Designation: ~~D5111 – 99 (Reapproved 2006)~~ D5111 – 12

Standard Guide for Choosing Locations and Sampling Methods to Monitor Atmospheric Deposition at Non-Urban Locations[1]

This standard is issued under the fixed designation D5111; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide assists individuals or agencies in identifying suitable locations and choosing appropriate sampling strategies for monitoring atmospheric deposition at non-urban locations. It does not purport to discuss all aspects of designing atmospheric deposition monitoring networks.

1.2 The guide is suitable for use in obtaining estimates of the dominant inorganic constituents and trace metals found in acidic deposition. It addresses both wet and dry deposition and includes cloud water, fog and snow.

1.3 The guide is best used to determine estimates of atmospheric deposition in non-urban areas although many of the sampling methods presented can be applied to urban environments.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

2. Referenced Documents

2.1 *ASTM Standards:*[2]
D1356 Terminology Relating to Sampling and Analysis of Atmospheres
D1357 Practice for Planning the Sampling of the Ambient Atmosphere
D3249 Practice for General Ambient Air Analyzer Procedures
D4841 Practice for Estimation of Holding Time for Water Samples Containing Organic and Inorganic Constituents
D5012 Guide for Preparation of Materials Used for the Collection and Preservation of Atmospheric Wet Deposition

3. Terminology

3.1 For definitions of terms used in this guide, refer to Terminology D1356.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *collocated sampling*—the use of more than one sampling device within a monitoring site.

3.2.2 *event sampling*—a special form of intermittent sampling (Terminology D1356) where the duration of a sampling period is defined as a single, discrete occurrence of precipitation, dew, fog or frost.

3.2.3 *fetch*—a vector within the local area which describes the direction and area of, or within, an air mass that will be sampled by a sampling device.

3.2.4 *filter-pack*—a sampling device comprised of one or more filters in series where each filter is designed to sample an atmospheric chemical species or remove interferences to a subsequent filter. Filters may be of different design; material; or be coated or impregnated to obtain the specificity of chemical species required.

3.2.5 *inferential sampling*—an indirect sampling method that utilizes a mathematical model to quantify an unmeasurable or difficult to measure property of atmospheric deposition.

3.2.6 *local area*—an area of a few square kilometers which describes an area of common vegetation, land-surface form and land use surrounding the monitoring site and defines the local characteristics surrounding the sampling device, see Fig. 1.

3.2.7 *monitoring site*—a radius of a few decameters which immediately surrounds the sampling device, see Fig. 1.

[1] This guide is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.03 on Ambient Atmospheres and Source Emissions.

Current edition approved ~~April 1, 2006~~Oct. 1, 2012. Published ~~June 2006~~November 2012. Originally approved in 1990. Last previous edition approved in ~~1999~~2006 as ~~D5111 - 99.~~D5111 - 99 (2006). DOI: ~~10.1520/D5111-99R06.~~10.1520/D5111-12.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

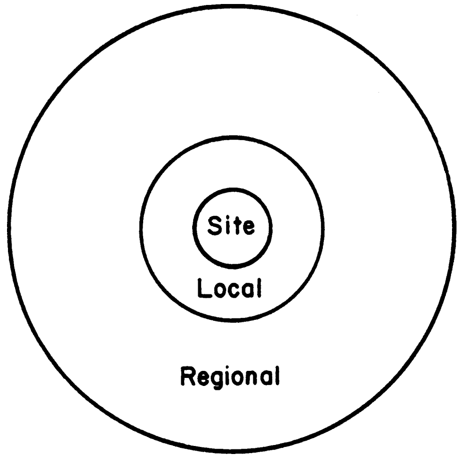

FIG. 1 Diagram of Siting Guidelines

3.2.8 *regional area*—an area between the local area and a threshold that defines where any single local area characteristic can not be distinguished from regional characteristics, see Fig. 1.

3.2.9 *sequential sampling*—withdrawal of a portion of the atmosphere over a period of time with continuous analysis or with separation of the desired material continuously and in a linear form. Such a sample may be obtained with a considerable concentration of the contaminant but it still indicates fluctuations in that property which occur during the period of sampling (Terminology D1356; see *sample, running*).

3.2.10 *surrogate surface sampling*—a sampling technique that utilizes an artificial surface to estimate dry deposition. Ideally, the artificial surface chosen will approximate the real surface's roughness and wetness properties. In practice this is impossible. Therefore, comparisons of the surrogate surface to the real surface must always be done as a part of the technique.

3.2.11 *wet deposition*—the deposition of water from the atmosphere in the form of hail, mist, rain, sleet and snow. Deposits of dew, fog and frost are excluded (Terminology D1356; see *precipitation, meteorological*).

4. Significance and Use

4.1 The guide consolidates into one document, siting criteria and sampling strategies used routinely in various North American atmospheric deposition monitoring programs.

4.2 The guide leads the user through the steps of site selection, sampling frequency and sampling equipment selection, and presents quality assurance techniques and other considerations necessary to obtain a representative deposition sample for subsequent chemical analysis.

4.3 The guide extends Practice D1357 to include specific guidelines for sampling atmospheric deposition including acidic deposition.

5. Summary of Guide

5.1 The guide assists the user in establishing siting guidelines and in choosing sampling frequencies and sampling devices for atmospheric deposition monitoring. Special considerations for the monitoring of specific types of atmospheric deposition are discussed.

5.2 A worksheet is provided to assist the user in documenting the final siting criteria and sampling strategy chosen—see Appendix X1.

5.3 The guide references site selection and sampling documents of some of the currently operating deposition monitoring networks in North America (Appendix X2).

6. Sampling Locations

6.1 *General Requirements:*

6.1.1 General requirements for choosing atmospheric deposition sampling locations follow Practice D1357. This guide should be used in conjunction with that document.

6.1.2 A standardized site description questionnaire should be developed and completed during the site selection process. The questionnaire will describe the chosen location in detail. Examples of these questionnaires can be found in Refs **(1-3)**.[3]

[3] Boldface numbers in parentheses refer to references at the end of this guide.

6.1.3 Fig. 1 illustrates the concentric organization of location guidelines used in this document. Monitoring site requirements are common to all types of monitoring stations, while regional area requirements invoke a combination of monitoring site, local area and regional area guidelines. Which guidelines within each area category are chosen and whether all area categories are used will depend upon the purpose of the monitoring effort.

6.1.4 Some specific atmospheric deposition sample types require that additional criteria be met. These are identified ~~towards~~near the end of each sampling location section with an appropriate key word; DRY for dry deposition; FOG for fog; etc. Guidelines that contain no key word are common to all types of deposition monitoring within their monitoring site, local area, or regional area grouping.

6.1.5 The user of this guide should use all of the guidelines listed for the deposition type being monitored and all of the guidelines that are not deposition type specific. Exceptions to the use of all of the guidelines should be noted on the worksheet in Appendix X1 of the guide and be accompanied with a brief exclusion statement.

6.2 *Regional Area Guidelines:*

6.2.1 Regional area guidelines should be based upon a consensus interpretation of the concept of regional representativeness by the monitoring project management. Regions may be identified based upon physiography, meteorology, demography or some other more specific goal of the monitoring project. Ground-based concepts of representativeness, such as the ecological classifications of Bailey and others **(4,5)** or areas sensitive to ~~acid~~acidic deposition, are often more easily defined than meteorological concepts which tend to be highly variable both spatially and temporally. For this reason definitions of regional representativeness based heavily upon meteorological phenomena are best developed *a posteriori* using mathematical and statistical models **(6)**.

6.2.2 When developing regional area guidelines, distance criteria should reflect the thresholds where any characteristics of a local area become indistinguishable from those of other local areas and are instead typical of the area that will be declared a region.

~~6.2.3 Population centers of greater than 10 000 should be at least 10 km from the sampling device. This distance should be increased dramatically if the sampling device is located downwind of the center in the prevailing wind direction.~~

6.2.3 All industrial and natural sources of emissions greater than 10 000 tons per annum of each analyte of interest should be at least ~~10~~20 km from the sampling device. This distance should be increased ~~dramatically~~ if the sampling device is located downwind of the source in the prevailing wind direction.

6.2.4 Complex terrain should be avoided unless its influence is necessary to meet the specific goal of the monitoring effort.

6.3 *Local Area Guidelines:*

6.3.1 The local area surrounding a monitoring site should describe a small geographic area where land use, topography and meteorology are common and representative of the regional area. No single emission source should dominate the air quality at the site except as it typifies the common emission characteristics of the regional area. Ideal sites will be located in areas where land use practices are not expected to change over the course of the monitoring effort.

6.3.2 Emission source amounts, their frequency and intensity, and meteorological diversity will dominate the actual influence of each guideline on samples collected in any monitoring program. Because of this, local area guidelines are typically the portion of a site selection plan that is not met. A relaxation of the guidelines can be tolerated when the impact of non-compliance on program objectives can be quantified.

6.3.3 Monitoring sites should be ~~located away from population centers. A recommended distance is 1 km per 1000 persons.~~classified according to the surrounding population density within 15 km radius of the site. See Table 1.

6.3.4 Intensive agricultural and waste treatment activities should be more than 500 meters from the sampling device. Dairy operations, crop cultivation, especially in areas where chemical applications are used and solid waste and wastewater treatment facilities are of particular concern.

6.3.5 Transportation related sources of emissions should be no closer than 100 meters from the sampling device. Parking lots, unpaved roadways and high volume vehicular, railroad and airplane traffic are of particular concern. One hundred meters is a minimum acceptable distance cited by some of the existing atmospheric monitoring networks (See X2.3-X2.5). The distance should be increased in proportion to increases in traffic volume and diversity. One kilometer is considered adequate under most conditions.

6.3.6 The open or surface storage of agricultural or industrial products should be kept at least 100 m from the sampling device. Examples of these products would include salt and sand piles, fuels and chemicals.

TABLE 1 Site Classification

Site Classification	Population within 15 km of the site (people/km^2)
Isolated	< 10
Rural	10 – 99
Suburban	100 – 399
Urban	>400
Research	not applicable

6.3.7 *Dry*—For methods employing the estimation or use of atmospheric fluxes (see 9.2.3 and 9.2.9), the surface micro-meteorology and surface composition should be as uniform as possible within 500 m of the sampling device.

NOTE 1—The success of tower based eddy correlation techniques and many other dry deposition techniques utilizing deposition velocity estimates, are dependent upon the uniformity of the upwind surface roughness and wetness. If the upwind micro-meteorology and surface characteristics enhance the turbulent mixing of the parameter of interest as it approaches the point sampling then the distance requirements for fetch can sometimes be relaxed. If on the other hand deposition rate estimates are expected to be small, the fetch distance requirements may need to be increased (**(7)** see 9.2.3).

6.3.8 *Dry*—For methods employing the estimation of atmospheric fluxes, see 9.2.3, the sampling device should be located at least 5 km from prominent discontinuities in terrain such as large bodies of water, isolated hills or valleys and cliffs.

6.4 *Monitoring Site Guidelines:*

6.4.1 Monitoring sites should be located on naturally vegetated or grassed, open, level areas. Ground cover should be homogeneous and the area should slope no more than 15 %.

6.4.2 The distance from the sampling device to any object greater than the height of the sampling device should be at least twice the height of the object (2:1). This will ensure that no object or structure will project onto the sampling device with an angle greater than 30° from the ~~horizontal.~~horizontal plane measured from the sample orifice.

6.4.3 With the exception of wind shields, objects with sufficient mass to deflect the wind or otherwise change the aerodynamic properties of the sampling device should be located no closer than 2 m from the sampling device.

NOTE 2—Wind shields are considered to be an integral part of the sampling device in this guide.

6.4.4 Residential structures should be outside of a 30° cone of the prevailing wind ~~direction.~~direction measured from the sample orifice.

6.4.5 Sampling devices should be oriented towards the annual averaged prevailing wind. In the absence of site specific wind direction information projects should standardize the orientation of the device to one direction.

6.4.6 ~~Seasonal vegetation should be maintained at a level that is at least 1 meter below the orifice~~ Within 5m of the sampling ~~device to a distance that defines one-half of the monitoring site.~~device, vegetation should be less than 0.6m in height as measured from its base.

6.4.7 Grazing animals and the cultivation of agricultural crops should not be permitted within the monitoring site.

6.4.8 All activities not directly related to sampling should be discouraged within the monitoring site.

6.4.9 *Snow*—The sampling device should be located in a setting that is sheltered from the wind. Locating the monitoring site within a forest clearing or installing a wind shield around the sampling device improves snow capture **(8)**.

NOTE 3—Wind speeds in excess of 1 m/sec significantly reduce the efficiency of snow sampling devices **(8)**. Light, dry snows are the most difficult to sample. Reducing or eliminating the wind around the sampling device by either shielding the device or locating the device below the vegetation canopy improves snow capture and eliminates re-entrainment of already collected samples.

6.4.10 *Dry*—For methods utilizing towers in the estimation of atmospheric fluxes (9.2.3), the tower heights should be standardized and be at least 5 meters above the surface of interest (for example, forest canopy and agricultural crops). For measurements over bare ground this distance may need to be doubled.

6.4.11 *Dry*—Methods utilizing micro-meteorological measurements in the estimation of atmospheric deposition require stricter slope requirements of 5 % and stricter projection requirements of 5:1, see 6.4.1 and 6.4.2.

7. General Sampling Requirements

7.1 Once the goals of the monitoring effort have been established and site locations have been identified, sampling frequency and sampling equipment decisions can be made. Location decisions should be made in advance of sampling decisions since, in addition to cost, the latter are almost always limited by site availability and accessibility.

7.2 The choice of a sampling method for atmospheric deposition monitoring oftentimes will be a compromise brought about by the availability of a suitable site, the ability of a particular sampling device to selectively measure the deposition type and chemical species of interest, and the differences in cost of implementing some of the available techniques. The selection of sampling intervals and sampling devices may be an iterative exercise especially if a wide variety of chemical species are of interest.

7.3 Users of this guide should recognize that all of the sampling techniques mentioned in this guide are not directly comparable and may not be interchangeable. Comparability, especially in the area of dry deposition, has only recently begun. For projects requiring a wide variety of deposition estimates or short sampling intervals, this often means selecting multiple methods.

7.4 Projects requiring comparability or additivity of estimates derived from more than one method should establish the level of uncertainty in using this approach.

8. Sampling Frequency

8.1 *Continuous Sampling:*

8.1.1 Continuous Sampling in the context of atmospheric deposition monitoring is a combination of both continuous and instantaneous sampling (Terminology D1356). It is frequently used for the estimation of ambient air concentrations in sampling techniques which compute dry deposition rates. Continuous measurements are typically the most expensive form of measurements to obtain since they most always require sophisticated instrumentation and a high level of expertise to minimize and troubleshoot periods of non-sampling.

8.1.2 Continuous sampling should only be considered when instantaneously sampled deposition data are necessary, as in dose response types of effects studies, when averaged information is necessary to statistically reduce error estimates, or, as in the calculation of dry deposition rates, instantaneous sampling results must be paired with instantaneous meteorological measurements.

8.1.3 General recommendations for continuous ambient air analyzers are given in Practice D3249.

8.2 *Cumulative Sampling:*

8.2.1 Cumulative samples represent a temporal composite or integration of the parameter being monitored. The length of time a sample accumulates in the sampling device can be adjusted to match the temporal resolution required in the monitoring program. Intervals of days through months are typical for wet deposition and hours through weeks are typical for dry deposition. Cumulative sampling is the most widely used technique in both wet and dry deposition.

8.2.2 When using cumulative sampling, attention must be paid to the possibility of sample degradation that can occur during the accumulating time period. Short accumulation times are recommended, especially when samples are not preserved. Both loss and transformation of chemical species have been observed in cumulative samples **(9,10)**.

8.2.3 Cumulative sampling can be used to reduce the number of samples collected and analyzed along with their associated costs, and to increase the sensitivity of a method by averaging over time. Filter packs, denuders and impingers all use the principle of cumulative sampling.

8.3 *Event Sampling:*

8.3.1 Event sampling is a special form of intermittent sampling used to collect liquid deposition from discrete occurrences of precipitation, dew, frost, and fog.

8.3.2 Event sampling is used for studying atmospheric processes and for determining noncumulative effects of atmospheric deposition on agricultural and natural ecosystems. Event sampling is especially useful when monitoring objectives are associated with episodic phenomena such as storm types, direction or intensity, or when the tracking of a parameter through time and space is required.

8.3.3 Event sampling is less susceptible to the sample integrity problems associated with cumulative sampling **(9,10)**. This is especially noticeable when events are of short duration (for example, less than days).

8.3.4 Event sampling is not an effective monitoring frequency when the predominant sample collected contains too small an amount of analyte mass for analysis or consistently produces analyte concentrations below the method detection limit. The cost of standby time (time waiting for events to occur) should also be considered when selecting event sampling frequencies.

8.4 *Sequential Sampling:*

8.4.1 Sequential sampling is used to characterize within event variability. Sequential sampling strategies typically break events into consecutive, equal-volume or equal-time subsamples of the event. Like event sampling, sequential sampling is limited to liquid deposition types and is used to study atmospheric processes.

8.4.2 Sequential sampling should only be used when project goals emphasize within event variability as more or equally as important as between event variability. It is seldom considered for long-term monitoring.

8.4.3 All of the cautions of event sampling—see 8.3.3 and 8.3.4—also apply to sequential sampling.

9. Sampling Devices and Techniques

9.1 *Wet Deposition:*

9.1.1 *General Characteristics*—Wet deposition sampling devices typically consist of a precipitation detector or sensor and a mechanically operated lid which covers a sample container or inlet. The sensor detects the presence of water and activates the mechanical lid which exposes the sample container or inlet to precipitation. At the cessation of precipitation the lid returns to a position which protects the sample container from dry deposition. Any sampling system that has the ability to capture wet-only precipitation and protect the captured sample from dry deposition can be used.

9.1.2 A wet deposition collector is designed to capture a representative sample of precipitation for subsequent chemical analysis and prevent this captured precipitation from mixing with other forms of deposition. Because the emphasis of the design is towards representative chemistry and not necessarily on the quantification of precipitation amount, the collector should not be relied upon for estimates of precipitation volume (see 9.1.4).

9.1.3 *Precipitation Sensors*—~~Most precipitation sensors~~ There are two common types of precipitation sensors: resistance, and optical. Sensors that work on a resistance ~~principle, interrupting or establishing~~ principle open an electrical ~~current when their surface becomes wet. Heating devices in the sensor attempt~~ circuit when the sensor is dry, and close the circuit when wet. When the circuit is closed, the surface of the sensor is heated to evaporate the accumulated ~~water from~~ precipitation and dry the sensor ~~surface, returning the sensor to a dry status. The resistance setting, surface area and heating rate of the sensor determines the~~ surface. The sensitivity of the sensor is determined by the resistance setting, the surface area, and the rate of heating of the sensor's surface. By contrast, optical sensors operate by detecting interruptions in a light path. Incidence filters are used to distinguish between precipitation and other interruptions of the light path (e.g., insects, bird droppings, leaves, etc). The sensitivity of the sensor ~~to the wetness created during a precipitation, fog, dew or frost event. A sensor's selectiveness towards these deposition types can be altered by altering the resistance, heating rate, temperature and surface area of the sensor, and by controlling the response time between the electrical detection of wetness and the activation of the collector's mechanical system. Sensor resistance, heating rates and temperature, surface area and activation delay capability should be chosen to emphasize the goals of the monitoring project.~~is defined by a threshold and a delay. The threshold is the minimum number of interruptions needed within a set period of time. When this value is exceeded, the collector will open. The delay is the amount of time to wait before assessing whether the trigger condition is still met. When the trigger condition is no longer met, the collector will close. Optical sensors may or may not be heated. Heating the surface of an optical sensor prevents the formation of ice, and the accumulation of snow on the sensor's surface. Both conditions may impact the operation of the sensor.

NOTE 4—It should be recognized, that all wet deposition collectors capture small amounts of dew, frost and fog and that the sensor plays a critical role in determining the sensitivity of the collector to these forms of deposition. The sensor design should restrict the collection of dew, frost and fog and improve the likelihood of collecting a wet-deposition-only sample.

9.1.4 *Collector Sampling Efficiency*— Because a wet deposition collector relies on the movement of a mechanical lid to expose its sampling container or activate its sampling system, it does not always open or close in perfect sequence with the initiation or cessation of precipitation. Differences in the collector's aerodynamic design and its' sensor's characteristics will largely determine the suitability of the collector for certain geographic and climatic conditions. Snow accompanied by wind is especially difficult to sample. The performance of the collector under the geographic and seasonal climatic conditions in which it will operate should be established so that sampling biases towards specific deposition types or conditions are minimized and so that the sampling efficiency of the device is characterized. Collector ~~sampling~~ efficiency is best determined ~~by comparing the volume in the wet deposition collector to the volume of a collocated national meteorological service or World Meteorological Organization (WMO) rain gage.~~ using collectors and calibrated rain gages collocated within 30 meters of each other, and having similar sensor exposures.

9.1.5 *Sample Integrity Considerations*— The construction and workings of the mechanical lid which covers the wet deposition sample is a critical component of the wet deposition collector. The lid should be designed in such a manner as to seal the deposition sample during periods of dry deposition in order to minimize the chance for sample degradation due to evaporation, diffusion, thermal decomposition and wind-borne contamination. No device will perform ideally, but careful attention to the workings and materials of construction of the lid will improve the representativeness of the wet deposition sample collected.

9.2 *Dry Deposition:*

9.2.1 *General Principles*—Sampling techniques used for the measurement of dry deposition are as varied as the substances they are designed to quantify. Each requires a different level and area of expertise and has only limited flexibility for sampling a variety of chemical species and deposition types. Most techniques represent innovative approaches to resolving the critical needs of dry deposition sampling in specific locations (forests vs. grasslands) or for specific receptors (such as a plant species or blocks of marble).

9.2.2 Many of the dry deposition estimation techniques involve the measurement of one or more chemical or meteorological parameter and the application of some type of mathematical model to quantify dry deposition. The model may be a simple difference equation or a complex sequence of equations designed to simulate natural science theories under different conditions of meteorology, and other site specific physiographic features.

NOTE 5—The use of a model to estimate dry deposition requires that meteorological and chemical measurement techniques be available for the time and spatial scales used by the model and for the complexity of the terrain. It is further required that the combination of model and measurements be specific to the surface that is receiving the deposition. Models and measurements for most chemical species under various terrain and meteorological conditions are still rather limited. For a more complete compilation of current applications the reader is referred to Ref (**10**).

9.2.3 *Inferential Methods*—These methods require micro-meteorological measurements, air concentration measurements, a suitable mathematical model **(11,12)** that allows the user to infer the dry deposition velocity (V_d) for the chemical species being monitored from the reported micro-meteorological data and site surface observations of specific type and condition. The methods result in deposition rate estimates which can be used to establish deposition loading. The methods are often limited by the lack of chemical analysis techniques or the costs of utilizing continuous gas analyzers. The current models tend to be very specific to terrain, surface composition and surface condition. When choosing these techniques users should be certain that 1) there is an available model for the chemical species and time scale of interest 2) there is a chemical measurement technique for the chemical state and sampling frequency required 3) sampling sites meet the surface composition and condition requirements of the model and 4) the assumptions implicit to the chosen model are appropriate for the proposed project.

9.2.4 For studies requiring chemical measurements spanning days or weeks, continuous meteorological measurements are typically integrated as appropriate to the model. Impingers, denuders and filter packs are the chemical sampling methods of choice**(13)** . Changes in micro-meteorological conditions and in surface characteristics (wetness, stage of growth, etc.) during the sampling period however, often results in abnormal or unrealistic integrations of meteorological or surface parameters causing the models to run outside of their designed limits.