) per vehicle kilometer.[13]

- Research by the B.C. Ministry of Transportation and Highways estimates that water pollution and hydrologic impacts from motor vehicles and their facilities average at least 2¢ (Canadian) per vehicle kilometer.[14]

---

[12] CEC (1994), *1993-1994 California Transportation Energy Analysis Report* (www.energy.ca.gov), p. 31.

[13] David Bray and Peter Tisato (1998), "Broadening the Debate on Road Pricing," *Road & Transport Research*, Vol. 7, No. 4, (www.arrb.com.au),Dec. 1998, pp. 34-45.

[14] Dr. Peter Bein (1997), *Monetization of Environmental Impacts of Roads*, Planning Services Branch, B.C. Ministry of Transportation and Highways (www.gov.bc.ca/tran); at www.geocities.com/davefergus/Transportation/0ExecutiveSummary.htm

- Delucchi estimates that leaking motor-fuel storage tanks, large oil spills and urban runoff by oil from motor vehicles imposes environmental costs of 0.4 to 1.5 billion 1991 U.S. dollars, or about 0.05¢ per vehicle mile, using the mid-point value.[15]

- Paul Chernick and Emily Caverhill estimate average petroleum marine oil spill costs by multiplying Exxon Valdez cleanup costs by 5 (because the cleanup only collected 20% of total oil released), for an estimated cost of $6.4 billion, or $582 per gallon spilled.[16] They consider this estimate conservative:

    "While Exxon has been criticized for doing too little, and spending too little, we are not aware of any criticism of Exxon spending too much. If cleaning up 20% of the spill was worth $1.28 billion, cleaning up all the oil must have been worth more than $6.4 billion. The first barrel in the environment probably has greater impact than the last 20% (After all, each animal can only be killed once. The practical difference between pristine water and slightly polluted water is almost certainly greater than the difference between very polluted water and slightly more polluted water), so the value of cleaning up all the oil would probably be much higher than $6.4 billion."

    They cite estimates that oil tankers spill 0.02-0.11% of their contents with a cost of 10-47¢ per gallon of imported crude oil, based on $582 per gallon spilled. Because of uncertainty concerning whether such costs are transferable the authors use only 2.6¢ per gallon for electrical generation sprawl costs. A 1994 jury awarded $5 billion in Valdez spill damages, which in addition to the $3 billion Exxon claims to have spent on cleanup implies total costs greater than $8 billion, since the legal judgment does not compensate for all damages, particularly ecological damages. This estimate implies costs greater than $728 per gallon of spilled oil.

- Jacob and Lopez calculated how land use development density affects stormwater runoff volumes, and the amount of phosphorous, nitrogen and suspended solid water pollution.[17] They found that these impacts increased with density measured per acre but declined per capita. For a constant or given population higher density urban development patterns tend to dramatically reduce loadings compared with diffuse suburban densities. The model showed that doubling standard suburban densities [to 8 dwelling units per acre (DUA) from about 3 to 5 DUA] in most cases could do more to reduce contaminant loadings associated with urban growth than many traditional stormwater best management practices (BMPs), and that higher densities such as those associated with transit-oriented development outperform almost all traditional BMPs, in terms of reduced loadings per capita.

---

[15] Mark Delucchi (2000), "Environmental Externalities of Motor-Vehicle Use in the US," *Journal of Transportation Economics and Policy*, Vol. 34, No. 2, (www.bath.ac.uk/e-journals/jtep), May, pp. 135-168.

[16] Paul Chernick and Emily Caverhill (1989), *Valuation of Externalities from Energy Production, Delivery and Use*, Boston Gas Company (Boston), p. 85.

[17] John S. Jacob and Ricardo Lopez (2009), "Is Denser Greener? An Evaluation Of Higher Density Development As An Urban Stormwater-Quality Best Management Practice," *Journal of the American Water Resources Association* (JAWRA), Vol. 45, No. 3, pp. 687-701.

- Douglass Lee estimates annual uncompensated oil spills average $2 billion, totaling about 0.1¢ per VMT.[18]

- Yen and Bras estimate the water consumption required for various transport modes and fuels.[19] According to their analysis, vehicles powered by locally produced biofuels and electricity (assuming average local grid mix) consume more water than locally refined gasoline and CNG-powered vehicles. Improvements in power plant technologies, electricity generation (e.g., use of solar and wind versus hydro power) and vehicle efficiencies can reduce such water consumption significantly.

- King and Webber estimate the water intensity of various transport fuels measured as gallons of water consumed per mile traveled, as summarized in the figure below.
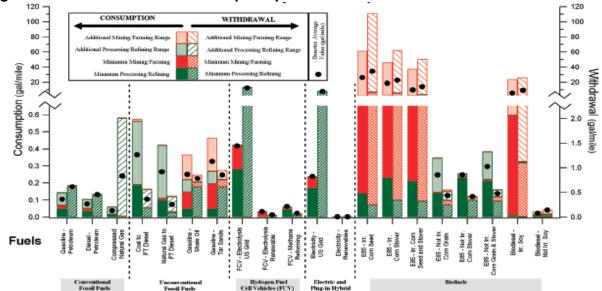
Figure   5.15.4-1   **Water Consumption per Mile For Various Modes and Fuels[20]**

Water consumption (left stacked bars read on left axis) and withdrawal (right stacked bars read on right axis) in gallons of water per mile (gal/mile) for various fuels for light duty vehicles. Water use from mining and farming is designated differently from that used for processing and refining. Where a range of values exists (e.g., different irrigation amounts in different states), a minimum value is listed with an 'additional range'. Otherwise, the values plotted are considered average values. Irr.) irrigated, Not Irr.) not irrigated, FT) Fischer-Tropsch, FCV) fuel cell vehicle, U.S. Grid) electricity from average U.S. grid mix, and Renewables) renewable electricity generated without consumption or withdrawal of water (e.g., wind and photovoltaic solar panels).

---

[18] Douglass Lee (1995) *Full Cost Pricing of Highways*, USDOT, National Transportation Systems Center (www.volpe.dot.gov), p. 21.

[19] Jeff Yen and Bert Bras (2012), "A System Model For Assessing Vehicle Use-Phase Water Consumption In Urban Mobility Networks," *Energy Policy*, Vol. 51, pp. 474-492; http://dx.doi.org/10.1016/j.enpol.2012.08.052.

[20] Carey W. King and Michael E. Webber (2008), "Water Intensity of Transportation," Environmental Science & Technology, Vol. 42, No. 21, pp. 7866-7872; at http://pubs.acs.org/doi/abs/10.1021/es800367m.

- Nixon and Saphores examine motor vehicle impacts on non-point groundwater water pollution, including sediments from road construction and erosion, oils and grease, heavy metals (from car exhaust, tires, engine parts, brake pads, rust and antifreeze), road salts and fertilizers, pesticides and herbicides used on roadways.[21] They estimate the present value of cleaning up leaking underground storage tanks and controlling highway runoff for major U.S. roads ranges from $45-235 billion (2002 dollars). Their monetized estimate only includes a portion of the total water pollution impacts they identify since it excludes improper disposal of used oil, roadway sediments, salt, fertilizers, pesticides and herbicides. They recommend various incentives, information and enforcement measures to mitigate these impacts.

- Nixon and Saphores estimate that annualized costs of cleaning-up leaking underground storage tanks in the US would range from $0.8 billion to $2.1 billion per year over ten years. Annualized costs of controlling highway runoff from principal arterials in the US are estimated to range from $2.9 billion to $15.6 billion per year over 20 years. They assert that cleaning up water pollution from motor vehicles is much more expensive than prevention would be. [22]

- Transport 2021 estimates external water pollution costs from automobile use to be 0.2¢ Canadian per km, or 0.25¢ U.S. per VMT, based on a review of studies.[23]

- Motor vehicle emissions increase levels of PAHs (polycyclic aromatic hydrocarbons) in urban surface waters as much as 100 times higher than pre-urban conditions, poisoning aquatic wildlife and disturbing ecological systems.[24]

- One study estimates road salt imposes infrastructure costs of at least $615 per ton, vehicle corrosion costs of at least $113 per ton, aesthetic costs of $75 per ton applied near environmentally sensitive areas, plus uncertain human health costs.[25]

- Environment Canada (2006) estimates that the claims cost for a well contaminated by road salt is about $10,000 Canadian per year; and that soil contaminated by salt can be treated with gypsum for $473 per hectare per year. [26]

---

[21] Hilary Nixon and Jean-Daniel Saphores (2003), *Impacts of Motor Vehicle Operation on Water Quality: A Preliminary Assessment*, UC Irvine (www.uctc.net); at www.uctc.net/papers/671.pdf.

[22] Hilary Nixon and Jean-Daniel Saphores (2007), *Impacts of Motor Vehicle Operation on Water Quality in the United States -Clean-up Costs and Policies*, UCTC (www.uctc.net); at www.uctc.net/papers/809.pdf.

[23] KPMG (1993), *The Cost of Transporting People in the British Columbia Lower Mainland*, Transport 2021/Greater Vancouver Regional District (www.metrovancouver.org).

[24] Peter Van Metre, Barbara J. Mahler and Edward T. Furlong (2000), "Urban Sprawl Leaves Its PAH Signature," *Environmental Science & Technology* (http://pubs.acs.org/journals/esthag/),October.

[25] Donald Vitaliano (1992), "Economic Assessment of the Social Costs of Highway Salting," *Journal of Policy Analysis & Management*, Vol. 11, No. 3, (www.appam.org), pp. 397-418.

[26] EC (2006),*Winter Road Maintenance Activities and the Use of Road Salts in Canada: A Compendium of Costs and Benefits Indicators*, Environment Canada (www.ec.gc.ca); at www.ec.gc.ca/nopp/roadsalt/reports/en/winter.cfm#19

Storm Water, Hydrology and Wetlands

- The City of Bellingham charges stormwater management fees of $3 per month for smaller buildings (300-1,000 square feet impervious surface), and $5 per month per 3,000 square feet for larger buildings.[27] This indicates annualized costs of 2¢ to 5.5¢ per square foot ($20-55 per 1,000 square feet) of impervious surface.

- A USEPA study estimates that 310,000 to 570,000 acres of wetlands could have been lost during the construction of U.S. federal highways between 1955 and 1980, at a cost to replace of between $153 million and $6 billion.[28]

- Center for Watershed Protection research finds that various watershed enhancement strategies to protect greenspace and reduce impervious surfaces tend to be cost effective due to stormwater management savings and increased property values.[29]

- Some jurisdictions charge stormwater management fees, which typically range from $5 to $20 per 1,000 square feet (see table below). If motor vehicles require an average of 3,000 square feet of urban pavement (3 off-street parking spaces with 333 square feet of pavement, and twice this amount for roads),[30] these costs average $15-60 per vehicle-year, or 0.1¢ to 0.5¢ per vehicle mile.

Table 5.15.4-2   **Water District Funding Sources Based on Impervious Surface**[31]

Jurisdiction	Fee	Per 1000 Sq. ft. (Annual)	Per Parking Space (Annual)
Chapel Hill, NC	$39 annual 2,000 sq. ft.	$19.50	$6.50
City of Oviedo Stormwater Utility, FL	$4.00 per month per ERU	$15.00	$5.00
Columbia Country Stormwater Utility, GA	$1.75 monthly per 2,000 sq. ft.	$10.50	$3.50
Kitsap County, WA	$47.50 per 4,200 sq. ft.	$11.30	$4.00
Minneapolis, MN	$9.77 monthly per 1,530 sq. ft.	$76.78	$25.56
Raleigh, NC	$4 monthly per 2,260 sq. ft.	$18.46	$6.00
Spokane Country Stormwater Utility, WA	$10 annual fee per ERU.	$3.13	$1.00
Wilmington, NC	$4.75 monthly per 2,500 sq. ft.	$22.80	$7.50
Yakima, WA	$50 annual per 3,600 sq. ft.	$13.88	$6.50

"Equivalent Run-off Unit" or ERU = 3,200 square foot impervious surface.

- The Washington Department of Transportation estimates that meeting its stormwater runoff water quality and flood control requirements will cost $75 to $220 million a year in increased capital and operating costs, or 0.2¢ to 0.5¢ per VMT.[32]

---

[27] Bellingham (2001), *Storm and Surface Water Utility Fees*, City of Bellingham (www.cob.org)

[28] Apogee Research (1997), *Quantifying the Impacts of Road Construction on Wetlands Loss*, USEPA; Summarized in *Road Management Journal* (www.usroads.com); www.usroads.com/journals/p/rmj/9712/rm971203.htm.

[29] Tom Schueler (1999), *The Economics of Watershed Protection*, CWP (www.cwp.org).

[30] Todd Litman (2002), *Transportation Land Valuation*, VTPI (www.vtpi.org).

[31] Project Clean Water (2002), *Some Existing Water District Funding Sources*, Legislative and Regulatory Issues Technical Advisory Committee, Project Clean Water (www.projectcleanwater.org).

5.15.5 Variability
Water quality impacts are related to vehicle maintenance and use. Hydrologic impacts generally proportional to lane miles and parking supply.

5.15.6 Equity and Efficiency Issues
Water pollution emissions are an external cost, and therefore inequitable and inefficient.

5.15.7 Conclusion
Motor vehicles and roads impose a number of water quality and hydrologic costs, including pollution from fluid drips and particulates, flooding and other hydrologic impacts, petroleum spills, road salting, and habitat loss. No existing estimate incorporates all identified impacts. The WSDOT's cost estimate for meeting water quality standards for state highway runoff is notable because it alone exceeds most other estimates, implying that total water quality and hydrologic costs are substantial. The following is an estimate of *total* water pollution costs from roads and motor vehicles:

1. State highways account for approximately 5% of U.S. road miles, 10% of lane miles, and carry about 50% of VMT.[33] An estimated 300 million off-street parking spaces increase road surface area 30%, and 50% in urban areas.[34] This indicates that *state* highway runoff impacts can be conservatively estimated at one-third of *total* roadway impacts, so the middle value of WSDOT highway runoff mitigation cost estimates ($218) is tripled to include other roads, parking, and residual impacts ($218 x 3 = $655 million), and scaled to the U.S. road system ($655 x 50) for total annual national runoff costs of $33 billion.

2. Add Douglass Lee's estimate of oil spills ($2.7 billion).

3. Add Murray and Ulrich's estimate road salting costs ($6.7 billion).[35]

This totals $42 billion per year; divided by the approximately 3,000 billion miles driven annually in the US gives 1.4¢ per automobile mile.[36]

This estimate can be considered a lower-bound value because it excludes costs of residual runoff impacts, shoreline damage, leaking underground storage tanks, reduced groundwater recharge and increased flooding due to pavement. This cost is applied equally to all petroleum powered vehicles. Although it could be argued that buses require more road surface and consume more petroleum per mile, private vehicle owners are

---

[32] Entranco (2002), *Stormwater Runoff Management Report*, Washington DOT (www.wsdot.wa.gov).

[33] FHWA 1992, *Annual Statistics*, (www.fhwa.dot.org). Assuming that interstates, freeways and principal arterials represent state facilities, and other roads are locally owned.

[34] Commercial parking estimate from Douglass Lee (1993), *Full Cost Pricing of Highways*, Volpe Transportation Systems Center, p. 21. Assumes 250 parking spaces equal one lane mile.

[35] All monetary values have been adjusted for inflation to 2007 dollars as per Table 5.14.4-1 above.

[36] FHWA (2008), *April 2008 Traffic Volume Trends*, (www.fhwa.dot.gov/ohim/tvtw/tvtpage.htm).

more likely to allow their vehicles to drip and to dispose of used fluids incorrectly, so overall impacts are considered equal. Electric cars and trolleys are estimated to cause half the water pollution as an average automobile because they use few petroleum products, but still require roads and parking. Bicycling, walking and telework are not considered to impose significant water pollution cost.

Table 5.15.7-1 Estimate **Water Pollution Costs** (2007 US Dollars per Vehicle Mile)

Vehicle Class	Urban Peak	Urban Off-Peak	Rural	Average
Average Car	0.014	0.014	0.014	0.014
Compact Car	0.014	0.014	0.014	0.014
Electric Car	0.007	0.007	0.007	0.007
Van/Light Truck	0.014	0.014	0.014	0.014
Rideshare Passenger	0.000	0.000	0.000	0.000
Diesel Bus	0.014	0.014	0.014	0.014
Electric Bus/Trolley	0.007	0.007	0.007	0.007
Motorcycle	0.014	0.014	0.014	0.014
Bicycle	0.000	0.000	0.000	0.000
Walk	0.000	0.000	0.000	0.000
Telework	0.000	0.000	0.000	0.000

Automobile Cost Range: The Minimum is based on literature cited. The Maximum is the estimate developed above doubled to reflect costs not included in this estimate.

Minimum	Maximum
$0.002	$0.028

5.15.8 Information Resources
Information sources on water pollution and hydrologic impact evaluation are described below.

Chester Arnold and James Gibbons (1996), "Impervious Surface Coverage: The Emergence of a Key Environmental Indicator," *American Planning Association Journal*, Vol. 62, No. 2, Spring, pp. 243-258; at http://nemo.uconn.edu/publications/tech_papers/IS_keyEnvironmental_Ind.pdf.

Center for Watershed Protection (www.cwp.org).

Caltrans (2007), *Storm Water Quality Handbook - Project Planning and Design Guide*, California Department of Transportation (www.dot.ca.gov); at www.dot.ca.gov/hq/oppd/stormwtr/Final-PPDG_Master_Document-6-04-07.pdf.

Mikhail Chester and Arpad Horvath (2008), "Herbicides and Salting," Section 5.2.5, *Environmental Life-cycle Assessment of Passenger Transportation*, UC Berkeley Center for Future Urban Transport, (www.its.berkeley.edu/volvocenter/), Paper vwp-2008-2; at http://repositories.cdlib.org/its/future_urban_transport/vwp-2008-2.

CTE (1999), *Indicators of the Environmental Impacts of Transportation*, Center for Transportation and the Environment, USEPA (www.itre.ncsu.edu/cte).

Ali Ebrahimian, John S. Gulliver and Bruce N. Wilson (2015), *Determination of Effective Impervious Area in Urban Watersheds*, Center for Transportation Studies at the University of Minnesota (www.cts.umn.edu); at www.cts.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=2626.

Richard T.T. Forman, et al (2003), *Road Ecology: Science and Solutions*, Island Press (www.islandpress.com).

Howard Frumkin, Lawrence Frank and Richard Jackson (2004), "Water Quantity and Quality," *Urban Sprawl and Public Health: Designing, Planning, and Building For Healthier Communities*, Island Press (www.islandpress.org).

The Green Values Calculator (http://greenvalues.cnt.org) automatically evaluates the economic and hydrological impact of green versus conventional stormwater management.

Michael Greenberg, Henry Mayer, Tyler Miller, Robert Hordon and Daniel Knee (2003), "Reestablishing Public Health and Land Use Planning To Protect Public Water Supplies," *American Journal of Public Health*, Vol. 93, No. 9 (www.ajph.org), Sept. 2003, pp. 1522-1526.

John S. Jacob and Ricardo Lopez (2009), "Is Denser Greener? An Evaluation Of Higher Density Development As An Urban Stormwater-Quality Best Management Practice," *Journal of the American Water Resources Association* (JAWRA), Vol. 45, No. 3, pp. 687-701.

Carey W. King and Michael E. Webber (2008), "Water Intensity of Transportation," Environmental Science & Technology, Vol. 42, No. 21, pp. 7866-7872; at http://pubs.acs.org/doi/abs/10.1021/es800367m.

LGEAP, *Long-Term Hydrologic Impact Assessment (L-THIA) Model* (www.ecn.purdue.edu/runoff/lthianew), Local Government Environmental Assistance Program at Purdue University. Evaluates how land use changes affect groundwater and water pollution.

Todd Litman (2011), "Why and How to Reduce the Amount of Land Paved for Roads and Parking Facilities," *Environmental Practice*, Vol. 13, No. 1, March, pp. 38-46; http://journals.cambridge.org/action/displayJournal?jid=ENP. Also see *Pavement Busters Guide: Why and How to Reduce the Amount of Land Paved for Roads and Parking Facilities*, Victoria Transport Policy Institute (www.vtpi.org); at www.vtpi.org/pavbust.pdf.

Travis Madsen and Mike Shriberg (2005), *Waterways at Risk: How Low-Impact Development Can Reduce Runoff Pollution in Michigan*, PIRGIM Education Fund (www.pirgim.org); at http://pirgim.org/reports/waterwaysatrisk.pdf

Metro (2003), *Green Streets: Innovative Solutions for Stormwater and Stream Crossings*, Portland Metro (www.metro-region.org).

NALGEP (2003), *Smart Growth for Clean Water: Helping Communities Address the Water Quality Impacts of Sprawl*, National Association of Local Government Environmental Professionals (www.nalgep.org), Trust for Public Land, Eastern Research Group, EPA, and the U.S. Forest Service; at www.nalgep.org/publications/PublicationsDetail.cfm?LinkAdvID=42157

NEMO Project (http://nemo.uconn.edu) provides information on impervious surface impacts. Publications at http://nemo.uconn.edu/tools/impervious_surfaces/literature.htm.

Hilary Nixon and Jean-Daniel Saphores (2007), *Impacts of Motor Vehicle Operation on Water Quality in the United States -Clean-up Costs and Policies*, University of California Transportation Center (www.uctc.net); at www.uctc.net/papers/809.pdf

David Sample, et al. (2003), *Costs of Best Management Practices and Associated Land For Urban Stormwater Management*, USEPA (www.epa.gov); at www.epa.gov/ORD/NRMRL/pubs/600ja03261/600ja03261.pdf.

USEPA (2006), *Growing Toward More Efficient Water Use: Linking Development, Infrastructure, and Drinking Water Policies*, U.S. Environmental Protection Agency (www.epa.gov); at www.epa.gov/dced/water_efficiency.htm.

USEPA (2009), *WaterQuality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scales*, U.S. Environmental Protection Agency (www.epa.gov); at www.epa.gov/dced/pdf/2009_1208_wq_scorecard.pdf.

H.D. van Bohemen (2004), *Ecological Engineering and Civil Engineering Works*, Directorate-General of Public Works and Water Management (http://home.tudelft.nl/en/); at http://repository.tudelft.nl/file/80768/161791.