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# FIELD BEHAVIOR OF NBC AGENTS (INCLUDING SMOKE AND INCENDIARIES)

## Table of Contents



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# Preface

Primary users of this manual are NBC staff officers, staff weather officers, fire support coordination personnel, artillery officers, and others involved in planning NBC operations. These soldiers must understand what effect weather and terrain have on nuclear, biological, and chemical (NBC) operations and smoke. This manual contains general information and the basic principles on how to get the best results. Commanders and staffs involved in planning for use of incendiaries or smoke operations will also benefit from the use of this manual along with other references such as FM 3-50, FM 3-100, FM 3-3, FM 3-4, and FM 3-5.

On the battlefield, the influences of weather and terrain on NBC operations provide opportunities to both sides. To retain the initiative, friendly forces leaders and staff officers must understand how weather and terrain can be used to their advantage.

FM 3-6 implements International Standardization Agreement (STANAG) 2103, Reporting Nuclear Detonations, Radioactive Fallout, and Biological and Chemical Attacks and Predicting Associated Hazards.

This manual explains how weather and terrain influence nuclear, biological, and chemical operations and discusses the following topics for use when planning operations:

- Basic principles of meteorology as they pertain to NBC operations.
- Influence of weather on the use and behavior of NBC agents.
- Local weather predictions and their use.
- Influence of terrain on the behavior of NBC agents.
- US Air Force Air Weather Service (AWS) forecasts and their use in planning for operations in an NBC environment. (The Navy gets meteorological forecasts from components of the Naval Oceanography Command. Meteorological report information is in the NAVOCEANCOMINST 3140.1 publications series. It also contains information on the behavior of smoke clouds and incendiaries. In addition, it discusses the influences of weather and terrain on the thermal, blast, and radiation effects of a nuclear detonation.)

Staffs planning the use of chemical weapons and commanders approving strikes must understand basic weather characteristics. Therefore, weather analyses significantly influence the selection of agents and munitions for employment. The target analyst must know his or her weather data needs and where to get this information in a combat environment. Chapter 1 covers meteorology and the impact of weather on chemical agent use. The remaining chapters address the impact of weather on smoke, incendiaries, biological agents, and nuclear detonations.

Users of this publication are encouraged to recommend changes and submit comments for its improvement. Key each comment to the specific page and paragraph in which the change is recommended. Provide a reason for each comment to ensure understanding and complete evaluation. To send changes or comments, prepare DA Form 2028 (Recommended Changes to Publications and Blank Forms) and forward it to Commandant, USACMLS, ATTN: ATZN-CM-NF, Fort McClellan, AL 36205-5020. Air Force comments go to HQ USAF/XOORF, Washington, DC 20330. Marine Corps comments go to Commanding General, Marine Corps Development and Education Command (CO93), Quantico, VA 22134. Navy comments go to Chief of Naval Operations (OP-954), Navy Department, Washington, DC 20350.

# CHAPTER 1

# Chemical Agents

The field behavior of chemical agents is dependent on weather variables such as wind, temperature, air stability, humidity, and precipitation. The influence of each variable depends upon the synoptic situation and is locally influenced by topography, vegetation, and soil.

Chemical agents may appear in the field in different forms: vapors, aerosols, or liquids. To understand the impact of chemical agents on the battlefield, the soldier must also understand how these agents are affected by weather and terrain. The following paragraphs give an overview of the basic characteristics of chemical agents and how weather and terrain influence and have specific effects on them.

## Basic Characteristics

Vapors and small particles are carried by the winds, while any large particles and liquid drops fall out in a ballistic-like trajectory and are quickly deposited on the ground. Many agents give off vapors that form vapor clouds. The speed at which an agent gives off vapors is called volatility. Agents may be removed naturally from the air by falling out (large particles fall out much more quickly), by sticking to the ground or vegetation, or by being removed by precipitation. Once deposited upon vegetation or other ground cover, volatile agents may be re-released to the atmosphere for further cycles of travel and present a hazard until sufficiently diluted or decontaminated.

During approximately the first 30 seconds, the size and travel of an agent are determined primarily by the functioning characteristic of the munition or delivery system. Thereafter, the travel and diffusion of the agent cloud are determined primarily by weather and terrain. For example, in high temperatures, volatile agents produce maximum agent vapor in 15 seconds. Light winds and low turbulence allow high local concentrations of agents. High winds and strong turbulence reduce the concentration and increase the area coverage by more quickly carrying away and diffusing the agent cloud.

### Vapors

When a chemical agent is disseminated as a vapor from a bursting munition, initially the cloud expands, grows cooler and heavier, and tends to retain its form. The height to which the cloud rises, due to its buoyancy, is called the height of the thermally stabilized cloud. If the vapor density of the released agent is less than the vapor density of air, the cloud rises quite rapidly, mixes with the surrounding air, and dilutes rapidly. If the agent forms a dense gas (the vapor density of the released agent is greater than the vapor density of air), the cloud flattens, sinks, and flows over the earth's surface. Generally, cloud growth during the first 30 seconds is more dependent upon the munition or delivery system than upon surrounding meteorological conditions.

Nevertheless, the height to which the cloud eventually rises depends upon air temperature and turbulence. These determine how much cooler, ambient air is pulled into the hot cloud (and, hence, determines its rate of cooling). The agent concentration buildup is influenced by both the amount and speed of agent release and by existing meteorological conditions.

Shortly after release, the agent cloud assumes the temperature of the surrounding air and moves in the direction and at the speed of the surrounding air. The chemical cloud is subjected to turbulence forces of the air, which tend to stretch it, tear it apart, and dilute it. The heavier the agent, the longer the cloud retains its integrity. Under conditions of low turbulence, the chemical agent cloud travels great distances with little decrease in agent vapor concentration. As turbulence increases, the agent cloud dilutes or dissipates faster.

### Aerosols

Aerosols are finely divided liquid and/or solid substances suspended in the atmosphere. Sometimes dissolved gases are also present in the liquids in the aerosols. Chemical agent aerosol clouds can be generated by thermal munitions and aerosol spray devices or as by-products of liquid spray devices and bursting munitions.

Airborne aerosols behave in much the same manner as vaporized agents. Initially, aerosol clouds formed from thermal generators have a higher temperature than clouds formed from other types of munitions. This may cause some initial rise of the cloud at the release point. Aerosol-generated clouds are heavier than vapor clouds, and they tend to retain their forms and settle back to earth. Being heavier than vapor clouds, they are influenced less by turbulence. However, as the clouds travel downwind, gravity settles out the larger, heavier particles. Many particles stick to leaves and other vegetative surfaces they contact.

### Liquids

When a chemical agent is used for its liquid effect, evaporation causes the agent to form into vapor. Depending upon volatility, vapor clouds are usually of low concentration, have about the same temperature as the surrounding air, and tend to stay near the surface because of high vapor density. Additionally, vapor density governs the extent that the vapor will mix with the air. Liquid agents with high vapor density impact at ground level with very little evaporation of the agent. These agents are termed persistent agents. While drops are airborne, and after impacting, the liquid continues to evaporate. Agent vapor pressure will govern the rate at which the liquid will evaporate at a given temperature and pressure. Initial concentrations are lower, since the vapor source is not instantaneous as a vapor agent is but evolves over a long period (until the liquid source is gone). Liquid agents may be absorbed (soaked into a surface) and adsorbed (adhered to a surface), and they may also evaporate. Once the liquid is no longer present on the surface, desorption (going back into the air) begins. The vapor concentration over areas contaminated with a liquid agent tends to be less than with newly formed vapor clouds, and downwind agent concentrations are not nearly as great as with other types of agents.

### Atmospheric Stability

One of the key factors in using chemical weapons is the determination of the atmospheric stability condition that will exist at the time of attack. This determination can be made from a meteorological report or by observing field conditions.

When a meteorological report is available, it should contain a description of the current or projected atmospheric stability condition. If the data given are based on an atmospheric description, Figure 1-1 may be used to convert the data into traditional atmospheric stability categories/conditions. When meteorological reports are not readily available, the stability condition can be derived by using the stability decision tree shown in Figure 1-2. Figure 1-2 is entered at the top with the current observed weather conditions (or estimated weather conditions). Follow the decision tree to determine the stability condition. The stability condition plus the wind speed indicates the dispersion category of an agent vapor cloud.

| DISPERSION CATEGORY | ATMOSPHERIC DESCRIPTION | TRADITIONAL ATMOSPHERIC CONDITIONS |
|---|---|---|
| 1 | Very Unstable | Lapse |
| 2 | Unstable | Lapse |
| 3 | Slightly Unstable | Neutral |
| 4 | Neutral | Neutral |
| 5 | Slightly Stable | Neutral |
| 6 | Stable | Inversion |
| 7 | Extremely Stable | Inversion |

Figure 1-1. Atmospheric stability categories and conditions.

Unstable conditions will cause lower concentrations and/or poorer target coverage. Stable conditions will cause greater agent stability and higher concentrations. Use Figure 1-2 as guidance for employing an agent by starting in the upper left corner at the word START. Follow the arrowed line to the first question. Answer the question “Is it nighttime?” by selecting, in

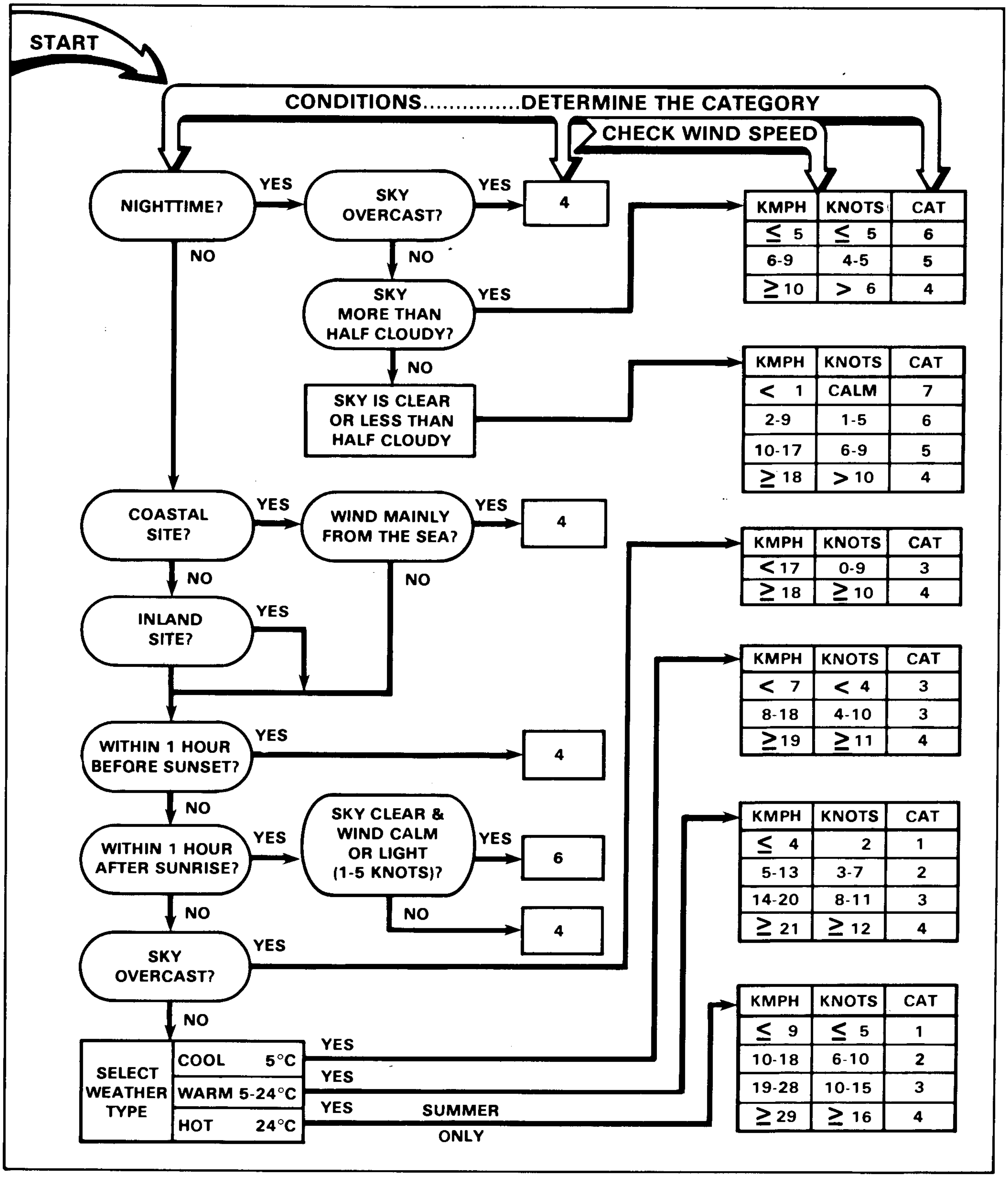


Figure 1-2. Stability decision tree.

accordance with the facts, the yes or no arrow indicating your decision. At each branch in the arrows, follow the arrow most nearly correct for the conditions under which the stability category is required. As questions are encountered along your path, answer each and proceed along the most nearly correct path until a dispersion category is identified. The result from Figure 1-2 is the stability category. An example of the use of Figure 1-2 is if you are inland one hour before sunset and the winds are calm, the stability category is neutral (N) (category 4).

The dispersion category, the wind speed in knots, and the wind direction are the most important meteorological data for deciding the influence of weather on vapor cloud dispersion. For any given dispersion category, a lower wind speed will produce higher dosages, smaller area coverage, and, consequently, higher toxic effects. This is because when the wind speed is lower, the cloud moves more slowly past the individual in the target area; and the individual is in the cloud longer, yielding a higher dose of the agent. See Table 1-1 for the dispersion categories and wind speeds during which atmospheric conditions are either generally favorable, marginal, or unfavorable for employment of chemical agents. Factors such as agent toxicity, target vulnerability, and the amount of the agent released will determine the actual doses, casualties, and other effects. Elevated agent releases will alter the table results somewhat, but the same trends occur. The main effect to be considered for elevated release effectiveness over a specific target is that the agent must be released further upwind to compensate for the drift as the agent comes down.

Table 1-1 is a general reference tool to provide an estimate, based on dispersion category and wind speed, when it would generally be most effective to employ a chemical agent vapor. Table 1-2 indicates the typical cloud widths at given downwind distances from a point source release for a chemical agent vapor cloud. Note that the cloud width depends upon dispersion category and not directly upon wind speed. The cloud width distances represented in Table 1-2 are the dosage contours for 0.01 milligram-minutes per cubic meter (mg-min\M³). If the agent is released from a line source (spray system), the line length should be added to the cloud width (Table 1-2) to determine total cloud width for travel distances up to 1 kilometer. For longer travel distances, the length of the line source loses its importance (due to dissipation), and the total cloud width is represented by the values in Table 1-2. The chemical cloud widths listed in Table 1-2 are estimates. The widths will vary depending on the weather and terrain of a specific area.

The following examples are cited to explain further the use of Table 1-2. Based on a chemical agent vapor being released from a point source in dispersion category 4, the chemical cloud width at 7 kilometers downwind would be approximately 2.3 kilometers. Based on a chemical agent vapor being released from a line source that is 0.1 kilometer in length (dispersion category 2), the chemical cloud width at a 0.5 kilometer downwind distance would be .850 kilometer (0.75+0.1).

Table 1-3 presents the relative center line dosages (mg-min/M³) at different distances downwind for different dispersion categories and wind speeds. Remember, low wind speeds at the same dispersion category give higher dosages. The dosages listed in Table 1-3 are estimates and will vary depending on the estimated category and wind speed in the target area. The dosage values in Table 1-3 are based on 100 kilograms of the nonpersistent nerve agent (GB) being released at ground level from a point source.

The information reflected in Table 1-3 is the dosage that would be incurred if the target were stationary. The dosage would decrease if the target were moving through the downwind cloud hazard area. Additionally, in general, if the source strength (100 kg) were doubled, the dosage would also double, and if the source strength were halved, the dosage would also decrease approximately one-half.

To aid in using Table 1-3, the following example is provided. With dispersion category 4, wind speed 8 knots, and a downwind distance of 2 kilometers, the center line dosage would be 18.91 mg-min/M³. With dispersion category 2, wind speed 3 knots, and at a downwind distance of 4 kilometers, the center line dosage would be 1.030 mg-min\M³.

## Vapor Concentration and Diffusion

Agent concentration is governed by the volume of the agent cloud. Since clouds

Table 1-1. Relative effectiveness of vapor agent usage for different wind speeds and dispersion categories.

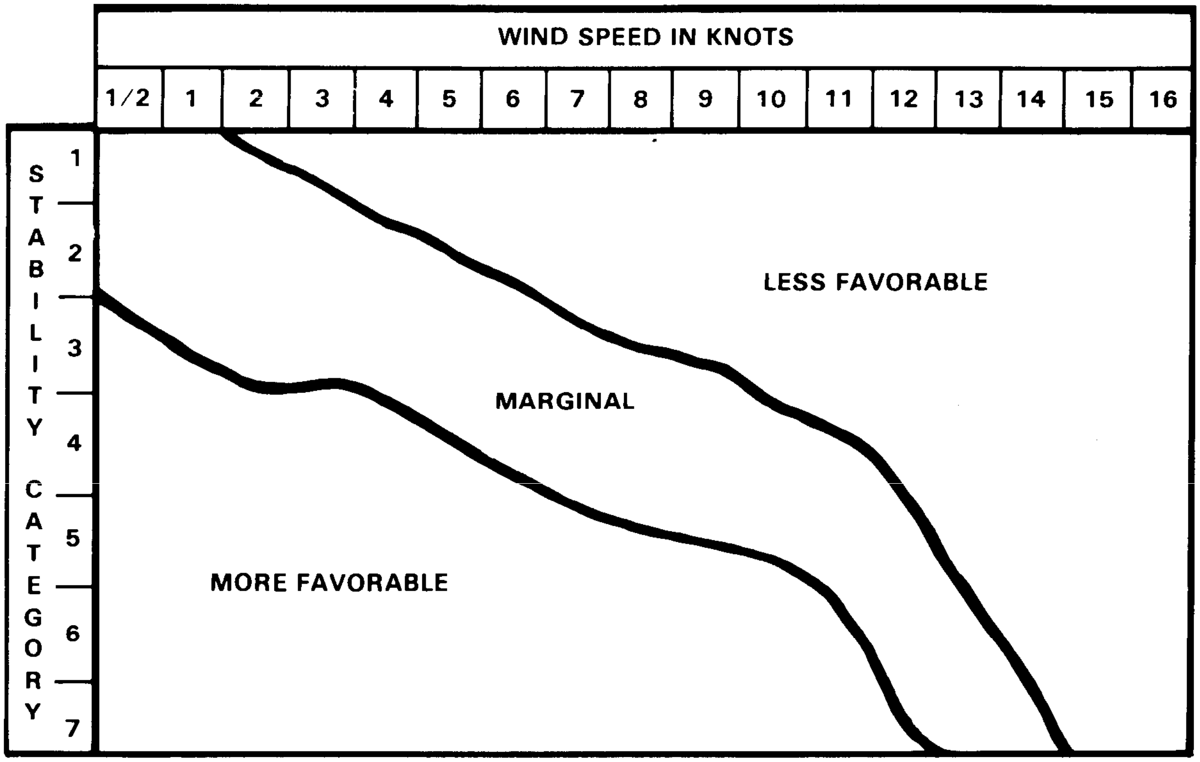


Table 1-2. Chemical cloud width.

| STABILITY CATEGORY | DOWNWIND DISTANCE IN KM | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | .5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 20 | 30 |
| 1 | .9 | 1.6 | 2.8 | 3.9 | 5.0 | 6.0 | 6.9 | 7.8 | 8.6 | 9.4 | 10.2 | 15.4 | 19.0 |
| 2 | .75 | 1.3 | 2.4 | 3.2 | 4.1 | 4.8 | 5.4 | 6.0 | 6.6 | 7.3 | 7.8 | 12.9 | 16.4 |
| 3 | .5 | .9 | 1.7 | 2.4 | 3.1 | 3.7 | 4.2 | 4.7 | 5.2 | 5.7 | 6.2 | 9.7 | 12.8 |
| 4 | .3 | .5 | .9 | 1.2 | 1.5 | 1.8 | 2.1 | 2.3 | 2.6 | 2.8 | 3.1 | 4.9 | 6.4 |
| 5 | .2 | .3 | .5 | .7 | 1.0 | 1.0 | 1.1 | 1.3 | 1.4 | 1.5 | 1.6 | 2.6 | 3.3 |
| 6 | .1 | .2 | .3 | .3 | .4 | .5 | .5 | .6 | .6 | .7 | .7 | 1.1 | 1.4 |
| 7 | VERY LITTLE INCREASE IN CLOUD WIDTH WITH DOWNWIND DISTANCE | | | | | | | | | | | | |

Table 1-3. Center line dosages at different distances downwind for different dispersion categories and wind speeds for a unit source.

| STABILITY CATEGORY | Wind Speed | DOWNWIND DISTANCE IN KM | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | .5 | 1 | 2 | 4 | 6 | 10 | 20 | 30 |
| | | DOSAGES (mg-min/M³) | | | | | | | |
| 1 | 1 | 57.82 | 10.960 | 2.4820 | 1.2070 | .8048 | .48290 | .24140 | .16100 |
| 1 | 3 | 19.15 | 3.628 | .8224 | .3998 | .2665 | .15990 | .07995 | .05330 |
| 1 | 5 | 11.47 | 2.174 | .4928 | .2396 | .1597 | .09582 | .04791 | .03194 |
| 2 | 3 | 65.93 | 16.480 | 4.121 | 1.0300 | .4671 | .22840 | .11360 | .07575 |
| 2 | 6 | 32.86 | 8.215 | 2.054 | .5135 | .2328 | .11380 | .05663 | .03775 |
| 2 | 10 | 19.75 | 4.938 | 1.235 | .3087 | .1400 | .06843 | .03404 | .02269 |
| 3 | 3 | 172.60 | 46.26 | 12.400 | 3.321 | 1.5370 | .5825 | .18010 | .11510 |
| 3 | 7 | 73.86 | 19.79 | 5.302 | 1.421 | .6576 | .2492 | .07703 | .04925 |
| 3 | 12 | 43.09 | 11.55 | 3.094 | .829 | .3837 | .1454 | .04494 | .02874 |
| 4 | 3 | 572.4 | 170.20 | 50.590 | 15.040 | 7.398 | 3.0260 | .8997 | .44450 |
| 4 | 8 | 213.9 | 63.61 | 18.910 | 5.622 | 2.765 | 1.1310 | .3363 | .16620 |
| 4 | 16 | 107.1 | 31.84 | 9.467 | 2.814 | 1.384 | .5662 | .1683 | .08318 |
| 5 | 2 | 1,837.0 | 606.0 | 199.90 | 65.94 | 34.470 | 15.220 | 5.021 | 2.6250 |
| 5 | 5 | 736.2 | 242.9 | 80.12 | 26.43 | 13.810 | 6.101 | 2.012 | 1.0520 |
| 5 | 9 | 408.7 | 134.8 | 44.47 | 14.67 | 7.668 | 3.387 | 1.117 | .5839 |
| 6 | 1 | 10,080.0 | 3,691.0 | 1,351.0 | 494.50 | 274.70 | 131.00 | 47.930 | 26.630 |
| 6 | 3 | 3,339.0 | 1,222.0 | 447.4 | 163.80 | 90.96 | 43.37 | 15.870 | 8.818 |
| 6 | 5 | 2,001.0 | 732.4 | 268.1 | 98.12 | 54.51 | 25.99 | 9.5120 | 5.284 |
| 7 | HIGHER DOSAGES THAN ABOVE | | | | | | | | |

continually expand, agent concentration levels decrease over time. Wind speed determines the downwind growth of the cloud. Vertical and horizontal turbulence determines the height and width of the cloud. The rate at which the downwind, vertical, and horizontal components expand governs the cloud volume and the agent concentration.

To be effective the agent cloud, at a specific concentration level, must remain in the target area for a definite period. Wind in the target area mixes the agent and distributes it over the target after release. For ground targets, high concentrations and good coverage can best be achieved with low turbulence and calm winds when the agent is delivered directly on target. A steady, predictable wind drift over the target is best when the agent is delivered on the upwind side of the target. Conditions other than these tend to produce lower concentrations and/or poorer target coverage. However, unless weather conditions are known within the target area, the effects of the agent on target will be approximations.

The concentration and diffusion of a chemical agent cloud are also influenced by the factors of hydrolysis, absorption, adsorption, lateral spread, drag effect, and vertical rise.

Hydrolysis is the process of the agent reacting with water vapor in the air. It does not influence most agent clouds in tactical use because the rate of hydrolysis is too slow. However, hydrolysis can be important for smoke screens. See the discussion of the effect of humidity on increasing smoke screen effectiveness in Chapter 2.

Absorption is the process of the agent being taken into the vegetation, skin, soil, or material. Adsorption is the adding of a thin layer of agent to vegetation or other surfaces. This is important in dense vegetation. Both absorption and adsorption of chemical agents may kill vegetation, thus defoliating the area of employment.

When a chemical cloud is released into the air, shifting air currents and horizontal turbulence blow it from side to side. The side-to-side motion of the air is called meandering. While the agent cloud meanders, it also spreads laterally. Lateral spreading is called lateral diffusion. Figure 1-3 shows a cloud with lateral spread and meandering. Table 1-2 indicates the amount of lateral spread that occurs under different dispersion categories and distances downwind. In more unstable conditions, the lateral spread tends to be greater than in stable conditions.

Wind currents carry chemical clouds along the ground with a rolling motion. This is caused by the differences in wind velocity. Wind speeds increase rapidly from near zero at the ground to higher speeds at higher elevations above the ground. The drag effect by the ground, together with the interference of vegetation and other ground objects, causes the base of an agent cloud to be retarded as the cloud stretches out in length. When clouds are released on the ground, the drag amounts to about 10 percent of the vertical growth over distance traveled over grass, plowed land, or water. It amounts to about 20 percent over gently rolling terrain covered with bushes, growing crops, or small patches of scattered timber. In heavy woods, the drag effect is greatly increased. The vertical spread of the cloud is illustrated in Figure 1-4.

Wind speeds can vary at different heights. The wind direction can also change with an increase in height. This is known as wind shear. Because of wind shear, a puff (or chemical cloud) may become stretched in the downwind direction and may travel in a direction different from that of the surface wind. Additionally, a chemical cloud released in the air may be carried along faster than it can diffuse downward. As a result, air near the

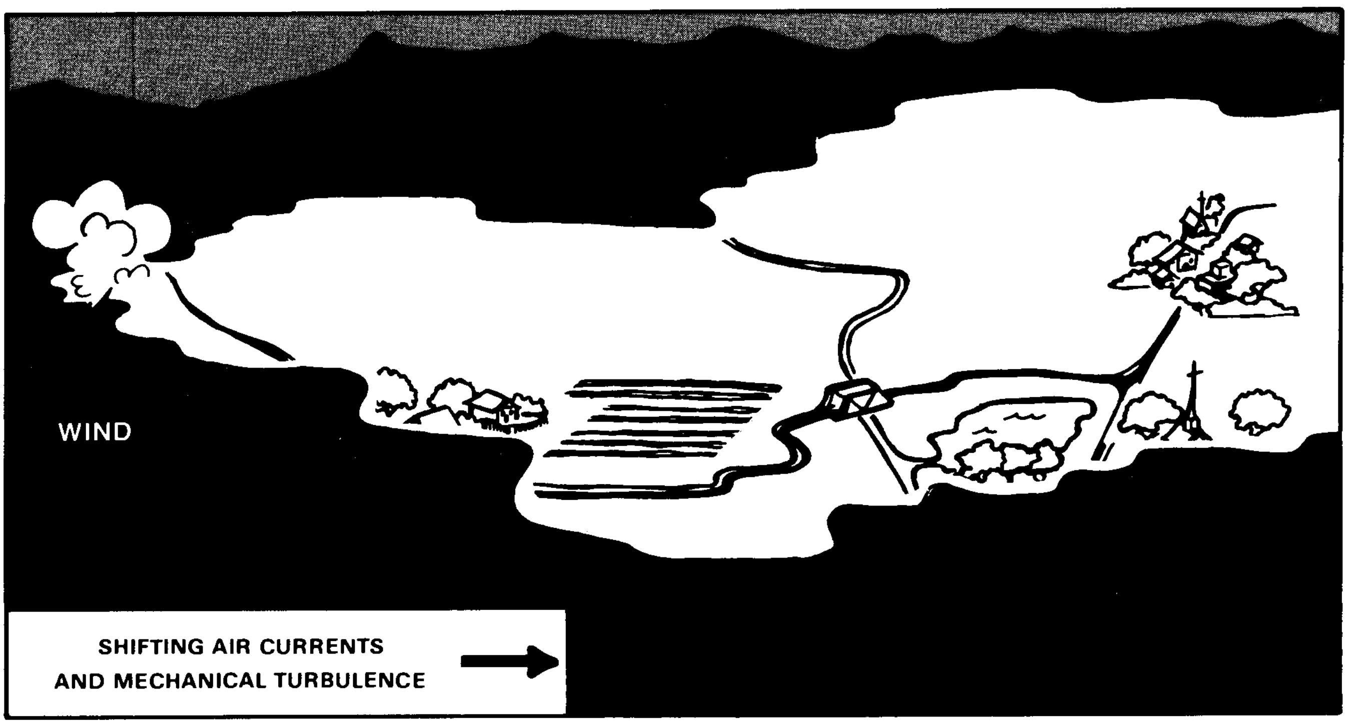


Figure 1-3. Lateral spread of a chemical cloud with some meandering.

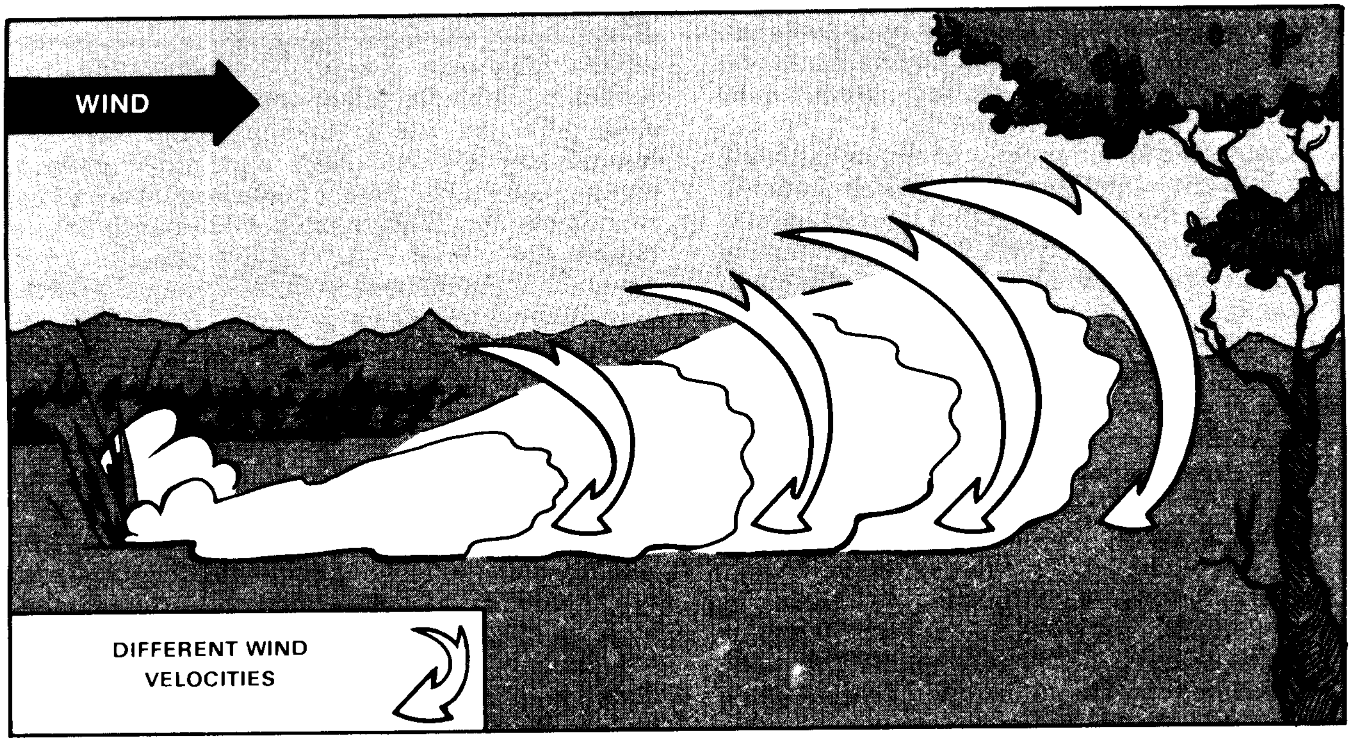


Figure 1-4. Vertical spread of a chemical cloud with drag effect.

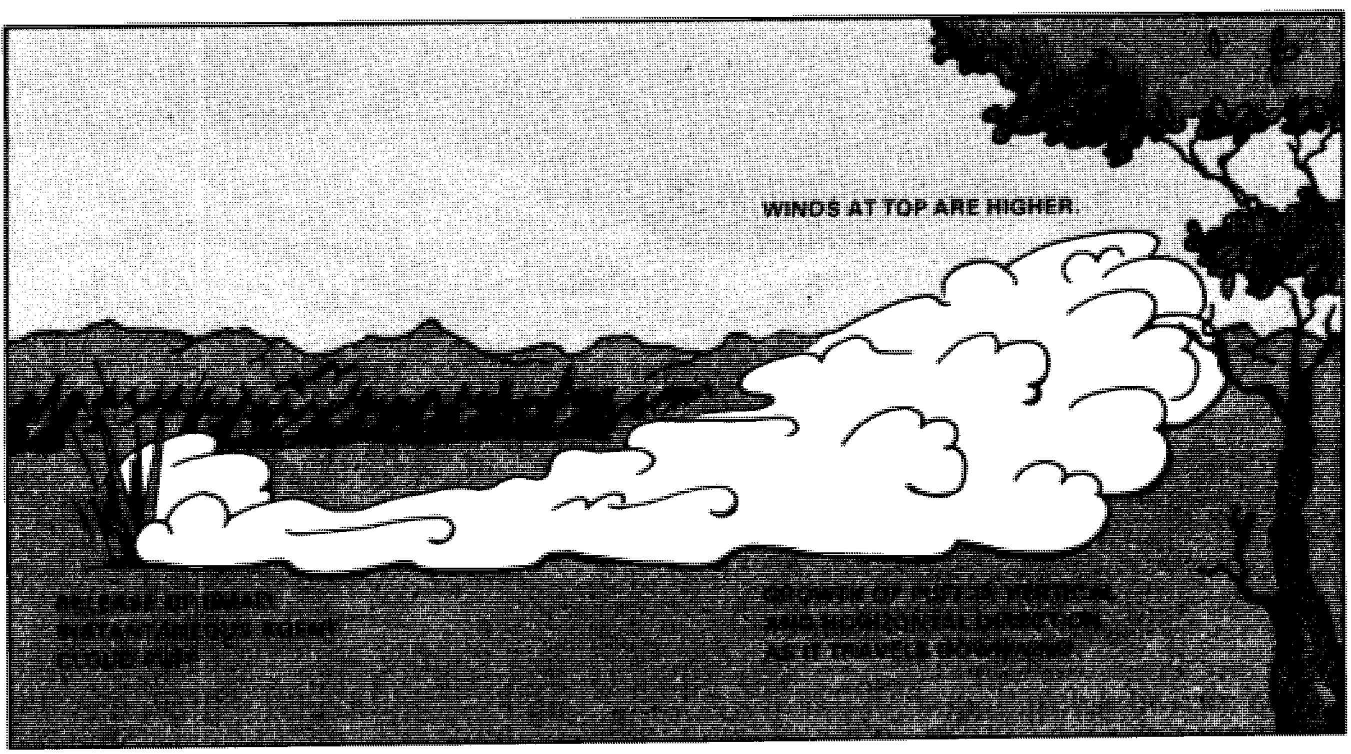


Figure 1-5. Horizontal and vertical spread of a cloud puff.

ground on the forward edge of the cloud may be uncontaminated, while the air a few feet up may be heavily contaminated. This layering effect becomes more pronounced and increases proportionately with the distance of the forward edge of the cloud from the source. Figure 1-5 illustrates this. A small puff of agent cloud released from its source some time earlier has tilted forward, while the bottom has been retarded due to slower winds caused by drag.

The vertical rise of a chemical cloud depends upon weather variables, such as temperature gradient, wind speed, and turbulence, and the difference between the densities of the clouds and the surrounding air. As mentioned earlier, the temperature of both the cloud and the air influences their relative densities. Hotter gases are less dense and, therefore, lighter than cooler gases and air. Therefore, they rise until they are mixed and somewhat diluted and attain the same temperature and approximately the same density as surrounding air.

The vapor cloud formed by an agent normally employed for persistent effect rises in a similar manner, but vapor concentrations build up more gradually.

## Vapors and Aerosols

Wind, temperature, humidity, precipitation, terrain contours, and surface cover influence the field behavior of vapors and aerosols. For example, in a chemical attack on US forces (lst Division) 26 February 1918 in the Ansauville section, extremely stable conditions, calm winds, and heavy underbrush in the target area contributed to the overall effectiveness of a chemical attack. Several additional casualties resulted due to the increased chemical agent persistency caused by the favorable weather conditions. Favorable and unfavorable weather

Table 1-4. Summary of favorable and unfavorable weather and terrain conditions for tactical employment of chemical agent vapor or aerosol. (The stability condition listed for the south slope is for the northern hemisphere; due to solar loading on the slope, the situation would be reversed for the southern hemisphere.)

| FACTOR | UNFAVORABLE | MODERATELY FAVORABLE | FAVORABLE |
|---|---|---|---|
| Wind | Artillery employment if speed is more than 7 knots. Aerial bombs if speed is more than 10 knots. | Steady, 5 to 7 knots, or land breeze. | Steady, less than 5 knots, or sea breeze. |
| Dispersion Category | Unstable (lapse). | Neutral. | (Stable) inversion. |
| Temperature | Less than 4.4°C. | 4.4° to 21.1°C. | More than 21.1°C. |
| Precipitation | Any. | Transitional. | None. |
| Cloud Cover | Broken, low clouds during daytime. Broken, middle clouds during daytime. Overcast or broken, high clouds during daytime. Scattered clouds of all types during daytime. Clouds of vertical development. | Thick, low overcast. Thick, middle overcast. | Broken, low clouds at night. Broken, middle clouds at night. Overcast or broken, high clouds at night. Scattered clouds of all types at night. Clear sky at night. |
| Terrain | Hilltops, mountain crests. South slopes* during daytime. | Gently rolling terrain. North slopes at night. | Even terrain or open water. |
| Vegetation* | Heavily wooded or jungle. | Medium dense. | Sparse or none. |

*Cloud dissemination occurs above the canopy.

and terrain conditions for tactical employment of a chemical aerosol or vapor cloud are summarized in Table 1-4.

If a chemical cloud is to be placed directly on an occupied area, the best possible weather conditions are calm winds with a strong, stable temperature gradient. Under these conditions, the cloud diffuses over the target with minimum dilution and does not move away. Such conditions are most apt to occur on a calm, clear night. If a small amount of air movement is required to spread the cloud evenly over the target area, a low wind speed and stable or neutral conditions are most favorable. These conditions most often occur on a clear night, a cloudy night, or a cloudy day.

When the desired effect is for the chemical cloud to travel, the most favorable conditions are stable or neutral conditions with a low to medium wind speed of 3 to 7 knots. These conditions may be present on a clear night, a cloudy night, or a cloudy day. The presence of low to medium wind speeds keeps the cloud traveling over the area without too much diffusion, and the stable or neutral conditions keep the agent concentration high and the cloud close to the ground.

Favorable terrain conditions for a chemical cloud are smooth or gently rolling contours or wooded areas. Unfavorable conditions for chemical clouds (usually found on clear days) are extreme or marked turbulence, wind speeds above 10 knots, an unstable dispersion category, rain, and rough terrain.

## Wind

High wind speeds cause rapid dispersion of vapors or aerosols, thereby decreasing effective coverage of the target area and time of exposure to the agent. In high winds, larger quantities of munitions are required to ensure effective concentrations. Agent clouds are most effective when wind speeds are less than 4 knots and steady in direction. The clouds move with the prevailing wind as altered by terrain and vegetation. Steady, low wind speeds of 3 to 7 knots enhance area coverage unless an unstable condition exists. With high winds, chemical agents cannot be economically employed to achieve casualties. The chart at Figure 1-2 indicates the effect of wind on stability categories. Tables 1-1, 1-2, and 1-3 indicate the effects of wind and dispersion categories upon dosage and area coverage.

Unstable conditions, as indicated in Figure 1-2 and Tables 1-1, 1-2, and 1-3, are the least favorable conditions. Unstable conditions (such as many rising and falling air currents and great turbulence) quickly disperse chemical agents. Unstable is the least favorable condition for chemical agent use because it results in a lower concentration, thereby reducing the area affected by the agent. Many more munitions are required to attain the commander's objectives under unstable conditions than under stable or neutral conditions.

Stable conditions (such as low wind speeds and slight turbulence) produce the highest concentrations. Chemical agents remain near the ground and may travel for long distances before being dissipated. Stable conditions encourage the agent cloud to remain intact, thus allowing it to cover extremely large areas without diffusion. However, the direction and extent of cloud travel under stable conditions are not predictable if there are no dependable local wind data. A very stable condition is the most favorable condition for achieving a high concentration from a chemical cloud being dispersed.

Neutral conditions are moderately favorable. With low wind speed and smooth terrain, large areas may be effectively covered. The neutral condition occurs at dawn and sunset and generally is the most predictable. For this reason, a neutral dispersion category is often best from a military standpoint.

## Temperature

There will be increased vaporization with higher temperatures. Also, the rate of evaporation of any remaining liquid agent from an exploding munition can vary with temperature. Generally, the rate of evaporation increases as the temperature increases. See FM 3-9/AFR 355-7 for specific information on chemical agents, such as their boiling and freezing points and vapor density.

## Humidity

Humidity is the measure of the water vapor content of the air. Hydrolysis is a process in which compounds react with water resulting in a chemical change. Chemical agents with high hydrolysis rates are less effective under conditions of high humidity.

Humidity has little effect on most chemical agent clouds. Some agents (phosgene and lewisite) hydrolyze quite readily. Hydrolysis causes these chemical agents to break down and change their chemical characteristics. If the relative humidity exceeds 70 percent, phosgene and lewisite can not be employed effectively except for a surprise time-on-target (TOT) attack because of rapid hydrolysis. Lewisite hydrolysis by-products are not dangerous to the skin; however, they are toxic if taken internally because of the arsenic content. Riot control agent CS (see glossary) also hydrolyzes, although slowly, in high humidities. High humidity combined with high temperatures may increase the effectiveness of some agents because of body perspiration that will absorb the agents and allow for better transfer.

## Precipitation

The overall effect of precipitation is unfavorable because it is extremely effective in washing chemical vapors and aerosols from the air, vegetation, and material. Weather forecasts or observations indicating the presence of or potential for precipitation present an unfavorable environment for employment of chemical agents.

## Terrain Contours

Terrain contours influence the flow of chemical clouds the same as they influence airflow. Chemical clouds tend to flow over low rolling terrain and down valleys and settle in hollows and depressions and on low ground. Local winds coming down valleys at night or up valleys during the day may deflect the cloud or reverse its flow. On the other hand, they may produce conditions favorable for chemical cloud travel when general area forecasts predict a calm.

A chemical cloud released in a narrow valley subjected to a mountain breeze retains a high concentration of agent as it flows down the valley. This is because of minimal lateral spread. Hence, high dosages are obtained in narrow valleys or depressions. High dosages are difficult to obtain on crests or the sides of ridges or hills. After a heavy rain, the formation of local mountain or valley winds is sharply reduced. In areas of adjacent land and water, daytime breezes from the water and nighttime breezes from the land control chemical cloud travel.

## Surface Cover

Ground covered with tall grass or brush retards flow. Obstacles, such as buildings or trees, set up eddies that tend to break up the cloud and cause it to dissipate more rapidly. However, street canyons or spaces between buildings may have pockets of high concentrations. Flat country (during a neutral or inversion condition) or open water promotes an even, steady cloud flow. Figure 1-5 illustrates the horizontal and vertical spread of a cloud over flat country.

The amount and type of vegetation in the area of the chemical operation also influence the travel of a chemical cloud. Vegetation, as it relates to meteorology or diffusion, is called vegetative canopy or just canopy. The effects of canopies are considered below.

Woods are considered to be trees in full leaf (coniferous or deciduous forests). The term "heavily wooded canopy" denotes jungles or forests with canopies of sufficient density to shade more than 90 percent of the ground surface beneath. For chemical operations, areas containing scattered trees or clumps of bushes are considered to be open terrain although drag is somewhat increased. In wooded areas where trees are not in full leaf or where foliage has been destroyed by previous attack so that sunlight strikes the ground, the diffusion (stability) category will be similar to those in the open.

When bombs are dropped into a wooded area, some may be expected to burst in the treetops. Although the released aerosol and vapor settle toward the ground, some of the agent is lost, depending upon the thickness and height of the foliage. The initial burst and pancake areas of chemical clouds released within woods or jungles are smaller than those released in the open. However, concentrations within the initial clouds are higher in wooded areas, sometimes three times that of bursts in the open. The magnitude of concentration from ground bursts depends upon the density of undergrowth and trees.

Generally, when conditions in the open are most favorable for the use of chemical agents, conditions also are favorable in heavily wooded areas if dispersion occurs below the canopy. Low wind speeds under the canopies spread agent clouds slowly in a downwind and downslope direction. Areas of dense vegetation also increase the potential surface area for the deposition of chemical agents. If there are gullies and stream beds within the woods, clouds tend to follow these features. This flow may be halted or diverted by upslope winds.

Vegetation absorbs some agents. However, for an attack against troops poorly trained in NBC defense (where lethal dosages may be obtained in 30 seconds or less), the amount of agent absorbed by foliage will have little or no effect on the success of the attack. High concentrations of chemical agents may destroy vegetation, since the leaves absorb some of the agent. In some instances, the absorbed agent may be released or desorbed when the vegetation is disturbed or crushed, creating a secondary toxic hazard.

## Liquids

Weather, terrain contours, vegetation, soil, and some other surfaces affect the rate of evaporation. That, in turn, influences the persistence of a chemical agent liquid and the concentration of the vapor. Most weather conditions do not affect the quantity of munitions needed for an effective initial liquid contamination. Table 1-5 summarizes favorable and unfavorable weather and terrain conditions for the employment of a liquid chemical agent.

When a liquid agent is used to cause casualties through contact with the liquid in crossing or occupying the area, its duration of effectiveness is greatest when the soil temperature is just above the agent's freezing point. This limits the rate of evaporation of the liquid. Other favorable conditions are low wind speed, wooded areas, and no rain.

Conversely, unfavorable conditions are high soil temperature, high wind speed, bare terrain, and heavy rain.

Favorable and unfavorable conditions for liquid agents for vapor concentration effects are much the same as those for chemical clouds. In woods, however, a high temperature with only a very light wind gives the highest vapor concentrations.

### Weather

Duration of the effectiveness of initial liquid contamination may be affected by wind speed; stability, mixing height, and temperature; and precipitation.

#### *Wind Speed*

Wind direction is important in determining the upwind side of a target for release purposes but has little impact on the duration of effectiveness, regardless of the method of release The vapor created by evaporation of the liquid agent, however, moves with the wind. Therefore, the vapor concentration is greatest on the downwind side of the contaminated area. Vapors are moved by the wind as discussed earlier in this chapter.

Evaporation due to wind speed depends on the amount of the liquid exposed to the wind (the surface of the liquid) and the rate at which air passes over the agent. Therefore, the duration of effectiveness is longer at the places of greater liquid agent contamination and in places where the liquid agent is sheltered from the wind.

The rate of evaporation of agents employed for persistent effect in a liquid state is proportional to the wind speed. If the speed increases, evaporation increases, thus shortening the duration of effectiveness of the contamination. Increased evaporation, in turn, creates a larger vapor cloud. The vapor cloud, in turn, is dispersed by higher winds. The creation and dispersion of vapor are a continuous process, increasing or decreasing in proportion to wind speed.

Releasing agents for persistent effect by point dispersal via bombs, shells, rockets, or land mines results in an unevenly distributed contaminant. Heavier concentrations of the liquid are found around the point of burst. Lighter concentrations result farther from the bursting position. There probably will be small areas between the points of burst that are not contaminated, depending upon the number of munitions used and the uniformity of dispersal.

Liquid agents released in the form of a spray are fairly evenly distributed, exposing the maximum surface area of the contaminant to the wind. This results in a more rapid evaporation