

## **5.15 Water Pollution and Hydrologic Impacts**

*This chapter describes water pollution and hydrologic impacts caused by transport facilities and vehicles.*

### **Definition**

*Water pollution* refers to harmful liquids released into the environment. *Hydrologic impacts* refers to changes in surface (streams and rivers) and groundwater flows.

### **Discussion**

Motor vehicles, roads and parking facilities are a major source of water pollution and hydrologic disruptions.<sup>1</sup> These include:

#### **Water Pollution**

- Crankcase oil drips and disposal.
- Road de-icing (salt) damage.
- Roadside herbicides.
- Leaking underground storage tanks.
- Air pollution settlement.

#### **Hydrologic Impacts**

- Increased impervious surfaces.
- Concentrated runoff, increased flooding.
- Loss of wetlands.
- Shoreline modifications.
- 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.

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.<sup>2</sup> Runoff from roads and parking lots have high concentrations of toxic metals, suspended solids, and hydrocarbons, which originate largely from automobiles.<sup>3</sup> Highway runoff is toxic to many aquatic species.<sup>4</sup> Table 5.15-1 shows pollution measured in roadway runoff.

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

<sup>2</sup> Helen Pressley, "Effects of Transportation on Stormwater Runoff and Receiving Water Quality," internal agency memo, Washington State Department of Ecology (Olympia), 1991.

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

<sup>4</sup> Ivan Lorant, *Highway Runoff Water Quality, Literature Review*, Ontario Ministry of Transportation, Research and Development Branch, MAT-92-13, 1992.

**Table 5.15-1 Pollution Levels in Road Runoff Waters (micrograms per litre)<sup>5</sup>**

| 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.<sup>6</sup> Road de-icing salts cause significant environmental and material damages.<sup>7</sup> Roadside vegetation control is a major source of herbicide dispersal.

Roads and parking facilities have major hydrologic impacts.<sup>8</sup> 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.<sup>9</sup> Reduced flows and plant canopy along 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.<sup>10</sup>

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 concern about water quality and increased vehicle use may increase total costs even if impacts per vehicle-mile decrease.

<sup>5</sup> Eugene Driscoll, et al, *Pollution Loadings and Impacts from Highway Stormwater Runoff*, Publication Number FHWA-RD-88-007, FHWA (Washington DC), April 1990. Also see Forman, et al, 2003.

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

<sup>7</sup> R. Field and M. O’Shea, Environmental Impacts of Highway Deicing Salt Pollution, EPA/600/A-92/092; Gregory Granato, Peter Church & Victoria Stone, “Mobilization of Major and Trace Constituents of Highway Runoff in Groundwater Potentially Caused by Deicing Chemical Migration,” *Transportation Research Record 1483*, 1996, pp. 92.

<sup>8</sup> *Impervious Surface Reduction Study*, City of Olympia Public Works (Olympia), May 1995.

<sup>9</sup> Tom Burns, Greg Johnson, Tanja Lehr, *Fish Passage Program; Progress Performance Report for the Biennium 1991-1993*, Washington Dept. of Fisheries, WSDOT (Olympia), Dec. 1992.

<sup>10</sup> Waste Management Group, *Urban Runoff Quality Control Guidelines for the Province of British Columbia*, BC Ministry of Environment, Environmental Protection Division (Victoria), June 1992.

## Estimates:

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

- A study by Apogee Research for the U.S. EPA concludes that that between about 310,000 and 570,000 acres of wetlands could potentially have been lost due to the construction of FAHP roads between 1955 and 1980, at a cost to replace of between \$153 million and \$6 billion.<sup>11</sup>
- 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.<sup>12</sup>
- Australian researchers estimate motor vehicle water pollution averages 0.2¢ 1996 AUS. (0.12¢ U.S.) per vehicle kilometer.<sup>13</sup>
- 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.<sup>14</sup>
- 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.<sup>15</sup> This indicates annualized costs of 2¢ to 5.5¢ per square foot (\$20-55 per 1,000 square feet) of impervious surface.
- 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.<sup>16</sup>
- Center for Watershed Protection research finds that various watershed enhancement strategies to protect greenspace and reduce impervious surfaces tend to be cost

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<sup>11</sup> Apogee Research, *Quantifying the Impacts of Road Construction on Wetlands Loss*, USEPA, Summarized in *Road Management Journal* ([www.usroads.com/journals/p/rmj/9712/rm971203.htm](http://www.usroads.com/journals/p/rmj/9712/rm971203.htm)), 1997.

<sup>12</sup> 1993-1994 *California Transportation Energy Analysis Report*, CEC, (Sacramento), Feb. 1994, p. 31.

<sup>13</sup> David Bray and Peter Tisato, "Broadening the Debate on Road Pricing," *Road & Transport Research*, Vol. 7, No. 4, Dec. 1998, pp. 34-45.

<sup>14</sup> Dr. Peter Bein, *Monetization of Environmental Impacts of Roads*, Planning Services Branch, B.C. Ministry of Transportation and Highways (Victoria, [www.th.gov.bc.ca/bchighways](http://www.th.gov.bc.ca/bchighways)), 1997.

<sup>15</sup> Bellingham, *Storm and Surface Water Utility Fees*, City of Bellingham ([www.cob.org/cobweb/pw/DRAINAGE/SSWU\\_RateInfo.pdf](http://www.cob.org/cobweb/pw/DRAINAGE/SSWU_RateInfo.pdf)), 2001.

<sup>16</sup> Mark Delucchi, "Environmental Externalities of Motor-Vehicle Use in the US," *Journal of Transportation Economics and Policy*, Vol. 34, No. 2, May 2000, pp. 135-168.

effective due to stormwater management cost savings and increased property values.<sup>17</sup>

- 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.<sup>18</sup> 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, for an estimated cost of 10-47¢ per gallon of imported crude oil, based on \$582 per gallon. However, because of uncertainty concerning the application of this spill to other situations the authors use only 2.6¢ per gallon to represent this cost for electrical generation impacts. 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 non-market damages. This estimate implies costs greater than \$728 per gallon of spilled oil.

- Douglass Lee estimates annual uncompensated oil spills average \$2 billion, totaling about 0.1¢ per VMT.<sup>19</sup>
- Miller and Moffet cite leaking storage tanks, oil spills, and road deicing costs to estimate annual automobile water pollution costs at \$3.8 billion, or 0.2¢ per VMT.<sup>20</sup>
- Murray and Ulrich estimate road salting costs at \$4.7 billion (in 1993 dollars).<sup>21</sup>

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<sup>17</sup> Tom Schueler, *The Economics of Watershed Protection*, CWP ([www.cwp.org](http://www.cwp.org)) 1999.

<sup>18</sup> Paul Chernick and Emily Caverhill, *Valuation of Externalities from Energy Production, Delivery and Use*, Boston Gas Company (Boston), Dec. 1989, p. 85.

<sup>19</sup> *Full Cost Pricing of Highways*, USDOT, National Transportation Systems Center (Cambridge), p. 21.

<sup>20</sup> *The Price of Mobility*, National Resources Defense Council (Washington DC), Oct. 1993, p.50.

<sup>21</sup> Murray & Ulrich, *Economic Assessment of the Environmental Impact of Highway Deicing*, EPA 1976.

- 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.<sup>22</sup> 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.
- 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.
- 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.<sup>23</sup>
- 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),<sup>24</sup> these costs average \$15-60 per vehicle-year, or 0.1¢ to 0.5¢ per vehicle mile.

**Table 5.15-2 Water District Funding Sources Based on Impervious Surface<sup>25</sup>**

| Jurisdiction                           | Fee                              | Per 1000 Sq. ft. (Annual) | Per Parking Space (Annual) |
|--|----------------------------------|---------------------------|----------------------------|
| Chaple 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 County 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.

<sup>22</sup> Hilary Nixon and Jean-Daniel Saphores, *Impacts of Motor Vehicle Operation on Water Quality: A Preliminary Assessment*, School of Civil & Environmental Engineering, UC Irvine ([www.uctc.net](http://www.uctc.net)), 2003.

<sup>23</sup> Peter Van Metre, Barbara J. Mahler and Edward T. Furlong, “Urban Sprawl Leaves Its PAH Signature,” *Environmental Science & Technology*, October 2000.

<sup>24</sup> Todd Litman, *Transportation Land Valuation*, Victoria Transport Policy Institute ([www.vtpi.org](http://www.vtpi.org)), 2002.

<sup>25</sup> Project Clean Water, *Some Existing Water District Funding Sources*, Legislative and Regulatory Issues Technical Advisory Committee, Project Clean Water ([www.projectcleanwater.org](http://www.projectcleanwater.org)), 2002.

- 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.<sup>26</sup>
- 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.<sup>27</sup>

### Variability

Water quality impacts are related to vehicle maintenance and use. Hydrologic impacts of stormwater depend on the amount of paved surface, so impacts are generally proportional to lane miles.

### Equity and Efficiency Issues

Water pollution emissions are an external cost, and therefore inequitable and inefficient.

### 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.<sup>28</sup> An estimated 300 million off-street parking spaces increase road surface area 30%, and 50% in urban areas.<sup>29</sup> 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 (\$147.5) is tripled to include other roads, parking, and residual impacts (\$147.5 x 3 = \$442.5 million), and scaled to the U.S. road system (\$442.5 x 50) for a total annual national runoff cost of \$22 billion.
2. Add Douglass Lee's estimate of oil spills (\$2 billion).
3. Add Murray and Ulrich's estimate road salting costs (\$4.7 billion)

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<sup>26</sup> Entranco, *Stormwater Runoff Management Report*, Washington DOT (Seattle), 1992.

<sup>27</sup> Donald Vitaliano, "Economic Assessment of the Social Costs of Highway Salting," *Journal of Policy Analysis & Management*, Vol. 11, No. 3, 1992, pp. 397-418.

<sup>28</sup> FHWA Annual Statistics, 1992, assuming that interstates, freeways and principal arterials represent state facilities, and other roads are locally owned.

<sup>29</sup> Commercial parking estimate from Douglass Lee, *Full Cost Pricing of Highways*, Volpe Transportation Systems Center ([www.volpe.dot.gov](http://www.volpe.dot.gov)), 1993, p. 21. Assumes 250 parking spaces equal one lane mile.

This totals \$29 billion per year, or about 1.3¢ per automobile mile. Note that this estimate excludes costs of residual runoff, shoreline damage, leaking underground storage tanks, reduced groundwater recharge and increased flooding due to pavement, so it is considered a conservative value. 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 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.

**Estimate Water Pollution Costs (1996 U.S. Dollars per Vehicle Mile)**

| Vehicle Class        | Urban Peak | Urban Off-Peak | Rural | Average |
|----------------------|------------|----------------|-------|---------|
| Average Car          | 0.013      | 0.013          | 0.013 | 0.013   |
| Compact Car          | 0.013      | 0.013          | 0.013 | 0.013   |
| Electric Car         | 0.007      | 0.007          | 0.007 | 0.007   |
| Van/Light Truck      | 0.013      | 0.013          | 0.013 | 0.013   |
| Rideshare Passenger  | 0.00       | 0.00           | 0.00  | 0.00    |
| Diesel Bus           | 0.013      | 0.013          | 0.013 | 0.013   |
| Electric Bus/Trolley | 0.007      | 0.007          | 0.007 | 0.007   |
| Motorcycle           | 0.013      | 0.013          | 0.013 | 0.013   |
| Bicycle              | 0.00       | 0.00           | 0.00  | 0.00    |
| Walk                 | 0.00       | 0.00           | 0.00  | 0.00    |
| Telework             | 0.00       | 0.00           | 0.00  | 0.00    |

**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  
\$0.001

Maximum  
\$0.026

## Information Resources

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

Caltrans (2002), *Storm Water Quality Handbook: Stormwater Pollution Prevention and Water Pollution Control*, CalTrans ([www.dot.ca.gov/hq/oppd/stormwtr/PPDG-stormwater-2002.pdf](http://www.dot.ca.gov/hq/oppd/stormwtr/PPDG-stormwater-2002.pdf)).

Chester Arnold and James Gibbons (1996), “Impervious Surface Coverage: Emergence of a Key Environmental Indicator,” *American Planning Association Journal*, Vol. 62, No. 2, Spring, pp. 243-258.

Center for Watershed Protection ([www.cwp.org](http://www.cwp.org)).

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

*Environmental Valuation Reference Inventory* ([www.evri.ca](http://www.evri.ca)) is a searchable storehouse of empirical studies on the economic value of environmental benefits and human health effects. It is sponsored by a number of major North American and European organizations.

FHWA (1999), *The Environmental Guidebook*, Federal Highway Administration, FHWA-99-005 ([www.fhwa.dot.gov/environment/guidebook/index.htm](http://www.fhwa.dot.gov/environment/guidebook/index.htm)).

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

Howard Frumkin, Lawrence Frank and Richard Jackson (2004), *Urban Sprawl and Public Health: Designing, Planning, and Building For Healthier Communities*, Island Press ([www.islandpress.org](http://www.islandpress.org)). In particular, see chapter 7 “Water Quantity and Quality.”

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

LGEAP, *Long-Term Hydrologic Impact Assessment (L-THIA) Model* ([www.ecn.purdue.edu/runoff/lthianew](http://www.ecn.purdue.edu/runoff/lthianew)), Local Government Environmental Assistance Program at Purdue University. Internet tool evaluates how land use changes are likely to affect groundwater recharge, stormwater drainage, and water pollution. Includes comprehensive bibliography.

Todd Litman (2002), *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](http://www.vtpi.org)); available at [www.vtpi.org/pavbust.pdf](http://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 (<http://pirgim.org/reports/waterwaysatrisk.pdf>).

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

Minneapolis (2005), *Minneapolis Stormwater Utility Fee*, ([www.ci.minneapolis.mn.us/stormwater/fee/Stormwater\\_FAQ.asp](http://www.ci.minneapolis.mn.us/stormwater/fee/Stormwater_FAQ.asp)).

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](http://www.nalgep.org)), Trust for Public Land, Eastern Research Group, EPA, and the U.S. Forest Service. Based on the experiences of communities across the nation, this report highlights case studies and innovative approaches to help local government officials implement smart growth programs in their communities that can address various water quality challenges.

*NEMO Project* (<http://nemo.uconn.edu>) provides information on impervious surface economic and environmental impacts.

Reed Noss (1995), *Ecological Effects of Roads; or The Road To Destruction*, Wildland CPR ([www.wildrockies.org](http://www.wildrockies.org)).

David Sample, et al. (2003), *Costs of Best Management Practices and Associated Land For Urban Stormwater Management*, U.S. Environmental Protection Agency ([www.epa.gov/ORD/NRMRL/pubs/600ja03261/600ja03261.pdf](http://www.epa.gov/ORD/NRMRL/pubs/600ja03261/600ja03261.pdf)).

USEPA (1999), *Indicators of the Environmental Impacts of Transportation*, Office of Policy and Planning, USEPA ([www.itre.ncsu.edu/cte](http://www.itre.ncsu.edu/cte)).

USEPA (2006), *Growing Toward More Efficient Water Use: Linking Development, Infrastructure, and Drinking Water Policies*, Development, Community, and Environment Division (DCED); U.S. Environmental Protection Agency ([www.epa.gov](http://www.epa.gov)).

H.D. van Bohemen (2004), *Ecological Engineering and Civil Engineering Works: A Practical Set Of Ecological Engineering Principles For Road Infrastructure And Coastal Management*, Delft University of Technology, Road and Hydraulic Engineering Institute, Directorate-General of Public Works and Water Management, Delft, Netherlands (<http://repository.tudelft.nl/file/80768/161791>).

VTPI (2002), "Land Use Evaluation," *Online TDM Encyclopedia*, VTPI ([www.vtpi.org/tdm/tdm104.htm](http://www.vtpi.org/tdm/tdm104.htm)).