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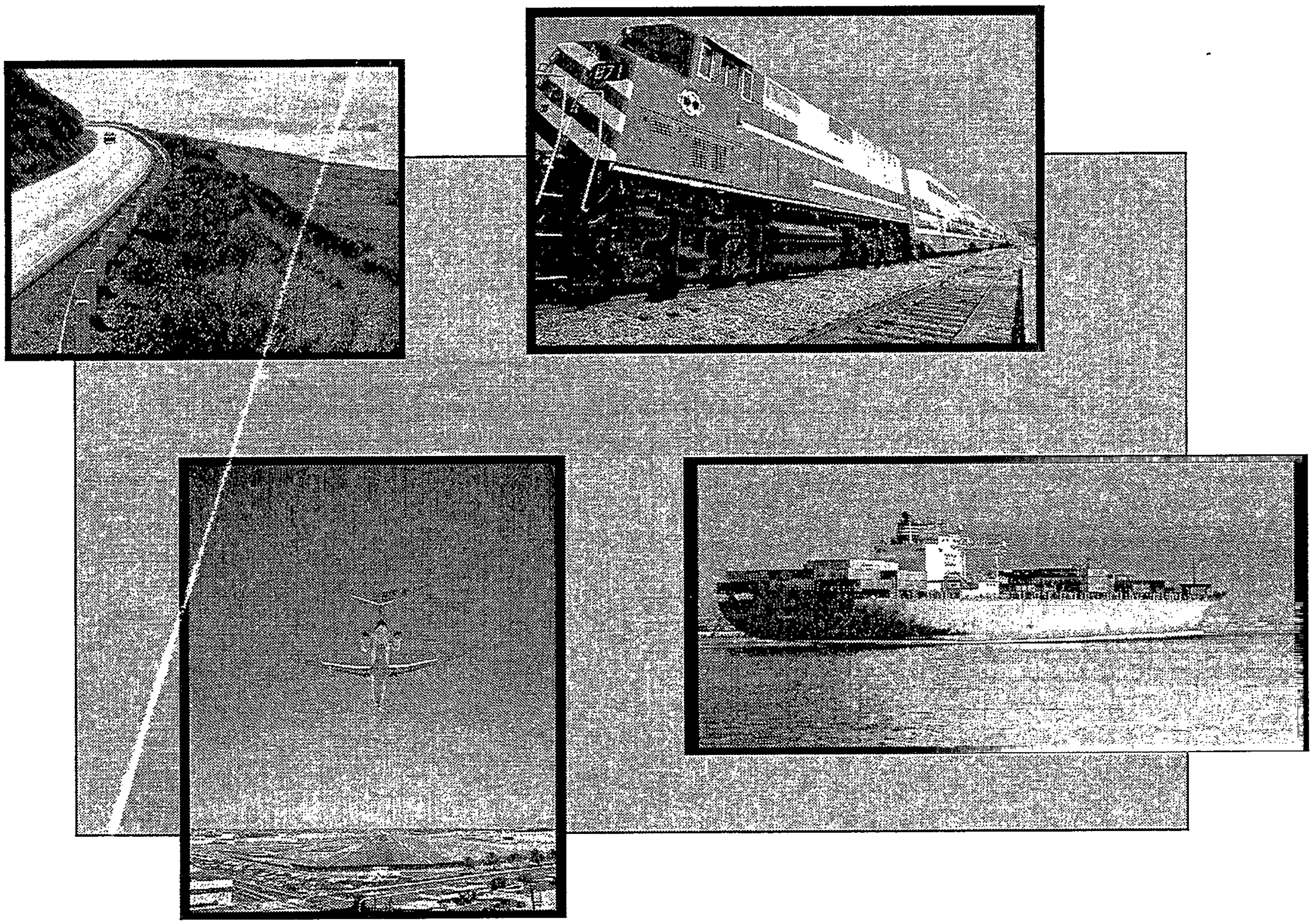
Indicators of the Environmental Impacts of Transportation

Highway, Rail, Aviation, and Maritime Transport



FOREWORD

This document presents quantitative national estimates of the magnitude of transportation's impacts on the natural environment. It is the most comprehensive compilation of environmental and transportation data to date. This document addresses *all primary modes of transportation* (highway, rail, aviation, and maritime transport) and *all environmental media* (air, water, and land resources), and covers the *full "life-cycle"* of transportation, from construction of infrastructure and manufacture of vehicles to disposal of vehicles and parts. The information presented in this report highlights that the impacts of transportation are multi-media and extend beyond the air quality impacts of vehicle travel.

In addition to presenting quantitative data, this report presents a framework for developing various types of indicators and for categorizing transportation activities that affect the environment. This framework is useful for understanding the limitations and uses of different types of indicators and for identifying existing data gaps. In some cases, where quantified indicators were not available from existing sources, new indicators were developed for this report. In other cases, it is clear that significant gaps in knowledge remain. The report concludes with a description of next steps in the effort to develop and utilize indicators of the environmental impacts of transportation.

The development of this report involved cooperative work between EPA and DOT/BTS in collecting data, and addresses issues on which these and other agencies can continue to collaborate to develop tools for measuring and modeling impacts. This report was prepared under contract for the United States Environmental Protection Agency, Office of Policy, Planning, and Evaluation by Mark Corrales, Michael Grant, and Evelyn Chan of Apogee Research, Inc.

This report is part of a series on transportation and the environment issued by the Office of Policy, Planning, and Evaluation. Additional information can be obtained by calling 202-260-4034.

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EXECUTIVE SUMMARY

INTRODUCTION AND PURPOSE

In early 1995, the Environmental Protection Agency (EPA) initiated a study to develop environmental indicators for the transportation sector. The purpose of this report is the following:

1. Develop a logical framework for thinking about indicators
2. Identify and categorize the full range of environmental impacts of transportation
3. Develop indicators of these impacts
4. Quantify the impacts at the national level, using the indicators
5. Assess data gaps and recommend next steps

This report presents the most comprehensive compilation of environmental and transportation data to date. The term "indicators" is used throughout this report to refer to quantitative estimates of the magnitude or severity of environmental impacts of transportation. These indicators may be based on either measurements or modeling and may refer to either historical or projected estimates.

This report addresses all four primary modes of transportation:

- Highway[1]
- Rail
- Aviation
- Maritime[2]

In addition, this report addresses all environmental media—air, water, and land resources. It covers the full "life-cycle" of transportation, from construction of infrastructure and manufacture of vehicles to disposal of vehicles and parts.

In addition to presenting quantitative data, this report presents a valuable framework for developing various types of indicators and categorizing transportation activities affecting the environment. It also identifies existing data gaps. The report concludes with a description of next steps in the effort to develop and utilize indicators of the environmental impacts of transportation.

ORGANIZATION OF THIS REPORT

The report is organized in the following sections:

- Study approach
- What indicators can and cannot provide
- Selecting appropriate indicators
- Categorizing the environmental impacts of transportation
- Indicators for highway, rail, aviation, and maritime transportation

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[1] In this report, the term "highway" is used to refer to mobile sources of travel on *all* roads, not only those in the National Highway System.
[2] In this report, the term "maritime" is used to refer to all mobile sources of travel on water, including ocean-going vessels, inland barges, and recreational boats.

- Next steps
- Bibliography
- Appendices on infrastructure and travel measures and additional statistics

Each is summarized briefly below.

STUDY APPROACH

This study may be viewed in the context of numerous related efforts to develop and utilize environmental indicators. Other such efforts generally have been limited, however, in that they have examined a smaller number of environmental issues (only air quality) or have focused on total environmental change rather than isolating transportation's share of that change.

This study is uniquely broad, since it covers several modes of transportation and all environmental media. It is an attempt to address a wide range of issues at a summary level.

This study has some important limitations as well:

LIMITATIONS OF THIS STUDY

- It provides only national estimates of impact, not local details.
- It is not a textbook on the environmental issues, although it describes each environmental impact briefly.
- It de-emphasizes the impacts of related infrastructure (gas stations, the petroleum industry, etc).
- Aesthetics/visual impacts, historic preservation, nonrenewable energy use, and social and community impacts are not included.
- Impacts of related development are not included here (impacts of new housing enabled by road construction).
- The benefits of travel are outside the scope of this study, although they should be weighed along with the environmental impacts of travel in a broader policy analysis.

The study's scope was limited to providing the following products, which correspond to the goals set out initially:

PRODUCTS OF THIS STUDY

1. Framework for indicators
2. Categories including all impacts
3. Indicators
4. Quantitative data
5. List of data gaps and recommended next steps

WHAT INDICATORS CAN AND CANNOT PROVIDE

In using indicators, it is important to keep in mind that they can be misapplied, and that care should be taken to consider what indicators can and cannot provide.

WHAT INDICATORS *CANNOT* OR *SHOULD NOT* DO

- Isolate effects of individual regulations

  Indicators may show improvement in a certain area (e.g., mobile source air emissions and air quality) but generally will not describe the root causes underlying that improvement. In other words, they may show the net results but not why the situation improved. For example, indicators may show falling air emissions, but these could result either from policy-driven per-mile emissions reductions or from reduced travel due to an economic downturn or rising fuel prices.

- Provide a full economic analysis

  In particular, indicators do not provide information about the benefits of travel and related activities. For example, deicing salt application has significant environmental impacts but it also has enormous benefits in allowing travel and saving lives during storms. Also, indicators say nothing about the costs of policies that might alleviate environmental impacts. Some solutions may be quite costly, and these costs should be balanced against the environmental impacts.

- Define acceptable levels of impact or rates of progress

  Indicators may describe objectively the amount of impact or rate of progress, but policy decisions must be made subjectively about whether a given impact or rate of progress is acceptable.

- Set true priorities

  Indicators of environmental impact alone should not be used for setting priorities for regulatory action. The cost-effectiveness of policy options should also be considered. This combines costs and benefits, whereas indicators of environmental impact describe only potential benefits of policies.

As long as these limitations are understood, indicators can be extremely useful in transportation and environmental policy discussions.

WHAT INDICATORS *CAN* BE USED FOR

- Provide broad perspective on transportation and environmental issues
- Encourage a comprehensive look at all environmental impacts
- Track progress of policies as a whole
- Highlight remaining problems
- Help set priorities, particularly for research and among issues needing new or improved policies
- Educate the public, media-focused offices, and others
- Feed into economic/policy analysis

SELECTING APPROPRIATE INDICATORS

One important goal of this study was to consider the types of indicators that would be most appropriate for tracking the environmental impacts of transportation. To do so, we first examined the limitations of commonly cited indicators and considered what an ideal indicator would look like. A framework was presented that demonstrates how indicators may be designed to focus on different stages of the link between transportation and the environment, from outputs to outcomes (see the graphic entitled "Causes and Effects of Transportation Activities"). Finally, the report highlighted data gaps that make the use of ideal indicators impossible at present, but point to areas where research would be most beneficial (see the graphic entitled "Data Availability").

In the process of de[illegible]ing ideal indicators and identifying data gaps, we noted several areas where the ideal is not available. This report, therefore, describes ideal indicators as long-term objectives requiring further data collection and modeling. The indicators actually quantified in the report are often simply measures of emissions or outputs, because data on outcomes were generally unavailable. In some cases, even emissions or habitat change data were not available, in which case the report cites measures of activities that lead to those emissions or habitat changes.

Many discussions of the impacts of transportation use activity measures rather than true indicators of environmental outcomes. For example, many reports cite vehicle-miles traveled (VMT) as an indicator of transportation's potential impacts on the environment. Such measures are seriously flawed for the purpose of assessing environmental impacts, however.

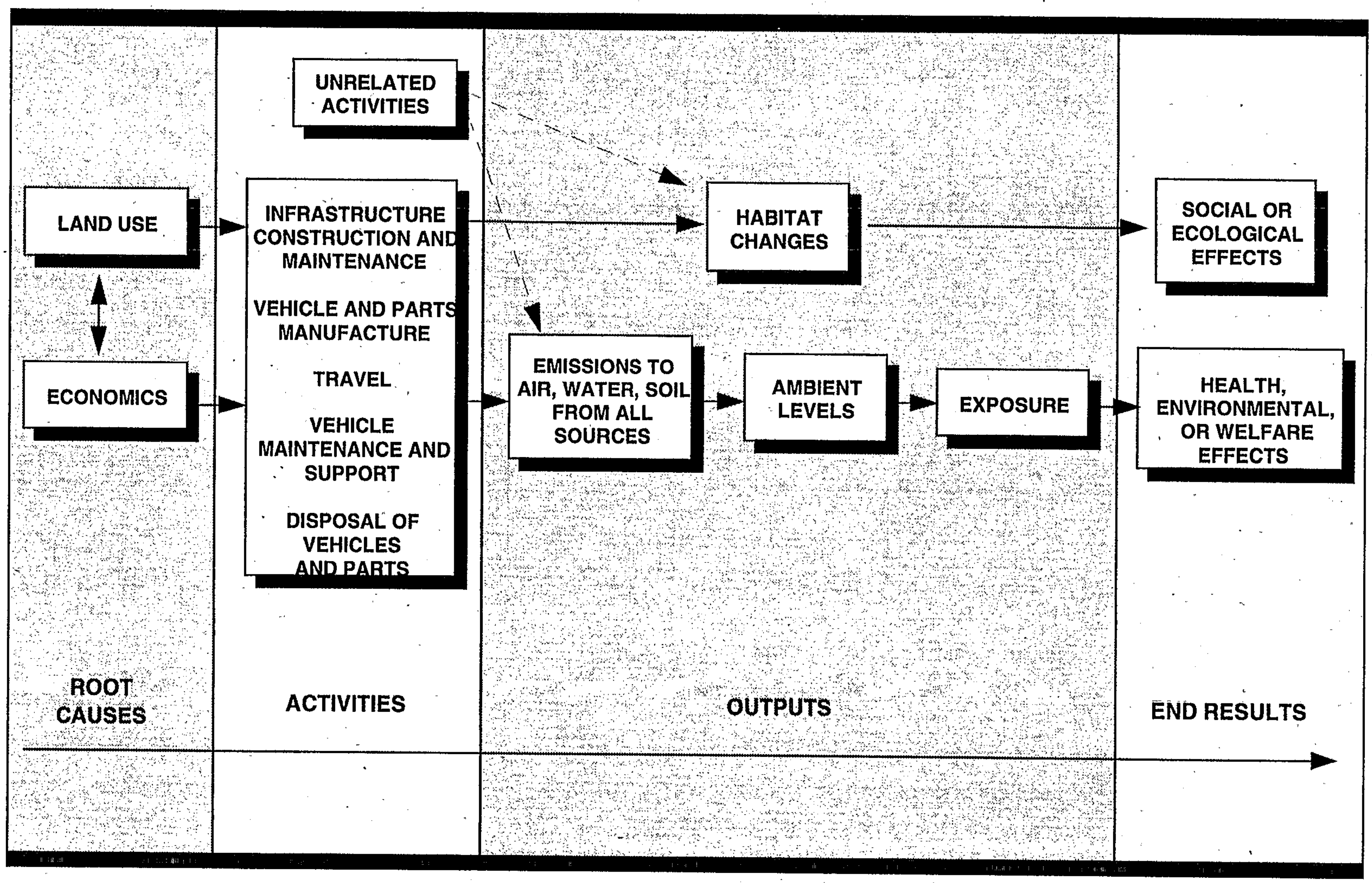
LIMITATIONS OF VMT AND OTHER COMMON MEASURES

- Results are more important to track than activities.
- Impacts per VMT or other activity measure vary a great deal by location.
- Impacts per VMT or other activity measure vary over time.
- Average impacts are not useful when one should be measuring marginal impacts (the effects of incremental increases in travel are marginal impacts; there may be thresholds or other circumstances so that the impact associated with additional VMT differs from the average impact per VMT).
- The benefits per passenger-mile traveled (PMT) or per ton-mile are not equal for all modes and locations.

As stated above, though, VMT and other activity measures may be the only relevant quantitative data providing perspective on certain impacts. This report refers to activity measures where necessary and discusses them further in an appendix.

This report also presents a framework for describing different types of indicators, based on the extent to which they address end results rather than activities. The framework, shown in the flow chart, suggests that an indicator may be designed to focus on activities (e.g., VMT), outputs such as emissions and habitat changes (e.g., tons of CO_2 emitted or acres paved), or outcomes/end results (e.g., number of illnesses caused by mobile source pollution). This framework is often used to emphasize the need for results-oriented measures. Again, this study made clear that such indicators are generally unavailable at present, and output measures must be used in the short term.

CAUSES AND EFFECTS OF TRANSPORTATION ACTIVITIES



Data Availability

Nationwide Estimates of Transportation's Environmental Impacts

Impacts on Media	Type of Indicator				
	Activities	Emissions	Ambient Levels/ Habitat Changes	Exposure	End Results (Health, Environmental, or Welfare Effects)
Air Pollution	●	●	●	●	○
Water Pollution	●	○	○	○	○
Waste Spills and Disposal	●	○	○	○	○
Habitat Modification	●	Not Applicable	○	Not Applicable	No Data

● Good indicators of transportation sector's impact available

○ Limited or weak data on transportation

○ Available data measures do not indicate transportation's share of total impact

We recommend that improved indicators be developed through data collection and modeling efforts, to reach the long-term goal of designing ideal indicators of transportation's environmental implications. The characteristics of indicators that should be developed over time are described below:

THE IDEAL INDICATOR

- Focuses on results (i.e., outcomes, such as number of illnesses caused, not activities or outputs, such as tons emitted)
- Isolates transportation's share of the impact
- Provides a useful level of detail to the intended audience
- Is stated in comparable units (allowing comparisons among impacts, modes, etc.)
- Is in meaningful units (i.e., the quantity is compared to a standard or goal)
- Is reasonably certain

These are the traits that should be sought in ongoing development of new indicators. For the purposes of this study, we have been able to design indicators that meet only some of these criteria. Most indicators in this study isolate transportation's share and provide sufficient detail at the national level. Many are not in comparable units (e.g., dollars) because of the additional analysis required and uncertainty introduced when dollar terms are used. The units are more meaningful if the quantities are compared with standards or goals, but such benchmarks are not yet available for most of these indicators. Additional work is needed to develop ideal indicators.

CATEGORIZING THE ENVIRONMENTAL IMPACTS OF TRANSPORTATION

An important contribution of this study is the relatively comprehensive nature of the list of environmental impacts. We have quantified a much wider range of impacts than is typically included in a single study. To do so, we utilized a categorization scheme that groups the impacts logically and encourages a broad perspective of the environmental implications of transportation. This scheme is based on grouping impacts by the activities that cause them rather than by environmental media, such as water and air. The advantage of this approach is that it follows the way data are collected and the way activities are commonly thought about and addressed in policy discussions. The five basic activities included are as follows:

BASIC TRANSPORTATION ACTIVITIES AFFECTING THE ENVIRONMENT

1. Infrastructure construction, maintenance, and abandonment (e.g., building roads)
2. Vehicle and parts manufacture
3. Vehicle travel
4. Vehicle maintenance and support
5. Disposal of used vehicles and parts

Within each of these five broad activities, several individual activities and their impacts are described.

THE INDICATORS FOR HIGHWAY, RAIL, AVIATION, AND MARITIME TRANSPORTATION

This report contains not only a listing of available indicators but also the values of those indicators for recent years. The body of the report contains these quantitative data and graphics, while the indicators are listed in tables below for each of the four modes.

It is important to note two points about what is included in these tables: First, indicators are listed only where they have been quantified at the national level; if an impact has not been quantified, no "potential" indicator is listed here. For each specific activity and its impact, the table provides a summary of the availability of quantitative data for indicators of outcomes, output, and activity.

Second, the tables show only the best indicator for each impact rather than listing alternative types of indicators. The exceptions are when multiple indicators are needed to address all aspects of an issue or where some indicators are otherwise insufficient. Although outcome indicators are theoretically the most desirable type of indicator, actual quantified outcome data are often unavailable or of poor quality. As a result, output indicators—such as emissions levels—tend to be the most reliable and valid measures available in most cases. Activity indicators are presented in these tables when they are the best available indicators or when outcome and output indicators are not adequate.

Summary of National Indicators Quantified: Highway Transportation

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
1. Road Construction and Maintenance				
Habitat disruption and land take for road and right-of-way	• States reporting highway-related wetland losses	• Cumulative land area covered by roads • New land area taken for roadway use	• New road mileage and lane mileage constructed.	National estimates of fragmentation and other impacts are not available. Some useful state data are available.
Emissions during construction and maintenance	• Percent of surface waters degraded from land development projects (not just highways)	• Changes in surrounding water quality conditions near typical construction site • States reporting contamination problems at maintenance facilities	• Acres sprayed with herbicide • Energy used in construction	Emissions result from use of heavy machinery, pesticide application, and discovery of hazardous material in the right-of-way.
Releases of deicing compounds	• States reporting degraded wetlands integrity due to salinity • States reporting road salting as a significant source of ground water contamination	(Data unavailable)	• Quantity of road salt used	Deicing creates costs in terms of installing corrosion protection features during bridge construction and maintenance. Data is available on the number of roadside trees killed per year due to salting typical road.
Highway runoff	• River miles, lakes, and ocean shore miles impaired by urban runoff (not just highways)	• Average pollutant concentrations of various metals, suspended solids, and toxic organics in road runoff • Quantity of oil and grease loading via road runoff	• Percentage of roads that are paved	Road runoff's share of pollutant loading to nearby water bodies has been estimated locally.
2. Motor Vehicle and Parts Manufacture				
Toxic releases and other emissions	(Data unavailable)	• Quantity of reported releases of toxic chemicals included in TRI database • Quantity of CO, NO_2, PM-10, TP, SO_2, VOC released to air		Impacts of imported products/components are not included in statistics.

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
3. Road Vehicle Travel				
Tailpipe and evaporative emissions	• Cases of chronic respiratory illness, cancer, headaches, respiratory restricted activity days, and premature deaths due to motor vehicle pollution	• Quantity of CO, NO_X, VOC, SO_2, PM, Pb, CO_2, CH_4, N_2O, Benzene, Butadiene, and Formaldehyde released		Health and welfare impacts have been estimated. Road transport's share of total national emissions and loadings to lakes and bays have also been estimated.
Fugitive dust emissions from roads	• Cases of chronic respiratory illness, asthma attacks, respiratory restricted activity days, and premature deaths due to particulates associated with motor vehicles	• Quantity of fugitive dust (PM-10) emitted		Health and welfare impacts have been estimated. Road transport's shares of total national emissions of fugitive dust and PM-10 have also been estimated.
Emissions of refrigerant agents from vehicle air conditioners	(Data unavailable)	• Quantity of CFCs, HFCs emitted from all sources • Percentage of emissions attributable to motor vehicles	• Quantify of CFCs consumed in autos	CFCs are being phased out.
Noise	• Percentage of population exposed to levels of roadway noise associated with health and other effects (1980 only)	• Typical noise emissions levels by vehicle type and road type		Since noise dissipates from its source, a national aggregate noise emissions level is not meaningful. Recent exposure estimates are not available.
Hazardous materials incidents during transport	(Data unavailable)	• Type and quantity of material reported released		Some of the quantity spilled is generally recovered, and is not a permanent release to the environment. Amount recovered is not measured.
Roadkill	• Approximate number of animals killed			

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
4. Motor Vehicle Maintenance and Support				
Releases during terminal operations: tank truck cleaning, maintenance, repair, and refueling	(Data unavailable)	• Quantity of VOCs emitted	• Number of terminals and types of materials used during terminal operations	
Releases during passenger vehicle cleaning, maintenance, repair, and refueling	(Data unavailable)	(Data unavailable)	• Percentage of transit agencies that wash bus fleets daily	
Leaking underground storage tanks (USTs) containing fuel	• States reporting leaking USTs to be a significant source of ground water contamination	• Number of confirmed releases from storage tanks	• Number of active petroleum USTs	Some of the quantity released is generally recovered or cleaned-up, and is not a permanent release to the environment. Amount recovered is not measured.
5. Disposal of Vehicles and Parts				
Scrappage of vehicles	(Data unavailable)	(Data unavailable)	• Number of vehicles scrapped, quantity of various materials in vehicle, percentage of mass landfilled	Percentage of all landfilled material is known.
Motor oil disposal	(Data unavailable)	(Data unavailable)	• Quantity of used motor oil improperly disposed	Improperly disposed oil's share of total motor oil disposed has also been estimated.
Tire disposal	(Data unavailable)	(Data unavailable)	• Quantity of used tires landfilled or stockpiled	Recovery/recycle rate for used tires and their share of the solid waste stream have also been estimated.
Lead-acid batteries disposal	(Data unavailable)	(Data unavailable)	• Quantity of lead-acid batteries discarded into municipal waste stream	Recovery/recycle rate for spent batteries and their share of lead and total tonnage in the solid waste stream have also been estimated.

Summary of National Indicators Quantified: Rail Transportation

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
1. Railway Construction, Maintenance, and Abandonment				
Habitat disruption and land take	(Data unavailable)	• Cumulative land area covered by surface track • New land area taken for track	• Track mileage constructed and abandoned • Number of rail stations	National estimates of habitat fragmentation and other impacts are not available. Rail track may be elevated, surface, or underground.
Emissions during construction and maintenance	(Data unavailable)	(Data unavailable)	• Number of crossties laid • Tons of rail laid	Creosote is a toxic preservant that is applied to rail crossties.
2. Rail Car and Parts Manufacture				
Toxic releases	(Data unavailable)	• Quantity of reported releases of toxic chemicals included in TRI database		Impacts of imported products/components are not included in statistics.
3. Rail Travel				
Exhaust emissions	(Data unavailable)	• Quantity of CO, NO_X, VOC, SO_2, PM-10, CO_2, CH_4, N_2O, and ammonia released		Rail's share of total national emissions has also been estimated.
Noise	• Percentage of population exposed to levels of roadway noise associated with health and other effects (1980 only)	• Typical noise emissions levels for trains		Since noise dissipates from its source, a national aggregate noise emissions level is not meaningful. Recent exposure estimates are not available.
Hazardous materials incidents during transport	(Data unavailable)	• Type and quantity of material reported released		Some of the quantity spilled is generally recovered, and is not a permanent release to the environment.

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
4. Rail Car Maintenance and Support				
Releases during terminal operations: car cleaning, maintenance, repair, and refueling	(Data unavailable)	• Quantify of VOCs emitted		Environmental effects of cleaning of rail tank interiors have not been quantified.
Emissions from utilities powering rail	(Data unavailable)	• Quantity of CO, NO_X, TP, SO_X, VOC, and Pb released	• Quantity of electricity consumed by rail	Rail's share of total national emissions from electric utilities has also been estimated.
5. Disposal of Rail Cars and Parts				
Rail car and parts disposal	(Data unavailable)	(Data unavailable)	• Quantity of new cars installed to replace those disposed	No information found on disposal of parts, oil, etc.

Summary of National Indicators Quantified: Aviation Transportation

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
1. Airport Construction, Maintenance, or Expansion				
Habitat disruption and land take	(Data unavailable)	(Data unavailable)	• Number of airports constructed • Length of runways constructed • Cumulative number of airports	Potential impacts on existing wetlands, vegetation, and wildlife habitat.
Emissions during construction and maintenance	(Data unavailable)	(Data unavailable)	• Number of airports constructed • Length of runways constructed	Construction related activities generally result in temporary visual, noise, air quality, erosion, water quality, and solid waste impacts.
Releases of deicing compounds	(Data unavailable)	• Percentage of urea discharged directly to surface waters	• Quantity of deicing agents used	Glycol and urea may mix with runway runoff and other local sources of stormwater resulting in overland flow, and release to surface waters.
Airport Runoff	(Data unavailable)	(Data unavailable)	• Cumulative number of airports • Number/percent of airports with paved runways	
2. Aircraft and Parts Manufacture				
Toxic releases	(Data unavailable)	• Quantity of reported releases of toxic chemicals included in TRI database	• Number of new jet aircraft delivered	Impacts of imported products/components are not included in statistics. Emissions of non-toxic air pollutants are unknown.

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
3. Aviation Travel				
High altitude emissions	(Data unavailable)	• Quantity of CO_2, CH_4, and N_2O released	• Fuel consumption	There are cases where fuel dumping in the atmosphere has occurred. For most pollutants, altitude of emissions is unknown, although damage is known to differ depending on altitude.
Low altitude/ground level emissions	(Data unavailable)	• Quantity of CO, NO_X, VOC, SO_2, PM, and butadiene released		For most pollutants, altitude of emissions is unknown.
Noise	• Percentage of population exposed to levels of aircraft noise associated with health and other effects	• Typical noise emissions levels by aircraft type during takeoff and landing		Improvements in aircraft design has reduced noise despite tremendous growth in airline traffic.
Hazardous material incidents during transport	(Data unavailable)	• Type and quantity of material reported released		Some of the quantity spilled is generally recovered, and is not a permanent release to the environment. Amount recovered is not measured.
4. Airport Operation				
Emissions from ground support equipment	(Data unavailable)	• Quantity of CO, NO_X, VOC, and PM released		
5. Disposal of Aircraft and Parts				
Airplane and parts disposal	(Data unavailable)	(Data unavailable)	• Number of aircraft ordered	Longevity of the airline fleet, exportation, and recycling result in relatively low rates of aircraft scrappage.

SUMMARY OF NATIONAL INDICATORS QUANTIFIED: MARITIME TRANSPORTATION

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
1. Construction and Maintenance of Navigation Improvements				
Direct deterioration of habitats and water quality from dredging or other navigation improvements	• States reporting dredging-related wetland losses	• Quantity of dredged material	• Commercially navigable channel mileage	Direct effects of navigation improvements vary widely with the scale and type of project. Physical impacts of one dredging project may cause little harm, while another may alter an ecosystem. The reported total amount of material dredged fluctuates among various sources.
Habitat disruption and contamination from disposal of dredged material	• States reporting disposal of dredged material as a source of direct wetlands losses	• Quantity of dredged material disposed at various sites (ocean, coastal waters) and used for various purposes (wetlands creation)		
Habitat disruption and land take for ports and marinas	(Data unavailable)	(Data unavailable)	• Number of U.S. ports and marinas	Allocating the amount of habitat loss caused by a port is difficult, because shoreline habitat losses may be caused by a wide variety of factors.
2. Manufacture of Maritime Vessels and Parts				
Toxic releases during manufacture of maritime vessels and parts	(Data unavailable)	• Quantity of reported releases of toxic chemicals included in TRI database		
3. Maritime Travel				
Air pollutant emissions	(Data unavailable)	• Quantity of CO, NO_X, VOC, SO_2, PM, CO_2, CH_4, and N_2O released		

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
Habitat disruption caused by wakes and anchors	(Data unavailable)	(Data unavailable)	(Data unavailable)	Given the highly local nature of this problem, national outcome indicators, and even output indicators are unavailable.
Introduction of nonnative species	(Data unavailable)	• Number of species introduced into the Great Lakes by vessels		Total environmental impacts caused by introduction of nonnative species are difficult to estimate, since effects may take an extremely long time to occur.
Hazardous materials incidents during transport	(Data unavailable)	• Quantity of oil and other hazardous wastes spilled in U.S. waters		
Wildlife collisions	• Numbers of certain endangered species killed by collisions with vessels	(Data unavailable)		No national indicators of animal losses from vessel collisions are available, but studies have been conducted for individual species.
Overboard dumping of solid waste	• Numbers of certain species killed by entanglement in plastic marine debris	(Data unavailable)	• Quantity of garbage generated by the maritime sector (amount disposed at sea is unknown)	
Sewage dumping	• Percentage of shellfish waters reported contaminated due to sewage dumping	(Data unavailable)	• Percentage of commercial vessels with on-board sanitation devices	
4. Maritime Vessel Maintenance and Support				
Releases of pollutants during terminal operations	(Data unavailable)	• Quantity of hazardous air pollutants emitted	• Number of marine repair establishments	
5. Disposal of Maritime Vessels and Parts				
Scrappage of old vessels and dilapidated parts	(Data unavailable)	(Data unavailable)	(Data unavailable)	Boat scrappage estimates are unavailable, but changes in fleet size may provide some information.

NEXT STEPS

There are several logical next steps in the effort to develop and utilize indicators of the environmental impacts of transportation. This study has taken initial steps in presenting a framework for the design of ideal indicators and a comprehensive list of impacts. It has also provided quantitative data on various impacts. There are still, however, considerable gaps in the data and analyses needed to fully describe indicators in this area. Next steps include the following:

- **Collect raw data or local data where needed**

  There are several areas in which local or state data exist but have never been aggregated at the national level. There are other areas in which raw data would have to be collected for development of indicators. Examples include the following:

  - Wetlands impacts
  - Habitat fragmentation and disruption from all modes
  - Hazardous materials entering the environment
  - Maritime terminal operation releases
  - Emissions during construction and maintenance of infrastructure
  - Leaking underground storage tank (LUST) releases attributable to transportation
  - Scrappage of aircraft, marine vessels, and rail cars/locomotives

- **Develop new estimates of certain impacts**

  National estimates of certain impacts have not been developed to date. In some cases, such estimates could be developed without the collection of additional raw data. Existing or new models could be applied to develop new national estimates of certain environmental impacts. In particular, new estimates of the following impacts are needed:

  - Emissions from road construction and paving
  - Impacts of and quantities of emissions from aircraft at high altitudes
  - Deicing runoff impacts on water quality
  - Quantities released from spills and leaks at airports
  - Other runoff impacts on water quality
  - Motor vehicle scrappage (tons disposed of, by material)
  - Noise exposure (updated estimates)
  - Roadkill (some data collection may be needed)

  At least two types of estimates should be developed:

  - Measures of emissions, loadings, or ambient levels, and
  - Actual health or welfare risks

- **Describe effectiveness of mitigation options**

  Various mitigation options, such as noise barriers, runoff detention ponds, and wetlands mitigation efforts, for example, have been studied to some extent. It would be useful to track the effectiveness of such efforts and the extent of their utilization in cases where more direct, accurate estimates of actual results are difficult to obtain.

- **Consider impacts not listed here**

  Environmental damage may be caused by several transportation-related activities not included in this study:

  - Gas stations, including auto repair and maintenance
  - Parking facilities (lots and garages)
  - Related land-use development patterns
  - Petroleum industry (transportation's share of these upstream impacts)
  - Steel industry (transportation's share of these upstream impacts)
  - Chemical industry (transportation's share of these upstream impacts)

- **Set up ongoing, consistent use of indicators**

  Implementing the findings and recommendations in this study will require an organized, broad initiative to begin using a consistent set of indicators. This effort should take into account the various state, federal, and private efforts to track the environmental impacts of transportation and use those data in the policy process.

- **Regularly update outdated, one-time estimates**

  Several of the indicators in this report have been quantified only once, or only sporadically in surveys or one-time modeling exercises. These estimates should be updated regularly. Examples of such outdated or one-time estimates that require updating include the following:

  - Noise exposure (especially for road travel)
  - Air toxic emissions during travel
  - Runoff (typical concentrations of pollutants in runoff)
  - Use of airport deicing agents

- **Conduct policy analysis**

  Now that this study has compiled data on environmental impacts, and as improved indicators are developed, they should be used to improve national policy understanding. This could entail several types of relatively modest studies, which could provide policy-relevant results.

  - Compare across modes, across media, across impacts
  - Compare with other environmental issues
  - Consider costs of policies

- **Provide state and local tools**

Ideally, further work would determine which impacts vary directly with VMT and which vary based on various other parameters. This work would essentially consist of developing true models to predict the magnitudes of various impacts, based on inputs such as VMT, temperature, or other causal factors such as those listed in the report. Some such models exist, such as the highway runoff predictive model, or noise models, but they do not exist for very many of these impacts. Also, the models typically require numerous site-specific inputs that are costly to collect. New models could be developed, perhaps for screening purposes.

I. STUDY APPROACH

INTRODUCTION AND PURPOSE

In early 1995, the Environmental Protection Agency (EPA) initiated a study to develop environmental indicators for the transportation sector. The purpose of this report is the following:

1. Develop a logical framework for thinking about indicators
2. Identify and categorize the full range of environmental impacts of transportation
3. Develop indicators of these impacts
4. Quantify the impacts at the national level, using the indicators
5. Assess data gaps and recommend next steps

This report presents the most comprehensive compilation of environmental and transportation data to date. The term "indicators" is used throughout this report to refer to quantitative estimates of the magnitude or severity of environmental impacts of transportation. These indicators may be based on either measurements or modeling, and may refer to either historical or projected estimates.

This report addresses all four primary modes of transportation:

- Highway[1]
- Rail
- Aviation
- Maritime[2]

In addition, this report addresses all environmental media—air, water, and land resources. It covers the full "life-cycle" of transportation, from construction of infrastructure and manufacture of vehicles to disposal of vehicles and parts.

In addition to presenting quantitative data, this report presents a valuable framework for developing various types of indicators and categorizing transportation activities affecting the environment. It also identifies existing data gaps. The report concludes with a description of next steps in the effort to develop and utilize indicators of the environmental impacts of transportation.

ORGANIZATION OF THIS REPORT

The report is organized in the following sections:

I. STUDY APPROACH
This section describes the study's goals and policy context. It also describes the study's scope and limitations.

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[1] In this report, the term "highway" is used to refer to mobile sources of travel on *all* roads, not only those in the National Highway System.
[2] In this report, the term "maritime" is used to refer to all mobile sources of travel on water, including ocean-going vessels, inland barges, and recreational boats.

II. WHAT INDICATORS CAN AND CANNOT PROVIDE

This section clarifies the purpose of developing environmental indicators of transportation's environmental impacts by describing how such indicators can and should be used. We emphasize, however, that there are certain types of analysis for which indicators are insufficient and should be used only with caution.

III. SELECTING APPROPRIATE INDICATORS

Many of the "indicators" commonly cited to gauge environmental impacts have significant limitations. This section discusses those shortcomings. We then present a framework for thinking about what types of indicators would be most appropriate. Ideal indicators are contrasted with available ones, and general data gaps are identified.

IV. CATEGORIZING THE ENVIRONMENTAL IMPACTS OF TRANSPORTATION

Transportation affects the environment in numerous ways. In this section, we present a scheme for categorizing the full range of activities making up the "transportation sector" and list the impacts resulting from each.

V. THE INDICATORS

In this section, we present the numbers. For each environmental impact, indicators are listed, with quantitative estimates. We also describe each impact briefly, and list the main causal factors and location-specific variables that determine the magnitude of the impact in a given location or in a specific year. This section covers highway, rail, aviation, and maritime indicators.

VI. NEXT STEPS

This section addresses the gaps in the current list of indicators. The need to collect data and develop estimates of certain impacts. The usefulness of setting up ongoing, consistent use of indicators is also discussed, along with the types of policy studies that could be conducted using these indicators.

BIBLIOGRAPHY

Selected references are included.

APPENDIX A. INFRASTRUCTURE AND TRAVEL MEASURES

This appendix provides a discussion of how indicators of infrastructure and travel activities are relevant to environmental indicators. Quantitative data are provided.

APPENDIX B. ADDITIONAL STATISTICS ON IMPACTS

This study uncovered a wide range of statistics that were not always ideal as indicators, but relevant and useful in providing additional perspective on various environmental impacts. Some of these statistics are provided in this section.

PRIOR AND RELATED EFFORTS

We view this study as part of a broad effort among decision makers, scientists, and the public to better understand and take into account environmental results. It may be helpful, therefore, to place this report in the context of the various prior and related efforts at developing environmental indicators or assessing the impacts of transportation.

Performance measurement has gained renewed attention across the public and private sectors in recent years. Several high profile reports, including the *National Performance Review* and *Reinventing Government,*[3] have stressed measuring the value of public programs in terms of the extent to which they are attaining goals. These reports and related initiatives have spurred further development and reporting of indicators. New requirements have also increased the attention given to indicators. OMB Circular A-11 requires that performance indicators be included in budget documents, and ISTEA mandates development and use of performance indicators related to air quality and other factors for assessment of the effects of the surface transportation system.[4]

It is clear that numerous types of indicators have been developed to track the effects of government programs or the status of environmental quality generally. This study differs from most or all of those efforts because it attempts to discern the environmental impacts of a single "sector". Rather than measuring the effects of a program or tracking environmental quality in general, we are attempting to isolate the effects of the set of activities and infrastructure that constitute the transportation sector.

In this study, we have drawn upon an enormous range of prior literature, including the following notable efforts:

- The OECD and others, including some states, have discussed or presented indicators of the environmental impacts of transportation.[5] These studies are useful because they demonstrate a pragmatic, local perspective or provide insightful discussions of conceptual issues in indicator design. Most of these reports, however, address a limited range of impacts (e.g., only air pollution) or offer simple activity-based measures (e.g., tonne-kilometers of hazardous waste transported).

- Performance measures for the National Transportation System are being developed by the U.S. Department of Transportation (DOT), and a recent report mentioned some environmental measures. The 34-page draft report, however, devoted merely 2 pages to environmental indicators, addressed a limited range of impacts and modes, and provided no actual numbers.[6] The DOT's Bureau of Transportation Statistics (BTS) has recently been working on environmental statistics.

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[3] See National Performance Review 1993. Also see Status Reports under the same name. Also, see Osborne, David, and Ted Gaebler, *Reinventing Government: How Entrepreneurial Spirit is Transforming the Public Sector*. Addison-Wesley: 1992.
[4] Section 6001(b)(3), in Title VI (Research) of the Intermodal Surface Transportation Efficiency Act of 1991.
[5] For example, see OECD, 1993; SRI International, 1993 for state efforts; and IndEco Strategic Consulting, Inc., 1995 for Canadian indicator development.
[6] Indicators are suggested in Cambridge Systematics, Inc. 1995b. A companion working paper, Cambridge Systematics 1995a, classifies environmental measures as "secondary" concerns that should be given less weight than the "primary" issues of economic and social impacts. This contradicts the Federal Highway Administration's Environmental Policy Statement (1994) which states, "Social, economic, and environmental issues must be considered equally...in reaching project decisions."

- The literature on the economic costs of transportation contains a significant amount of information on certain impacts, particularly air pollution's effects. Apogee Research's 1994 study, *The Costs of Transportation*, for example, reviews quantitative estimates of air pollution costs. These studies, however, generally address a limited range of environmental impacts and in less depth. Estimates given in dollar terms entail additional uncertainty and sometimes controversy compared with non-economic measures of these effects.

- Several detailed reviews of transportation's environmental impacts are available, providing thorough explanations of these impacts. We have chosen not to duplicate those discussions in this report. We have, however, drawn upon those reviews. For example, three books, *Highway Pollution*, *The Environmental Impact of Railways*, and *Ecological Risks of Highways*, provide useful discussions but few numbers.[7]

- Many studies are available which report on transportation's impacts for individual projects, including Environmental Impact Statements and Reviews (EISs and EIRs),[8] as well as academic papers. These provide a useful perspective on how impacts are determined by various location-specific parameters.

- Some reports generalize results to the national level but typically address only one impact (e.g., a review of highway runoff predictive models). These are useful for a more complete understanding of certain impacts.

In addition to these highly relevant studies, we also drew on other literature that covered environmental indicators more broadly. Some of these provide useful discussions of how indicators should be designed and point to available data sources. An important limitation to these, it should be noted, is that they do not isolate the environmental changes that result from a particular set of activities, such as travel. Some examples of such efforts include the following:

- Apogee Research recently prepared a *1995 Indicators Report* for EPA, a compilation of readily available environmental indicators organized according to environmental goals, such as clean water. The report includes graphics and statistical information on dozens of aspects of environmental quality.

- EPA's *Compendium of Selected National Environmental Statistics* and *Guide to Selected National Environmental Statistics in the Federal Government* are examples of recent efforts to disseminate data on several environmental media.[9]

- EPA is engaged in ongoing efforts to develop improved indicators of environmental quality, focused on results.[10] EPA also has a Center for Environmental Statistics in the Office of Policy, Planning, and Evaluation. EPA is furthermore leading the long-term Environmental

[7] Hamilton and Harrison, 1991; Carpenter, 1994; and Atkinson and Cairns in Cairns et al., 1992; respectively.
[8] For example, see FAA, 1990; U.S. DOT/FHWA and MD DOT, 1995; or U.S. DOT/FRA, 1994a.
[9] EPA databases are available on-line through the EPA web page at "www.epa.gov"
[10] For example, see EPA's 1995 report *Prospective Indicators for State Use in Performance Partnership Agreements.* Specific offices have initiatives as well: EPA's Office of Water created an Indicators Workgroup. Also see EPA's annual *Accompanying Report of the National Performance Review*, in which EPA cited the commitment to developing measurable environmental goals.

Monitoring and Assessment Program (EMAP). EPA's 1994 Strategic Plan articulates goals for the agency and a 1995 report addresses EPA's information resources management.[11]

- The Council on Environmental Quality (CEQ) has published widely read reports on the state of the environment for many years.[12] In 1991 CEQ convened an Interagency Committee on Environmental Trends. The Worldwatch Institute issues *State of the World* reports annually, with a global focus.[13] The United Nations and European Union also have major initiatives to collect and disseminate environmental data.[14]

- EPA's *National Water Quality Inventory* reports to Congress[15] summarize data from the states (required by the Clean Water Act Section 305(b)), covering topics such as the percentage of assessed river-miles meeting certain standards and the share of impairment attributable to certain broad types of causes (e.g., urban runoff). The Intergovernmental Task Force on Monitoring Water Quality has issued reports on more detailed measures of conditions.[16] Federal Status and Trends Programs are coordinated among numerous agencies and seek a nationwide strategy for monitoring environmental quality.

This study has drawn upon and taken into consideration all of these prior and ongoing efforts related to indicators and environmental impacts, but it has also attempted to build upon those efforts and go beyond them.

SCOPE OF STUDY

MULTIMODAL AND MULTIMEDIA

This study is unique in its attempt to quantify the full range of environmental impacts that result from transportation. Two features of the study are important. It is both multimodal and multimedia:

- *MULTIMODAL* – ALL MODES OF TRANSPORTATION[17]
  - Highway
  - Rail
  - Aviation
  - Maritime

[11] U.S. EPA, 1995h.
[12] Council on Environmental Quality, *Environmental Quality.*
[13]Worldwatch Institute, 1994.
[14] The U.N. has developed a core set of environmental indicators for sustainable development and has asked member countries to gather data in these common formats. The European Environment Agency, based in Denmark, issued a 600-page study called the Dobris Assessment, *Europe's Environment*, covering global and European data.
[15] U.S. EPA, 1994b.
[16]Intergovernmental Task Force on Monitoring Water Quality, September 1994.
[17] Transport by pipeline is sometimes included in such listings but is outside the scope of this study. Pipeline does carry a significant amount of material, however, and could be considered for analysis in a separate effort.

- *MULTIMEDIA* – ALL ENVIRONMENTAL MEDIA[18]

  - Air
  - Water
  - Waste (solid/hazardous)
  - Habitat

WHICH TYPES OF IMPACTS WERE EXCLUDED

Addressing all modes and all media already implies a vast scope. For this reason, we have chosen to limit the scope somewhat to emphasize the direct, short-run impacts of operating vehicles and the infrastructure that most directly supports them (e.g., highways, train tracks, airports, and ports). We have de-emphasized or excluded the indirect, upstream, downstream, and historical impacts. These emphases are summarized below with some examples of each type of impact.

IMPACTS EMPHASIZED

- **Direct impacts of travel and its key infrastructure** (e.g., hazardous materials incidents during transport, runoff of deicing compounds)
- **Short-run variable costs and certain ongoing costs** (impacts that are related to the amount of travel or other activities, such as construction and maintenance, and can be tracked on an annual basis; e.g., air pollutant emissions from vehicle operation)

IMPACTS DE-EMPHASIZED OR EXCLUDED

- **Impacts of other related infrastructure** (e.g., auto repair shops, shipyards)
- **Certain long-run costs, including some fixed costs** (e.g., no analysis of the historical destruction of wetlands and forests to build existing highways or the environmental benefits that would accrue if land use reverted to historical uses)
- **Upstream impacts** (e.g., some examination of the manufacture of vehicles, but not the raw inputs into that process, such as the impacts of the steel or chemical industry; very limited consideration of gasoline/oil refining[19])
- **Downstream impacts** (some consideration of the disposal of tires, waste oil, and vehicles, but not a full analysis of all disposal impacts)

[18] Habitat is listed as a separate category, despite the fact that it can be affected by air, water, or waste. "Habitat" here refers more to physical disruption of habitat through road construction, than to pollution of habitat. Likewise, waste can enter the air or water and affect habitat but is considered as its own category in this listing. These distinctions are not essential since these "media" are not used in the report as a major categorization scheme. Instead, we categorize impacts by activities that cause them, as discussed later.

[19] A number of sources provide information on the upstream impacts of fuel extraction, transportation, refining and distribution. U.S. EPA, 1995c, includes data on toxic releases from the petroleum refining industry; Ross, et al., 1995, provides information on upstream emissions of CO, HC, and NO_X per mile for Model Years 1993, 2000, and 2010 passenger cars; DeLuchi, 1991, provides data on upstream greenhouse gas emissions (CH_4, N_2O, NMOC, CO, NO_X, and CO_2), including emissions from materials manufacture and vehicle assembly, per mile.

- **Indirect impacts** (e.g., no analysis of the effects of industrial or residential development that arises near new roads/airports, effects on a natural area such as a lake when a road is built close to it)
- **Cultural, aesthetic, and some resource depletion issues** (No analysis of these impacts. The focus here is on pollution and habitat disruption. Cultural and aesthetic (e.g., visual)[20] impacts are more "social" effects than environmental, as defined here. Nonrenewable resource depletion (i.e., the use of oil) is not included because it does not damage the environment per se. We view it as a self-regulating economic phenomenon, where increasing shortages in oil would drive up prices and encourage more efficient use or a shift to alternatives. Depletion of living resources, on the other hand, such as forests or wetlands, is considered here as an impact on habitats.)

PRODUCTS OF THIS STUDY

The study's scope is limited to providing the following products, which correspond to the goals set out earlier:

1. Framework for indicators
2. Categories including all impacts
3. Indicators
4. Quantitative data
5. List of data gaps

LIMITATIONS OF STUDY

In addition to the bounds discussed above, this study has the following limitations:

- **NOT A PRIMER**
  This study does not provide a full introduction to the nature of each environmental impact. Primers are available elsewhere which thoroughly explain these impacts. For a complete explanation of how highways generate contaminated water runoff, for example, those other sources should be consulted.

- **NATIONAL ONLY**
  The study does not provide indicators or tools that can simply be applied at the local level to assess the environmental impacts of a single project or for a given urban area. Instead, national-level estimates are provided of the total impacts of transportation.

The text does, of course, provide basic introductions to these impacts and references to studies that can be used in local assessments.

[20] For information on visual impacts of highway projects, see DOT/FHWA, 1981.

II. WHAT INDICATORS CAN AND CANNOT PROVIDE

THE LIMITATIONS OF INDICATORS

Given the current level of interest in the use of indicators and performance measures, there is some risk that the benefits of indicators could be overemphasized. While very useful, indicators are more a tool than an answer to all policy questions, and can be misapplied if their limitations are not understood.

There are several important policy uses to which indicators cannot and should not be applied. They include the following:

WHAT INDICATORS *CANNOT* OR *SHOULD NOT* DO

- Isolate effects of individual regulations
- Provide a full economic analysis
- Define acceptable levels of impact or rates of progress
- Set true priorities

Each of these limitations is briefly explained below.

INDICATORS CANNOT ISOLATE THE EFFECTS OF INDIVIDUAL REGULATIONS

The indicators presented in this report describe the effects of all existing transportation infrastructure and activities and cannot isolate the effects that result from a single regulation or even set of regulations. In other words, the indicators are based on total costs rather than incremental or marginal costs of a particular requirement or activity.

When presented with total costs, one may be tempted to divide them by a measure of activity such as vehicle-miles traveled (VMT) and assume that this average impact is equivalent to a marginal impact. For example, if one chemical's total impact is 2 billion tons of pollution, the national average is about 1 ton per 1,000 VMT. This does not mean, however, that a policy that reduces VMT by 1,000 would reduce emissions by 1 ton. Speeds and many other local factors determine the effectiveness of any policy. In effect, the indicators represent the total environmental costs of transportation rather than the incremental or marginal costs of changes in level of activity or infrastructure. This issue is raised again in the discussion of selecting appropriate indicators. Unfortunately, one cannot accurately assess the effects of policies using most types of indicators.

INDICATORS CANNOT PROVIDE A FULL ECONOMIC ANALYSIS

Policy decisions must be based on a full range of criteria, including the costs and benefits of various options. Environmental indicators only describe an upper bound on the potential environmental benefits of additional policy efforts. They exclude several important pieces of information:

- **Costs of policies/Benefits of travel:** The environmental damage from transportation may constitute a substantial cost to society and the environment, but the costs of solving the problem may be large as well. Transportation provides great benefits which may be lost if policies restrict travel. Some statutes limit the extent to which costs can be considered in environmental protection decisions (e.g., ambient air quality standards are health-based, and the Delaney Clause in food and drug law requires protection of health at any cost). It is widely accepted, however, that costs are an important consideration in governmental decisions. Indicators provide no information on the cost of addressing an environmental impact.

- **Policy effectiveness:** How much of the environmental impact could actually be alleviated through feasible policy measures? It is unlikely that the entire harm described by the indicator could be removed through a single policy.
- **Other benefits of policies:** There are often non-environmental benefits to certain policies. For example, promoting walking may create a more livable neighborhood. This is not captured in an environmental indicator of pollution.

INDICATORS CANNOT DEFINE ACCEPTABLE LEVELS OF IMPACT OR RATES OF PROGRESS

Indicators that show "large" impacts may be interpreted as meaning that action must be taken to address a certain environmental problem. This would not be a completely accurate interpretation, at least according to the economist's view of the world. The neoclassical microeconomic argument would be that some level of pollution is acceptable. If the marginal cost of reducing the pollution is equal to the marginal cost of the pollution, then further reductions would cost more than they would be worth. It is possible that society is unwilling to improve environmental quality further in cases where it would be exceedingly costly to do so. Political factors, public opinion, and legal requirements all make the reality more complex than this simple economic argument would suggest, of course. The point is simply that an indicator that seems to show a "large" impact is not an ironclad argument that something must be done.

Rates of progress are equally difficult to interpret. Would a 2 percent annual improvement in a certain environmental indicator represent rapid or unacceptably slow progress? Such an indicator is open to some interpretation, and in some cases even 10 percent annual progress may be deemed insufficient. Trends in indicators must be interpreted carefully.

INDICATORS CANNOT SET TRUE PRIORITIES

In some cases, indicators cannot be put into comparable units, such as dollars of impact or numbers of people injured. In those cases, it is clearly very difficult to use the indicators to set priorities. Even when seemingly common units are used, such as tons released, the units may not be truly comparable, since a ton of benzene causes more harm than a ton of NO_x, and the harm may be greater if it is released to a water supply near a city than if it enters the air in a rural area.

Furthermore, even when indicators are in comparable units (such as numbers of people affected with respiratory problems or dollars of damage) it may *still* be inappropriate to set regulatory or budgetary priorities based solely on such indicators. This is because, again, the costs of policies are not being considered. Just because runoff is a bigger problem than tire disposal, for example, it may be much less expensive to solve the tire problem. *Setting priorities based on cost-effectiveness* rather than just environmental costs will accomplish more environmental benefit for a given, fixed budget.

That being said, we know that society often sets some rough priorities based on the size of various problems, without considering the costs of fixing those problems. It may be reasonable to use indicators as a first tier of priority-setting, in the allocation of budgetary resources, for example, where cost-effectiveness analysis would be impractical.

HOW INDICATORS CAN BE USEFUL

Given all of the caveats described above, one might be left with the impression that indicators are not useful. That is far from true. As long as they are used appropriately, indicators are a very powerful policy-making tool. Some of the uses of indicators are listed and then discussed below.

WHAT INDICATORS *CAN* BE USED FOR

- Provide broad perspective
- Encourage a comprehensive look at all environmental impacts
- Track progress of policies as a whole
- Highlight remaining problems
- Help set priorities, particularly for research and among issues needing new or improved policies
- Educate the public, media-focused offices, and others
- Feed into economic/policy analysis

PROVIDE BROAD PERSPECTIVE

Indicators can provide a sense of the magnitude of transportation's environmental impacts relative to other issues. Transportation could be compared with other sources of environmental damage, for example, or these problems could be viewed relative to other large policy issues such as health, education, economic problems, and crime. Indicators are very useful in conveying the importance of an issue at the broad level. In this capacity, they can assist in resource allocation at the national level.

ENCOURAGE A COMPREHENSIVE LOOK

In the process of developing indicators, this study has had to identify the full range of environmental impacts of transportation. Likewise, in the process of using indicators, policy makers and the public become aware of the whole gamut of ways transportation affects our environment. The awareness and education that results is one of the often overlooked benefits of using indicators.

TRACK PROGRESS OF POLICIES AS A WHOLE

Indicators allow us to track progress, to measure success. While the results of a particular policy initiative may not be discernible, the overall impacts of all of our activities, planned and unplanned, can be seen with the appropriate indicators. This provides feedback that allows society to make mid-course corrections and learn from past experience.

HIGHLIGHT REMAINING PROBLEMS

In using indicators to take a comprehensive look at environmental impacts, we may stumble upon a "sleeper" issue: a problem that has been overlooked or neglected. Indicators encourage a full review of environmental issues and can highlight areas that have been ignored or have not been successfully addressed.

HELP SET RESEARCH PRIORITIES

Indicators can also be useful in setting research priorities. The potential benefits of research are larger when it is focused on the most significant environmental problems.

Reviewing the full range of impacts can be helpful in setting priorities. As discussed above, indicators ideally would not be used as the sole method of priority setting, but they still can be valuable in this role.

EDUCATE THE PUBLIC, MEDIA-FOCUSED OFFICES, AND OTHERS

Indicators are useful for educating the public about the range of issues, progress of policies, and remaining challenges. They can provide a relatively simple overview of an issue such as transportation's environmental effects.

They are also useful in governmental offices traditionally organized by environmental media, such as air or water. For example, for a water-focused office, indicators could summarize the water quality implications of a particular sector, such as transportation.

FEED INTO ECONOMIC/POLICY ANALYSIS

Indicators are an excellent starting point for policy analysis because they compile key quantitative data on environmental impacts.

Now that we have taken account of the ways in which indicators should and should not be used, we can consider how the most appropriate indicators can be selected. The next section examines the question of how to design indicators.

III. SELECTING APPROPRIATE INDICATORS

In this section, we examine the limitations of commonly cited indicators and then consider what an ideal indicator would look like. We do so by presenting a framework that demonstrates how indicators may focus on different stages of the link between transportation and the environment. Finally, this section highlights data gaps that make use of ideal indicators unavailable at present, pointing to areas in which research would be most beneficial.

COMMONLY CITED "INDICATORS" HAVE LIMITATIONS

Many of the measures often presented as indicators of transportation's environmental impacts are flawed. Some examples of these measures and their limitations are listed in the table below.

LIMITATIONS OF COMMONLY CITED "INDICATORS"

MEASURE	LIMITATION
VMT	Only a partial determinant of impacts. Increased VMT will not increase emissions if technology improves, for example.
MPG	Only a partial determinant of impacts.
Emissions per vehicle-mile	This is not a constant for all locations and all years. An average national impact for one year cannot be applied to other years or locations. Also, incorrectly implies that benefits per VMT are constant.
Emissions per PMT or per ton-mile	Same as above. Incorrectly implies that benefits per PMT or ton-mile are equivalent for different modes.
Modal split	Only a partial determinant of impacts.
Acres of wetlands lost	Does not consider the severity of the loss; assumes any acre lost has equal value. May not consider mitigation efforts, depending on how it is measured.

Perhaps the most important limitation to these measures is that they do not directly address the actual impact, perhaps with the exception of the wetland measure. They only measure activities that play some role in leading to the impact. The need for results-oriented measures is discussed in the section on ideal indicators.

The limitations of such measures can be briefly summarized as follows, and are discussed in some more detail elsewhere in the report:

LIMITATIONS OF VMT AND OTHER COMMON MEASURES

- Results are more important to track than activities.
- Impacts per VMT or other activity measure vary a great deal by location.
- Impacts per VMT or other activity measure vary over time.
- Average impacts are not useful when one should be measuring marginal impacts (the effects of incremental increases in travel are marginal impacts; there may be thresholds or other

circumstances so that the impact associated with additional VMT differs from the average impact per VMT).

- The benefits per passenger-mile traveled (PMT) or per ton-mile are not equal for all modes and locations.

While very limited as indicators, these types of measures do play some very important roles:

USES OF VMT AND OTHER COMMON MEASURES

- They are critical data in models that predict environmental impacts. Local and national analyses depend on these component data to model possible future impacts.
- They convey the magnitude and pervasiveness of the transportation system.
- They allow simple, rapid, cross-modal comparisons.
- They help explain historical and ongoing impacts, allowing policy makers to focus efforts on these causal factors. For example, it may be helpful to observe that the fraction of commuters driving to work alone ranges from just 46 percent in New York State to 73 percent in Michigan.[21] In several cities, one third to one half of workers use public transportation, compared with under one tenth in most cities and one twentieth nationwide.[22] Such comparisons may spur certain locations to reexamine their policies or infrastructure.

Some of these activity measures are discussed in Appendix A, which deals with infrastructure and travel measures, as they relate to environmental quality.

One other type of indicator commonly cited deserves particular mention here. That is the group of indicators measuring mitigation or control efforts. These are often programmatic measures that track the dollars spent on mitigating environmental impacts or measure results such as the number of miles of noise barrier installed, for example. Some of these measures go even further, to assess the effectiveness of those mitigation or control efforts, citing statistics such as "current controls have reduced emissions per mile by 90 percent" or "these mitigation efforts are effective in 85 percent of the cases." This report does not focus on mitigation or control efforts; instead, it looks at the net impacts that result after such efforts have been attempted. This is not to say that such measures would be useless. Measures of mitigation and control can be useful for the following purposes:

USES OF MITIGATION AND CONTROL INDICATORS

- To determine how well mitigation and control efforts are working
- To identify those practices or technologies that are most effective
- To identify where such methods are not being implemented, to determine the need for technology transfer, education, or incentives.

[21] See World Resources Institute 1992. That report ranks cities based on usage of transit, walking, and carpooling; time spent commuting; and share of population with commutes longer than 45 minutes.
[22] APTA, 1995.

While development of mitigation and control indicators would be useful for these purposes, they are not well suited for the goal of this study, which is to track the environmental impacts of transportation.

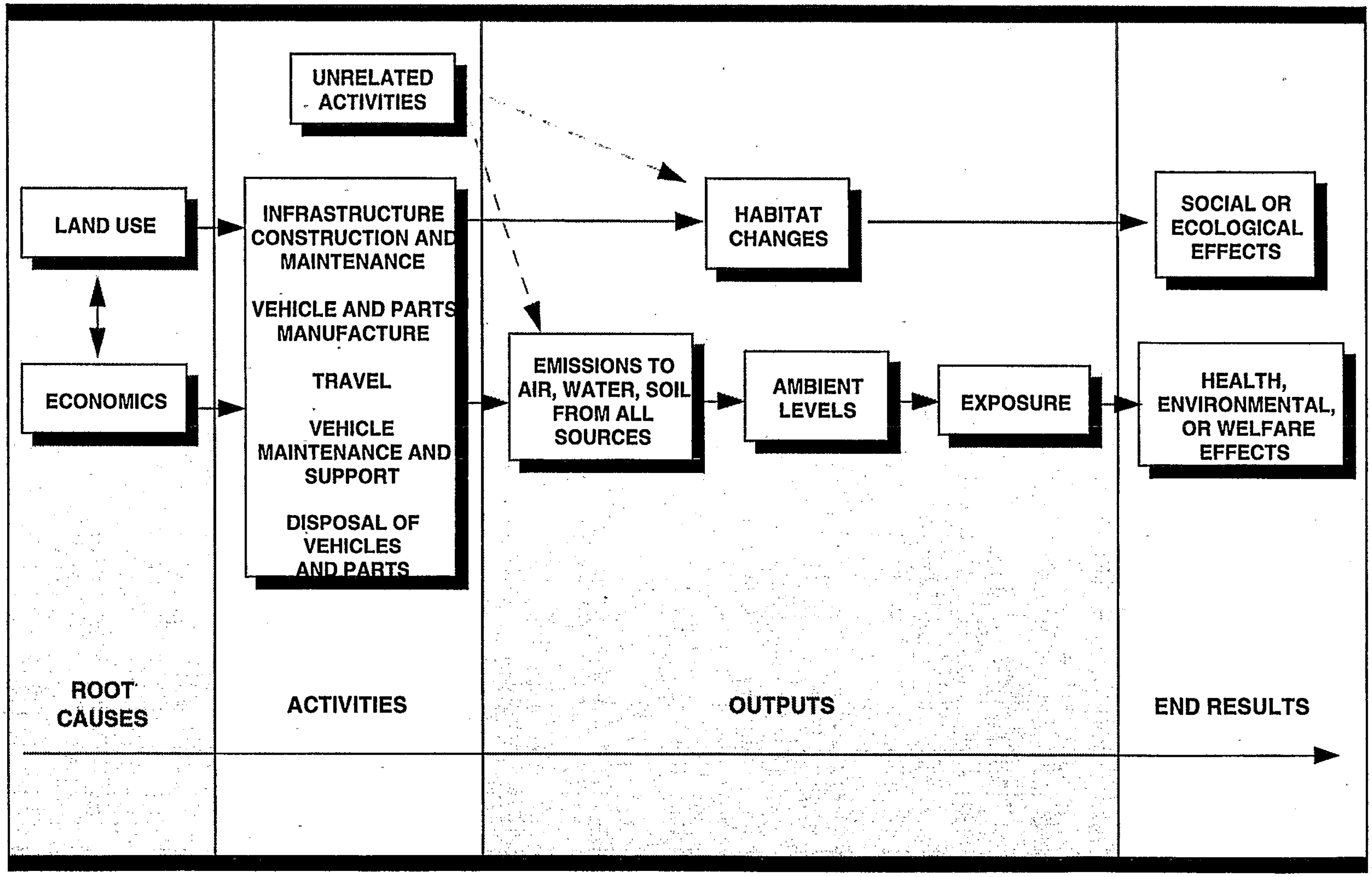
Part of the reason that so many inappropriate measures are used as indicators of environmental impacts is that a consistent framework is not being used to understand the process and design appropriate indicators. Such a framework is presented below.

FRAMEWORK: HOW TO DESIGN INDICATORS

The figure on the following page presents a framework for the design and selection of environmental indicators. It demonstrates how transportation activities (e.g., construction of infrastructure) ultimately lead to impacts. It highlights the fact that indicators can be focused on any one of several stages. Thus, indicators could measure the root causes such as land use changes, or the activities themselves (e.g., VMT), or the "outputs" of those activities (e.g., emissions), or finally, the actual results, such as changes in public health. The figure also shows that unrelated activities, such as industrial operations, also contribute to total emissions, making it difficult to isolate the impacts of transportation if indicators are measuring ambient levels of pollution or public health, for example.

The framework shown here is very similar to a framework that has been used by EPA's Office of Policy, Planning, and Evaluation, and the general approach has been found to be useful in a variety of efforts. Variations of this framework have been used by the Chesapeake Bay Foundation, for example, and cited by the U.S. General Accounting Office in its *EPA Management Review* of 1988, in a chapter entitled "Environmental Measures and Links to Program Activities Are Needed to Assess Program Effectiveness" (GAO 1988). Because it has been found useful in past efforts, we have adapted the framework to use in designing transportation environmental indicators.

CAUSES AND EFFECTS OF TRANSPORTATION ACTIVITIES



The stages shown in the framework are listed below, with some examples of what is included in each stage or what might be measured at each stage. These are not fully developed indicators in most cases, and are not the actual quantitative indicators reported in this study. They are simply examples representative of the range of factors that could be measured. The relative merits of various types of indicators are discussed in the section, "What is an Ideal Indicator?" The actual indicators quantified in this study are presented in Section V.

EXAMPLES OF INDICATORS TARGETING VARIOUS STAGES IN THE FULL TRANSPORTATION CYCLE

ROOT CAUSE INDICATORS

Root cause indicators provide information on underlying factors, such as land use, demographics, and economics, that influence transportation activities. However, they are far removed from the actual environmental effects and so tend to be poor measures of environmental damage. While these measures do not provide a great deal of information for estimating the environmental consequences of transportation, they do help explain the reasons why certain impacts may be increasing or decreasing. As a result, tracking these root causes may have useful policy implications. Examples include the following:

LAND USE (including demographics and geographic issues)

Population growth rate
Density (commercial, residential, or mixed; per square mile or zonal mile)
Transit access
Pedestrian environment factor (level of pedestrian accessibility)
Bike friendliness (including climate, terrain, safety issues, etc.)

ECONOMICS

Costs of travel by various modes
Income
Attitudes about environmental protection, transit, etc.
Knowledge/level of information regarding transportation costs (internal and environmental) and travel alternatives

ACTIVITY INDICATORS

Activity indicators provide information on transportation actions, such as infrastructure construction and maintenance; travel; and vehicle manufacture, maintenance, and disposal. In addition, transportation infrastructure and vehicle fleet characteristics are included as indicators because they may change over time and have continuing impacts (e.g., habitat fragmentation continues due to existing roadways). Activities often have direct environmental consequences, and tend to be the most consistently tracked indicators over time. However, the level of environmental damage associated with a specific activity or set of infrastructure varies by location and over time. Examples include the following:

INFRASTRUCTURE CONSTRUCTION AND MAINTENANCE

Number of lane miles constructed annually
Percent of roads that are paved/unpaved
Number of transit stations
Quantity of deicing compounds applied

VEHICLE AND PARTS MANUFACTURE

Number of vehicles manufactured
Number of railcars purchased by transit agencies
Number of new aircraft delivered
Number of registered vehicles

TRAVEL

Vehicle-miles traveled (VMT) (or VMT per capita)
Passenger-miles traveled (PMT) (or PMT per capita)
Number of trips
Average vehicle occupancy (AVO)
Modal split (percentage using transit, walking, driving alone, etc.)
Speeds (peak and off-peak)
Acceleration, stops, etc.
Congestion levels (e.g., share of travel in level of service "F", number of delay hours)
Gallons of fuel used (or average MPG for a given city or year)

VEHICLE MAINTENANCE AND SUPPORT

Number of cleaning or refueling stations/terminals
Number of active petroleum underground storage tanks

DISPOSAL OF VEHICLES AND PARTS

Number of vehicles scrapped
Number of used tires landfilled
Percent of mass landfilled or recycled

OUTPUT INDICATORS

Output indicators provide information on land take, emissions, ambient concentrations, or exposure. They provide quantitative information about the actual environmental change that results from transportation activities.

Ambient concentrations can be directly measured. However, they are by definition a local measure (i.e., ambient air quality for a metropolitan area, water quality for a body of water), and thus, national measures related to ambient concentrations generally do not provide a significant amount of detailed information (e.g., number of metro areas exceeding the NAAQS, number of states reporting poor water quality due to runoff). In addition, ambient concentrations alone do not explain what portion of the problem is attributable to a specific source (i.e., measuring ambient air quality does not directly provide information about the contribution of transportation).

On the other hand, emissions can be estimated for a specific type of activity and tracked over time. However, emissions estimates are generally based on models, which may be somewhat flawed and require improvement over time. Examples of each of these indicators include the following:

HABITAT CHANGES/LAND TAKEN

Acres of various types of land disrupted or divided by roads, by type of land, including changes in habitat fragmentation caused by transportation (e.g., number and size of parcels of forest or other ecosystem)
Acres of various types of land destroyed, accounting for mitigation/restoration (e.g., classified by summarized wetland functions and values)
Number of threatened/endangered species in affected areas

EMISSIONS[23]

Tons emitted by mode, location, and chemical
Levels of noise pollution
Number of vehicles in use violating emissions standards

AMBIENT LEVELS

Parts per million of pollutant in ambient atmosphere, by location and chemical, for various averaging times
Number or percentage of areas in nonattainment of Federal air quality standards
Stream miles not meeting designated uses

EXPOSURE TO POLLUTANTS

Number of people living in nonattainment areas
Estimated amount of exposure in ppm-hours or other units
Population near hazardous waste sites
Population downstream of areas with water quality problems or drinking affected water

OUTCOME INDICATORS

Outcome indicators are measures of end results. They provide quantitative information on health, environmental, and welfare effects resulting from transportation and are theoretically the most desirable type of indicator. Unfortunately, quantified data on outcomes are often unavailable or uncertain. Estimating end results generally requires using models (such as emissions dispersion models and dose-response functions) that may involve various assumptions and introduce uncertainty. Quantifying end results in dollar terms for purposes of comparison adds an additional step with

[23] *Emissions* is a term typically used for pollutants released to the atmosphere, while *discharge* is the term used for pollutants released to bodies of water. To avoid repetition of both words, this report used the term *emissions* to denote releases of any type of pollutant to air, water, or land.

considerable uncertainty. As a result, many of the current outcome indicators are nonspecific (e.g., states reporting habitat loss).

EFFECTS OF HABITAT CHANGE

Changes in abundance of various species caused by transportation
Changes in species diversity caused by transportation
Other detailed measures of:

 Fishery impacts (e.g., number of fish kills, changes in catch, and economic impacts on fishing, recreation)
 Forestry impacts
 Agricultural impacts
 Avian species impacts

EFFECTS OF POLLUTANT EMISSIONS

Expected (estimated) number of cases of a given health effect (e.g., cancer cases) attributable to transportation emissions
Percentage of all cases thought to be caused by transportation
Risk level (i.e. probability that an individual will be affected)
Dollar costs of health or welfare impacts (e.g., dollars of textile damage from corrosive air pollution)
Person-days in exceedance of ambient standard (this is a measure of ambient levels but is also an indicator of their effects)

The indicators listed above are representative of a very wide range of possible measures. The next section discusses how one might go about selecting the most appropriate types of measures from among these choices, taking into account both the traits of an ideal measure and the reality of existing data gaps.

WHAT IS AN IDEAL INDICATOR?

Using the framework presented above, we can begin to consider the types of indicators that are most appropriate. Data limitations and practical constraints currently require the use of indicators that are less than ideal. It is important to consider, though, what an ideal indicator would look like so that improved measures can be developed in the long term.

We believe that ideal indicators would have the following characteristics:

CHARACTERISTICS OF IDEAL INDICATORS

- Results-oriented
- Limited to only the share of harm attributable to transportation
- Detailed enough for the target audience
- Presented in comparable units (e.g., dollars)
- Presented in meaningful units (e.g., compared with a standard or goal)
- Reasonable level of certainty

Essentially, an indicator should accurately describe the actual damage caused by transportation in units allowing comparison between indicators and providing a clear sense of the importance of the impact. Each of these issues is briefly explained below.

RESULTS-ORIENTED

Results-oriented indicators would focus on the last stages of the process shown in the framework, namely health, environmental quality, and welfare. The advantage of results-oriented measures is that they measure the factors with which people are really concerned. Unfortunately, actual measurements of these results are typically scarce. This necessitates modeling, making the indicators less certain.

RESULTS-ORIENTED INDICATORS	
PROS	Measure the problem itself; get incentives right Data often available for overall extent of problem
CONS	Data often unavailable to attribute share of damage to a single sector Data often uncertain, based on numerous modeling assumptions Do not explain causes of problem or solutions

Another problem with pure results-oriented measures is that they provide no insight into possible solutions, or what the specific root causes are. Even if one knew how many cases of cancer are caused by automobiles, one would still need to understand more about why so many people are exposed to these pollutants, why emissions are so high per mile, how much travel occurs and why, and so on. To better understand root causes and possible solutions, policy makers often measure activities such as miles traveled, average vehicle occupancy, or miles per gallon. The disadvantage to measuring root causes or travel activities is that they are not equivalent to the problem one is trying to solve. Using indicators of VMT, for example, does not set the perfect incentives. Tracking VMT suggests the goal is to reduce VMT, but the real goal is to reduce health or other problems. Thus, VMT could remain constant, but a shift to more polluting vehicles would still pose a threat.

Perhaps a larger challenge, though, in developing results-oriented measures, is limiting the indicator to transportation's share of the impact, as explained below.

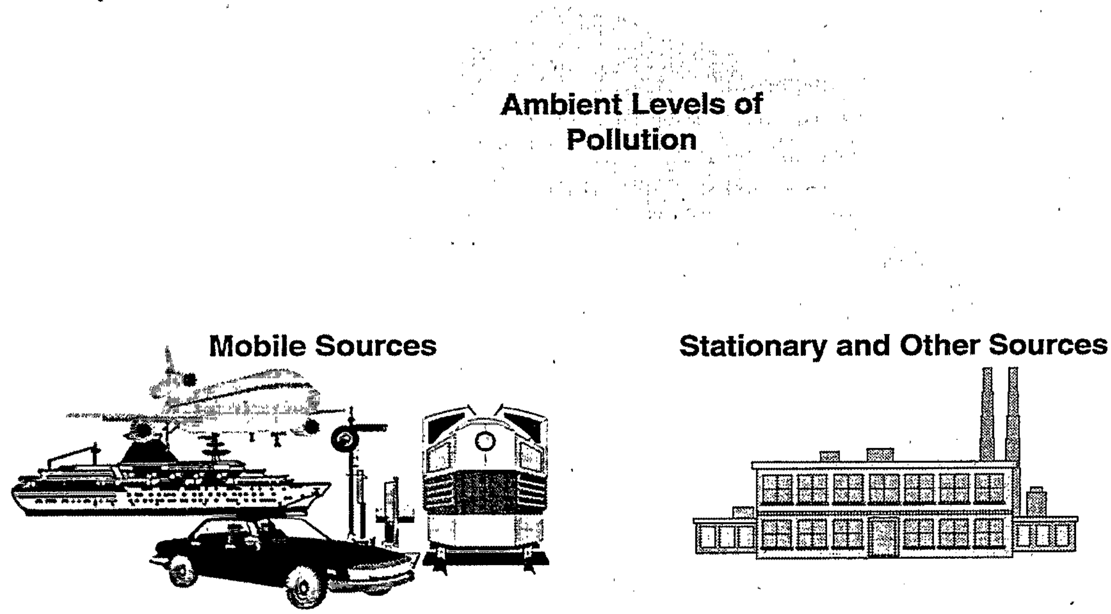
LIMITED TO ONLY THE SHARE OF HARM ATTRIBUTABLE TO TRANSPORTATION

Data are often available for at least overall health indicators, such as the number of Americans dying from respiratory diseases in a given year. The problem with such indicators is attributing some share of these effects to a single set of activities, such as transportation. Ideally one would like to know the number of deaths caused by air or water pollution from transportation. Even if one can measure ambient air quality or the number of cases of respiratory disease, it is difficult to isolate the share of these problems that stems from transportation (see the following figure). Industrial and other sources contribute emissions and it is often impossible to measure transportation's impacts separately. The exceptions would be in cases where transportation emits a unique pollutant (e.g., perhaps road salt or car batteries) or entails an activity that could be observed and counted directly, such as the acreage of wetlands filled by highway projects.

If transportation's share of impacts cannot be directly measured, it must be modeled. Modeling results-oriented measures introduces some uncertainty and sometimes requires data that are unavailable or impractical to obtain. For example, it is difficult to accurately estimate the amount of pollution entering lakes that results from automobiles.[24]

Because of these data limitations, results-oriented measures focused on only transportation's share of the problem are currently very difficult to develop. This report therefore presents many indicators focused on emissions, an earlier stage in the process shown in the framework above.

The variety of sources of air pollution mean that it is difficult to determine transportation's share of impacts by measuring ambient pollution levels alone.



DETAILED ENOUGH FOR THE TARGET AUDIENCE

The design of indicators must take into account the audience. Indicators that are ideal for regional officials implementing highway programs may not be useful to Congress in considering new legislation. The appropriate level of detail depends on the consumers of the information. We have chosen to attempt a balance between excessive detail (e.g., numerous measures of flora and fauna impacts) and insufficient detail (e.g., total dollar cost of all environmental impacts, VMT growth rate, or total tons emitted for all air pollutants added together).

PRESENTED IN COMPARABLE UNITS (E.G., DOLLARS)

Ideal indicators would be expressed in comparable units, to allow comparisons among impacts, modes, and media. Dollars are one common unit that has been used to assess some environmental impacts, but there is considerable uncertainty and sometimes controversy over using such units. Estimates in common terms currently are not available for many of the impacts. This report does not present indicators in common units.

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[24] Estimates of air deposition do exist, as discussed in the section presenting indicators.

PRESENTED IN MEANINGFUL UNITS (E.G., COMPARED WITH A STANDARD OR GOAL)

Meaningful units provide a sense of how important an impact is. Indicators expressed in terms of tons emitted or percentage improvement per year, for example, are limited because they do not convey a sense of how many tons is "bad" or what rate of progress is "good." Comparison with a standard places the impact in context. The standard could be a legal one or a goal set through the political process. Compliance rates or comparisons with health standards provide such a perspective. Unfortunately, there are not yet sufficient standards or related data to allow indicators that provide this full level of context for all environmental impacts of transportation. Developing such standards and data would make indicators even more useful.

REASONABLE LEVEL OF CERTAINTY

An ideal indicator would have a reasonable degree of certainty. Nearly all indicators at the national level—from root causes to outcomes—have some unavoidable degree of uncertainty. Total national VMT is not directly measured but instead is estimated based on traffic counts from a sample of roads. Undertaking the additional step of estimating emissions requires modeling assumptions, which further reduce certainty. Estimating end results (e.g., health effects, damage) again introduces a series of assumptions which deters from the certainty of the final indicator. While outcome indicators measure what is most important to people, it is important to balance the goal of having results-oriented indicators with the goal of reasonable certainty.

AVAILABLE INDICATORS

As the preceding discussion makes evident, ideal indicators are a long-term goal but are rarely available. This report presents results-oriented measures, or outcome measures, where they are available. Most of the indicators presented here, however, are output measures, or measures of emissions and habitat change rather than actual results. They are presented as interim solutions, with the understanding that ideal indicators should be developed.

DATA GAPS

Ideal indicators are not yet available for most of the environmental impacts of transportation, largely as a result of data gaps. This section gives an overview of those gaps.

LOCAL VERSUS NATIONAL DATA

Particularly in national-level data, the necessary statistics are not available to describe many of the impacts associated with various modes of transportation. This is because most impacts are first measured or estimated locally, in environmental impact statements (EISs) or laboratory studies, for example, and then converted to national estimates. National estimates may be compiled in a few different ways: 1) by directly observing, or counting, *all* of a given transportation impact (e.g., counting every acre of wetland affected on a project-by-project basis) and then adding up the numbers; 2) by observing typical impacts, ideally based on a representative sample, and multiplying by a scaling variable like VMT; 3) by forming a multivariate model, scaling up to a national estimate using several variables rather than VMT alone; or 4) by observing the total impact (e.g., ambient air quality or human morbidity) and estimating the fraction attributable to transportation. Each of these approaches has been used for some estimates of transportation's impacts, and we present the most reliable of the various figures available.

SUMMARY TABLES OF DATA GAPS ORGANIZED BY ENVIRONMENTAL MEDIA

The specific data gaps in national environmental indicators for transportation will become apparent in the presentation of actual indicators, but the charts below provide an overview of the broad areas where more information is needed. The summary table provides a synopsis of the general types of environmental impacts that should be measured, and the next table provides a sketch of where data gaps exist. It should be noted that where the table states "good indicators" are available, the term "good" is used in a relative sense. Very few excellent indicators exist, since they would require further research and development. As a result, the table simply identifies areas in which data are generally better.

It is important to note that these tables, unlike the rest of the report, classify impacts by environmental medium, such as air or water. This approach (organizing by media) is taken only in these tables, as a convenient means to provide a brief summary and because much of the necessary scientific research is medium-specific.

Following these tables on data gaps, the next section of this report introduces the primary classification scheme actually used to categorize impacts and indicators of those impacts

Summary of Possible Environmental Impacts by Mode of Transportation

Mode/Media	*Air*	*Water Resources*	*Land Resources*	*Other Impacts*
Road/Highway Automobiles, trucks, buses. Streets, highways.	Engine and evaporative emissions of CO, HC, NO_X, PM, lead. Emissions of CO_2 from fossil fuel combustion. CFCs released during vehicle manufacture and disposal.	Surface and groundwater pollution from runoff (lubricants, coolants, vehicle deposits, road salt). Modification of water systems from road building.	Land taken for infrastructure. Extraction of road building materials. Abandoned rubble from road works. Road vehicles withdrawn from service. Waste oil, tires, batteries.	Local noise. Congestion.
Railroad Freight, intercity passenger, transit rail. Railway track.	Engine and evaporative emissions of CO, HC, NO_X, PM. Emissions of CO_2 from fossil fuel combustion. CFCs released during vehicle manufacture and disposal.	Oil and grease. Creosote from track beds.	Land taken for rights-of-way and terminals. Dereliction of obsolete facilities. Abandoned lines, equipment, and stock.	Local noise.
Aviation Aircraft. Airports.	Engine and evaporative emissions of CO, HC, NO_X, PM. Emissions of CO_2 from fossil fuel combustion. CFCs released during vehicle manufacture and disposal.	Modification of water tables, river courses, and field drainage in airport construction. Deicing chemicals and degreasers on runways.	Land taken for infrastructure. Dereliction of obsolete facilities. Aircraft withdrawn from service. Buffer zones for noise abatement.	Local noise.
Maritime Marine vessels, ferries. Port facilities, canals.	Engine and evaporative emissions of CO, HC, NO_X, PM. Emissions of CO_2 from fossil fuel combustion. CFCs released during vehicle manufacture and disposal.	Discharge of ballast wash, oil, spills. Modification of water systems during port construction and canal cutting and dredging. Sanitation device discharge.	Land taken for infrastructure. Dereliction of obsolete port facilities and canals. Vessels and craft withdrawn from service. Land disposal of dredged material.	Plastic wastes at sea.

Source: VHB, 1992, p.1117. Adapted from OECD, 1991.

Data Availability

Nationwide Estimates of Transportation's Environmental Impacts

Impacts on Media	Type of Indicator				
	Activities	Emissions	Ambient Levels/ Habitat Changes	Exposure	End Results (Health, Environmental, or Welfare Effects)
Air Pollution	●	●	●	●	○
Water Pollution	●	○	○	○	○
Waste Spills and Disposal	●	○	○	○	○
Habitat Modification	●	Not Applicable	○	Not Applicable	No Data

● Good indicators of transportation sector's impact available

○ Limited or weak data on transportation

○ Available data measures do not indicate transportation's share of total impact

IV. CATEGORIZING THE ENVIRONMENTAL IMPACTS OF TRANSPORTATION

One of the potential benefits of environmental indicators is that they encourage a comprehensive view of impacts. A key part of this study was the development of a scheme to categorize the full range of environmental impacts of transportation. This section describes this scheme and summarizes the impacts we have considered. The section after this one lists the actual quantitative indicators of each impact.

Many reports citing the impacts of transportation do not use a set of categories, often focusing on air pollution and noise to the exclusion of other impacts. Some include a few additional impacts, but not in any organized, comprehensive manner. A long list of impacts without a scheme for categorizing them logically can be confusing.

Some governmental agencies are traditionally organized by environmental medium. That is to say, there is an air office, a water office, a hazardous waste office, and so on. While this approach has some advantages, it is not well suited for an examination of a single industrial sector or group of related activities, such as transportation.

We have chosen to classify the impacts of transportation according to five key types of activities rather than by media. Focusing on activities as the primary organizing principle makes the categories easy to understand and policy relevant. The key activities that are involved in transportation are listed below.

FIVE BASIC ACTIVITIES CAUSING ENVIRONMENTAL IMPACTS

The five basic groups of transportation activities that cause environmental impacts are listed below. These are listed in a somewhat chronological order, following the life cycle of transportation.

BASIC TRANSPORTATION ACTIVITIES AFFECTING THE ENVIRONMENT

1. Infrastructure construction, maintenance, and abandonment
2. Vehicle and parts manufacture
3. Vehicle travel
4. Vehicle maintenance and support
5. Disposal of used vehicles and parts

As noted earlier, these groups cover a wider range than typically considered. This study and most data sources emphasize the third group, vehicle travel, but we have included at least some information on each of these steps in the full life cycle of transportation.

DETAILED LIST OF ACTIVITIES CAUSING ENVIRONMENTAL IMPACTS

Each of the five basic types of transportation activities can be subdivided into several types of environmental impacts. For example, vehicle travel causes exhaust emissions, noise, and hazardous materials spills. Infrastructure development results in disrupted habitat as well as emissions during construction or maintenance. The environmental impacts are listed below, as subcategories of the five basic transportation activities.

It should be noted that the lists below identify the impacts but are not the actual indicators that would be used to measure those impacts. The indicators of these impacts are shown in the section following this one.

HIGHWAY TRANSPORTATION ACTIVITIES AND THEIR IMPACTS

1. ***Road Construction and Maintenance***
   - Habitat disruption and land take for road and right-of-way
   - Emissions during construction and maintenance
   - Releases of deicing compounds
   - Highway runoff

2. ***Motor Vehicle and Parts Manufacture***
   - Toxic releases and other emissions

3. ***Road Vehicle Travel***
   - Tailpipe and evaporative emissions
   - Fugitive dust emissions from roads
   - Emissions of refrigerant agents from vehicle air conditioners
   - Noise
   - Hazardous materials incidents during transport
   - Roadkill

4. ***Motor Vehicle Maintenance and Support***
   - Releases during terminal operations: tank truck cleaning, maintenance, repair, and refueling
   - Releases during passenger vehicle cleaning, maintenance, repair, and refueling
   - Leaking underground storage tanks containing fuel

5. ***Disposal of Motor Vehicles and Parts***[25]
   - Scrappage of vehicles
   - Improper disposal of motor oil
   - Tire disposal
   - Lead-acid batteries disposal

[25] The disposal of used motor oil and tires could have been classified as part of vehicle maintenance. It occurs during maintenance, not only at final disposal of the vehicle and its parts. We have chosen to include it in this category, however, for convenience and because waste disposal policy issues differ from those involved with other impacts of vehicle maintenance.

RAIL TRANSPORTATION ACTIVITIES AND THEIR IMPACTS

1. Railway Construction, Maintenance, and Abandonment

- Habitat disruption and land take
- Emissions during construction and maintenance

2. Rail Car and Parts Manufacture

- Toxic releases

3. Rail Travel[26]

- Exhaust emissions
- Noise
- Hazardous materials incidents during transport

4. Rail Car Maintenance and Support

- Releases during terminal operations: car cleaning, maintenance, repair, and refueling
- Emissions from utilities powering rail[27]

5. Disposal of Rail Cars and Parts[28]

- Rail car and parts disposal

[26] Emissions of refrigerant agents could also be included here, but no data were identified to address this potential impact.
[27] Emissions from utilities powering rail could also be categorized as a part of rail travel but are listed here because it is a stationary source legally and emissions do not occur at the point of travel.
[28] Disposal of oil and other used parts could be included here, but no relevant data were identified.

AVIATION TRANSPORTATION ACTIVITIES AND THEIR IMPACTS

1. Airport Construction, Maintenance, or Expansion

- Habitat disruption and land take
- Emissions during construction and maintenance
- Releases of deicing compounds
- Airport runoff

2. Aircraft and Parts Manufacture

- Toxic releases

3. Aviation Travel

- High altitude emissions
- Low altitude/ground level emissions
- Noise impacts
- Hazardous materials incidents during transport

4. Airport Operation

- Emissions from ground support equipment involved in aircraft loading, cleaning, maintenance, repair, and refueling

5. Disposal of Aircraft and Parts[29]

- Airplane and parts disposal

[29] The disposal of used motor oil and tires could have been classified as part of vehicle maintenance. It occurs during maintenance, not only at final disposal of the vehicle and its parts. We have chosen to include it in this category, however, for convenience and because waste disposal policy issues differ from those involved with other impacts of vehicle maintenance.

MARITIME TRANSPORTATION ACTIVITIES AND THEIR IMPACTS

1. Construction and Maintenance of Navigation Improvements

- Direct deterioration of habitats and water quality from dredging or other navigation improvements
- Habitat disruption and contamination from disposal of dredged material
- Habitat disruption and land take for ports and marinas

2. Manufacture of Maritime Vessels and Parts

- Toxic releases

3. Maritime Vessel Travel

- Air pollutant emissions
- Habitat disruption caused by wakes and anchors
- Introduction of non-native species
- Hazardous materials incidents during transport
- Wildlife collisions
- Overboard dumping of solid waste
- Sewage dumping

4. Maritime Vessel Maintenance and Support

- Releases of pollutants during terminal operations

5. Disposal of Maritime Vessels and Parts

- Scrappage of old vessels and dilapidated parts

V. THE INDICATORS

This section of the report presents the actual indicators and uses them to quantify the various environmental impacts of transportation. Separate subsections describe the following modes:

- Highway
- Rail
- Aviation
- Maritime

As explained in the previous section, the primary categories used here are types of activities. The discussion of each environmental impact includes the following information:

- Presentation of indicators
- Description of impact
- Causal factors

Three types of indicators are presented throughout this report:

- **Outcome/Results Indicators**
  Outcome indicators are measures of end results. They provide quantitative information on health, environmental, and welfare effects resulting from transportation, and are theoretically the most desirable type of indicator. Examples of good outcome indicators include the number of cases of headaches or other human health symptoms incurred, the number of animals killed, and the extent of wetlands or other specific habitats destroyed. Unfortunately, in many instances quantitative data are available for only crude outcome indicators, such as the number of states reporting wetland degradation or groundwater contamination. In other cases, large uncertainties exist regarding transportation's share of a given outcome. While this information is useful, it is not a sufficient indicator for most environmental or policy analysis.

- **Output Indicators**
  Output indicators provide information on emissions, ambient concentrations, land take, or exposure. These indicators tend to be more reliable than many of the available outcome indicators. Examples of good output indicators include the area of new land taken, quantity of air pollutants emitted, and quantity of oil spilled. While these data are recognized as fairly accurate, much of the information is based on models or reports of incidents which may not be comprehensive. In most cases, estimates of actual exposure, such as the number of people exposed to air pollution from motor vehicle manufacture or the amount of hazardous materials spilled that actually enters the environment, are not reported.

- **Activity Indicators**
  Activity indicators provide information on infrastructure, travel, and other transportation-related activities, such as vehicle and parts manufacture, maintenance, and disposal. Examples of infrastructure data include the number of railroad terminals, road mileage, and number of underground petroleum storage tanks. Examples of travel and other activity measures include the number of vehicles scrapped, quantity of deicing agents used, energy consumed, and

vehicle-miles traveled. Although these measures provide only an indirect indication of environmental impact, in some cases they are the best indicators available.

HIGHWAY ENVIRONMENTAL INDICATORS

This section presents the quantitative indicators available for tracking the nationwide environmental impacts of highway (on-road motor vehicle) transportation. For each of the five basic categories of activities affecting the environment, the various impacts are listed.

HOW EACH IMPACT IS PRESENTED IN THIS SECTION

Each environmental impact is covered in one or more pages of text and graphics, with the following key subsections:

- **Presentation of indicators**

  The key indicators that have been quantified are presented. *Outcome* indicators are listed first since they provide information on end results and are theoretically the most desirable type of indicator. Unfortunately, actual quantified data are often unavailable or of poor quality. In many instances, the only available data on outcomes are the numbers of states reporting a problem. This information is often incomplete (not all states may examine the problem), vague (states may define the problem differently), or only somewhat relevant (the contribution of transportation to the problem may be unknown). As a result, *output* indicators—such as emissions data—are presented. These statistics may be an easier and more valid measure for policy makers to examine and track over time. *Activity* indicators (defined broadly to include infrastructure, travel, and other activities) are listed when they are the best available indicators or when outcome and output indicators are not adequate. In some cases, local examples are also provided.

  To avoid repetition within the report, basic infrastructure and travel indicators are listed in Appendix A for each mode of transportation. Appendix B contains additional relevant statistics on monetized values of health and other impacts; these outcome indicators are listed separately since there is generally more uncertainty regarding these figures.

- **Description of impact**

  The nature of the impact is briefly defined and explained here. More complete descriptions of these impacts are available in reference works listed in the bibliography.

- **Causal factors: Variables that change over time and between locations**

> Policy makers find it very useful to understand the driving forces behind environmental impacts. Understanding the key causal factors, such as VMT or emissions rates in grams per mile, is critical to *explaining* observed trends in indicators. They also help in estimating how local impacts may differ from national averages. These causal variables, then, explain how the impacts differ over *time* and *geographic location*. Most importantly, they suggest potential *policy levers*. Policies can be designed to focus on any of the key variables (e.g., grams emitted per mile) that determine the magnitude of an environmental impact.

The following table provides an overview of the available indicators for each impact. It is important to note two points about what is included in this table: First, indicators are listed only where they have been quantified at the national level; if an impact has not been quantified, no "potential" indicator is listed here. For each specific activity and its impact, the table provides a summary of the availability of quantitative data for indicators of outcomes, output, and activity. Second, the table shows only the best indicator for each impact rather than listing various alternative types of indicators for a given impact. The exceptions are when multiple indicators are needed to address all aspects of an issue or where some indicators are otherwise insufficient. Although outcome indicators are theoretically the most desirable type of indicator, actual quantified outcome data are often unavailable or of poor quality. As a result, output indicators—such as emissions levels—tend to be the most reliable and valid measures available in most cases. Activity indicators are presented in this table when they are the best available indicators or when outcome and output indicators are not adequate.

SUMMARY OF NATIONAL INDICATORS QUANTIFIED: HIGHWAY TRANSPORTATION

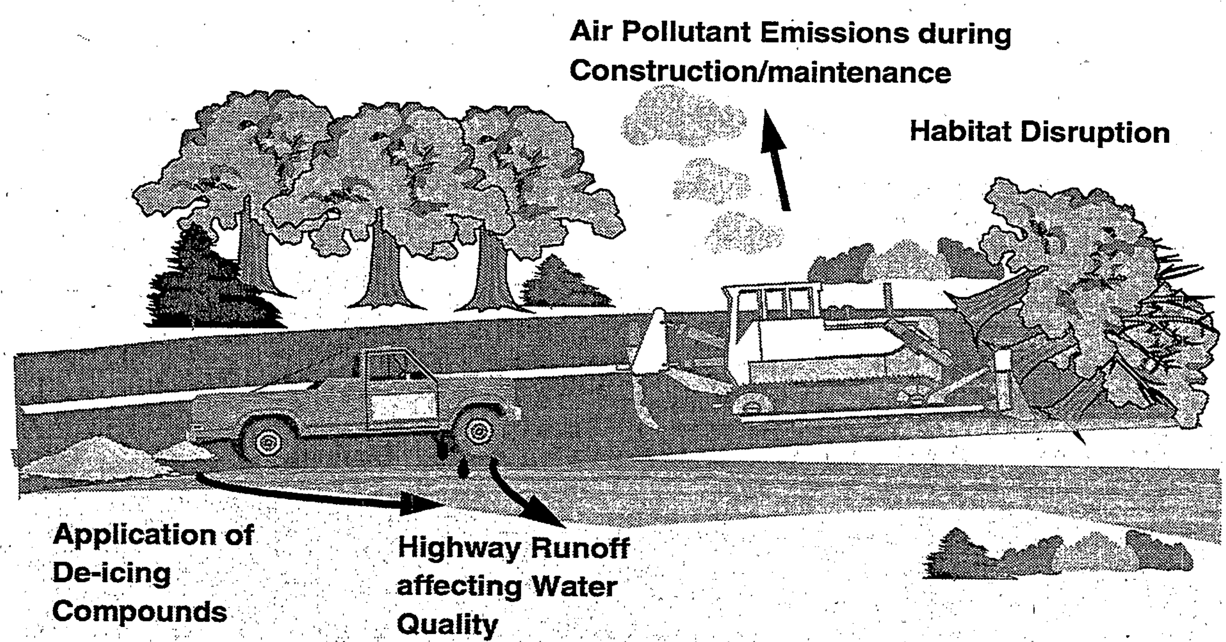
Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
1. Road Construction and Maintenance				
Habitat disruption and land take for road and right-of-way	• States reporting highway-related wetland losses	• Cumulative land area covered by roads • New land area taken for roadway use	• New road mileage and lane mileage constructed.	National estimates of fragmentation and other impacts are not available. Some useful state data are available.
Emissions during construction and maintenance	• Percent of surface waters degraded from land development projects (not just highways)	• Changes in surrounding water quality conditions near typical construction site • States reporting contamination problems at maintenance facilities	• Acres sprayed with herbicide • Energy used in construction	Emissions result from use of heavy machinery, pesticide application, and discovery of hazardous material in the right-of-way.
Releases of deicing compounds	• States reporting degraded wetlands integrity due to salinity • States reporting road salting as a significant source of ground water contamination	(Data unavailable)	• Quantity of road salt used	Deicing creates costs in terms of installing corrosion protection features during bridge construction and maintenance. Data is available on the number of roadside trees killed per year due to salting typical road.
Highway runoff	• River miles, lakes, and ocean shore miles impaired by urban runoff (not just highways)	• Average pollutant concentrations of various metals, suspended solids, and toxic organics in road runoff • Quantity of oil and grease loading via road runoff	• Percentage of roads that are paved	Road runoff's share of pollutant loading to nearby water bodies has been estimated locally.
2. Motor Vehicle and Parts Manufacture				
Toxic releases and other emissions	(Data unavailable)	• Quantity of reported releases of toxic chemicals included in TRI database • Quantity of CO, NO_2, PM-10, TP, SO_2, VOC released to air		Impacts of imported products/components are not included in statistics.

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
3. Road Vehicle Travel				
Tailpipe and evaporative emissions	• Cases of chronic respiratory illness, cancer, headaches, respiratory restricted activity days, and premature deaths due to motor vehicle pollution	• Quantity of CO, NO_X, VOC, SO_2, PM, Pb, CO_2, CH_4, N_2O, benzene, butadiene, and formaldehyde released		Health and welfare impacts have been estimated. Road transport's share of total national emissions and loadings to lakes and bays have also been estimated.
Fugitive dust emissions from roads	• Cases of chronic respiratory illness, asthma attacks, respiratory restricted activity days, and premature deaths due to particulates associated with motor vehicles	• Quantity of fugitive dust (PM-10) emitted		Health and welfare impacts have been estimated. Road transport's shares of total national emissions of fugitive dust and PM-10 have also been estimated.
Emissions of refrigerant agents from vehicle air conditioners	(Data unavailable)	• Quantity of CFCs, HFCs emitted from all sources • Percentage of emissions attributable to motor vehicles	• Quantity of CFCs consumed in autos	CFCs are being phased out.
Noise	• Percentage of population exposed to levels of roadway noise associated with health and other effects (1980 only)	• Typical noise emissions levels by vehicle type and road type		Since noise dissipates from its source, a national aggregate noise emissions level is not meaningful. Recent exposure estimates are not available.
Hazardous materials incidents during transport	(Data unavailable)	• Type and quantity of material reported released		Some of the quantity spilled is generally recovered, and is not a permanent release to the environment. Amount recovered is not measured.
Roadkill	• Approximate number of animals killed			

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
4. Motor Vehicle Maintenance and Support				
Releases during terminal operations: tank truck cleaning, maintenance, repair, and refueling	(Data unavailable)	• Quantity of VOCs emitted	• Number of terminals and types of materials used during terminal operations	
Releases during passenger vehicle cleaning, maintenance, repair, and refueling	(Data unavailable)	(Data unavailable)	• Percentage of transit agencies that wash bus fleets daily	
Leaking underground storage tanks (USTs) containing fuel	• States reporting leaking USTs to be a significant source of ground water contamination	• Number of confirmed releases from storage tanks	• Number of active petroleum USTs	Some of the quantity released is generally recovered or cleaned-up, and is not a permanent release to the environment. Amount recovered is not measured.
5. Disposal of Vehicles and Parts				
Scrappage of vehicles	(Data unavailable)	(Data unavailable)	• Number of vehicles scrapped, quantity of various materials in vehicle, percentage of mass landfilled	Percentage of all landfilled material is known.
Motor oil disposal	(Data unavailable)	(Data unavailable)	• Quantity of used motor oil improperly disposed of	Improperly disposed oil's share of total motor oil disposed has also been estimated.
Tire disposal	(Data unavailable)	(Data unavailable)	• Quantity of used tires landfilled or stockpiled	Recovery/recycle rate for used tires and their share of the solid waste stream have also been estimated.
Lead-acid batteries disposal	(Data unavailable)	(Data unavailable)	• Quantity of lead-acid batteries discarded into municipal waste stream	Recovery/recycle rate for spent batteries and their share of lead and total tonnage in the solid waste stream have also been estimated.

1. ROAD CONSTRUCTION AND MAINTENANCE

Because of the space and infrastructure required by some roads, particularly multi-lane freeways, the construction and maintenance of roads can have a significant impact on natural resources in and around the right of way. Common problems associated with infrastructure include habitat disruption, hydrologic alterations, and polluted runoff. In addition, road construction activities may have temporary, but significant, environmental impacts caused by land take for depots and road hauls, drilling and excavation activities, disposal of excess material, discovery of hazardous material in the right-of-way, and use of construction machinery. Such impacts are discussed below, and further material on infrastructure is available in Appendix A.



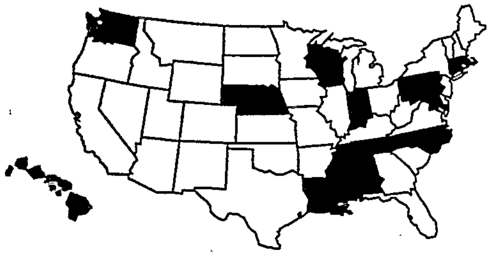
HABITAT DISRUPTION AND LAND TAKE FOR ROAD AND RIGHT-OF-WAY

PRESENTATION OF INDICATORS

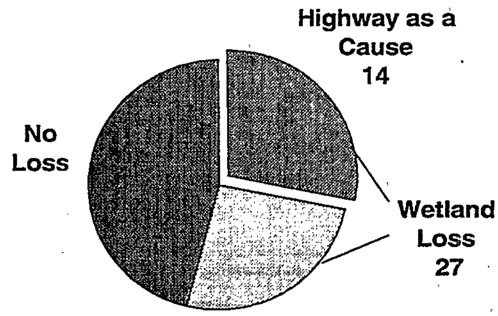
QUANTIFIED OUTCOME/RESULTS INDICATORS

- Of the 27 states that listed wetlands losses in their 1992 305(b) reports, 14 states reported they had losses due to highway construction (U.S. EPA, 1994b). Other sources of loss included agriculture (21 states), commercial development (19 states), and residential development (16 states).

States Reporting Loss of Wetlands Due to Highways



States Reporting Wetlands Loss



Source: U.S. EPA, 1994b.

- Eight states reported that road construction was a source of degraded wetlands integrity, out of 14 states that describe wetland integrity impacts (U.S. EPA, 1994b). Most states do not quantify wetlands areas affected by pollutants and their sources.

QUANTIFIED OUTPUT INDICATORS

- Nationwide, roads take up approximately 10.93 million acres of land, or 17,080 square miles of land, not including road shoulders and medians (Apogee estimate).[30] Of this total:
  - Rural roads and highways take up approximately 8.47 million acres of land or 13,240 square miles of land. This area is larger than that of the state of Maryland.
  - Urban roads and highways take up approximately 2.46 million acres of land or 3,840 square miles of land. This area is larger than that of the state of Delaware.
- Nationwide, roads occupy less than 0.5 percent of U.S. land area (Apogee estimate).[31]
- Interstate highways occupy approximately 457 square miles of land, or less than 0.01 percent of U.S. land area.[32]
- In 1993, roads (including local and unpaved roads) occupied an average of about 1.1 mile of road per square mile of land (however, the amount of roads per square mile in urban areas is significantly higher) (Apogee estimate).[33]
- In 1993, interstate highways occupied an average of about 23 yards (0.013 mile) of road per square mile of land in the U.S. (Apogee estimate).[34]

QUANTIFIED ACTIVITY INDICATORS

- Between 1983 and 1993, there was a net increase of 25,083 road miles in the U.S., a 0.6 percent increase in road-mileage during the 10-year period (FHWA, 1995e).

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[30] Values calculated based on number of lane miles in 1993 times average width per type of road: Interstate highways-12 ft., Rural other arterials-11.9 ft., urban other arterials-11.8 ft., rural collectors-11 ft, urban collectors-11.3 ft., local roads-11 ft. (U.S. DOT, FHWA, 1994c).

[31] 17,080 square miles of land, as calculated above, divided by 3,536,278 square miles U.S. land area.

[32] Values calculated based on number of lane-miles in 1993 times average width per interstate highways (12 ft). (U.S. DOT, FHWA, 1994c).

[33] 3,904,721 miles of road (U.S. DOT, FHWA, 1994c) per 3,536,278 square miles U.S. land area.

[34] 45,530 miles of interstate highway (U.S. DOT, FHWA, 1994c) per 3,536,278 square miles U.S. land area.

- Between 1988 and 1993, there was a net increase of 41,605 lane miles in the U.S. on non-local roads (interstate, other arterials, and collectors), a 1.5 percent increase in lane-mileage during the 5-year period (Apogee estimate).[35]
- In 1993, roadway projects under construction consisted of 504 miles of new routes and 3,188 miles of capacity additions (FHWA, 1994c).
- From 1989 to 1993, an average of 13,724 miles of roadway were under construction in each of the 5 years. System preservation represents the largest portion of roadway projects. Construction of new routes fell by 24 percent nationwide between 1989 and 1993. Growth rates in some regions, however, are much higher (FHWA, 1994c).
- From 1989 to 1993, an average of 529 miles of new routes and 2,933 miles of capacity additions were under construction annually (FHWA, 1994c).[36]

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- Some states track acreage of wetlands lost and gained as a result of highway construction, with the objective of realizing no net loss (e.g., Florida, Kentucky, New Jersey) (SRI International, 1993).
- Florida and Oregon track the number and type of endangered or threatened species impacted by highway construction and operation (SRI International, 1993).
- Four states (13 percent of those responding) have conducted studies on biodiversity effects of highways: Louisiana, West Virginia, Virginia, and Pennsylvania (Herbstritt and Marble, 1996).
- Wisconsin reports that from 1982 to 1989, a total of 11,800 acres of wetlands were lost due to permitted discharges of dredged or fill material from state DOT highway projects, or almost 70 acres per year (U.S. EPA, 1994b).

DESCRIPTION OF IMPACT

Viewed in broad, relative terms, the habitat impacts of road construction have taken place over decades, and new impacts are now growing at an extremely low rate. While a substantial amount of construction occurred in the past, road mileage is barely increasing nationwide. The habitat impacts of existing infrastructure, however, are ongoing in the sense that habitats remain fragmented as long as they are divided by roads. Furthermore, road construction in certain high-growth locations and near sensitive habitats can still have significant impacts.

The total land area occupied by all existing roads is relatively small: all roads, paved and unpaved, occupy less than 0.5 percent of U.S. land area. This may be contrasted with forests, which cover roughly 31 percent of the country, and land used for crops and pasture, which also covers large percentages of the country (WRI, 1994). Even wetlands still cover about 5 percent of the lower 48 states (Dahl and Johnson, 1991), and the 39 largest metropolitan areas cover about 5 percent of U.S. land. This makes clear that roads themselves, and even cities, do not occupy a very large amount of potential habitat in simple percentage terms. Their impact on habitat results more from indirect effects on surrounding habitat and bodies of water than from actual displacement of acreage, as discussed below. In addition, the physical land area estimates reported above underestimate the extent of total

[35] Lane miles on non-local roads increased from 2,733,309 miles in 1988 to 2,774,914 miles in 1993 (U.S. DOT, FHWA, 1994c and 1988 edition).
[36] Note that construction on a project may span more than one year.

habitat affected by highways since they exclude road shoulders and medians, and transport-related areas, such as parking lots, garages, and gas stations.

Introducing roads and associated infrastructure into the environment has led to the destruction or disruption of habitats in the right-of-way. Roads damage existing vegetation, interfere with wildlife crossings, displace forests and communities of animals and birds, and alter the hydrology of various areas, including drainage, permeability, and stream flow patterns.

Roads split natural habitats such as forests, causing "fragmentation," decreasing habitat size and reducing interaction with other communities. This fragmentation is known to produce declines in both the number of species (diversity) and their populations (abundance) (Tolley, 1995). A study of the influence of narrow forest-dividing corridors (small roads and powerlines) on forest-nesting birds in southern New Jersey revealed that, although not generally viewed as sources of forest fragmentation, such corridors measurably affect the diversity and abundance of birds in ways that are associated typically with the effects of forest fragmentation (Rich et al., 1994).

Highway construction has also been cited as an activity that contributes to wetlands destruction and loss of mangroves, seagrass, marshes, and swamps—habitats that support a diverse range of species and provide other desirable functions such as flood control (Hall and Naik, 1989 as cited in Barrett et al., 1993). In the past 200 years, the U.S. has lost over half of the original wetlands acreage in the 48 coterminous states. In recent years, 300,000 acres have been lost annually, or a 3 percent loss per decade. Over half of these recent losses have been caused by conversion to agricultural use, and only 4 percent were identified as conversion to urban land (Dahl and Johnson, 1991). The amount of wetlands acreage lost annually is over 20 times higher than the amount of new land used by roads. Furthermore, compensatory mitigation efforts are currently undertaken to mitigate for unavoidable habitat loss, under a "no net loss" policy. However, a FHWA study evaluating the success of 23 highway-related wetland mitigation projects indicated that very few of the sites resulted in full replacement of all wetland functions lost to construction (U.S. DOT, 1992). Also, as stated in the indicators above, some states still report wetlands loss due to highways.

Wetlands are an important resource. Wetlands are essential to over half of the endangered fish species and half of the endangered amphibian species in the U.S. (Water Environment Federation, 1992). As some scholars suggest, "Destruction and modification of habitat are probably the most serious causes of falling amphibian populations [worldwide]. Like other animals, amphibians are threatened when forests are destroyed and wetlands are filled in or paved. Indeed, such activities probably account for the decrease in a majority of species threatened today...The loss...deserves attention...because frogs and their kin...may serve as indicators of the overall condition of the environment." (Blaustein and Wake, 1995) Wetlands also provide economic benefits: a $28 million sport fishing industry and two thirds of commercially harvested fish and shellfish species (Water Environment Federation, 1992).

Runoff from construction sites can cause erosion, sedimentation, and other changes disrupting aquatic habitats such as fish-spawning areas and river-bottom habitats. Suspended solids reduce the aquatic food supply by blocking light and reducing photosynthesis. They also abrade aquatic organisms, affect fishing and recreation uses, and reduce capacities in downstream reservoirs (Barrett, 1995).

Construction of roads can also reduce water storage and spring flow, threatening species during droughts. When natural ground cover is present over an entire site, normally less than 10 percent of the stormwater runs off into nearby rivers and lakes. As paved surfaces increase, both the volume and the rate of runoff increase. When paved surfaces cover 10-30 percent of the site area, approximately

20 percent of the stormwater can be expected to run off (U.S. EPA, 1982). Pollutants, washed from land surfaces and carried by runoff into lakes and streams, may add to existing water quality problems, as discussed in the section on runoff impacts.[37] Furthermore, paved surfaces prevent natural infiltration of stormwater into the ground.

Other road transportation infrastructure, such as buildings and bridges, also may have habitat impacts. For example, bridges and stream crossings are likely to have significant impacts on hydrology and aquatic habitat. However, the physical extent of roads is far greater than that of these other structures.

CAUSAL FACTORS

- Size of habitat fragments between roads and width of corridors
- Lane-miles of new road (widening and new routes)
- Bridges and other highway infrastructure constructed
- Type of construction activity (maintenance versus capacity expansion)
- Type of road surface (paved/unpaved)
- Successful implementation of various efforts to avoid or mitigate impacts (e.g., wildlife crossings)
- Ecological conditions/type of land (i.e., wetlands, forest, etc.)
- Species/habitat in and near the right of way

EMISSIONS DURING CONSTRUCTION AND MAINTENANCE

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- New building and major land development projects, including highway construction, produce sediment and toxic materials which are estimated to degrade up to 5 percent of the nation's surface waters (Griffen, 1991). The contribution of highway construction is unknown, but is most likely a small proportion.

QUANTIFIED OUTPUT INDICATORS

- National statistics for emissions from transportation-related construction activities are generally not available. At the local level, emissions from construction are discussed on a case-by-case basis in the project's EIS.
- Construction activity impacts, though localized, may generate sediment levels 10-20 times greater than agricultural land uses, affecting aquatic habitat (Griffen, 1991).
- Contamination is often reported as encountered in highway maintenance.

[37] For a more detailed discussion on pollutants contained in urban runoff, see the section, "Highway and Road Runoff."

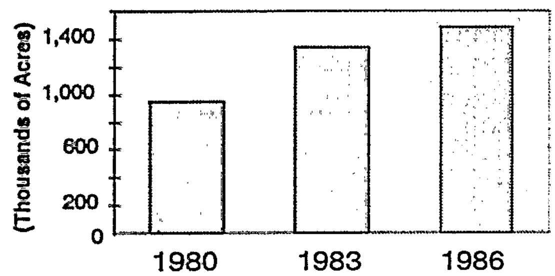
CONTAMINATION ENCOUNTERED IN HIGHWAY OPERATIONS AND MAINTENANCE
(NCHRP, 1993; based on telephone survey of 16 states[38])

- **Lead Paint:** All states reported that lead paint residues from bridges were a problem.
- **Solvents and Pesticides:** Four states had significant problems with solvents and pesticides at maintenance yards and with solvents as laboratory wastes, from asphalts in particular.
- **Salt:** Two states had problems with salt runoff from maintenance stockpiles contaminating groundwater.
- **General Maintenance:** Six states volunteered that they had problems at their maintenance facilities.

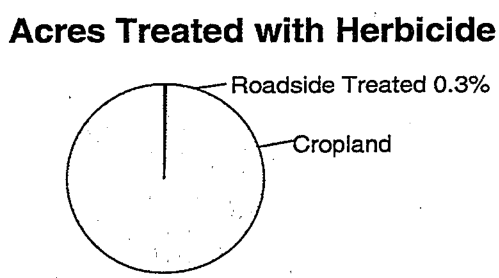
Quantified Activity Indicators

- Between 4.1 to 12 million tons crude oil equivalent were required to lay the 25,083 miles of new road constructed in the U.S. between 1983 and 1993 (VHB, 1992; FHWA, 1995e).
- Approximately 90 percent of the steel bridges in the U.S. are protected from corrosion with lead-based paints. Use of such paints can lead to significant containment and disposal problems (Pinney, 1995).
- In 1986, herbicides (e.g., Roundup and 2,4-D) were used on 1.5 million roadside acres in the 38 states reporting. Acreage treated rose 56 percent from 1982-1986 while reported acreage of responsibility fell by 6 percent (TRB, 1988).

Roadside Acres Treated with Herbicides



Source: TRB, 1988.



Source: TRB, 1988

Other Indicators and Local Examples

- Highway construction in West Virginia uncovered pits and caverns overlaying an aquifer supplying a fish hatchery. Large quantities of clay and silt washed into the caverns, resulting in very turbid springflow during storms. In one dramatic (not typical) event, more than 150,000 trout died due to silt build-up on their gills (Garton, 1977 as cited in Barrett et al., 1993).
- Repainting of the Verrazano Bridge is expected to generate 2,800 tons of hazardous waste, and will involve a containment system with negative air pressure to capture paint spray (Greenman et al., 1995).

[38] States surveyed: Alaska, Arizona, Florida, Illinois, Louisiana, Minnesota, Missouri, Montana, New Hampshire, New York, Oregon, Pennsylvania, Tennessee, Texas, Virginia, and Washington.

DESCRIPTION OF IMPACT

The quantity of emissions from construction operations is related to the area of land being worked and the type and level of construction activity. The environmental impact of any particular project depends on the location and condition of the surrounding area, the size and type of road constructed, and the project's duration. Environmental impacts will also vary according to construction techniques and pollution management techniques employed, as well as mitigation measures undertaken. Emissions during road construction are associated with land clearing, blasting, ground excavation, and cut and fill operations. The construction of the facility itself may cause changes in turbidity, suspended solids concentration, and color of receiving waters. Temporary storage facilities for equipment and supplies used during the construction phase may also damage vegetation and displace communities of animals. Note that it is difficult to isolate the effects of highway construction from the effects of land-use changes, socioeconomic changes, and natural ecological changes in receiving water bodies.

Dust emissions, much of which result from equipment traffic over temporary roads at the construction site, may have substantial temporary impacts on local air and water quality. Construction can also affect the environment through exhaust emissions from machinery and haulage vehicles, spillage during refueling, and noise. In general, between 270 and 800 tons of crude oil equivalent are required to lay 1 mile of a paved four-lane highway (OECD, 1988 as cited in VHB, 1992). This figure does not include energy used in asphalt production or preparing the ground for paving. Based on this estimate, between 4.1 to 12 million tons crude oil equivalent would be required to lay the 25,083 miles of new road constructed in the U.S. between 1983 and 1993 if they all consisted of paved highway (Apogee estimate).

Hazardous waste in the right-of-way is another type of problem associated with road construction and maintenance. Sometimes the problem is discovered when a major project unexpectedly runs into hazardous waste during construction. The most common problems encountered by DOTs working in the right-of-way are asbestos, underground storage tanks (USTs) (usually storing gasoline, diesel, or other petroleum products), and other petroleum wastes, but the range of potential hazardous wastes also includes organic and inorganic compounds, pesticides, cyanides, corrosives, and biological and radioactive wastes (NCHRP, 1993).

Often, road maintenance facilities and operations are themselves the source of hazardous waste problems due to the use of hazardous materials, such as lead paint, solvents, and pesticides, in operations and maintenance activities. Some states track progress in replacing toxic products or improving processes used in construction and maintenance (e.g., Washington) (SRI International, 1993).

Lead-based paints were commonly used to paint bridges in the first half of this century; zinc-based paints have been used more recently. There is a potential for contaminant releases where toxic substances are utilized during construction and maintenance. For example, heavy metals have been found to create health and environmental problems, and elevated levels of lead have been discovered in soils near bridges. Near the Golden Gate Bridge in San Francisco, highly contaminated sand and soils were fenced off and closed to the public and then were removed or treated (Witt, 1995).

Many bridges with lead-based paint are undergoing lead abatement and recoating efforts. The Manhattan Bridge in New York City is the site of the largest lead abatement and recoating project in the country, at a cost of $85 million (Greenman et al., 1995).

It should be noted that construction of new capacity also may induce additional travel, which would have environmental impacts as well. This indirect impact of construction is not considered here, since the impacts of travel are considered in the section on travel.

Causal Factors

- Level of construction activity
- Type and quantity of energy consumed during construction/maintenance activities
- Emissions control technologies for plant and equipment
- Quantity of hazardous material buried in the right of way and/or used in maintenance operations and how it is managed when found
- Topographical conditions (hills, valleys, etc.)
- Climatic conditions (temperature, wind, rain, etc.)
- Population density
- Local environmental resources/habitats

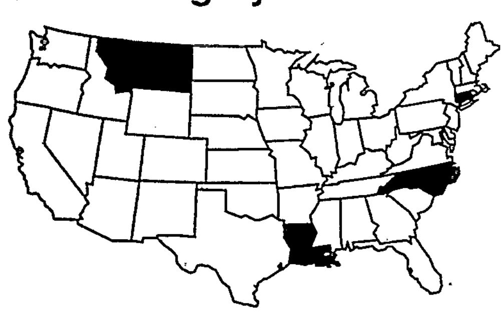
RELEASES OF DEICING COMPOUNDS

Presentation of Indicators

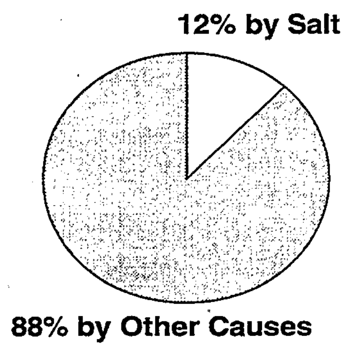
Quantified Outcome/Results Indicators

- Typically, 5-10 percent of trees along heavily traveled roads are affected by road salt application. Based on typical experiences in the states, salting of a hypothetical road could kill 1 to 25 roadside trees per year, depending on the road's salt application rates and proximity to trees (TRB, 1991).
- In 1992, 17 states in the U.S. reported that road salting is a significant source of ground water contamination, and four reported wetlands impacts from salinity (U.S. EPA, 1994b).
- Four states report degraded wetlands integrity due to salinity (U.S. EPA, 1994b).
- Salt was cited as a cause of 11 percent of impaired river miles in 1992 (U.S. EPA, 1994b).

States Reporting Degraded Wetlands Integrity Due to Salinity



Impaired River Miles



Source: U.S. EPA, 1994b.

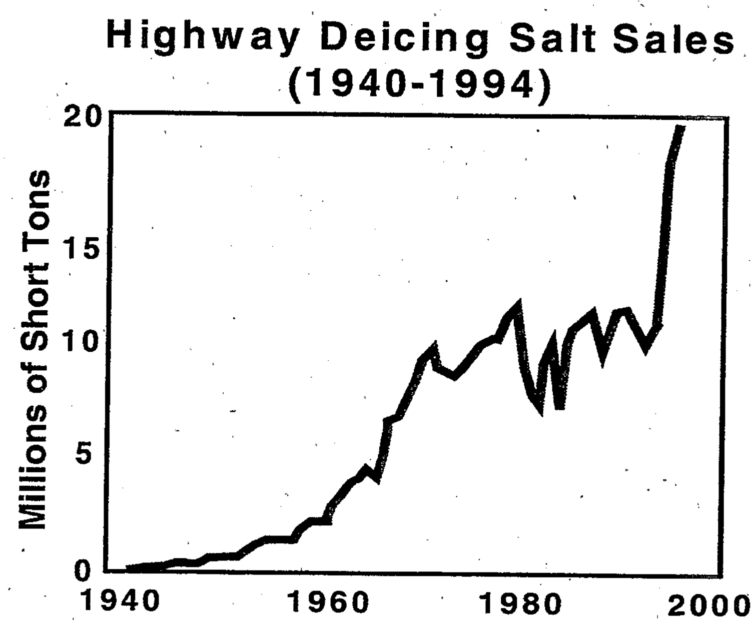
- Specific outcomes, including wildlife habitat damage, reduced fish stocks, loss of unique natural features, and corrosion damage to vehicles from increased salinity, are not quantified nationally.

QUANTIFIED OUTPUT INDICATORS

- No quantified data are available to estimate how much road salt enters groundwater, rivers, and lakes.

QUANTIFIED ACTIVITY INDICATORS

- In the past decade, 10 million tons of rock salt have been applied in a typical year, but 1994 and 1995 applications were unusually high, as shown in the graph below (Salt Institute, 1992).



OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- The cost of installing corrosion protection features during bridge deck construction and maintenance will total between $125-$325 million per year during the next 10 years, according to a TRB study. An equivalent amount will be spent on the protection and repair of other affected bridge components, such as structural components exposed to salt from splash, spray, and poor deck drainage (TR News, 1992).
- A study of streams 50-100 meters downstream from a highway in New York State found chloride concentrations up to 30 times higher than comparative upstream levels. Elevated levels lasted for 6 months after termination of winter salt application (Demers and Sage, 1990).

DESCRIPTION OF IMPACT

Rock salt is the principal deicing agent used in winter road maintenance throughout the nation. The use of road salt allows highway travel during snow conditions and is important for delivery of vital goods and services (including emergency support vehicles which save lives) to large segments of the country. Although salt is cheap and effective, it can cause adverse secondary effects. A recent literature review ranked the top three environmental impacts of road salt as (from most severe to least): 1) effects on roadside vegetation, 2) harm to soil structure, and 3) impacts on drinking water and aquatic life (TRB, 1991).

Road salt disintegrates pavements, corrodes auto bodies and bridges, pollutes groundwater, and alters the water chemistry of nearby lakes, rivers, and wetlands. Freshwater plants are often unable to survive in wetlands areas that receive high quantities of salt-polluted runoff. The actual extent of water contamination and habitat alteration per quantity of road salt used depend on highly site-specific conditions such as watershed characteristics, amount of runoff and/or snowmelt, and type of indigenous vegetation. The effect of deicing runoff is not limited to roadside vegetation: 90 percent of the salt applied to the street of Buffalo, NY, for example, enters into the city sewerage system and then reaches Lake Ontario (Tolley, 1995).

Calcium magnesium acetate (CMA) has been developed as an environmentally benign, non-corrosive alternative to road salt for deicing, but its application has been limited due to its higher price and greater volume demands. To be effective, it must be applied early in a storm and used in quantities 20-30 percent greater than salt. In addition, CMA is often less effective than salt in freezing rain, dry snow, or light traffic; and it costs 10-25 percent more. And although widespread use of CMA might reduce corrosion of motor vehicles and infrastructure components not already contaminated, its use would have little effect on many older infrastructure components already contaminated by salt (TR News, 1992). CMA has been extensively studied as an option (TRB, 1991).

CAUSAL FACTORS

- Amount of roadway deicing agent applied
- Type of deicing agent used
- Climate/weather conditions (amount of snow, ice, rainfall)
- Amount of high salinity runoff/snowmelt that reaches bodies of water (based on runoff controls and local geography)
- Depth of groundwater table
- Sensitivity of nearby habitats

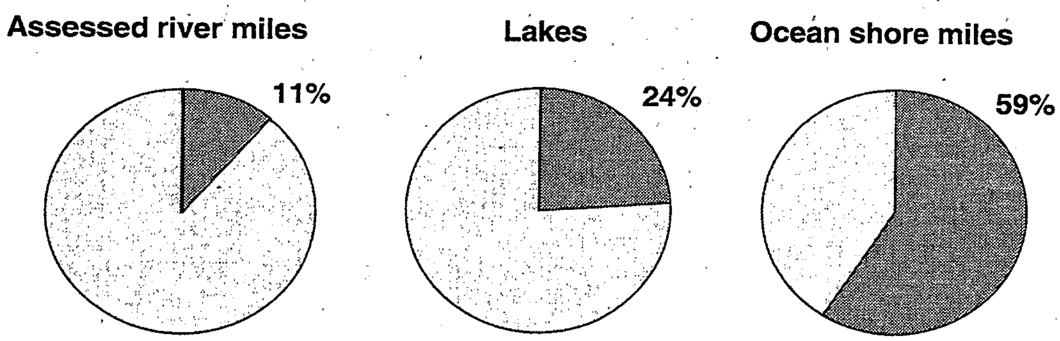
HIGHWAY RUNOFF

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- In 1992, urban runoff contributed to the impairment of 11 percent of the nation's assessed river miles, 24 percent of assessed lake acres, and 59 percent of assessed ocean shore miles. It was cited as a major source of impairment for 5-15 percent of assessed surface water bodies (U.S. EPA, 1994b). The exact contribution of transportation to urban runoff is not known, but it is expected to be large, since road surfaces occupy a significant portion of land in urban areas, 19 percent according to Tolley, 1995.

Percentage Impaired by Urban Runoff



Source: U.S. EPA, 1994b.

QUANTIFIED OUTPUT INDICATORS

- Average pollutant concentrations of lead and copper in road runoff are more than twice as great as those from residential and commercial areas (U.S. DOT, 1986; U.S. EPA, 1983).
- Pollutant concentration levels in highway runoff exceed concentrations from residential and commercial areas (see table).
- Oil and grease in road runoff may total hundreds of thousands of tons per year (Apogee estimate).[39]

[39] Simply as an example to provide perspective, suppose that a meter of rainfall and water in the form of snow is typical per year (not an unreasonable figure, at least for some parts of the country). This means that roughly a meter of water falls on a square meter of pavement, or a volume of 1 cubic meter of water per year. If oil and grease concentration in this water is 9 mg/l as it runs off, the mass of oil and grease in this cubic meter would be 9 grams. This would equal almost a metric ton of oil and grease per year per 100,000 square meters of road surface (a length of road 10 meters wide and 10 km long). Assuming roughly 3 meters width per lane and perhaps about 4 million paved lane-miles, there are approximately 20,000 square kilometers of paved road in the U.S.

The above implies there could be 200,000 metric tons of oil and grease in road runoff annually nationwide if the above assumptions were valid (actual average rainfall may be half as high). It is worth noting that this very crude estimate corresponds to a scenario where the average U.S. vehicle (of which there are roughly 200 million) leaks 1 liter of oil and grease onto roads per year, or less than one tenth of a quart per month (assuming oil has the density of water for simplicity here). This average rate of leakage seems at least plausible. It is also worth noting that if such loadings are occurring, they are larger than estimated improper disposal of used motor oil and larger than reported air or water releases of many pollutants in auto manufacture.

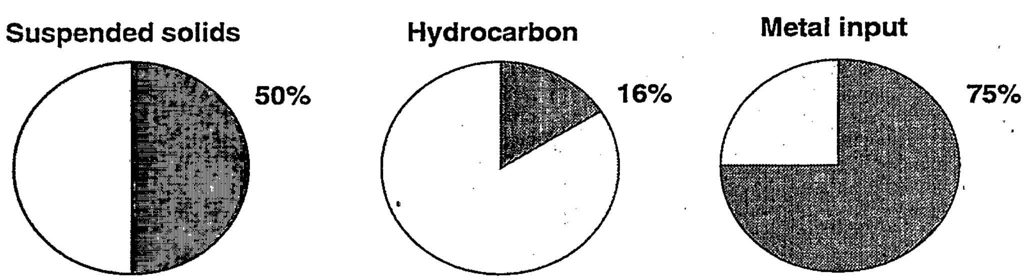
Selected Road and Highway Storm Water Pollutant Concentrations and Comparisons with Typical Runoff from Residential and Commercial Areas

Constituent	Road/Highway Runoff Mean Concentration (mg/l)	Runoff from Residential and Commercial Areas (mg/l)
BOD (biological oxygen demand)	24	12
COD (chemical oxygen demand)	160	94
TKN (a measure of nitrogen)	3.0	2.3
Total Phosphate	0.9	0.5
Lead	4.3	0.24
Copper	0.19	0.053
Cadmium	0.02	-
Nickel	5.0	-
Oil and grease	9	-
PAHs (polycyclic aromatic hydrocarbons)	4.6	-
Pesticides/Herbicides	0.03	-
PCBs (polychlorinated biphenyls)	0.335	-

Source: U.S. DOT, 1986; U.S. EPA, 1982 as cited in Weiss, 1993. Note: lead levels have dropped considerably since these estimates were developed.

- ♦ Highways have been found to contribute up to 50 percent of suspended solids, 16 percent of hydrocarbons, and 75 percent of metals in some streams (Hamilton and Harrison, 1991).

Highway Contribution to Some Streams: Loading



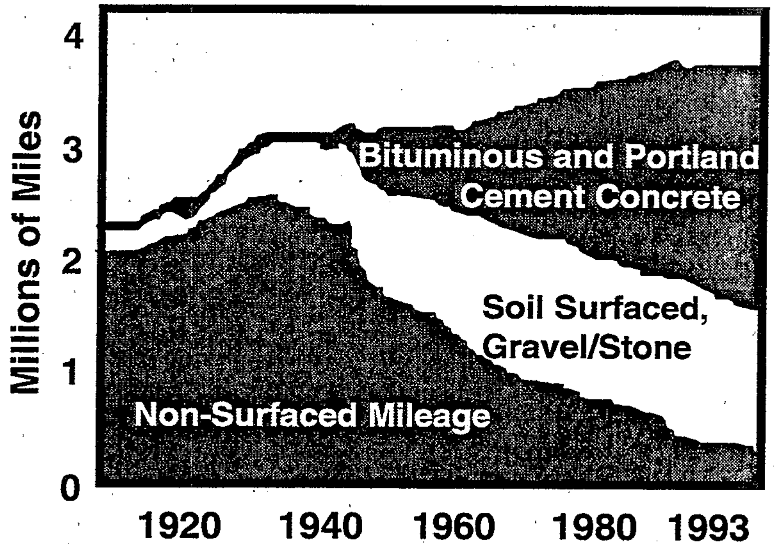
Source: Hamilton and Harrison, 1991.

The impacts of runoff, of course, depend on many factors other than tons emitted. Oil and grease may undergo biodegradation and dilution before they ever reach any body of water or sensitive ecosystem.

QUANTIFIED ACTIVITY INDICATORS

- ♦ Roads occupy about 19 percent of the surface areas in large cities (Tolley, 1995).
- ♦ The percentage of roads in the U.S. that are paved has increased from about 27.3 percent in 1953 to 58.2 percent in 1993 (FHWA, 1994c).

Total Road and Street Mileage in the United States By Surface Type (1900-1993)



Source: FHWA, 1995c

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- Of the vehicle-related particulates in highway runoff, 37 percent come from tire wear, 37 percent from pavement wear, 18.5 percent from engine and brake wear, and 7.5 percent from settleable exhaust (PEDCO as cited in Hamilton and Harris, 1991).
- One study of runoff in California's Santa Clara Valley found that vehicles were the source of 67 percent of the zinc, 50 percent of the copper, and 50 percent of the cadmium found in runoff. (Santa Clara Valley Nonpoint Source Pollution Control Program as cited in Weiss, 1993)
- In a study to assess the effects of highway construction on water quantity and quality in creeks near construction in the Edwards aquifer (Texas) district, downstream concentrations of total suspended solids below the right-of-way during construction of a highway in Texas were roughly 10 times greater than before construction began. Flow rate in the creek nearby also increased significantly due to increased impermeable ground cover. Silt fences sometimes used to control such sediment were found to be ineffective in the Texas study, and problems were also seen in the expensive runoff control systems used (a sedimentation basin and sand filter). (Barrett et al., 1995)
- Over 50 percent of the annual pollutant loads in entering a section of the Pawtuxet River adjacent to I-95 in Rhode Island came from highway runoff (Hoffman, 1985).
- Investigations on a small Norwegian lake ecosystem found that the road had no effects on oxygen condition but considerable effects on conductivity and high concentrations of cadmium, zinc, sodium, and chloride. Also the diversity and abundance of the benthic communities near the highway were reduced relative to a control location (Baekken, 1994).

DESCRIPTION OF IMPACT

Highway contaminants are deposited on roadway surfaces, median areas, and rights-of-way from atmospheric fallout, fuel combustion processes, lubrication system losses, tire and brake wear, transportation load losses, deicing agents, and paint from infrastructure. During storm events, rainwater first washes out atmospheric pollutants and, upon surface impact (or snowmelt), picks up roadway deposits, and runs off into receiving water bodies. This highway runoff can be highly polluted and have negative impacts—such as sedimentation, eutrophication, accumulation of pollutants in sediments and benthic organisms, and destruction of native species—on receiving waters.

Runoff from roads is affected by both the amount and type of infrastructure (paved or unpaved surfaces), as well as by the amount of travel.[40] Whether the road is paved or not has a great effect on runoff. Pavement and structures may cover soils and destroy vegetation that would otherwise slow and absorb runoff before it reaches receiving bodies of water. The graph above shows that while road mileage has not been growing especially quickly, paved mileage has been growing very rapidly. This has implications for increased runoff impacts, but also has other implications, such as reduced particulate emissions from reentrained dust and perhaps higher speeds of travel and greater emissions per VMT for certain pollutants. Although these tradeoffs are not discussed further here, the trend in paved mileage is notable.

FHWA research in the 1970s on highway runoff water quality found that runoff had significant effects only from highways with traffic volumes greater than 30,000 vehicles per day (major freeways and urban arterials). Average daily traffic (ADT) has a strong influence on the quality of stormwater as it leaves the highway; because ADT levels are higher in urban areas than rural locations, pollutant levels in highway runoff are higher in urban areas.

The impacts and significance of roadway runoff are highly site-specific. The quantity of runoff generated depends on the frequency, intensity, and duration of precipitation in an area. The water quality characteristics of runoff are affected by local air quality (because of deposition of air pollutants onto roads) and, to some extent, the level of traffic activity. The quantity of pollutants originating from highways and motor vehicles, however, is not well understood as pollutants are hard to measure and vary by location.

Pollutants found in runoff are generally classified under six broad categories: suspended solids or particulates, oxygen-consuming constituents (BOD, COD), nutrients, heavy metals, trace organics, and microorganisms. Direct vehicle deposits are a major source of particulates and heavy metals: settleable exhaust, copper from brake pads, tire and asphalt wear deposits, and drips of oil, grease, antifreeze, hydraulic fluids, and cleaning agents. An estimated 46 percent of vehicles on U.S. roads leak hazardous fluids (AAMA, 1990). Indirectly, vehicles also contribute by carrying solids from parking lots, urban roadways, construction sites, farms, and dirt roads. More than 95 percent of the solids on roadways originate from sources other than the vehicles themselves (Barrett et al., 1993). Secondary runoff pollutant sources associated with vehicular traffic include gas stations and other auto-related facilities, oil production and transportation operations, petroleum refineries, and improper disposal of used motor oil. Nitrogen and phosphorus-based nutrients generally originate from atmospheric and roadside fertilizer applications. Atmospheric deposition is the main source of PCBs.

[40] Note that this impact is discussed here alone rather than in both this section and the road vehicle travel section.

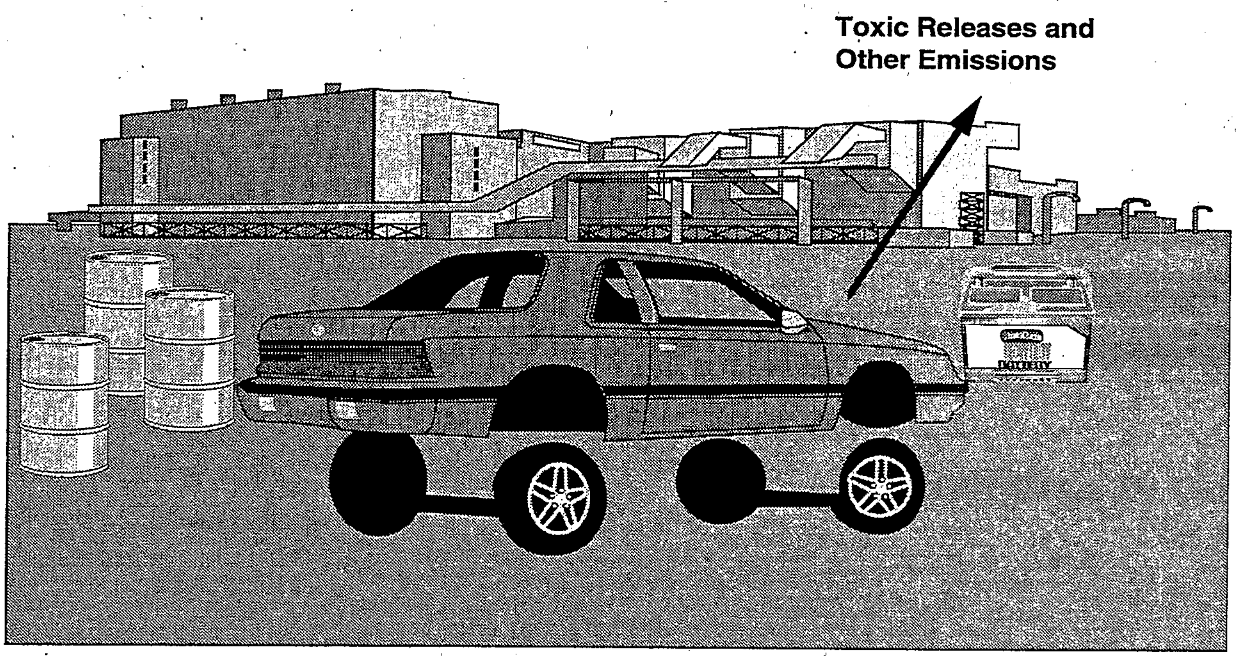
These pollutants can harm the environment in various ways. Oxygen consumption (from high BOD) harms aquatic life, while nutrients cause eutrophication, where excess aquatic plant growth can block sunlight, also harming aquatic life. Toxic substances can affect human health or various plant or animal species.

CAUSAL FACTORS

- Level of traffic activity: the number of vehicles during a storm event (VPS) is a better determinant of pollutant loading than the average daily traffic (ADT) or antecedent dry period (Barrett et al., 1993). DOT considers impacts negligible on roads with less than 30,000 ADT. Levels over 30,000 ADT are not very common outside urban areas, though some roads surpass 200,000 ADT.
- Rate of deposition of contaminants on road surface per vehicle
- Paved surface area (see graphic on growth in paved surface above)
- Precipitation activity: antecedent dry period, storm intensity and duration, total amount of rainfall/snowmelt
- Drainage characteristics
- Ecology and other aspects of receiving water bodies: type, size, diversity, potential for dispersion
- Toxicity and chemical/physical characteristics of pollutants

2. MOTOR VEHICLE AND PARTS MANUFACTURE

The manufacture of motor vehicles and parts results in environmental impacts through the release of toxics and other pollutants to the air, soil, and water.



TOXIC RELEASES AND OTHER EMISSIONS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No quantified data on human health impacts, such as increased incidence of cancer from toxics, or habitat and species impacts are available.

QUANTIFIED OUTPUT INDICATORS

- 114.5 million pounds (or about 57,000 tons) of toxic chemicals were reported released on-site from vehicle manufacturing facilities in 1993 (see table).[41]

[41] Note that these figures do not include impacts of equipment and parts manufactured outside the U.S. but do count impacts of exported U.S. products.

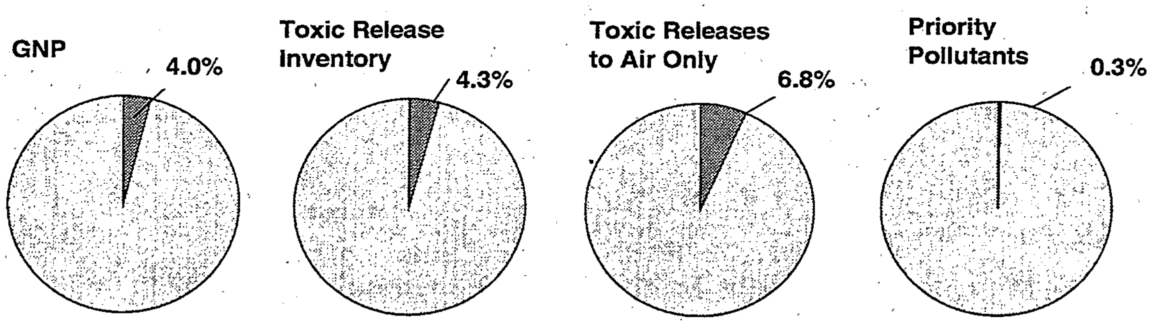
Toxic Chemicals Released from Vehicle Manufacturing Facilities and Related Sources (Pounds per Year)

SIC Code	Industry Type	On-Site Releases					
		Air	Water	Land	Total	POTW Transfer	Off-Site Locations Transfer
3711	Motor Vehicles & Passenger Car Bodies	52,878,028	3,038	255	52,881,321	2,519,072	51,603,667
3713	Truck & Bus Bodies	12,977,951	3,916	3,983	12,985,850	260,887	15,907,099
3714	Motor Vehicle Parts & Accessories	34,540,544	147,394	1,348,978	36,036,916	890,432	112,999,744
3715	Truck Trailers	2,522,371	27	1,500	2,523,898	1,894	6,223,948
3716	Motor Homes	2,680,082	-	-	2,680,082	250	395,759
3537	Industrial Trucks, Tractors, Trailers & Stackers	561,110	10	5	561,125	10,000	672,320
3751	Motorcycles, Bicycles & Parts	6,740,758	8,209	-	6,748,967	3,029	6,033,915
4213	Trucking (No Local)	56,763	-	10	56,773	-	27,705
5013	Wholesale-Motor Vehicle Supplies & New Parts	12,259	60	-	12,319	-	7,075,069
	TOTAL HIGHWAY VEHICLES	*112,969,866*	*162,654*	*1,354,731*	*114,487,251*	*3,685,564*	*200,939,226*

Source: Toxic Releases Inventory, 1993
POTW = Publicly owned treatment works
SIC = Standard Industrial Classification

- About 33 percent of the industry's TRI wastes were managed through on-site recycling, energy recovery, or treatment rather than being released or transferred in 1993 (U.S. EPA, 1995b).
- In 1993, 609 facilities reported TRI releases in the motor vehicle manufacturing industry (only large facilities are required to report), and the average facility reported 130,000 pounds (65 tons) of toxic releases.

Vehicle Manufacturing Industry's Contribution to:



- The motor vehicles, bodies, parts, and accessories industries also emit the following quantities of other pollutants per year:

Other Emissions from Vehicle Manufacturing Facilities

Pollutant	Short tons per year emitted in these industries	U.S. total for all industries	Percentage of total for all industries
CO	35,303	97,208,000	0.04%
NO_2	23,725	23,402,000	0.10%
PM-10	2,406	45,489,000	0.01%
TP	12,853	7,836,000	0.16%
SO_2	25,462	21,888,000	0.12%
VOC	101,275	23,312,000	0.43%

Source: U.S. EPA, Office of Air and Radiation, AIRS Database, May 1995.

- It is noteworthy that emissions from vehicle travel are much higher than emissions from vehicle manufacture, at least for several key pollutants.

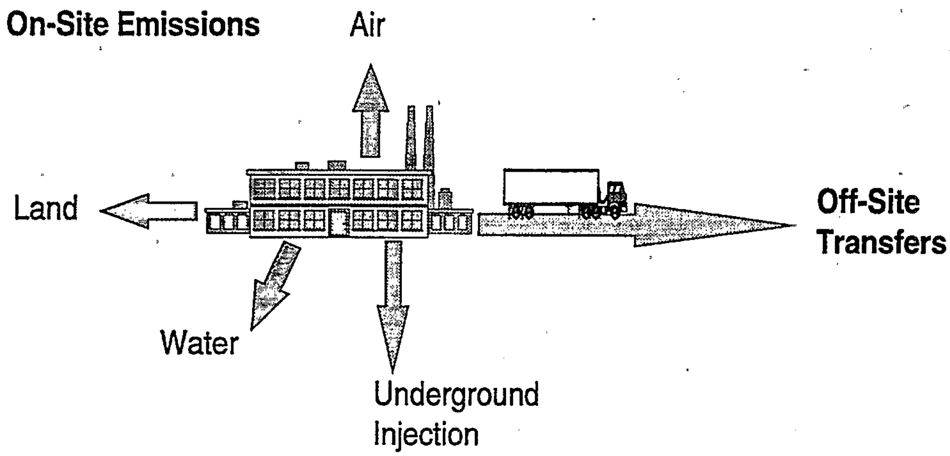
OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- One General Motors assembly plant has reduced packaging waste going to landfills per vehicle to less than one pound per vehicle (U.S. EPA, 1995b).

DESCRIPTION OF IMPACT

The motor vehicle and equipment industry is the largest manufacturing industry in North America, accounting for about 4 percent of gross national product (GNP). There are approximately 4,467 motor vehicle and equipment facilities in the U.S., 39 percent of which are in the Great Lakes Region (U.S. EPA, 1995b).

The manufacture of automobiles, trucks, and other road vehicles involves the use of a variety of materials and chemicals. During the manufacturing process, toxic chemicals are released from vehicle manufacturing facilities into the environment. Releases occur as on-site discharges of toxic chemicals, including emissions to the air, discharges to water, releases to land, and contained disposal or injection underground. Chemicals are transferred off-site when they are shipped to other locations, as the following diagram shows.



On-site releases to air occur as either stack emissions, through confined air streams such as stacks or vents, or fugitive emissions, which include equipment leaks, evaporative losses from surface impoundments and spills, and releases from building ventilation systems. Surface water releases occur through process and treatment discharge pipes, as well as diffuse runoff from the plant site. Releases to land may result from landfills, surface impoundments, and other types of land disposal within the boundaries of the reporting facility. Underground injection is a contained release of a fluid into a subsurface well for the purpose of waste disposal.

Off-site transfers represent a movement of the material or chemical away from the reporting facility. However, except for off-site transfers for disposal, these quantities do not necessarily represent entry of the chemical into the environment. Chemicals are often shipped to other locations for recycling, energy recovery, or treatment. In many cases, transfers are to publicly owned treatment works (POTWs). Wastewaters are transferred through pipes or sewers to a POTW, where treatment or removal of a material or chemical from the water depends upon the nature of the chemical and treatment methods used. Some chemicals are destroyed in treatment. Others evaporate into the atmosphere. Some are removed but are not destroyed by treatment and may be disposed of in landfills (U.S. EPA, 1992).

The top five toxic pollutants (by volume) reported released include xylene, glycol ethers, toluene, methyl isobutyl ketone, and N-butyl alcohol. These are solvents used to clean equipment and metal parts and used in many coatings and finishes (U.S. EPA, 1995b). It should also be noted that the industry has reduced toxic releases considerably in the recent years.

Other non-toxic air pollutant are emitted by the motor vehicle manufacturing industry, such as carbon monoxide (CO), particulate matter (PM), and volatile organic compounds (VOCs). These pollutants can cause human health effects, as well as materials damage and visibility degradation.

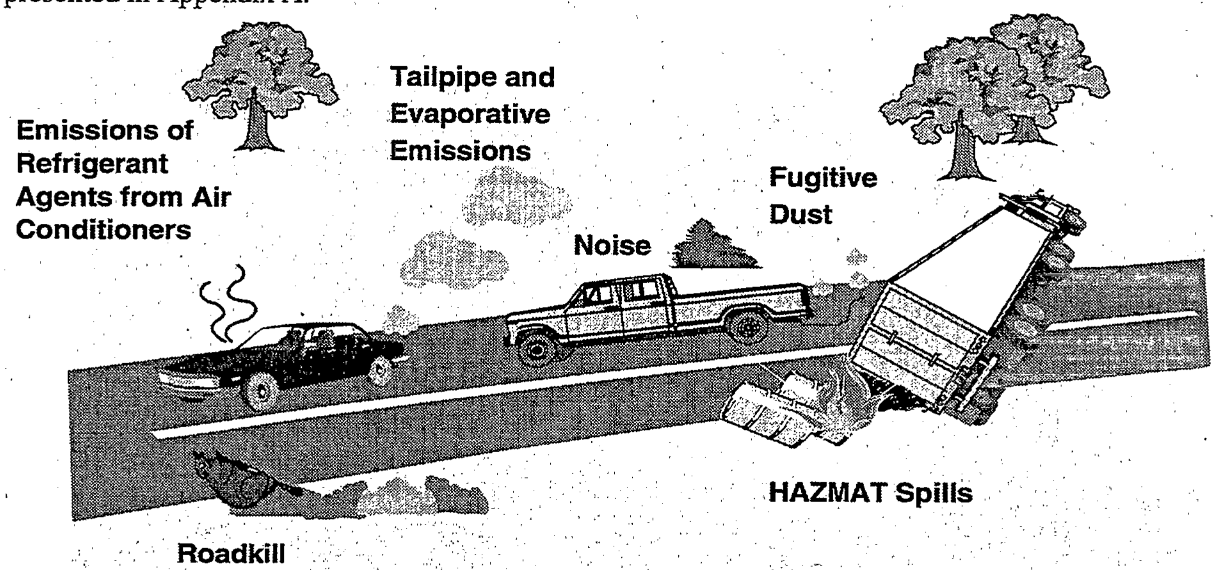
CAUSAL FACTORS

- Number of vehicles built
- Amount of chemicals used per vehicle
- Efficiency of controls and efforts to reuse or recycle chemicals, including pollution prevention
- Amount of chemicals transferred to other locations for recycling, energy recovery, or treatment
- Types of chemicals released and toxicity
- Population density and extent of exposure
- Environmental conditions such as climate, topography, or hydrogeology affecting fate and transport of chemicals in the environment

3. ROAD VEHICLE TRAVEL

Road vehicle travel is the dominant form of transportation in the United States. About 2.3 trillion vehicle miles were traveled on U.S. roads in 1994 by passenger cars, motorcycles, buses, light-duty trucks, and heavy-duty trucks (FHWA, 1995d). Vehicle travel has a number of environmental effects. Vehicles emit air pollutants from their exhaust, evaporation, use of air conditioners, as well as fugitive dust which is stirred up from the road surface by automobiles. In addition, vehicles create noise, and strike and kill animals that attempt to cross roadways. Hazardous materials incidents may release harmful chemicals to the environment.

These impacts are discussed below. For all of these impacts, data on travel is an activity indicator that provides a crude indication of environmental damage. Information on vehicle travel activity is presented in Appendix A.



TAILPIPE AND EVAPORATIVE EMISSIONS

PRESENTATION OF INDICATORS

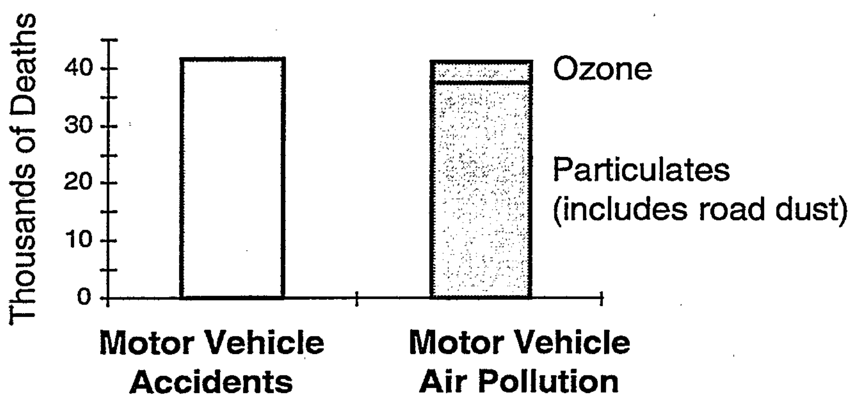
QUANTIFIED OUTCOME/RESULTS INDICATORS

- Air pollution from highways caused a significant number of health effects in 1991 (these estimates include health impacts from travel, road dust, and upstream activities) (McCubbin and Delucchi, 1995):
  - Approximately 20,000-46,000 cases of chronic respiratory illness (chronic cough, phlegm, wheezing, chest illness, and bronchitis)
  - Roughly 50-70 million respiratory-related restricted activity days (RRADs), of which about 43-60 million of these can be attributed to particulate matter alone
  - An estimated 530 cases of cancer from air toxics associated with highway use. Estimates of cancer risk, however, are highly uncertain. Various estimates have attributed 50 to

19,000 cancer deaths per year to carcinogens from motor vehicle emissions (U.S. EPA, 1993c). Much of this uncertainty is over the carcinogenicity of diesel particulate matter. Heavy duty diesel trucks account for perhaps 25 percent to almost 100 percent of the cancer risk from motor vehicles (U.S. EPA, 1989a).

- About 852 million headaches from CO associated with motor vehicle use.
- An estimated 40,000 premature deaths in the U.S.—of which 33,300 can be attributed to particulate matter—a number comparable to the number of deaths from motor vehicle accidents.

Comparison of Estimated Mortality, 1991



Source: Motor vehicle estimate from McCubbin and Delucchi, 1995.

- Impacts on plants and animals, including forests and crops, have generally not been quantified.

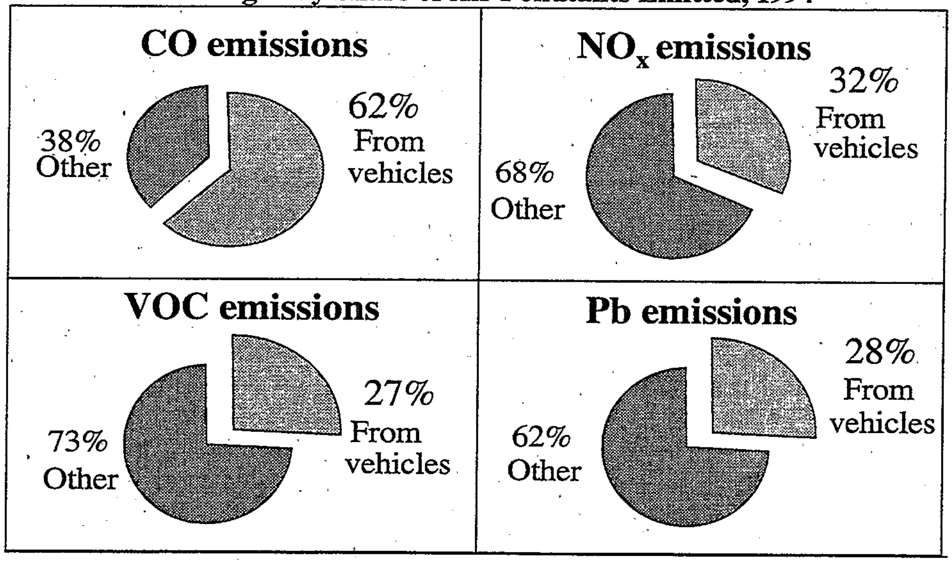
QUANTIFIED OUTPUT INDICATORS

- In 1994, highway vehicle operations were responsible for the following emissions nationwide (U.S. EPA, 1995e):

Pollutant	Quantity Emitted (1994, thousand short tons)	Percentage of total Emissions of that Pollutant[42]
Carbon Monoxide (CO)	61,070	62.3%
Nitrogen Oxides (NO_x)	7,530	31.9%
Volatile Organic Compounds (VOCs)	6,295	27.2%
Sulfur Dioxide (SO_2)	295	1.4%
Particulate Matter (PM-10)	311	0.7%
Lead (Pb)	1.4	28.3%

[42] Note: percentages are based on anthropogenic emissions, except for PM-10, which includes natural emissions.

Highway Share of Air Pollutants Emitted, 1994



- In 1993, CO_2 emissions from highway vehicle operations accounted for approximately 320 million metric tons of carbon equivalent (mmtCe), or 23percent of total national anthropomorphic CO_2 emissions (Apogee estimate).[43]

- Highway vehicle travel contributed to emissions of other greenhouse gases, as reported below (U.S. EPA, 1994a):

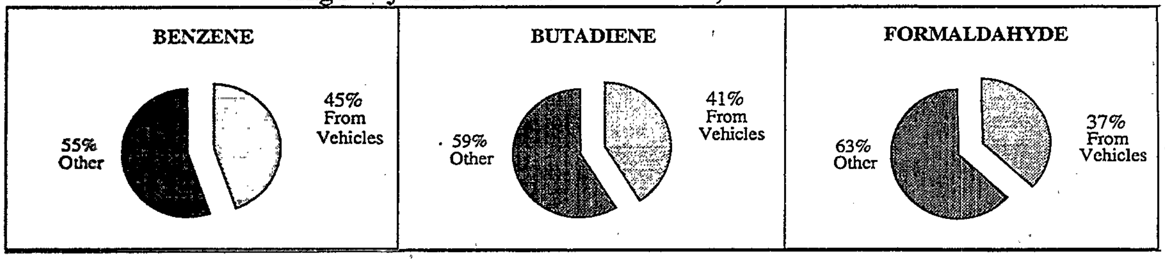
Pollutant	Quantity Emitted (1990, thousand metric tons)
Methane (CH_4)	201
Nitrous Oxide (N_2O)	87

- In 1990, highway vehicle operations were responsible for the following emissions of toxics (U.S. EPA, 1995e):

Pollutant	Quantity Emitted (1990, short tons)	Percent of total Emissions of that Pollutant
Benzene	217,765	45%
Butadiene	41,883	41%
Formaldehyde	101,722	37%

[43] Estimate is based on the following methodology: transportation sector energy use by fuel type within a mode (DOE/EIA, 1995b) was multiplied by carbon coefficients (mmtCe/quadrillion Btu) for each fuel (DOE/EIA, 1995a), then adjusted by fraction of carbon that does not oxidize during combustion (DOE/EIA, 1995a). Note that this estimate does not account for upstream emissions, such as emissions from car assembly and fuel production; refer to DeLuchi, 1991, for carbon coefficients needed to compute total fuel-cycle CO_2 emissions.

Highway Share of Toxics Emitted, 1990

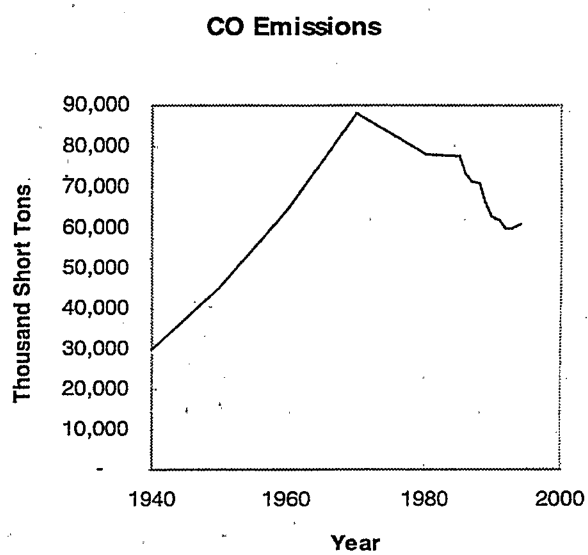


- The share of total emissions attributable to on-road mobile sources varies greatly by location: the share of NO_x can range from 20 to 60 percent of total (not only anthropogenic) emissions in most ozone nonattainment areas, and on-road VOC emissions can range from 10 to 40 percent of the total (Apogee, 1996).

CO Emissions from Highway Vehicles

Year	Thousand Short Tons	Percentage of Total CO Emissions
1940	30,121	32.2
1950	45,196	44.0
1960	64,266	58.6
1970	88,034	68.7
1980	78,049	67.5
1985	77,387	67.5
1986	73,347	67.2
1987	71,250	66.0
1988	71,081	61.4
1989	66,050	64.0
1990	62,858	62.5
1991	62,074	63.7
1992	59,859	63.7
1993	59,989	63.7
1994	61,070	62.3

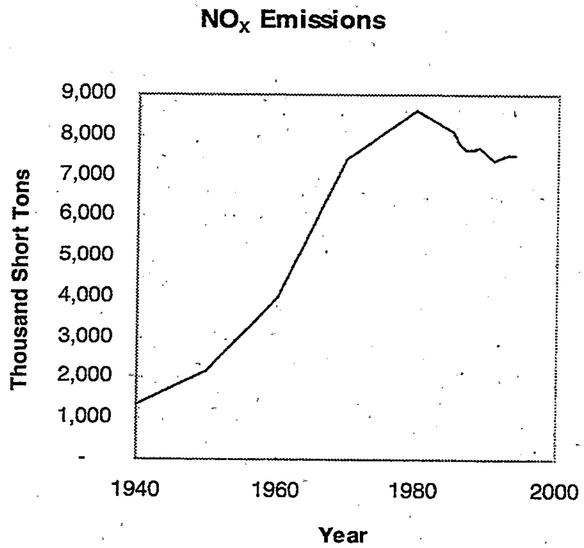
Source: U.S. EPA, 1995e.



NO_x Emissions from Highway Vehicles

Year	Thousand Short Tons	Percentage of Total NO_x Emissions
1940	1,330	18.0
1950	2,143	21.2
1960	3,982	28.2
1970	7,390	35.8
1980	8,621	37.0
1985	8,089	35.4
1986	7,773	34.8
1987	7,651	34.2
1988	7,661	32.4
1989	7,682	33.1
1990	7,488	32.5
1991	7,373	32.5
1992	7,440	32.6
1993	7,510	32.3
1994	7,530	31.9

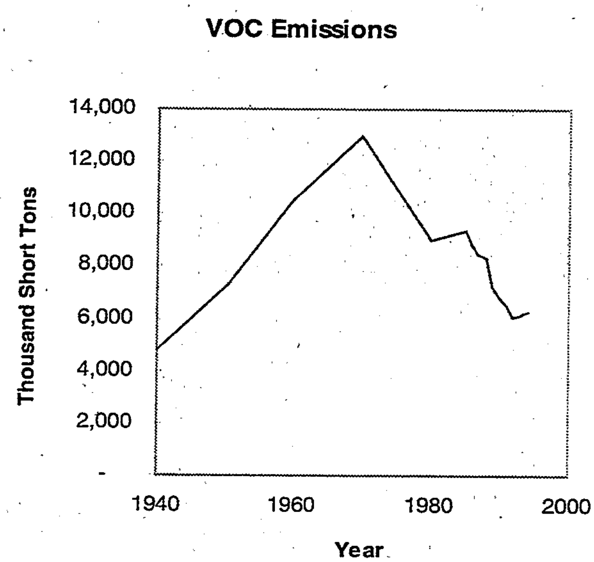
Source: U.S. EPA, 1995e.



VOC Emissions from Highway Vehicles

Year	Thousand Short Tons	Percentage of Total VOC Emissions
1940	4,817	28.1
1950	7,251	34.6
1960	10,506	43.0
1970	12,972	42.3
1980	8,979	34.7
1985	9,376	36.3
1986	8,874	35.5
1987	8,477	34.2
1988	8,290	32.2
1989	7,192	30.0
1990	6,854	29.0
1991	6,499	28.4
1992	6,072	27.1
1993	6,103	27.0
1994	6,295	27.2

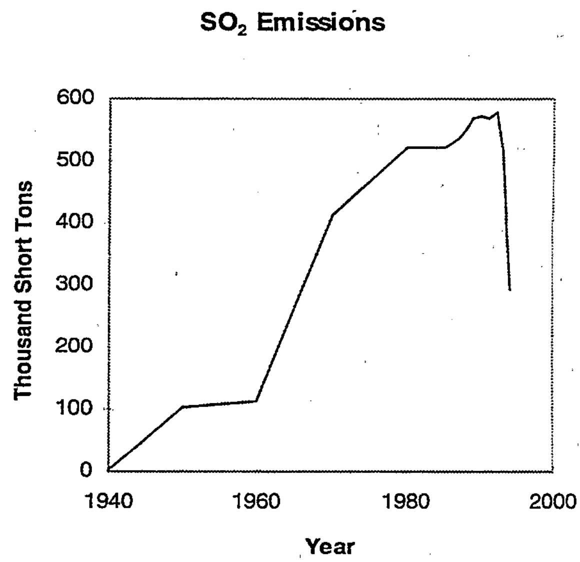
Source: U.S. EPA, 1995e



SO_2 Emissions from Highway Vehicles

Year	Thousand Short Tons	Percentage of Total SO2 Emissions
1940	3	0.0
1950	103	0.5
1960	114	0.5
1970	411	1.3
1980	521	2.0
1985	522	2.2
1986	527	2.3
1987	538	2.4
1988	553	2.4
1989	570	2.5
1990	571	2.5
1991	570	2.6
1992	578	2.6
1993	517	2.4
1994	295	1.4

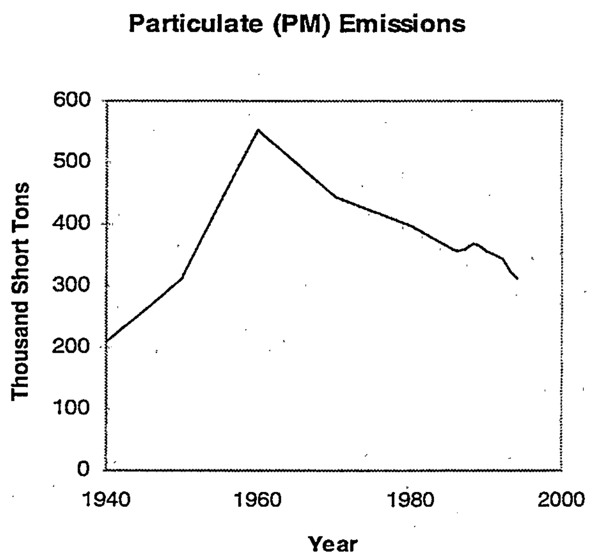
Source: U.S. EPA, 1995e



Direct Particulate Matter (PM-10) Emissions from Highway Vehicles[44]

Year	Thousand Short Tons	Percentage of Total PM-10 Emissions
1940	210	-
1950	314	-
1960	554	-
1970	443	-
1980	397	-
1985	363	0.81%
1986	356	0.71%
1987	360	0.86%
1988	369	0.61%
1989	367	0.70%
1990	357	0.82%
1991	349	0.71%
1992	343	0.78%
1993	321	0.75%
1994	311	0.68%

Source: U.S. EPA, 1995e

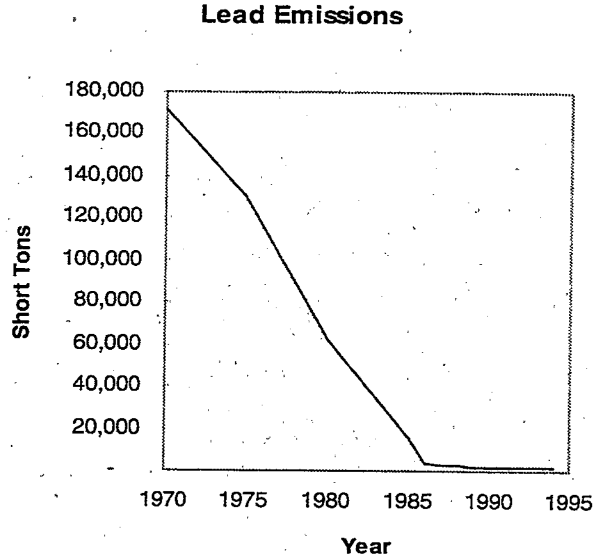


[44] Percentage of total emissions are not reported for particulate matter prior to 1985 because of changes in total emissions inventories; fugitive dust and wind erosion are reported only for the period 1985 to 1994.

Lead Emissions from Highway Vehicles

Year	Short Tons	Percentage of Total Pb Emissions
1970	171,961	78.4
1975	130,206	82.1
1980	62,189	83.0
1985	15,978	79.4
1986	3,589	49.2
1987	3,121	45.5
1988	2,700	41.5
1989	2,161	35.8
1990	1,690	29.8
1991	1,519	28.8
1992	1,444	29.5
1993	1,401	28.4
1994	1,403	28.3

Source: U.S. EPA, 1995e



It is important to note that there is considerable uncertainty regarding the values of the emissions statistics used for these output indicators. Since actual measurement of all vehicle emissions is impractical, the emissions estimates come from models which are based on travel data, speeds, vehicle fleet characteristics, and other variables, and emissions factors. These models are updated over time, and thus, historical data from different years are not comparable if based on different methodologies. For example, EPA reports 1990 CO emissions from highway vehicles as 59,801 thousand short tons in their *National Air Pollutant Emission Trends, 1990-1992* report, and as 62,858 thousand short tons in their more recent *National Air Pollutant Emission Trends, 1993* report.

There is some evidence that air pollution can have a significant impact on water quality. Not all atmospheric deposition results from motor vehicle emissions, but some statistics on such pollution at least provide a sense of how air pollution impacts surface waters[45]:

- Estimates of atmospheric nitrogen input to water bodies such as the Chesapeake Bay and other major east coast estuaries range from 5 percent to 50 percent of the controllable load of nitrogen (most estimates are in the range of 30 percent). The error in such estimates, however, is cited as at least plus or minus 20 percent and up to a factor of two or three, depending on location and pollutant considered.
- Atmospheric loadings of metals to water bodies such as the Chesapeake Bay may range from over 95 percent of total loadings in the case of lead to about 10 percent in the case of cadmium.
- Annual fluxes from wet deposition reported at various coastal locations range from under 5 mg per square meter for copper, nickel, and lead to 15-30 mg per square meter for iron and zinc.

[45] Air deposition data from AQCG/STAC 1994/95, and Valigura et al., 1994/95

- Wet deposition of various polycyclic aromatic hydrocarbons such as benzo[ghi]perylene (including some carcinogenic products of incomplete combustion) are in the range of 1-10 micrograms per square meter per year.

QUANTIFIED ACTIVITY INDICATORS

- Refer to Appendix A for data on vehicle travel.

DESCRIPTION OF IMPACT

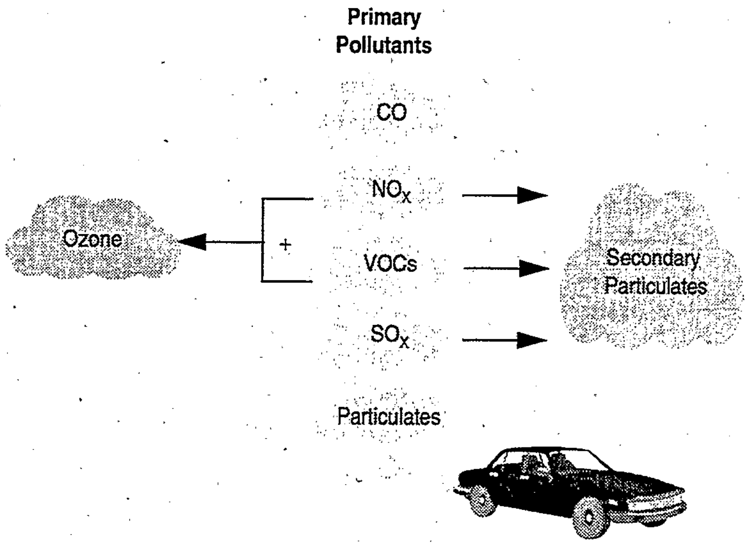
Air pollution is generally considered the main environmental impact of motor vehicle transportation. During the combustion process, automotive engines emit several types of pollutants, including: carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds and other hydrocarbons (VOCs/HCs), particulate matter (PM), and carbon dioxide (CO_2). These pollutants affect the environment, health, and welfare by causing respiratory and other illnesses, reduced visibility, and soiling and corrosion of materials. They also affect the environment by causing adverse effects on ecosystems including damage to crops, forests, and other terrestrial and aquatic plants and animals. Although CO_2 is not harmful to human health or habitat directly, it is important as a greenhouse gas that contributes to global warming.

Certain chemicals interact in the air to form secondary pollutants. Ozone is one key secondary pollutant, formed by the combination of NO_x and VOCs. In addition, the combination of sunlight, water, and chemicals like SO_2, NO_x, and HCs can form secondary particulate matter, as the diagram below shows.

Highway vehicles emit pollutants into the atmosphere during start-up (especially during a cold start), travel, and cooling down (hot-soak emissions). Pollution from highway vehicles comes from byproducts of fossil fuel combustion process (exhaust) and from evaporation of the fuel itself. In the first few minutes of a trip, emissions are higher because the emissions control equipment has not yet reached its optimal operating temperature.

In addition, pollutants escape into the air through fuel evaporation. With efficient exhaust emission controls and gasoline formulations, evaporative losses can account for a majority of the pollution from current model cars on hot days. Evaporative emissions include diurnal emissions (as temperature rises during the day, the fuel tank heats and vents gasoline vapors), running losses (vaporization of gasoline during car operations), hot-soak emissions (gasoline evaporation that continues after a vehicle is parked since the engine remains hot for a period of time), or refueling losses (vapors escape when the tank is filled).[46]

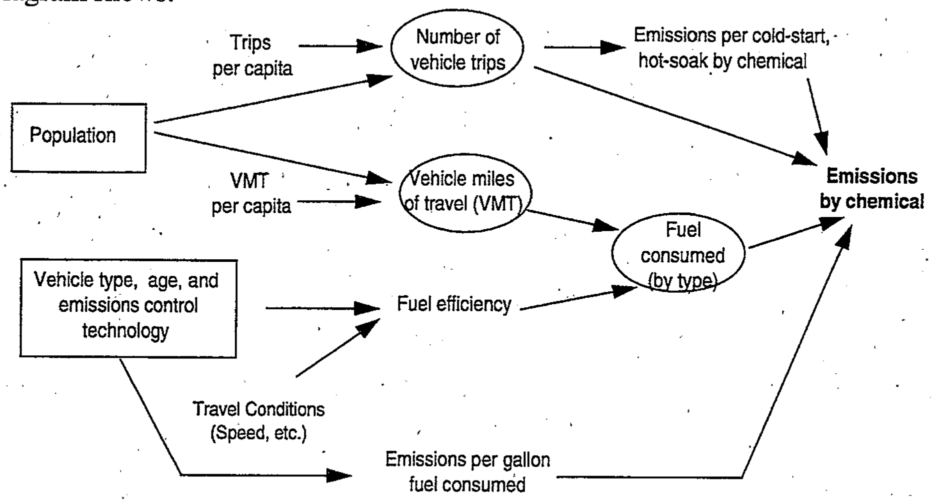
[46] Losses from refueling are counted as stationary source emissions by EPA's Office of Air Quality and Planning Standards, but can be modeled separately in the MOBILE model.



CAUSAL FACTORS

- Number of vehicle trips: number of cold-starts, hot-starts, hot-soaks
- Vehicle miles of travel (VMT)
- Vehicle type, age, weight, and emissions control technology
- Type of fuel consumed (gasoline, diesel fuel, etc.)
- Travel characteristics: speed, acceleration, etc. affects emissions per mile

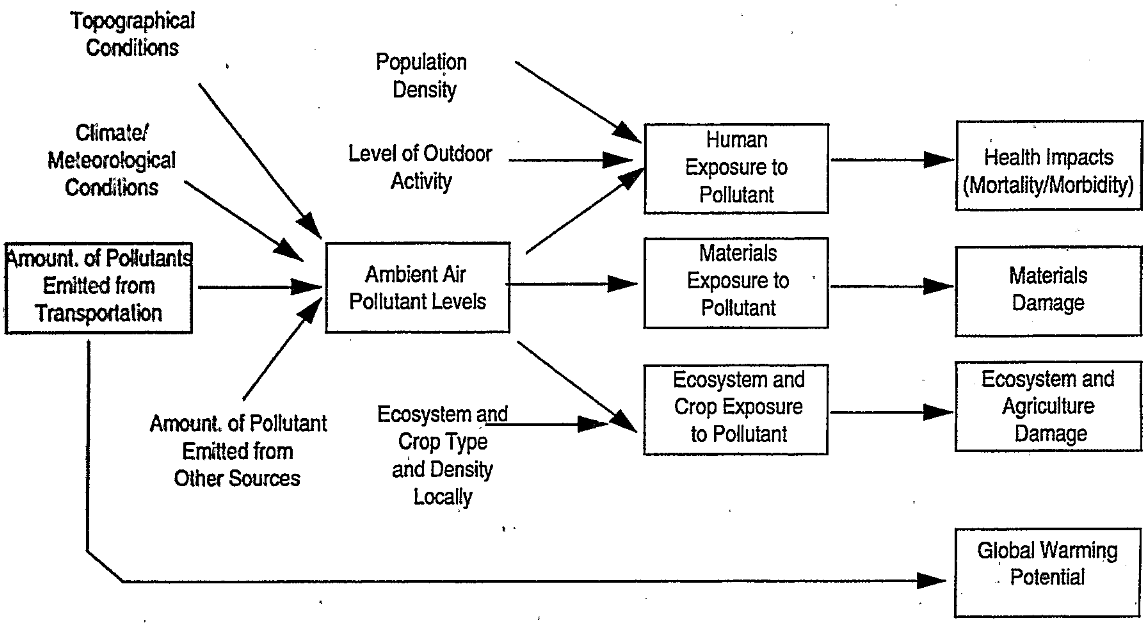
The above factors work in combination to influence the total amount of pollution emitted, as the following diagram shows:



For example, travel conditions and vehicle type together influence fuel efficiency (gallons of fuel consumed per mile) and pollutant emissions rates. Typically, faster speeds tend to reduce emissions per mile, although for some pollutants, emission rates begin to increase once again when travel speeds exceed a certain level. Meanwhile, different types of vehicles (e.g., gasoline powered automobiles and diesel trucks) emit different amounts of pollution at any given speed. Some factors, like population demographics, influence the level of travel, and thus, indirectly affect emissions levels.

Factors that influence the amount of environmental damage that occurs from air pollutant emissions include:

- Topographical conditions (hills, valleys, etc.) affects dispersion/dilution of pollutants
- Climatic conditions (temperature, wind, rain, etc.) affects dispersion/dilution of pollutants and formation of secondary pollutants
- Population density affects number of people exposed to pollution
- Sensitivity of local ecosystems



FUGITIVE DUST EMISSIONS FROM ROADS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Particulate matter associated with motor vehicle use was responsible for approximately 33,300 deaths (see graphic on particulate-related mortality in emissions section above); between 17,700 and 41,600 cases of chronic respiratory illness; 1.12 million asthma attacks; and between 42.9 and 59.9 million respiratory restricted activity days (RRADs) in 1991 (McCubbin and Delucchi, 1995). Of these impacts, road dust is responsible for the great majority, since road dust constitutes about 98 percent of particulate matter associated with motor vehicles (calculated from U.S. EPA, 1995e).
- Quantified national data on materials damage (soiling of buildings) and visibility degradation from road dust are not readily available.

QUANTIFIED OUTPUT INDICATORS

- Fugitive dust from highways constituted 32.0 million short tons of particulate matter (PM-10) released into the air in 1994 (see table).
- Fugitive dust from highways accounts for about 40percent of particulate matter emissions.

Fugitive Dust Contribution to National PM-10 Emissions, 1994

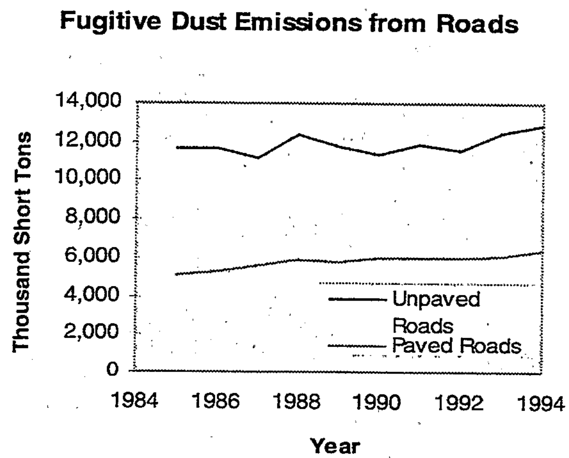
Source	Quantity Emitted (thousand short tons)	Percentage of total fugitive dust	Percentage of total PM-10
Unpaved Roads	*12,883*	*40%*	*28%*
Paved Roads	*6,358*	*20%*	*14%*
Other	12,771	40%	28%
Total Fugitive Dust	32,012	100%	70%
Total All Particulates (PM-10)	45,431	-	100%

Source: U.S. EPA, 1995e

Fugitive Dust Emissions (PM-10), Historical

Year	Thousand Short Tons	
	Unpaved Roads	Paved Roads
1985	11,644	5,080
1986	11,673	5,262
1987	11,110	5,530
1988	12,379	5,900
1989	11,798	5,769
1990	11,338	5,992
1991	11,873	5,969
1992	11,540	5,942
1993	12,482	6,095
1994	12,883	6,358

Source: U.S. EPA, 1995e



QUANTIFIED ACTIVITY INDICATORS

- Refer to Appendix A for data on vehicle travel.

DESCRIPTION OF IMPACT

Fugitive dust from travel on roads constitutes a significant portion of national PM-10 emissions, which in turn contribute to total suspended particulate matter in air. Dust generated from road travel is called "fugitive" because it does not enter the atmosphere in a confined flow stream. Two sources of dust are important to consider when evaluating the environmental impacts of road travel: paved and unpaved roads.

The quantity of dust emissions from a given section of unpaved road varies roughly linearly with the volume of traffic. When a vehicle traverses a segment of unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the surface after the vehicle has passed.

Fugitive dust from paved roads consists primarily of mineral matter, similar to common sand and soil, mostly tracked or deposited onto the roadway by vehicle traffic itself. Vehicle carryout from unpaved areas is probably the largest single source of street deposit. Other particulate matter is emitted directly by the vehicles from engine exhaust, wear of bearings and brake linings, and abrasion of tires against the road surface.

Although unpaved roads recently comprised about 42 percent of total road mileage in the U.S., they accounted for 64 percent of the fugitive dust from travel on roads in 1993. It is notable that paved road mileage has been growing rapidly, as existing roads are paved at a much higher rate than new roads are built. As recently as around 1980, unpaved mileage exceeded paved mileage.

CAUSAL FACTORS

- Lane mileage, paved and unpaved
- VMT, by pavement type
- Topographical conditions (hills, valleys, etc.) affecting pollutant dispersion
- Climatic conditions (temperature, wind, rain, etc.) affecting pollutant dispersion and secondary pollutant formation
- Population density affecting potential exposure

EMISSIONS OF REFRIGERANT AGENTS FROM VEHICLE AIR CONDITIONERS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Quantified data on the contribution of vehicle refrigerant agents to depletion of the ozone layer and global warming are not available.

QUANTIFIED OUTPUT INDICATORS

- Nationwide, leaky vehicle air conditioners are responsible for 25 percent of all CFC emissions (Washington, 1991).
- 71,000 metric tons of CFC-12 were released in 1994 from all sources (not only vehicles) (DOE, 1995a) (see table).

Estimated U.S. Emissions of CFC-12 and HFC-134a (all sources), 1987-1994
(thousand metric tons of gas)

Gas	1987	1988	1989	1990	1991	1992	1993	1994
CFC-12	110	110	114	112	108	102	99	71
HFC-134a	NA	NA	NA	1	1	3	6	10

Source: DOE, 1995a.

Quantified Activity Indicators

- U.S. autos were responsible for approximately 175 million pounds of CFCs consumed in 1989 of 700 million total (NRDC, 1993). As of 1996, CFCs are no longer being produced.

Description of Impact

Automobile air conditioners are subject to significant leakage, with nearly all of the refrigerant leaking out over a 5-year time period. Until recently, the chlorofluorocarbon CFC-12 has been the principal refrigerant agent used in automobile air conditioners. Other major end uses of CFC-12 include commercial air conditioning, refrigeration (refrigerators and freezers), and as a blowing agent for foams, insulation, and packaging. CFCs are potent greenhouse gases. (U.S. DOE 1995a)

CFCs are currently being phased out because they damage the stratospheric ozone layer. By signing the *Montreal Protocol on Substances that Deplete the Ozone Layer* and *Copenhagen Amendments*, the U.S. committed to eliminating the production of all CFCs by January 1, 1996. Stratospheric ozone, beneficial for its ability to absorb ultraviolet radiation, is, however, also a greenhouse gas. Gases that destroy stratospheric ozone thus have indirect cooling effects. Chlorine-containing chemicals such as CFCs tend to react with ozone, and the net effect on global climate is ambiguous (U.S. DOE, 1994b).

Hydrofluorocarbon HFC-134a became the standard automobile air conditioner refrigerant in 1994, and HFC emissions will grow rapidly as CFCs gradually disappear from the automobile fleet. HFCs, which contain no chlorine, have no effect on ozone and simply are unambiguously greenhouse gases. Automobile air conditioners are the principal end-use for HFC-134a. In 1993, Ford sold nearly 40,000 vehicles that each used about 2 pounds of HFC-134a in their air conditioners. Previous models used about 2.5 pounds of CFC-12. As of 1994, practically all new automobiles were using HFC-134a as the refrigerant in their air conditioners, and many manufacturers now offer conversion packages through their dealerships (DOE, 1994b).

CFC-12 has a atmospheric lifetime of 102 years, and one molecule of CFC-12 has a 100 year global warming potential 8,500 times that of one molecule of CO_2. HFC-134a has a lifetime of 14 years. One molecule of HFC-134a has a 100-year global warming potential 1,300 times that of one molecule of CO_2. But the lack of chlorine in HFCs and their shorter atmospheric lifetimes reduce the indirect cooling effects of CFCs. Thus, HFC replacement compounds may be worse from a global climate perspective than their predecessors.

The outcome is affected directly by output of CFCs. It does not depend on climate, geography, exposure by humans or habitat, or other factors. Location will influence air-conditioner use since areas with high temperatures will tend to emit more CFCs. However, in this case location is a causal factor for the emissions, not a factor that influences the outcome of the emissions.

Causal Factors

- Quantity of refrigerant agent used
- Net global warming potential of refrigerant agent used
- Net ozone depleting potential of refrigerant agent used

NOISE

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- 37.0 percent of the U.S. population was exposed to noise levels from road transport great enough to cause annoyance—defined as Leq greater than 55dB(A)—in 1980 (OECD, 1993). A more recent estimate is not available.
- Significant portions of the U.S. population were exposed to daily noise levels from road transport great enough to cause other effects, such as communication interference, muscle/gland reaction, and changed motor coordination, as the following chart shows:

Percent of U.S. Population Exposed to Road Transportation Noise, 1980

Outdoor Sound Level in Leq [dB(A)]

>55 dB(A) Annoyance	>60 dB(A) Normal Speech Level	>65 dB(A) Communication Interference	>70 dB(A) Muscle/Gland Reaction	>75 dB(A) Changed Motor Coordination
37.0%	18.0%	7.0%	2.0%	0.4%

Source: OECD, 1993.

QUANTIFIED OUTPUT INDICATORS

- Noise levels are site specific and dissipate with increasing distance from the source; as a result, an aggregate national noise emissions figure is not meaningful.
- Typical noise levels at 100 feet are 50 dB(A) for light auto traffic; 70 dB(A) for freeway traffic, and 90 dB(A) for city traffic (BTS, 1994).
- Typical noise emissions per vehicle are 85 dB(A) for an auto, 95 dB(A) for a heavy truck, 100 dB(A) for a bus, and 110 dB(A) for a motorcycle (BTS, 1994).

QUANTIFIED ACTIVITY INDICATORS

- Refer to Appendix A for data on vehicle travel.

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- An FHWA survey estimated that more than 929 miles of noise barriers had been constructed as of 1992[47] (FHWA, 1994b).
- Between 1980 and 1992 there were an average of 57 miles of new noise barriers built per year (FHWA, 1994b). Note that there are almost 13,000 miles of urban interstate and almost 150,000 miles of other urban arterials (FHWA, 1993).
- Effective noise barriers can lower noise levels by 10-15 decibels (dB), which reduces traffic noise by as much as one half in many cases. (FHWA, 1992b)

DESCRIPTION OF IMPACT

Noise associated with road transport comes from engine operations, pavement-wheel contact, aerodynamic effects, and vibrating structures during operations. Heavy trucks and buses cause more

[47] California did not provide data for the years 1990, 1991, and 1992.

noise per vehicle than cars. The issue of noise is generally discussed in terms of the number or proportion of people affected. The findings of numerous research projects in OECD countries on the effects of noise and its wider repercussions indicate that an outdoor sound level of 65 dB(A) is "unacceptable," and an outdoor level of less than 55 dB(A) is desirable (OECD, 1993). Noise is thought to cause stress and other health problems and lower property values. It can also affects local habitats of species near roads.

CAUSAL FACTORS

- Level of road activity; traffic volumes
- Speed of traffic
- Proportion of heavy vehicles (one truck emits the equivalent noise of 28 to 60 cars)
- Population density near road.
- Existence and effectiveness of noise barriers
- Effectiveness of devices such as mufflers and quiet vehicles

HAZARDOUS MATERIALS INCIDENTS DURING TRANSPORT

PRESENTATION OF INDICATORS

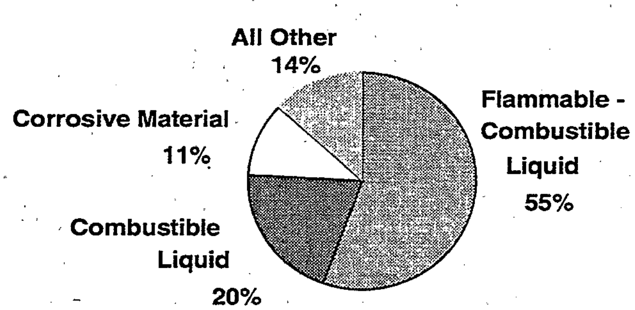
QUANTIFIED OUTCOME/RESULTS INDICATORS

- No statistics were found regarding the number of species or acres nationwide affected by commodity spills or other hazardous materials incidents.

QUANTIFIED OUTPUT INDICATORS

- An average of 646,000 gallons of hazardous materials were reported spilled annually on highways from 1990 to 1994, more than three fourths of which was flammable and/or combustible liquid (U.S. DOT, RSPA, HMIS database) (see tables and graphics).
- Almost 10,000 hazardous materials releases were reported annually from 1990 to 1994 (U.S. DOT, RSPA, HMIS database) (see tables and graphics).

Distribution of Gallons of Hazardous Materials Spilled in Highway Transport, 1990-1994



Source: U.S. DOT, RSPA, HMIS

Hazardous Material Highway Incidents, Annual Average, 1990-1994[48]

Class	Number of Incidents	Gallons Released	Pounds Released	Cubic Feet Released	mCi Released	Clean-up Cost and Loss of Material
Flammable - Combustible Liquid	3,984.0	358,341.2	1123.3			13,571,050
Corrosive Material	3,477.2	71,726.4	11,010.2			3,266,310
Poisonous Materials	594.6	5,622.0	9,764.6	15.4		1,237,813
Combustible Liquid	552.0	132,395.2				3,029,450
Miscellaneous HAZMAT	289.2	26,781.0	121,406.7			626,084
Oxidizer	226.8	5,453.1	69,305.2			293,549
Nonflammable Compressed Gas	138.0	28,064.7	111.7	342,646.0		424,636
Flammable Gas	74.4	10,573.9		32,370.3		594,446
Organic Peroxide	72.8	135.9	502.7			61,467
Flammable Solid	42.4	1,048.9	1,054.2			101,809
Other Regulated Material, Class A	37.8	655.5	15.9			43,397
Other Regulated Material, Class E	25.8	586.3	42,812.3			110,859
Poisonous Gas	21.8	265.0	400.2	219.0		43,093
Very Insensitive Explosive	10.8	653.1	17,867.4			56,423
Flammable Solid (per-1991)	9.2	7.0	4,042.7			13,251
Radioactive Material	9.0	2,000.9	308.0		18.9	31,982
Dangerous when Wet Material	8.2	2.2	705.4			11,297
Spontaneously Combustible	7.0	3.6	145.5			10,377
Other Regulated Material, Class B	3.8	164.6	220.5			9,858
Other Regulated Material, Class C	3.6	1,883.0	5,017.7			36,949
Explosive No Blast Hazard	1.2	0.0	163.4			104,263
Explosive Mass Explosion Hazard	1.0	40.3	5.3			24,764
Explosive Fire Hazard	0.8		0.2			3
Explosives, Class A	0.8		2,584.4			27,486
Other Regulated Material, Class D	0.6		0.4			55
Explosives, Class C	0.6	0.2				64
Irritating Material	0.6	2.4	0.4			139
Infectious Substance (Etiologic)	0.4		0.2			185
Explosive Protection Hazard	0.2	0.1				24
Total	9,594.6	646,406.3	288,568.6	375,250.6	18.9	23,731,081

Source: U.S. DOT, RSPA, HMIS.

- Materials release rates associated with transporting hazardous materials by truck appear to be as large as potential releases at treatment and disposal sites (U.S. EPA, 1984).
- The quantity of hazardous materials remaining in the environment after cleanup efforts is unknown.

Quantified Activity Indicators

- Trucks carry over 60 percent of the hazardous materials transported in the U.S. (Atkinson, 1992).

[48] U.S. DOT, RSPA, HMIS Database.

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- Of the 7,585 hazardous materials highway incidents reported to HMIS in 1991, 79 percent were a result of human error, 15 percent from packaging failure, 3 percent from vehicle accidents, and 3 percent from other causes (U.S. DOT, RSPA, 1991).
- Approximately 99 percent of the fatalities and injuries in accidents involving hazardous materials trucks resulting from physical collision were not related to the hazardous materials release (Harwood et al., 1990).

DESCRIPTION OF IMPACT

The potential for commodity releases during highway transportation is important to consider because of the large and growing role truck transport plays in domestic freight movement. In 1993, truck transport accounted for 35 percent of the ton-miles and 53 percent of the tonnage moved during domestic intercity transport, excluding pipelines (Eno, 1994). In particular, commodity spills of hazardous materials may impose substantial costs for product loss, carrier damage, property damage, evacuations, and response personnel and equipment. The Hazardous Materials Information System (HMIS) database, maintained by U.S. DOT/RSPA, contains a record of all reported hazardous materials incidents occurring during truck transport (except for intrastate only operators), including type of material spilled, number of injuries/fatalities, and estimated clean up costs.

The number of hazardous material incidents is not necessarily indicative of the environmental impact of such incidents, since it may be possible to clean up most of the materials released. If not properly contained, however, hazardous materials incidents may cause environmental damage such as air and water pollution, damage to fish and wildlife, and habitat destruction. The environmental impact of any given hazardous materials spill is highly site-specific. It depends on the type and quantity of material spilled, amount recovered in cleanup, chemical properties (such as toxicity and combustibility), and impact area characteristics (such as climatic conditions, flora and fauna density, and local topography). It should be noted that while the overall impact of incidents may be small for the nation as a whole, any hazardous material spill may have severe impacts on flora and fauna in the location of occurrence.

CAUSAL FACTORS

- Quantity of hazardous materials transported and distance transported
- Accident or spill rate
- Type (toxicity/hazard) and quantity of materials spilled
- Effectiveness of cleanup efforts
- Population density
- Sensitivity of local habitats/species

ROADKILL

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- In the United States, roadkill losses are estimated to be at least 1 million animals per day due to conflict with traffic while crossing roads (Tolley, 1995).

- When a new road is built, roadkill is estimated to increase by at least 200 percent (Aaberg et al., 1978; Green and Reilly, 1974).

Quantified Output Indicators

- An output indicator for roadkill is not meaningful since the immediate impact—killed animals—is an outcome. There are no emissions or indirect means to measure environmental harm.

Quantified Activity Indicators

- Refer to Appendix A for data on vehicle travel.

Other Quantified Data and Local Examples

- In 1981, deer-related accidents constituted 7 percent of police-reported accidents in Michigan and resulted in direct costs exceeding $17 million (Hansen and Wolfe, 1983).

Description of Impact

Roads passing through wildlife habitat are a threat to various kinds of wildlife, especially in the first several years after a new road is constructed. It may take several years for wildlife to adapt to changes such as a new roadway in their habitat. Roadkill incidents in the initial few years of a road are at least double the rate of incidents observed over the long term.

Most studies and statistics on roadkill focus on deer, elk, antelope, moose and similar large wilderness animals. However, several studies of specific roadway corridors have documented incidents relating to a broader range of creatures (Foster and Humphrey, 1992). Although few national composite figures are available, many states track the number of animal-related incidents on their major roadways.

VMT likely has some relationship to wildlife strikes, but the exact nature of that relationship is unclear. In the case of a new road, the introduction of "new" VMT into a region generally results in increased strikes. Once the habitat adapts to the presence of the road, however, the impact of increased VMT is less clear. Road mileage may have a significant impact on wildlife strikes, and may be a more important factor than VMT. The size of the animal population in a given area is also a primary determinant of roadkills.

There is little consensus regarding the most effective means of preventing roadkill incidents. Wildlife often manages to circumvent protective fencing by jumping over, going around, or going through open gates and holes. Reflectors, lighting, underpasses dedicated to wildlife, mirrors and signage have been shown by some studies to be relatively ineffective at changing the behavior of both drivers and wildlife (Fornwalt et al., 1980; Colorado Division of Wildlife, 1980; California Department of Transportation, 1980; Lehtimaki, 1981).

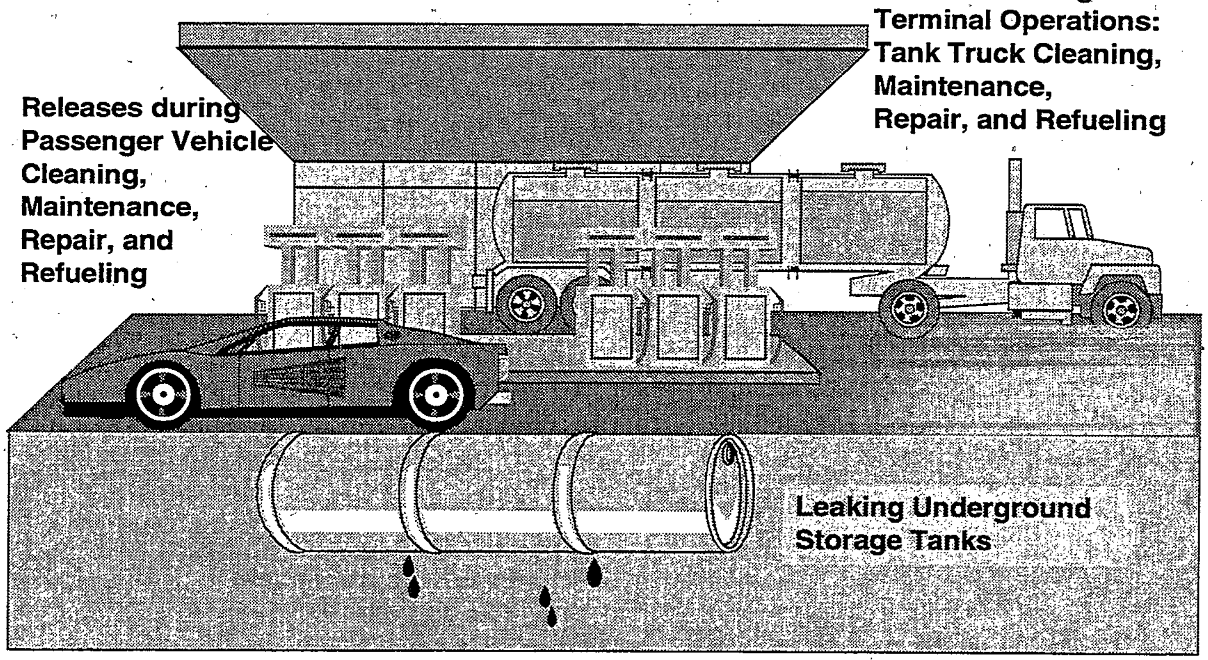
Causal Factors

- Habitat fragmentation, barriers to crossing formed by roads
- Lack of driver education on wildlife hazards and alertness
- Gaps in barriers and fences due to human activities
- Distance between edge of road and forest/vegetation

- Visibility (alignment, lighting, etc.)
- Location of road relative to wildlife habitat (urban/rural)

4. MOTOR VEHICLE MAINTENANCE AND SUPPORT

Besides vehicles and streets, road transport requires support facilities such as motor freight terminals, bus yards, fuel storage tanks, and auto fueling and service stations. These are discussed below.



RELEASES DURING TERMINAL OPERATIONS: TANK TRUCK CLEANING, MAINTENANCE, REPAIR, AND REFUELING

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Data on water quality impacts to streams, rivers, and lakes, and related habitat due to tank truck terminal operations are not available. Data on health effects from air pollution coming from terminals are also not available.

QUANTIFIED OUTPUT INDICATORS

- Tank car and rail car cleaning operations emit 1.25 million pounds of VOCs per year (U.S. EPA Source Assessment Study of 1978 as cited in U.S. EPA, 1995a).
- Data on other wastes generated from motor freight terminal operations have not been estimated at the national level (see table for list of wastes generated).

Typical Motor Freight Terminal Operations: Materials Used and Types of Waste Possibly Generated

Process/Operation	Materials Used	Types of Waste Generated
Unloading or Cleaning of Tank Cars	Solvents, alkaline cleaners	Acid/alkaline wastes Toxic wastes Solvent wastes Residual tank contents
Rust Removal	Naval jelly, strong acids, strong alkalis	Acid/alkaline wastes
Painting	Enamels, lacquers, epoxies, alkyds, acrylics, primers, solvents	Ignitable wastes Toxic wastes Paint wastes Solvent wastes
Paint Removal	Solvents, paint thinners, enamel, white spirits	Paint wastes Toxic wastes Solvent wastes
Exterior Washing	Solvents, cleaning solutions	Solvent wastes Oil and grease
Equipment degreasing	Degreasers, engine cleaners, acids, alkalis, cleaning fluids	Ignitable waste Combustible solids Acid/alkaline wastes
Refueling	Gasoline, diesel fuel	Evaporative losses - VOCs Fuel drips and spills
Changing of batteries	Lead-acid batteries	Acid/alkaline wastes Batteries (lead acid)

Source: U.S. EPA/RCRA Fact Sheet: Motor Freight/Railroad Terminal Operations, 1993; U.S. EPA, 1995a.

QUANTIFIED ACTIVITY INDICATORS

- There are 1,841 truck/land tank cleaning facilities in the U.S. (EPA Office of Water as cited in U.S. EPA, 1995a).[50]
- Approximately 90 percent of transportation equipment cleaning facilities discharge wastewater to publicly owned treatment works or combined treatment works (privately owned by multiple facilities) after some amount of treatment. Some facilities discharge directly to surface waters under the National Pollution Discharge Elimination System (NPDES) permits or to underground injection wells under Safe Drinking Water Act permits (U.S. EPA, 1995a). Allowable emissions could be tracked based on these permits, although actual emissions may vary.

DESCRIPTION OF IMPACT

Terminal operations include short- and long-haul truck activities (such as tank car unloading and cleaning), furnishing of terminal facilities for passenger or freight traffic, and cleaning and

[50] Land facilities are those that clean any combination of the following equipment: tank trucks, rail tank cars, intermediate bulk carriers, intermodal tank containers.
[51] National Pollutant Discharge Elimination System

maintenance functions including equipment degreasing, exterior washing, and painting. Many of these processes use materials that are hazardous or may in turn generate hazardous waste or wastewater. In addition, refueling operations impact the environment through spills and drips of fuel, and through fuel tank vapors that are displaced when the tank is filled with liquid fuel. The actual impact of terminal activities on the environment depends in a large part on the type and volume of operations, level of cleanliness required, type of waste generated, and efficacy of wastewater treatment systems in place.

A significant source of pollution is the cleaning of tank truck interiors. The typical tank truck car has a volume of 3,500-8,000 gallons and generates about 500-1,000 gallons of wastewater during cleaning, resulting in the output of spent cleaning fluids, fugitive VOC emissions, water treatment system sludges, and tank residues. The disposal and treatment of tank heels can also be source of pollution for tank cleaning facilities. The typical heel volume of a tank truck car is 5-10 gallons per tank, and a facility's wastewater treatment system may be adversely affected by, or may not adequately treat, a slug of concentrated tank residue. Incompatible heels are usually segregated and resold to a reclaimer or shipped off-site for disposal. Heels that are composed of detergents, solvents, acids, or alkalis can be stored on-site and used as a tank cleaning fluid or to neutralize other tank heels (U.S. EPA, 1995a).

Relatively small amounts waste and wastewater are generated from the washing, maintenance, and painting of motor vehicle exteriors. Typical hazardous wastes generated include spent solvents, spent caustics, strippers, paint chips, and paint sludges. Wastewater is generally treated on-site and then discharged to a public treatment works.

The primary source of toxic chemicals released during terminal operations are substances dissolved or suspended in wastewater, primarily during cleaning of tank interiors. Other potential environmental impacts of terminal operations include air emissions and residual wastes. Fugitive emissions of VOCs arise from tank heels and residues, cleaning solutions, painting and paint stripping, and refueling vapors. Residual wastes are generated as sludges from wastewater treatment systems, residues removed from the inside of tanks, and hazardous wastes from painting, paint removal, and cleaning of parts (U.S. EPA, 1995a).

CAUSAL FACTORS

- Number of terminals
- Type and level of terminal operations
- Materials used during terminal operations
- Wastewater treatment capabilities

RELEASES DURING PASSENGER VEHICLE CLEANING, MAINTENANCE, REPAIR, AND REFUELING

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Data on water quality impacts on streams, rivers, and lakes, and related habitat due to gas and service station operations are not available. Data on health and habitat effects from air pollution related to gas and service stations are also not available.

Quantified Output Indicators

- National statistics are not readily available, although EPA's MOBILE model produces emissions factors for hydrocarbons due to refueling on a per mile basis.

Quantified Activity Indicators

- 75 percent of transit agencies surveyed collect and treat wastewater from bus washing operations.[52] (TCRP, 1995a)
- 65 percent of transit agencies wash their active bus fleets daily during summer months; 81 percent wash daily during the winter.[53] (TCRP, 1995a)

Description of Impact

Facilities such as gas stations, maintenance shops, and service stations impact the environment through runoff of gas, oil, and dirt; waste releases to sewer systems; air emissions; and waste disposal. Research has found that areas where motor vehicles are serviced, fueled, or parked may have higher loadings of pollutants in road runoff.

Fueling activities generate air emissions due to VOC losses during transfer. There are two types of refueling losses: Stage 1 losses associated with the refilling of underground storage tanks, and Stage 2 losses occurring during the transfer of fuel from pump to automobile gas tank. Both Stage 1 and Stage 2 losses are counted as stationary source emissions by EPA's Office of Air Quality Planning and Standards. These are not included in this report because they are not reported separately.

Causal Factors

- Number of maintenance facilities
- Type and level of maintenance operations
- Materials used during maintenance operations
- Wastewater treatment capabilities

LEAKING UNDERGROUND STORAGE TANKS (USTs) CONTAINING FUEL

Presentation of Indicators

Quantified Outcome/Results Indicators

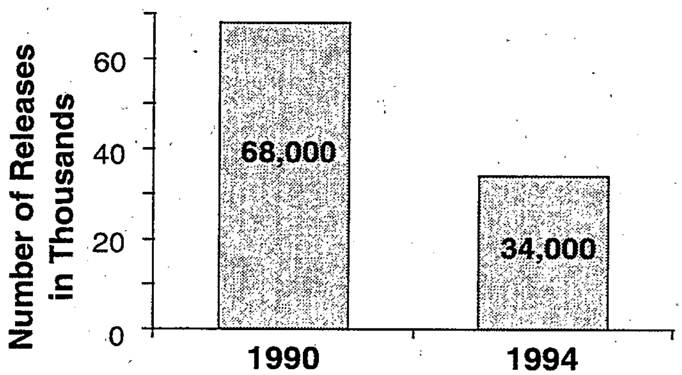
- In 1992, 50 states and U.S. territories reported leaking USTs to be a significant source of ground water contamination. Above ground storage tanks were reported as a problem by 12 states (U.S. EPA, 1994b).

[52] Based on survey of TCRP survey (1995) of 120 geographically diverse transit agencies in the U.S. and Canada; 52 respondents.
[53] Based on survey of TCRP survey (1995) of 120 geographically diverse transit agencies in the U.S. and Canada; 52 respondents.

QUANTIFIED OUTPUT INDICATORS

- 34,000 confirmed annual releases from underground storage tanks (USTs) occurred in 1994, a 50 percent reduction from the 68,000 releases in 1990 (U.S. EPA as cited in Industrial Economics, 1995). A majority of these tanks likely are associated with transportation.
- Quantities emitted are unknown.

Total Releases from Underground Storage Tanks



QUANTIFIED ACTIVITY INDICATORS

- There were 1.6 million active petroleum USTs in 1995, an 11 percent decrease from the estimated 1.8 million tanks in 1991 (U.S. EPA, as cited in Industrial Economics, 1995).
- More than 20 percent of existing USTs are installed partially or completely below the water table (U.S. EPA, as cited in Industrial Economics, 1995).
- Over 170,000 USTs are closed annually, resulting in the elimination of many older, bare-steel tanks (U.S. EPA, as cited in Industrial Economics, 1995).
- Some 232,835 leaking UST cleanups have been initiated since 1988; 126,608 of these cleanups have been completed (U.S. EPA, as cited in Industrial Economics, 1995).
- Over 1,000 emergency responses to tank situations relating to potential environmental releases are conducted by federal and state UST officials each year (U.S. EPA, as cited in Industrial Economics, 1995).
- Highway/road transport accounts for 76 percent of all transportation-related petroleum consumption (U.S. DOE, 1994a).

DESCRIPTION OF IMPACT

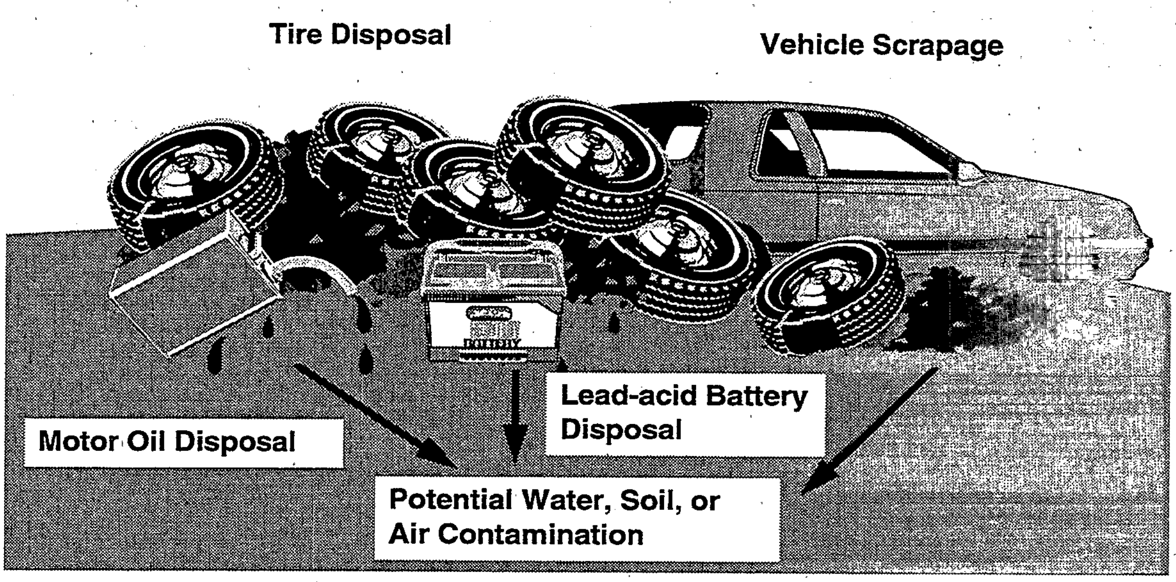
Although USTs may contain various hazardous substances or other regulated materials, the vast majority store petroleum and are commonly discussed in the context of transportation, particularly highway transportation. EPA estimates that there are approximately 1.6 million petroleum USTs and an additional 37,000 tanks containing hazardous substances (U.S. EPA, as cited in Industrial Economics, 1995). At the same time, 96.6 percent of all transportation sector operations in the U.S. use petroleum for fuel. Highway/road transport accounts for 76 percent of all transportation-related petroleum consumption (U.S. DOE, 1994a).

Leaking USTs can be a major source of groundwater contamination. Releases from tanks and piping occur from corrosion of older, unprotected steel tanks and piping, or from cracks in tanks made from other materials. Overfilling and spillage during refueling are also responsible for significant numbers of accidental releases. More stringent regulation of USTs (design, citing, installation, monitoring) is resulting in a decrease in the total number of active USTs and the volume of contaminants released. The 1986 amendments to the Resource Conservation and Recovery Act (RCRA) established a $500 million Leaking Underground Storage Tank Trust Fund, financed through a tax on gasoline, to cleanup leaking UST sites. In 1998, all existing USTs will require spill protection through catchment basins, automatic shutoff devices, overfill alarms, and mandatory corrosion protection for steel tanks and piping.

CAUSAL FACTORS

- Number of leaking underground storage tanks (USTs)
- Type and quantity of materials released from leaking USTs
- Spill protection mechanisms
- Cleanup efforts initiated and completed
- Location of groundwater table
- Sensitivity of local ecosystems
- Treatment of drinking water

5. DISPOSAL OF VEHICLES AND PARTS



SCRAPPAGE OF VEHICLES

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

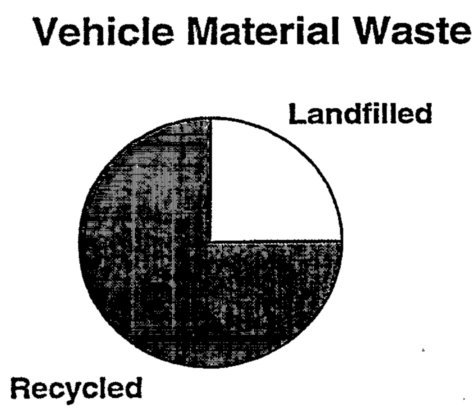
- Estimates are not available on the health and environmental impacts of landfilling or other disposal of scrapped vehicles.

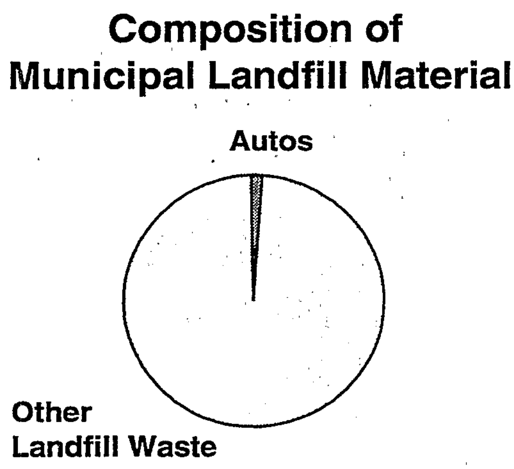
QUANTIFIED OUTPUT INDICATORS

- National data on emissions from the disposal of vehicles are not available.

QUANTIFIED ACTIVITY INDICATORS

- Approximately 9 million automobiles (about 94 percent of all scrapped vehicles) are collected and recycled annually at one of the 12,000 scrappage/disassembly locations in the U.S. (U.S. EPA, 1995b).
- At least 75 percent of the material collected from scrapped vehicles is recycled for raw material use, and 25 percent landfilled. This comprises about 1.5 percent of total municipal landfill waste (U.S. EPA, 1995b).





OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- Data on tonnages of these items were not readily available, but about 21 percent of a vehicle's weight (total is approx. 3000 pounds) is non-metals (of which, 38 percent is plastic, 12 percent fluids, 21 percent rubber, 14 percent glass, and 16 percent other) (U.S. EPA, 1995b).

DESCRIPTION OF IMPACT

When a vehicle is dismantled, fluids can be recovered, including oil, antifreeze, and refrigerant. Solid parts such as the radiator and catalytic converter are removed for recycling or reuse. The battery, fuel tank, and tires are also separated. The remaining vehicle is shredded (at one of the 200 shredding operations in North America) and sorted into ferrous, nonferrous (8.7 percent of the whole vehicle), and residual components. The residue contains plastics, glass, textiles, metal fines, and dirt, which are generally all landfilled.

CAUSAL FACTORS

- Number of vehicles scrapped
- Fraction disposed of properly (through recycling, recovery, etc.)
- Use of hazardous materials in vehicles
- Recovery rate of materials in scrapped vehicles

MOTOR OIL DISPOSAL

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

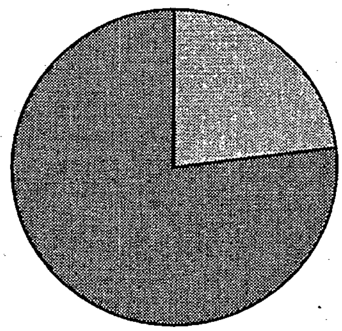
- Statistics are not available on amount of groundwater contamination or other environmental outcomes specifically attributable to motor oil disposal.

QUANTIFIED OUTPUT INDICATORS

- No data are available on the amount of motor oil that is released to land or water.

QUANTIFIED ACTIVITY INDICATORS

- 161 million gallons (23 percent) of the 714 million gallons of used motor oil collected annually are improperly disposed (U.S. EPA, 1994c).



23% of used oil is improperly disposed

DESCRIPTION OF IMPACT

Disposal of used motor oil can pollute sewers, wastewater treatment plants, and groundwater supplies. Used motor oil contains toxicants such as lead and benzene and, if improperly disposed of, can be a significant source of water pollution. The oil from just one oil change is enough to significantly contaminate a million gallons of fresh water.

CAUSAL FACTORS

- Quantity of oil used in motor vehicle operations.
- Recovery rate
- Groundwater contamination and seepage prevention measures at the disposal site
- Sensitivity of local ecosystems
- Water treatment technologies

TIRE DISPOSAL

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Statistics are not available on amount of groundwater contamination, air pollution, or other environmental outcomes specifically attributable to disposal of tires from motor vehicles.

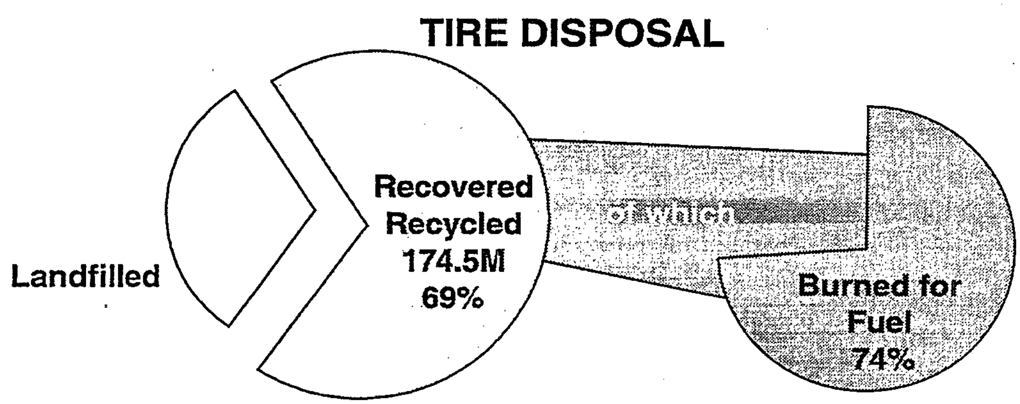
QUANTIFIED OUTPUT INDICATORS

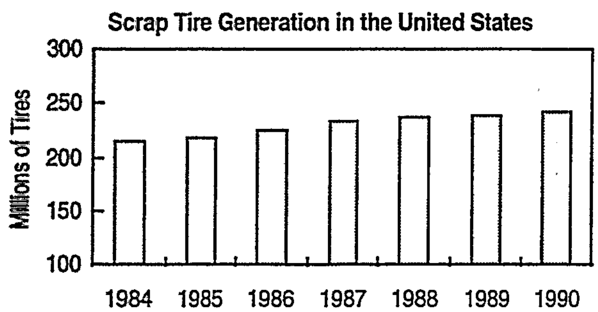
- Waste tire incineration was responsible for approximately 2 pounds of polychlorinated biphenyl (PCB) emissions out of total national emissions of 282 pounds in 1990. Since 1990, the rate of tire incineration has increased dramatically (U.S. EPA, 1995e).

QUANTIFIED ACTIVITY INDICATORS

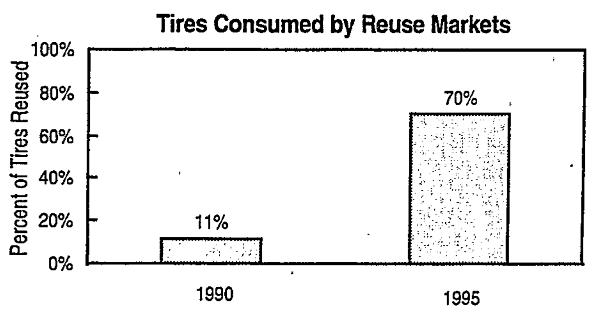
- In 1995, 252 million scrap tires were generated, with 69 percent recovered (174.5 million). 74.4 percent of those recovered were burned as tire-derived fuel (Scrap Tire Management Council)

- In the early 1990s, by contrast, 242 million tires were scrapped annually, with only a 30 percent recovery rate, leaving 169 million tires to be landfilled or stockpiled each year (U.S. EPA, 1993b).
- In 1990, 1.6 million tons of rubber tires were discarded into the municipal waste stream, accounting for 1.0 percent of municipal waste stream (U.S. EPA, 1992).
- Approximately 800 million tires remain in stockpiles in the U.S. (Hilts, 1996).





Source:US EPA, *Markets for Scrap Tires*, 1991.



Source:Hilts, 1996.

DESCRIPTION OF IMPACT

Disposal of used tires from motor vehicles can pollute sewers, wastewater treatment plants, and groundwater supplies, as well as take up landfill capacity. Many landfills do not allow tire disposal because tires decompose extremely slowly; they collect gases released by decomposing garbage, and then gradually float up to the surface of the landfill. In addition, used tires contain oil, making them a fire hazard, and may retain stagnant water, an ideal breeding ground for mosquitoes.

Tires pose a considerable fire hazard because once ignited, they can emit toxic gases, such as polyaromatic hydrocarbons, CO, SO_2, NO_2, and HCl (U.S. EPA, October 1991). The use of water to extinguish tire fires can result in soil and water contamination from oils generated by the burning tires. Furthermore, these fires can be extremely difficult to extinguish. Stockpiles of tires have been known to burn continuously for more than a year (U.S. EPA, October 1991).

CAUSAL FACTORS

- Quantity of tires disposed (based on number of vehicles and tire service life)
- Recovery rate
- Method of disposal or recycling
- Proximity to human population or habitat
- Toxic constituents in tires

LEAD-ACID BATTERIES DISPOSAL

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Statistics are not available on amount of groundwater contamination or other environmental outcomes specifically attributable to disposal of batteries.

QUANTIFIED OUTPUT INDICATORS

- No data are readily available on discharge of toxics from the disposal of lead-acid batteries.

QUANTIFIED ACTIVITY INDICATORS

- In 1990, 1.7 million tons of spent lead-acid batteries were generated in the municipal waste stream, but 96.6 percent of these were recovered and recycled nationwide, leaving only 100,000 tons to be discarded (U.S. EPA, 1992).
- In 1990, 100,000 tons of spent lead-acid batteries were discarded into the municipal waste stream, which is less than 0.05 percent of the total municipal waste stream (U.S. EPA, 1992).
- According to the U.S. Bureau of Mines, about 79 percent of lead consumed in 1989 was used in lead-acid batteries. Close to three fourths (by weight), or 0.75 million metric tons, of the lead-acid batteries shipped domestically in 1989 were automotive batteries (U.S. EPA, January 1992).
- The 1985 battery recycling rate was estimated to be 69.5 percent in a report prepared for EPA in 1987. The report also found that battery recycling rates fluctuated widely over the period 1960 to 1985, with recycling rates having a strong correlation to the price of lead (U.S. EPA, January 1992).
- A 1991 study by the Battery Council International (BCI), a battery manufacturers' trade association, estimated that the lead-acid battery recycling rate (excluding "consumer" batteries) is roughly 95 percent. A study by the Oregon Department of Environmental Quality estimated that the state of Oregon's lead-acid battery recycling rate was between 90 and 99.9 percent for 1990 (U.S. EPA, January 1992).

DESCRIPTION OF IMPACT

Disposal of used parts and fluids from vehicles and batteries can pollute sewers, waste water treatment plants, and groundwater supplies, as well as take up landfill capacity. The typical car battery weighs 30-36 pounds and contains 18-20 pounds of lead acid and electrolyte solution. Lead-acid batteries, primarily from automobiles, rank first, by a wide margin, of the products containing lead that enter the waste stream. The disposal (versus recycling) of such batteries means the introduction of lead, sulfuric acid, and polypropylene, all hazardous waste, into landfills or the environment.

An accurate battery recycling rate is difficult to establish due to a number of factors, including fluctuations in annual battery sales, time lags in data due to various batteries' life spans, and imports and exports of batteries and scrap lead. Still, information from several sources suggests that the recycling rate for lead-acid batteries is increasing (U.S. EPA, January 1992). Recycling of batteries to recover lead has a significant influence on the amount of lead discarded. A number of states have made a strong commitment to recycling.

CAUSAL FACTORS

- Quantity of batteries used in motor vehicle operations
- Recovery rate
- Groundwater contamination and seepage prevention measures at the disposal site
- Proximity to human population or habitat

RAIL ENVIRONMENTAL INDICATORS

This section presents the quantitative indicators available for tracking the nationwide environmental impacts of rail transportation. Rail is defined broadly to encompass freight transportation, as well as intercity (Amtrak) and intracity passenger rail. Intracity passenger rail includes heavy rail (subways and elevated systems), light rail, and commuter rail. In some cases, data for all these forms of transportation were not available, so rail indicators may provide partial data (for example, transit impacts may be excluded in some categories). For each of the five basic categories of activities affecting the environment, the various impacts are listed.

HOW EACH IMPACT IS PRESENTED IN THIS SECTION

Each environmental impact is covered in one or more pages of text and graphics, with the following key subsections:

- **Presentation of indicators**

  The key indicators that have been quantified are presented. *Outcome* indicators are listed first since they provide information on end results and are theoretically the most desirable type of indicator. Unfortunately, actual quantified data are often unavailable or of poor quality. In many instances, the only available data on outcomes are the number of states reporting a problem. This information is often incomplete (not all states may examine the problem), vague (states may define the problem differently), or only somewhat relevant (the contribution of transportation to the problem may be unknown). As a result, *output* indicators—such as emissions data—are presented. These statistics may be an easier and more valid measure for policy makers to examine and track over time. Finally, *activity* indicators (defined broadly to include infrastructure, travel, and other activities) are listed when they are the best available indicators or when outcome and output indicators are not adequate.

  To avoid repetition within the report, basic infrastructure and travel indicators are listed in Appendix A for each mode of transportation. Appendix B contains additional relevant statistics on monetized values of health and other impacts; these outcome indicators are listed separately since there is generally more uncertainty regarding these figures.

- **Description of impact**

  The nature of the impact is briefly defined and explained here. More complete descriptions of these impacts are available in reference works listed in the bibliography.

- **Causal factors: Variables that change over time and between locations**

  Policy makers find it very useful to understand the driving forces behind environmental impacts. Understanding the key causal factors is critical to *explaining* observed trends in indicators. They also help in estimating how local impacts may differ from national averages. These causal variables, then, explain how the impacts differ over *time* and *geographic location*. Most importantly, they suggest potential *policy levers*. Policies can be designed to focus on any of the key variables (e.g., grams emitted per mile) that determine the magnitude of an environmental impact.

The following table provides an overview of the available indicators for each impact. It is important to note two points about what is included in this table: First, indicators are listed only where they have been quantified at the national level; if an impact has not been quantified, no "potential" indicator is listed here. For each specific activity and its impact, the table provides a summary of the availability of quantitative data for indicators of outcomes, output, and activity. Second, the table shows only the best indicator for each impact rather than listing various alternative types of indicators for a given impact. The exceptions to this are when multiple indicators are needed to address all aspects of an issue or where some indicators are otherwise insufficient. Although outcome indicators are theoretically the most desirable type of indicator, actual quantified outcome data are often unavailable or of poor quality. As a result, output indicators—such as emissions levels—tend to be the most reliable and valid measures available in most cases. Activity indicators are presented in this table when they are the best available indicators or when outcome and output indicators are not adequate.

Summary of National Indicators Quantified: Rail Transportation

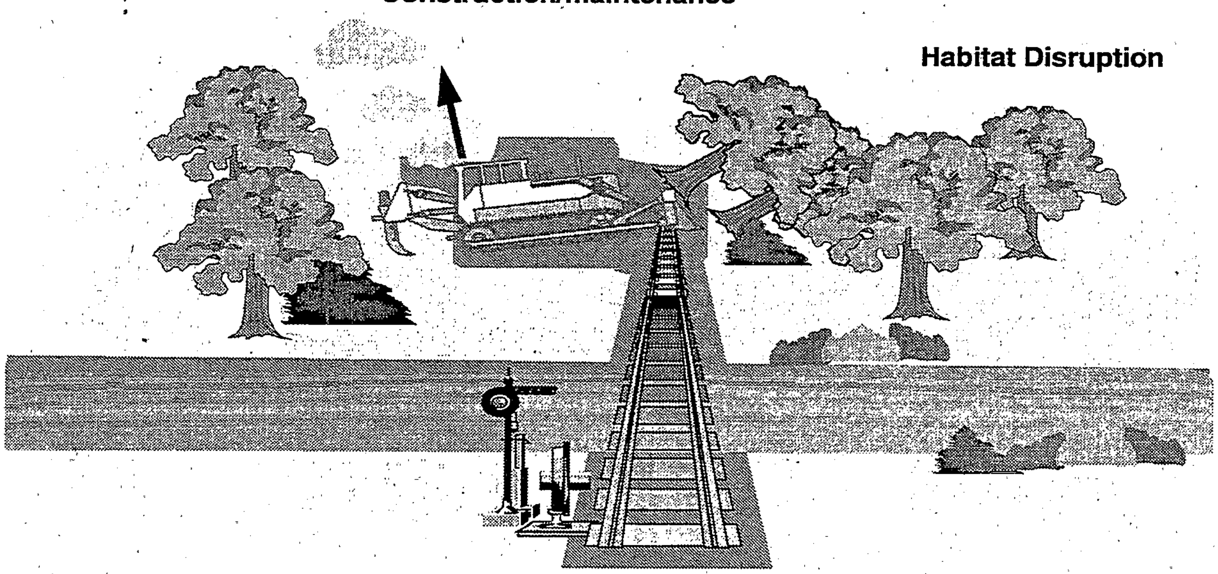
Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
1. Railway Construction, Maintenance, and Abandonment				
Habitat disruption and land take	(Data unavailable)	• Cumulative land area covered by surface track • New land area taken for track	• Track mileage constructed and abandoned • Number of rail stations	National estimates of habitat fragmentation and other impacts are not available. Rail track may be elevated, surface, or underground.
Emissions during construction and maintenance	(Data unavailable)	(Data unavailable)	• Number of crossties laid • Tons of rail laid	Creosote is a toxic preservant that is applied to rail crossties.
2. Rail Car and Parts Manufacture				
Toxic releases	(Data unavailable)	• Quantity of reported releases of toxic chemicals included in TRI database		Impacts of imported products/components are not included in statistics.
3. Rail Travel				
Exhaust emissions	(Data unavailable)	• Quantity of CO, NO_X, VOC, SO_2, PM, CO_2, CH_4, N_2O, and ammonia released		Rail's share of total national emissions has also been estimated.
Noise	• Percentage of population exposed to levels of roadway noise associated with health and other effects (1980 only)	• Typical noise emissions levels for trains		Since noise dissipates from its source, a national aggregate noise emissions level is not meaningful. Recent exposure estimates are not available.
Hazardous materials incidents during transport	(Data unavailable)	• Type and quantity of material reported released		Some of the quantity released is generally recovered, and is not a permanent release to the environment.

Activity	**Outcome Indicators** Health or Ecological Results Measure	**Output Indicators** Emissions, Habitat Change, or Exposure Measure	**Activity Indicators** Infrastructure, Travel, or Other Action Measure	**Notes**
4. Rail Car Maintenance and Support				
Releases during terminal operations: car cleaning, maintenance, repair, and refueling	(Data unavailable)	• Quantity of VOCs emitted		Environmental effects of cleaning of rail tank interiors have not been quantified.
Emissions from utilities powering rail	(Data unavailable)	• Quantity of CO, NO_X, TP, SO_X, VOC, Pb released	• Quantity of electricity consumed by rail	Rail's share of total national emissions from electric utilities has also been estimated.
5. Disposal of Rail Cars and Parts				
Rail car and parts disposal	(Data unavailable)	(Data unavailable)	• Quantity of new cars installed to replace those disposed	No information found on disposal of parts, oil, etc.

1. RAILWAY CONSTRUCTION, MAINTENANCE, AND ABANDONMENT

Although rail construction was once significant, new construction is extremely limited in comparison to historical levels. Purposes for new construction include more efficient operations, competitive service, better access to industrial facilities, and high-speed passenger service. The only recent growth in rail transportation infrastructure of significance is transit rail. In practice, abandonment of rail lines and facilities is more of an issue than new construction. Although the short line and regional railroad industry continues to grow, accounting for nearly 25 percent of the nation's 174,000-mile railroad system, currently most new short line and regional railroads have been created from marginal lines purchased from Class I railroads that would otherwise have abandoned them (ICC, 1993). Until recently, in the U.S., the Interstate Commerce Commission (ICC) has authorized and monitored interstate railway track construction and abandonment and played a role in environmental impact assessment.

In addition to long-term land take in the right of way, railway construction or salvage activities may have temporary, but significant, environmental impacts due to drilling and excavation activities, disposal of excess material, and discovery of hazardous material in the right-of-way.



HABITAT DISRUPTION AND LAND TAKE

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

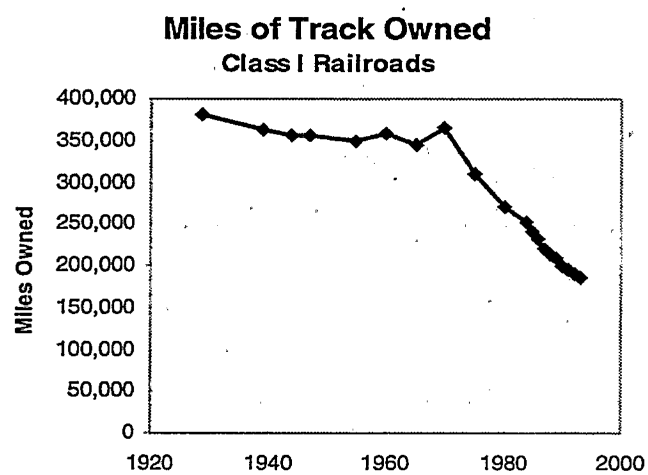
- The number of species or acres of sensitive habitat adversely affected by rail construction and/or abandonment is not known. Since construction and abandonment cases have been subject to environmental review by the ICC, the impacts of such activities presumably have been considered and minimized.

QUANTIFIED OUTPUT INDICATORS

- In 1993, 1.3 square miles of land were taken for new construction of intercity track, and land area used for intercity rail transport grew by about 0.05 percent (Apogee estimate based on ICC, 1993; Carpenter, 1994).
- Railway track and buffers occupy about 4 percent of the surface area in large cities (Tolley, 1995).
- Existing intercity (freight) rail covers an estimated 2,784 square miles of land in the U.S., occupying less than 0.1 percent of total land area (ICC, 1993; Carpenter, 1994).

QUANTIFIED ACTIVITY INDICATORS

- In 1993, 82 new miles of intercity track were constructed (ICC, 1993).
- In 1993, 441,381 tons of new rail were laid (AAR, 1993).
- As of January 1995, 170 miles of commuter rail, 71 miles of heavy rail, and 83 miles of light rail were under construction in the U.S. (APTA, 1995).
- Existing rail mileage is 177,000 miles of track, of which 168,964 miles are owned and operated by freight railroads; Amtrak operates a majority of its system on track owned by freight companies (AAR, 1993). Miles of track owned by Class I railroads has been decreasing due to sale of track to non-Class I railroads and some abandonment.



Source: AAR, 1994.

- Passenger rail stations include 540 stations served by Amtrak (Amtrak, 1994), 911 heavy rail transit stations (U.S. DOT, 1994), and 958 commuter rail stations (U.S. DOT, 1994).54
- The ICC authorized over 1,897 miles of track abandonment in Fiscal Year 1993, and 1,824 miles the previous year. Environmental review was conducted for over 130 abandonment cases in Fiscal Year 1993, and in 60 cases the ICC imposed limitations on salvage activities to prevent wildlife disturbance or other environmental impacts (ICC, 1993).

[54] Figures for Amtrak stations are from 1994, heavy rail and commuter rail stations from 1990.

Description of Impact

Since the addition of new railway infrastructure involves land take in the right-of-way and fragmentation of habitat, both flora and fauna in wetlands and terrestrial habitats are affected. The average width of land occupied by a railway track and buffer zone is about 0.016 miles (25 meters) (Carpenter, 1994). Rail transport thus requires about 0.016 square miles of land space per mile of railway track and surrounding buffer; as a result, only about 2,784 square miles of land in the U.S. are devoted to railway infrastructure.

The linear nature of railway lines leads to the splitting of natural habitats, possibly decreasing habitat size and reducing interaction between communities of species. Railway structures may damage existing vegetation, interfere with wildlife crossings, displace communities of animals and birds, and/or alter the hydrology of the area, such as drainage and stream flow patterns. Over time, rail lines can act as long-terms dams, causing the buildup of wetlands in the area. Certain species may also become accustomed to nesting along the right-of-way. When rail lines are abandoned, salvage activities (such as the removal of track, bridges, or culverts) may cause wetlands destruction or habitat disruption.

Measures can be taken, however, to mitigate environmental damage, such as route selection to bypass particularly sensitive areas, compensatory habitat creation and relocation, fine adjustments to vertical or horizontal alignments, and limiting salvage and construction activities to certain times and locations. In 1993, the ICC conducted over 130 environmental reviews for rail abandonment cases and imposed salvage restrictions in approximately 60 of these cases to mitigate impacts on environmental resources (ICC, 1993). Limitations on salvage activities include restricting salvage to certain times of year when species of concern are not present or breeding in the area, and limiting salvage to the right-of-way to prevent disturbing nearby wildlife habitat.

Many heavy-rail systems have been constructed underground as subways, either through cut-and-cover methods or tunneling. While subways typically are built in highly urban areas, this construction may still have environmental impacts related to drainage, soils, and geology.

Causal Factors

- Miles of track constructed
- Miles of track abandoned and salvaged
- Current land use
- Type of construction (elevated, at-grade, underground)
- Ecological conditions/type of land (i.e., wetlands, forest, etc.)

Emissions During Construction and Maintenance

Presentation of Indicators

Quantified Outcome/Results Indicators

- No data are available on the health or habitat effects of emissions from rail station construction or laying of rail track.

QUANTIFIED OUTPUT INDICATORS

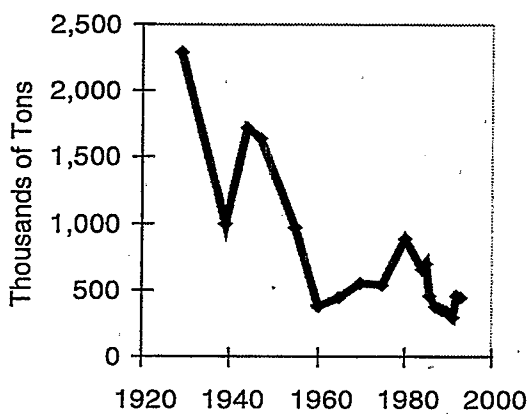
- National statistics for emissions from construction are not collected because of their temporary and project-specific nature. They are unlikely to be large in national terms given the limited amount of construction.

QUANTIFIED ACTIVITY INDICATORS

- Class I railroads laid 13,233,000 crossties and 441,381 tons of new rail in 1993 (AAR, 1993). Creosote is a toxic preservant that is applied to crossties.

Class 1 Railroads

Tons of New Rail Laid



Source: AAR, 1994.

DESCRIPTION OF IMPACT

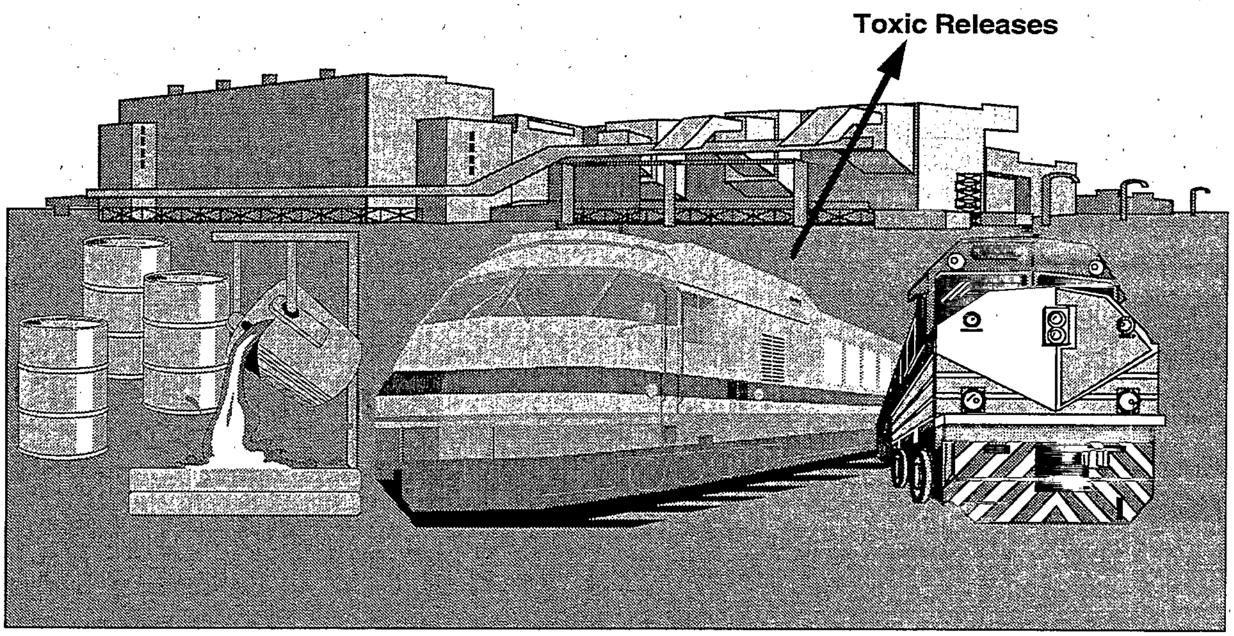
Construction or salvage of plant and equipment can affect the environment through diesel fumes from excavating machinery and haulage vehicles, spillage during refueling, dust from earthworks, and noise. In addition, construction traffic may also emit air pollutants.

CAUSAL FACTORS

- Miles of track constructed, tons of new rail laid
- Miles of track salvaged
- Level of construction and/or salvage activities
- Fuel consumed by construction equipment
- Topographical conditions (hills, valleys, etc.)
- Climatic conditions (temperature, wind, rain, etc.)
- Population density

2. RAIL CAR AND PARTS MANUFACTURE

The manufacture of railcars, locomotives, and parts results in environmental impacts through the release of toxics to the air, soil, and water.



TOXIC RELEASES

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No quantified data on human health impacts, such as increased incidence of cancer from toxics, or habitat and species impacts are available.

QUANTIFIED OUTPUT INDICATORS

- Nearly 2.2 million pounds of toxic chemicals were reported released on-site from railroad equipment manufacturing facilities in 1993 (U.S. EPA, 1995d).[55]

[55] Impacts of imported equipment and parts are not counted here. Only U.S. facilities are included here, including the impacts of exported equipment.

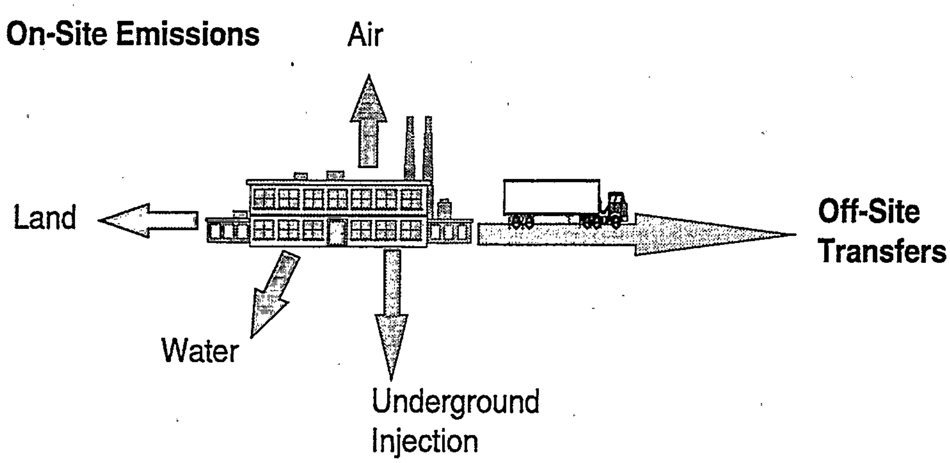
Toxic Chemicals Released from Railroad Equipment Manufacturing Facilities (pounds per year)

SIC Code	Industry Type	On-Site Releases					Off-Site	
		Air	Water	Land	Underground Injection	Total	POTW Transfer	Locations Transfer
3743	Railroad Equipment	2,157,138	458	15	500	2,158,111	176,632	8,165,741

Source: U.S. EPA, 1993 Toxic Releases Inventory (1995)

DESCRIPTION OF IMPACT

The manufacture of railroad vehicles and engines involves use of a variety of materials and chemicals. During the various processes, toxic chemicals are released from vehicle manufacturing facilities into the environment. Releases occur as on-site discharges of toxic chemicals, including emissions to the air, discharges to water, releases to land, and contained disposal or injection underground. In addition, chemicals are transferred off-site, as the following diagram shows.



On-site releases to air occur as either stack emissions, through confined air streams, fugitive emissions, which include equipment leaks, evaporative losses from surface impoundments and spills; and/or releases from building ventilation systems. Surface water releases may include releases from discharge pipes and from diffuse runoff from the plant facility's parking lots, roofs, and other areas. Releases to land may include disposal in landfills, surface impoundments, and other types of land disposal within the boundaries of the reporting facility. Underground injection is a contained release of a fluid into a subsurface well.

Off-site transfers involve shipments of chemicals away from the reporting facility. Except for off-site transfers for disposal, these quantities do not necessarily represent entry of the chemical into the environment. Chemicals are often shipped to other locations for recycling, energy recovery, or treatment at publicly owned treatment works (POTWs). Wastewaters are transferred through pipes or sewers to a POTW, where treatment or removal of a chemical from the water depends upon the nature of the chemical and treatment methods used. Some chemicals are destroyed in treatment.

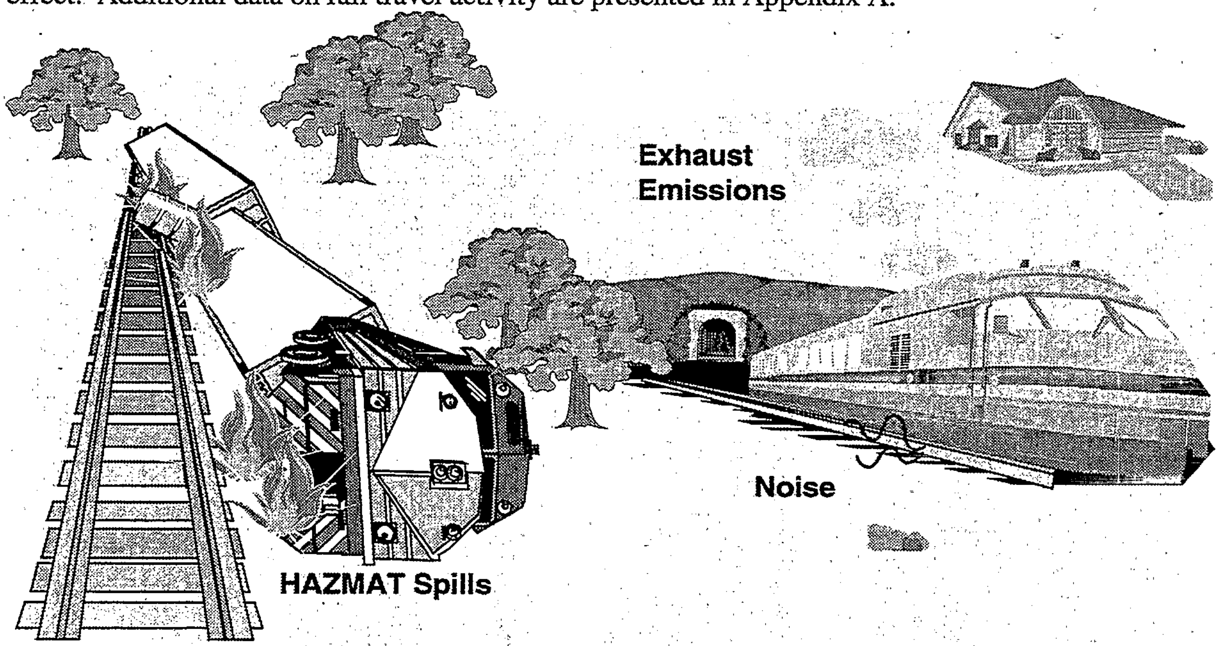
Others evaporate into the atmosphere. Some are removed but are not destroyed by treatment and may be disposed of in landfills (U.S. EPA, 1992b).

CAUSAL FACTORS

- Number of vehicles or parts built
- Amount of chemicals used in manufacture per vehicle or part
- Efficiency of processes and pollution prevention efforts
- Amount of chemicals transferred to other locations for recycling, energy recovery, or treatment
- Types of chemicals released and toxicity
- Population density and extent of exposure
- Environmental conditions such as climate and topography

3. RAIL TRAVEL

Rail transport directly affects the environment through emissions from fuel combustion, noise, and hazardous materials incidents. These impacts are discussed below. In most cases, the amount of travel (freight and passenger) is an activity indicator that provides a crude indication of the level of effect. Additional data on rail travel activity are presented in Appendix A.



EXHAUST EMISSIONS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No data are available on the health or habitat effects of emissions from rail travel.

QUANTIFIED OUTPUT INDICATORS

- In 1994, railroad operations were responsible for the following emissions nationwide (U.S. EPA, 1995e):

Pollutant	Quantity Emitted (1994, thousand short tons)	Percentage of total Emissions of that Pollutant
Carbon Monoxide (CO)	124	0.13 %
Nitrogen Oxides (NO_x)	947	4.01 %
Volatile Organic Compounds (VOCs)	43	0.19 %
Sulfur Dioxide (SO_2)	69	0.33 %
Particulate Matter (PM-10)	48	0.11 %
Ammonia	1.79	0.03 %

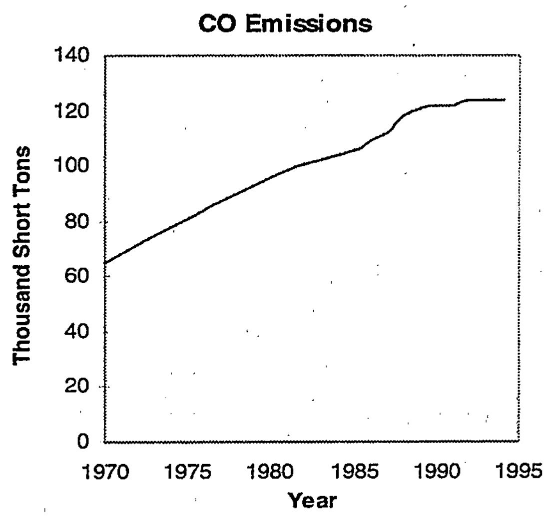
- In 1993, CO_2 emissions from railroad operations accounted for approximately 12 million metric tons of carbon equivalent (mmtCe), or 0.9 percent of total national anthropomorphic CO_2 emissions (Apogee estimate).[56]
- Railroad travel contributed to emissions of other greenhouse gases, as reported below (U.S. EPA, 1994a):

Pollutant	Quantity Emitted (1990, thousand metric tons)
Methane (CH_4)	2
Nitrous Oxide (N_2O)	1

CO Emissions from Railroads

Year	Thousand Short Tons	Percentage of Total National Emissions
1970	65	0.05 %
1980	96	0.08 %
1985	106	0.09 %
1986	109	0.10 %
1987	112	0.10 %
1988	118	0.10 %
1989	121	0.12 %
1990	122	0.12 %
1991	122	0.13 %
1992	124	0.13 %
1993	124	0.13 %
1994	124	0.13 %

Source: U.S. EPA, 1995e.

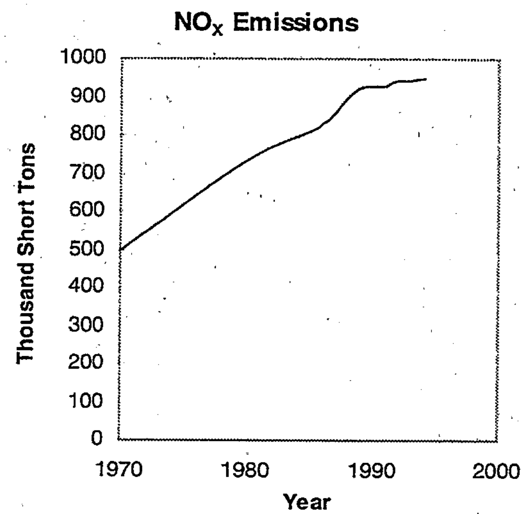


[56] Estimate is based on the following methodology: transportation sector energy use by fuel type within a mode (DOE/EIA, 1995b) was multiplied by carbon coefficients (mmtCe/quadrillion Btu) for each fuel (DOE/EIA, 1995a), then adjusted by fraction of carbon that does not oxidize during combustion (DOE/EIA, 1995a). Note that this estimate does not account for upstream emissions, such as emissions from car assembly and fuel production.

NO_X Emissions from Railroads

Year	Thousand Short Tons	Percentage of Total National Emissions
1970	495	2.40 %
1980	731	3.13 %
1985	808	3.53 %
1986	829	3.71 %
1987	854	3.81 %
1988	897	3.80 %
1989	923	3.97 %
1990	929	4.03 %
1991	929	4.10 %
1992	946	4.14 %
1993	945	4.06 %
1994	947	4.01 %

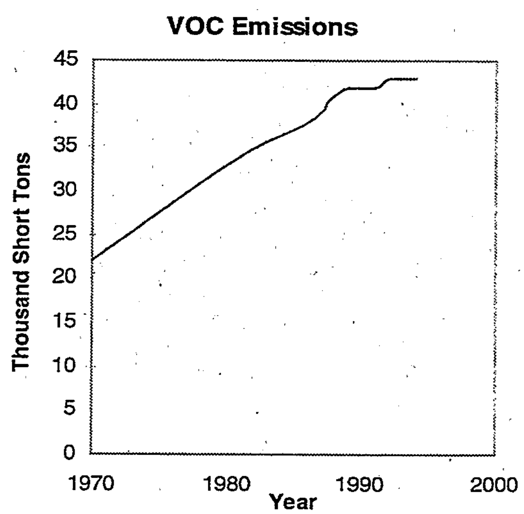
Source: U.S. EPA, 1995e.



VOC Emissions from Railroads

Year	Thousand Short Tons	Percentage of Total National Emissions
1970	22	0.07 %
1980	33	0.13 %
1985	37	0.14 %
1986	38	0.15 %
1987	39	0.16 %
1988	41	0.16 %
1989	42	0.18 %
1990	42	0.18 %
1991	42	0.18 %
1992	43	0.19 %
1993	43	0.19 %
1994	43	0.19 %

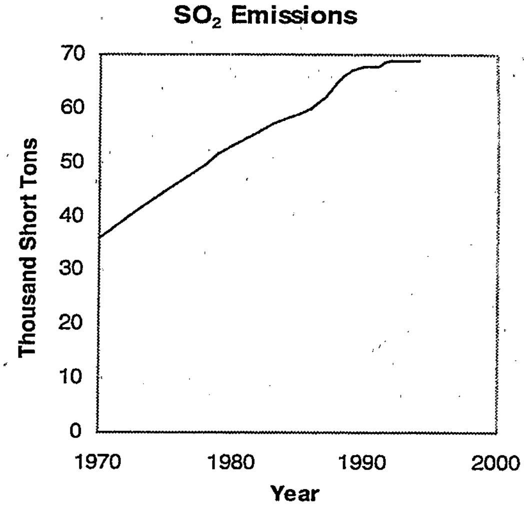
Source: U.S. EPA, 1995e.



SO_2 Emissions from Railroads

Year	Thousand Short Tons	Percentage of Total National Emissions
1970	36	0.12%
1980	53	0.20%
1985	59	0.25%
1986	60	0.27%
1987	62	0.28%
1988	65	0.29%
1989	67	0.29%
1990	68	0.30%
1991	68	0.31%
1992	69	0.32%
1993	69	0.32%
1994	69	0.33%

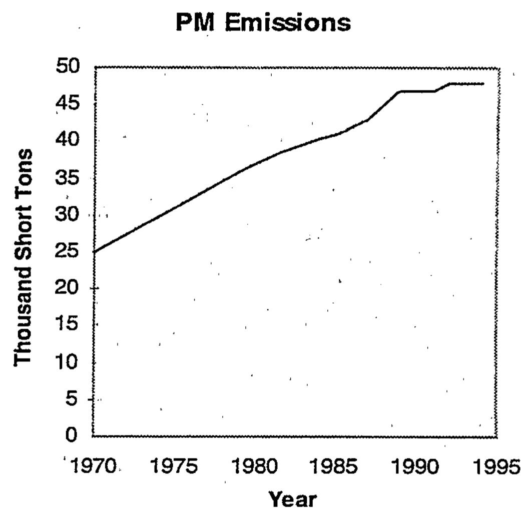
Source: U.S. EPA, 1995e.



PM Emissions from Railroads[57]

Year	Thousand Short Tons	Percentage of Total National Emissions
1970	25	-
1980	37	-
1985	41	0.09%
1986	42	0.08%
1987	43	0.10%
1988	45	0.07%
1989	47	0.09%
1990	47	0.11%
1991	47	0.10%
1992	48	0.11%
1993	48	0.11%
1994	48	0.11%

Source: U.S. EPA, 1995e.



QUANTIFIED ACTIVITY INDICATORS

- Refer to Appendix A for data on rail travel.

[57] Percentage of total emissions are not reported for particulate matter prior to 1985 because of changes in total emissions inventories; fugitive dust and wind erosion are reported only for the period 1985 to 1994.

DESCRIPTION OF IMPACT

Exhaust emissions from fuel combustion are a function of type and quantity of energy consumed. Quantity of energy consumed, in turn, depends on fuel efficiency and distance traveled. Trains in the U.S. generally burn diesel fuel, but some, particularly in passenger transport, use electric power sources. Note that while electric trains themselves are "clean" and do not emit air pollutants, electric generating facilities, depending on power source, may emit CO, NO_X, PM, SO_X, VOC, and CO_2.

CAUSAL FACTORS

- Vehicle miles of travel (VMT), by type of engine
- Fuel efficiency
- Fuel consumed, by type
- Emissions rates
- Topographical conditions affecting pollutant dispersion (hills, valleys, etc.)
- Climatic conditions affecting pollutant dispersion and formation (temperature, wind, rain, etc.)
- Population density–exposure to pollution

NOISE

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

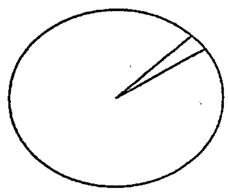
- Less than 3 percent of the U.S. population in 1980 was exposed to noise levels from rail operations great enough to cause annoyance—expressed in Leq greater than 55 dB(A) (OECD, 1993). A more recent estimate is not available.
- A small portion of the U.S. population was exposed to daily noise levels from rail transport great enough to cause other effects, such as communication interference, muscle/gland reaction, and changed motor coordination, as the following chart shows:

Percentage of U.S. Population Exposed to Rail Transportation Noise, 1980

Outdoor Sound Level in Leq [dB(A)]

>55 dB(A) Annoyance	>60 dB(A) Normal Speech Level	>65 dB(A) Communication Interference	>70 dB(A) Muscle/Gland Reaction	>75 dB(A) Changed Motor Coordination
2.4%	1.4%	1.0%	0.2%	n/a

Source: OECD, 1993.



Source: OECD, 1993.

QUANTIFIED OUTPUT INDICATORS

- Noise levels are site specific and dissipate with increasing distance from the source; as a result, an aggregate national noise emissions figure is not meaningful.
- Typical noise emissions are 100 dB(A) for a diesel train, and 120 dB(A) for a locomotive whistle (BTS, 1994).

QUANTIFIED ACTIVITY INDICATORS

- Refer to Appendix A for data on rail travel.

DESCRIPTION OF IMPACT

Noise associated with rail transport comes from engine operations, rail-wheel contact, aerodynamic effects, and vibrating structures during operations. The issue of noise is generally discussed in terms of the number or proportion of people affected. The findings of numerous research projects in OECD countries on the effects of noise and its wider repercussions indicate that an outdoor sound level of 65 dB(A) is "unacceptable," and an outdoor level of less than 55 dB(A) is desirable (OECD, 1993). Although at the national level, railroad noise does not appear to be a significant problem, at the local level, noise impacts from rail may be severe depending on population density near rail lines and frequency of operations.

CAUSAL FACTORS

- Level of rail activity (miles of travel, frequency of service) by rail type
- Speed
- Population density near rail
- Distance between population/housing and rail operations
- Background noise level
- Natural noise barriers (topography, vegetation)
- Designed noise barriers and control devices

HAZARDOUS MATERIALS INCIDENTS DURING TRANSPORT

PRESENTATION OF INDICATORS

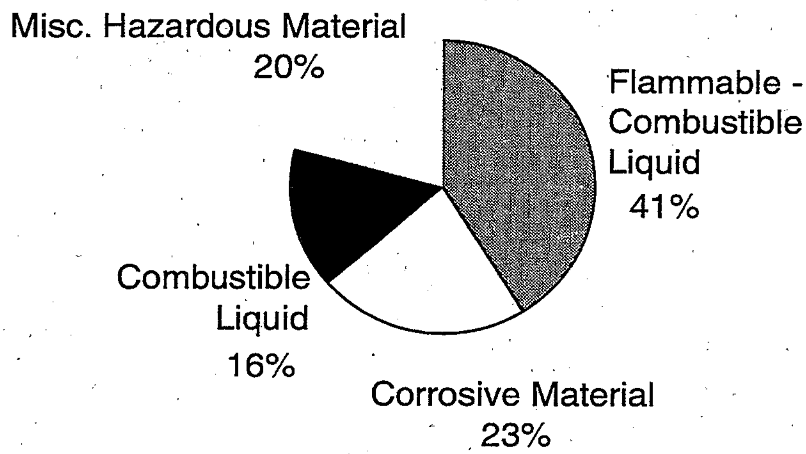
QUANTIFIED OUTCOME/RESULTS INDICATORS

- No statistics were found regarding the number of species or acres nationwide affected by commodity spills.

QUANTIFIED OUTPUT INDICATORS

- An average of 1,172 hazardous materials spills occurred annually during rail transport in the U.S. between 1990 and 1994, some of which were recovered (HMIS, 1995) (see table and graphic).

Distribution of Gallons of Hazardous Materials Spilled in Rail Transport, 1990-1994



Source: HMIS, 1991

Hazardous Materials Rail Incidents, Annual Average, 1990-94

Class	Number of Incidents	Gallons Released	Pounds Released	Cubic Feet Released	$ Clean-up Cost and Loss of Material
Corrosive Material	523.6	91,002.8	714.1		1,459,253
Flammable – Combustible Liquid	288.6	165,626.3			3,323,142
Nonflammable Compressed Gas	102.2	40,942.2	1.6	506.0	98,560
Flammable Gas	76.0	10,965.3		843.2	314,359
Combustible Liquid	64.4	63,107.3			813,559
Oxidizer	36.0	1,721.0	416,904.7		696,681
Miscellaneous Hazardous Material	28.0	14,096.9	65,599.8		156,403
Poisonous Materials	23.0	8,524.5	34,107.6		2,492,427
Poisonous Gas	12.2	4.8	0.6	0.1	283,551
Other Regulated Material, Class E	5.8	12.5	100,041.2		225,128
Flammable Solid	3.6	55.3	248.8		9,985
Flammable Solid (per-1991)	2.2	0.2	1,009.8		222,404
Spontaneously Combustible	2.0	0.0	20,586.2		79,179
Dangerous when Wet Material	1.6	0.3	544.4		22,400
Other Regulated Material, Class C	1.2	40.6	220.5		2,000
Other Regulated Material, Class A	1.0	7,401.1			349,403
Very Insensitive Explosive	0.2	0.0	20.0		10
Radioactive Material	0.2	0.0			0
Total	1,171.8	403,701.0	639,999.2	1,349.2	10,548,645.2

Source: HMIS Database

- The quantity of hazardous materials remaining in the environment after cleanup efforts is unknown.

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- For Class I railroads in 1993, chemicals and allied products accounted for 135,063 tons (9.7 percent) of freight originated. Petroleum and coke accounted for 40,132 tons (2.9 percent) originated (AAR, 1993).
- Of the 1,130 hazardous materials rail incidents reported to HMIS in 1991, 41% resulted from human error, 50 percent from packaging failure, 5 percent from vehicle accidents/derailments, and 4 percent from other causes (HMIS, 1991).
- Class I claims for freight loss and damage, including non-hazardous commodities, accounted for only 0.34 percent of Class I freight revenue in 1993 (AAR, 1993).

DESCRIPTION OF IMPACT

The potential for commodity spills during rail transportation is important to consider because of the large, albeit decreasing, role rail plays in domestic freight movement. In 1993, rail transport accounted for 46 percent of the ton-miles and 29 percent of the tonnage moved during domestic intercity transport, excluding pipelines (Eno, 1994). In particular, commodity spills of hazardous materials may impose substantial costs for product loss, carrier damage, property damage, evacuations, and response personnel and equipment. The Hazardous Materials Information System (HMIS) database, maintained by U.S. DOT/Research and Special Projects Administration (RSPA), contains a record of all reported hazardous materials incidents occurring during rail transport, including type of material released, number of injuries/fatalities, and estimated cleanup costs.

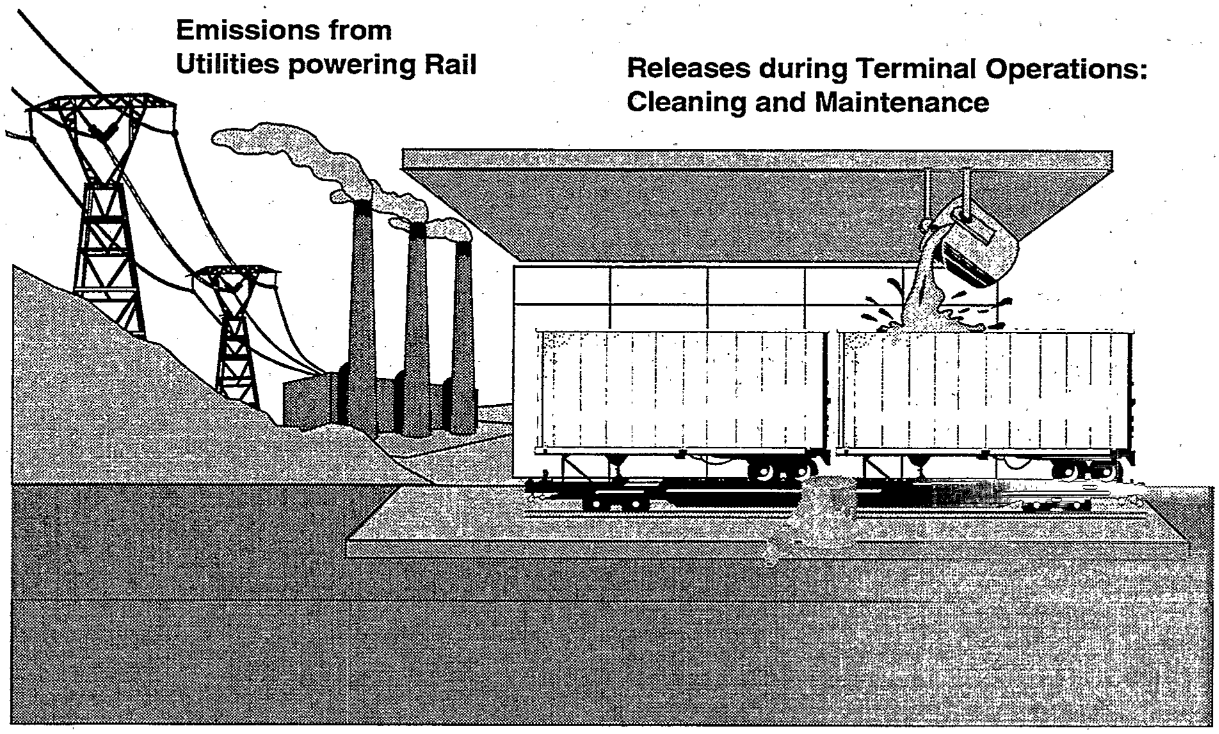
The number of hazardous material incidents is not necessarily indicative of the environmental impact of such incidents, since it may be possible to clean up most of the materials released. If not properly contained, however, hazardous materials incidents may cause long-term environmental damage such as water pollution, damage to fish and wildlife, habitat destruction, and aesthetic or recreational losses. The environmental impact of any given hazardous materials spill is highly site-specific. It depends on the type and quantity of material spilled, amount recovered in cleanup, chemical properties (such as toxicity and combustibility), and impact area characteristics (such as climatic conditions, flora and fauna density, and local topography). It should be noted that while the overall impact of rail spills may be small for the nation as a whole, any hazardous material spill may have severe impacts on flora and fauna in the location of occurrence.

Causal Factors

- Quantity of hazardous materials transported and distance transported
- Accident or spill rate
- Type and quantity of materials spilled
- Cleanup efforts
- Population density
- Sensitivity of local habitats/species

4. RAIL CAR MAINTENANCE AND SUPPORT

Besides trains and track, rail transport requires support facilities such as terminal areas, fueling stations, and electric generating facilities (to power electrified passenger rail systems).



RELEASES DURING TERMINAL OPERATIONS: CAR CLEANING, MAINTENANCE, REPAIR, AND REFUELING

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Data on water quality impacts on streams, rivers, and lakes, and related habitat due to rail terminal operations are not available. Data on health effects from air pollution coming from terminals are also not available.

QUANTIFIED OUTPUT INDICATORS

- Tank car and rail car cleaning operations emit 1.25 million pounds of VOCs per year (EPA Source Assessment Study of 1978 as cited in U.S. EPA, 1995).
- Quantified estimates of other emissions are not known nationally. However, a variety of wastes are known to be generated from typical railroad terminal operations.

Typical Railroad Terminal Operations: Materials Used and Types of Waste Possibly Generated

Process/Operation	Materials Used	Types of Waste Generated
Unloading or Cleaning of Tank Cars	Solvents, alkaline cleaners	Acid/alkaline wastes Toxic wastes Solvent wastes Residual tank contents
Rust Removal	Naval jelly, strong acids, strong alkalies	Acid/alkaline wastes
Painting	Enamels, lacquers, epoxies, alkyds, acrylics, primers, solvents	Ignitable wastes Toxic wastes Paint wastes Solvent wastes
Paint Removal	Solvents, paint thinners, enamel, white spirits	Paint wastes Toxic wastes Solvent wastes
Exterior Washing	Solvents, cleaning solutions	Solvent wastes Oil and grease
Equipment degreasing	Degreasers, engine cleaners, acids, alkalies, cleaning fluids	Ignitable waste Combustible solids Acid/alkaline wastes
Refueling	Diesel fuel	Evaporative losses Fuel drips and spills

Source: U.S. EPA/RCRA Fact Sheet: Motor Freight/Railroad Terminal Operations, 1993; U.S. EPA, 1995

QUANTIFIED ACTIVITY INDICATORS

- Approximately 90 percent of transportation equipment cleaning facilities discharge wastewater to POTWs or combined treatment works (privately owned by multiple facilities) after some amount of treatment. Some facilities discharge directly to surface waters under NPDES permits or to underground injection wells under Safe Drinking Water Act permits (U.S. EPA, 1995).

DESCRIPTION OF IMPACT

Terminal operations include line haul railroad activities (such as tank car unloading and cleaning, equipment degreasing, exterior washing, and painting), furnishing of terminal facilities for passenger or freight traffic, and the movement of railroad cars between terminal yards. Many of these processes use materials that are hazardous or may in turn generate hazardous waste or wastewater. In addition, refueling operations impact the environment through spills and drips of fuel, and through fuel tank vapors that are displaced when the tank is filled with liquid fuel. The actual impact of terminal activities on the environment depends in a large part on the type and volume of operations, level of cleanliness required, type of waste generated, and efficacy of wastewater treatment systems in place.

The cleaning of rail tank interiors is a major source of pollution during terminal operations. The typical rail tank car has a volume of 20,000-30,000 gallons and generates about 3,000-5,000 gallons of wastewater during cleaning, resulting in the output of spent cleaning fluids, fugitive VOC emissions, water treatment system sludges, and tank residues. The disposal and treatment of tank heels can also be a source of pollution for tank cleaning facilities. The typical heel volume of a rail tank car (i.e., amount left in tank after unloading) is 10-30 gallons per tank, and a facility's wastewater treatment system may be adversely affected by, or may not adequately treat, a slug of concentrated tank residue. Incompatible heels are usually segregated and resold to a reclaimer or shipped off-site for disposal. Heels that are composed of detergents, solvents, acids, of alkalis can be stored on-site and used as tank cleaning fluids or to neutralize other tank heels.

Relatively small amounts of waste and wastewater are generated from the washing and maintenance of rail car exteriors. Typical hazardous wastes generated include spent solvents, spent caustics, paint chips, and paint sludges. Wastewater is generally treated on-site and then discharged to a public treatment works (U.S. EPA, 1995).

The primary source of toxic chemicals released are substances dissolved or suspended in wastewater, primarily during the cleaning of tank interiors. Other potential environmental impacts of terminal operations include air emissions and residual wastes. Fugitive emissions of VOCs arise from tank heels and residues, cleaning solutions, painting and paint stripping, and refueling vapors. Residual wastes are generated as sludges from wastewater treatment systems, residues removed from the inside of tanks, and hazardous wastes from painting, paint removal, and cleaning of parts (U.S. EPA, 1995).

CAUSAL FACTORS

- Number of terminals
- Type and level of terminal operations
- Materials used during terminal operations
- Wastewater treatment capabilities

EMISSIONS FROM UTILITIES POWERING RAIL[58]

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No data are available on the health or habitat effects of emissions from utilities powering rail.

QUANTIFIED OUTPUT INDICATORS

- Rail transport's share of emissions from electric utilities accounts for less than 0.01 percent of total national emissions of CO, NO_X, TP, SO_X, VOC, and lead (U.S. EPA, 1995e; DOE, 1994a).

[58] Emissions from utilities powering rail could also be categorized as part of rail travel, but they are listed here because utilities are legally stationary sources, and emissions do not occur near the point of travel.

Rail Share of Emissions from Electric Utilities, 1992

Type of Emission	National Emissions from Utilities (thousand short tons)	Rail Share (0.2%) of Utility Emissions (thousand short tons)	Percentage of Total National Emissions from Rail
CO	313	0.63	< 0.01 %
NO_X	7,473	14.95	< 0.01 %
Total Particulates (TP)	255	0.51	< 0.01 %
SO_X	15,417	30.8	< 0.01 %
VOC	34	0.07	< 0.01 %
Lead	0.059	<0.01	< 0.01 %

Source: U.S. EPA, 1993a; DOE, 1994a

QUANTIFIED ACTIVITY INDICATORS

- Passenger rail transport accounted for 0.2 percent of total national electric consumption in 1992. Electric rail did not consume any nuclear or hydro-electric power in 1992 (U.S. DOE, 1994a).
- Passenger rail transport consumed 59.8 trillion Btu of electricity in 1993, compared with 21.6 trillion Btu of diesel fuel (U.S. DOE, 1995c)

DESCRIPTION OF IMPACT

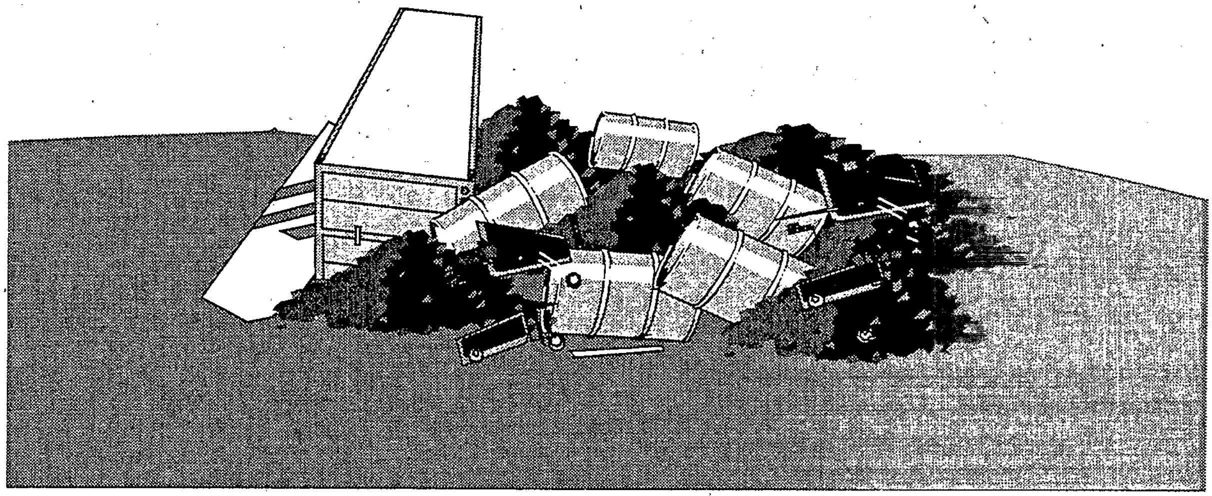
To the extent that passenger transport by rail is the only significant transportation-related consumer (excluding pipelines) of electricity for fuel, and that electricity provides about 75 percent of the energy used in such operations, emissions from utilities should be considered when evaluating the environmental impacts of rail. The contribution of electric rail transport to atmospheric pollution depends of the type of power source used to generate electricity.

While air pollution from nuclear and hydro-electric power stations is minimal, coal and other fossil fuel power plants emit large quantities of NO_X, SO_X, and particulate matter, as well as smaller amounts of CO, VOC, and lead. Such power plants may be significant contributors to acid rain, for example. Water pollution from nuclear, coal, and other fossil fuel power plants consists primarily of thermal discharges from cooling water, which can cause substantial adverse impacts to water chemistry, habitat, and species. Thermal discharges are regulated under the Clean Water Act. Hydro-electric power stations affect the flow and temperature of rivers by retaining water in reservoirs.

CAUSAL FACTORS

- Electrified rail VMT
- Quantity of electricity consumed (total or per VMT)
- Power source/technology used to generate electricity
- Emissions controls at power plants
- Topographical conditions (hills, valleys, etc.)
- Climatic conditions (temperature, wind, rain, etc.)
- Population density

5. DISPOSAL OF RAIL CARS AND PARTS



RAIL CAR AND PARTS DISPOSAL

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Estimates are not available on the health and environmental impacts of landfilling or other disposal of scrapped rail cars and parts.

QUANTIFIED OUTPUT INDICATORS

- National data on emissions from the disposal of vehicles are not available.

QUANTIFIED ACTIVITY INDICATORS

- Each year, 35,000 new rail cars are installed, suggesting that a comparable number are scrapped or exported annually since the fleet size is not increasing significantly. (AAR, 1993).

DESCRIPTION OF IMPACTS

Rail cars and their parts—such as nickel-cadmium batteries, metals, spent oil—are scrapped, refurbished or recycled as they wear out. In addition, many rail cars and their components are exported. However, disposal practices may allow the release of toxic substances into water, air, or soil.

CAUSAL FACTORS

- Quantity of metals and oil used in rail operations.
- Recovery rate
- Groundwater contamination and seepage prevention measures at the disposal site

AVIATION ENVIRONMENTAL INDICATORS

This section presents the quantitative indicators available for tracking the nationwide environmental impacts of aviation. There are three key environmental issues for which there is enough quantitative data to produce national indicators. Other types of environmental impacts are identified and intermittently tracked by airports, states, and EPA through individual environmental impact statements (EISs), but data are not consolidated at the national level. For each of the five basic categories of activities affecting the environment, the various impacts are listed.

HOW EACH IMPACT IS PRESENTED IN THIS SECTION

Each environmental impact is covered in one or more pages of text and graphics, with the following key subsections:

- **Presentation of indicators**

  The key indicators that have been quantified are presented. *Outcome* indicators are listed first since they provide information on end results and are theoretically the most desirable type of indicator. Unfortunately, actual quantified data are often unavailable or of poor quality. In many instances, the only available data on outcomes are the number of states reporting a problem. This information is often incomplete (not all states may examine the problem), vague (states may define the problem differently), or only somewhat relevant (the contribution of transportation to the problem may be unknown). As a result, *output* indicators—such as emissions data—are presented. These statistics may be an easier and more valid measure for policy makers to examine and track over time. *Activity* indicators (defined broadly to include infrastructure, travel, and other activities) are listed when they are the best available indicators or when outcome and output indicators are not adequate. In some cases, local examples are also provided.

  To avoid repetition within the report, basic infrastructure and travel indicators are listed in Appendix A for each mode of transportation. Appendix B contains additional relevant statistics on monetized values of health and other impacts; these outcome indicators are listed separately since there is generally more uncertainty regarding these figures.

- **Description of impact**

  The nature of the impact is briefly defined and explained here. More complete descriptions of these impacts are available in reference works listed in the bibliography.

- **Causal factors: Variables that change over time and between locations**

  Policy makers find it very useful to understand the driving forces behind environmental impacts. Understanding the key causal factors, such as VMT or emissions rates in grams per mile, is critical to *explaining* observed trends in indicators. They also help in estimating how local impacts may differ from national averages. These causal variables, then, explain how the impacts differ over *time* and *geographic location*. Most importantly, they suggest potential *policy levers*. Policies can be designed to focus on any of the key variables (e.g., grams emitted per mile) that determine the magnitude of an environmental impact.

The following table provides an overview of the available indicators for each impact. It is important to note two points about what is included in this table: First, indicators are listed only where they have been quantified at the national level; if an impact has not been quantified, no "potential" indicator is listed here. For each specific activity and its impact, the table provides a summary of the availability of quantitative data for indicators of outcomes, output, and activity. Second, the table shows only the best indicator for each impact rather than listing various alternative types of indicators for a given impact. The exceptions are when multiple indicators are needed to address all aspects of an issue or where some indicators are otherwise insufficient. Although outcome indicators are theoretically the most desirable type of indicator, actual quantified outcome data are often unavailable or of poor quality. As a result, output indicators—such as emissions levels—tend to be the most reliable and valid measures available in most cases. Activity indicators are presented in this table when they are the best available indicators or when outcome and output indicators are not adequate.

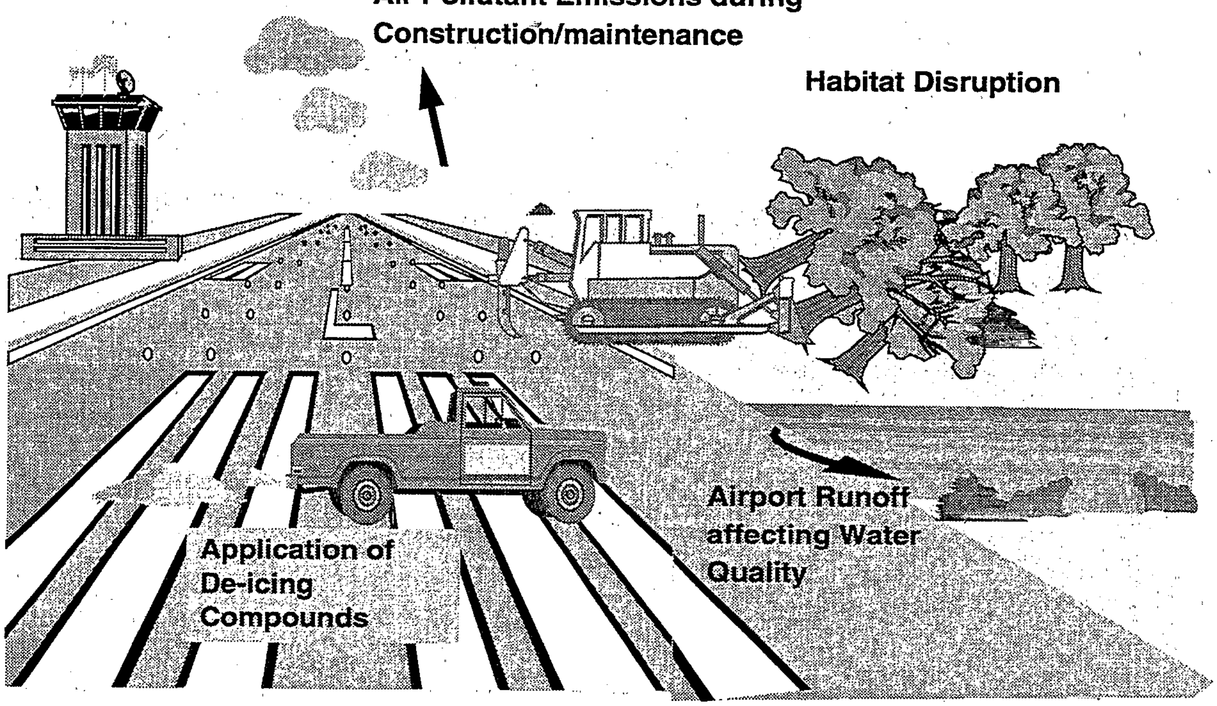
Summary of National Indicators Quantified: Aviation Transportation

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
1. *Airport Construction, Maintenance, or Expansion*				
Habitat disruption and land take	(Data unavailable)	(Data unavailable)	• Number of airports constructed • Length of runways constructed • Cumulative number of airports	Potential impacts on existing wetlands, vegetation, and wildlife habitat.
Emissions during construction and maintenance	(Data unavailable)	(Data unavailable)	• Number of airports constructed • Length of runways constructed	Construction related activities generally result in temporary visual, noise, air quality, erosion, water quality, and solid waste impacts.
Releases of deicing compounds	(Data unavailable)	• Percent of urea discharged directly to surface waters	• Quantity of deicing agents used	Glycol and urea may mix with runway runoff and other local sources of stormwater resulting in overland flow, and release to surface waters.
Airport Runoff	(Data unavailable)	(Data unavailable)	• Cumulative number of airports • Number/percentage of airports with paved runways	
2. *Aircraft and Parts Manufacture*				
Toxic releases	(Data unavailable)	• Quantity of reported releases of toxic chemicals included in TRI database.	• Number of new jet aircraft delivered	Impacts of imported products/components are not included in statistics. Emissions of non-toxic air pollutants are unknown.

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
3. Aviation Travel				
High altitude emissions	(Data unavailable)	• Quantity of CO_2, CH_4, and N_2O released	• Fuel consumption	There are cases where fuel dumping in the atmosphere has occurred. For most pollutants, altitude of emissions is unknown, although damage is known to differ depending on altitude
Low altitude/ground level emissions	(Data unavailable)	• Quantity of CO, NO_X, VOC, SO_2, PM, and Butadiene released		For most pollutants, altitude of emissions is unknown,
Noise	• Percentage of population exposed to levels of aircraft noise associated with health and other effects	• Typical noise emissions levels by aircraft type during takeoff and landing		Improvements in aircraft design has reduced noise despite tremendous growth in airline traffic.
Hazardous material incidents during transport	(Data unavailable)	• Type and quantity of material reported released		Some of the quantity released is generally recovered, and is not a permanent release to the environment. Amount recovered is not measured.
4. Airport Operation				
Emissions from ground support equipment	(Data unavailable)	• Quantity of CO, NO_X, VOC, and PM released		
5. Disposal of Aircraft and Parts				
Airplane and parts disposal	(Data unavailable)	(Data unavailable)	• Number of aircraft ordered	Longevity of the airline fleet, exportation, and recycling result in relatively low rates of aircraft scrappage.

1. AIRPORT CONSTRUCTION, MAINTENANCE, AND EXPANSION

Airport construction, maintenance, and expansion result in a number of environmental effects. Common problems associated with infrastructure include habitat disruption, hydrologic alterations, introduction of deicing compounds to the environment, and increased runoff. In addition, airport construction activities may have temporary environmental impacts, such as air pollutant emissions from construction equipment, These impacts are discussed below, and further material on infrastructure is available in Appendix A.



HABITAT DISRUPTION AND LAND TAKE

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- The number of species or acres of sensitive habitat adversely affected by airport construction and expansion is not known.

QUANTIFIED OUTPUT INDICATORS

- No quantified data are readily available on the amount of land taken annually or cumulatively by airport runways and other infrastructure.

QUANTIFIED ACTIVITY INDICATORS

- Only one major scheduled passenger service airport (Denver International Airport) has been constructed since 1974. However, the total number of airports (including private airports) in the U.S. has increased by about 3,182 from 1980 to 1994—a nearly 21 percent increase—from 15,161 in 1980 to 18,343 in 1994 (BTS, 1994).

- In 1994, there were planned construction activities at 60 major airports for approximately 1,022,350 feet (194 miles) of new runway/taxiway (FAA, ACE Plan, 1994). Generally, this construction will be done over a period of five or more years.
- There were 18,343 airports in the U.S. in 1994, which is more airports than in every other nation in the world combined (BTS, 1994).
- Airports vary significantly in size. The U.S. contains 26 large hub airports (handling 1 percent or more of total air passenger enplanements) and 570 commercial service airports (2,500 or more enplanements annually) (BTS, 1994).

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- A typical major new airport requires approximately 25,000 acres of land (Wood and Johnson, 1989).
- Runway construction at Dallas/Fort-Worth International Airport was expected to significantly affect some natural features and resources. Wetlands that existed on the property included drainage-ways, creeks, and small isolated systems that would be affected by runway construction (U.S. DOT, DFW Air Development Plan, 1991).

DESCRIPTION OF IMPACT

Airport construction and expansion activities have the potential to affect endangered or threatened species. Impacts on wildlife from construction activity depend on the extent and types of habitat that are disturbed and the availability of comparable habitats near the site. Long term impacts from increased airport surfaces include elimination of and damage to existing vegetation, interference with wildlife, displacement of forests and communities of animals and birds, and alteration in the hydrology of various areas.

CAUSAL FACTORS

- Number of new airports constructed
- Number of runway and other airport capacity enhancements
- Ecological conditions/type of land (i.e., wetlands, forest, etc.)
- Successful airport implementation of various efforts to avoid or mitigate impacts (i.e., stormwater treatment)

EMISSIONS DURING CONSTRUCTION AND MAINTENANCE

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No data are available on the health or habitat effects of emissions from airport construction or maintenance.

QUANTIFIED OUTPUT INDICATORS

- National statistics for emissions from airport-related construction activities are generally not available. At the local level, emissions from construction are discussed on a case-by-case basis in the project's EIS.

Quantified Activity Indicators

- Only one major scheduled passenger service airport (Denver International Airport) has been constructed since 1974.
- In 1994, there were planned runway/taxiway construction activities at 60 major airports for approximately 1,022,350 feet (194 miles) of new runway/taxiway (FAA, ACE Plan, 1994). Generally, this construction will be done over a period of five or more years.
- The number of airports in the U.S. has increased by about 3,182 from 1980 to 1994—a nearly 21 percent increase—from 15,161 in 1980 to 18,343 in 1994 (BTS, 1994).
- National data on the amount of fuel consumed during airport construction and maintenance have not been identified.

Description of Impact

Construction-related activities generally result in temporary visual, noise, air quality, erosion, water quality, and solid waste impacts. Emissions during airport construction and expansion are associated with land clearing, blasting, ground excavation, earth moving; cement, asphalt, and aggregate handling; heavy equipment operation; use of haul roads; and wind erosion of exposed areas and material storage piles. The quantity of emissions from construction operations is proportional to the area of land being worked and the level of construction activity. Dust emissions, a large portion of which result from equipment traffic over temporary roads at the construction site, may have substantial temporary impacts on local air and water quality.

Construction can also affect the environment through exhaust emissions from machinery and haulage vehicles, spillage during refueling, and noise. The environmental impact of any particular project depends on the condition of the surrounding area, the size of airport, and the length of project duration. Temporary storage facilities for equipment and supplies used during the construction phase may also damage vegetation and displace communities of animals.

Hazardous waste on airport property (especially older army and air force bases) is another type of problem associated with airport construction and expansion. Sometimes the problem is discovered when a major construction project unexpectedly runs into hazardous material.

Often, airport construction, maintenance and operations are themselves the source of hazardous waste problems due to the use of hazardous materials, such as lead paint, solvents, and pesticides.

Causal Factors

- Number of new airports constructed
- Number of runway and other airport capacity enhancements
- Ecological conditions/type of land (i.e., wetlands, forest, etc.)
- Successful airport implementation of various efforts to avoid or mitigate impacts (i.e., stormwater treatment)

RELEASES OF DEICING COMPOUNDS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No data are available to quantify the extent to which deicing chemicals in airport runoff cause groundwater contamination and habitat or health effects.

QUANTIFIED OUTPUT INDICATORS

- Deicing one aircraft typically results in the pollution load about equal to the daily wastewater of 5,000 people (Backer, et al, 1994).
- A recent survey shows that 46 percent of the airports discharge runway runoff directly into public waterways without treatment or monitoring (Airport Magazine, March/April 1991).
- As much as 64 to 100 percent of applied urea may discharge directly to surface waters through overland flow (D'Itri, 1992).
- Some 75 percent of glycol used at airports ends up in surface drainage during spring thaw (Eady, 1990).

QUANTIFIED ACTIVITY INDICATORS

- Based on the 1989-90 season, the nationwide use of deicing products is estimated at 11.5 million gallons per year (D'Itri, 1992).
- The amount of deicer required per aircraft ranges from 10 gallons to several thousand gallons (D'Itri, 1992).
- Mean annual glycol usage at airports surveyed is 44,589 gallons (AAAE).
- Large airports can use over 150,000 gallons of deicer in a single storm event (D'Itri, 1992).

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- Of the deicing solution applied to aircraft, it is estimated that 49 to 80 percent falls to the apron (D'Itri, 1992).
- Organic, alcohol-based chemicals used to de-ice airplanes at the Des Moines International Airport are winding up in Yeader Creek every winter, according to state and airport officials. As they decompose, the compounds take oxygen out of the water, harming small fish and algae and helping an unsightly fungus (Des Moines Register, November 19, 1993).
- Glycol-based deicing fluid has recently (March 1996) been connected to onion-like odors at Milwaukee's General Mitchell International Airport. Toll operators have complained of similar odors, headaches, nausea, sore throats, and itchy eyes from Boston's Logan International Airport (ENR, March, 1996).
- At Logan International Airport, deicing runoff flows into storm drains and is discharged untreated into nearby areas, including Boston Harbor (ENR, March, 1996).
- In Milwaukee, untreated deicing fluid flows across 400 acres of airport land and drains into Lake Michigan (ENR, March, 1996).

DESCRIPTION OF IMPACT

Airports' wintertime use of deicing chemicals on aircraft and runways/taxiways is beginning to receive greater attention. Aircraft deicers used in North America have formulations based on ethylene or propylene glycol. Runway deicers are typically formulated with urea and glycols. As mentioned above, it is estimated that 11.5 million gallons of deicing products are used every year. Of the deicing solution applied to aircraft, it is estimated that 49 to 80 percent falls to the apron. The amount of deicer required per aircraft ranges from 10 gallons to several thousand gallons.

Urea and glycols may rapidly appear in stormwater runoff or temporarily remain in snow piles. The aquatic toxicity of ethylene and propylene glycols is relatively low and oral toxicity to humans and terrestrial life is also relatively low. Presence of ethylene glycol in the environment as puddles, however, may pose hazards to animals attracted to its sweet taste. Although none of the glycols used in deicers have been shown experimentally to be harmful, the animal carcinogen 1,4-dioxane does occur as a trace contaminant in technical grade ethylene glycol. Although glycols are biodegradable under normal conditions, the biodegradation is so rapid and oxygen demanding that they can affect oxygen-dependent aquatic life in receiving waters.

The urea that is used in runway deicers degrades to ammonia and the ammonia is converted to nitrate. Although both of these processes are slowed considerably at wintertime temperatures, the formation of ammonia and nitrate from urea pose environmental concerns. The toxicity of ammonia to aquatic life is high and excessive nitrate exposure through contaminated drinking water can be hazardous to humans (D'Itri, 1992).

Unless captured in on-site collection basins or discharged to a municipal wastewater treatment plant, glycol and urea may mix with runway and other local sources of stormwater resulting in on-site puddling and soil infiltration, overland flow, and release to surface waters.

CAUSAL FACTORS

- Amount of aircraft/runway deicing agents applied
- Type of deicing agent used
- Climate/weather conditions (amount of snow, ice, rainfall)
- Amount of high salinity rainfall/snowmelt that reaches bodies of water (based on runoff controls and local geography)
- Depth of groundwater table
- Sensitivity of nearby habitats

AIRPORT RUNOFF

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No data are available to quantify the extent to which airport runoff causes groundwater contamination, impairment of water quality in rivers and lakes, and habitat or health effects.

QUANTIFIED OUTPUT INDICATORS

- No data are readily available to quantify the pollutant loading of runoff from airports.

QUANTIFIED ACTIVITY INDICATORS

- There were 18,343 airports in the U.S. in 1994, which is more airports than in every other nation in the world combined (BTS, 1994).
- Most airports are small private-use airports, many of which have unpaved runways, as the following table shows:

U.S. Airports, 1992

	Number	**Percentage with Paved Runways**	**Percentage with Lighted Runways**
Public-Use Airports	5,545	71.7	72.3
Private-Use Airports	12,301	36.6	7.6
Total All Airports	17,846	47.5	27.7

Source: BTS, 1994

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- High flows from a nearby airport during major storm events are believed to be responsible for displacing juvenile fish from the Des Moines Creek.

DESCRIPTION OF IMPACT

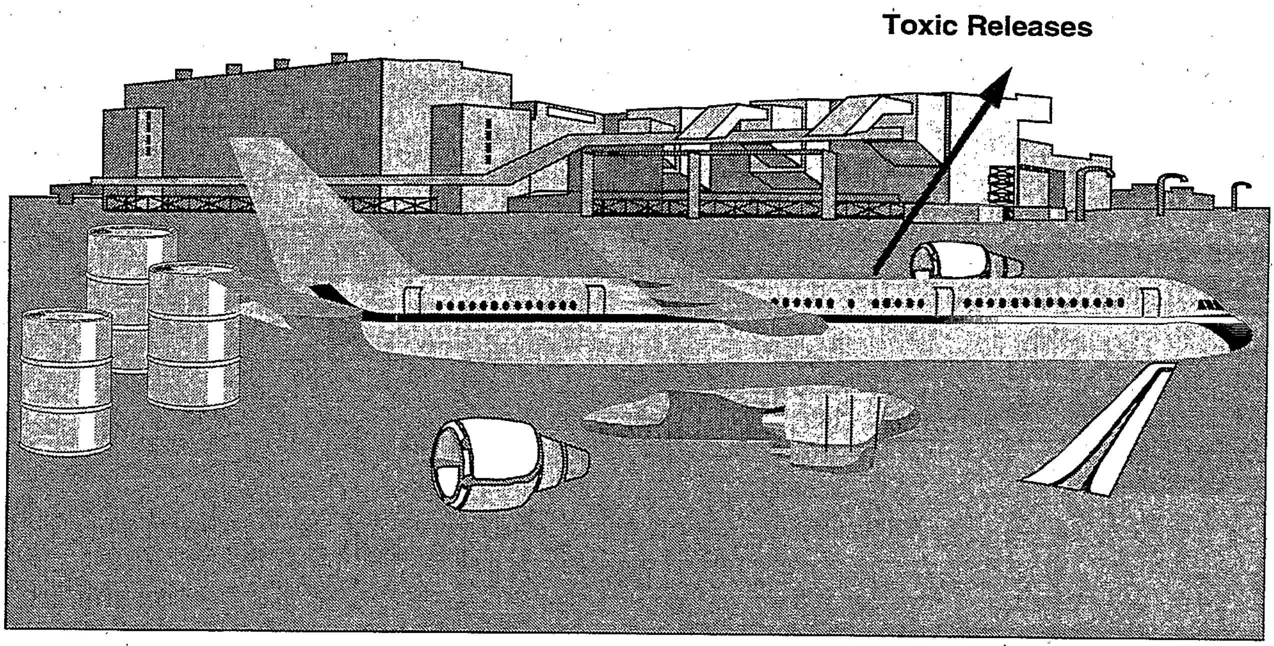
Water quality in wetlands and streams may be affected by construction and post-construction activities. Stormwater run-off from runways/taxiways, aprons, roads and parking lots, for example, will result in an increase in pollutant loading to wetlands and streams unless stormwater treatment facilities are included as part of airport construction. An increase in the amount of such impervious surface area and the elimination of recharge areas such as wetlands affects the low flow characteristics of steams by reducing groundwater recharge capabilities. This may result in the reduction of carrying capacity of streams and elevated water temperatures, which, in turn, may increase stress levels in fish, as well as reduction in feeding and growth levels.

CAUSAL FACTORS

- Number of airports and paved surface area
- Number of runway and other airport capacity enhancements
- Precipitation activity
- Drainage characteristics
- Ecology and other aspects of receiving water bodies: type, size, diversity, potential for dispersion
- Successful implementation of mitigation efforts (i.e., stormwater treatment)

2. AIRCRAFT AND PARTS MANUFACTURE

The manufacture of aircraft and parts results in environmental impacts through the release of toxics to the air, soil, and water.



TOXIC RELEASES

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No quantified data on human health impacts, such as increased incidence of cancer from toxics, or habitat and species impacts are available.

QUANTIFIED OUTPUT INDICATORS

- 28.7 million pounds of toxic chemicals were reported released on-site from aircraft manufacturing facilities in 1993 (see table).[59]

[59] Impacts of imported equipment and parts are not counted here. Only U.S. facilities are included here, including the impacts of exported equipment.

Toxic Chemicals Released from Aircraft Manufacturing Facilities and Related Sources (Pounds per Year)

SIC Code	Industry Type	On-Site Releases Air	Water	Land	Total	POTW Transfer	Off-Site Locations Transfer
3720	Aircraft & Parts	75,790			75,790		14,339
3721	Aircraft	12,239,470	4,917	81	12,244,468	125,166	4,632,947
3724	Aircraft Engines & Engine Parts	5,848,914	50,519	122	5,899,555	31,527	18,165,359
3728	Aircraft Part & Auxiliary Equipment, NEC	10,331,033	2,465	81,210	10,414,708	87,773	6,594,777
4581	Airports, Flying Fields & Airport Terminal Services			60,000	60,000		
	TOTAL AIRCRAFT	*28,495,207*	*57,901*	*141,413*	*28,694,521*	*244,466*	*29,947,422*

Source: Toxic Releases Inventory, 1993
POTW = Publicly owned treatment works
SIC = Standard Industrial Classification

- The top five pollutants (by volume) reported (SIC code 3721) released include methyl ethyl ketone, trichloroethane, dichloromethane, tetrachloroethylene, and toluene. These are solvents used to clean equipment and metal parts, and are used in many coatings and finishes (U.S. EPA, 1995f).
- At one plant where the aircraft painting hangar was used as a test site, approximately 51 tons of VOCs were emitted per year (based on 1988 emission estimates), representing approximately 7 percent of the total VOC emissions (on a mass basis) into the air from the plant, and making the hangar the second largest source of airborne VOC emissions at the plant (Larsen and Pilat, September 1991).

QUANTIFIED ACTIVITY INDICATORS

- Between 1990 and 1993, 947 new jet aircraft were delivered to U.S. customers (Boeing, 1993).

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

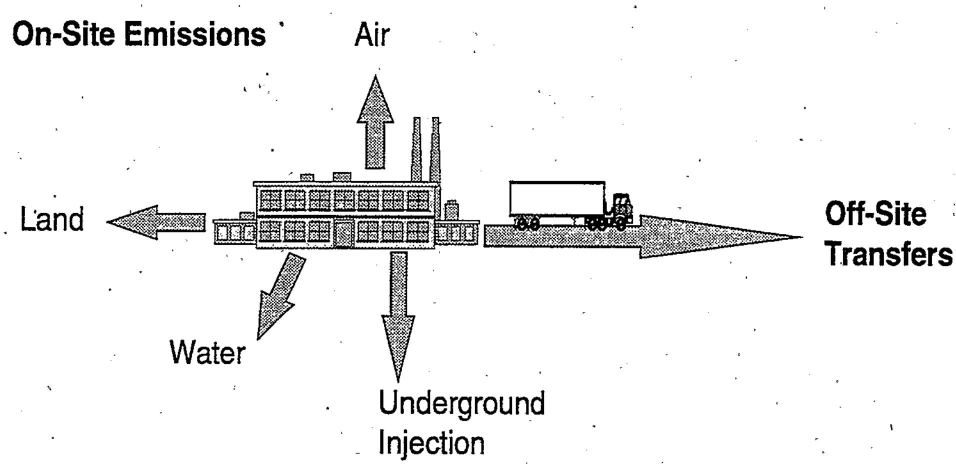
- In July 1991, Lockheed joined EPA's 33/50 Program, agreeing to voluntarily reduce releases and transfers of targeted chemicals by 33 percent in 1992 and by 50 percent in 1995, using 1988 as a baseline year. Based upon 1988 figures, these reductions would total 1,820,094 and 2,757,718 pounds, respectively. In the 1988 baseline year, Lockheed companies reported releases and transfers of 6,842,485 pounds of all TRI chemicals (U.S. EPA's, 1995f).
- By eliminating chlorinated solvent usage in metal cleaning, printed circuit board coating operations, and hazardous chemical use during paint stripping by using plastic media blasting, Lockheed surpassed its 33/50 Program commitment far in advance of set deadlines, reporting 1,298 pounds of releases and transfers of 33/50 Program chemicals in 1993, compared with 5,515,435 pounds in 1988. This reduction included a complete elimination of releases and transfers of cadmium compounds, lead compounds, and tetrachloroethylene. The other major contributors to Lockheed's success include the following reductions:

Chemical	Amount Reduced
Dichloromethane	88,085 pounds (51 percent)
Methyl Ethyl Ketone	115,371 pounds (80 percent)
Methyl Isobutyl Ketone	23,128 pounds (80 percent)
Toluene	74,884 pounds (86 percent)
1,1,1 – Tricholorethane	293,493 pounds (73 percent)
Trichloroethylene	482,103 pounds (76 percent)
Xylene	73,198 pounds (85 percent)

Source: U.S. EPA, 1995f.

Description of Impact

The manufacture of aircraft involves use of a variety of materials and chemicals. During the manufacturing process, toxic chemicals are released from vehicle manufacturing facilities into the environment. Releases occur as on-site discharges of toxic chemicals, including emissions to the air, discharges to water, releases to land, and contained disposal or injection underground. Chemicals are transferred off-site when they are shipped to other locations, as the following diagram shows.



On-site releases to air occur as either stack emissions, through confined air streams such as stacks or vents, or fugitive emissions, which include equipment leaks, evaporative losses from surface impoundments and spills, and releases from building ventilation systems. Surface water releases may include releases to rivers, lakes, oceans, and other bodies of water. Releases to land may include landfills, surface impoundments, and other types of land disposal within the boundaries of the reporting facility. Underground injection is a contained release of a fluid into a subsurface well for the purpose of waste disposal.

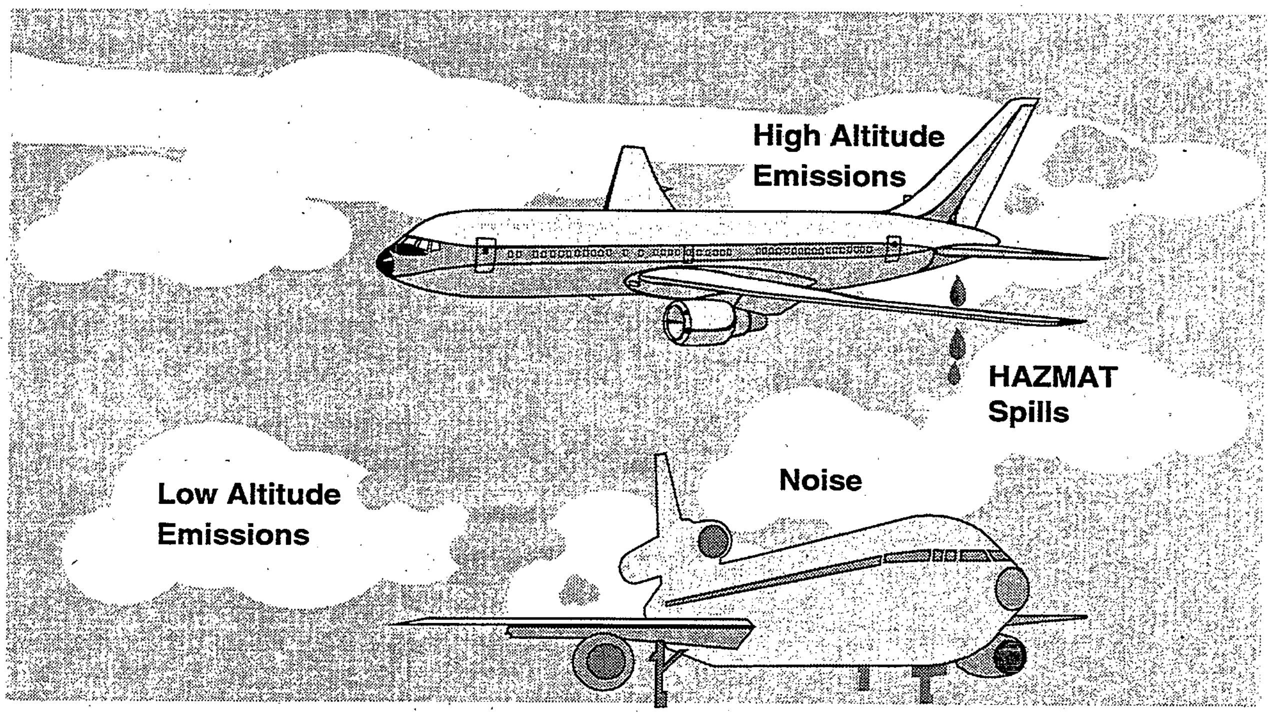
Off-site transfers represent a movement of the chemical away from the reporting facility. Except for off-site transfers for disposal, these quantities do not necessarily represent entry of the chemical into the environment. Chemicals are often shipped to other locations for recycling, energy recovery, or treatment. Transfers often are to publicly owned treatment works (POTWs). Wastewaters are transferred through pipes or sewers to a POTW, where treatment or removal of a chemical from the water depends upon the nature of the chemical and treatment methods used. Some chemicals are destroyed in treatment. Others evaporate into the atmosphere. Some are removed but are not destroyed by treatment and may be disposed of in landfills (U.S. EPA, 1992).

CAUSAL FACTORS

- Number of aircraft built
- Amount of chemicals used per aircraft
- Efficiency in mitigation efforts
- Types of chemicals released and toxicity
- Population density and extent of exposure
- Environmental conditions such as climate, topography, or hydrogeology affecting fate and transport of chemicals into the environment

3. AVIATION TRAVEL

Air travel has increased at a rate of 5.0 percent per year over the past decade and is expected to continue at this rapid pace over the next decade. In fact, Boeing projects that world air travel will increase by 70 percent over the next 10 years. Boeing estimates that 15,900 aircraft will be added to the world fleet by 2015. This significant growth has important implications for aircraft noise and atmospheric emissions.



HIGH ALTITUDE EMISSIONS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- In terms of global warming, NO_x emitted from aircraft above 10,000 feet have up to 50 times the effect of NO_x emitted closer to the ground (WWF, 1991).
- Quantitative data on the amount of global warming and stratospheric ozone loss due to high altitude aircraft emissions are not available.

QUANTIFIED OUTPUT INDICATORS

- In 1993, CO_2 emissions from aviation accounted for approximately 45 million metric tons of carbon equivalent (mmtCe), or 3 percent of total national CO_2 emissions (Apogee estimate).[60]
- Air transport is responsible for at least 2 percent of anthropogenic CO_2 emissions (EDF, 1994).
- Aviation contributed to emissions of other greenhouse gases, as reported below (U.S. EPA, 1994a):

Pollutant	Quantity Emitted (1990, thousand metric tons)
Methane (CH_4)	6
Nitrous Oxide (N_2O)	negligible

- Although environmental significance varies by altitude, most pollutants are emitted by aircraft at all levels. For data on total emissions of NO_x, CO, VOC, SO_2, and PM, by aircraft, see the following section on "Ground Level Emissions." These data are not broken down by altitude.

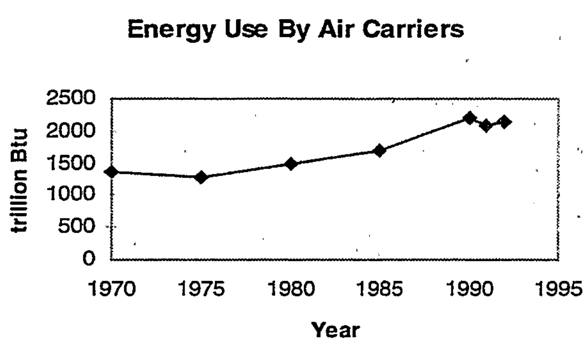
QUANTIFIED ACTIVITY INDICATORS

- The nation's commercial airlines consumed 16 billion gallons of jet fuel in 1992 (Business Dateline; Minneapolis/ St. Paul City Business).
- Aircraft consume about 2.5 percent of fossil fuel used (Green and Santini, 1993).
- Energy use by air carriers has increased significantly since 1970, totaling over 2,144 trillion Btu in 1992 (see table and graphic). However, energy use per passenger mile has decreased by 58 percent since 1970 (U.S. DOE, 1994a).

Energy Use By Air Carriers[61]

Year	Energy Use (trillion Btu)
1970	1363.4
1975	1283.4
1980	1489.6
1985	1701.5
1990	2191.3
1991	2069.2
1992	2144.2

Source: U.S. DOE. 1994a.



[60] Estimate is based on the following methodology: transportation sector energy use by fuel type within a mode (DOE/EIA, 1995b) was multiplied by carbon coefficients (mmtCe/quadrillion Btu) for each fuel (DOE/EIA, 1995a), then adjusted by fraction of carbon that does not oxidize during combustion (DOE/EIA, 1995a). Note that this estimate does not account for upstream emissions, such as emissions from aircraft assembly and fuel production; refer to DeLuchi, 1991, for carbon coefficients needed to compute total fuel-cycle CO_2 emissions.
[61] Energy use includes fuel purchased abroad for international flights.

- Aviation is one of the few petroleum users projected to have a continuing growth in fuel consumption of approximately 30 percent from 1990 to 2000 worldwide (Green and Santini, 1993).
- Fuel dumping is typically done above 10,000 feet so that the fuel will evaporate before reaching the ground. But even small amounts of pollution at that altitude can amount to much bigger problems, scientists believe (Business Dateline; Minneapolis St. Paul City Business).

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- On at least 68 occasions in 1992, Northwest jets dumped fuel before they could get down to a safe landing weight. The airline dumped about 471,500 gallons of jet fuel and lost about $300,000 in the process (Business Dateline; Minneapolis St. Paul City Business).

DESCRIPTION OF IMPACT

Aircraft emissions can occur at three altitude zones: (1) the boundary layer, (2) the upper troposphere, and (3) the lower stratosphere. CO_2, NO_x, CO, VOC, SO_2, and PM are emitted by aircraft at all altitudes. With the exception of CO_2, their environmental significance varies on the altitude of emission (EDF, 1994). There is, however, a great deal of uncertainty in the quantity of pollution emitted by aircraft at different altitude levels.

Aircraft spend most of their time in the cruise mode, directly injecting most nitrogen oxides into the higher levels of the atmosphere (WWF, 1994). According the World Meteorological Organization (WMO), the addition of NO_x to the atmosphere is expected to decrease ozone in the stratosphere. Also, NO_x emissions are expected to increase ozone in the troposphere, which may be a cause of global warming. In terms of ozone formation, NO_x emissions from aircraft may have 50 times the effect per unit emitted compared with surface level anthropogenic emissions (WWF, 1991). The resulting changes in ozone, water vapor, and aerosol loading in the altitudes around the tropopause may have a climatic impact.

Anthropogenic NO_x emissions also contribute to acid rain which may have a direct effect on wildlife, ecosystems, and buildings, although aircraft account for less than 2 percent of total anthropogenic NO_x emissions, the tremendous growth in air travel may have future implications on acid rain.

Water vapor emissions may lead to increases in the formation of high altitude clouds, which act as a potential global warming agent. Water vapor emissions may also increase the formation of polar stratospheric clouds that are implicated in ozone loss and the formation of the ozone hole (WWF, 1994).

Although other gases are emitted by aircraft at all altitudes, carbon dioxide, methane, and nitrous oxide are described here in order to describe the major greenhouse gases together. It is estimated that CO_2 emissions from aircraft account for about 2-3 percent of the total global emissions from fossil fuels. According to the World Wildlife Fund (WWF), CO_2 emissions are responsible for at least 2 percent of global warming. In addition, according to WWF, NO_x and water from aircraft may be as large as their emissions of CO_2.

It is also believed that the dumping of jet fuel can cause severe hydrocarbon pollution, which contributes toward global warming (Business Dateline; Minneapolis/St. Paul City Business). Fuel dumping is typically done above 10,000 feet so that the fuel will evaporate before reaching the ground. However, scientists believe that even small amounts of pollution at that altitude can amount to more significant problems than at lower levels (Business Dateline; Minneapolis/St. Paul City Business).

CAUSAL FACTORS

- Altitude of aircraft in cruise mode
- Type of aircraft and engine
- Number of aircraft
- Quantity of fuel dumped at 10,000 feet

LOW ALTITUDE/GROUND LEVEL EMISSIONS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No data are available on the health or habitat effects of low altitude emissions by aircraft.

QUANTIFIED OUTPUT INDICATORS

- In 1994, aircraft operations were responsible for the following emissions nationwide (U.S. EPA, 1995e):

Pollutant	Quantity Emitted (1994, thousand short tons)	Percentage of total Emissions of that Pollutant[62]
Carbon Monoxide (CO)	1,063	1.08 percent
Nitrogen Oxides (NO_x)	153	0.65 percent
Volatile Organic Comp. (VOCs)	212	0.91 percent
Sulfur Dioxide (SO_2)	8	0.04 percent
Particulate Matter (PM-10)	48	0.11 percent
Butadiene*	107 short tons	0.10 percent

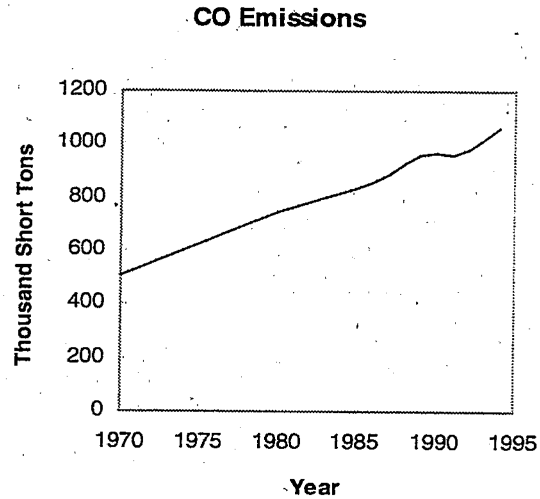
*Note: Butadiene estimate is for 1990; units are in short tons.

[62] Note: percentages are based on anthropogenic emissions, except for PM-10, which includes natural emissions.

CO Emissions from Aircraft

Year	Thousand Short Tons	Percentage of Total CO Emissions
1970	506	0.40%
1980	743	0.64%
1985	831	0.72%
1986	858	0.79%
1987	887	0.82%
1988	931	0.80%
1989	955	0.93%
1990	966	0.96%
1991	962	0.99%
1992	980	1.04%
1993	1,019	1.08%
1994	1,063	1.08%

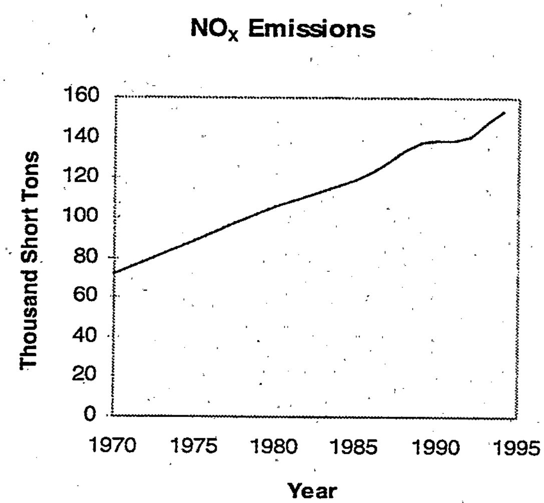
Source: U.S. EPA, 1995e.



NO_x Emissions from Aircraft

Year	Thousand Short Tons	Percentage of Total NO_x Emissions
1970	72	0.35%
1980	106	0.46%
1985	119	0.52%
1986	123	0.55%
1987	128	0.57%
1988	134	0.57%
1989	138	0.59%
1990	139	0.60%
1991	139	0.61%
1992	141	0.62%
1993	147	0.63%
1994	153	0.65%

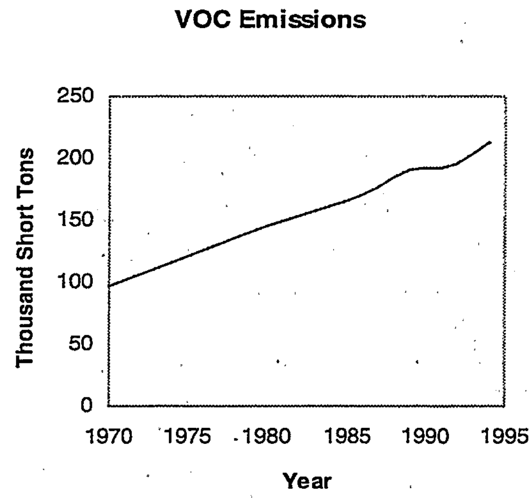
Source: U.S. EPA, 1995e.



VOC Emissions from Aircraft

Year	Thousand Short Tons	Percentage of Total VOC Emissions
1970	97	0.32%
1980	146	0.56%
1985	165	0.64%
1986	170	0.68%
1987	176	0.71%
1988	185	0.72%
1989	190	0.79%
1990	192	0.81%
1991	192	0.84%
1992	195	0.87%
1993	203	0.90%
1994	212	0.91%

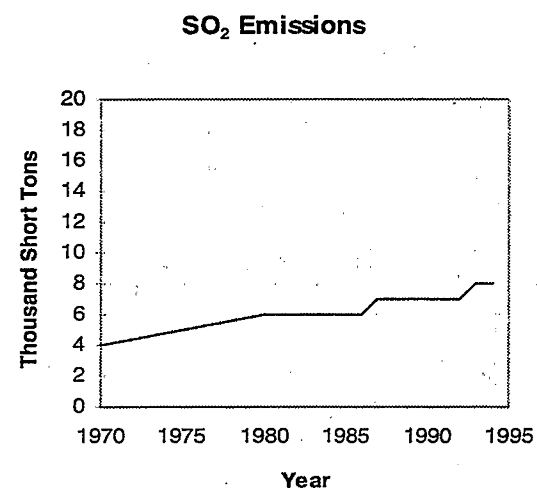
Source: U.S. EPA, 1995e.



SO2 Emissions from Aircraft

Year	Thousand Short Tons	Percentage of Total SO_2 Emissions
1970	4	0.01%
1980	6	0.02%
1985	6	0.03%
1986	6	0.03%
1987	7	0.03%
1988	7	0.03%
1989	7	0.03%
1990	7	0.03%
1991	7	0.03%
1992	7	0.03%
1993	8	0.04%
1994	8	0.04%

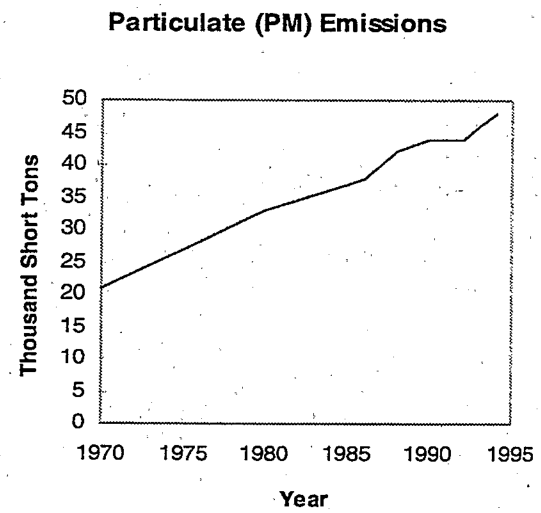
Source: U.S. EPA, 1995e.



Particulate Matter (PM-10) Emissions from Aircraft [63]

Year	Thousand Short Tons	Percentage of Total PM-10 Emissions
1970	21	-
1980	33	-
1985	37	0.08%
1986	38	0.08%
1987	40	0.10%
1988	42	0.07%
1989	43	0.08%
1990	44	0.10%
1991	44	0.09%
1992	44	0.10%
1993	46	0.11%
1994	48	0.11%

Source: U.S. EPA, 1995e.



QUANTIFIED ACTIVITY INDICATORS

- Refer to Appendix A for data on vehicle travel.

DESCRIPTION OF IMPACT

Ground-level emissions result from five specific modes in the landing and takeoff cycle (LTO):

- Approach
- Taxi/idle-in
- Taxi-idle-out
- Takeoff
- Climb-out

The factors that determine the quantity of pollutants emitted by aircraft depend on the duration of each operating mode and the fuel consumption rate. HC and CO emissions are very high when the aircraft is in taxi-idle mode. Emissions fall when the aircraft moves into higher power operating modes (CEPA, 1994). NO_x emissions, on the other hand, are low when engine power is low but increase as power level is increased. In addition, particulate emissions are higher at low power rates and improve at higher engine power. The table below presents the LTO cycle times for the three commercial aircraft types:

[63] Percentage of total emissions are not reported for particulate matter prior to 1985 because of changes in total emissions inventories; fugitive dust and wind erosion are reported only for the period 1985 to 1994.

Aircraft	Default Time-in-Mode for Commercial Aircraft (minutes) Taxi/ idle-out	Takeoff	Climb-out	Approach	Taxi/ idle-in	Total
Jumbo, long & medium range jet	19.0	.07	2.2	4.0	7.0	32.9
Turboprop	19.0	.05	2.5	4.5	7.0	33.5
Transport-piston	6.5	0.6	5.0	4.6	6.5	23.2

The nature of pollutants emitted by aircraft is the same as those emitted by on-road mobile sources. Similar to on-road mobile sources, carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOC), and particulate matter (PM) are all byproducts of the combustion process. These pollutants affect the environment, health, and welfare by causing respiratory and other illnesses, reduced visibility, and soiling and corrosion of materials. They also affect the environment by causing adverse effects on ecosystems including damage to crops, forests, and other terrestrial and aquatic plants and animals. Although CO_2 is not harmful to human health or habitat directly, it is an important greenhouse gas that contributes to global warming.

Certain chemicals interact in the air to create secondary chemicals. Ozone is a key secondary pollutant, caused by the interaction of NO_x and VOCs. In addition, the combination of sunlight, water, and chemicals like SO_2, NO_x, and HCs can form secondary particulate matter.

It is important to note, however, that these pollutants are also emitted by other sources, including motor vehicles, dry cleaning establishments, and painting factories. In fact, aircraft only account for a small percentage of the pollutants emitted. The quantity of pollutants emitted from aircraft operations is a function of the type of aircraft and engine, mode of operation, and how long the engine is operated in each mode.

CAUSAL FACTORS

- Number of aircraft
- Type of aircraft/engine type
- Landing and take-off cycle (LTO) cycle
- Airport congestion levels
- Meteorological conditions

NOISE

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- In 1989, FAA estimated that 3.2 million people lived in noise-impacted areas, which the agency defines as receiving noise levels of DNL 65 or above (DNL = day-night sound level, a common measurement of community noise exposure (GAO-ns).[64]

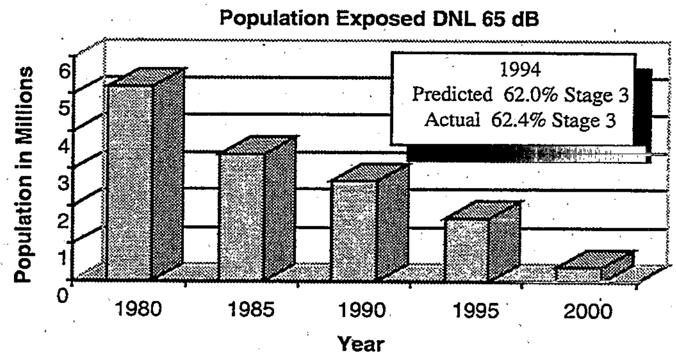
[64] DNL represents an energy-averaged sound level for a 24-hour period measured from midnight to midnight after adding 10 decibels to nighttime noise events between 10 p.m. and 7 a.m.). It is equivalent to Ldn.

- Population exposed to day-night noise level (DNL) of 65 dB or greater from aircraft has fallen from approximately 7.0 million to 1.7 million, largely due to the phasing out of Stage 2 aircraft and increased use of Stage 3 aircraft.

Population Exposed to DNL 65 dB

Year	Population in Millions
1975	7.0
1980	5.2
1985	3.4
1990	2.7
1995	1.7*
2000	0.4*

*Prediction based on Stage 3 implementation
Source: FAA, 1995b.



- About 9 percent of the U.S. population in 1980 was exposed to noise levels from aircraft great enough to cause annoyance—expressed in Leq greater than 55 dB(A)] (OECD, 1993).
- A small portion of the U.S. population was exposed to daily noise levels from aircraft great enough to cause other effects, such as communication interference, muscle/gland reaction, and changed motor coordination, as the following chart shows:

Percent of U.S. Population Exposed to Aircraft Noise, 1980

Outdoor Sound Level in Leq [dB(A)]

>55 dB(A) Annoyance	**>60 dB(A) Normal Speech Level**	**>65 dB(A) Communication Interference**	**>70 dB(A) Muscle/Gland Reaction**	**>75 dB(A) Changed Motor Coordination**
9.0 percent	4.0 percent	2.0 percent	0.4 percent	0.1 percent

Source: OECD, 1993.

QUANTIFIED OUTPUT INDICATORS

- Noise levels are site specific and dissipate with increasing distance from the source; as a result, an aggregate national noise emissions figure is not meaningful.
- Typical noise emissions at takeoff and landing are:

Aircraft	Takeoff, dBA	Landing, dBA
Propeller	88	78
DC10	90	83
727	97	87
707	102	95
747	104	93

Source: BTS, 1994.

QUANTIFIED ACTIVITY INDICATORS

- Refer to Appendix A for data on aviation travel.

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- According to an 1985 FAA report, a one decibel increase in DNL usually results in a 0.5 to 2.0 percent decrease in property values (GAO).
- In September 1992 and in May 1994, the City of Grapevine conducted surveys within the Sunshine Harbor subdivision immediately north of the Dallas/Fort Worth Airport. The surveys had the following results:
  - 94 percent of the respondents indicated that their normal activities (i.e., watching TV, talking on the phone) were interrupted by noise (September 1992 survey); 92 percent in the May 1994 survey.
  - 64 percent of the respondents indicated that their sleep was regularly interrupted by aircraft noise (September 1992 survey); 71 percent in the May 1994 survey.
  - 61 percent of respondents indicated that their quality of life had been effected in some way by the operation of the Dallas/Fort Worth Airport. Of those responses, noise pollution was ranked as the number one problem affecting quality of life.
  - 19 percent of the respondents indicated that their children had been endangered outdoors because of noise levels. Most felt that this is because the children cannot hear cars coming down the street.

DESCRIPTION OF IMPACT

The widespread introduction of jet aircraft in the 1960s and the tremendous growth in airline traffic after deregulation in 1978 resulted in a considerable increase in aircraft noise. Noise is the most cited and recognized environmental impact from aircraft and significantly affects millions of people in the U.S. every day. As a result, most of the nation's predominantly jet airports developed noise control programs. The federal government also issued regulations defining three classes of aircraft in terms of their noise levels:

Stage 1: aircraft certified before 1969 that do not meet the noise standards issued in that year
Stage 2: aircraft meeting the 1969 standards
Stage 3: aircraft complying with the latest standards issued in 1977

Because of the long operating life of commercial jets, the FAA issued a new rule in 1976 to phase out all Stage 1 aircraft by 1985.

Although all aircraft designs certified after March 1977 had to meet Stage 3 noise standards, Stage 2 designs continued to be manufactured until 1988. As a result, Stage 2 aircraft are still widely in use and consist of about 45 percent of the U.S. air carrier fleet as of December 31, 1994. In 1990, new legislation was introduced to phase out Stage 2 aircraft. This legislation set the phase-out of Stage 2 aircraft by the end of 1999 (FAA, 1994 Progress Report).

There are three main documented environmental effects of aviation noise:

1. Hearing loss is a well-documented effect of noise in general, but is not generally a concern in community airport noise problems. Even in a very noisy airport environment, the duration of noise is not sufficiently long to cause hearing loss. The Occupational Safety and Health Administration (OSHA) has defined a noise exposure limit of 90 dBA for 8 hours per day to

prevent hearing loss. The typical indoor maximum noise level in the 65 dBA noise contour will range from 55 to 75 dBA.

2. Communication and sleep interference are also major environmental concerns associated with aircraft noise. These interferences lead to a difficult to quantify "annoyance" factor, since people respond differently to noise. In general, however, annoyance can be measured based on the types of activities disrupted by the noise (i.e., speech or sleep interference).

3. Some research also points to physiological, psychological, and social behavior problems stemming from noise effect on humans (FAA, 1985). These effects, however, are subject to debate, but generally include changes in pulse rate and blood pressure. Some studies have pointed to increased risk of hypertension as well as other stress related problems. There is some evidence to show that noise may have the greatest impacts on children and those with a variety of mental illnesses.

In addition, aircraft noise has also been shown to affect real estate values, land use, wildlife and farm animals (FAA, 1985).

CAUSAL FACTORS

- Number of aircraft operations
- Population in area affected by aircraft noise
- Number of Stage 2 aircraft
- Aircraft flight path
- Aircraft glide path

HAZARDOUS MATERIALS INCIDENTS DURING TRANSPORT

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No statistics were found regarding the number of species or acres nationwide affected by commodity spills.

QUANTIFIED OUTPUT INDICATORS

- An average of 256 gallons and 477 pounds of hazardous materials were reported released during aviation transport between 1990 and 1994.
- An average of 518 releases were reported annually, more than 60 percent of which consisted of flammable-combustible liquid.

Aviation Hazardous Material Incidents, Annual Average, 1990-1994

Class	Number of Incidents	Gallons Released	Pounds Released	Cubic feet Released	Clean-up Cost and Loss of Material
Flammable - Combustible Liquid	316.2	174.8	11.0		29,431
Corrosive Material	92.2	48.0	0.4		51,177
Poisonous Materials	30.2	13.8	23.3		17,070
Misc. Hazardous Material	18.0	8.4	59.3		4,433
Other Regulated Material, Class D	15.6	1.0	5.3		1,075
Nonflammable Compressed Gas	10.0	2.9	9.2		582
Flammable Gas	9.6	0.9			417
Other Regulated Material, Class A	4.8	1.3			147
Radioactive Material	4.2	0.0		80.9	991
Oxidizer	4.0	0.4	223.1		514
Combustible Liquid	2.8	6.8	11.0		3,205
Organic Peroxide	2.2	0.0			50
Infectious Substance (Etiologic)	2.2	0.0	0.0		100
Flammable Solid	1.2		4.4		7
Flammable Solid (pre 1991)	1.2		4.8		0
Other Regulated Material, Class B	1.2	0.1	0.4		7,393
Dangerous When Wet Material	0.8		15.3		110
Explosive Projection Hazard	0.4				0
Explosive No Blast Hazard	0.4		8.8		120
Poisonous Gas	0.4	0.2			0
Other Regulated Material, Class E	0.4	0.1			40
Explosives, Class A	0.2		100.0		100
Explosives, Class C	0.2				0
Total	518.4	258.9	476.4	80.9	116,961

Source: HMIS

- Aviation accounted for only 3.2 percent of all transportation-related hazardous materials incidents reported to HMIS in 1991 (HMIS, 1991).
- The quantity of hazardous materials remaining in the environment after cleanup is unknown.

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- Of the 293 aviation-related incidents reported in 1991, 76 percent resulted from human error, 15 percent from packaging failure, and 28 percent from other causes, not including vehicle accidents. No incidents occurred as a result of vehicle accidents (HMIS, 1991).

DESCRIPTION OF IMPACT

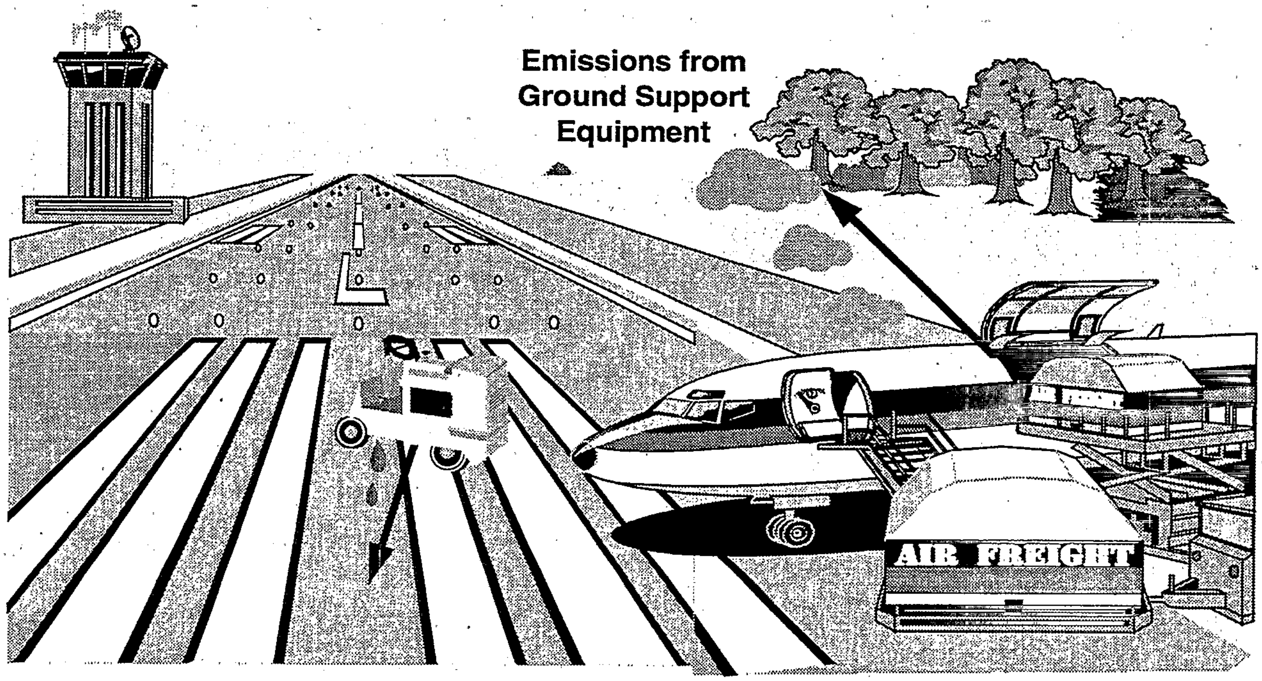
Hazardous materials releases during aviation may occur en route, as well as during the loading/unloading process. Hazardous materials incidents may cause environmental damage such as air and water pollution, damage to fish and wildlife, and habitat destruction. The environmental impact of any given hazardous material release is highly site-specific. It depends on the type and quantity of material released, amount recovered in cleanup, chemical properties (such as toxicity and combustibility), and impact area characteristics (such as climatic conditions, flora and fauna density, and local topography). While the nationwide impact of hazardous materials releases from aviation may be small, any hazardous materials incident may have severe impacts on the flora and fauna in the location of occurrence.

CAUSAL FACTORS

- Type and quantity of hazardous material transported
- Number of incidents
- Quantity of material released
- Toxicity/hazard of materials released
- Effectiveness of cleanup efforts
- Population density
- Sensitivity and location of affected ecosystems

4. AIRPORT OPERATION

The growth in air travel has increased at a rapid pace over the past decade. Although airports account for only a small portion of total regional environmental impacts, the growth in air travel has raised concern that airport-generated environmental impacts will continue to increase. It is important to note that only one new major airport has been built since 1974. This, in turn, raises concerns that congestion levels at major airports will continue to increase. Airport operations include cleaning, maintenance, repair, and fueling of aircraft, as well as baggage handling and other cargo support services. Environmental impacts of these operations include air emissions from ground support equipment, fuel spills, oil leakages, and emissions of toxic substances.



EMISSIONS FROM GROUND SUPPORT EQUIPMENT INVOLVED IN AIRCRAFT LOADING, CLEANING, MAINTENANCE, REPAIR, AND REFUELING

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No national data are available on the health or habitat effects of emissions from airport ground support equipment.

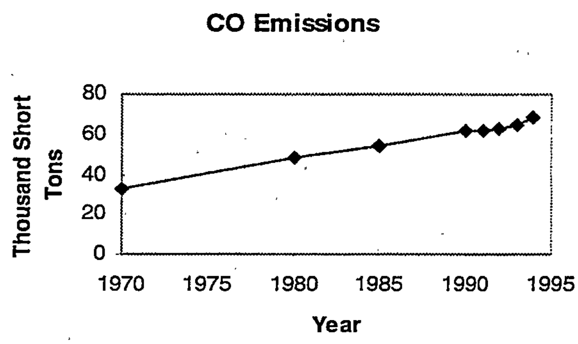
QUANTIFIED OUTPUT INDICATORS

- Emissions from ground support equipment (GSEs) range from 2-6 percent of total emissions at commercial airports (CEPA, 1994).

CO Emissions from Airport Service

Year	Thousand Short Tons	Percentage Total Emissions from Airport Service
1970	33	0.03%
1980	48	0.04%
1985	54	0.05%
1990	62	0.06%
1991	62	0.06%
1992	63	0.07%
1993	65	0.07%
1994	68	0.07%

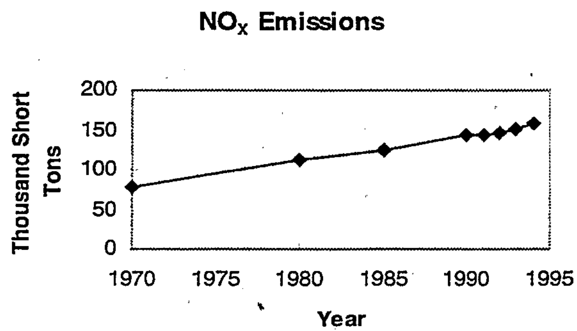
Source: U.S. EPA, 1995e.



NO_X Emissions from Airport Service

Year	Thousand Short Tons	Percentage Total Emissions from Airport Service
1970	78	0.38%
1980	113	0.49%
1985	125	0.55%
1990	144	0.63%
1991	144	0.64%
1992	146	0.64%
1993	152	0.65%
1994	159	0.67%

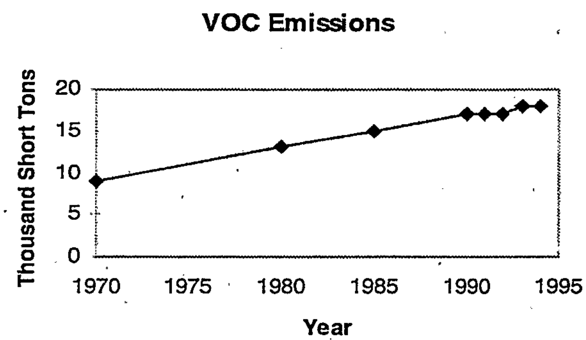
Source: U.S. EPA, 1995e.



VOC Emissions from Airport Service

Year	Thousand Short Tons	Percentage Total Emissions from Airport Service
1970	9	0.03%
1980	13	0.05%
1985	15	0.06%
1990	17	0.07%
1991	17	0.07%
1992	17	0.08%
1993	18	0.08%
1994	18	0.08%

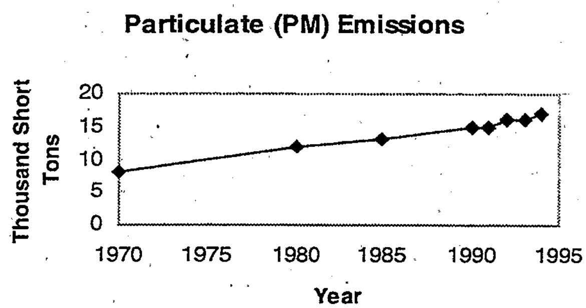
Source: U.S. EPA, 1995e.



Particulate Matter (PM-10) Emissions from Airport Service[65]

Year	Thousand Short Tons	Percentage Total Emissions from Airport Service
1970	8	-
1980	12	-
1985	13	0.03%
1990	15	0.03%
1991	15	0.03%
1992	16	0.04%
1993	16	0.04%
1994	17	0.04%

Source: U.S. EPA, 1995e.



DESCRIPTION OF IMPACT

A variety of ground support equipment (GSE) are used to move, service, load, fuel, and power aircraft at airports:

- Baggage tractors
- Aircraft tractors
- Ground power units
- Air-conditioning units
- Air start units
- Baggage conveyors
- Auxiliary power units
- Other secondary GSE (forklifts, deicing vehicles, lavatory vehicles, fuel vehicles, etc.)

The majority of GSE have engines that operate on gasoline, diesel, or LPG (most APUs burn jet fuel). Like on-road mobile sources, GSE have tailpipe, evaporative, and crankcase HC emissions. NO_x and PM are also emitted from the tailpipe. Their effects on the environment, therefore, are similar to on-road mobile sources and aircraft (CEPA, 1994).

Other environmental impacts associated with airport operations include fuel, oil, and other substance spills, as well as release of toxic chemicals. These releases occur during aircraft cleaning, maintenance, repair, and refueling.

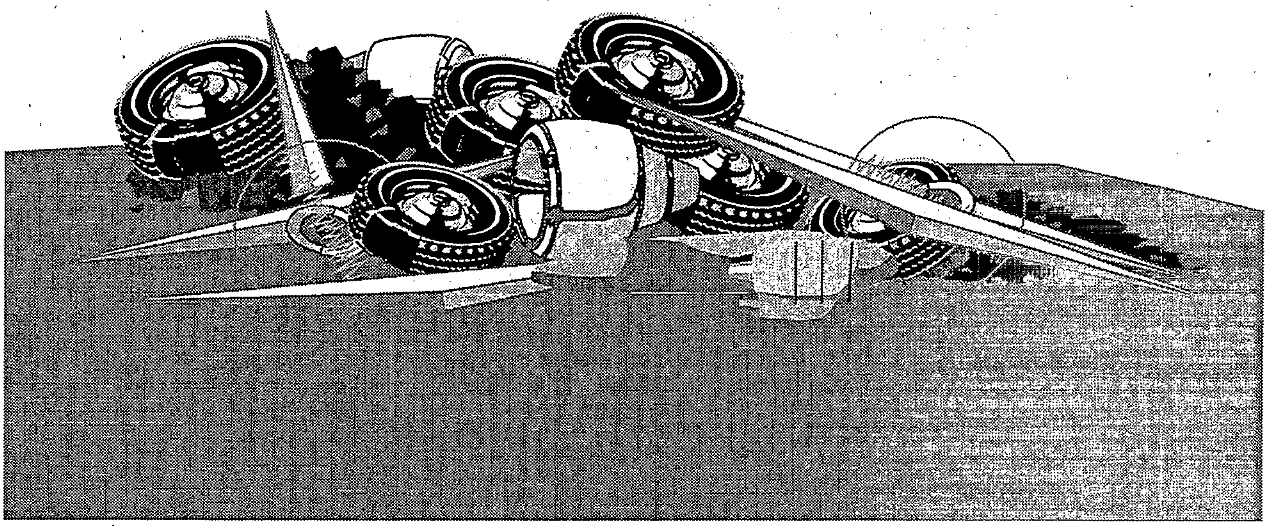
CAUSAL FACTORS

- Number of aircraft support vehicles
- Type of fuel used and size of engine
- Distance traveled by aircraft support vehicles
- Number of trips (operations)/number of cold starts
- Fuel efficiency
- Type and level of maintenance operations

[65] Percentage of total emissions are not reported for particulate matter prior to 1985 because of changes in total emissions inventories; fugitive dust and wind erosion are reported only for the period 1985 to 1994.

- Materials used during maintenance operations
- Wastewater treatment capabilities

5. DISPOSAL OF AIRCRAFT AND PARTS



AIRPLANE AND PARTS DISPOSAL

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Estimates are not available on the health and habitat impacts of landfilling or other disposal of scrapped airplanes and parts.

QUANTIFIED OUTPUT INDICATORS

- No data are readily available on the amount of aircraft and parts disposed annually.

QUANTIFIED ACTIVITY INDICATORS

- World air carriers placed orders for an estimated 490 large jet aircraft with U.S. and foreign aircraft manufacturers during FY 1995, 54.0 percent more orders than in 1994. Aircraft manufacturers delivered approximately 449 large jet aircraft worldwide in 1995 (Boeing, 1995). Although the air carrier fleet is increasing, the increase in aircraft suggests that as they reach the end of their lifecycle, additional aircraft and parts will be either disposed or recycled.

DESCRIPTION OF IMPACT

Disposal of airplanes and parts consists of refuse from the use and maintenance of aircraft and ground support equipment, as well as other sources. In general, this waste includes batteries, tires, brake pads, and other used vehicle components. Data on the amount of waste are unavailable on the national level.

Airplanes often are shifted to other uses when retired from commercial service, or are exported. This fact, coupled with the longevity of the current fleet of airplanes, results in relatively low rates of scrappage.

CAUSAL FACTORS

- Number of aircraft scrapped
- Quantity of metals and oil used in operations
- Disposal method/recovery rate of materials
- Groundwater contamination and seepage prevention measures at the disposal site

MARITIME ENVIRONMENTAL INDICATORS

This section presents the quantitative indicators available for tracking the nationwide environmental impacts of maritime transportation. In this report, maritime transportation is defined to include all water-borne mobile sources, such as ocean-going vessels, inland barges, and recreational boats. For each of the five basic categories of activities affecting the environment, the various impacts are listed.

HOW EACH IMPACT IS PRESENTED IN THIS SECTION

Each environmental impact is covered in one or more pages of text and graphics, with the following key subsections:

- **Presentation of indicators**

  The key indicators that have been quantified are presented. *Outcome* indicators are listed first since they provide information on end results and are theoretically the most desirable type of indicator. Unfortunately, actual quantified data are often unavailable or of poor quality. In many instances, the only available data on outcomes are the number of states reporting a problem. This information is often incomplete (not all states may examine the problem), vague (states may define the problem differently), or only somewhat relevant (the contribution of transportation to the problem may be unknown). As a result, *output* indicators—such as emissions data—are presented. These statistics may be an easier and more valid measure for policy makers to examine and track over time. *Activity* indicators (defined broadly to include infrastructure, travel, and other activities) are listed when they are the best available indicators or when outcome and output indicators are not adequate. In some cases, local examples are also provided.

  To avoid repetition within the report, basic infrastructure and travel indicators are listed in Appendix A for each mode of transportation. Appendix B contains additional relevant statistics on monetized values of health and other impacts; these outcome indicators are listed separately since there is generally more uncertainty regarding these figures.

- **Description of impact**

  The nature of the impact is briefly defined and explained here. More complete descriptions of these impacts are available in reference works listed in the bibliography.

- **Causal factors: Variables that change over time and between locations**

  Policy makers find it very useful to understand the driving forces behind environmental impacts. Understanding the key causal factors is critical to *explaining* observed trends in indicators. They also help in estimating how local impacts may differ from national averages. These causal variables, then, explain how the impacts differ over *time* and *geographic location*. Most importantly, they suggest potential *policy levers*. Policies can be designed to focus on any of the key variables (e.g., grams emitted per mile) that determine the magnitude of an environmental impact.

The following table provides an overview of the available indicators for each impact. It is important to note two points about what is included in this table: First, indicators are listed only where they have been quantified at the national level; if an impact has not been quantified, no "potential" indicator is listed here. For each specific activity and its impact, the table provides a summary of the availability of quantitative data for indicators of outcomes, output, and activity. Second, the table shows only the best indicator for each impact rather than listing various alternative types of indicators for a given impact. The exceptions are when multiple indicators are needed to address all aspects of an issue or where some indicators are otherwise insufficient. Although outcome indicators are theoretically the most desirable type of indicator, actual quantified outcome data are often unavailable or of poor quality. As a result, output indicators—such as emissions levels—tend to be the most reliable and valid measures available in most cases. Activity indicators are presented in this table when they are the best available indicators or when outcome and output indicators are not adequate.

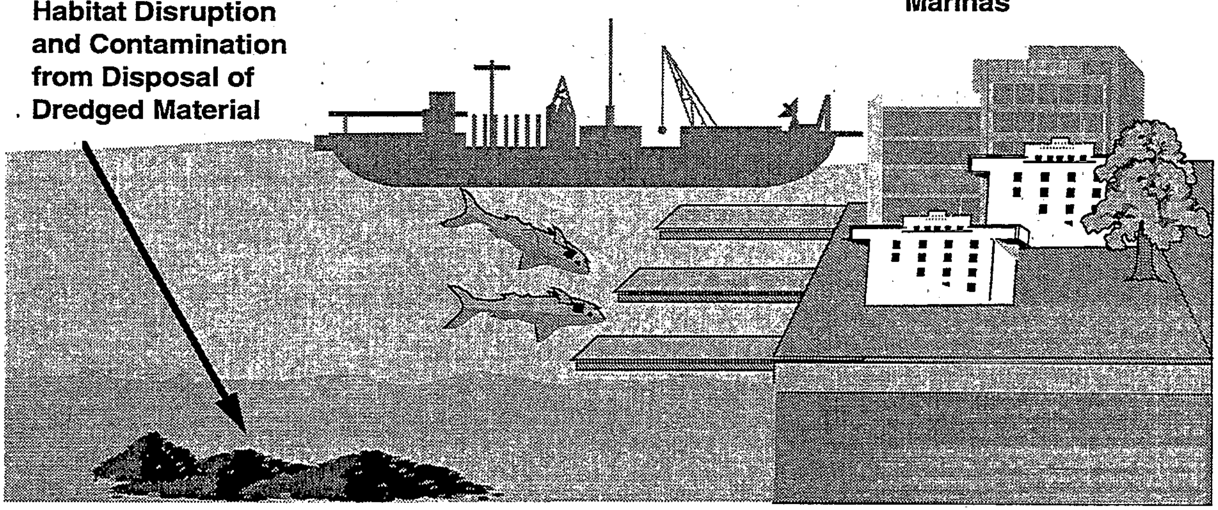
SUMMARY OF NATIONAL INDICATORS QUANTIFIED: MARITIME TRANSPORTATION

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
1. Construction and Maintenance of Navigation Improvements				
Direct deterioration of habitats and water quality from dredging or other navigation improvements	• States reporting dredging-related wetland losses	• Quantity of dredged material	• Commercially navigable channel mileage	Direct effects of navigation improvements vary widely with the scale and type of project. Physical impacts of one dredging project may cause little harm, while another may alter an ecosystem. The reported total amount of material dredged fluctuates among various sources.
Habitat disruption and contamination from disposal of dredged material	• States reporting disposal of dredged material as a source of direct wetlands losses	• Quantity of dredged material disposed at various sites (e.g., ocean, coastal waters) and used for various purposes (e.g., wetlands creation)		
Habitat disruption and land take for ports and marinas	(Data unavailable)	(Data unavailable)	• Number of U.S. ports and marinas	Allocating the amount of habitat loss caused by a port is difficult, because shoreline habitat losses may be caused by a wide variety of factors.
2. Manufacture of Maritime Vessels and Parts				
Toxic releases during manufacture of maritime vessels and parts	(Data unavailable)	• Quantity of reported releases of toxic chemicals included in TRI database		
3. Maritime Travel				
Air pollutant emissions	(Data unavailable)	• Quantity of CO, NO_X, VOC, SO_2, PM, CO_2, CH_4, and N_2O released		

Activity	Outcome Indicators Health or Ecological Results Measure	Output Indicators Emissions, Habitat Change, or Exposure Measure	Activity Indicators Infrastructure, Travel, or Other Action Measure	Notes
Habitat disruption caused by wakes and anchors	(Data unavailable)	(Data unavailable)	(Data unavailable)	Given the highly local nature of this problem, national outcome indicators, and even output indicators are unavailable.
Introduction of nonnative species	(Data unavailable)	• Number of species introduced into the Great Lakes by vessels		Total environmental impacts caused by introduction of nonnative species are difficult to estimate, since effects may take an extremely long time to occur.
Hazardous materials incidents during transport	(Data unavailable)	• Quantity of oil and other hazardous wastes released in U.S. waters		
Wildlife collisions	• Numbers of certain endangered species killed by collisions with vessels	(Data unavailable)		No national indicators of animal losses from vessel collisions are available, but studies have been conducted for individual species.
Overboard dumping of solid waste	• Numbers of certain species killed by entanglement in plastic marine debris	(Data unavailable)	• Quantity of garbage generated by the maritime sector (amount disposed at sea is unknown)	
Sewage dumping	• Percentage of shellfish waters reported contaminated due to sewage dumping	(Data unavailable)	• Percentage of commercial vessels with on-board sanitation devices	
4. Maritime Vessel Maintenance and Support				
Releases of pollutants during terminal operations	(Data unavailable)	• Quantity of hazardous air pollutants emitted	• Number of marine repair establishments	
5. Disposal of Maritime Vessels and Parts				
Scrappage of old vessels and dilapidated parts	(Data unavailable)	(Data unavailable)	(Data unavailable)	Boat scrappage estimates are unavailable, but changes in fleet size may provide some information.

1. CONSTRUCTION AND MAINTENANCE OF NAVIGATION IMPROVEMENTS

In order to allow passage for various types of marine vessels, some waterways require navigation improvements. The most common navigation improvement is dredging. Development and maintenance of navigation improvements can cause serious environmental harm. Problems include degradation of habitats, hydrologic alterations, contaminated sediments, and deterioration of water quality. These impacts are discussed below.



DIRECT DETERIORATION OF HABITATS AND WATER QUALITY FROM DREDGING OR OTHER NAVIGATION IMPROVEMENTS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- In 1992, nine states reported that dredging was a source of wetlands loss (Council on Environmental Quality, 1993).
- Between 5 and 15 percent of surface waters (and aquatic life in them) are affected by hydromodification projects (Griffin, 1991). Note that only a portion of hydromodification projects have a primary purpose of allowing or improving maritime transportation. Many hydromodification projects are implemented for other purposes, such as water supply, recreation, hydroelectric power production, and flood control.
- Of 14 reporting states, 9 listed channelization as a source of wetlands degradation in 1992 (U.S. EPA, 1994b).[66]

[66] The portion of channelization projects constructed to improve maritime navigation is unknown.

QUANTIFIED OUTPUT INDICATORS

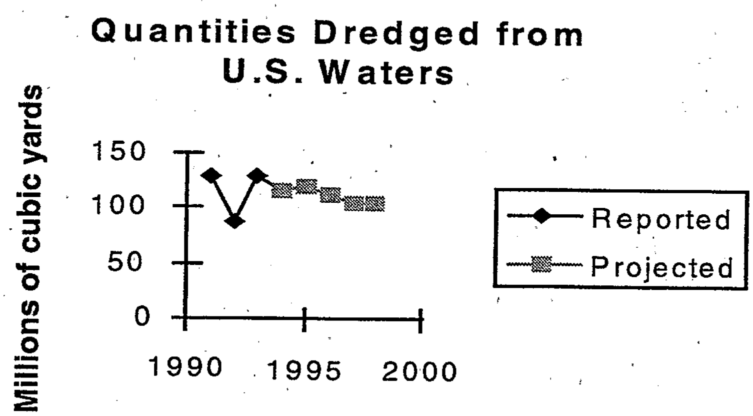
- Dredged material generated in the U.S. is estimated to total between 400 and 480 million cubic yards annually, based on a number of studies (Cullinane et al., 1990).
- Based on studies from the mid 1980s, 79 percent of dredged material is generated by maintenance projects, and 21 percent is generated by new work. (Cullinane et al., 1990) 84 to 101 million cubic yards of dredged material, therefore, are generated annually by new work, and 316 to 379 million cubic yards are from maintenance projects (Apogee estimate). Sediments from maintenance dredging are more likely than sediments from new work to be contaminated because they are composed of recent deposits. Sediments that originate from new work, on the other hand, are cleaner because they were deposited before industrialization of the U.S. (U.S. EPA, 1989b).

Lower-bound Estimates of Annual Quantities Dredged from U.S. Waters by Various Sources, 1991 - 1998[67]

	Thousand Cubic Yards (Percentage of Total)			
Year	USACE	Port Authorities	Other	Total
1991	100,243	24,401	3,906	128,550
	78.0%	19.0%	3.0%	100.0%
1992	76,580	6,460	3,734	86,774
	88.3%	7.4%	4.3%	100.0%
1993	114,608	10,126	4,020	128,754
	89.0%	7.9%	3.1%	100.0%
1994	98,532	13,085	4,247	115,864
	85.0%	11.3%	3.7%	100.0%
1995	96,429	19,419	3,935	119,783
	80.5%	16.2%	3.3%	100.0%
1996	91,803	18,262	4,345	111,410
	82.4%	13.7%	3.9%	100.0%
1997	85,412	15,888	3,935	105,235
	81.2%	15.1%	3.7%	100.0%
1998	92,959	7,970	3,795	104,724
	88.8%	7.6%	3.6%	100.0%

Source: American Association of Port Authorities, 1995.

[67] Figures for the years 1991 to 1993 are actual amounts, while figures for years beyond 1993 are projections. Figures are from a survey of sources. Not all sources responded to the survey, so the figures do not represent total quantities for the nation. Responses from the Army Corps of Engineers represent national figures, but only 46 (61 percent) of U.S. member ports responded. Quantities obtained from the survey seem to be approximately one third of actual quantities for each source, and USACE numbers are low compared with other estimates.



Source: American Association of Port Authorities, 1995.

QUANTIFIED ACTIVITY INDICATORS

- The U.S. Army Corps of Engineers maintains approximately 25,000 miles of commercially navigable channels, serving 400 ports, including 130 of the nation's 150 largest cities (U.S. EPA, 1989b).

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- One study revealed that the immediate effects of dredging on a soft-bottom habitat were a 40 percent loss in number of species, 65 percent loss in density of macroinfauna, and a 90 percent loss in biomass of invertebrates (Canter, 1985).
- In a study of the Wild Rice Creek Watershed in North and South Dakota, wetland drainage rates were 5.3 times higher in channeled sections than those in unchanneled sections (Canter, 1985).

DESCRIPTION OF IMPACT

Navigation improvements have the potential to cause a variety of harmful environmental impacts. Dredging is the primary infrastructure activity undertaken to improve navigation for water-borne transportation. In addition, engineering projects, such as stream channelization, have environmental impacts. While channelization projects are typically not undertaken to improve transportation, they may reduce flooding and prevent changes in a river's course, which affects inland transport. Other infrastructure improvements may influence the amount of recreational boating.

Two aspects of dredging can cause environmental damage: (1) disturbance and removal of bottom material and (2) disposal of dredged material. The second of these impacts is discussed in the next section. Dredging, which involves the mechanical displacement of sediments for the purpose of creating, maintaining, or extending ports and navigational waterways, necessarily disrupts bottom habitats (U.S. EPA, 1989b). One study revealed that the immediate effects of dredging on benthic and other animal communities can be substantial, although dredged areas recover if left undisturbed (Canter, 1985). Maintenance dredging, however, which entails dredging a particular channel periodically to sustain a prescribed depth, can prohibit recovery. Dredging can also alter natural water circulation patterns, which can affect ecosystems in a variety of ways, such as through increased or decreased salinity (Canter, 1985).

Engineering projects, such as stream channelization, result in changes in water flow patterns, often with serious side effects, such as increases in sediment deposits (Griffin, 1991). It should be noted that many channelization and dam projects are not undertaken for the purpose of navigation improvement. Channelization projects can have negative impacts on water quality, aquatic ecosystems, and terrestrial ecosystems. Some possible water quality problems associated with channelization are altered turbidity and pH values, conductivity, dissolved oxygen levels, and temperatures in streams. Fluvial ecosystems can experience decreased habitat variability, reduced invertebrate populations, and decreased fish populations due to channelization. Within terrestrial ecosystems, channelization projects can cause reduced or altered riparian habitat (any habitat located on the bank of a natural body of water), drained wetlands, decreased bird and mammal populations, loss of ground cover, and raised water tables (with associated detrimental effect on some tree species) (Canter, 1985).

It should also be noted that navigation improvements may spur additional maritime travel, which would have environmental impacts (see the section on travel impacts below). This indirect effect of navigation improvements is not considered here.

Causal Factors

- Demand for new or expanded waterways
- Need for maintenance dredging
- Type of dredge and other construction equipment used
- Successful implementation of various efforts to avoid or mitigate impacts
- Size of vessels using ports
- Species/habitats in channels

HABITAT DISRUPTION AND CONTAMINATION FROM DISPOSAL OF DREDGED MATERIAL

Presentation of Indicators

Quantified Outcome/Results Indicators

- Nine states reported that disposal of dredged material was a source of direct wetlands losses in 1992 (U.S. EPA, 1994b).
- In a test of the effects of contaminated dredged sediments on eleven species of benthic macroinvertebrates by EPA and the Army Corps of Engineers, one amphipod species experienced acute mortality. Other species experienced milder impairments, such as limited burrowing activity and tube building. Such impairments can impact the abundance of a species (U.S. EPA, 1989b). Nationwide impacts have not been estimated.

Quantified Output Indicators

- Dredged material is the largest source of waste disposal in U.S. coastal waters (U.S. EPA, 1989b).

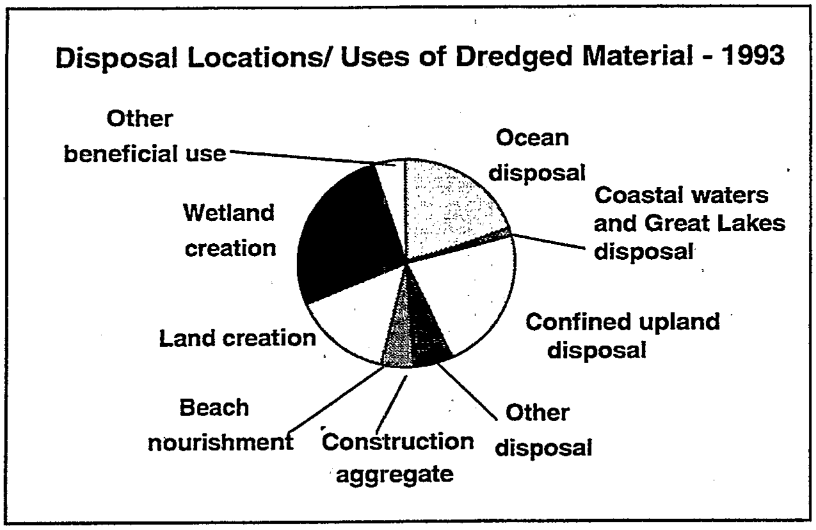
- Estimates of the annual amount of U.S. dredged material disposed in the ocean range from 75 million to 180 million wet metric tons (U.S. EPA, 1989b). The table below presents additional information on quantities of dredged materials disposed in various places.

Disposal/Use of Dredged Material from U.S. Waters by Various Dredgers, 1993[68]

Disposal/Use	Thousand Cubic Yards (Percentage of All Material)			
	U.S. Army Corps	Port Authorities	Other Dredgers	All Dredgers
Ocean Disposal	21,817 23.9%	1,092 3.0%	7,535 29.4%	30,444 19.9%
Coastal Waters Disposal	1,207 1.3%	534 1.5%	93 0.4%	1,834 1.2%
Great Lakes Disposal	0 0.0%	0 0.0%	0 0.0%	0 0.0%
Confined Upland Disposal	23,409 25.7%	6,794 18.8%	2,817 11.0%	33,020 21.6%
Other Disposal	500 0.5%	750 2.1%	7,000 27.3%	8,250 5.4%
Construct. Aggregate	300 0.3%	200 0.6%	76 0.3%	576 0. %
Beach Nourishment	3,689 4.0%	3,565 9.9%	100 0.4%	7,354 4.8%
Land Creation	6,500 7.1%	16,418 45.4%	0 0.0%	22,918 15.0%
Wetland Creation	31,528 34.6%	1,700 4.7%	8,000 31.2%	41,228 27.0%
Wetland Restoration	0 0.0%	100 0.3%	0 0.0%	100 0.1%
Other Beneficial	2,154 2.4%	5,000 13.8%	0 0.0%	7,154 4.7%
All Use and Disposal	91,104 100.0%	36,153 100.0%	25,621 100.0%	152,878 100.0%

Source: American Association of Port Authorities, 1995.

[68] Figures are from a survey of sources. Not all sources responded to the survey, so the figures do not represent total quantities for the nation. Responses from the Army Corps of Engineers represent national figures, but only 46 (61 percent) of U.S. member ports responded. Quantities obtained from the survey seem to be low compared with aggregate estimates from other sources.



Source: American Association of Port Authorities, 1995.

- The percentage of dredged material in the U.S. that is contaminated enough to require special handling is less than 10 percent and possibly lower than 5 percent, although past estimates have ranged as high as 30 percent (Cullinane et al., 1990). Certain ports, however, have reported much higher percentages. For example, MASSPORT reported that a third of its dredged material was contaminated, and the ports of both Jacksonville and San Diego reported that half of their material was contaminated in 1993 (American Association of Port Authorities, 1995).
- The U.S. Army Corps of Engineers considers approximately 3 percent of its dredged material to be highly contaminated and 30 percent to be moderately contaminated (U.S. EPA, 1989b).
- Concentrations of lead, mercury, and other metals in dredged material have been found to be much higher than naturally occurring levels in some cases (see table).

Chemical Characteristics of Dredged Material Compared with Average Material from the Earth's Crust

Constituent	Dredged Materials	Average Crustal Materials
Trace Metals	***Moles per kg***	***Moles per kg***
Iron	0.02 -- 0.90	0.61 -- 1.03
Manganese	$(0.4 - 10) \times 10^{-3}$	$(12 - 18) \times 10^{-3}$
Zinc	$(0.5 - 8) \times 10^{-3}$	$(0.92 - 1.26) \times 10^{-3}$
Copper	$(0.8 - 9{,}400) \times 10^{-6}$	$(460 - 1{,}090) \times 10^{-6}$
Nickel	$(0.2 - 2.6) \times 10^{-3}$	$(0.62 - 1.69) \times 10^{-3}$
Chromium	$(0.02 - 3.8) \times 10^{-3}$	$(0.92 - 1.92) \times 10^{-3}$
Lead	$(5 - 1{,}900) \times 10^{-6}$	$(48 - 77) \times 10^{-6}$
Cadmium	$(0.4 - 600) \times 10^{-6}$	$(0.89 - 1.6) \times 10^{-6}$
Mercury	$(1 - 10) \times 10^{-6}$	$(0.149 - 0.398) \times 10^{-6}$
Synthetic Organics	***mg per kg***	
Chlorinated pesticides	0 – 10	
Polychlorinated biphenyls	0 – 10	

Source: U.S. EPA, 1989b.

OTHER INDICATORS AND LOCAL EXAMPLES

- Within the New York Bight, dredged material, sewage sludge, and acid and chemical wastes (the total of ocean-dumped wastes) contribute 15,000 tons/day of suspended solids, 3,200 tons/day of chemical oxygen demand, 660 tons/day of total organic carbon, 50 tons/day of ammonia nitrogen, 2 tons/day of cadmium, 0.026 tons/day of mercury, 5.6 tons/day of lead, and 9.3 tons/day of zinc. Dredged material is the largest contributor of these pollutants, with a low of approximately 50 percent of the total mercury contribution and a high of nearly 100 percent of the cadmium contribution (U.S. EPA, 1989b).
- Repeated disposal of dredged material at a site in Central Long Island Sound has resulted in the formation of several mounds 1 to 3 meters in height with radii of up to 400 meters (U.S. EPA, 1989b).

DESCRIPTION OF IMPACT

Dredging (and other navigation improvements) results in accumulation of extensive amounts of material from the bottoms of bodies of water. Some of this material is used for beneficial purposes, such as construction, beach nourishment, land creation, wetland creation, and wetland restoration. The rest of this material, especially contaminated sediments, must be disposed.

Disposal of dredged material has the potential to cause far-reaching environmental impacts. There are two major methods of disposal: (1) disposal in open water, and (2) disposal on land. Disposal in open water can alter bottom habitats, decrease water quality, and befoul marine organisms. Repeated disposal at a site can form mounds in bottom habitats, because most material sits where it is dumped. Disposal of dredged material in open waters can affect water quality by physical means, such as increasing turbidity, or chemical means, such as raising pollutant concentrations. Open water disposal can harm marine organisms in a number of ways. Benthic organisms can be killed simply by physical burial under dredged material. A more widespread effect of disposal on marine fauna, however, is uptake of toxics. Contaminants may impact the benthic community even if dredged material is capped, and larger animals may ingest contaminants either directly or indirectly through feeding on smaller animals (U.S. EPA, 1989b).

Disposal of dredged material on land can be beneficial or detrimental, depending for the most part on the quality of the material. Clean material can be used for beneficial projects. Disposal of contaminated dredged material on land is highly controversial for many reasons, including its high cost and the possibility of pollution. Contaminants can potentially escape from upland containment facilities and enter groundwater aquifers or surface waters (U.S. EPA, 1989b).

CAUSAL FACTORS

- Level of construction activity
- Quantity and types of hazardous materials in dredged material
- Type of disposal (e.g., capped, uncapped, contained)
- Location of disposal (land, coastal waters, open ocean)
- Quantity of past dredging activity

HABITAT DISRUPTION AND LAND TAKE FOR PORTS AND MARINAS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Habitat, species, recreational, and other impacts of ports and marinas have not been estimated at the national level.

QUANTIFIED OUTPUT INDICATORS

- Amount of shoreline acreage developed specifically to support maritime transportation is unknown.

QUANTIFIED ACTIVITY INDICATORS

- There are approximately 10,000 marinas in the U.S. (International Marina Institute, 1991 database).
- The U.S. Army Corps of Engineers maintains channels that serve 400 U.S. ports, including 130 of the nation's 150 largest cities (U.S. EPA, 1989b).

DESCRIPTION OF IMPACT

Maritime transportation impinges on coastal, riparian, and other marine habitats through the taking of land to construct and operate ports and marinas (Button, 1993). In many cases, ports and marinas sequester and develop extensive natural areas, resulting in degraded ecosystems and loss of habitats.

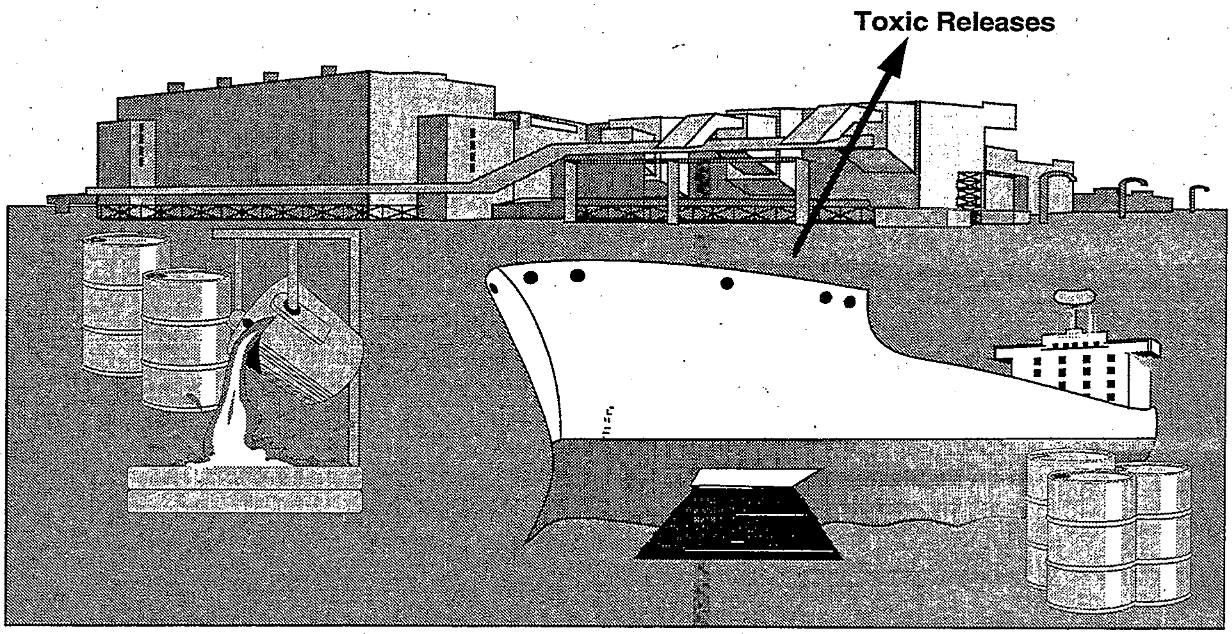
It is extremely difficult to attribute a share of this impact to maritime transportation. A great deal of coastal development is not directly related to transportation. For example, some of the development in coastal cities, such as New York City, is directly attributable to maritime transportation (e.g., loading docks). Other developments, such as office buildings for managers of loading dock facilities, may or may not be attributable to marine transportation. Determining what shoreline development is attributable to marine transportation is difficult; determining the portion of habitat loss caused by that development is even more difficult.

CAUSAL FACTORS

- Number of new port facilities constructed
- Level of expansion of existing ports and marinas
- Inappropriate siting of marinas or port facilities

2. MANUFACTURE OF MARITIME VESSELS AND PARTS

A large variety of maritime vessels are manufactured. The inventory of vessels includes non-self-propelled barges, tankers, and floats; ferries; tankers; towboats; sailing vessels; recreational boats (primarily small pleasure craft), and large ocean-liners. The manufacture of these vessels results in environmental impacts through the release of toxics to the air, soil, and water.



TOXIC RELEASES

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No quantified data on human health impacts, such as increased incidence of cancer from toxics, or habitat and species impacts are available.

QUANTIFIED OUTPUT INDICATORS

- Some 203,722 pounds (or about 102 tons) of toxic chemicals were reported released on-site from vessel manufacturing facilities in 1994 (see table).[69]

[69] Impacts of imported equipment and parts are not counted here. Only U.S. facilities are included here, including the impacts of exported equipment.

Toxic Chemicals Released from Vessel Manufacturing Facilities (Pounds in 1994)

SIC[a] Code	Industry Type	On-Site Releases (Pounds)				POTW[b] Transfer	Off-Site Locations Transfer
		Air	Water	Land	Total		
3730	Ship and boat building and repair	203,702	20	0	203,722	0	36,454

[a]SIC = Standard Industrial Classification
[b]POTW = Publicly owned treatment works
Source: Toxic Releases Inventory, 1994

QUANTIFIED ACTIVITY INDICATORS

- The number of vessels in the U.S. has increased dramatically over the past 30 years, as the following table shows. The increase in the vessel fleet provides an indication of the amount of vessel manufacture, but does not signify that new vessels were produced in the U.S.

Vessel Inventory, 1960-1992

Year	Non-self propelled (barges/floats)	Self-propelled	Recreational boats (thousands)
1960	16,777	6,543	2,450
1970	19,377	6,455	7,400
1980	31,662	7,130	14,600
1990	31,017	8,216	19,500
1992	30,899	8,311	20,300

Source: BTS, 1995.

DESCRIPTION OF IMPACT

The manufacture of ships and boats involves use of a variety of materials and chemicals. During the manufacturing process, toxic chemicals are released from vessel manufacturing facilities into the environment. Releases occur as on-site discharges of toxic chemicals, including emissions to the air and discharges to water. Chemicals are transferred off-site when they are shipped to other locations.

On-site releases to air occur as either stack emissions, through confined air streams such as stacks or vents, or fugitive emissions, including equipment leaks, evaporative losses from surface impoundments and spills, and releases from building ventilation systems. Surface water releases may include releases from discharge pipes as well as diffuse runoff from land, roofs, parking lots, and other facility infrastructure.

Off-site transfers represent a movement of the chemical away from the reporting facility. Except for off-site transfers for disposal, these quantities do not necessarily represent entry of the chemical into the environment. Chemicals are often shipped to other locations for recycling, energy recovery, or treatment.

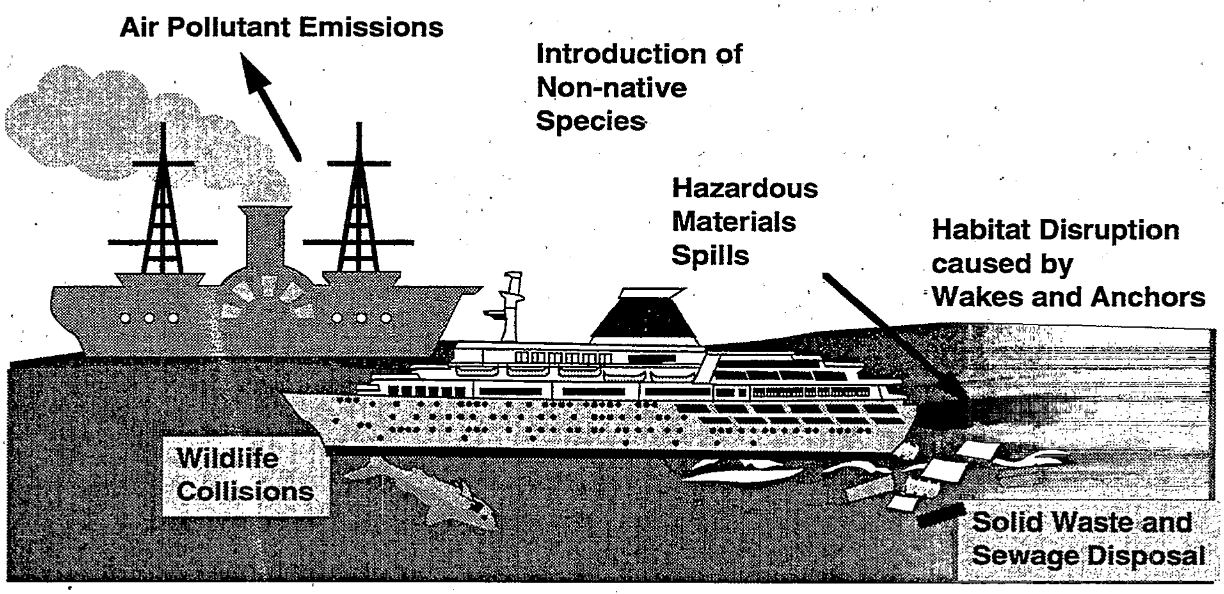
The toxic releases from manufacturing facilities cause many of the same problems as releases from vessel terminal operations. These problems include ecosystem impacts (e.g., unhealthy wildlife) and human health effects (e.g., respiratory problems). In general, the scale of pollution from the vessel building industry is relatively minor compared with many other industries, such as automobile manufacturing.

CAUSAL FACTORS

- Number of vessels built
- Amount of chemicals used per vessel
- Efficiency of controls and efforts to reuse or recycle chemicals and other materials, including pollution prevention efforts
- Amount of chemicals and materials transferred to other locations for recycling, energy recovery, or treatment
- Types of chemicals released and toxicity
- Population density and extent of exposure
- Environmental conditions such as climate, topography, or hydrogeology affecting fate and transport of chemicals and materials in the environment

3. MARITIME TRAVEL

Maritime travel is responsible for a number of environmental impacts, including air pollution from fuel consumption; habitat disruption caused by wakes and anchors; wildlife collisions; introduction of non-native species; and releases of solid waste, sewage, and hazardous materials. Based on data availability, statistics for both recreational vessels (primarily small pleasure craft) and non-recreational vessels are presented. There is some disagreement about whether recreational boating serves a transportation purpose (the movement of goods or people from one place to another); however, data on recreational boating are presented here since recreational boats are mobile sources that have significant impacts on the environment, and it is difficult to separate the recreational component of any mode of transportation.



AIR POLLUTANT EMISSIONS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No data are available on the health or habitat effects of emissions from water-based travel.

QUANTIFIED OUTPUT INDICATORS

- In 1994, maritime vessel operations were responsible for the following emissions nationwide, including recreational vessels (U.S. EPA, 1995e):

Pollutant	Quantity Emitted (1994, thousand short tons)	Percentage of total Emissions of that Pollutant[70]
Carbon Monoxide (CO)	1,319	1.35%
Nitrogen Oxides (NO_x)	208	0.88%
Volatile Organic Comp. (VOCs)	489	2.11%
Sulfur Dioxide (SO_2)	206	0.98%
Particulate Matter (PM-10)	29	0.06%

- In 1993, CO_2 emissions from maritime vessel operations (including recreational boats and international shipping vessels) accounted for approximately 34 million metric tons of carbon equivalent (mmtCe), or 2.5 percent of total national anthropomorphic CO_2 emissions (Apogee estimate).[71]

- Maritime vessels contributed to emissions of other greenhouse gases, as reported below (U.S. EPA, 1994a):

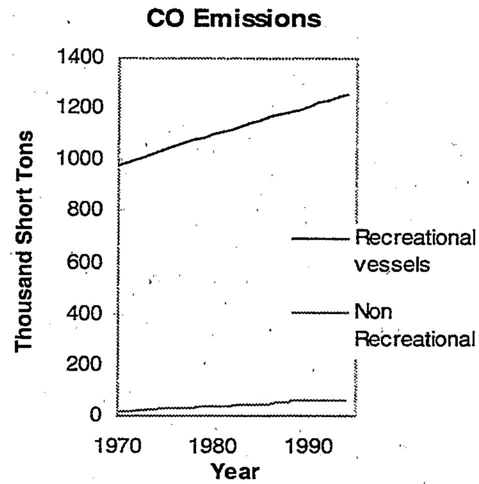
Pollutant	Quantity Emitted (1990, thousand metric tons)
Methane (CH_4)	3
Nitrous Oxide (N_2O)	1

[70] Percentages are based on anthropogenic emissions, except for PM-10, which includes natural emissions.
[71] Estimate is based on the following methodology: transportation sector energy use by fuel type within a mode (DOE/EIA, 1995b) was multiplied by carbon coefficients–mmtCe/quadrillion Btu–for each fuel (DOE/EIA, 1995a), then adjusted by fraction of carbon that does not oxidize during combustion (DOE/EIA, 1995a). Note that this estimate does not account for upstream emissions, such as emissions from vessel assembly and fuel production.

CO Emissions from Maritime Vessels

Year	Recreational Vessels (Thousand Short Tons)	Non Recreational Vessels (TST)	Percentage Total National Emissions
1970	976	14	0.77%
1980	1102	37	0.98%
1985	1157	44	1.04%
1986	1167	47	1.11%
1987	1175	50	1.13%
1988	1185	56	1.07%
1989	1195	59	1.22%
1990	1207	58	1.26%
1991	1221	58	1.31%
1992	1233	60	1.37%
1993	1245	62	1.39%
1994	1256	63	1.35%

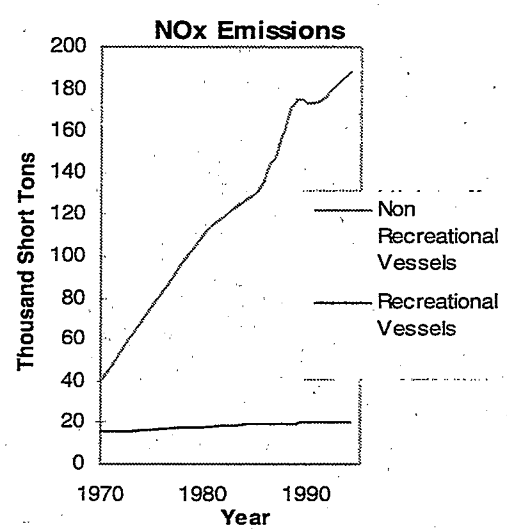
Source: U.S. EPA, 1995e.



NO_x Emissions from Maritime Vessels

Year	Recreational Vessels (Thousand Short Tons)	Non Recreational Vessels (TST)	Percentage Total National Emissions
1970	16	40	0.27%
1980	18	110	0.55%
1985	19	131	0.66%
1986	19	140	0.71%
1987	19	149	0.75%
1988	19	165	0.78%
1989	19	175	0.84%
1990	20	173	0.84%
1991	20	174	0.86%
1992	20	179	0.87%
1993	20	183	0.87%
1994	20	188	0.88%

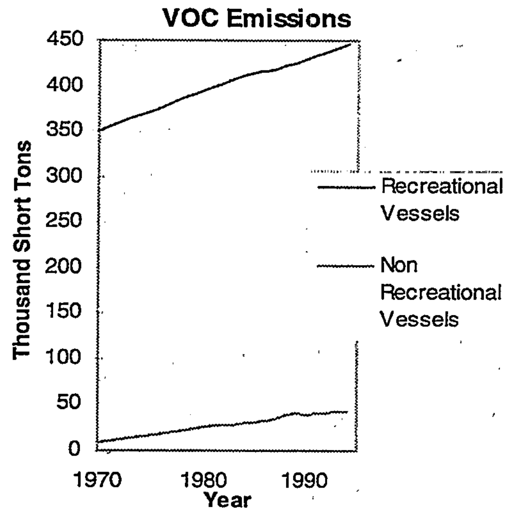
Source: U.S. EPA, 1995e.



VOC Emissions from Maritime Vessels

Year	Recreational Vessels (Thousand Short Tons)	Non Recreational Vessels (TST)	Percentage Total National Emissions
1970	350	9	1.17%
1980	395	25	1.62%
1985	413	30	1.72%
1986	416	32	1.79%
1987	419	34	1.83%
1988	422	38	1.79%
1989	425	40	1.94%
1990	429	39	1.98%
1991	434	40	2.07%
1992	438	41	2.14%
1993	442	42	2.14%
1994	446	43	2.11%

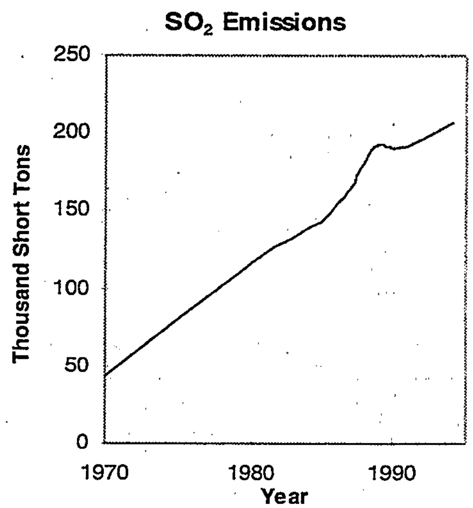
Source: U.S. EPA, 1995e.



SO_2 Emissions from Maritime Vessels

Year	(Thousand Short Tons)	Percentage Total National Emissions
1970	43	0.14%
1980	117	0.45%
1985	143	0.62%
1986	154	0.68%
1987	164	0.74%
1988	181	0.80%
1989	193	0.83%
1990	190	0.85%
1991	191	0.87%
1992	197	0.90%
1993	201	0.93%
1994	206	0.98%

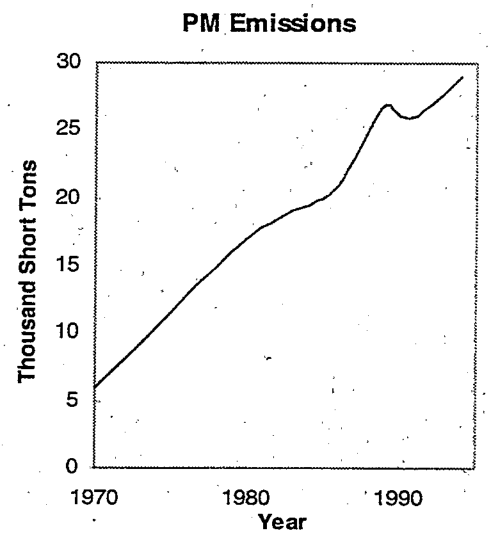
Source: U.S. EPA, 1995e.



PM-10 Emissions from Maritime Vessels[72]

Year	(Thousand Short Tons)	Percentage Total National Emissions
1970	6	-
1980	17	-
1985	20	0.04%
1986	21	0.04%
1987	23	0.05%
1988	25	0.04%
1989	27	0.05%
1990	26	0.06%
1991	26	0.05%
1992	27	0.06%
1993	28	0.07%
1994	29	0.06%

Source: U.S. EPA, 1995e.



It is important to note the uncertainty regarding the values used for these output indicators. Since actual measurement of all vessel emissions is impractical, the emissions estimates come from models, which can produce varying estimates based on alternative methodologies and assumptions.

There is some evidence that air pollution can have a significant impact on water quality. Some portion of atmospheric deposition may result from maritime vessel emissions, although statistics on such pollution cannot be disaggregated to separate modes. See the section on highway air pollutant emissions for more information on atmospheric deposition.

QUANTIFIED ACTIVITY INDICATORS

- Refer to Appendix A for data on maritime travel.

DESCRIPTION OF IMPACT

Although similar pollutants are emitted from maritime vessels and motor vehicles, there are several key differences regarding emissions: (1) maritime vessels produce a much lower total quantity of emissions; (2) emissions from maritime vessels tend to occur over different ecosystems than those from motor vehicles; and (3) emissions from vessels have a chemical composition different from that of motor vehicle emissions. Lower quantities of total emissions make the effects of vessel emissions less pronounced than those of motor vehicles. Although emissions can travel widely and cause harm in places that are removed from the point of release, emissions from vessels are less likely to affect humans and land-based ecosystems and structures. Emissions from vessels, however, cause somewhat different effects, since they produce more SO_2, NO_x, and PM-10 and less CO and VOC per volume emitted than motor vehicle emissions (U.S. EPA 1993g).

[72] Percentage of total emissions are not reported for particulate matter prior to 1985 because of changes in total emissions inventories; fugitive dust and wind erosion are reported only for the period 1985 to 1994.

Air emissions from vessels affect ecological and human health in a number of ways. Pollutants in emissions can cause respiratory and other illnesses, reduced visibility, soiling and corrosion of materials, damage to land-based and marine plants and animals, and contribution to global warming. While the percentage of total national emissions from vessels is minor compared with some other sources of air pollutants, vessel emissions have the potential to cause serious local and regional impacts. In addition, unlike auto emissions, total air emissions of pollutants from vessels are on the rise in the U.S.

Causal Factors

- Number of vessel trips
- Emissions per volume of fuel consumed, per trip, or per distance traveled, by chemical
- Distance traveled
- Engine type, age, and emissions control technology
- Fuel consumed (by type) affects emissions per mile
- Travel characteristics: speed, acceleration, etc. affects emissions per mile
- Climatic conditions (temperature, wind, rain, etc.) affects dispersion/dilution of pollutants and formation of secondary pollutants
- Population density affects number of people exposed to pollution
- Rate of wet deposition
- Sensitivity of local ecosystems

HABITAT DISRUPTION CAUSED BY WAKES AND ANCHORS

Presentation of Indicators

Quantified Outcome/Results Indicators

- The total area of shoreline erosion caused by wakes and the amount of vegetation and coral damaged and species affected by wakes and anchors is not known.

Quantified Output Indicators

- No data are available regarding the number and size of wakes in sensitive locations.

Quantified Activity Indicators

- No data have been found regarding the number of anchors dropped, the amount of traffic, or the average size and speed of boats in sensitive locations.

Description of Impact

Several environmental impacts are the result of wakes from large or high-speed maritime vessels and anchoring. Wakes from large (e.g., cruise ship) or fast-moving vessels can cause erosion and vegetative and coral damage in confined or shallow waters. Wakes can cause strong wave propagation that is capable of eroding shorelines or stirring up bottom sediments in shallow areas. Vegetation can be disturbed both by erosion processes and by sedimentation resulting from wakes. Sedimentation reduces the amount of sunlight available for photosynthetic processes. Corals also are susceptible to damage from sediments that have been suspended by the action of wakes. The impacts of wakes are very local in nature and likely to be more pronounced in confined areas of high traffic.

Dropping of anchors from vessels, like wakes, can cause local habitat damage. This damage occurs through direct physical disruptions, as anchors are dropped on habitats and sometimes dragged through them. Anchor damage can be especially serious in highly productive but sensitive ecosystems, such as coral reefs.

CAUSAL FACTORS

- Volume of vessel traffic
- Size of vessels
- Speed of vessels
- Number of anchors dropped
- Sensitivity of local ecosystems to physical abuse

INTRODUCTION OF NON-NATIVE SPECIES

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No data are available on the damages to ecosystems or species loss due to introduction of nonnative species to habitats via boat. No data are available on impacts to fisheries, water treatment facilities, or other resources.

QUANTIFIED OUTPUT INDICATORS

- Over 130 non-native species have been introduced to the Great Lakes since 1800, and nearly a third are believed to have been carried in by ships (Council on Environmental Quality, 1993).

DESCRIPTION OF IMPACT

The introduction of non-native species to certain habitats may result in severe environmental strain or damage to a functioning ecosystem. Non-native species may compete with native species for food and force out existing creatures. For example, the zebra mussel, a non-native nuisance species, probably entered the Great Lakes through discharge of ballast water from an ocean-going vessel. The mussels could potentially disrupt the food web in the lakes by devouring microscopic plants that form the foundation of the web. Colonies of zebra mussels also clog water intake pipes at power plants and water treatment facilities (Council on Environmental Quality, 1993). Other non-native species may out-compete existing species, resulting in significant alterations to the aquatic ecosystem.

CAUSAL FACTORS

- Number of foreign ships entering U.S. waterways
- Lack of proper disposal or exchange of ballast water or other contaminated cargo
- Lack of enforcement of ballast water management

HAZARDOUS MATERIALS INCIDENTS DURING TRANSPORT

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- No statistics were found regarding the number of species nationwide affected by hazardous materials incidents.

QUANTIFIED OUTPUT INDICATORS

- In 1994, 5,295 incidents were reported involving oil spills in U.S. navigable waters (U.S. DOT, 1996).

Oil Spills from Vessels in U.S. Navigable Waters, 1982-1994

Year	Number of Incidents	Gallons Spilled
1982	2,209	3,778,982
1983	2,225	2,332,256
1984	2,267	9,011,868
1985	1,662	4,862,911
1986	1,612	2,835,916
1987	1,779	2,945,770
1988	2,008	4,386,289
1989	2,268	12,693,817
1990	2,486	6,437,158
1991	2,428	730,489
1992	5,310	665,432
1993	5,430	1,177,157
1994	5,295	1,276,914

Source: U.S. DOT, 1996.

- Corrosive materials constituted the class of hazardous materials with the largest number of reported incidents—17—and the largest reported quantity released—8,446.9 gallons—over 1990-1994.

Incidents Involving Releases of Hazardous Materials from Non-Bulk, Interstate Vessels in U.S. Waters (Total, 1990-1994)[73]

Class of Hazardous Material	Number of Incidents	Quantity Released	Economic Damages ($)
Corrosive material	17	8,446.9 gal.	276,507
Flammable combustible liquid	8	578.2 gal.	201,925
Poisonous material	6	64.7 gal.	8,250
Nonflammable compressed gas	3	1.5 gal.	47,880
Oxidizer	2	0.4 gal.	132,412
Radioactive material	2	4.3 lbs.	3,000
Combustible liquid	1	3.0 gal.	2,300
Organic peroxide	1	1.0 gal.	28
Other	1	2.0 gal	200

Source: U.S. DOT, RSPA, HMIS

- In 1992, vessels caused 60 percent of all oil spill incidents in navigable waters of the U.S. (Council on Environmental Quality, 1993).
- Tanker accidents cause 10 to 15 percent of the annual input of oil into the world's oceans (Miller, 1990).

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- In 1989, the grounding of the *Exxon Valdez* oil tanker resulted in a spill of approximately 11 million gallons of crude oil into wildlife-rich Prince William Sound. The oil slick coated and killed more than 34,000 birds, 10,000 sea otters, and an unknown quantity of fish. The total count of wildlife deaths from the incident is unknown because most of the dead animals sank and decomposed (Miller, 1990).
- Water transportation of hazardous materials is primarily the enforcement responsibility of the U.S. Coast Guard. Nine states have adopted the federal regulations for such transportation, but none are actively enforcing the regulations (RSPA; National Governors' Association).

DESCRIPTION OF IMPACT

Releases of hazardous materials, especially petroleum products, from vessels are one of the most publicized impacts of maritime transportation. Many factors determine the extent of damages caused by petroleum spills, including type of oil spilled (crude or refined), quantity spilled, distance of release from shore, time of year, weather conditions, water temperatures, and currents.

[73] The data in the HMIS database do not capture releases from bulk marine vessels, which are the most likely class of vessels to be transporting hazardous materials. Bulk marine vessels and intrastate vessels are not required to report release information for the data base. The numbers in the table, therefore, are only a tiny fraction of actual volumes released. For example, petroleum crude oil is classified as a flammable liquid. Comparing the data in this table with the data on oil spills contained in the previous table reveals the magnitude of underestimation. Data in this table, therefore, only reveal the types of wastes being released, and provide some level of insight into the relative quantities of each class of materials released.

When an oil spill occurs, toxic hydrocarbons, such as benzene and toluene, cause immediate wildlife deaths. Shellfish and nonmigratory fish, especially those in the larval stage, are the most susceptible to these chemicals. Other chemicals form sticky, tar-like globs on the surface that adhere to marine wildlife such as birds, otters, and seals, as well as to sand, rocks, and almost all other substances. Many animals that come into contact with such chemicals die from drowning or loss of body heat. Heavy components of oil that sink to the bottom of bodies of water may have the most profound impacts on ecosystems. Such pollution can kill or damage benthic organisms and adversely affect food webs (Miller, 1990). Studies of some oil spills have shown that it takes most species of marine life 3 years to recover from exposure to large quantities of crude oil. Recovery times may be much longer (10 or more years) for exposure to refined oil, especially in areas with weak currents or cold waters (Miller, 1990). Oil pollution in the vicinity of shorelines can cause ecological harm in coastal ecosystems.

Humans also experience health effects from oil spills. Exposure depends on how much oil washes ashore and how much seafood is contaminated and eaten. For the most part, oil chemicals are not biologically magnified in food webs (Miller, 1990), so seafood impacts may not be that large. Some of the chemicals resulting from spills, however, such as benzene, are highly toxic to humans (Miller, 1990).

Ecosystems and humans also experience impacts from maritime spills of non-petroleum hazardous waste. Such spills can lead to wildlife kills, non-swimmable and non-fishable waters, shellfish bed closures, and human exposure through contact and food. In addition, some hazardous substance may undergo biological amplification in food chains, causing serious damage to organisms at high trophic levels. Human contact with non-petroleum hazardous waste spills can be greater where a hazardous substance spill goes undetected and warnings are not given to avoid body-contact through water recreation.

CAUSAL FACTORS

- Quantity of hazardous materials transported
- Accident or spill rate
- Type and quantity of material released
- Toxicity/hazard of materials released
- Effectiveness of cleanup efforts
- Proximity to coastal areas
- Sensitivity and location of affected ecosystems

WILDLIFE COLLISIONS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Approximately one-third of known right whale fatalities are caused by human activities, principally ship strikes in their calving and wintering grounds in the coastal waters of Florida and Georgia (Council on Environmental Quality).

Quantified Output Indicators

- Data on the number of collisions between maritime vessels and wildlife are not known.

Quantified Activity Indicators

- Refer to Appendix A for data on maritime travel.

Description of Impact

Many slow-moving marine species, especially large mammals and reptiles, are often victims of encounters with motorized vessels. Fauna can be killed or severely injured through collisions with propellers or hulls. Some of the most publicized and damaging U.S. incidents involve endangered species, such as the West Indian manatee, the right whale, and various species of sea turtles. Propellers are a significant source of injuries and deaths for the West Indian manatee in coastal Florida.

Causal Factors

- Number of high-speed motorized vessels
- Volume of vessel traffic
- Presence and quantity of wildlife

Overboard Dumping of Solid Waste

Presentation of Indicators

Quantified Outcome/Results Indicators

- As many as 50,000 northern fur seals die annually from entanglement in plastic marine debris, primarily fishing nets and strapping bands (National Research Council, 1995). The amount of this debris attributable to vessels as opposed to land-based sources and other marine sources is unknown.
- Cases of entanglement have been recorded for 51 of the world's 312 seabird species and 10 of the world's 75 cetacean species (National Research Council, 1995).
- Ingestion of plastic debris has been recorded for at least 108 species of seabirds and 33 species of fish.
- Impacts on human health are unavailable.

Quantified Output Indicators

- Quantity of garbage disposed of at sea by vessels is unknown.

Quantified Activity Indicators

- U.S. maritime sectors generate an estimated total of 825,168 metric tons of garbage annually (see table).

Estimated Annual Garbage Generation by U.S. Maritime Sectors[74]

Vessel Type	Number of Vessels[c]	Annual Garbage Generation (metric tons)	Typical Voyage Area
Recreational Boats	7,300,000	159,900	Nearshore
Fishing Vessels	129,000	230,500	Nearshore and Offshore
Cargo Ships	7,800	111,700	Offshore
Day Boats	5,200	57,623	Nearshore and Offshore
U.S. Navy Vessels	284	10,262	Nearshore and Offshore
U.S. Coast Guard Vessels	2,316	4,058	Nearshore and Offshore
U.S. Army Vessels	580	254	Nearshore and Offshore
School Boats	14	358	Nearshore and Offshore
Offshore Industry Service Vessels	1,500	7,665	Nearshore and Offshore
Navy Combatant Surface Vessels	360	37,812	Offshore
Passenger Cruise Ships	128	201,830	Nearshore
Research Vessels	125	1,779	Nearshore and Offshore
Misc. Private Industry Vessels	85	1,427	Nearshore and Offshore
Total	7,447,392	825,168	

Source: National Research Council, 1995.

DESCRIPTION OF IMPACT

The three major types of shipboard solid waste are domestic garbage (e.g., galley waste and food packaging), operational garbage (e.g., used fishing gear, fish processing materials, and items used for onboard maintenance), and cargo-related garbage (e.g., packaging materials and dunnage) (National Research Council, 1995). While garbage generation is substantial for U.S. maritime sectors (see the table above), quantifying the amount of garbage dumped overboard is difficult. Maritime travel is not the source of all marine debris. Land-based sources and stationary maritime sources, such as oil platforms, account for some portion of marine debris. Even data on garbage generation are highly uncertain. Other factors, such as the fact that floatable debris can travel extremely long distances and cross international borders, also complicate statistics about vessel garbage. While these uncertainties affect the accuracy of indicators, the impacts of debris from vessels are genuine and can be described to some extent.

The most readily observable ecological effects of solid waste dumping from marine vessels are entanglement, ingestion, and ghost fishing. Entanglement occurs when wildlife come into contact with marine debris and become trapped. Affected wildlife includes mammals, turtles, birds, fish, and land animals that inhabit coastlines. Researchers believe that substantial numbers of animals die or are injured because of entanglement. In fact, entanglement is thought to be the cause of serious population declines among some species. Non-deadly injuries can be serious, causing inability to breathe, swim, feed, or raise young properly (National Research Council, 1995).

[74] This table depicts garbage generation by U.S. fleets, not overboard dumping. Some of the generated wastes, however, are dumped overboard. Many of the vessels generate some portion of their wastes while operating in non-U.S. waters. Data were collected from various sources dating from 1990 to 1994. Number of vessels was tabulated as follows: recreational boats - boats registered in coastal states or in states bordering the Great Lakes; cargo ships - different ships of all flags calling at U.S. ports.

Ingestion refers to instances in which animals swallow debris. The most publicized cases of ingestion involve sea turtles and cetaceans swallowing plastic waste. Ingestion of plastic and other debris can cause immediate death or result in a number of injuries or handicaps to wildlife. While very few data describe the extent of damage caused by ingestion, many anecdotal cases have been documented (National Research Council, 1995).

Ghost fishing involves lost or discarded fishing gear that continues to catch finfish and shellfish. The extent of this problem is not well specified, but some evidence suggests that some lobster, crab, and other fisheries experience depletion due to ghost fishing. Most of the problems from ghost fishing are caused by lost or discarded trapping devices, such as gill nets (National Research Council, 1995).

Other possible ecological effects of overboard dumping have not been researched extensively. Effects on coral reefs, water and sediment toxicity, invertebrates, plants, bottom habitats, and other areas may be substantial but are not well documented (National Research Council, 1995).

In addition to ecological problems, shipboard solid wastes that are dumped overboard can cause human health problems. These problems are most notably associated with direct human contact with debris. Examples of this type of problem include wounds on beaches from sharp debris that washes up on or near shore and injuries caused by contact with hazardous chemicals. Other human health hazards associated with debris include diver entanglement and boat collisions and malfunctions caused by debris. While human health impacts from overboard dumping of solid waste are possible, data on exposure are unavailable.

CAUSAL FACTORS

- Quantity of food, packaging, fishing equipment, and other items used on vessels
- Difficulty in transporting garbage on boats, and ease of overboard disposal
- Difficulty in enforcement of laws and policies
- Perceptions of the assimilative capacity of large bodies of water

SEWAGE DUMPING

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- In 1990, pollution from boating and marinas affected 25 percent of the harvest-limited shellfishing waters in half of the shellfish-producing states (harvest-limited waters are those in which shellfish beds may be contaminated) (Council on Environmental Quality, 1993).
- In a survey of nine states, the states revealed that marinas were the third largest source of restrictions on shellfish harvesting (behind urban runoff/storm sewers and municipal discharges). In these states, marinas accounted for 51 total harvesting restrictions in 1992 (U.S. EPA, 1994b). It is not clear whether these reported impacts are due to sewage or other toxic releases (e.g., oils, fuel).
- No outbreaks of shellfish-borne disease have been traced epidemiologically to discharge of sewage from recreational boats. Reported outbreaks, however account for a small fraction of all shellfish-borne illness (Hackney and Pierson, eds., 1994).

QUANTIFIED OUTPUT INDICATORS

- Estimates of the total amount of sewage dumped by vessels in U.S. waters are not readily available.

QUANTIFIED ACTIVITY INDICATORS

- Some 90 to 95 percent of commercial U.S. vessels have marine sanitation devices on board. 75 to 80 percent of recreational vessels have marine sanitation devices (U.S. Coast Guard).

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- Nationwide, shellfish harvesting in waters around marinas is typically restricted during the boating season as a precautionary measure (Hackney and Pierson, eds., 1994).
- A 1988 survey of 379 boaters in Puget Sound revealed the following problems experienced by boaters at shoreside pump-out stations: 17 percent found pump-outs inaccessible, 8 percent encountered crowded conditions, 5.3 percent experienced unsanitary conditions, 5.3 percent viewed fees as excessive or did not know how to use facilities, 37 percent experienced a complete lack of available pump-outs, 27.4 percent found frequently malfunctioning pump-outs (Washington State Parks and Recreation Commission).

DESCRIPTION OF IMPACT

The popularity of recreational boating in coastal areas has spurred rapid development of marinas, many of which are not equipped to collect and process sewage. Boaters who use these marinas often dump sewage in the water, rather than transporting it to proper pump-out facilities. Even in cases where marinas or ports are equipped with sewage collection facilities, many vessels are still responsible for sewage pollution. Some vessels do not contain a marine sanitation device (boat toilet), and, as a result, boaters sometimes dump sewage overboard. Some vessels are equipped with marine sanitation devices that are meant to treat sewage and dump it in the water. If these devices are functioning improperly, untreated sewage can be dumped. Fees for pump-out of sewage holds on vessels also give boaters the incentive to dump sewage illegally.

Sewage from vessels can cause serious local impacts on water quality and human health, especially in areas of high recreational boat use. Studies in Puget Sound, Long Island Sound, Narragansett Bay, and Chesapeake Bay have shown that boats can be a significant source of human wastes in coastal waters, especially where the volume of boat traffic is high and hydrologic flushing is low. The two major impacts of sewage discharges are introduction of microbial pathogens into the environment and reduction in dissolved oxygen levels. Waterborne bacteria and/or viruses that enter waterways from vessel sewage discharges can cause serious ailments and diseases, such as acute gastroenteritis, hepatitis, typhoid, and cholera (U.S. EPA, June 1991). Many marinas are located in or near shellfish-growing areas, and sewage dumped from the boats or at marinas has the potential to contaminate shellfish (Council on Environmental Quality, 1993). Pathways of exposure for humans include both direct water contact and ingestion of contaminated seafood.

Vessel sewage has a high capacity for reducing dissolved oxygen in bodies of water. Although the volume of wastewater discharged from vessels is typically small, the organic substances in the wastewater are highly concentrated. These organics can lead to low levels of dissolved oxygen where vessel traffic is high. (U.S. EPA, June 1991)

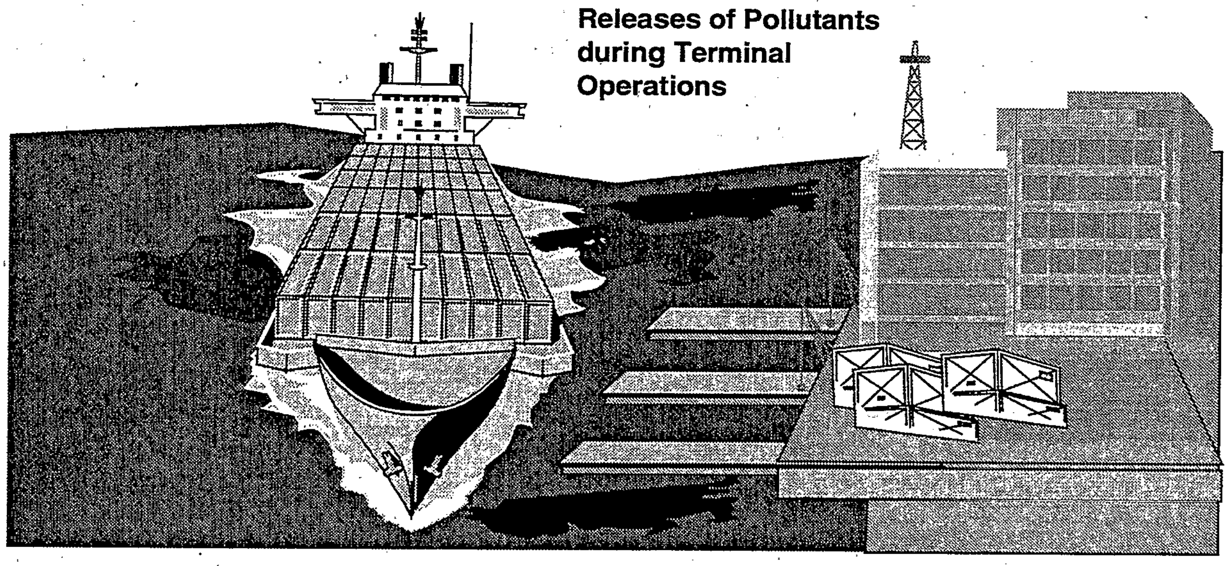
Another effect of vessel sewage occurs when treated wastewaters are discharged from vessels. These wastewaters are treated with chemical additives, such as chlorine and formaldehyde, which are generally toxic to marine life (U.S. EPA, June 1991). Vessel sewage that is removed from vessels at pump-out facilities is typically transported to POTWs for treatment. Impacts of wastewater discharges from POTWs, therefore, are partially attributable to vessel sewage in some cases.

CAUSAL FACTORS

- Vessel traffic, especially recreational vessel traffic in an area
- Poor siting of marinas near shellfish beds
- Poor flushing of marina areas
- Difficulties enforcing marine sanitation laws
- Lack of functional marine sanitation devices on vessels
- Lack of pump-out facilities at marinas
- Inaccessibility, crowding, or malfunction of pump-out facilities at marinas

4. MARITIME VESSEL MAINTENANCE AND SUPPORT

Maritime transport requires support facilities such as ports for loading and unloading cargo and people, repair and maintenance facilities, fueling stations, and marinas. The environmental impacts of those facilities and indicators of those impacts are discussed below.



RELEASES OF POLLUTANTS DURING TERMINAL OPERATIONS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Data on water quality, habitat, and health impacts associated with maritime vessel terminal operations are not available.

QUANTIFIED OUTPUT INDICATORS

- Marine vessel loading and unloading operations are believed to emit as many as 60 of the 189 hazardous air pollutants (HAPs) defined in the Clean Air Act Amendments, including benzene, toluene, ethyl benzene, and xylene. Approximately 350 facilities emitted 8,000 metric tons of HAPs in 1990 (U.S. EPA, 1994e).
- One investigation reported significant increases in tributyltin levels in marina waters. Another study reported significant uptake of lead, copper, and zinc by hard clams at moderately and poorly flushed marina sites (Hackney and Pierson, eds., 1994).
- Data on other wastes generated from marine vessel terminal operations have not been estimated at the national level (see table for list of wastes generated).

Marine Vessel Terminal Operations: Processes and Types of Waste Possibly Generated

Processes/Operations	Description of Wastes
Air emissions from storage tanks and open processing equipment emissions	VOC emissions
Grit blasting and chemical stripping	Wastewater containing blasting media, organic paint sludges, heavy metals, stripping chemicals, VOC emissions
Spray painting, resin application	Waste paints, thinners, degreasers, solvents, resins and gelcoat, VOC emissions
Engine Repair	Waste turbine oil, lubricants, degreasers, mild acids, batteries, carburetor cleaners, VOC emissions
Electroplating/metal finishing	Cyanide solutions, heavy metal sludges, corrosive acid, alkali solutions
Machine shops	Spent cutting and lube oils, scrap metal, degreasers, VOC emissions
Equipment cleaning, area washdown	Wastewater containing paints, solvents, oils, and degreasers
Degreasing, equipment cleaning, chemical paint stripping, reinforced plastic fabrication	Resin and paint contaminated solvents, VOC emissions
Vessel bilge cleaning	Bilge wastes (oily water)

Source: U.S. EPA, October 1991.

QUANTIFIED ACTIVITY INDICATORS

- There are approximately 700 establishments involved in marine repair in the U.S. (U.S. EPA, October 1991).[75]

OTHER QUANTIFIED DATA AND LOCAL EXAMPLES

- An estimated 0.02 percent of the total volume of fertilizer shipped to/from port facilities in Tampa Bay are lost as fugitive air emissions. These fugitive emissions deposit an estimated 291 tons per year of nitrogen and 424 tons per year of phosphorus into the bay (Tampa Bay National Estuary Program, 1994).

DESCRIPTION OF IMPACT

Terminal operations for maritime vessels involve boat yards and ship yards. Boat yards typically handle recreational or small commercial boats, offering services such as painting and engine repair. Ship yards service relatively larger vessels, and often contain extensive industrial machinery. Operations may include structural repairs, painting, engine or power plant maintenance, electroplating, air conditioning and refrigeration service, and electrical repair (U.S. EPA, October 1991). Other terminal operations include vessel unloading and cleaning, vessel storage, and refueling. Many of these processes use materials that are hazardous or may in turn generate hazardous waste, vapors, or wastewater (see the table above). The actual impact of terminal activities on the environment depends on the type and volume of operations, level of cleanliness required, type of waste generated, and efficiency of treatment systems in place. Wastes from such facilities, however, can often seep into waterways and damage marine environments.

[75] These 700 establishments consist of facilities that fall under SIC codes 3731 and 3732, including ship and boat building and repair yards.

Painting, which is a common operation in marine repair yards, involves three activities that generate wastes. The first is surface preparation, which is usually accomplished by abrasive blasting and/or chemical stripping. Surface preparation can cause air and water pollution, as well as generate waste material in need of disposal. Application of paints is the second activity. Most top side and interior paints are not significantly toxic, unlike some bottom paints. These bottom paints, referred to as antifouling paints (to describe their function in preventing barnacle or other marine life growths), typically contain toxic pigments such as chromium, titanium dioxide, lead, or tributyltin compounds. Topside and interior paints may emit VOCs if oil-based. The third waste-generating activity related to vessel painting is equipment cleaning. The equipment used for painting must be cleaned after use, sometimes with strong cleaning solvents. Wastewaters generated from this process may contain hazardous substances, and air pollution can result as solvents volatalize (U.S. EPA, October 1991).

Engine repair work on small boats produces the same types of wastes as auto engine repair, including lube oils, hydraulic fluids, waste fuels, hydrocarbon solvents, and batteries. Larger ship yards produce higher quantities of engine-related waste and may generate supplementary wastes, such as machine-shop cutting fluids and other degreasing and cleaning solvents (U.S. EPA, October 1991).

Vessel unloading can be a source of marine pollution. Emissions at marine terminal loading operations result from the displacement of vapors as liquids are loaded into cargo holds either directly through open hatches or from pipe header systems which collect the vapors and vent to the atmosphere. In May 1994, EPA proposed a marine vessel rule, which is expected to reduce emissions of air toxics by 95 percent (U.S. EPA, 1994e). Releases of hazardous materials or other pollutants can occur during loading and unloading or through dust emissions. For example, portions of fertilizer shipments are sometimes spilled in waterways or dust from movement of fertilizer shipments enters waterways.

Vessel cleaning is a significant generator of wastes. The most common waste is bilge waste, which is actually generated by the vessels themselves. Bilge waste contains wastewater mixed with oil and fuel (U.S. EPA, October 1991).

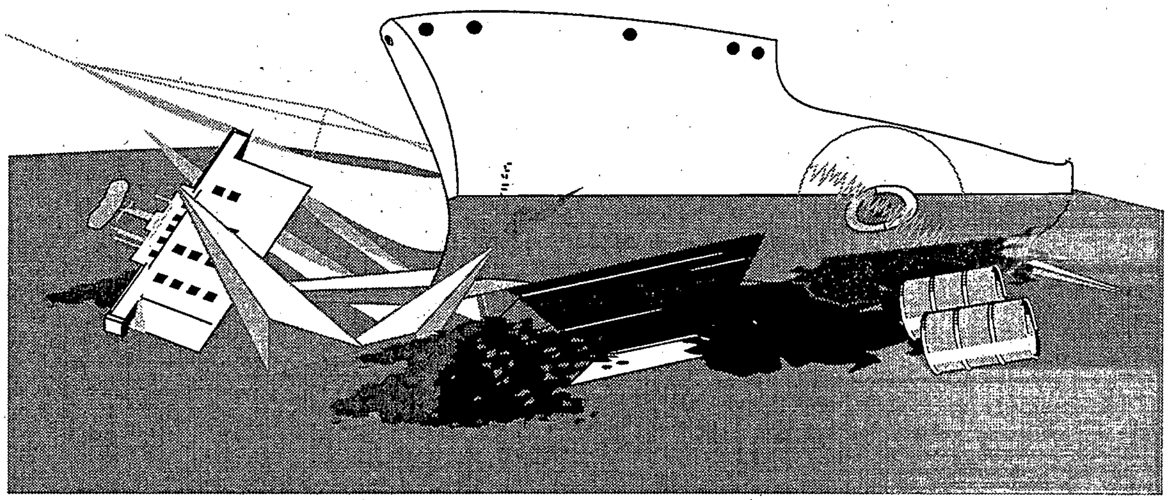
Refueling causes problems similar to those of auto refueling stations. One major difference, however, is that spills can enter waterways directly during marine refueling. Like auto refueling, VOCs can be emitted in vapors. Underground storage tanks used to hold vessel fuels can also leak their contents into waterways.

The nature of wastes and emissions generated by terminal operations makes them harmful to many forms of life, including humans. Humans can be exposed to toxicants directly (e.g., through swimming in polluted waters or breathing polluted air) or indirectly (e.g., through eating seafood that has ingested toxicants). Non-toxic pollution, such as excessive nutrient loading caused by fertilizer releases from loading docks, damages ecosystems. Such releases can cause algal blooms, which lead to lower water quality (often by reducing the quantity of dissolved oxygen).

CAUSAL FACTORS

- Number of terminals
- Type and level of terminal operations
- Materials used during terminal operations
- Fugitive material collection systems in place at port facilities
- Wastewater treatment capabilities

5. DISPOSAL OF MARITIME VESSELS AND PARTS



SCRAPPAGE OF OLD VESSELS AND DILAPIDATED PARTS

PRESENTATION OF INDICATORS

QUANTIFIED OUTCOME/RESULTS INDICATORS

- Estimates are not available on the health and environmental impacts of landfilling or other disposal of scrapped vehicles.

QUANTIFIED OUTPUT INDICATORS

- National data on emissions from the disposal of vehicles are not available.

QUANTIFIED ACTIVITY INDICATORS

- Data on the number of vessels scrapped/recycled annually in the U.S. have not been identified.
- The large increase in the inventory of vessels signifies that more vessels will eventually be scrapped or recycled than in the past.

DESCRIPTION OF IMPACT

The major impact of vessel scrappage is landfilling and other means of disposal of non-recycled parts, some of which contain toxic components (e.g., batteries). The contribution of boat scrappage to problems associated with landfilling and hazardous waste disposal is unknown.

CAUSAL FACTORS

- Number of vessels scrapped
- Size of vessels
- Use of hazardous materials in vessels
- Disposal method/fraction disposed of properly (recycling, recovery, etc.)
- Recovery rate of materials in scrapped vessels

VI. NEXT STEPS

This section describes the logical next steps in the effort to develop and utilize indicators of the environmental impacts of transportation. This study has taken some initial steps in presenting a framework for indicators and a comprehensive list of environmental impacts. It has also provided quantitative data on indicators for various impacts. There are still, however, considerable gaps in the data and analyses needed to fully implement environmental indicators in this area. Next steps are listed below.

COLLECT RAW DATA OR LOCAL DATA WHERE NEEDED

This report has made clear that some impacts cannot be tracked at the national level until additional data are collected. Sensitivity to existing reporting burdens at the state and local level is important, and some additional data collection could be conducted by researchers rather than by requiring data submissions. Some data are available in regional or state offices but have never been aggregated at the national level. Impacts where new data collection or aggregation would be particularly useful include the following:

- Wetlands impacts
- Habitat fragmentation and disruption from all modes
- Hazardous materials entering the environment from incidents
- Emissions from vehicle maintenance and repair
- Maritime terminal operation releases
- Emissions during construction and maintenance of infrastructure
- Leaking underground storage tank (LUST) releases attributable to transportation
- Scrappage of aircraft, marine vessels, and rail cars/locomotives

DEVELOP NEW ESTIMATES OF CERTAIN IMPACTS

National estimates of certain impacts have not been developed to date. In some cases, such estimates could be developed without the collection of additional raw data. Existing or new models could be applied to develop new national estimates of certain environmental impacts. In particular, new estimates of the following impacts are in need of development:

- Emissions from road construction and paving
- Impacts of and quantities of emissions from aircraft at high altitudes
- Deicing runoff impacts on water quality
- Quantities released from spills and leaks at airports
- Other runoff impacts on water quality
- Motor vehicle scrappage (tons disposed of, by material)
- Noise exposure (updated estimates)
- Roadkill (some data collection may be needed)

At least two types of estimates should be developed:

- Measures of emissions, loadings, or ambient levels, and
- Actual health or welfare risks

MODEL EMISSIONS/ LOADINGS/ AMBIENT LEVELS/ HABITAT CHANGES

For some activities or impacts, such as runoff, national estimates of typical transportation contributions to loadings or ambient levels are unavailable. Some additional analysis could apply existing models to develop national estimates, which could serve as improved indicators of these impacts.

CALCULATE HEALTH AND WELFARE RISKS OF AMBIENT LEVELS

In some cases, transportation emissions may be known but the results of those emissions have not been analyzed. Standard health risk assessment approaches may be used to estimate health impacts, using fate and transport or dispersion modeling, exposure modeling, and dose-response data. Welfare impacts may be calculated in dollar terms in some cases, based on existing estimates of dollar impacts per unit of damage or development of such estimates with standard approaches to valuation of environmental assets, such as hedonic pricing, for example.

DESCRIBE EFFECTIVENESS OF MITIGATION OPTIONS

Various mitigation options (noise barriers, runoff detention ponds, and wetlands mitigation efforts, for example) have been studied to some extent. It would be useful to track the increasing effectiveness of such efforts and the extent of their utilization in cases where more direct, accurate estimates of actual results are difficult to obtain. In many cases, estimates of environmental impacts implicitly assume a certain mitigation or control effectiveness anyway. Although mitigation efforts are not an ideal subject for results-oriented indicators, it can be quite useful to compile summaries of trends in the effectiveness and usage of mitigation options over time. For example, one might track how many airports are following certain management practices with regard to toxic substances, or what percentage of wetland mitigation efforts are successful.

CONSIDER IMPACTS NOT LISTED HERE

In addition to the impacts listed in this report, transportation has other impacts on the environment that are due to supporting land-use development patterns and industries. These effects are indirect, and often it is difficult to apportion the damage that stems from transportation versus other sources. Environmental damage may be caused by a variety of sources:

- Gas stations, including auto repair and maintenance
- Parking facilities (lots and garages)
- Related land-use development patterns
- Petroleum industry (transportation's share of these upstream impacts)
- Steel industry (transportation's share of these upstream impacts)
- Chemical industry (transportation's share of these upstream impacts)

A broad analysis of transportation as a whole would include the development of indicators of environmental harm caused by these related developments and industries.

SET UP ONGOING, CONSISTENT USE OF INDICATORS

This report identifies numerous potential indicators that have not been reported or tracked consistently to date. It recommends the development of an organized, broad initiative to report a consistent set of indicators. This effort should take into account the various state, federal, and private efforts to track the environmental impacts of transportation and use those data in the policy process. At a minimum, it would be useful to assess which indicators are being quantified annually and which are available only for selected years, for example, and to coordinate efforts among various organizations developing and reporting these indicators.

REGULARLY UPDATE OUTDATED, ONE-TIME ESTIMATES

Several of the indicators in this report have been quantified only once, or only sporadically – in surveys or one-time modeling exercises. These estimates should be updated regularly. Examples of such outdated or one-time estimates that require updating include the following:

- Noise exposure
- Air toxic emissions during travel
- Runoff (typical concentrations of pollutants in runoff)
- Use of airport deicing agents

CONDUCT POLICY ANALYSIS

Now that this study has compiled data on environmental impacts, and as improved indicators are developed, they should be used to improve national policy. This could entail several types of relatively modest studies, which could provide policy-relevant results.

COMPARE ACROSS MODES, ACROSS MEDIA, ACROSS IMPACTS

One type of policy study will involve comparisons. One obvious comparison is between modes. Past studies have already provided such comparisons, but not on the basis of the wide range of impacts considered here. Based on the indicators in this report, it is possible to make comparisons of total environmental impacts among modes of transportation. However, it is important to keep in mind that these indicators describe total national impacts of transportation, not impacts per vehicle-mile or passenger-mile traveled, per ton-mile of freight, or per vehicle produced. As a result, these indicators should not be used to make comparisons of how changes in mode of travel would affect the environment. Appendix A provides information on the total amount of infrastructure and travel associated with each mode.

The various environmental media can also be compared with determine whether water or habitat impacts deserve more attention than they have received relative to air quality. The many impacts could also be compared with provide a sense of whether certain important environmental effects have not been sufficiently addressed. Such comparisons can assist in setting legislative or budgetary priorities.

COMPARE TO OTHER ENVIRONMENTAL ISSUES

Several years ago, EPA's "Unfinished Business" report attracted a great deal of attention by comparing a wide range environmental issues and attempting to identify topics that still required significant regulatory and scientific work. With this new set of environmental statistics in hand, such a comparison would be somewhat more complete and feasible.

CONSIDER COSTS OF POLICIES

As discussed earlier in this report, indicators provide only part of the picture. They describe the potential benefits of environmental and transportation policies, but stop short of considering the costs of such policies. Indicators should be coupled with cost studies to provide a more complete picture of policy and technological options and their relative desirability.

PROVIDE STATE AND LOCAL TOOLS

Often, planners would like to be able to describe quickly the environmental implications of projected increases in VMT or of shifts in highway spending, such as an increase in construction of urban roads. One might, at first glance, view the indicators in this report as a means to develop such estimates. For example, one might assume that the average national impact per VMT or per lane-mile is also the local and marginal impact of added VMT. This is often not the case, however.

Ideally, further work would determine which impacts vary directly with VMT and which vary based on other parameters. This work would essentially consist of development of models to predict the magnitudes of various impacts, based on inputs such as VMT, temperature, or other causal factors such as those listed in the report. Some such models exist, such as the highway runoff predictive model, or noise models, but they do not exist for very many of these impacts. Also, the models typically require numerous site-specific inputs that are costly to collect. New models could be developed, perhaps for screening purposes.

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APPENDIX A. INFRASTRUCTURE AND TRAVEL MEASURES

Infrastructure and travel are useful, but not ideal, indicators of environmental damage from transportation. These measures may be classified as *activity indicators*, since the extent of infrastructure and travel activity is often a causal factor that influences the level of environmental damage. They provide important information when more direct output and outcome indicators are not available. However, it is important to note that environmental damage does not correspond directly with infrastructure or activities, and that many other factors complicate an analysis. For example, while vehicle-miles of travel (VMT) is a relevant statistic to examine when discussing vehicle emissions, other factors—such as emissions control technologies on vehicles and the amount of congestion on roadways—influence the amount of pollution emitted per mile traveled.

The statistics presented below may be used as activity indicators to supplement the indicators presented in the body of this report. Typically, statistics will be most relevant in combination with the following basic categories of activities as outlined in the report:

Category described in report	Appendix section most relevant	Example of type of data
Infrastructure construction, maintenance, and abandonment	Infrastructure	System mileage
Vehicle and parts manufacture	Infrastructure	Vehicle fleet characteristics
Vehicle travel	Travel	Miles of travel
Vehicle maintenance and support	Travel	Fuel consumption
Disposal of used vehicles and parts	Infrastructure	Vehicle fleet characteristics

Data in this appendix are divided by mode into highway, railroad, aviation, and maritime transportation.

MODE: HIGHWAY

INFRASTRUCTURE

While parking lots, garages, and other facilities, such as gas stations, repair garages, auto sales dealerships, parts shops, and manufacturing plants could all be discussed, the focus of this discussion is roads. Highways and roads alone constitute a significant portion of the built environment.

ROAD MILEAGE

Road mileage is at least a crude indicator of some environmental impacts, such as habitat disruption and runoff. It provides a sense of the possible magnitude of these effects, but is not a good indicator of VMT-related effects (e.g., air pollution or HAZMAT incidents) since vehicle travel per mile varies by type of road, location, and over time.

- Total national road mileage in 1993 was 3,904,721 miles. This equals about 80 road-feet per person.

All public roads and streets in the U.S. are classified by type and use into three major functional systems: arterials, collectors, and local roads. These major systems are further subdivided into rural and urban areas.[1]

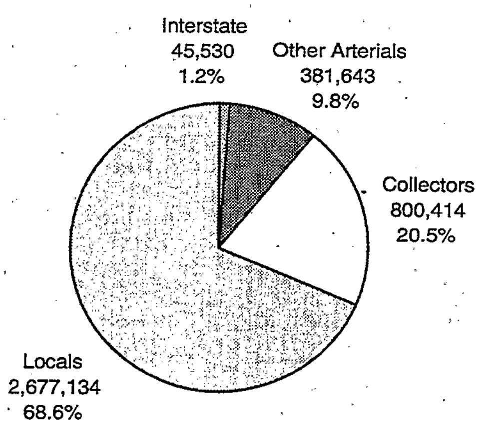
Road Mileage by Functional System Type, 1993

System	Rural Mileage	Percentage	Urban Mileage	Percentage	Total Mileage	Percentage
Interstate	32,652	0.84	12,878	0.33	45,530	1.17
Other Arterials	234,129	6.00	147,514	3.78	381,643	9.78
Collectors	715,036	18.31	85,378	2.19	800,414	20.50
Locals	2,119,826	54.29	557,308	14.27	2,677,134	68.56
Total	3,101,643	79.43	803,078	20.57	3,904,721	100.00

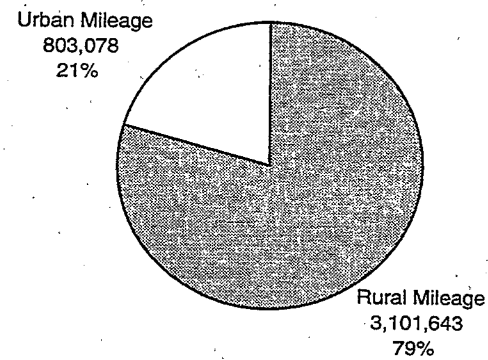
Source: U.S. DOT, FHWA, 1994c.

[1] Function types are defined as follows: *Arterial* (including the Interstate and other freeways) - The highest classification of roads and streets, these provide the highest level of mobility, at the highest speed, for long uninterrupted distances. *Collector* – These provide a lower level of mobility than arterials at lower speeds and for a shorter distance. Collectors connect local roads with arterials and provide some access to abutting land. *Local* - The lowest classification of roads, these provide a high level of access to abutting land, but limited mobility.

Mileage by Function System



Mileage by Urban/Rural Location

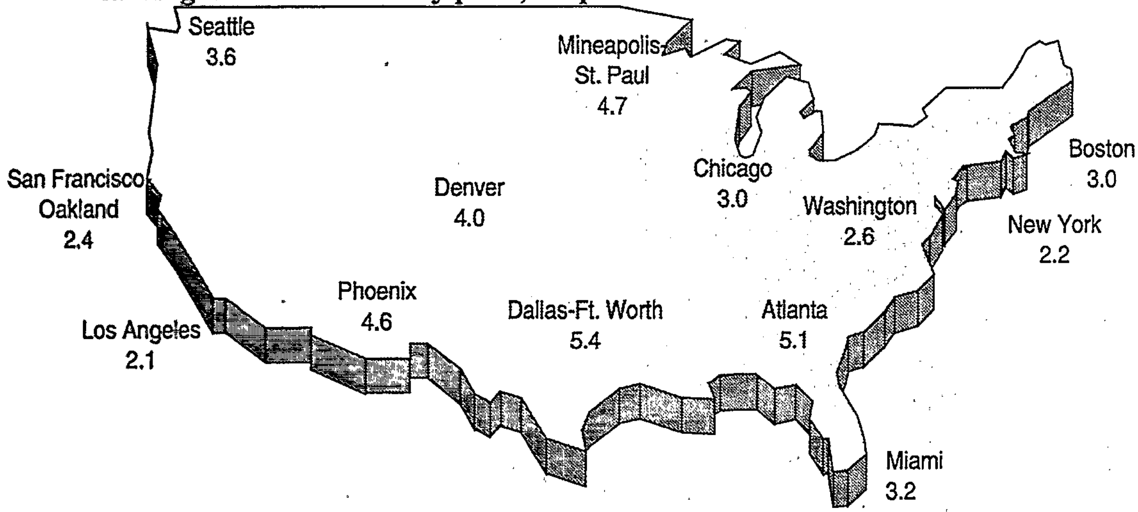


For all 391 urbanized areas in the United States (defined as an area with 50,000 or more persons that at a minimum, encompasses the land area delineated by the Bureau of the Census):

- Total roadway mileage is 639,045 miles (out of 803,078 miles on all urban roads).
- Average miles of roadway per 1,000 persons is 3.8.
- Total freeway mileage is 18,759 miles.
- Average percentage of total mileage serving as freeways is 2.9 percent (compared with U.S. average of interstates as 1.2 percent of total mileage).
- Total estimated freeway lane mileage is 96,657 miles.

However, the amount of roadway mileage per person varies significantly among urbanized areas. Dallas and Atlanta each have over twice as many roadway miles per person as New York or Los Angeles.

Average Miles of Roadway per 1,000 persons in Selected Urbanized Areas



Source: U.S. DOT, FHWA, 1994c.

LANE MILES

Lane miles provide a better indicator of environmental impact than road miles since the average number of lanes varies by type of road. Interstate and other arterial roads tend to have more lanes than local roads.

- In 1993, there were 8.1 million lane-miles of highways in the nation (U.S. DOT, 1995a). This equals 166 lane-feet per person.

Lane-Miles by Functional System Type, 1993

	Lane-Miles	Percent
Rural		
Interstate	129,600	1.6
Other Arterial	518,400	6.4
Collector	1,425,600	17.6
Local	4,228,200	52.2
Subtotal Rural	6,309,900	77.9
Urban		
Interstate	72,900	0.9
Other Arterial	437,400	5.4
Collector	178,200	2.2
Local	1,109,700	13.7
Subtotal Urban	1,790,100	22.1
Total Highway	8,100,000	100

Source: U.S. DOT, 1995a.

AMOUNT OF PAVEMENT

The amount of pavement is a crude indicator related to runoff and particulate matter, especially road dust. In addition, pavement affects travel speeds and, as a result, has some effect on emissions. Habitat disruption and runoff may be smaller problems on unpaved roads since less impervious surfaces, culverts, and drainage systems are involved. However, unpaved roads may have significant erosion or other drainage and runoff impacts. In addition, unpaved roads have a much higher rate of emissions of fugitive dust per VMT than paved roads.

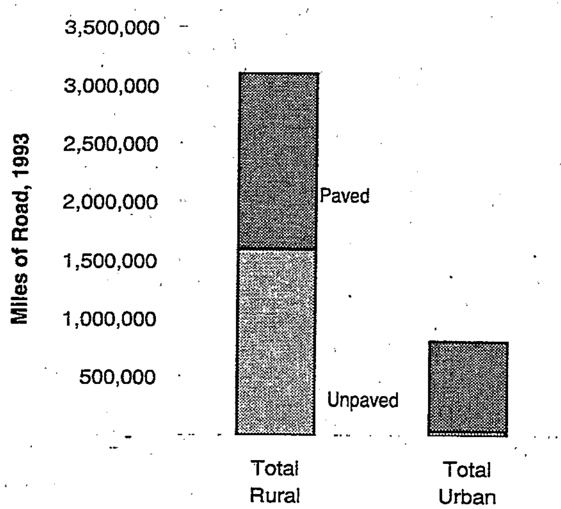
- In 1993, about 58.2 percent of all roads in the U.S. were paved.

This is an increase from 51.9 percent in 1983, 46.3 percent in 1973, 37.8 percent in 1963, and only 27.3 percent in 1953 (U.S. DOT, FHWA, 1995e). Essentially all of the unpaved mileage is on lightly traveled rural roads

- In 1993, over 95 percent of roads in urban areas were paved. However, over half of all rural road mileage was unpaved.

Road Type	Unpaved	Paved	TOTAL
Total Rural	1,594,579	1,507,064	3,101,643
Percent, Rural	51.4	48.6	100.0
Total Urban	38,917	764,161	803,078
Percent, Urban	4.8	95.2	100.0
TOTAL U.S.	1,633,496	2,271,225	3,904,721
Percent, Total	41.8	58.2	100.0

Source: U.S. DOT, FHWA, 1994c.



BRIDGES

- In 1994, there were more than 576,000 bridges on U.S. roads, of which 455,319 were on rural roads and roughly 230,000 were on local roads (U.S. DOT. FHWA/FTA/MARAD. 1995a).

HIGHWAY VEHICLES

The number of vehicles provides some insight into the environmental effects of vehicle manufacture and disposal and partially explains the rise in VMT by type of vehicle.

- There are 194.06 million registered motor vehicles in the U.S.
- There are 146,314,296 automobiles, 654,432 buses, and 47,094,754 trucks registered in the U.S. (U.S. DOT, FHWA, 1994c). Almost three fourths of all registered vehicles are automobiles.

Vehicles Registered, 1993

Type of Vehicle	Number of Registered Motor Vehicles, 1993
Passenger cars	146,314,296
Motorcycles	3,977,856
Buses	654,432
2-axle 4-tire trucks (light duty)	40,902,865
Other single-unit trucks	4,465,692
Combination trucks	1,726,197
All motor vehicles	198,041,338

Source: U.S. DOT, FHWA, 1994c.

- In 1993, new sales of domestically produced vehicles totaled approximately 6.73 million automobiles and 5.29 million trucks (U.S. DOE, 1994a).

New Sales of Vehicles in the U.S., 1993

Type of Vehicle	Domestic (thousands)	Import (thousands)	Total (thousands)
Automobiles	6,734	1,783	8,518
Motorcycles	243	245	488
Recreational vehicles	429	0	429
Trucks	5,287	394	5,681

Source: U.S. DOE,1994a.

TRAVEL

VEHICLE MILES TRAVELED (VMT)

VMT is a common measure of travel, chosen for inclusion here because it is a rough but easy to measure and readily understood indicator of several environmental impacts. All else being equal, an increase in VMT suggests a rise in certain impacts, such as air pollution and perhaps noise. Factors such as technology, congestion, and population density also affect emissions per mile or total impacts for a given level of VMT. These other factors vary over time and between locations, making VMT a somewhat limited indicator. In addition, some impacts do not vary with VMT in a simple linear manner. For example, a 10 percent increase in VMT may not cause a 10 percent increase in hazardous materials incidents. Similarly, a 10 percent reduction in VMT might cause a negligible reduction in ozone for some cities.

VMT BY ROAD TYPE

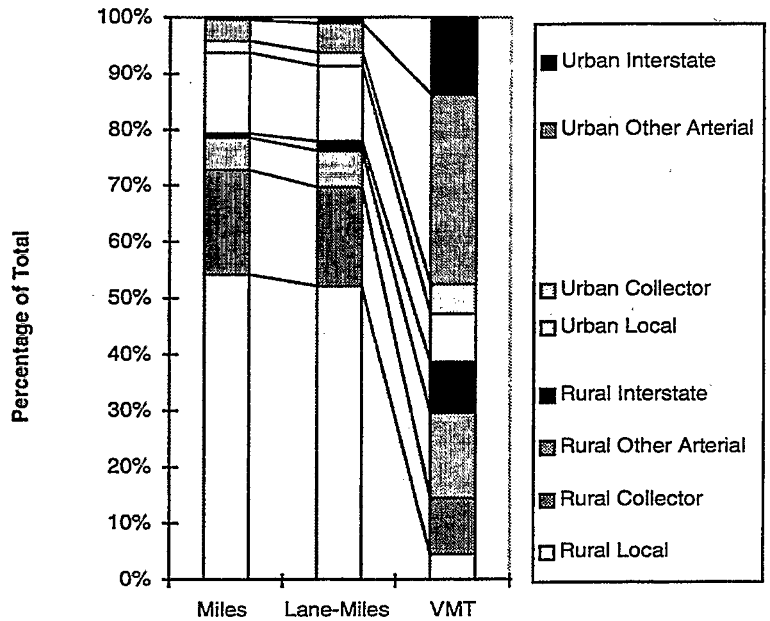
The level of travel by functional system does not correspond proportionately to the number of miles or lane-miles of roadway. Interstate highways contain a disproportionately high share of total vehicle travel. For example, although rural interstates make up only 1.6 percent of lane-miles, and 0.8 percent of road miles, they carry 9.1 percent of all vehicle miles. Urban interstates make up only 0.9 percent of lane-miles and 0.3 percent of road miles but carry 13.8 percent of all vehicle miles, thus carrying 15 times as many vehicles per lane mile as the national average. Although urban roads only constitute 22.1 percent of lane-miles and 20.6 percent of road miles, they carry 61.4 percent of all vehicle traffic, as the following table shows:

Percent Highway Miles, Lane-Miles, and Vehicle-Miles Traveled, 1993

	Miles	Lane-Miles	VMT
Rural			
Interstate	0.8	1.6	9.1
Other Arterial	6.0	6.4	15.2
Collector	18.3	17.6	9.9
Local	54.3	52.2	4.5
Subtotal	79.4	77.9	38.6
Urban			
Interstate	0.3	0.9	13.8
Other Arterial	3.8	5.4	33.7
Collector	2.2	2.2	5.3
Local	14.3	13.7	8.6
Subtotal	20.6	22.1	61.4
Total Highway	100.0	100.0	100.0

Source: U.S. DOT, FHWA, 1994c.

The following diagram visually depicts the relative size of VMT on various road types in comparison with lane-miles and road-miles:



INCREASE IN VMT

The amount of road travel in the nation has increased by roughly one third over the past 10 years, with the most rapid growth in urban areas and on interstate highways. The amount of vehicle travel increased by nearly 50 percent on urban interstates from 1983 to 1993.

Highway Vehicle Miles of Travel (millions of miles)

Highways Type:	Increase in annual VMT, 1983-93 (millions of miles)	Percentage Increase annual VMT, 1983-93	Average annual Percentage increase, 1983-93
Rural			
Interstate	60,278	41.6	3.5
Other Arterial	61,466	22.5	2.1
Collector	45,015	22.4	2.0
Local	16,329	20.0	1.8
Subtotal Rural	183,088	26.1	2.3
Urban			
Interstate	94,176	49.3	4.1
Other Arterial	177,047	33.4	2.9
Collector	20,679	23.9	2.2
Local	48,118	34.3	3.0
Subtotal Urban	340,020	35.8	3.1
All Roads	**523,108**	**31.7**	**2.8**

Source: U.S. DOT, FHWA, 1994c.

As the following table shows, the rate of VMT growth has slowed somewhat in recent years.

VMT Growth Rates, 1980-95

Time Period	Annualized Rate of Light-Duty VMT Growth
1980-85	3.1%
1985-90	3.9%
1990-95 (estimate)	2.4%

Apogee estimate, computed from U.S. DOT, FHWA, 1994c., and annual editions, 1980-1992

Measures of congestion are another relevant group of statistics for understanding environmental impacts. Congestion can increase emissions of certain air pollutants per vehicle mile traveled, and is also a key factor driving construction of additional highway capacity, which further affects the environment.

Highway travel has increased at a faster rate than the capacity of the highway system.

- Travel per lane-mile increased by over 28 percent on urban interstate highways, and by nearly 27 percent on other urban principlal arterials over the 10 years from 1983 to 1993.
- On a per-lane-mile basis, the higher functional systems carried the most travel per lane-mile, with urban interstate highways carrying the most travel per lane-mile in 1993, with 12,520 annual average daily traffic per lane-mile.

Daily Vehicle Miles of Travel (DVMT) per Lane-Mile

Highways Type:	1983	1993	Percentage Increase
Rural			
Interstate	3,000	4,310	44
Other Principal Arterial	1,900	2,310	22
Minor Arterial	1,180	1,410	19
Major Collector	500	560	12
Minor Collector	210	240	14
Local	50	70	40
Urban			
Interstate	9,810	12,520	28
Other Freeway and Expressway	7,720	9,770	27
Other Principal Arterial	4,640	5,540	19
Minor Arterial	3,000	3,490	16
Collector	1,550	1,830	18
Local	420	490	17
All Roads	560	770	38

Source: U.S. DOT, 1995a.

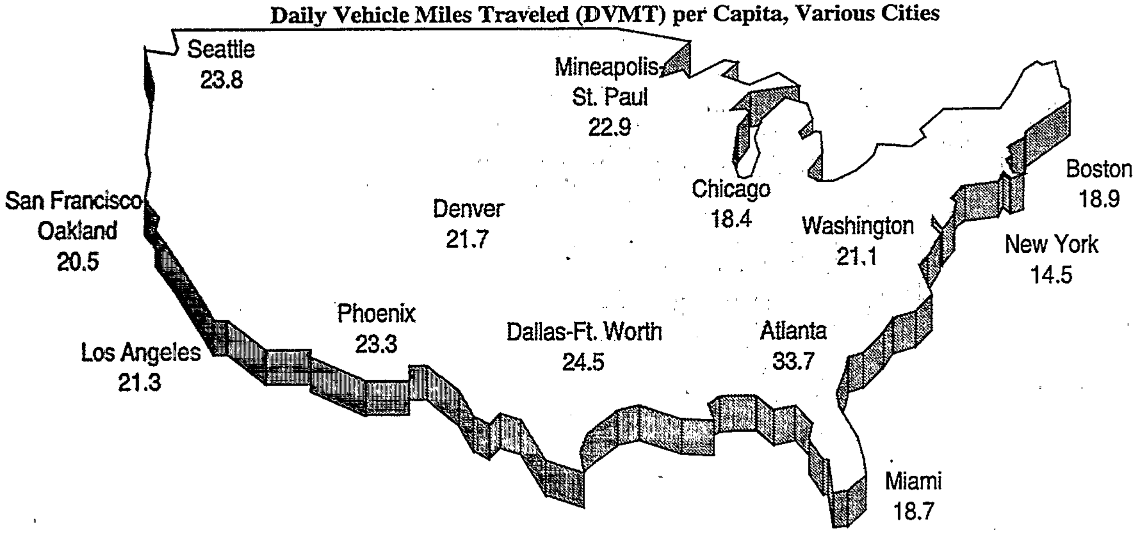
VMT PER CAPITA

VMT per capita is a useful statistic because it varies by location, suggesting that certain characteristics of areas, such as population density, or public policies, such as provision of transit services, might reduce VMT, and thus reduce environmental impacts.

- For all 391 urbanized areas in the United States, the average daily vehicle miles traveled (DVMT) per capita was 20.7 in 1993 (U.S. DOT, FHWA, 1994c).

However, travel per capita varies significantly between metro areas. New York has only 14.5 miles traveled daily per person on roads, whereas Atlanta has an average 33.7 miles traveled daily per person on roads. The average resident of the Atlanta metro area travels over twice as many miles daily in a vehicle as the typical New Yorker.

Daily Vehicle Miles Traveled (DVMT) per Capita, Various Cities



Source: U.S. DOT, FHWA, 1994c.

VMT BY VEHICLE TYPE:

Examining VMT by vehicle type provides some information that helps explain the underlying air pollutant emissions. Passenger cars dominate travel; trucks tend to be less fuel efficient and emit more emissions per mile. Buses constitute a very limited percentage of total vehicle travel, although they carry more passengers per mile than autos.

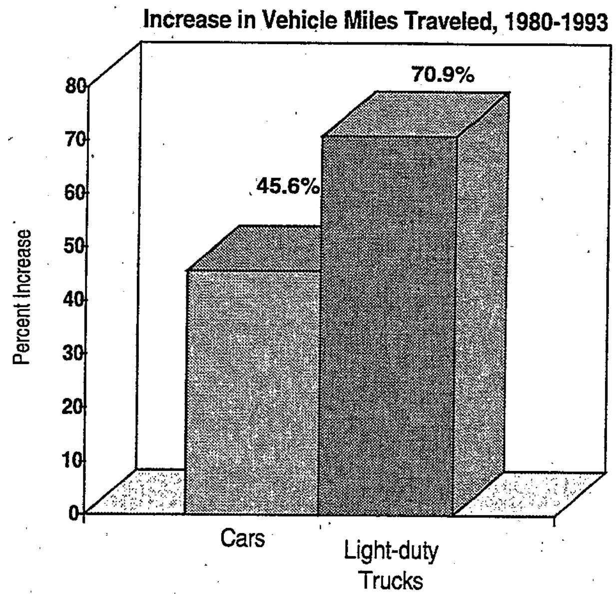
Miles of Travel by Vehicle Type, 1993

Type of Vehicle	Miles Traveled (millions of vehicle miles)	Percentage of Total Miles Traveled
Passenger cars	1,623,972	70.7
Motorcycles	9,889	0.4
Buses	6,121	0.3
2-axle 4-tire trucks (light duty)	497,201	21.6
Other single-unit trucks	56,693	2.5
Combination trucks	102,709	4.5
All motor vehicles	2,296,585	100.0

Source: U.S. DOT, FHWA, 1994c.

Travel by light-duty trucks has been increasing significantly faster than travel by automobiles since 1980.

- From 1980 to 1993, auto travel increased by 45.6 percent while light-duty truck travel increased by 70.9 percent.



Source: U.S. DOT, FHWA, 1995d and annual editions

PERSON MILES TRAVELED (PMT) BY VEHICLE TYPE

Person miles traveled provides a sense of some of the benefits gained from travel, in terms of the number of people served. Buses provide more service per VMT than cars, with about 21 people per vehicle, in comparison with 1.7 people per average car.

Person Miles of Travel by Vehicle Type, 1993

Type of Vehicle	Person Miles Traveled (millions of miles)	Average Vehicle Occupancy
Passenger cars	2,825,711	1.74
Motorcycles	10,878	1.10
Buses	129,765	21.20
2-axle 4-tire trucks (light duty)	750,774	1.51
Other single-unit trucks	56,693	1.46
Combination trucks	102,709	1.00
All motor vehicles	3,876,530	1.69

Source: U.S. DOT, FHWA, 1994c.

FUEL CONSUMED

Fuel consumption is a crude but easy to measure indicator of environmental damage. It is relevant to air emissions, potential spills during storage and transport, and environmental impacts during extraction and refining. Fossil fuels also constitute a non-renewable resource.

- In 1993, motor vehicles consumed 137.194 billion gallons of fuel, up from 132.888 billion gallons in 1992 (U.S. DOT, FHWA, 1994c).

Fuel Consumption by Vehicle Type

Type of Vehicle	Fuel Consumed, 1993 (thousands of gallons)	Fuel Efficiency (Average miles per gallon), 1993
Passenger cars	75,058,655	21.64
Motorcycles	197,780	50.00
Buses	946,878	6.46
2-axle 4-tire trucks (light duty)	34,806,524	14.28
Other single-unit trucks	7,667,354	7.39
Combination trucks	18,517,044	5.55
All motor vehicles	137,194,235	16.74

Source: U.S. DOT, FHWA, 1994c.

MODE: RAIL

INFRASTRUCTURE

MILEAGE

Miles of railway track provide a crude indicator of the extent of habitat destruction from rail facilities.

- There were a total of 177,000 miles of railway track in 1993.[2]

Type of Railroad	Miles of Track Owned and Operated[3]
Freight	
Class I Railroads	123,723
Regional Operators	21,581
Local Operators	23,645
Passenger	
Amtrak[4]	775
Heavy Rail	1,744
Light Rail	687
Commuter Rail	4,830
Total	177,000

Source: AAR, 1993; Amtrak, 1994; U.S. DOT, 1994

CONSTRUCTION

- Miles of new track constructed, 1993: 82 miles (ICC, 1993)
- Tons of track laid by Class I railroads, 1993: 441,381 tons (AAR, 1993)[5]
- Cross ties laid by Class I railroads, 1993: 13,223,000 (AAR, 1993)

FACILITIES

- Rail-truck intermodal terminals (number active), 1994: 360 (300) (FRA, 1995)
- Stations served by Amtrak, 1994: 540 (Amtrak, 1994)
- Heavy rail transit stations, 1990: 911 (U.S. DOT, 1994)
- Commuter rail stations, 1990: 958 (U.S. DOT, 1994)
- Rail service facilities, 1990: 905

[2] Freight: AAR, 1993; Amtrak: Amtrak, 1994; Transit: U.S. DOT, 1994
[3] Transit rail (heavy, light, commuter) figures from 1990
[4] The Amtrak system encompasses 25,000 miles of track, but only 775 miles are owned by Amtrak. Most of the track in the Amtrak system is owned and operated by freight rail companies.
[5] Although Class I railroad systems comprise only 2 percent of the number of railroads in the U.S., they account for 73 percent of the mileage operated, 89 percent of the employees, and 91 percent of the freight revenue.
[6] Transit rail: U.S. DOT, 1994; Freight Tank Cleaning: EPA/Office of Water as cited in EPA, 1995.

Rail Service Facilities, 1990

Type of Service	Number of Facilities
Rail Tank Car Cleaning	809
Heavy Rail Maintenance	43
Light Rail Maintenance	18
Commuter Rail Maintenance	35
Total	905

Source: EPA, 1995; U.S. DOT, 1994

TRANSIT RAIL SYSTEMS

The number and size of rail systems provides an indicator of the extent of environmental damage, and the concentration of damage in various geographic areas.

Transit rail systems are concentrated in a small number of large metropolitan areas.

- Total number of transit agencies operating passenger rail systems: 50

Type of Rail Service	Number of transit authorities operating service
Heavy Rail	14
Light Rail	20
Commuter Rail	16
Total	50

Source: APTA, 1994.

Among U.S. transit systems, the New York City metropolitan area dominates in terms of facilities, with the world's largest subway fleet of 5,951 cars and 469 stations.

The New York City Transit Authority's subway system consists of the following (Metropolitan Transportation Authority, 1994):

- The world's largest subway fleet of 5,951 passenger cars, or 58 percent of all rapid transit vehicles nationwide.
- 469 stations, or 51 percent of all subway stations nationwide.
- 842 miles of track, including 186 miles in transit yards, shops, and storage areas.
- 10,900 signals and 2,700 miles of cable.

VEHICLES IN OPERATION

The number of vehicles in operation provides some insight into the environmental effects of vehicle maintenance and disposal.

- Freight cars in the active fleet, 1993: 1,173,132 (AAR, 1993)[7]
- Locomotives (all diesel) in the active freight fleet, Class I, 1993: 18,161 (AAR, 1994)
- Locomotives in Amtrak fleet, 1994: 352 (287 diesel, 65 electric) (Amtrak, 1994)
- Passenger cars in Amtrak fleet, 1994: 1,852 (Amtrak, 1994)
- Heavy-rail vehicles in the transit fleet, 1993: 10,261(APTA, 1994)
- Light-rail vehicles in the transit fleet, 1993: 1,025 (APTA, 1994)
- Commuter rail cars in the transit fleet, 1993: 4,494 (APTA, 1994)

VEHICLE PURCHASES

The number of vehicles purchases each year provides some insight into the environmental effects of vehicle manufacture, maintenance, and disposal.

- New freight cars installed, 1993: 35,239 (plus 8,093 rebuilt cars) (AAR, 1994)[8]
- New locomotives installed, 1993: 504 (plus 217 rebuilt units) (AAR, 1994)[9]
- New passenger rail cars purchased by Amtrak and commuter railroads, 1992: 110 (Eno, 1994)
- New urban transit rail cars purchased by transit authorities, 1992: 198 (Eno, 1994)
- Including rebuilt cars, 91 passenger cars were delivered to Amtrak, and 353 passenger cars (rapid transit, commuter, and light-rail) were delivered to metropolitan transit authorities in the U.S. in 1994.[10]

TRAVEL

The level of travel provides an indication of certain impacts, such as emissions from diesel locomotives and energy consumption by electric vehicles.

Freight traffic dominates the total number of car miles traveled by rail, with intraregion transit a minor second, and intercity travel third.

- Total railcar miles traveled, 1992: 28.98 billion miles[11]

Type of Travel	Railcar miles traveled	Percentage of total
Freight	27,900,000,000 miles	96.3
Transit	777,000,000 miles	2.7
Amtrak	302,000,000 miles	1.0

Freight: AAR, 1993 plus 3.8% (Eno, 1994) to reflect other Class II and III traffic; Amtrak: AAR, 1993; Transit: APTA, 1994

[7] Includes all railroads and private car companies
[8] Includes those installed by Class I railroads, other railroads, and private car owners.
[9] Includes those installed by Class I railroads, other railroads, and private car owners.
[10] *Railway Age*. January 1995.
[11] Freight: AAR, 1993 plus 3.8 percent (Eno, 1994) to reflect other Class II and III traffic; Amtrak: AAR, 1993; Transit: APTA, 1994

FREIGHT TRAVEL

- Freight ton-miles transported by rail in 1992 was 1,107 billion miles; 37.4 percent of total freight ton-miles were transported by rail (Eno, 1994).
- The average freight rail trip length was 673 miles (Eno, 1994).
- In 1992, 1,646 million tons of freight were transported by rail; 25.0 percent if total freight tonnage was transported by rail (Eno, 1994).
- Average number of cars per freight train, Class I, 1993, was 66.4 cars (AAR, 1993).
- Average tons per carload, Class I, 1993, was 64.4 tons (AAR, 1993).
- Average length of haul, Class I, 1993, was 794 miles (AAR, 1993).
- Number of Class I revenue car loadings in 1993 was 21,682,894 (AAR, 1993).

PASSENGER TRAVEL

- Rail passenger miles traveled, 1993 : 25.3 billion miles (AAR, 1993).

- Over 40 percent of all passenger miles traveled on rail systems in the United States was on heavy rail (subway or elevated) systems.

Passenger Rail Travel, 1993

Type of Rail Service	Passenger Miles Traveled (millions)	Percentage of Total	Average Trip Length (miles)
Amtrak	6,319	25.0	271.1
Commuter Rail	7.489	29.7	21.5
Heavy Rail	10,740	42.5	3.8
Light Rail	705	2.8	1.6
Total	25,253	100.0	-

Source: Eno, 1994; APTA, 1994

Because large transit systems are located in the largest metropolitan areas, the vast majority of all customers are in the largest U.S. cities, and especially the Northeast. The New York City metropolitan area dominates nationally, with approximately 3.5 million subway customers on an average weekday, and about one billion subway passengers per year (New York City MTA, 1994b). Overall, about 4 out of every 10 mass transit trips in the United States occur in New York City (New York MTA, 1994a).

ENERGY CONSUMPTION

Energy consumption provides an indication of total emissions and resources consumed by rail transport.

- Energy consumption, 1992: 505.7 trillion Btus. The majority of energy consumption is in frieght operations. Overall, rail transport consumed 2.2 percent of total transportation sector energy consumption (DOE, 1994a).

Freight	425.4 Btus
Passenger	61.7 Btus
diesel fuel	441.2 Btus
electric power	59.2 Btus

All electric-powered rail is used in passenger operations, not freight.

MODE: AVIATION

INFRASTRUCTURE

The number of aircraft and airports is a crude estimate of the some environmental impacts, such as noise, emissions, habitat disruption and runoff. The increase in the number of aircraft may provide a basic indicator of emissions and the extent of noise. It is important to remember, however, the newer aircraft are more efficient in terms of fuel consumption and emissions and that increases in the number of aircraft are not likely to be associated with a similar increase in emissions. The same is true for noise—newer aircraft are required to meet the quieter Stage 3 noise standards.

AIRPORTS

The number of airports is a basic indicator of habitat disruption and runoff. Although only one major new airport has been constructed in the last 20 years, there has been construction of a number of smaller public and private airports. This increase in airports in general, may have implications on habitat and runoff.

- There were 18,343 airports in the U.S. in 1994, which is more airports than in every other nation in the world combined (U.S. DOT, BTS, 1994).
- The number of airports in the U.S. has increased by 3,182 from 1980 to 1992—a nearly 21 percent increase—from 15,161 in 1980 to 18,343 in 1994 (U.S. DOT, BTS, 1994).

Year	Number of Airports
1980	15,161
1990	17,490
1992	17,846
1993	18,317
1994	18,343

Source: U.S. DOT, BTS, 1994

- Airports vary significantly in size. The U.S. contains 26 large hub airports (handling 1 percent or more of total air passenger enplanements) and 570 commercial service airports (2,500 or more enplanements annually) (U.S. DOT, BTS, 1994). Most airports are small private-use airports, many of which have unpaved runways, as the following table shows:

U.S. Airports, 1992

	Number	Percentage with Paved Runways	Percentage with Lighted Runways
Public-Use Airports	5,545	71.7	72.3
Private-Use Airports	12,301	36.6	7.6
Total All Airports	17,846	47.5	27.7

Source: U.S. DOT, BTS, 1994

AIR CARRIER FLEET

- World air carriers placed orders for an estimated 490 large jet aircraft with U.S. and foreign aircraft manufacturers during FY 1995, 54.0 percent more orders than in 1994. Of this total, 338 (69.0 percent) were for two-engine narrowbody (B-737, B-757, MD-80, MD-90, A-320/321 and F-100) aircraft (Boeing, 1995).

- Aircraft manufacturers delivered approximately 449 large jet aircraft worldwide in 1995. Of this total, 287 (63.9 percent) were two-engine narrowbody aircraft, and 90 (20.0 percent) were for two-engine widebody aircraft (Boeing, 1995).

- At the year ending December 1995, the fleet for U.S. air carriers increased by an estimated 138 aircraft, an increase of 3.0 percent. This compares with 1994, when the fleet increased by 156 aircraft (U.S. DOT, BTS, 1995).

- Total fleet of air carriers has increased, while the fleet of general aviation aircraft has decreased, since 1980 (U.S. DOT, BTS, 1994).

Year	**Number of Aircraft**	
	Air Carrier	**General Aviation**
1980	2,818	202,487
1990	4,727	196,800
1992	4,884	183,620
1993	5,234	176,006
1994	5,221	170,600

Source: U.S. DOT, BTS, 1994

TRAVEL

Demand for aviation has grown rapidly over the last 30 years and is expected to continue to do so for the next decade. For example, passenger enplanements, a key measure of demand for air services, has grown by an average of 1.27 percent annually over the last 10 years. Underlying this basic statistic, however, are a series of important trends that can have a direct influence on the implications for environmental impacts. For example, perhaps the single most important determinant of the level of environmental impact of aviation activity is *aircraft operations* (takeoffs and landings), which indicate the overall number of aircraft flights.

Operations are a function of several factors that change over time:

- Passenger and cargo demand (domestic and international)
- Aircraft load factors (the percentage of seats or cargo space filled)
- The amount of "hubbing" (connecting)
- Aircraft size

Combined aircraft operations have grown little over the last 5 years despite rapidly increasing travel demand. This slow growth has been due in large part to dramatic increases in aircraft load factors.

However, as load factors approach a technical maximum, the number of commercial operations will need to grow to meet demand. As a result, the environmental impacts per passenger may increase. Still, environmental consequences are a function of a number of factors, including operations and aircraft engine efficiency.

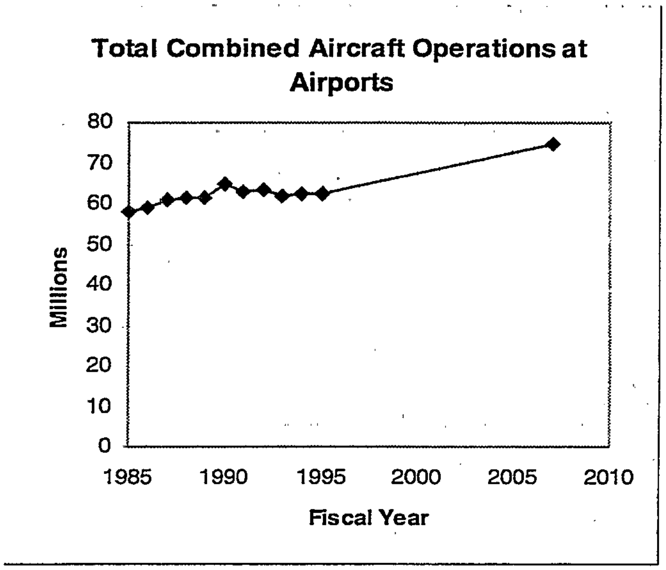
Activities associated with airport operations are discussed below.

TOTAL COMBINED AIRCRAFT OPERATIONS AT AIRPORTS

Total combined aircraft operations (takeoffs and landings) at airports, including air carrier, air taxi/commuter, general aviation and military categories totaled 62.5 million in 1995, representing a 0.3 percent increase from 1994 (U.S. DOT, FAA, 1996).

Fiscal Year	Total Combined Aircraft Operations at Airports (In Millions)
1985	57.9
1986	59.0
1987	61.0
1988	61.3
1989	61.4
1990	64.9
1991	62.8
1992	63.2
1993	61.9
1994	62.3
1995	62.5
2007*	74.5

*projection
Source: U.S. DOT, FAA, 1996.



REVENUE PASSENGER MILES

- U.S. scheduled air carriers recorded a total of 558 billion revenue passenger miles in 1995, up 3.6 percent from the previous year (U.S. DOT, BTS, 1997).

- International growth is anticipated to be somewhat higher than domestic growth, with the average annual growth in RPMs during the 1995-2007 forecast period being 5.3 percent, compared with 3.8 percent for the domestic market (U.S. DOT, FAA, 1996).

- In the year 2007, the international share of the U.S. carriers' system RPMs is expected to be 30.2 percent, up from 26.9 percent in 1995 and 21.1 percent in 1980 (U.S. DOT, FAA, 1996).

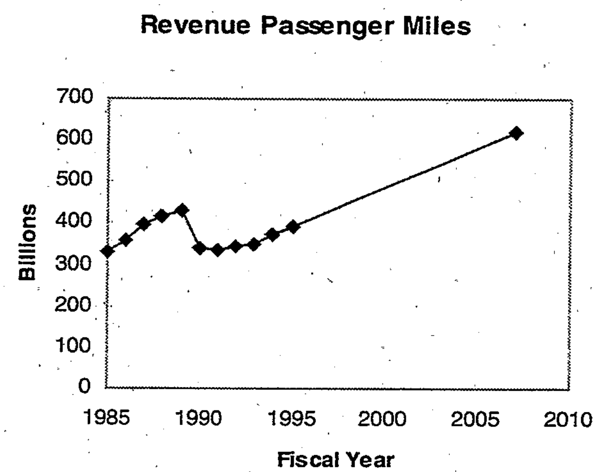
[12] Energy use includes fuel purchased abroad for international flights.

DOMESTIC REVENUE PASSENGER MILES

- Scheduled domestic revenue passenger miles (RPMs) totaled 392.4 billion in 1995, up 5.7 percent from 1994 (U.S. DOT, FAA, 1996). This outcome was largely the result of the relatively strong growth in the economy and the continued decline in real yields.

Fiscal Year	Revenue Passenger Miles (billions)
1985	330.6
1986	358.5
1987	398.1
1988	416.0
1989	429.0
1990	339.2
1991	333.6
1992	346.7
1993	348.6
1994	371.3
1995	392.4
2007*	617.3

*projection
Source: U.S. DOT, FAA, 1996.



INTERNATIONAL REVENUE PASSENGER MILES

- International RPMs grew 4.1 percent in 1995. The growth was uneven, however, with increases of 10.4 percent in Latin American markets, 6.0 percent in Pacific markets, and only 0.3 percent in Atlantic markets (U.S. DOT, FAA, 1996).

- Total RPMs in international markets are expected to approximately double during the forecast period, increasing from 144.2 billion in 1995 to 266.6 billion in 2007. The average annual growth rate over this period is 5.3 percent (U.S. DOT, FAA, 1996).

PASSENGER ENPLANEMENTS

- In 1995, U.S. scheduled air carriers enplaned a total of 544.3 million passengers (U.S. DOT, FAA, 1996).

- Overall average annual growth in system passenger enplanements for the 12-year forecast period, 1995-2007, is expected to be 3.9 percent (U.S. DOT, FAA, 1996).

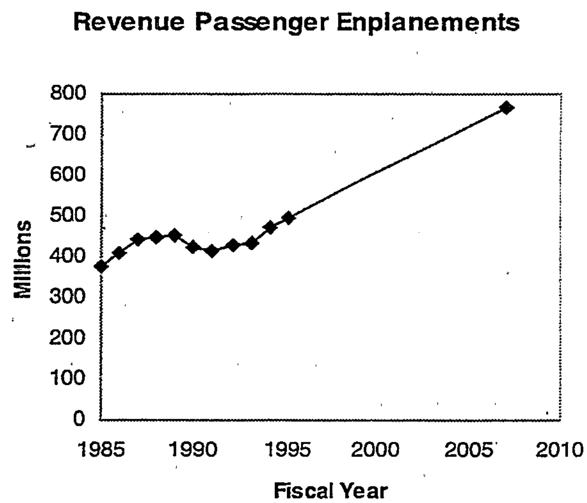
- In 1995, 91.1 percent of enplanements were domestic. This will drop to 89.5 percent in 2007 (U.S. DOT, FAA, 1996).

DOMESTIC PASSENGER ENPLANEMENTS

- Domestic passenger enplanements (495.9 million) increased by 5.1 percent in 1995; in 1994 the increase was 8.8 percent (U.S. DOT, FAA, 1996).

Fiscal Year	Domestic Passenger Enplanements (millions)
1985	375.0
1986	409.8
1987	444.9
1988	448.5
1989	452.4
1990	424.1
1991	413.3
1992	430.3
1993	434.0
1994	472.0
1995	495.9
2007*	766.8

*projection
Source: U.S. DOT, FAA, 1996.



- The growth in domestic enplanements is expected to average 3.7 percent during the 12-year forecast period, with the number of domestic enplanements reaching 766.8 million in 2007 (U.S. DOT, FAA, 1996).

INTERNATIONAL PASSENGER ENPLANEMENTS

- A total of 48.4 million passengers were enplaned by U.S. scheduled international airlines in 1995, up 4.6 percent (U.S. DOT, FAA, 1996).

- The average annual rate of growth during the 1995-2007 forecast period will be 5.3 percent (U.S. DOT, FAA, 1996).

PASSENGER LOAD FACTOR

- U.S. scheduled air carriers recorded a system-wide load factor of 66.8 percent in 1995, up significantly from the previous peak of 65.7 reached in 1994 (U.S. DOT, FAA, 1996).

DOMESTIC PASSENGER LOAD FACTOR

- U.S. scheduled domestic air carriers had a load factor of 65.2 percent in 1995, up 1.0 point from 1994. Domestic load factors have varied very little over the period 1985 through 1993, ranging from a low of 60.3 percent in 1986 to 65.2 percent in 1995 (U.S. DOT, FAA, 1996).
- Capacity increased 4.1 percent between 1994 and 1995 (U.S. DOT, FAA, 1996).

INTERNATIONAL PASSENGER LOAD FACTOR

- The international load factor edged up to 71.4 percent in 1995, up from 70.0 percent in 1994—the highest annual load factor in history. The previous high of 69.2 percent was achieved in 1990 (U.S. DOT, FAA, 1996).
- The international load factor is forecast to remain relatively stable over the twelve year forecast period, increasing from 71.4 percent in 1995 to 71.6 percent in 2007 (U.S. DOT, FAA, 1996).

AIR CARGO TRAFFIC

- Air cargo revenue ton miles (RTMs) flown by U.S. air carriers reporting on BTS Form 41 totaled 23.2 billion in 1995, up 11.5 percent from 1994 (U.S. DOT, FAA, 1996).
- Freight/express RTMs increased 12.5 percent, while mail RTMs increased 4.4 percent. Domestic cargo RTMs were up 9.0 percent, while international RTMs increased 14.4 percent (U.S. DOT, FAA, 1996).

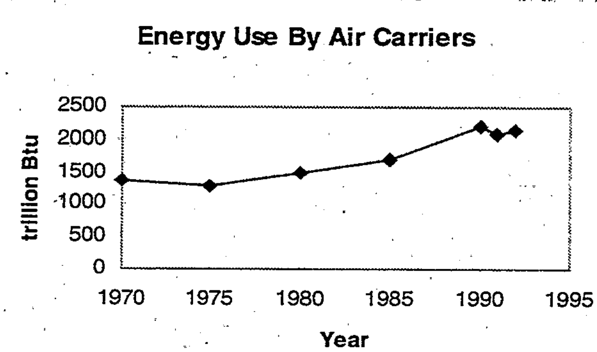
ENERGY CONSUMPTION

- Energy consumption by air carriers has increased significantly since 1970.

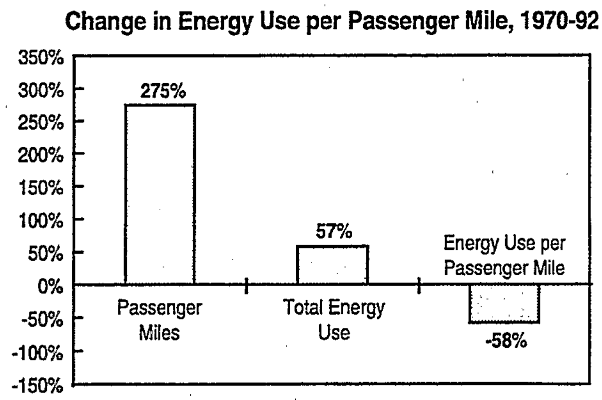
Energy Use By Air Carriers[13]

Year	Energy Use (trillion Btu)
1970	1363.4
1975	1283.4
1980	1489.6
1985	1701.5
1990	2191.3
1991	2069.2
1992	2144.2

Source: U.S. DOE. 1994a.



[13] Energy use includes fuel purchased abroad for international flights.

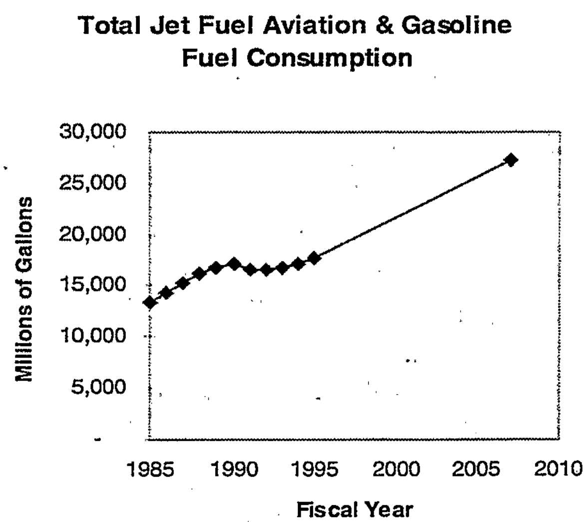


JET FUEL CONSUMPTION

- Fuel consumption in aviation increased to a record high of 17,795 million gallons in 1995.

Fiscal Year	Total Jet Fuel & Aviation Gasoline Fuel Consumption (millions of gallons)
1985	13,437
1986	14,412
1987	15,313
1988	16,146
1989	16,713
1990	17,207
1991	16,590
1992	16,610
1993	16,754
1994	17,163
1995	17,795
2007*	27,156

*projection
Source: U.S. DOT, FAA, 1996.



PASSENGER TRIP LENGTH

- The average system passenger trip length (986 miles) increased by 2.1 miles in 1995, largely the result of increases in trip lengths in the domestic, Atlantic, and Latin American routes (U.S. DOT, FAA, 1996).

- The domestic passenger trip length increased about 5 miles, primarily due to some of the major carriers eliminating short-haul markets and/or turning these markets over to their code-sharing regional partners (U.S. DOT, FAA, 1996).

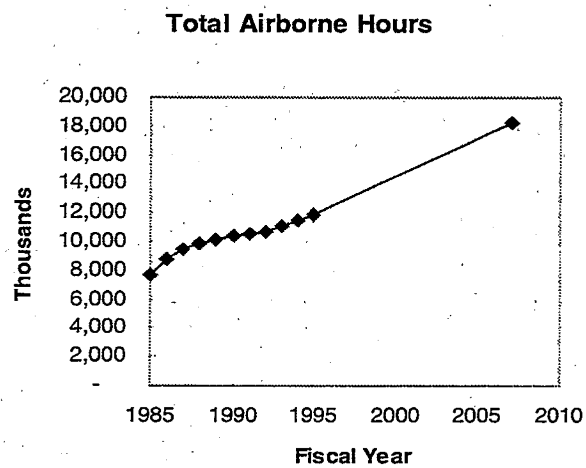
- In 1995, seven out of the nine majors increased their trip lengths, while the average domestic trip length for all major carriers increased more than 7 miles (U.S. DOT, FAA, 1996).

AIRBORNE HOURS

- U.S. commercial air carriers flew an estimated total of 11.9 million hours in 1995, up from 11.5 million hours in 1994 (U.S. DOT, FAA, 1996).

Fiscal Year	Total Airborne Hours (in thousands)
1985	7,718
1986	8,774
1987	9,397
1988	9,842
1989	10.097
1990	10,457
1991	10,480
1992	10,679
1993	11,138
1994	11,482
1995	11,940
2007*	18,212

*projection
Source: U.S. DOT, FAA, 1996.



- Two aircraft categories accounted for over three fourths of total airborne hours: two-engine narrowbody aircraft (63.9 percent) and three-engine narrowbody (13.0 percent). In 2007, the number of hours is forecast to increase to 18.2 million, an average annual increase of 3.7 percent.

- Two-engine aircraft (both narrowbody and widebody) are projected to account for 85.7 percent of all airborne hours flown in 2007. Two-engine narrowbody aircraft make up 15.1 percent of the hours in 2007, up an average of 9.1 percent per year (U.S. DOT, FAA, 1996).

- The number of hours flown by three-engine narrowbody aircraft will decline significantly over the forecast period. Hours for this aircraft type drop from 1.6 million in 1995 to 0.9 million in 2007, or 44.6 percent (U.S. DOT, FAA, 1996).

MODE: MARITIME

INFRASTRUCTURE

NAVIGABLE WATERWAY MILEAGE

- Mileage of commercially navigable waterways has remained stable since 1990.

Mileage of Commercially Navigable Waterways

1960	1970	1980	1990	1992	1993	1994
25,253	25,543	25,543	25,777	25,777	25,777	25,777

Source: U.S. DOT, BTS, 1996.

MARITIME VESSELS

- The vast majority of vessels in the U.S. are recreational boats.

Number of U.S. Vessels

Type of Vessel	1960	1970	1980	1990	1992	1993	1994
Non-self-propelled	16,777	19,377	31,662	31,017	30,899	30,785	30,723
Total self-propelled	6,543	6,455	7,130	8,216	8,311	8,323	8,341
Total U.S. flag merchant marine	5,852	1,579	864	636	603	564	543
Recreational	-	-	8,600,000	11,000,000	11,100,000	11,300,000	11,400,000

Source: U.S. DOT, BTS, 1996.

PORTS

- There were 196 commercial ports (ports receiving commerce over 1,000,000 tons) in the U.S. in 1993 (U.S. DOT, BTS, 1995b).

U.S. Ports, Ranked by Total Tons Shipped in 1993

Rank	Port Name	Tons Shipped
1	Port of South Louisiana, LA	193,796,104
2	Houston, TX	141,476,979
3	New York, NY & NJ	116,735,760
4	Valdez, AK	85,722,337
5	Baton Rouge, LA	85,078,863
6	New Orleans, LA	67,037,285
7	Corpus Christi, TX	59,649,751
8	Long Beach, CA	54,320,932
9	Texas City, TX	53,652,781
10	Plaquemine, LA	53,110,120

Source: U.S. Army Corps of Engineers, 1993.

TRAVEL

VESSEL USE

- Although the typical recreational boat is used less often (days per year) than other vessels, recreational boats comprise the majority of vessel days.

Vessel Utilization in the U.S. Maritime Sector[14]

Vessel Type	Number of Vessels[c]	Average Number of Days of Vessel Use Per Year	Estimated Annual Number of Vessel Days
Recreational Boats	7,300,000	21.9	159,870,000
Fishing Vessels	129,000	240.9	31,076,100
Cargo Ships	7,800	350.4	2,733,120
Day Boats	5,200	240.9	1,252,680
U.S. Navy Vessels	284	120.5	34,222
U.S. Coast Guard Vessels	2,316	109.5	253,602
U.S. Army Vessels	580	73.0	42,340
School Boats	14	127.8	1,789
Offshore Industry Service Vessels	1,500	365.0	547,500
Navy Combatant Surface Vessels	360	120.5	43,380
Passenger Cruise Ships	128	350.4	44,851
Research Vessels	125	200.8	25,100
Misc. Private Industry Vessels	85	365.0	31,025
Total	7,447,392		195,955,709

Adapted from National Research Council, 1995.

[14] U.S. maritime sectors include foreign-flag vessels that call at U.S. ports in addition to all U.S.-flag vessels. Data were collected from various sources dating from 1990 to 1994. Number of vessels was tabulated as follows: Recreational boats: boats registered in coastal states or in states bordering the Great Lakes. Cargo Ships: different ships of all flags calling at U.S. ports.

- Coastwise and internal shipping of freight on water (in ton-miles) has increased significantly from 1960 to 1994, while lakewise and intraport ton-miles have fallen.

Ton-Miles of Domestic Water Freight

	Millions of Ton-Miles						
Place of Travel	1960	1970	1980	1990	1992	1993	1994
Coastwise	256,000	359,748	631,149	479,134	502,311	448,404	457,601
Internal	89,614	155,816	227,343	292,393	297,639	283,894	297,762
Lakewise	65,990	79,416	61,747	60,930	55,785	56,438	58,263
Intraport	1,730	1,179	1,596	1,087	950	921	1,293

Source: U.S. DOT, BTS, 1996.

Average Length of Haul for Domestic Interstate Freight Vessels

	Miles					
Place of Travel	1960	1970	1980	1990	1992	1993
Coastwise	1,496	1,509	1,915	1,604	1,762	1,650
Internal	282	330	405	469	479	468
Lakewise	522	506	536	553	519	514

Source: U.S. DOT, BTS, 1996.

- Petroleum and petroleum products comprise the majority of waterborne freight traffic, in ton-miles.

Domestic Waterborne Freight Traffic, 1993[15]

	All Bodies of Water	Coastwise	Lakewise	Internal (River)	Intraport
All Freight					
Millions of Ton-Miles	789,657	448,404	56,438	283,893	921
% of All Domestic Traffic	100.0%	56.8%	7.1%	36.0%	0.1%
Petroleum and Petrol. Products					
Millions of Ton-Miles	403,557	365,755	660	36,695	445
% of All Domestic Traffic	51.1%	46.3%	0.1%	4.6%	0.1%
Chemicals and Related Products					
Millions of Ton-Miles	62,356	32,133	47	30,079	95
% of All Domestic Traffic	7.9%	4.1%	0.0%	3.8%	0.0%

Source: U.S. Army Corps of Engineers, 1993.

Crude Oil Transported by Water Carriers in the U.S.

Year	Billions of Ton-Miles	Percentage of Total U.S. Crude Oil Transportation
1975	40.6	12.2
1980	387.4	51.4
1985	449.2	57.1
1990	291.2	46.4
1991	296.4	46.7
1992	288.1	46.9
1993	276.0	47.2

Source: U.S. DOT, BTS, 1996.

[15] Ton-miles statistics not shown for foreign shipments (imports and exports). Tons of foreign shipments are approximately equal to tons of domestic shipments.

Refined Petroleum Products Transported by Water Carriers in the U.S.

Year	Billions of Ton-Miles	Percentage of Total U.S. Petroleum Products Transportation
1975	257.4	50.0
1980	230.4	46.8
1985	141.2	34.5
1990	157.8	35.2
1991	152.2	35.0
1992	158.0	35.5
1993	146.2	32.7

Source: U.S. DOT, BTS, 1996.

FUEL CONSUMPTION

- Vessel fuel consumption has decreased during the time period 1980 to 1993.

Fuel Consumed by U.S. Vessels

	Thousands of Barrels Consumed					
Type of Fuel	1960	1970	1980	1990	1992	1993
Diesel fuel & distillate	18,730	19,503	35,201	52,310	52,824	48,661
Residual fuel oil	94,084	89,850	213,131	148,764	171,407	149,283
Gasoline	9,200	14,238	25,048	30,962	31,337	20,802
Total	122,014	123,591	273,380	232,036	255,568	218,746

Source: U.S. DOT, BTS, 1996.

APPENDIX B. ADDITIONAL STATISTICS ON IMPACTS

Monetized values of health and welfare effects are useful because they measure the ultimate outcomes of pollution in comparable units. The weakness with using these indicators is that they are often uncertain. Given the numerous assumptions and methods that are used to determine the actual outcomes and the appropriate dollar values to assign to these outcomes, a broad range of dollar values appears in the literature. While these estimates are useful for understanding the magnitude of various problems, they are listed in this appendix separately from the other indicators because of the higher degree of uncertainty about these estimates and because monetized estimates are not available for many impacts.

HEALTH EFFECTS

Health effects are an end result of pollutant emissions. As an outcome measure, health effects are an ideal indicator of harm caused by transportation activities, providing direct and useful information on the results of pollution. In practice, however, this indicator is somewhat problematic due to a high degree of uncertainty in estimates.

Estimating health effects requires use of dose-response functions which explain the human health response to a particular dose of a pollutant over a period of time. The proper population exposure must be estimated in combination with the dose-response function in order to determine health impacts properly. Sub-populations which are most affected, such as children or asthmatics, may be separated if separate dose-response functions have been developed.

Since the dose-response function is based on an ambient-level "dose" of pollutant, the portion of the ambient level that is attributable to transportation sources must be estimated. Various methods might be used to estimate how auto emissions affect ambient levels of air pollution, and these may be quite complex, involving dispersion models which take into account geography, climate, wind, natural barriers, and other elements of topography. Difficulty arises since some ambient pollutants, such as ozone, are not emitted directly from vehicles. Instead, ozone is formed through a process which involves NO_x and VOCs as precursors. Even if transportation is responsible for 30 percent of NO_x emissions in a region, transportation may not be responsible for 30 percent of the ozone in the atmosphere.

A number of estimates are listed below, some developed through very simplified methodologies:

- Ketcham and Komanoff (1993) estimate that air pollution from motor vehicles causes 15,000 deaths annually, based on 75,000 deaths annually from air pollution with 20 percent attributable to motor vehicles.[16]

- Delucchi, Sperling, and Johnson (1987) assume that motor vehicle air pollution causes 7,500 to 31,250 deaths annually, based on 15-25 percent of 50,000 to 125,000 deaths from air pollution annually.[17]

[16] Ketcham, B. and C. Komanoff, 1992.
[17] Delucchi, M., D. Sperling and R. Johnson. *A Comparative Analysis of Future Transportation Fuels.* UC-Berkeley, 1987, as cited in Litman, 1994.

- McCubbin and Delucchi (1995) estimate various adverse health affects from motor vehicles using dose-response functions, as listed in the following table.[18] Their findings suggest that particulate matter, especially road dust, is responsible for the majority of health effects, including from 50 to 70 million cases of respiratory-related restricted activity days (RRAD) annually, and 19,700 to 46,100 cases of chronic respiratory illness.

Estimated Cases of Adverse Health Effect (thousands of cases), 1991 from Motor Vehicle Pollution

Health Effect	Air Pollutant								
	CO	NOx, in ambient air as:		SOx	Direct PM	VOCs in ambient air as:		Toxics	Total
		nitrate PM	NO2	Sulfate PM		Organic PM	Ozone		
Mortality		2.8		0.9	33.3	0.3	0 - 3.8		37.3 - 41.1
Airway obstructive disease (chronic respiratory illness)		1.3 - 3.1		0.4 - 1.0	17.7 - 41.6	0.1 - 0.3			19.7 - 46.1
Respiratory-related restricted activity days (RRAD)		4,994 - 6,960		1,502 - 2,087	42,948 - 59,899	510 - 712			49,954 – 69,658
Cancer-oral								0.01	0.01
Cancer-lung								0.23	0.23
Cancer-Leukemia								0.06	0.06
Cancer-other								0.23	0.23
Asthma attacks		65		21	1,115	7	2,879		4,087
Headaches	852,251								852,251
Excess phlegm			139,184 - 140,153						139,184 – 140,153
Eye irritation			63,860 - 64,322				17,533 - 23,592		
Sore throat			57,462 - 57,871						57,462 – 57,871
Lower respiratory illness							9,676 - 13,008		9,676 – 13,008
Upper respiratory illness							18,179 - 24,440		18,179 – 24,440

Source: McCubbin and Delucchi. *Health Effects of Motor Vehicle Air Pollution.* July 1995.

[18] McCubbin, D. and M. Delucchi. 1995.

Reported Chemical Emissions in Industries Related to Transportation, 1993

SIC Code	Industry Type	Air	Water	Land	Total	POTW Transfer	Off-Site Locations Transfer	Underground Injection
A. Motor Vehicles								
3711	Motor Vehicles & Passenger Car Bodies	52,878,028	3,038	255	52,881,321	2519072	51603667	
3713	Truck & Bus Bodies	12,977,951	3,916	3,983	12,985,850	260887	15907099	
3714	Motor Vehicle Parts & Accessories	34,540,544	147,394	1,348,978	36,036,916	890432	112999744	
3715	Truck Trailers	2,522,371	27	1,500	2,523,898	1894	6223948	
3716	Motor Homes	2,680,082	-	-	2,680,082	250	395759	
3537	Industrial Trucks, Tractors, Trailers & Stackers	561,110	10	5	561,125	10000	672320	
3751	Motorcycles, Bicycles & Parts	6,740,758	8,209		6,748,967	3029	6033915	
4213	Trucking (No Local)	56,763		10	56,773		27705	
5013	Wholesale-Motor Vehicle Supplies & New Parts	12,259	60		12,319		7075069	
		112,969,866	*162,654*	*1,354,731*	*114,487,251*	*3,685,564*	*200,939,226*	
B. Rail								
3743	Railroad Equipment	2,157,138	458	15	2,157,611	176632	8165741	500
C. Aircraft								
3720	Aircraft & Parts	75,790			75,790		14339	
3721	Aircraft	12,239,470	4,917	81	12,244,468	125166	4632947	
3724	Aircraft Engines & Engine Parts	5,848,914	50,519	122	5,899,555	31527	18165359	
3728	Aircraft Part & Auxiliary Equipment, NEC	10,331,033	2,465	81,210	10,414,708	87773	6594777	5
4581	Airports, Flying Fields & Airport Terminal Services			60,000	60,000			
		28,495,207	*57,901*	*141,413*	*28,694,521*	*244,466*	*29,407,422*	5
D. Ship and Boat								
3730	Ship & Boat Building & Repairing	203,702	20		203,722		36454	
E. Petroleum Related								
1311	Crude Petroleum & Natural Gas	20,817			20,817			3762430
1389	Oil, Gas Field Services, NBC	67,690			67,690	0	67700	
2911	Petroleum Refining	69,293,903	3,891,828	1,614,143	74,799,874	5244618	931143666	13307154
3533	Oil & Gas Field Machinery & Equipment	518,618	309	15,947	534,874	34040	1220764	
5171	Wholesale-Petroleum Bulk Stations & Terminals	4,542,142	620,461	142,179	5,304,782	2059	1627875	
5172	Wholesale-Petroleum & Petroleum Products (No Bulk Stations)	30			30	750	250	
		74,443,200	*4,512,598*	*1,772,269*	*80,728,067*	*5,281,467*	*934,060,255*	*17,069,584*
F. Miscellaneous								
2451	Mobile Homes	402,669			402,669	250	22064	
3011	Tires and Inner Tubes	907,574	7,103	10,624	925,301	12548	3974265	5
		1,310,243	*7,103*	*10,624*	*1,327,970*	*12,798*	*3,996,329*	5
Total		**219,579,356**	**4,740,734**	**3,279,052**	**227,599,142**	**9,400,927**	**1,176,605,427**	**17,070,094**

Source: Toxic Release Inventory, 1994.

MONETIZED VALUES

HIGHWAYS

TAILPIPE AND EVAPORATIVE EMISSIONS

Emissions from vehicle travel are responsible for five major categories of costs which may be monetized:

- Human health impacts
- Materials damage
- Agriculture damage
- Visibility degradation
- Global Warming

OVERALL AIR POLLUTION COSTS

- Moffet, 1993, estimates air pollution costs as $86 to $160 billion annually from autos and $34 to $62 billion annually from light trucks.[19]
- Cannon, 1990, estimates total U.S. automobile emissions costs are approximately $50 billion annually.
- The Office of Technology Assessment (1994) has estimated U.S. annual automobile air pollution costs, including human health effects, global warming, agricultural losses, material effects, visibility and aesthetic losses, to range from $47 to 242 billion.[20]
- Litman (1994) estimates national air pollution costs as $110 billion.[21]

HUMAN HEALTH COSTS

- McCubbin and Delucchi estimate emissions from auto travel are responsible for $64 to 223 billion per year in health costs in 1991, including road dust. Particulates are responsible for about 93-97 percent of the total.[22]
- Ketcham and Komanoff (1993) estimate U.S. national automobile air pollution health costs at $30 billion.
- Delucchi, Sperling, and Johnson (1987) estimate that roadway use causes from $7.5 to 181.3 billion per year in health damage (converted to 1991 dollars by DRI/McGraw-Hill).

MATERIALS DAMAGE

- Emissions from auto travel have been estimated as responsible for about $4 billion dollars annually in materials damage.
- Delucchi, Sperling, and Johnson (1987) estimate that roadway use causes from $3.9 to 11.7 billion per year in materials damage (converted to 1991$ by DRI/McGraw-Hill).

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[19] Moffet, 1993, p. 48.
[20] U.S. Office of Technology Assessment. *Saving Energy in U.S. Transportation.* 1994, p. 108, as cited in Litman, 1994.
[21] Litman, T. *Transportation Cost Analysis: Techniques, Estimates and Implications.* December, 1994. p. 3.10-8.
[22] McCubbin and Delucchi. 1995. Table 6.

AGRICULTURE DAMAGE

- Emissions from auto travel have been estimated as responsible for about $1.3 to $3.5 billion dollars annually in damage to crops and agriculture.
- Delucchi, Sperling, and Johnson (1987) estimate that roadway use causes from $2.0 to 8.0 billion per year in crop damage (converted to 1991$ by DRI/McGraw-Hill).

VISIBILITY DEGRADATION

- Emissions from auto travel have been estimated as responsible for about $4 billion dollars annually in visibility loss.
- U.S. aesthetic costs of smog have been estimated at $7.9 billion annually in 1982 (Crandall, Robert, et al. *Regulating the Automobile,* Brookings Institute, Washington DC, 1986).

GLOBAL WARMING

- Emissions from auto travel have been estimated as responsible for about $26 billion dollars annually from the risk of global warming.
- DRI/McGraw-Hill (1994) estimates that roadway use is responsible for $1.8 to 8.6 billion dollars per year in damage from climate change (1991$)

FUGITIVE DUST FROM ROADS

- McCubbin and Delucchi estimate that fugitive dust caused $59 to 216 billion dollars in human health cost damages in 1991.[23]
- The monetized cost of health damage from fugitive dust exceeds the health damage costs from tailpipe and evaporative emissions.

NOISE AND VIBRATION

- Ketcham (1991) estimates that roadway use is responsible for $4.1 to 6.6 billion dollars in noise damage annually (1991$).[24]
- Konheim and Ketcham (1991) estimate that roadway use is responsible for $0.3 billion dollars in vibration damage annually (1991$).[25]
- MacKenzie used estimates developed by Hokanson for the U.S. DOT to calculate total U.S. noise costs from roadway use to be $9 billion annually.[26]
- Changes in the value of U.S. houses between 0.08% and 0.88% occur per one unit change in Leq.[27]

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[23] McCubbin and Delucchi. July 1995. Table 6.

[24] Ketcham, Brian. *Making Transportation Choices Based on Real Costs.* October 1991, as reported by DRI/McGraw-Hill, 1994.

[25] Konheim and Ketcham. "Toward a More Balanced Distribution of Transportation Funds." Draft, 1991, as cited in DRI/McGraw-Hill, 1994.

[26] MacKenzie, J., R. Dower and D. Chen. *The Going Rate.* World Resources Institute, Washington, DC., 1992, p.21.

[27] Pearce and Markandya, 1986 and Button, 1990, as cited in Moffet, 1993, p. 34.

LEAKING FUEL TANKS AND OIL SPILLS

- The Office of Technology Assessment (1994) estimated that leaking fuel tanks and oil spills associated with motor vehicle use cost $1 to 3 billion per year in the U.S.[28]
- Lee estimates that annual uncompensated oil spills average $2 billion.[29]

ROADWAY DEICING

- An Apogee survey of cost estimates of damage attributable to roadway deicing found a range of from about $4.7 billion to $8 billion annually.
- Murray and Ernst (1976) estimate damage from road salting nationwide is $4.7 billion annually (converted to 1993$ by Lee).[30]
- A 1976 EPA study identified $8 billion in damages (1990 dollars) from road salt. Over 90 percent of this damage was to vehicles and highway structures. $600 million was damage to water supplies, health, and vegetation.[31]
- NRDC estimates the aesthetic damage to vegetation caused by road de-icing is about $650 million per year[32]

WASTE DISPOSAL

- Lee estimates external waste disposal costs associated with highways as $4.2 billion. This value includes $0.5 billion for waste oil, $0.7 billion for scrapped cars, and $3.0 billion for used tires.[33]

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[28] U.S. Office of Technology Assessment. *Saving Energy in U.S. Transportation.* 1994, p. 108, as cited in Litman, 1994.
[29] Lee, D. *Full Cost Pricing of Highways.* Paper presented at TRB. 1995.
[30] Murray and Ernst. *Economic Assessment of the Environmental Impact of Highway Deicing.* EPA, 1976, as cited in Litman, 1994.
[31] 1976 EPA study (Murray and Ernst), as cited by NRDC, 1993.
[32] NRDC, 1993, p. 50.
[33] Lee, D. *Full Cost Pricing of Highways.* Paper presented at TRB. 1995.