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Chapter 1 Air Quality Overview

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Air Quality Overview

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629.0100 Introduction**(a) Purpose of National Engineering Handbook air quality chapters**

The purpose of the National Engineering Handbook (NEH) air quality chapters is to provide the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) personnel with an introduction to air quality science, particularly regarding agricultural interactions, and to serve as a useful guide for addressing air quality resource concerns in the context of conservation planning. The NRCS has identified four basic resource concerns for agricultural air quality: particulate matter (PM), ozone (O_3) precursors, odors, and greenhouse gases (GHG)/carbon sequestration. Separate chapters will address each of these important resource concerns. In combination with this introductory chapter, these chapters seek to simplify and clarify the abundance of information on agricultural air quality issues and solutions.

(b) Definition of air quality

Air quality is the condition of the air as it is expressed in terms of the concentration of pollutants relative to established baseline values, such as standards set by the U.S. Environmental Protection Agency (EPA). Reference to “air quality” generally includes some description or measure of the relative purity of the air. Poor air quality may be expressed as a pollutant (gaseous or particulate) concentration, as an effect (such as deposition) or as a visual impact (decreased visual range).

(c) Atmospheric constituents, air pollutants, and air quality

The atmosphere is a fluid that surrounds the Earth with a “depth” comparable in scale to the thickness of the skin of an apple. The atmosphere is chiefly composed of two gases: nitrogen (N_2), accounting for nearly 78 percent of the Earth’s atmosphere (by volume), and oxygen (O_2), accounting for nearly 21 percent. These values are for a totally dry atmosphere. Water vapor can account for up to 4 percent of the atmosphere’s volume, which slightly alters these values for N_2 and O_2 . The remaining atmospheric constituents

are normally referred to as “trace gases.” Argon is the most abundant of these, accounting for approximately 0.9 percent of the atmosphere. Other principal trace gases, in approximate order by volume, are carbon dioxide (CO_2), neon, helium, methane (CH_4), krypton, nitrous oxide (N_2O) and hydrogen. In addition to the presence of these gases, there are background concentrations of PM.

Gaseous air pollutants are mostly made up of the elements of N_2 , O_2 , sulfur, carbon, and helium. Lead and mercury occur in low levels as gases and/or particles. PM varies widely in size, shape, and chemical composition.

Chemical and physical properties of the atmosphere, its components, and their effects on light allow us to view a blue sky above, which appears darker blue and finally black as we increase in elevation above sea level. The number and size of the molecules that make up our atmosphere, however, limit our visual range through the atmosphere. In a clean particle-free atmosphere, some light scattering occurs due to the Rayleigh scattering of light by gases (the scattering of light rays by the gas molecules). This limits the maximum visual range through the atmosphere to between 200 and 260 kilometers, or approximately 160 miles. We are able to observe the moon, sun, stars, and planets since the “depth” of atmosphere we are looking through is typically only a few miles.

Both natural and human-induced (anthropogenic) emissions can change the relative amounts of atmospheric components. Changes in trace gases are typically small in comparison to the total amount of compounds in the atmosphere, yet these changes can be important. For instance, it is well known that fossil fuel combustion (as well as many other processes) is responsible for increasing atmospheric CO_2 levels. This combustion also emits other gases, including nitrogen dioxide (NO_2), nitric oxide (NO), sulfur dioxide (SO_2), PM, and mercury. Many of these anthropogenic air emissions are compounds that are not typical in the atmosphere and are considered pollutants. In general, solid, liquid, or gaseous pollutants in the atmosphere are classified as such because they are not typically found in significant concentrations in the natural atmosphere. They are of particular concern when they may affect human, animal, or plant health, or various other human concerns (such as nuisance odors or reduced visibility).

Pollutant emissions can result in a variety of air quality effects. For a given emission rate or total amount of emissions, the effects on humans, animals, water, soil, and plants are largely determined by both the mass of emitted material and the resulting concentrations of the pollutants. Some of the principal factors controlling pollutant concentrations include atmospheric stability, lapse rate, dispersion, transport, and chemical processes.

When primary pollutants, those emitted directly from the emission source, change chemically in the atmosphere to form other pollutants, the pollutants formed are known as secondary pollutants. The reactions that form these secondary pollutants may be influenced by solar radiation, atmospheric moisture, temperature, and the concentration of chemical precursors. Two of the most common secondary pollutants are tropospheric O_3 and secondary aerosols, or fine particulates. More information on these secondary reactions is provided in relevant sections and in the PM and O_3 NEH chapters.

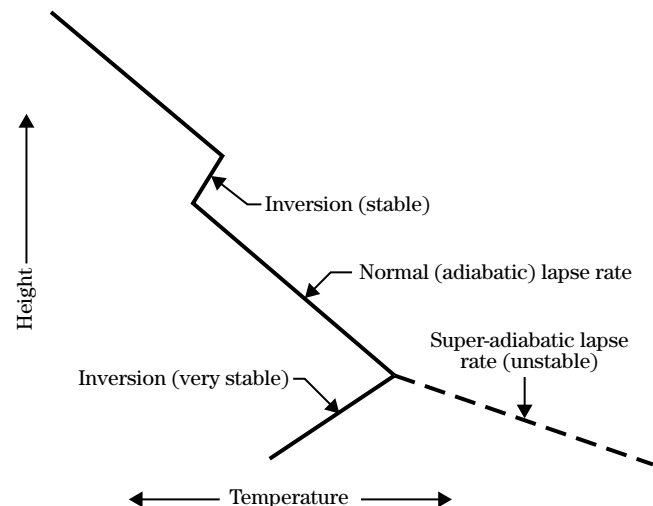
(d) Meteorological and topographical influences on air quality

Meteorological—Pollutants emitted into the atmosphere may or may not cause air quality impairment. Meteorological conditions and local to regional topography are significant factors that influence air quality. An important meteorological determinant is atmospheric stability, a reference to the condition of a given air mass favoring or reducing the vertical movement of an air parcel. An unstable atmosphere means an air parcel will move freely up and down, while in a stable atmosphere such movement is thwarted or stopped. Thus, a stable atmosphere is more conducive to the build-up of air pollutants released at the Earth's surface since they will tend to stay near the ground. There are various factors contributing to atmospheric stability. Among the most important is the temperature lapse rate of the atmosphere. This refers to the change of temperature with height (fig. 1-1). When temperatures decrease with height (a typical situation in the lower atmosphere, the troposphere) air emissions at the surface will rise into the atmosphere and be dispersed. This is observed when warm smoke rises vertically from a chimney or smoke stack. In an inversion situation, temperatures are colder at a lower level in the atmosphere than they are higher up (thus,

inverted from “normal”). Inversions are thus indicative of a very stable atmosphere. A typical example is the inversion common on most early mornings when the ground surface is colder than the air several hundred meters above it. This condition may be observed when smoke rising from a chimney or smoke stack levels off or flattens out after rising some distance from the emission source. The height where the smoke levels off is the level of the inversion layer. Inversions are not necessarily close to the Earth's surface. In fact, summer inversions can be 1,000 or 2,000 meters above the surface but can still significantly restrict the vertical mixing of pollutants. The height of the inversion layer above the ground is referred to as the “mixing height.” This is the top of the layer nearest the Earth's surface in which pollutants have the opportunity to mix with other atmospheric constituents. Mixing heights are typically lower over water and cooler land surfaces, including snow-covered ground. The high afternoon mixing height is also known as the boundary layer, planetary boundary layer, or atmospheric boundary layer and may reach a height of several kilometers under ideal conditions.

Dispersion is a term describing how pollutants are scattered or spread (dispersed). In air pollution nomenclature, “good” dispersion means emissions will

Figure 1-1 Temperature-height diagram illustrating various aspects of atmospheric stability



be well distributed over some area, while “poor” dispersion means pollutants will tend to stay confined to a small area, resulting in higher concentrations (and potential impacts) in those areas. Stability is a part of the dispersion process, but the gradient of the concentration of a pollutant (for instance, high concentrations only a short distance from low concentrations), and other factors also are important.

Once air pollutants are in the atmosphere, they can be moved around. Such movement is typically referred to as transport. Wind speed and direction are important influences upon transport. In general, wind speeds increase with increasing elevation above the Earth’s surface and as the frictional forces of the land decrease. Thus, if air pollutants released at the surface can rise and be dispersed (given appropriate stability and dispersion conditions), then these winds will generally transport them away from the emission source. Some cases of transport are not welcome, such as if dust or smoke from a rural area is transported into an urban area. Transport of pesticides from the target area is not desirable and is referred to as “chemical drift.”

All of these atmospheric conditions are influenced by the day-to-day weather. In general, high pressure systems have weaker winds, greater stability, more inversions, and more sunshine than the weather associated with low pressure systems. Thus, potential air quality issues are generally more significant under high pressure domination.

Topographical—Topography, describing the roughness and features of the Earth’s surface, also can have a significant impact on the fate and concentration of air pollutants. This is because topography can have a direct impact on many of the atmospheric factors described above. In general, the more complex the terrain or topography, the greater the potential for air quality issues to occur.

Mountain valleys often have significant inversions, particularly at night and throughout the cold season. The complex terrain can also restrict air movement. This combination can result in significant build-up of pollutants in the valley bottoms with very little dispersion. These locations, especially during these periods, are very susceptible to air quality problems, and air emission restrictions often are imposed in these areas. In contrast, flat terrain allows for nearly unrestricted air flow, enhancing dispersion and transport, and usually

resulting in fewer and more minor inversions (though in some situations, even flatter terrain areas like the Midwest and Plains can have meteorological inversions that result in air quality problems).

Ground surface characteristics also can impact factors important to air pollutant concentrations. A very dry soil surface with little vegetation will cool more quickly at night than a moist, vegetated surface. This can result in an enhanced inversion over the dry, bare area. Areas with little vegetation also typically have higher winds than areas with significant numbers of trees, which can enhance air pollutant transport and dispersion. Urban areas with tall buildings and covered with nonnatural materials (concrete, steel, etc.) will typically be warmer at night and more frequently calm, than nearby rural areas. This can have a complex variety of results, including reduced transport and dispersion, but a lesser inversion. Air emissions are often higher in urban areas as well, due to the greater anthropogenic sources in those areas. Indeed, a majority of nonattainment areas in the United States (see below) are found in urban areas and their surrounding counties.

(e) Air pollution regulation basics

The Clean Air Act of 1970 (1970 CAA) was preceded by the Air Pollution Control Act of 1955, Clean Air Act of 1963, and Federal Air Quality Act of 1967. Prior to this, however, in the 1940s and 1950s, the State of Texas and several urban areas including Los Angeles, New York, Cleveland, and Pittsburgh established agencies to address public health issues resulting from increasing air pollution problems. Pollutants of concern at that time were carbon monoxide and oxides of nitrogen (NO_x) from automobiles and industrial sources and SO_2 and PM from heavy industries, i.e., steel mills and smelters, transportation sources, and residential heating. Agricultural sources of air pollution were not specifically addressed when the CAA was promulgated.

It is important to note that even after the establishment of Federal air pollution regulations, States maintained the right to establish regulations and ambient air quality standards more stringent than Federal standards and also maintained the authority to regulate emissions sources within their jurisdictions.

The enactment of the 1970 CAA resulted in a major shift in the Federal Government's role in air pollution control. This legislation authorized the development of comprehensive Federal and State regulations to limit emissions from both stationary (industrial) sources and mobile sources. Four major regulatory programs affecting stationary sources were initiated: the National Ambient Air Quality Standards (NAAQS, pronounced "nax"), State Implementation Plans (SIP), New Source Performance Standards (NSPS), and National Emission Standards for Hazardous Air Pollutants (NESHAP). Enforcement authority was substantially expanded. The adoption of this very important legislation occurred at approximately the same time as the National Environmental Policy Act (NEPA) that established the EPA.

NAAQS were established for six criteria pollutants: PM, carbon monoxide, SO₂, lead, NO₂, and O₃. The CAA established two types of national air quality standards. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. By law, NAAQS are reviewed periodically, specifically every 5 years. During the NAAQS review, recent developments in the science related to health effects, monitoring, and atmospheric processes are considered, and the level and form of the standard are evaluated and changed as determined by the EPA and its science advisory groups.

Major amendments were added to the CAA in 1977 (1977 CAAA). The 1977 amendments primarily concerned provisions for the Prevention of Significant Deterioration (PSD) of air quality in areas attaining the NAAQS. The 1977 CAAA also contained requirements pertaining to sources in nonattainment areas for NAAQS. A nonattainment area is a geographic area that does not meet one or more of the Federal air quality standards. These 1977 amendments established major permit review requirements to ensure attainment and maintenance of NAAQS.

Another set of major amendments to the Clean Air Act occurred in 1990 (1990 CAAA). The 1990 CAAA substantially increased the authority and responsibility of the Federal Government. New regulatory programs were authorized for control of acid deposition (dry

deposition and wet deposition (acid rain)) and for the issuance of stationary source operating permits. The NESHAPs were incorporated into a greatly expanded program for controlling toxic air pollutants. The provisions for attainment and maintenance of NAAQS were substantially modified and expanded. Other revisions included provisions regarding stratospheric O₃ protection, increased enforcement authority, and expanded research programs.

The CAA, like other laws enacted by Congress, was incorporated into the United States Code (U.S.C.) as Title 42, Chapter 85. The U.S. House of Representatives maintains a current version of the U.S.C., which includes CAA changes enacted since 1990. Sections of the CAA are often referred to as "titles." Section numbers in the U.S.C. are different than the CAA's section numbers. Another difference is that titles in the CAA correspond to subchapters in the U.S.C. Table 1-1 shows the CAA Title and Parts with their corresponding CAA sections and subchapters in the U.S.C.

The EPA sets the regulatory framework for air quality protection, but most of the regulatory burden for implementing actions that will ensure air quality standards are met falls on appropriate State and local air authorities. The EPA requires each State to develop and implement a SIP, which is the set of regulations that the State will use to ensure that the Federal regulatory requirements are met in the State. SIPs can also include more stringent regulatory requirements than the Federal requirements. States may then delegate authority for meeting the SIP to local air districts, as appropriate. In most parts of the Nation, most agricultural activities are not considered to be significant contributors to air quality problems and are thus not highly regulated (or not at all). However, as standards are tightened and the size of individual agricultural operations increases, the likelihood that more air quality regulatory requirements will either be developed for agricultural sources or that more agricultural sources will be subject to air quality regulatory requirements also increases. NRCS personnel should be familiar with local and State air quality regulations that have specific bearing on agricultural operations. There are guidelines about when and how to address air quality resource concerns contained in the NRCS National Environmental Compliance Handbook (NECH).

The NRCS was largely founded due to an air quality issue—wind-blown dust (PM) associated with

the severe drought of the 1930s (the American Dust Bowl). These were times well before formal regulation, but even then there was broad public recognition of the need for methods to control soil erosion and consequent air quality deterioration. More recently, the NRCS has broadened its mission to include air as a resource that landowners should consider. The acronym SWAPA+H stands for soil, water, air, plants, and animals, plus humans—those resource concerns addressed by conservation activities of the Agency. In this regard, air is afforded equal status with these other natural resources, and the Agency attempts to address these issues in a holistic manner.

The CAA established emission standards for moving sources, acid deposition, stratospheric O₃ protection, and, in some cases, permitting of agricultural sources. These have all impacted a variety of agricultural activities. While many agricultural operations across most of the Nation are not subject to regulation, there is increasing scrutiny of all sources of air emissions,

particularly in nonattainment areas. Due to regulations, diesel-fueled on-road and off-road vehicles now burn low sulfur fuel. Ammonia (NH₃) emissions from farms can combine with acidic gas emissions from anthropogenic sources, including power plants and transportation sources, to form fine particles in the atmosphere. Farming operations, particularly larger ones in more heavily regulated areas, can be subject to permit requirements by States. Methyl bromide, a soil fumigant used to control pests, has been found to be a contributor to the depletion of the stratospheric O₃ layer, and thus has been phased out of operation across the Nation.

In general, the largest farming operations located in areas of the country that have the most significant air pollution problems are those that are most likely to be subject to regulatory control. This is particularly true for confined, concentrated animal production facilities.

Table 1-1 CAA titles and parts with their corresponding CAA sections and subchapters in the U.S.C.

Title	Part	CAA	U.S.C.
I: Air Pollution Prevention and Control	A: Air Quality and Emission Limitations	101–131	7401–7431
	B: Ozone Protection (replaced by Title VI)		
	C: Prevention of Significant Deterioration of Air Quality	160–169b	7470–7492
	D: Plan Requirements for Nonattainment Areas	171–193	7501–7515
II: Emission Standards for Moving Sources	A: Motor Vehicle Emission and Fuel Standards	201–219	7521–7554
	B: Aircraft Emission Standards	231–234	7571–7574
	C: Clean Fuel Vehicles	241–250	7581–7590
III: General		301–328	7601–7627
IV: Acid Deposition Control		401–416	7651–7651o
V: Permits		501–507	7661–7661f
VI: Stratospheric Ozone Protection		601–618	7671–7671q

629.0101 Air resource concerns in the NRCS

(a) Primary air quality concerns

There are four primary air-related resource concerns in the NRCS conservation planning structure, and nearly all air quality issues of interest to the Agency can be addressed by one or more of these concerns. They are:

- particulate matter, or PM
- ozone, or O₃, precursors
- odors
- greenhouse gases, or GHG, and carbon sequestration

There are numerous reasons why these four broad categories of concerns are significant issues. First and generally foremost are human health considerations. Additionally, these four air quality concerns can have impacts on other resources (secondary or tertiary effects). The following is a short overview of each of these four resource concerns. Much more thorough information about these four air quality issues and how they can best be addressed within the NRCS conservation planning structure is contained in the four succeeding NEH air quality chapters with these same titles.

(1) Particulate matter

PM defines a complex mixture of solid particles or liquid droplets that are suspended in the air. These can enter the air directly (often referred to as “direct or primary PM”) or be formed in the atmosphere through condensation or chemical reactions of certain pollutants, such as NO_x, NH₃, and volatile organic compounds (referred to as “indirect or secondary PM”). An example of secondary PM formation is when acidic gas ions (NO_x⁻ and SO_x⁻) combine with the ammonium ion (NH₄⁺) to form aerosols, which grow into fine particles. Directly emitted PM can be naturally generated (such as from wind erosion or fire) or from anthropogenic sources.

PM is generally classified into one of three class sizes. PM with aerodynamic diameter less than or equal to

2.5 micrometers (clay-size) is known as PM_{2.5}, or fine particulate; and similarly, PM with aerodynamic diameter less than or equal to 10 micrometers is known as PM₁₀, or coarse particulate. Particles between 2.5 and 10 micrometers in size are sometimes referred to as the “coarse fraction of PM₁₀.” Particles larger than PM₁₀ are known simply as larger PM. Large PM particles generally are of geologic origin, such as from the abrasion action of wind on soils. There are three primary, potential environmental concerns associated with PM: health issues, visibility concerns (includes safety and scenic impairment), and deposition on surfaces, such as structures, soils, and water bodies.

PM impacts can often be associated with the size of the particles. As a standard measure of relative size, a human hair is about 70 micrometers in diameter and fine beach sand has a diameter of 90 micrometers. By comparison, PM_{2.5} is approximately 30 times smaller than human hair while PM₁₀ is about 7 times smaller. It is PM’s small size that allows it to be breathed in and irritate the cardiovascular and respiratory systems in humans and animals. In general, the finer the particulate, the more impact it can have on human health because it can bypass our physiological filters and deposit deeper into the lungs. Particles can become lodged in the lung tissue, resulting in an immune response. Continual exposure to higher concentrations of PM can increase health concerns. The elderly, the young, and asthmatics are generally the first affected, but poor air quality can also cause eye and sinus irritation as well as cardiovascular and respiratory issues in all individuals.

The greatest human health threat from particulates comes from PM_{2.5}. It can be created by a number of activities, including some associated with agriculture. These include combustion (from engines, fires, etc.), directly emitted processes (including those producing dust, such as tillage and equipment movement), and indirectly emitted from a number of secondary formation processes. These secondary processes are chemical reactions in the atmosphere. Among the more significant indirect PM processes associated with agriculture is the formation of ammonium nitrates or ammonium sulfates. These compounds are formed in the air from the combination of NH₃ with nitrate or sulfate compounds. These particles are in the PM_{2.5} size range and can significantly penetrate the lungs. In addition, they can remain in the atmosphere for some time and distance and, thus, become health, visibility,

or deposition issues far from their individual sources. Smoke and fine dust can also be transported significant distances.

Coarse particles also can be irritants to human health and can raise health concerns when they are present in large concentrations. Coarse particles also can deposit on surfaces such as plants and buildings, particularly in the vicinity of tilled fields or unpaved roads and other surfaces. This type of deposition can become a significant issue. These same situations can create visibility concerns and be a local issue and, in cases of high winds over large areas, regional or even global issues. Deposition of PM occurs through either precipitation, also known as wet deposition, or through gravitational or inertial settling, called dry deposition. Deposition may adversely affect ecosystems by causing nuisance dusting, changing the pH balance, damaging plants, or by adding additional nitrogen to the environment, resulting in an increased rate of eutrophication.

(2) Ozone precursors

Ozone precursors are those compounds that chemically react in the atmosphere to form O_3 . Ozone is a molecule consisting of three oxygen atoms, and thus denoted as O_3 . It is not directly released into the atmosphere, but is instead formed from the chemical reactions involving its precursor gases in the presence of sunlight (an example of a photochemical reaction). There are two broad classes of O_3 precursor gas emissions (compounds): NO_x (and typically either nitric oxide or NO_2) and VOCs. Oxides of nitrogen, or NO_x , are generated either as a product of combustion or as an intermediate product in the nitrification/denitrification cycle in soils and manures. VOCs are gases arising from carbon-containing compounds and, ultimately, are generated as intermediate products in the decomposition, combustion, or conversion of carbon compounds forming CO_2 or CH_4 . There remains much to be learned about the reactivity of VOCs that have the potential to form O_3 , the chemical and physical processes involved in O_3 formation and transport in the atmosphere, and the physiological effects that O_3 has on living things.

Ozone in the lowest portion of the atmosphere (the troposphere) occurs naturally since there are natural sources of VOCs and NO_x that react to form O_3 in the presence of sunlight. Background concentrations of O_3 are typically 20 to 30 parts per billion (ppb). Ozone,

or O_3 , can be formed from lightning and sometimes penetrates into the troposphere from the atmosphere above (referred to as the “stratosphere”) during violent storms. Thus, stratospheric O_3 (the area of the atmosphere where O_3 is needed to block harmful radiation) may reach the troposphere as a result of violent vertical mixing.

Ozone in the troposphere is considered an air pollutant. It can be formed from either natural or anthropogenic source combinations of VOCs and NO_x reacting photochemically. Ozone is very reactive and can be harmful to plants, animals, and humans. Ambient O_3 concentrations vary seasonally, daily, hourly, and spatially and generally increase with increasing elevation within the planetary boundary layer of the atmosphere.

In contrast, stratospheric O_3 is naturally occurring and is necessary to protect living systems from harmful ultraviolet (UV) radiation from the Sun. In fact, there is concern that some anthropogenically created compounds, like chlorofluorocarbons, can deplete stratospheric O_3 (the “ozone hole”) and create harmful conditions at the Earth’s surface with increased UV radiation.

Ground-level O_3 is thus a focal point of air quality management activities associated with agriculture, particularly in O_3 nonattainment areas and areas immediately upwind, with the focus on reducing VOC and NO_x emissions from agricultural activities.

Ozone is a significant human health issue. Since O_3 is an allotrope of oxygen, its similar structure allows it to displace O_2 in the alveoli of the lungs. When this occurs, respiratory issues ensue. As with PM, the elderly, the young, and those with respiratory issues are most affected. Similarly, O_3 is an eye irritant that causes red, itchy eyes. Plants are also affected by O_3 . During the gas exchange process, O_3 enters the leaves through the stomata, causing chlorosis and necrosis. This reduces the plant’s photosynthetic ability and can result in reduced plant growth and lower crop yield.

(3) Odors

Odors are an issue when they are considered to be either undesirable and/or a nuisance to humans. Odor is usually associated with the sensation that results when olfactory receptors in the nose are stimulated by particular chemicals in gaseous form. There are a

number of gases that are most notably associated with objectionable odors from agricultural operations, but the principal ones are VOCs, NH_3 , and various sulfur compounds (including hydrogen sulfide (H_2S) and mercaptans).

Odors are mainly a local and a community perception issue, meaning that they can become a significant issue if they are perceived negatively by the neighboring population. As urban encroachment into rural areas increases, air quality concerns over odors will continue to become more significant. Although there are hundreds of odorous compounds, the main classes of agricultural odorous compounds originate primarily from animal-related production.

Gases that are determined to be objectionable can sometimes also be harmful. Oppositely, there are many odorless compounds (like carbon monoxide and CH_4) that are extremely harmful to humans in sufficiently high concentrations. Odors are addressed as a NRCS resource concern when they pose a nuisance problem.

There are no NAAQS or other EPA air regulations specifically for odors. The regulation of odors has been assumed by States and local jurisdictions. The chemical identification and quantification of odor-causing agents can be technically challenging and expensive. Because of this, odor regulations are typically based on odor thresholds as determined by odor panels or trained odor “sniffers.” The regulatory aspects of odors are addressed in detail in NEH 629.04.

(4) Greenhouse gases and carbon sequestration

GHG and carbon sequestration are significant but nontraditional air quality issues. None of the major GHG have direct impacts on humans (at least not at the typical concentrations found in the atmosphere), and there are no NAAQS for GHG. They are of concern because they are associated with changes in the net radiation balance, and thus the climate of the Earth. These gases derive their name from the term “greenhouse effect,” a process in which certain gases (i.e., GHG) in the atmosphere effectively absorb long wave infrared radiation from the Earth and then reemit some of it back to the Earth’s surface, thereby warming the Earth. Water vapor is the most significant GHG, but its concentration in the atmosphere is not greatly impacted on a global basis by human activities. There are three principal GHGs of concern relative to agri-

cultural production and natural resource management: CO_2 , N_2O , and CH_4 . Agriculture and natural systems are both emitters of all three of these GHGs, as well as absorbers—especially of CO_2 . Plants and soils are repositories or sinks for atmospheric CO_2 , and good land and natural resource management often enhances this process. The formal term for this is “carbon sequestration,” which is the removal from the atmosphere and secure storage of carbon in oceans, forests, soils, or geologic materials through biological processes such as photosynthesis or synthetic processes such as deep injection.

The three primary GHGs are of chief concern to NRCS and agriculture because of their impact on the global atmosphere and consequent changes in weather and ecosystem responses. These gases mix well throughout the atmosphere and concentrations are not greatly different from one part of the world to another. In fact, the most famous historical records of CO_2 are taken on the top of Mauna Loa on the Big Island of Hawaii.

Carbon dioxide, or CO_2 , CH_4 , and N_2O are of greatest concern because of their influence on the radiation balance of the Earth. All three gases allow shortwave radiation from the Sun to enter the Earth’s atmosphere, but absorb some of the longer wavelength radiation emitted from the Earth’s surface. As a result, the Earth is much warmer than it would be without the presence of these GHGs. Anthropogenic increases in these three gases, especially since the industrial revolution, may be changing the Earth’s climate. There may be a tendency for a warmer atmosphere as a result, and a warmer atmosphere can potentially hold more water vapor. Thus, there is concern about changes in the Earth’s climate and weather. These gases also may have more direct impacts, for instance enhanced plant growth with increasing CO_2 levels. However, these impacts are not necessarily straightforward or well understood.

It is important to note that not all GHGs affect the atmosphere in the same manner. GHGs are described in units of CO_2 equivalents as a measure of their potential to warm the atmosphere, and this is sometimes referred to as global warming potential (GWP). On a molecule by molecule basis, N_2O is approximately 300 times more potent at warming the atmosphere than CO_2 , and CH_4 is approximately 20 times more potent. However, CO_2 is produced in much greater quantities than CH_4 or N_2O . Thus, in the global atmosphere, CO_2

remains the primary gas of interest, but because of their greater potential to disrupt the radiation balance on a molecular basis, N_2O and CH_4 are significant issues of concern from agriculture as well.

(b) Scales of impacts of resource concerns

Each of these four major air quality resource concerns operates at one or more primary spatial scales. It is useful to keep these scales of influence in mind when using conservation activities to address each of them.

(i) Local

Odors primarily are a local scale issue, generally impacting receptors of concern within a range of a few miles, at most. Proximity to odor sources is a key issue. The closer the source to a critical receptor, the more likely there will be some type of nuisance issue.

PM also can be a local scale issue. Dust from unpaved roads, bare fields, other crop and livestock areas, and rangeland can create PM-related issues such as visibility concerns close to sources. Smoke can cause visibility, health, and deposition issues in the local area.

(ii) Regional

PM also can operate at regional scales (multiple counties to States). Larger dust and smoke events can result in the transport of PM tens and hundreds of miles from the source. Secondary (indirect) PM impacts typically are at these scales. $PM_{2.5}$ formed in this fashion is sometimes many miles from the sources of the individual components and can be transported great distances before being deposited or changed.

Ozone is primarily a regional issue. Like secondary PM, both NO_x and VOC sources may be some distance from where they eventually meet and form O_3 in the presence of sunlight. For instance, a power plant may generate NO_x that is transported several hundred miles to a region with relatively high VOC levels, and then on a sunny, warm day, O_3 is formed. The O_3 may then remain aloft for some time and can be transported even further from the region of formation. Indeed, in some cases, summertime O_3 in the Eastern United States can cover 10 to 20 States.

(iii) Global

GHGs are almost entirely a global issue because they do not create local or regional air quality issues. Their effects are at the global scale where they influence atmospheric processes.

PM can be a global issue in extreme cases. For instance, dust from one continent can sometimes be carried thousands of miles to another. Examples of this include dust from the Sahara desert being transported westward on easterly trade winds across the Atlantic to the Southeastern United States and dust from China's Gobi desert blowing across the Pacific Ocean and into the Western United States. Smoke from large fires or smoke and/or PM from volcanic eruptions similarly can sometimes become global issues. Very large volcanic eruptions have produced so much PM and transported it globally, that they have influenced temperatures worldwide for several years (such as Krakatoa in 1883).

Ozone may occasionally become a global issue if it is transported from one continent to another, though this is relatively rare. In most cases, O_3 operates at the regional scale, and long range transport typically causes it to dissipate or degrade because of its chemical reactivity.

629.0102 Principal agricultural air emissions: types, sources, and generating mechanisms

While there are a plethora of potential air emissions from agriculturally related activities, eight emissions are chiefly responsible for the bulk of the issues associated with the four air resource concerns described. Understanding these eight, including their sources and their control, will help achieve NRCS air quality objectives.

These eight emissions and the primary NRCS air resource concerns associated with them are:

- direct particulate matter emissions (PM)
- ammonia, or NH_3 (odors, PM)
- volatile organic compounds (O_3 precursor, odors, PM)
- oxides of nitrogen, or NO_x (O_3 precursor, PM)
- odorous sulfur compounds (odors)
- carbon dioxide, or CO_2 (GHGs)
- methane, or CH_4 (GHGs)
- nitrous oxide, or N_2O (GHGs)

(a) Direct particulate matter emissions

Direct PM emissions are those that are entrained into the air directly. Nearly all agricultural direct PM emissions are fugitive emissions; that is, they are not point sources, such as from a single smokestack, but rather are dispersed and scattered in their sources. Direct PM emissions have a variety of sources including road travel, tillage and other field operations, engine emissions, chemical drift, harvesting, wind erosion, burning, various animal operations, and animal movement. Each of these activities produces PM (typically larger PM, or PM_{10}). The mechanical abrasion of equipment moving across unpaved surfaces releases PM that can be readily entrained into the atmosphere. In the same way, harvesting operations generate dust, as well as PM from onsite processing applications, to produce directly emitted PM. An example of this is an almond harvest, which can generate significant amounts of

dust from the windrowing, collection, and cleaning activities in the orchard. Pesticide applications can produce various size distributions of PM as well. Droplets that do not hit their target and become entrained into the atmosphere (chemical drift) can be a significant issue to human health, plants, animals, and even soil. An additional issue with this is that pesticides can volatilize in the air and produce fine PM (and other emissions). Although stopping PM emissions completely from these sources is impossible, understanding how each source produces PM can aid in conservation plans that greatly reduce the amount and type of PM emitted or formed in the atmosphere.

(b) Ammonia

Ammonia, or NH_3 , is an odorous compound and a PM precursor emission derived primarily from animal operations and fertilizers. Agriculture is the largest emitter of NH_3 , accounting globally for up to 70 percent of all NH_3 released into the atmosphere. NH_3 is one of the important gases that participates in complex atmospheric chemical reactions to form fine PM in the atmosphere, commonly referred to as gas-to-particle conversions. These inorganic forms of secondary $\text{PM}_{2.5}$ are ammonium nitrate and ammonium sulfate and because of their small size can be health issues. These compounds also can deposit (wet and dry) onto soils, vegetation, and water bodies where they can lead to acidification of soil and water. Sources of NH_3 include nitrogen-based compounds in one of several forms from common fertilizers, which can volatilize and release NH_3 into the atmosphere. In general, NH_3 emissions are highest when soil pH and temperatures are high and fertilizers are surface applied. Most NH_3 emissions occur within the first few days after application. Another NH_3 source is from livestock production, where NH_3 is emitted as a result of the microbial conversion of nitrogen. Many animals are fed high-protein diets that contain relatively high concentrations of nitrogen, which are metabolized into animal proteins in products such as milk, eggs, and meat. Excess nitrogen is excreted mainly in the form of urea or uric acid, which can yield NH_3 emissions. The rate of NH_3 volatilization and disbursement is influenced by temperature, wind velocity, and manure properties, such as nitrogen content, pH, and moisture content. Approximately 35 to 40 percent of livestock NH_3 emissions are associated with the land application of manure, and nearly 35 percent are associated with housing, followed by

smaller percentages from manure storage (including lagoons) and grazing land.

(c) Volatile organic compounds

As mentioned, VOCs are gases arising from carbon-containing compounds, and ultimately are generated as intermediate products in the decomposition, combustion, or conversion of carbon compounds forming CO_2 or CH_4 . Most naturally produced VOCs are the result of the microbial conversion of longer chain carbon compounds into shorter chain carbon compounds, typically as an intermediate step in metabolism processes. In fact, VOCs:

- are produced by all living organisms (including humans)
- have high vapor pressures and thus can vaporize rather readily into the atmosphere
- are of concern because they can contribute to O_3 formation,
- can have very objectionable odors
- can be particulates
- are sometimes referred to as reactive organic gases

To be classified as a VOC, the compound must be photochemically reactive; thus, CH_4 is not considered a VOC. There are many classes of VOCs, including aldehydes, alcohols, and certain hydrocarbons. Regarding O_3 , those VOCs that chemically react with NO_x in the presence of sunlight are the most important to address. Animals can produce VOCs through the natural digestion process, and manure decomposition also releases VOCs. Animal VOCs include alcohols and volatile fatty acids.

Pesticides often contain VOCs, which may be released during storage, transport, application, or after application. This typically is a function of ambient temperature. Fumigants (such as methyl bromide) are a primary source of VOCs, most notably for field soil applications. Many plants naturally emit VOCs, including isoprenes and terpenes. Not all of these VOCs are reactive, but in those areas with naturally significant VOC background levels (such as most of the southeastern United States), if NO_x levels are high enough (from combustion sources), there can be significant O_3

formation (a common issue in the region during sunny summertime conditions).

(d) Oxides of nitrogen

Oxides of nitrogen is a generic term that includes both NO and NO_2 . Both are considered reactive nitrogen compounds. NO_x can play an important role in the formation of ground-level O_3 and fine PM. NO_x is generated either as a product of combustion (nitrogen in the fuel or air combines with O_2 in the air under combustion temperatures) or as an intermediate product in the nitrification and denitrification cycle in soils and manures. Agriculture produces some NO_x , though not as significantly as from other economic sectors where combustion is large—notably electricity generation, transportation, and industry. Nevertheless, there is concern about NO_x emissions from agriculture, particularly in areas where O_3 is a regulated pollutant. In agriculture, NO_x form as a result of several factors. In animal production, they originate from microbial nitrogen conversion in manure and the application of nutrients or fertilizers. The other major agricultural source is associated with the combustion process in fires and engines. In fires, NO_x emissions are primarily dependent upon the nitrogen levels in the burned material or on the temperature of the fire (the hotter the fire, the greater the NO_x emissions). In engines, NO_x emissions are a result of nitrogen in the air and fuel combining with O_2 in the air during combustion.

(e) Odorous sulfur compounds

Included in agricultural air emissions are gases known as odorous sulfur compounds, so known because they all contain sulfur in one form or another. These sulfur compounds, such as H_2S , have notably objectionable odors—in this case, the classic “rotten egg smell.” These compounds are generated from the anaerobic conversion of sulfur compounds, mainly in manure, but also possible in large composting operations. During times of manure agitation, the release of odorous sulfur compounds in solution in the manure can increase. The type of animal feed used also dictates the production of odorous sulfur compounds from the animals themselves, as well as from their manure. Land application of manure is another potentially significant emission source for these compounds, while manure incorporation into the soil can reduce these

emissions. Manure storage also is a possible source of sulfur emissions.

(f) Carbon dioxide

Carbon dioxide is not an air pollutant, but a very necessary and natural part of living systems. CO_2 is released as part of the respiration process in humans and animals and is taken in by plants in the photosynthesis process. CO_2 can be considered a trace gas compared to nitrogen and O_2 , comprising only 0.10 percent of the atmosphere. Nevertheless, it also plays an important role as a GHG in regulating the Earth's temperature and, therefore, the climate. Anthropogenic CO_2 sources are implicated in climate change. CO_2 levels have risen from approximately 310 parts per million (ppm) in the 1950s to more than 380 ppm today. This increase is of concern because climate models predict that further increases will increase global average temperatures by several degrees, with possible ensuing changes to other aspects of climate.

For this reason alone, management of CO_2 and the other two primary GHGs is now a significant issue. There are many natural sources of CO_2 . The focus on CO_2 management, though, is on those nonnatural sources that are associated with the build-up of atmospheric CO_2 over the past century. Most notably are combustion processes that release CO_2 . This includes the burning of fossil fuels, including coal, petroleum, and natural gas. Agricultural sources of CO_2 emissions include those activities that utilize combustion (engines, fires), and soil manipulation. Soils are a reservoir of carbon and when tilled, especially for the first time, a significant amount of carbon is lost from the soil and released into the atmosphere as CO_2 . Biomass also is largely made up of carbon and when it decomposes or is burned, it releases CO_2 to the atmosphere. Many of these are natural ecosystem processes, while others have been enhanced by agricultural activities. Other agriculturally related activities that release CO_2 include the production of NH_3 (such as anhydrous NH_3 fertilizer) and lime manufacture.

(g) Methane

Methane, or CH_4 , is the principal constituent in natural gas and biogas and is an important GHG. Its contribution to the greenhouse effect enhancement is one of the biggest concerns with this odorless gas. On a

molecular basis, CH_4 is approximately 21 times more powerful than CO_2 in its potential to cause warming (due to its molecular structure and other properties). Because of this, CH_4 emissions management is an important issue. Natural sources of CH_4 include the anaerobic decomposition of organic material by methanogenic bacteria, with the vast majority of this activity occurring in wetlands, and naturally emitted by termites. It is estimated that about 40 percent of the global emissions of CH_4 are from these (and a few other) natural processes. CH_4 sources include landfills, natural gas facilities, coal mining, and waste treatment facilities. Rice cultivation and the burning of crop and other biomass residues also contribute significantly to CH_4 emissions. Agriculture represents a modest percentage of all global CH_4 emissions, and of these agricultural emissions, most come from enteric fermentation (and most of that is belched out of these animals).

(h) Nitrous oxide

The most potent GHG (on a molecular basis) of concern to agriculture and natural resources managers is N_2O . Fortunately, N_2O concentrations in the atmosphere remain extremely small and much less than CO_2 . Nevertheless, N_2O remains a focal GHG for agriculture because its GWP is approximately 300 times that of CO_2 and because agricultural activities are responsible for a significant portion of total N_2O emissions. N_2O also is classified with the group of compounds known as reactive nitrogen. Agricultural processes most responsible for N_2O emissions are the conversion of nitrogen in the soil, nitrogen conversion in manure piles, and biomass burning. By far, the largest of these is the direct emission of N_2O from fertilizer applications to the soil. In general, N_2O soil emissions are a function of the nitrification/denitrification process, and an ideal setup for N_2O generation is with dry soils embedded with pockets of anaerobic (usually saturated) activity.

629.0103 Principles of agricultural air emissions management in conservation planning

Reducing emissions involves a holistic approach to SWAPA+H and must consider alternative and multiple methods of reduction. For example, a land manager might consider switching from diesel fuel to biodiesel along with increasing the number of no-till acres. The combination of reduced engine emissions, less time in the field, and different tillage practices will result in a greater reduction of PM than choosing only one method. In this scenario, reductions in O₃ precursors (NO_x) and GHG (CO₂) also will result, as well as enhanced carbon sequestration.

Each of the succeeding air quality chapters in this set of documents provides guidance on how to integrate management of these air resource concerns with other resource concerns, such as soil and water quality. It is important to remember that narrowly focused solutions to single resource concerns can exacerbate or create other concerns. Thus, management should include a very thoughtful consideration of how these air emissions and their control may interact with other resource concerns.

629.0104 Summary

The establishment of the Agency is often attributed to the long-range transport of particulates into Washington, DC, from the Dust Bowl region of the United States, but it took more than half a century for air quality issues to become part of the NRCS's mission goals. As agricultural operations have grown in size and the urban-rural community interface has narrowed, concerns about agricultural air emissions on the population and environment have grown. This concern is greatest in areas where the human population and air pollution has spread into rural areas and where ambient air measurements have led to nonattainment designations of NAAQS. Agricultural air quality will continue to be a priority of the agency as the Nation's agricultural operations and urban areas continue to overlap. The establishment of air resource concerns and the information provided in the NEH 629 chapters will provide valuable information to assist NRCS personnel and agricultural producers make decisions on air quality issues.