SECTION 1

WEATHER AND THE URBAN ENVIRONMENT: MEETING THE NEEDS OF URBAN COMMUNITIES

INTRODUCTION

A majority of Americans spend most of their lives in urban environments. Of the 280 million people living in the United States in 2000, nearly two-thirds lived in urban areas occupying less than two percent of the land area. Urban meteorology studies how weather and climate interact with the natural, built, and societal features of these urban environments.

Figure 1-1. A fast-moving summer thunderstorm swept through Las Vegas in August 2003, flooding this freeway interchange. A motorist climbs from her stalled car into the vehicle of an off-duty police officer to escape the flash flood. (AP Wide World Photos)

We typically think of weather and climate as natural conditions that affect our urban lives. Storms and inclement weather interfere with our work, our recreation, and all the systems that transport us and our goods to, from, and through our cities. Severe weather in urban areas causes thousands of deaths annually. When weather disrupts energy supply systems or surges energy demand, even our modern information systems can be shut down or degraded. But urban environments can also affect the weather, even the climate. Large cities may produce "heat island" effects on winds, weather fronts, and storm movements. Urban life is responsible for much of the greenhouse gas emissions that may be altering climate on regional to global scales.

For many of the consequences of greatest concern, the *interaction* of weather or climate conditions with the constructed and societal features of urban environments is most important. For example, pavement, buildings, and other structures prevent precipitation from penetrating the soil. Instead, drains and storm sewers channel the flows into limited drainage outlets, increasing the likelihood of flash flooding (Figure 1.1). Temperature inversions can hold in the airborne exhausts of vehicles and industrial emissions, degrading air quality for an entire metropolitan population, as well as for nearby agricultural or natural ecosystems. Many of the most pressing and serious issues for urban meteorology-the interdisciplinary study of these complex interactions-fall within five areas of environmental concern: air quality, water quality, severe weather, disaster response and homeland security, and climate change.

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URBAN WEATHER: FIVE AREAS OF CONCERN

Air Quality. Ever since cities first developed, their residents have noted that urban air differed from rural air, a difference now attributed to the load of urban pollutants. Ozone in urban air aggravates emphysema and reduces resistance to respiratory infections; it also interacts with other pollutants to form smog and respiratory irritants. Carbon monoxide interferes with the absorption of oxygen by the lungs. Sulfur dioxide can form sulfuric acid in the presence of atmospheric moisture and sunlight. Aerosols of iron in industrial emissions can catalyze chemical reactions. Other metallic pollutants, such as lead and vanadium (a component of fuel oil), are potential health hazards. Besides effects on human health, polluted air harms plants (by stunting growth), animals (by interfering with physiological processes), and the built environment (by eroding concrete, corroding metals, etc.). Air pollution damage in the United States costs billions of dollars each year.

Clouds, precipitation, fog, radioactive decay, and soil deposition are ways in which pollutants can be removed from the air. These weather elements are also factors in air and water contamination. Knowing the type and timing of precipitation is important for disaster response to hazardous materials dispersed into the atmosphere or urban water systems, as well as for managing the routine types of pollutants in urban air and water.

Water Quality. Water quality management remains a major urban problem. While urbanization creates growing demands for clean water, it also interferes with the natural cycle by which precipitation replenishes clean, potable ground and surface waters. Run-off from lawns, golf courses, and construction sites into storm sewers can cause excessive silting and eutrophication. The discharge of biological wastes and nutrients into lakes and rivers has multiple adverse effects on water quality. The high oxygen demand of biological wastes robs aquatic fauna of this essential ingredient for survival. In eutrophication, discharged nutrients fertilize the overgrowth of algae and other plant forms. Their eventual death and decay further deplete the water's dissolved oxygen. Microbial contaminants in effluents can cause public health hazards. Septic systems, salt-treated roads, landfills, and redeveloped brown fields can pollute groundwater as well as surface waters, particularly when heavy precipitation taxes the retention and cleansing capacities of the soils around these urban features.

Urbanized areas can vastly aggravate flooding, particularly localized flash flooding. The change from permeable soils and vegetation in rural environments to paved streets, parking lots, and roofs shortens the time for rain or meltwater to reach water collection areas. Storm drain systems designed to carry water away from residential and business districts further reduce the lag times. Poorly designed or overtaxed drainage systems can deteriorate water quality in the surface and ground water that receive the discharge, creating health and environmental risks.

Figure 1-2. Hurricane Claudette came ashore in Texas on July 15, 2003, peeling off roofs of homes such as this one in Palacios, Texas, knocking out power, and flooding low-lying areas. (AP Wide World Photos)

Severe Weather. Storms and extreme weather have both direct and indirect effects on the urban environment. Heavy rains can cause severe flooding at scales ranging from a single intersection to flooded basements in an entire neighborhood, to inundation of low-lying urban communities along a major river. Convective storms with accompanying lightning, hail, and high winds can cause power failures, damage vehicles and buildings, and fell trees. Hurricanes are a hazard for the large percentage of the U.S. urban population living within 50 miles of the Atlantic or Gulf coasts (Figure 1-2). Tornadoes are a hazard for urban communities throughout much of the United States.

Heat waves in urban environments increase the risk of heatstroke, heart attack, and other heat-related death and illness, particularly for susceptible populations (Figure 1-3). Weather extremes at the high end in summer and the low end in winter increase energy demand and prices. Temperature variability within a seasonal range can generally be handled by existing systems. Variations beyond the seasonal range, however, stress systems and energy supplies, triggering price volatility and sometimes system failure. Forecasts of these extreme events are vital to balancing urban energy supply and demand.

Every transportation mode that serves urban areas can be affected by severe winter weather. Snow, freezing rain, or high winds can disrupt transportation systems. Ice storms can break transmission lines, cutting power and communications. Rail service can be slowed or halted. Ice and freezing conditions impede the marine commerce important to the urban centers near the Great Lakes and upper Mississippi River. Icing can disrupt the flow of natural gas and oil within pipelines. Accurate forecasts of the type, location, and severity of winter precipitation enables mitigating actions to be taken by urban managers, commercial enterprises, and individuals. Given timely warning, public officials and the media can prepare urban populations for extreme cold, wind chill, and unsafe conditions.

Disaster Response and Homeland Security. The health and safety risks resulting from the accidental or deliberate release of hazardous materials depend in part on how weather conditions influence atmospheric and waterborne dispersion of the released material. Whether hazardous material disperses quickly or remains concentrated depends largely on the meteorological conditions. Most hazardous material

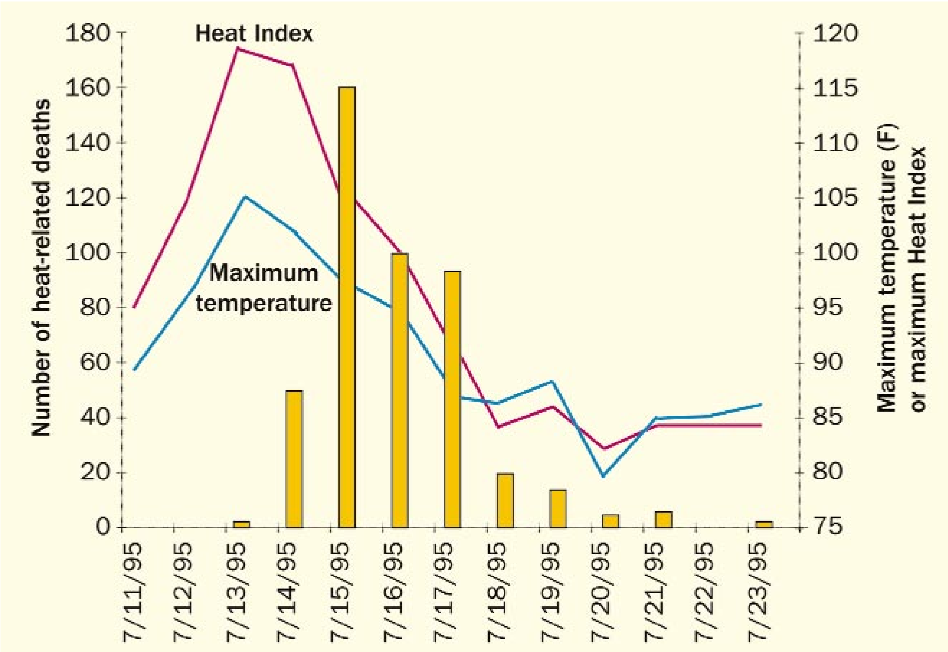

Figure 1-3. Heat-related deaths (bars), maximum temperature (T_{max}), and heat index (HI) during the Chicago heat wave of July 11-23, 1995. Adapted from National Oceanic and Atmospheric Administration, National Disaster Survey Report: July 1995 Heat Wave. U.S. Department of Commerce, December 1995, Figure 9 (pg. 23).

releases occur within the atmospheric boundary layer (ABL), the lower part of the atmosphere where the Earth's surface directly influences air movement. The stronger the wind shear within the ABL, the stronger the resulting mechanical turbulence will be. When the surface temperature is greater than the air temperature, buoyancy forces intensify the turbulence due to wind shear. Hazardous gases or aerosols are transported upward, then dispersed laterally by the prevailing wind, forming an atmospheric plume (Figure 1-4). If the ABL is relatively stable, less dispersion occurs. The urban canopy plays an important role in varying the ABL. Buildings and other structures affect flow fields, influencing the intensity of atmospheric turbulence and the depth of the ABL.

Climate Change. Climate oscillations such as the El Niño Southern Oscillation, the North Atlantic Oscillation, and the Pacific Decadal Oscillation have profound effects on atmospheric conditions such as stability, precipitation, and prevailing winds. They cause regional temperature fluctuations that alter seasonal energy demands for heating or cooling, as well as affecting the frequency and severity of storms. For example, a severe drought in the Columbia River basin in the summer of 2001 affected not only agriculture and water quality in the region but also hydroelectric power production. This reduction in power supply contributed significantly to California's energy crisis when heat waves drove demand up sharply. As the sensitivity of energy supply and demand to climate fluctuations becomes better understood, decision makers are turning to risk management instruments such as insurance, catastrophe bonds, and weather futures. These instruments depend on accurate climate and seasonal forecasts for their viability.

Climate simulations are predicting an overall warming of the atmosphere due to greenhouse gases. If these predictions are correct, the energy demand for cooling urban structures in summer will increase, while energy demands for winter heating may decrease. A changing climate can also affect the supply and demand for water for drinking, irrigation, and generating power. Some urban regions may experience more frequent and more intense storms, increasing problems of urban

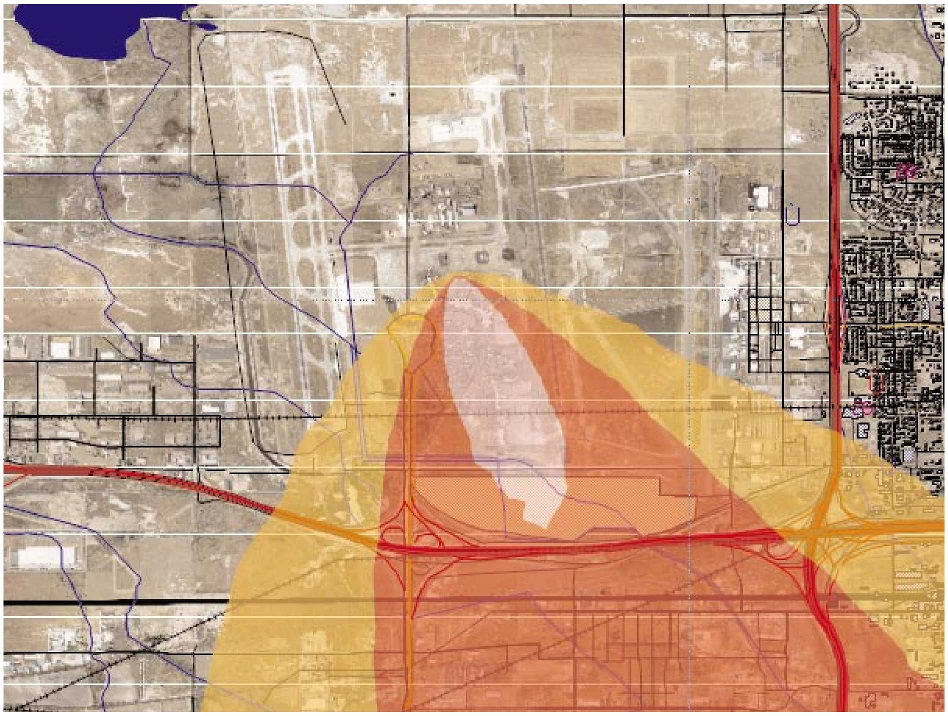

Figure 1-4. Atmospheric dispersion map, prepared for the Salt Lake City Olympics, showing a planning scenario for transport and dispersion of a plume of anthrax spores in case of a bioterrorism attack. Image courtesy DTRA.

flooding and water pollution. If regional precipitation declines, urban water users will compete with agricultural and industrial users.

APPLICATIONS FOR URBAN METEOROLOGY

Urban meteorology can contribute to many of the *tasks* that urban infrastructure managers and public officials confront in dealing with the environmental impacts described above (Figure 1-5). To understand, predict, and manage the consequences of weather interactions with the urban environment, these decision makers are demanding more accurate and specific information. They also need *tools* to help them understand what this information means for the aspects of urban environment and urban living under their care. Each of the tasks described below applies to many or all of the five areas of concern.

Public Health. Each of the five areas of environmental concern includes public health consequences. For severe weather or disaster response and homeland security, health and safety issues include immediate survival and avoidance of serious injuries. Health problems related to air and water quality or to winter weather may be less alarming, but some of the effects accumulate over time, and the risks for susceptible groups can be high. The emerging field of biometeorology provides the scientific basis for a more precise understanding of how atmospheric conditions affect individuals.

Transportation. As urban highways and streets become more crowded, even minor deviations from "fair weather" can disrupt traffic flows. Fog, sun glare, below-freezing temperatures, and even light rain can slow traffic and increase the likelihood of accidents (Figure 1-6). The descriptions above of severe weather concerns illustrate even more serious issues for transportation managers. In addition to this wide range of weather-related effects, urban transportation interacts with weather and climate conditions to produce its own environmental concerns. Emissions from vehicles can affect air and water quality for large areas downwind and downstream from the point of emission. Concentrations of emissions or accidental releases of hazardous materials from vehicles can pose serious health problems.

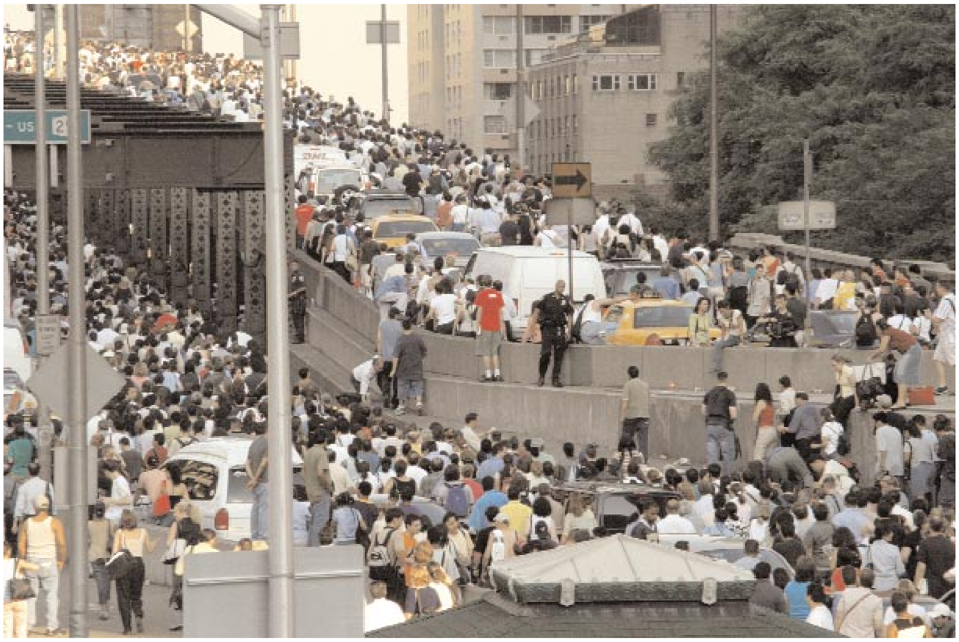

Figure 1-5. After a power blackout across the Northeast in August 2003, pedestrians leaving Manhattan flood New York's 59th Street Bridge to Queens. A prolonged period of summer heat and high humidity, which increased energy demand for air conditioning, was one factor in the massive power grid failure.
(AP Wide World Photos)

Information Dissemination. Communication of weather information has to be an end-to-end process. Observations and other data must be collected, assembled, reviewed for quality, and prepared for distribution to the wide spectrum of users in the public sector (urban, regional, and state government entities), the business community, and the general public. Weather data and products, including numerical models, forecasts, advisories, and warnings, must be available to all these users in readily useable forms.

Enterprise Continuity Planning. Planning for weather-related interactions with the urban environment can be critical to the effectiveness and even the survival of an organization, whether a for-profit company, a nonprofit entity, or a public-sector agency. All of these enterprises need to evaluate their susceptibility to risks in each area of environmental concern, but special attention should be given to potential weather disasters. Comprehensive plans must combine emergency response and business recovery. Assumptions must be based on a systematic re-analysis of hazards and their potential business impacts. In addition, businesses and local authorities must integrate their plans so that critical business functions can be restored in a timely fashion.

Regional Ecosystem Planning and Management. Urban environments are not ecologically isolated from agricultural areas or natural ecosystems (forests, grasslands, riparian and coastal wetlands, arid lands, etc.). Linkages with urban areas often occur through the weather-related environmental interactions described above. Air and water pollution from urban areas can affect agriculture and natural resources downwind and downstream

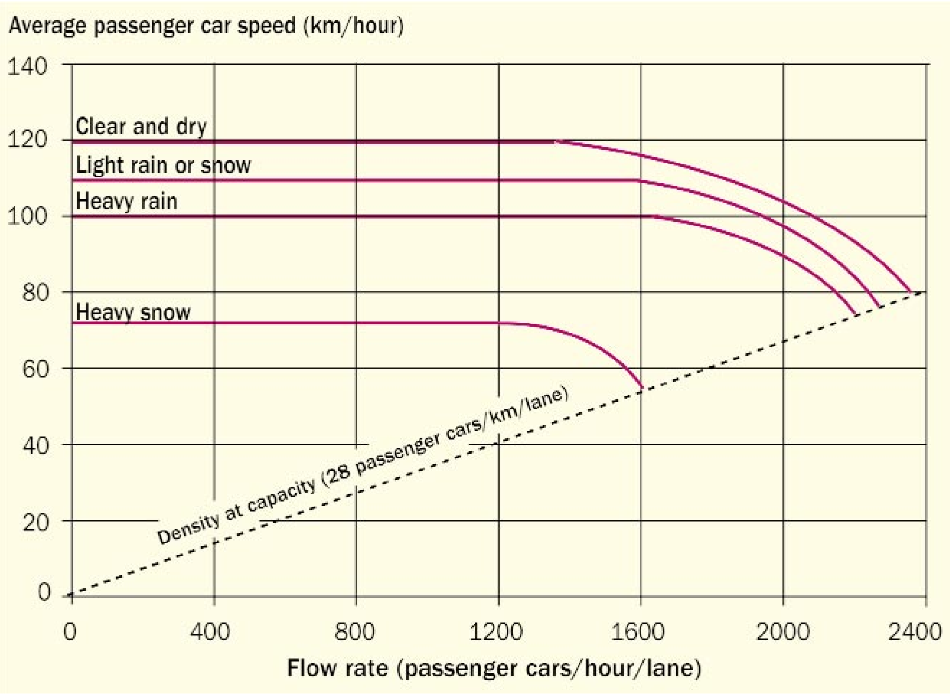

Figure 1-6. Speed-flow curves for different weather conditions on a highway, assuming a free-flow speed of 120 km/h. The point where the solid colored line for a weather condition intersects the maximum density limit (dotted line) represents the highway capacity (flow rate and average car speed) for the highway. Adapted from Highway Capacity Manual 2000, Washington, D.C.: Transportation Research Board, exhibit 22-7, pg. 22-12.

(Figure 1-7). Agricultural and urban communities often share the same groundwater and surface water resources. Agricultural practices can affect urban water and food supplies, as well as the recreational areas used by urban dwellers. Wildfires in natural areas can threaten the suburban zone around urban centers, just as urban populations seeking recreation provide both the demand for and multiple ecological stresses on natural areas.

TOOLS NEEDED TO SUPPORT APPLICATIONS

To provide the weather and climate information for the above tasks-and the many others that could be added-existing tools for collecting, processing, extending, communicating, and assimilating weather information must be improved and expanded. Improvements are needed in the following areas.

Integrated Global Observations. Observations are the lifeblood of the weather and climate forecasts, advisories, and warnings needed for urban environmental management tasks. The present state of weather and climate measuring stations in cities is inadequate at best. Stations are sited in locations and conditions that often violate the rules of observing practice adopted by the World Meteorological Organization (WMO).

Research and Technology Tools. A substantial amount of research and technology development is in progress, but more focus is needed on addressing gaps in the services and support capabilities needed by those responsible for urban management tasks. Mechanisms are needed for routinely translating research results and technological innovations into applications that support urban environmental management operations.

Education, Outreach, and Training. Education and outreach activities help end users understand and apply weather and climate information in their endeavors. Every new or improved product and service requires some level of education and training to ensure that the information is being interpreted and applied correctly. Outreach that creates and sustains dialogue with users is vital to identifying requirements and deficiencies, guiding R&D investment decisions, and tailoring final products and services for specific user applications.

Risk Management. Urban decision makers must assess the risks of alternative courses of action. Informed risk management requires that the decision makers understand and have current information about the uncertainties inherent in the science, technology, and applications on which they rely (Figure 1-8). For example, forecast uncertainties must be considered in decisions about future events and actions. The inclusion of forecast probabilities and confidence levels, combined with appropriate user education and outreach, helps users make informed risk management decisions.

Figure 1-7. Water contaminated with heavy metals seeps into a creek near Miami, Oklahoma, from a flooded abandoned mine. Even seasonal precipitation on contaminated soils can cause water quality problems for urban water supplies. (AP Wide World Photos)

KEY PLAYERS AND THEIR ROLES

If the goal of urban meteorology is to prepare for and manage the interactions of weather and climate with the urban environment, then teamwork and cooperation are essential. The agents of action in the urban setting are usually local (metropolitan and/or regional) and state authorities. Most of the tools and systems to make meteorological data timely and relevant to their decisions will be implemented and improved by the private sector. Commercial vendors use weather and climate information from government or private sources to generate value-added decision-support services and products for private enterprises, government and public-sector operations, and individuals. The private sector and the university community partner with federal agencies in R&D on new or improved tools and information flows, often with state and local agents participating as potential users. The academic community also educates the other players, as well as the public, about the consequences of urban weather and the opportunities to manage them.

The missions and capabilities of federal agencies can be understood within this cooperative context, which relies on partnering across public-private, federal-nonfederal governmental, and agency boundaries. Descriptions of agency missions elsewhere in this *Federal Plan* detail the roles and capabilities highlighted below. Also noted here are urban weather needs within the purview of an individual agency.

Figure 1-8. A transformer fire at an electric power substation in Apex, North Carolina. Lightning strikes at substations can disrupt electrical service to an urban community for variable durations. (AP Wide World Photos)

Within the Department of Commerce, the National Oceanic and Atmospheric Administration (NOAA) has several entities with urban weather roles. NOAA's National Weather Service (NWS) operates weather and climate observation networks to serve national needs and meet international obligations. It collects weather and climate data, checks the data quality, stores the data for access by other users, and assimilates the data into numerical and other models to develop forecasts, advisories, and warnings. NOAA's National Environmental Satellite, Data, and Information Service manages the U.S. environmental satellite systems used in civil operations. It also maintains archives of meteorological, oceanographic, geophysical, and solar-terrestrial data. The Office of Oceanic and Atmospheric Research supports NOAA meteorological, oceanographic, and space missions, including improving observation and forecast tools for severe weather and airborne volcanic ash. The National Ocean Service acquires data on water levels, currents, winds and other parameters to provide information products essential to marine transportation in coastal areas and ports. For urban weather, the greatest limitation in current NOAA services is the lack of sufficient observations and higher-resolution forecasts to meet the requirements for lead-time and location specificity of urban decision makers.

Within the Department of Transportation, the Federal Aviation Administration administers weather and climate information operations and research in support of aviation activities, including airports serving urban areas. The Federal Highway Administration, Federal Railroad Administration, and Federal Transit Administration conduct similar activi-

Figure 1-9. The Transit Control Center of Metro Transit, which serves the Minneapolis-St. Paul metropolitan region. The large graphical display on the right wall shows Doppler weather radar data from the NOAA National Weather Service. The display shows a line of convective weather moving into the region from the west. Courtesy Gary Nyberg, Metro Transit.

ties for roadway, rail, and transit systems, respectively (Figure 1-9). More observations and increased forecast resolution are needed to improve products and services for transportation systems in urban communities and surrounding areas.

The Department of Defense has responsibilities for reporting weather and producing weather warnings near its installations, many of which adjoin urban areas. The defense services use the observation data and forecast tools of NOAA's agencies to meet mission requirements, as well as maintaining observing and forecasting activities of their own.

The Department of Homeland Security includes the Federal Emergency Management Agency and the United States Coast Guard. These organizations require weather and climate data for emergency preparedness and for response and recovery operations in the event of natural and other disasters, including rescue and lifesaving activities (Figure 1-10).

The United States Department of Agriculture requires a range of high quality weather and climatological data for its operations. Many of its activities are essential for monitoring and understanding the interactions among ecologically linked agricultural areas, forests, and urban communities. The Department of the Interior responds to wildland fires, which may threaten adjacent urban communities or produce smoke and other contaminants that affect urban air and water quality. It also monitors air quality in national parks and collects water resource and water quality data.

The Environmental Protection Agency issues and enforces regulations on acceptable air and water quality for urban environments. Assessing the dispersion of airborne contaminants will require additional measuring equipment and networks.

The National Aeronautics and Space Administration (NASA) works with NOAA to develop new environmental satellite capabilities. It maintains archives of environmental satellite data available to researchers and other users. NASA's satellites provide data for urban and surrounding areas, often at resolutions greater than those available from terrestrial observing systems alone.

As part of the licensing for nuclear

Figure 1-10. A plume of nitric acid fumes rises from an industrial accident site. Local wind patterns will determine how an atmospheric release of hazardous material spreads into the urban environment. (AP Wide World Photos)

energy facilities, the Nuclear Regulatory Commission requires identification of atmospheric conditions, including severe weather, that could affect a facility's safe operation. Climate and weather data are used to assess the consequences of a radiological release. In the event of a release, detailed observations and forecasts of its dispersion would be used to prepare advisories and warnings for urban and other communities.

SUMMARY

A comparison of agency responsibilities and capabilities with the applications and tools of urban meteorology shows that interagency coordination and cooperation is essential if urban weather needs are to be met. Advances in observing systems, weather forecast models, and information technologies provide opportunities to address urban weather needs in ways not feasible just a decade ago. No one agency has the breadth of mission, capabilities, or resources to meet all these needs alone. Only a concerted effort by all the partners can meet the challenges and help mitigate the increasingly critical impacts of adverse urban weather on our citizens.

To coordinate this effort and focus resources on the most pressing needs, the OFCM is organizing a user forum on urban meteorology to be held in late spring 2004. The results from that forum will guide next steps toward a coordinated federal strategy for addressing weather-related needs of our urban communities.