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ABSTRACT

Three of the most common fire retardant formulations--Phos-Chek XA, Fire-Trol 100, and Fire-Trol 931 (liquid concentrate), in addition to water--were dropped from a TBM air tanker under various conditions to determine the effect that thickening agents, windspeed and direction, drop height, and aircraft speed would have on ground distribution patterns. Seventy-four drops were made over 820 cups in a grid system. The cups were collected, weighed, the concentration in gallons per 100 square feet computed and summarized, and a computer plot of the ground distribution patterns printed.

Drop height and windspeed were consistently the strong variables in models that were used for predicting ground distribution patterns of all retardants. Covariance analysis of the models indicated that the greatest real differences existed between gum-thickened Phos-Chek XA and the remaining retardants. The area of effective coverage, the length of effective coverage, and retardant recovery, all tended to decrease for Fire-Trol 100, Fire-Trol 931, and water, in that order. Predicted values of effective areas as a function of height, wind, and concentration are calculated from the mathematical model for each retardant. Predictions of recovery are given as a function of height and wind.

The greater total recovery and more concentrated patterns for Phos-Chek XA are attributed to a greater cohesiveness when subjected to airstream shearing forces. The result is larger mean droplet sizes when terminal velocity is reached. This phenomenon results in shorter drop times and less evaporation losses for Phos-Chek XA than for other materials.

Within the range tested (93 to 127 knots), the effect that aircraft drop speed had upon ground distribution patterns was small and quantitatively fell within uncontrolled variations of the data. The maximum effective drop speed for the TBM is probably near the maximum safe drop speed of 145 knots.

Maximum effective drop heights depend on the particular fire situation. However, assuming a particular effective concentration, the optimum height for any wind can be determined from prediction tables developed from the mathematical model for each retardant. In general, under low wind conditions (<6 m.p.h.), the optimum drop height is between 150 feet and 300 feet. Many drops under these conditions are currently being made at drop heights below this range; thus, it appears that some advantage in effectiveness and safety can be attained by raising drop heights under such situations.

This study provides the basic data from which trade-off studies between retardant salt content and effective areas can be performed. Optimum retardant salt contents for both thickened and unthickened retardants can then be established. The basic data can also be utilized in drop mechanization studies designed to improve either the retardant solution or the delivery systems.

INTRODUCTION

The Problem

More than 100 million gallons of fire retardant have been dropped on forest and rangeland fires by fire control agencies throughout the United States in the last 10 years. In 1970, nearly 17 million gallons of fire retardant were aerially applied by just three of these agencies--the USDA Forest Service, Bureau of Land Management, and California Division of Forestry. The cost of 17 million gallons of retardant is approximately $3.5 million. When mixing and delivery costs are added, a cost of $20 million is a reasonable estimate. This type of expenditure warrants information to assure that the retardants are being most efficiently used for given fuel, fire, and drop situations.

The effectiveness of fire retardant chemicals is related to the amount and type of salt and to the total surface area of the fuel coated (George and Blakely 1972). Depending on the fuel and fire characteristics, it may be desirable to deposit the chemicals on a certain portion of the fuel. For example, when fire is spreading through aerial fuel, the aerial fuel should be most heavily coated. For ground fires, penetration to and coating of the ground fuel is the primary objective. That portion of the total fuel complex primarily contributing toward fire spread (i.e., the critical fuel) should be uniformly coated for maximum retardant effectiveness. The retardant physical and chemical characteristics that may provide optimum retardancy in one type of fuel and fire situation may not provide the optimum retardancy in another type of fuel and fire situation. Because the critical fuel can be nearly any segment of the total fuel complex, it may be desirable to evenly coat all the fuel within the complex. Thus, the aerial application of fire retardants can be divided into two broad problem areas:

1. Delivery of the chemical from the aircraft to the fuel complex, and

2. Distribution of the chemical within the fuel complex.

The delivery and distribution of a retardant are related to the rheological[1] (or physical) properties of the retardant solution. A highly viscous and/or cohesive retardant that has been formulated to minimize delivery loss may not adequately flow and cover or coat the fuel. On the other hand, a retardant formulated for low viscosity and/or cohesion to maximize coverage and coating of the fuel may, before reaching the fuel, erode[2] and dissipate in the form of a near aerosol. This indicates the probable existence of physical and chemical properties that will maximize the efficiency of aerially applied retardants.

This study is devoted primarily to the methods and equipment used to deliver currently used fire retardants from aircraft to fuel complex. Previous studies designed to determine the ground distribution patterns of various products have been conducted under optimum experimental conditions--calm or very low wind and low drop heights (approximately 100 feet aboveground) (Johansen and Shimmel 1967; Grigel 1970; MacPherson 1967; Storey and others 1959; Davis 1959). Usually, under actual operational conditions, the topography, canopy heights, and general aircraft maneuverability and safety requirements dictate an increase in drop heights. Thus, range of conditions for effective drops using various types of retardants has not previously been defined.

Objectives

The objectives of this study were:

1. To determine the effect of thickening agents on drop characteristics by quantifying: the area covered at various concentration levels, the total area covered, and the amount of retardant reaching the ground.

2. To determine the effect of drop height, aircraft speed, and wind on drop characteristics.

3. To determine maximum effective drop heights as related to drop speed and wind.

4. To determine whether the salt content of unthickened retardants can be adjusted to provide the same amount of active salt on the ground as provided by thickened retardants.

5. To provide data necessary for the correlation and development of an adequate model for studying drop characteristics as a function of known rheological properties and types of gating and tank systems.

Test Location

The site for conducting the fire retardant drop tests was established at Porterville, California, because of its excellent facilities and favorable climate for test drops made between November 16 and December 4, 1970. The Porterville Municipal Airport (444 feet m.s.l.) is the location of a cooperative USDA Forest Service-California Division of Forestry air attack base. The loading facilities were suitable for dual use; therefore, the drop tests would not have hindered normal operations if fires had occurred.

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[1] Rheology, the science of the deformation and flow of material, is primarily concerned with deformation of *cohesive* bodies and their stress-strain-time relationship. As the term is used here, cohesion refers to the sticking together of particles or drops to maintain a homogeneous mass. Rheologic properties should be differentiated from viscous properties in that the viscosity of a retardant solution, as normally measured at a single rate of shear, is only one rheologic parameter and does not completely define the cohesiveness of a material.

[2] The term "erode" or "erosion" is used throughout the paper to describe the process of deterioration or wearing away of the retardant mass into smaller droplet size particles by airstream shearing forces.

EXPERIMENTAL DESIGN AND TESTING PROCEDURES

Primary Variables

The factors which determine the ground distribution pattern of a given aerial fire retardant drop are:

1. The physical and/or chemical properties of the fire retardant.

2. The size of the retardant drop and the physics of its release.

3. The position of the retardant load over the drop area when it is released.

4. The environmental conditions at the time the drop was made, e.g., temperature, humidity, windspeed, and wind direction.

A review of the objectives of the study and the variables affecting the ground distribution pattern indicates that the study goals could best be met by using currently formulated fire retardants and a presently used aircraft having a load capacity that is no less than the minimum increment usually dropped.

The Chemicals

Three fire retardant formulations currently account for over 99 percent of the retardant being aerially applied from fixed-wing aircraft--Fire-Trol® 100, Phos-Chek® XA, and Fire-Trol® 931 (liquid concentrate or LC). The nature of these products and the inclusion of water in the study as a standard provide two essentially unthickened products and two thickened retardants.

The standard mixing proportions and related physical-chemical properties were set as goals for the chemicals used in the study. Table 1 provides a description of the physical-chemical characteristics of these fire retardants (George 1971b). The composition of each formulation is given in table 3 of the Appendix (George 1971a).

TABLE 1.--PHYSICAL-CHEMICAL CHARACTERISTICS OF SELECTED FIRE RETARDANTS

Retardant[1]	Recommended use level or dilution rate	Viscosity[2]	Density of slurry	$(NH_4)_2HPO_4$ or DAP equivalent	Ammonium sulfate $(NH_4)_2SO_4$	P_2O_5 equivalent[3]
	Lb./gal.	*Centipoise*	*Lb./gal.*	*Percent*	*Percent*	*Percent*
Unthickened						
Water		1	8.33			
Fire-Trol 931 (LC)	[4] 4:1	30-120	9.1	15.4		8.3
Thickened						
Phos-Chek XA (202XA)	1.14	1,500-2,000	8.9	10.6		5.7
Fire-Trol 100	2.78	1,500-2,500	9.4		15.6	

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[1] Phos-Chek is a product of Monsanto, St. Louis, Missouri. Fire-Trol is a product of Chemonics Industries, Phoenix, Arizona. The composition of each formulation is given in table 3.

[2] Viscosities by Brookfield Viscometer Model LVF at 60 r.p.m.

[3] The P_2O_5 equivalent is determined from the percent by weight DAP using the formula: Percent P_2O_5 = percent DAP ÷ 1.86. The equivalent P_2O_5 content is not necessarily the same as the active salt content (because of other retardant ingredients) although the P_2O_5 equivalent can be used for quality control.

[4] The dilution rate is by volume; a dilution rate of 4:1 means 4 gallons of water are added to 1 gallon of liquid concentrate to provide approximately 5 gallons of retardant solution.

The chemicals were mixed using retardant mixing equipment and procedures that would insure the maximum quality control. Phos-Chek XA was mixed using a portable air slide hopper and a Monsanto-Hamp eductor type mixer (fig. 1). The Phos-Chek was mixed in two batches and stored in a 10,000-gallon tank. The Fire-Trol 100 was mixed in a high-shear CDF type batch mixer and transferred to a 5,000-gallon holding tank. Fire-Trol 931 (LC) was mixed using a proportioner on the suction side of a Homelite® pump and the diluted material was transferred to a 5,000-gallon holding tank where it could be circulated prior to use. (When Fire-Trol 931 is diluted to a 4:1 ratio, the coloring and clay will separate.) This procedure of mixing large amounts of each chemical and placing them in holding tanks permitted the changing of the chemical and physical properties if specifications were not met (fig. 2).

The storage of all three mixed retardants simultaneously allowed random selection of any product at any time during the tests. After the selection had been made, the fill lines were flushed with water and then with the retardant to be loaded. From each batch delivered to the aircraft samples were taken either from the end of the loading hose or the overflow valve on the aircraft tank.

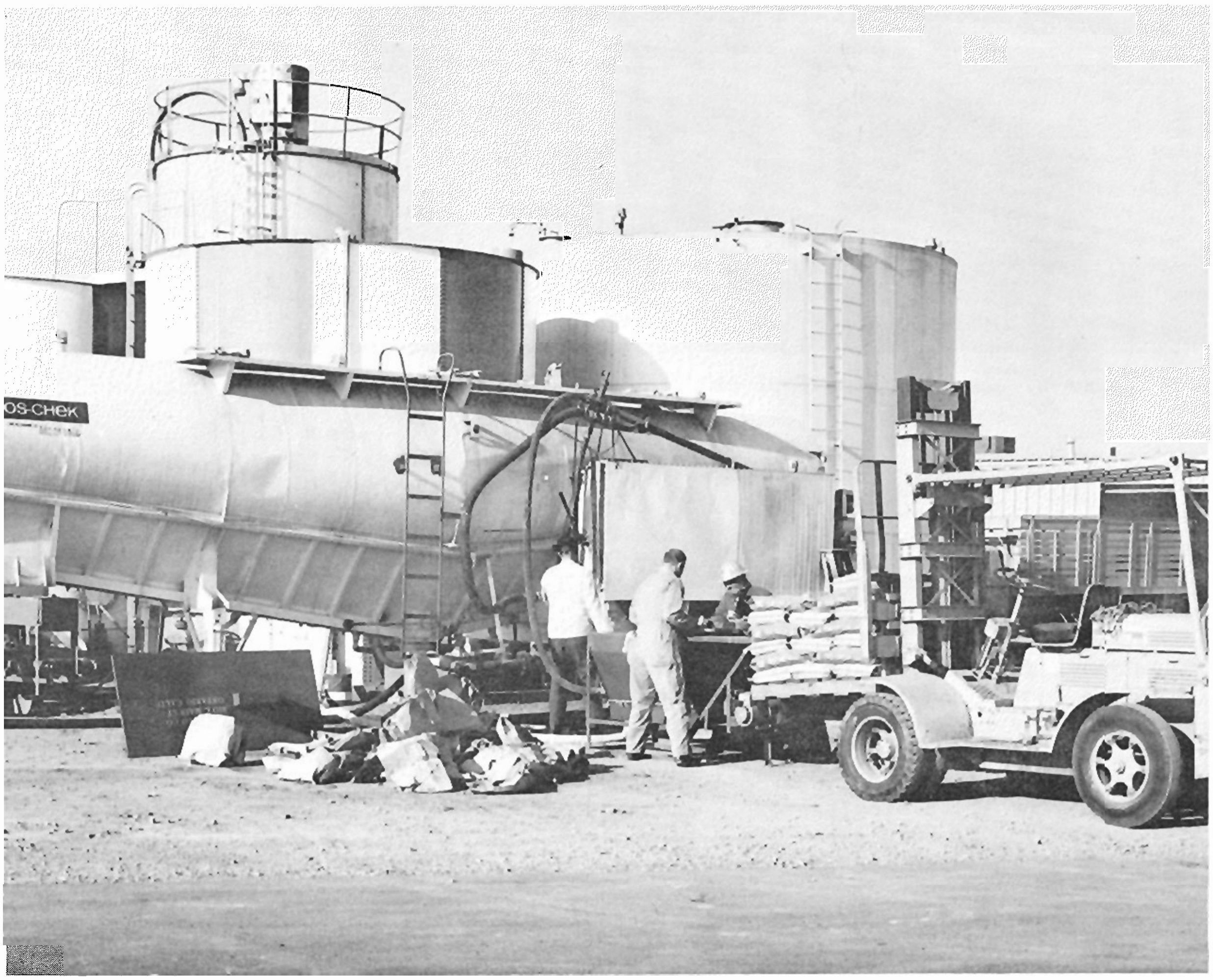


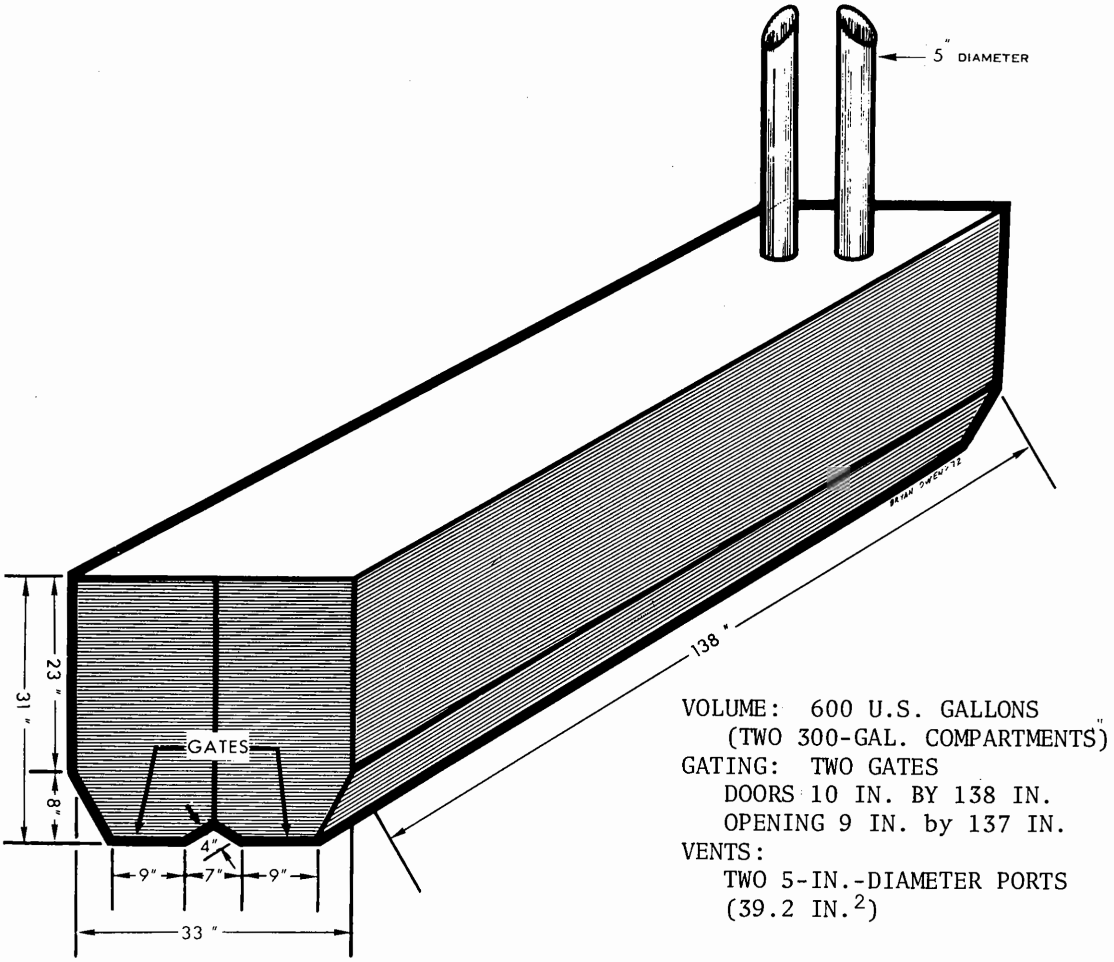
Figure 1.--Phos-Chek XA mixing operation using a Monsanto-Hamp eductor mixer.

Figure 2.--Loading Fire-Trol 931 (LC) into the TBM from a holding tank.

Aircraft, Tank, and Gating

In accordance with study objectives and aircraft requirements, and also considering availability and cost, a TBM "Avenger" was selected. The TBM has a total capacity of 600 gallons contained in two compartments (USDA Forest Service 1960). The contents of these compartments may be dumped separately or together, at the pilot's option. Except for TBM drops, the current drops are usually incremental in units of 500 gallons or more; therefore, it was decided "salvo" or 600-gallon drops would be made. To accomplish this, the pilot simultaneously actuates two buttons on the stick. To assure that the opening of both gates was synchronized, the switches were wired in common. Dimensions of the tank and gate opening are shown in figure 3.

The study provided a detailed characterization of the drop performance of this particular aircraft, tank, and gating system; this, however, is not of primary interest, for the TBM in this study served only as a convenient vehicle to deliver the different retardants under preselected conditions. It is assumed that similar differences in retardants, resulting from different chemicals, drop heights, speeds, etc., would be found if drops were made from other types of aircraft having conventional gating.



VOLUME: 600 U.S. GALLONS
(TWO 300-GAL. COMPARTMENTS)
GATING: TWO GATES
DOORS 10 IN. BY 138 IN.
OPENING 9 IN. by 137 IN.
VENTS:
TWO 5-IN.-DIAMETER PORTS
(39.2 IN.^{2})

Figure 3.--Dimensions of TBM tank and gate opening.

Drop Conditions

Drop heights of between 100 and 300 feet were selected because these are the drop heights usually encountered under actual operational conditions. The aircraft speeds were kept between 90 and 145 knots for safe operation of the TBM (USDA Forest Service and U.S. Army 1962). Because the range was rather limited, a low airspeed of 100 knots and a high of 125 knots were desirable.

Although it is not of primary interest to this study, the attitude of the aircraft at the time of retardant release is an important variable because it has a direct effect on the trajectory of the drop, duration of drop, and thus drop dispersion and erosion. This variable is difficult to determine but to minimize the effect of attitude, a flight pattern was selected so that altitude and speed were attained far in advance of the drop area, thus insuring that the attitude would be similar for all drops at the time of release.

The windspeed and wind direction were considered to be of extreme importance even though the opportunity to select these variables was limited. The drop area was oriented at a right angle to normal winds for the area and time of year so as to attain maximum crosswind effects. The humidity and temperature were thought to be of much lesser importance, but were monitored at the time of the drop and considered as independent variables in the analysis.

The Test Matrix

As previously discussed, a large number of variables were present; thus, if the study were to be done using a reasonable number of drops, some subjective decisions had to be made concerning the importance of each variable. A diagram of the general test matrix that provides the best detail on the primary variables (aircraft height, speed, and wind) for each of the four retardants is given in figure 4.

Using this test matrix, and a factorial combination of treatments, the minimum number of drops that could be made (no replications) would be 72 (four retardants × three heights × two speeds × three winds). This type of design lends itself to a multiple regression analysis wherein expected main effects and interactions can be evaluated along with the effects of uncontrolled variables such as humidity, temperatures, wind direction, and retardant viscosity and density.

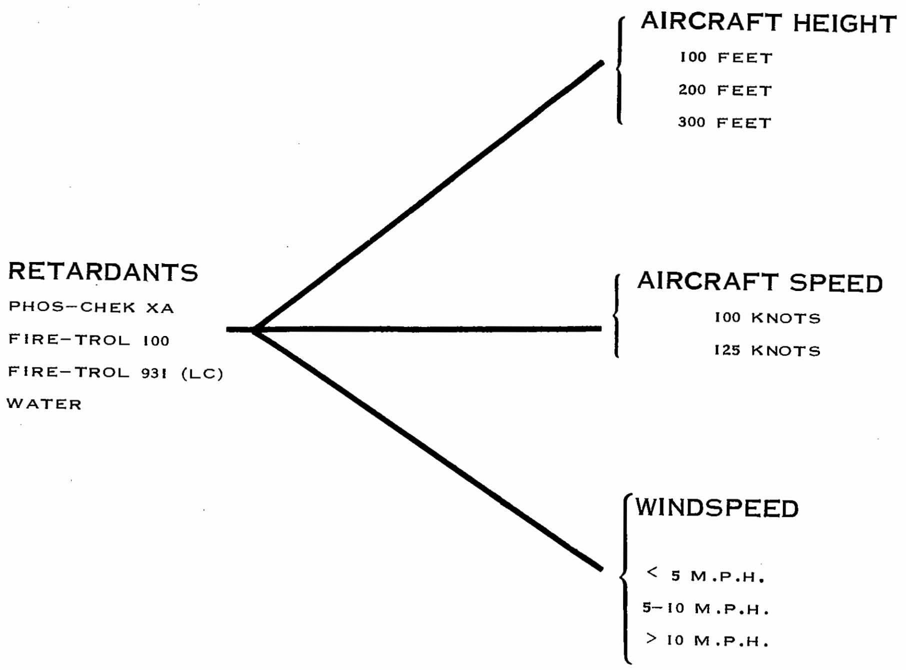


Figure 4.--Test matrix for the drop pattern evaluation.

Measurements

Retardant Properties

Prior to each drop, retardant samples were taken from the aircraft and immediately analyzed for salt content using the field method for salt content determination (George 1971b). In addition, the viscosity of each sample was measured using a Brookfield Viscometer Model LVF at 60 r.p.m. (National Fire Protection Association 1967; George and Hardy 1966). A sample of this material was bottled and returned to the laboratory; the density was measured using a pycnometer, and the salt content was chemically determined using the Kjeldahl method of analysis (USDA Forest Service 1969, 1970). The properties of the retardant used for each drop and the means for all drops are given by product in Appendix tables 4, 5, and 6.

The salt content and density were determined from retardant samples taken at random from cups in the grid, following their weighing. The amount of salt present before and after the drop was used to calculate the amount of water lost in the few minutes prior to capping each sample and through evaporation during the drop. Blank samples monitored in the laboratory under controlled conditions indicated that only insignificant evaporation occurred from the cups between the time of the drop and the weighing of the cups. Appendix tables 4 through 6 show the percent of increase in salt content due to evaporation, the corresponding water loss in gallons, and the percent of the original retardant dropped that was lost due to evaporation. It should be noted that the salt content for each retardant is expressed in the form (compound) in which it occurs prior to mixing or dilution. Thus the percentages should not be used to reflect comparisons of combustion retarding effectiveness.

Environmental Considerations

The wind was considered to be the primary environmental variable affecting distribution of retardant on the ground. A station for measuring wind was positioned about 100 feet from the drop area. A Beckman and Whitley wind system (Model 101) was used to monitor windspeed and wind direction at the standard 20 feet above ground surface. Both parameters were recorded on Esterline-Angus recorders at a chart speed of 0.2 inch per second. Depending upon drop height, this provided fairly good detail of windspeed and direction for the 5- to 30-second period during which the retardant fell to the ground. An event marker denoted the time that gates were opened and retardant released.

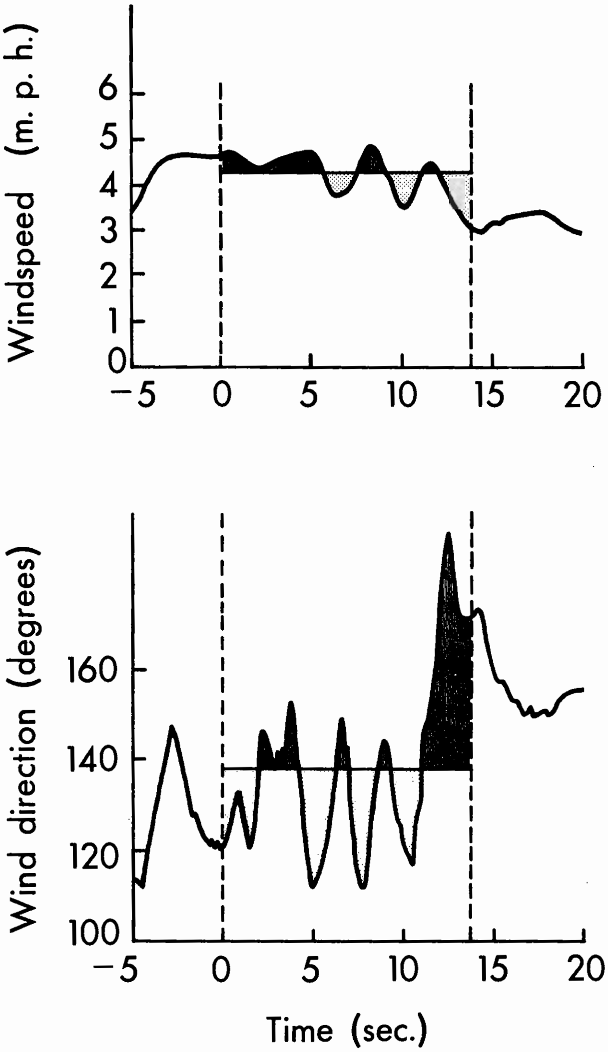
Also, a less sensitive recording wind system (Meteorology Research, Inc., Model 400) was positioned near the drop zone to record temperature in addition to speed and direction of wind. Both wind systems were oriented in relation to the drop area and expected flight path in such a manner that a tailwind would be from 0°, a headwind from 180°, and a crosswind at right angles to the flight path from 90° and 270°. For the analysis, the wind direction was reduced to a range of 0° to 180° left or right because the effect of a crosswind from either side at the same angle had an identical effect.

The average speed and direction of wind during each drop was determined by equalizing the area above and below a superimposed average line.

Figure 5 shows typical windspeed and direction traces and method of determining the average. This type of treatment allows a more precise look at the two parameters if it becomes necessary during the analysis.

In addition to being obtained from our instruments, prevailing windspeed and direction were also obtained from two nearby U. S. Weather Bureau Stations; humidity was obtained only from these two Stations.

Figure 5.--Windspeed and direction for drop showing the method of averaging.



In Appendix table 7, the temperature, relative humidity, average windspeed and direction for each of the retardant drops are recorded by product.

Aircraft Height and Speed

The aircraft's pressure altimeter was not sufficiently accurate; therefore, drop heights were measured by an alternative method. For planning and to assure that the test matrix was completed, it was essential that the approximate drop heights and aircraft speeds be immediately determined. Preceding each drop, a dry run was made using balloons for reference and a theodolite to measure the height. For the actual run, the theodolite was used to measure drop height at a known point located near but in front of the release point. This eliminated error in drop height measurements due to aircraft pitchup following load release.

For precise height measurements, movie film was exposed at right angles in a 70 mm. Hulcher camera and 16 mm. movie film was exposed from a front view. The aircraft's flight path and its distance from the grid centerline were determined from the 16 mm. film. The 70 mm. film was then inspected under a microscope and the release point identified. Using the aircraft length as a base scale, the vertical distance to ground level was calculated. Figure 6 shows a retardant drop over the grid as recorded by the 70 mm. Hulcher camera.

Figure 6.--A retardant drop being made over the grid as recorded by the 70 mm. Hulcher camera.

For an immediate groundspeed check, the aircraft was timed through 2,000 feet prior to and including the length of the grid. The time was measured to 1/100 of a second and the average groundspeed calculated. A more exact groundspeed was determined by using the Hulcher movie. A distance scale was calculated by comparing the actual and film aircraft length. Time markers on film and the calculated scale allowed the average groundspeed across the grid (near one frame width) to be computed. Appendix tables 8 through 11 give the exact aircraft speed and altitude at the time of retardant release.

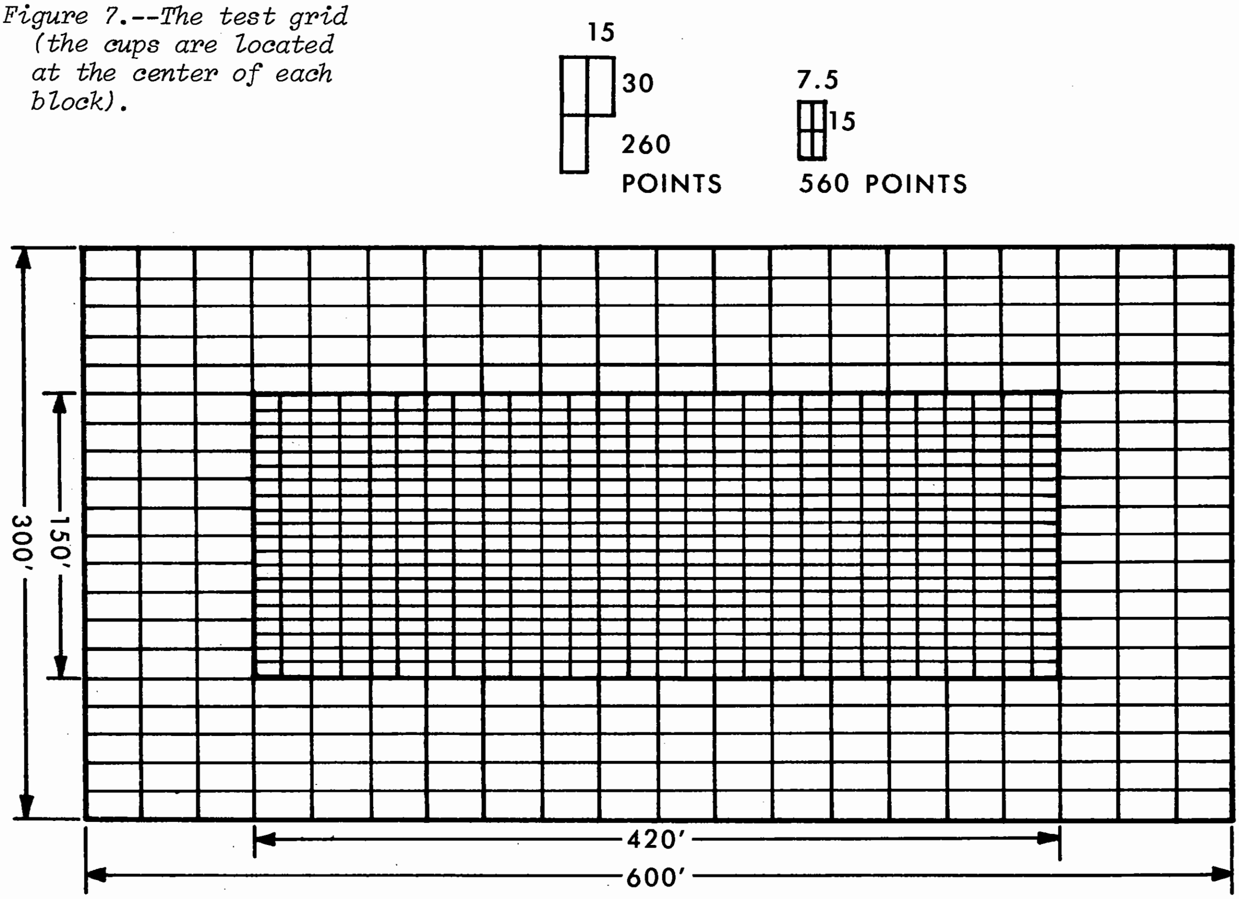
Retardant Drop History

The time required for the retardant to exit the tank for several drops was determined using the timing marks on the 70 mm. Hulcher movie film. This calculation was not possible for those drops where the release point was either slightly premature or late, causing the release or empty-tank point to be out of view of the stationary camera position.

From the 16 mm. films, (right-angle and head-on) the retardant drop trajectory was followed and the horizontal and vertical distance traveled from the release point calculated. The elapsed time from the release point to initial retardant touchdown and the time required for the retardant to settle to the ground were determined from the frame speed.

The area of the drop, as viewed from the right angle 16 mm. camera, was planimetered and plotted against time to empirically quantify the erosion rate. Difficulty was encountered in this analysis since determination of drop boundaries was rather vague due to differences in color intensity of the four products.

Figure 7.--The test grid (the cups are located at the center of each block).



Appendix tables 8 through 11 give the retardant exit and drop times and the horizontal and vertical trajectory distances.

Ground Distribution Patterns

The method used for measuring the ground distribution patterns for all drops consisted of a grid system of cups representing a defined area. The cups were collected and weighed to provide a measure of the concentration at each grid point. Based on the results of previous drop studies (Grigel 1970; MacPherson 1967), a grid which would best suit our expected drop dispersion patterns was constructed and is shown in figure 7. The grid was divided into two portions, an inner and outer grid. The inner grid was sampled rather intensively since it was expected that the majority of the pattern would fall within this area. Each point in the inner grid represented an area 7.5 feet wide by 15 feet long, or 112.5 square feet. The points in the outer grid represented an area 15 by 30 feet or 450 square feet. The inner grid was 150 by 300 feet while the combined grids were 300 by 600 feet.

Each individual point within the grid consisted of a cup permanently fastened to the lid of a garbage can which was foot activated. An identical cup was placed inside the first cup as the retardant receptacle. Two clips were fastened to the garbage can lid so that the inner cup could be held down for drops made from lower heights or when wind or drop turbulence might cause the cup to be blown out. The garbage can was fastened to the ground with two "hairpin" type of stakes. The distance from the ground to the top of the cup was approximately 19.5 inches, a height which would prevent dirt or debris from being splattered into the cup when lower drops were made. Figure 8 shows a garbage can and cup in place following a drop.

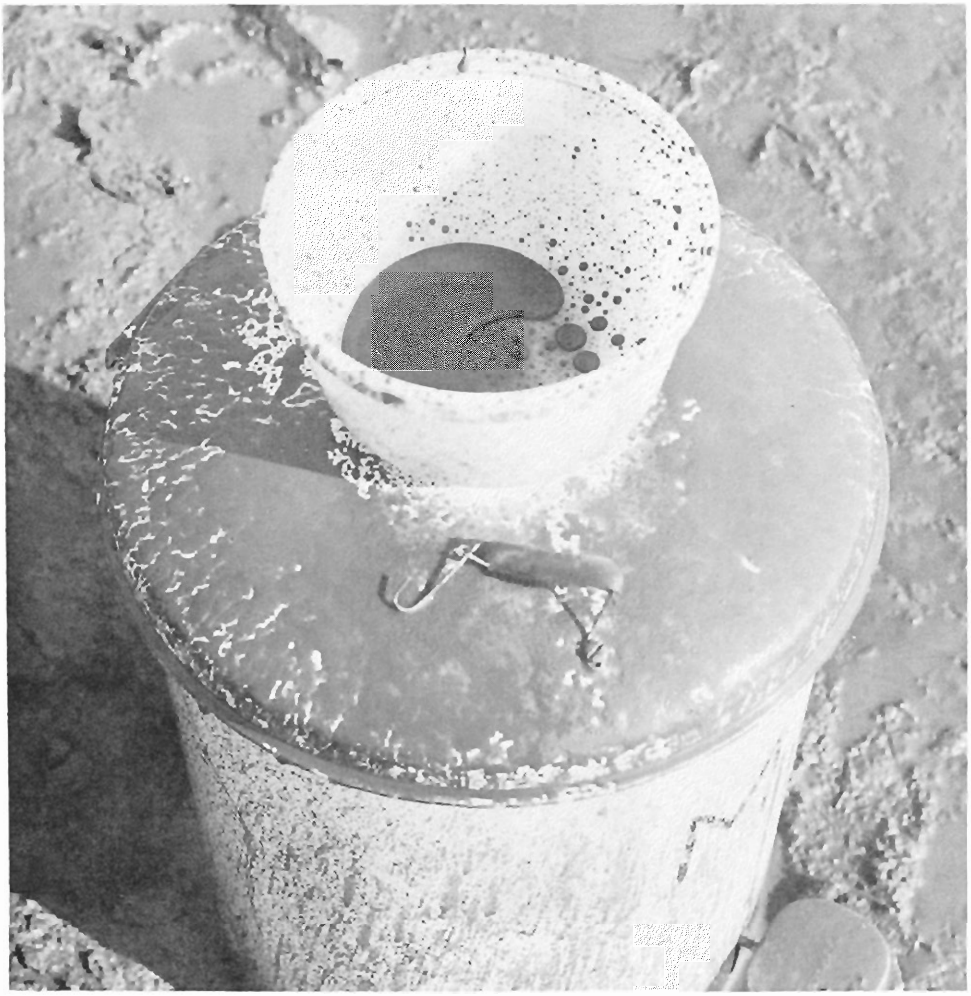


Figure 8.--A cup in place following a drop (recovery shown is approximately 2 gallons/ 100 feet^2).

The purpose of using a garbage can as a base for the cup was that following each drop the cups, which came with airtight lids, were capped and the cup placed inside the can (fig. 9). This allowed as many as five drops to be made prior to collecting all the cups.

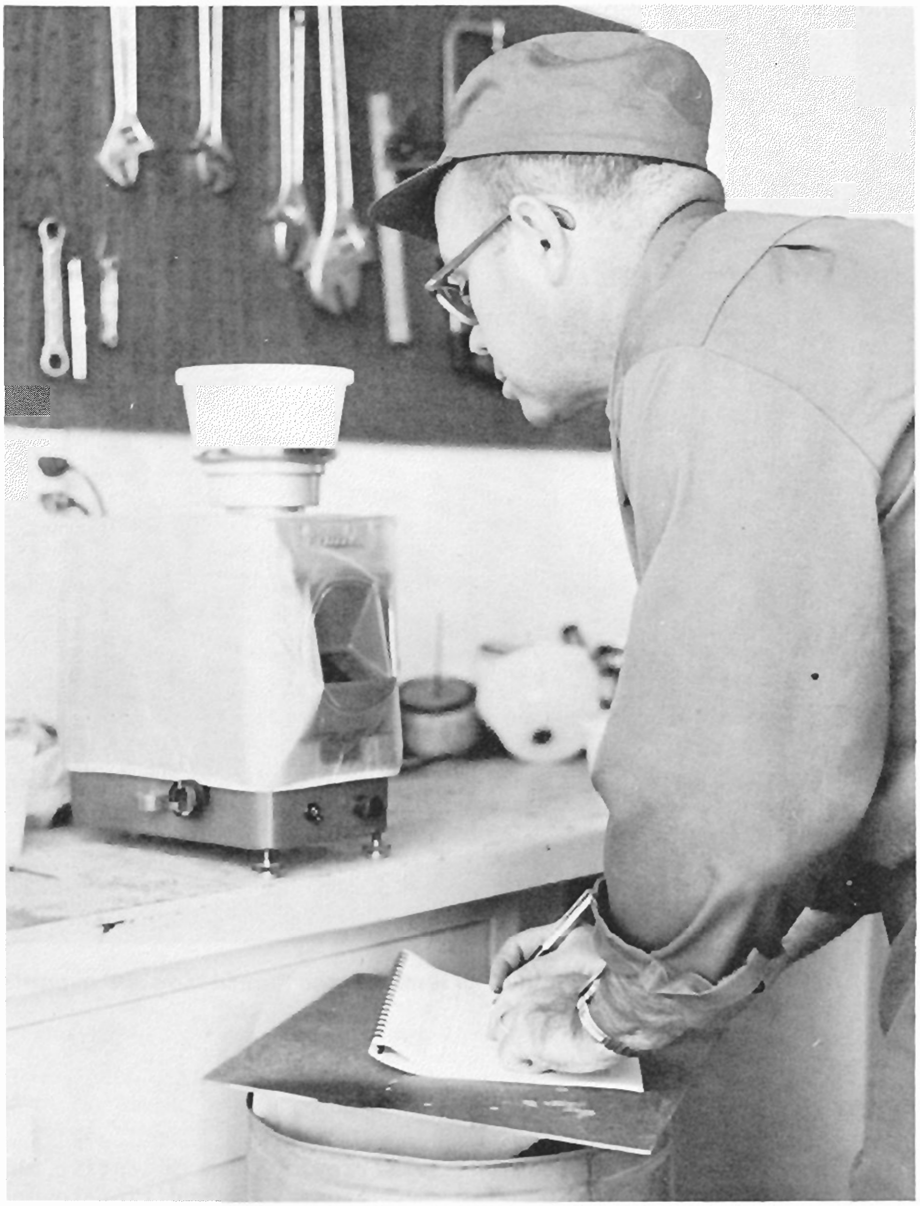
The cups and lids used at each grid point were made of natural polyethylene, or unpigmented plastic. The diameter of each cup was 5.7 inches, thus having an area of 25.52 square inches. All cups and lids were tared into 0.1-gram categories and color coded. In addition to signifying a tare weight, the color code on the lid was used to designate a particular drop for the day. Each cup was 3.12 inches deep which was thought to be sufficient to prevent splash out. Although the cups were much larger than any previously used in drop testing, the percent of area sampled is still relatively small--0.0016 percent in the inner grid and 0.0004 percent in the outer grid. Besides increasing the percent area sampled, the larger cups decreased the relative size of weighing errors and tare differences, because approximately 14 grams of retardant per cup are required to equal a concentration of 2 gallons/100 feet^2.

After no more than five drops, the cups were collected in compartmented boxes which were designed to hold two grid rows. The boxes were then moved to the weighing area where several top-loading Mettler balances were set up. The cups and retardant were collected, weighed (in grams) and weights recorded for the previous drop (figs. 10 and 11).

Figure 9.--Preparing to store a capped cup in preparation for the next drop.

Figure 10.--Collection of cups following several retardant drops.

Figure 11.--Weighing and recording cup weights.



In this study the sample arrangement and size were important considerations. Thus, two questions had to be answered--what is the accuracy or variation for a particular grid point, and is the overall grid spacing and sampling adequate. To answer these questions, nine tables containing nine cups each were installed in the inner grid at positions equidistant from four grid points. These tables were built to a height that placed tops of cups at the same level as tops of other cups in the grid. The nine cups on each table were within an area 20 by 20 inches to provide a measure of the variation about a single sample point. Also, this arrangement provided a value which could be compared to the predicted value for the point using the four surrounding grid points. Holes were cut in the tops of three tables and deep cans positioned so that their tops were the same height as tops of other cups on the table. These cans were weighed and the recovery on the representative area basis was used to determine whether any splash out of the plastic cups in the grid was occurring. Figure 12 shows the tables used to determine the variation about a single cup.

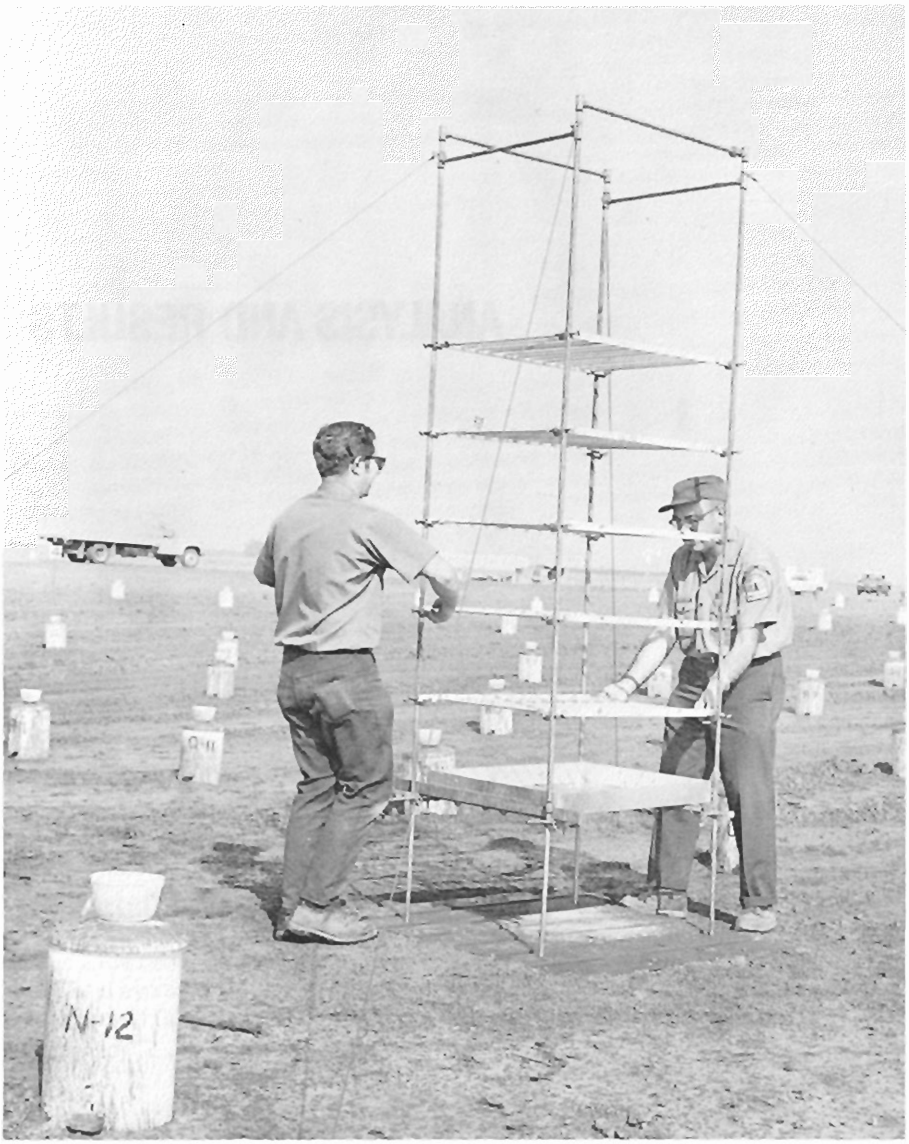
Figure 12.--Array used to determine the variation in a particular cup measurement.

Vertical Distribution

The ground distribution patterns provide a quantitative measure of the erosion of a given retardant under specific conditions. In addition to measurements of the deliverability of a retardant, the vertical distribution within any given fuel is also important. The distribution and retention are related to the rheological properties of the retardant (cohesive and adhesive properties, effect of shear, and time dependence), the droplet size and velocity at the time of impact, the surface characteristics of the fuel (texture, shape, etc.), and the surface area-to-fuel distribution.

In an attempt to determine whether differences in retention by the various retardants exist and to decide whether it would be feasible to construct a model to determine vertical distribution in future drop tests, two small-scale interception arrays were constructed. Vertical racks of 1/2-inch wooden dowels and sandblasted aluminum tubing were fabricated. The purpose of using the tubing was to determine whether an artificial material having a given texture could be used to obtain results similar to those results obtained when using a natural wood fuel array and whether there would be a correlation between such results. If such a correlation were found, then future studies could be simplified and modeled without the problems in measurement caused by fuel moisture content effects.

Figure 13.--Model used to measure the vertical distribution and retention of retardant.



Each of these dowel arrays contained five layers spaced 1 foot apart; each layer had 12 dowels cut to 24-inch lengths and spaced 2.5 inches apart. Also, each layer was constructed so that each dowel was offset from the dowel above by one-half inch, thus giving 100 percent vertical closure through the five layers. A pan was positioned at the bottom to determine the amount of penetration. Figure 13 shows a vertical distribution rack composed of 1/2-inch ponderosa pine dowels.

After the drop, the layers were weighed to determine the retention and the pan was weighed to provide a measure of penetration. The measurements were limited to a few drops because of the time consuming process of weighing and replacing the layers.

ANALYSIS AND RESULTS

Compilation of Grid Data

The basic grid data, the cup and lid tares, environmental data, retardant characteristics, and drop conditions were put on ADP cards. The weight of the retardant collected was then converted to a volume per unit area measurement. The most commonly used units for concentration are gallons/100 feet^2. The conversion was made using the formula:

$$R = K\frac{W-T}{d/A}$$

where

R = retardant concentration (gallons/100 feet^2)

K = conversion factor for units

W = weight of cup, lid, and retardant (grams)

T = tare for cup and lid (grams)

d = density of retardant (grams/cc.)

A = area of cup (25.52 inches^2).

or

$$R = 0.1491\frac{W-T}{d} \text{ gallons/100 feet}^2$$

The total volume falling on the area represented by the inner and outer grid points is:

Inner grid points volume = 1.125R gallons, and

outer grid points volume = 4.5R gallons.

The total retardant reaching the grid was calculated:

Total retardant = $\Sigma 1.125R$ inner grid points + $\Sigma 4.5R$ outer grid points.

A computer program that summarized the grid data by volumes and areas covered was used. The gallons of retardant in each concentration class and the area of coverage within each concentration class were calculated. A summary of these classes gives the total area covered and the total gallons recovered in the grid. Appendix tables 12, 13, 14, and 15 provide a breakdown of areas and gallons by concentration class.

A computer program was developed to plot the concentration calculated for each grid point. The plot was made to scale and the decimal point for each concentration represented the location of the grid point. Using a method of linear proportioning, contour lines were drawn for a trace, 0.2 gallon/100 feet^2, and whole gallons/100 feet^2. From the distribution patterns, contour lengths were determined. The 2 gallons/100 feet^2 contour is of primary interest because studies concerning the effectiveness of these retardants have shown that this level of concentration is the minimum level that will produce a maximum reduction in the rate of spread, intensity, and radiation in a light fuel (George and Blakely 1972). The 2 gallons/100 feet^2 measurements are given in Appendix tables 12 through 15 and include maximum lengths of continuous 2 gallons/100 feet^2 areas, lengths of areas >5-foot widths, and lengths of areas >10-foot widths.

Adequacy of Grid System

To determine whether the intensity of sampling within the inner grid was adequate, the average for the table concentration, as previously discussed (page 15), was plotted against the average of the surrounding grid points for each of the retardants.

It was assumed that if the table concentration could be predicted from the surrounding grid points, and the degree of certainty was acceptable, then more intense sampling would be unnecessary. Figure 14 shows a plot of these data and the regression line for each retardant. An analysis of covariance indicated that the four products showed no significant difference in predictability and that the regression equations were not significantly different from a direct relationship (a 45° line when table and grid concentration are graphed). From the analysis and the graphs in figure 14, we can conclude the sampling intensity is reasonably sufficient and predictions based on proportioning of any points within the inner grid points will usually be <±0.5 gallon/100 feet^2 from the true mean.

To define the variation associated with any given cup measurement, the standard deviation and standard error of the mean were calculated for each table (nine points). The standard deviation for each table was plotted against the average concentration for that table. These relationships are shown in figure 15. Although differences between retardants appear, the importance of the correlation is that for concentrations of 3 gallons/100 feet^2 and less a standard deviation of 0.2 gallon/100 feet^2 or less can be expected. This is a primary reason for using 0.2 gallon/100 feet^2 (trace) as the smallest concentration unit in area coverage determinations.

A comparison of the concentration in the three inset table cans and the six adjacent cups reveals that for drop conditions used in this study, no splash out of the cup occurs or the variation is less than that normally occurring between cups.

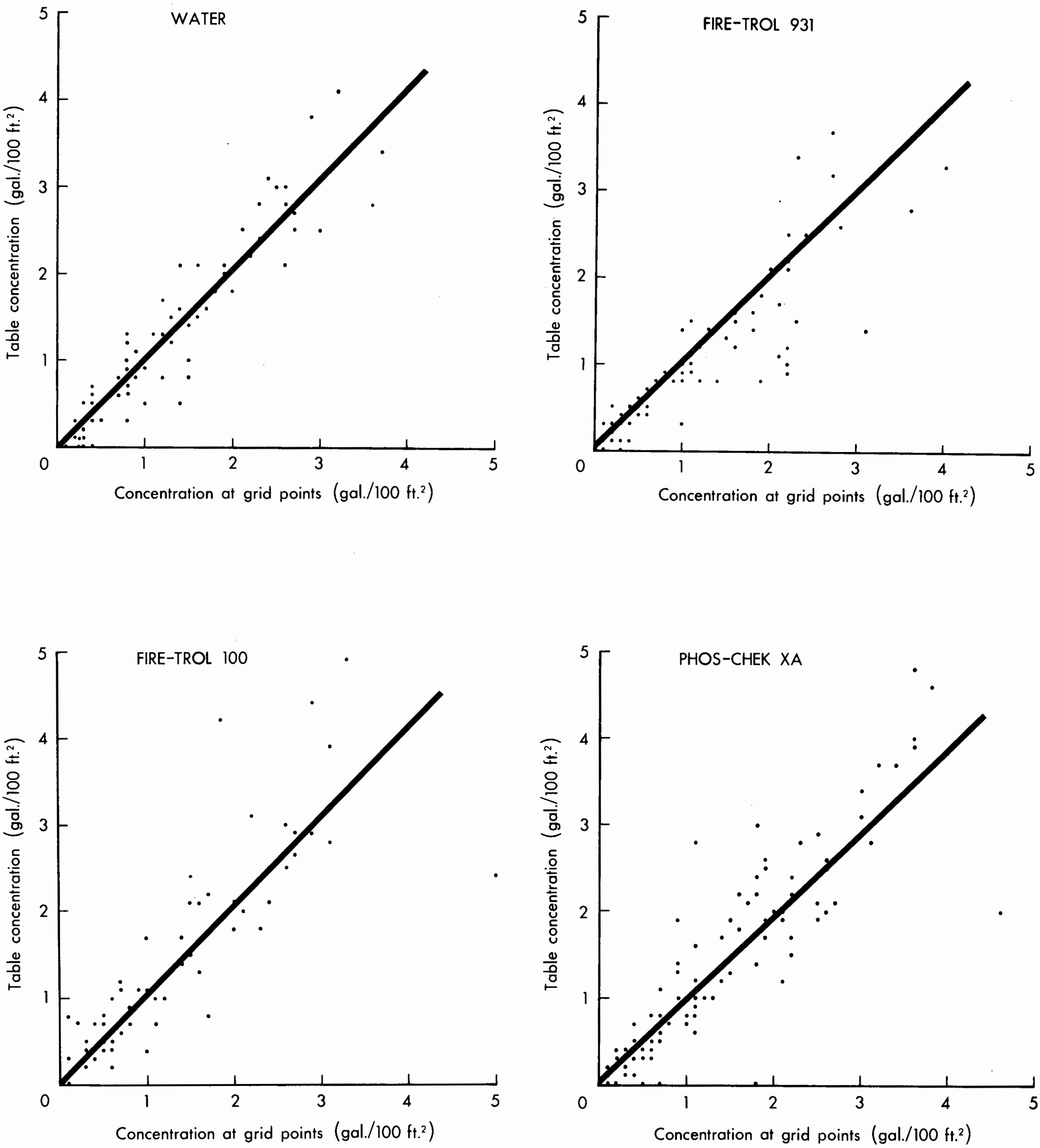


Figure 14.--Table concentration as compared to predicted values from surrounding grid points.

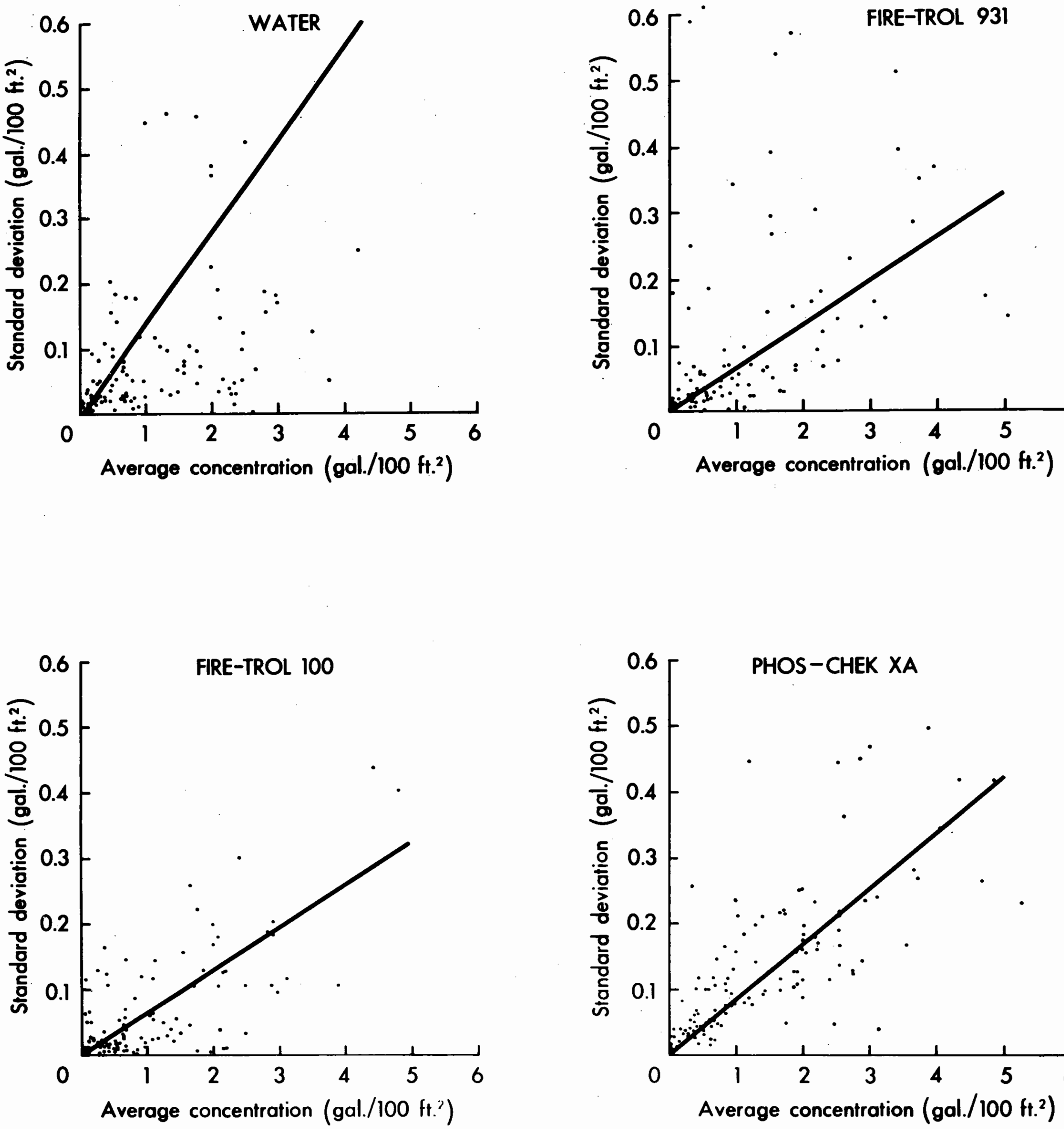


Figure 15.--The variation (standard deviation) as a function of concentration.

Ground Pattern Responses

Areas of Effective Concentration

Simple linear effects of temperature, relative humidity, retardant viscosity and density, windspeed and direction, aircraft speed, and drop height were first screened in additive regression models for predicting the area covered by ≥ 2 gallons/100 feet^2 for each of the four retardants. Drop height and windspeed were found to be consistently strong variables. After accounting for these two effects, the remaining variables failed to contribute consistently and materially to the models in accord with expectation and so were deleted. This does not mean, however, that the deleted variables do not actually affect coverage, but rather that we were unable to identify their effects by reason of limited range in these variables, correlations with the variables retained, and the amount of uncontrolled variation in the data. Figures 16 and 17 show the effect of the primary variables, drop height and windspeed, on retardant erosion drift and resultant ground distribution patterns.

Covariance analysis of the drop height-windspeed models suggested that real differences existed between Phos-Chek XA and the remaining retardants; Phos-Chek generally gave greater effective coverage (area ≥ 2 gallons/100 feet^2) for any given drop height and windspeed. The effective coverage of Fire-Trol 100, Fire-Trol 931, and water tended to decrease in that order. The results of tests for differences between the linear models are shown on page 25.

Since real differences appeared to exist among the simple additive models, a more exacting algebraic portrayal of the drop height-windspeed interaction was undertaken. Expectation was for maximum coverage at optimal drop heights, the optimum moving toward lower drop heights as the windspeeds increased. Sigmoidal decrease in coverage from the maximum was expected as increased departures occurred on either side of the optimal drop height. Also, a sigmoidal decrease in coverage was expected from low to high winds.

For each retardant, expected algebraic forms over drop height for each of three windspeed groups were fitted to the data by the approximate least deviations (the number of observations varied between 16 and 21 for the four retardants). The resulting curves were described and formulated as surfaces using algebraic forms identified from Matchacurve I and II (Jensen and Homeyer 1970, 1971). These forms were given a final adjustment to the data by least squares and the final algebraic models for the area of ≥ 2 gallons/100 feet^2 coverage are given on page 26. The graphic forms of these models are shown in figure 18. Appendix tables 16 and 17 provide predicted values from each surface. The distribution of data points over drop height and wind may be seen in these tables. It is suggested, of course, that most dependence be placed on the predicted values from the general surface area wherein data points are concentrated, i.e., within the boxed areas of the tables. Confidence should not be placed in differences between predicted values for the four retardants outside the data range (boxed area). These values are only given for general interpretation as to the effects of wind and drop height on effective pattern area. An abbreviated set of predicted values is given in table 2 for quick assessment of the magnitude of differences within and between products.

Length of Effective Patterns

Although the area of >2 gallons/100 feet^2 is of primary importance, the continuous length of this area also should be considered because the construction of the maximum amount of fireline per gallon of delivered retardant is often an operational objective. Using the lengths of ≥ 2 gallons/100 feet^2 area (Appendix tables 12 through 15), an analysis of pattern length as related to drop height and wind was made for each retardant.

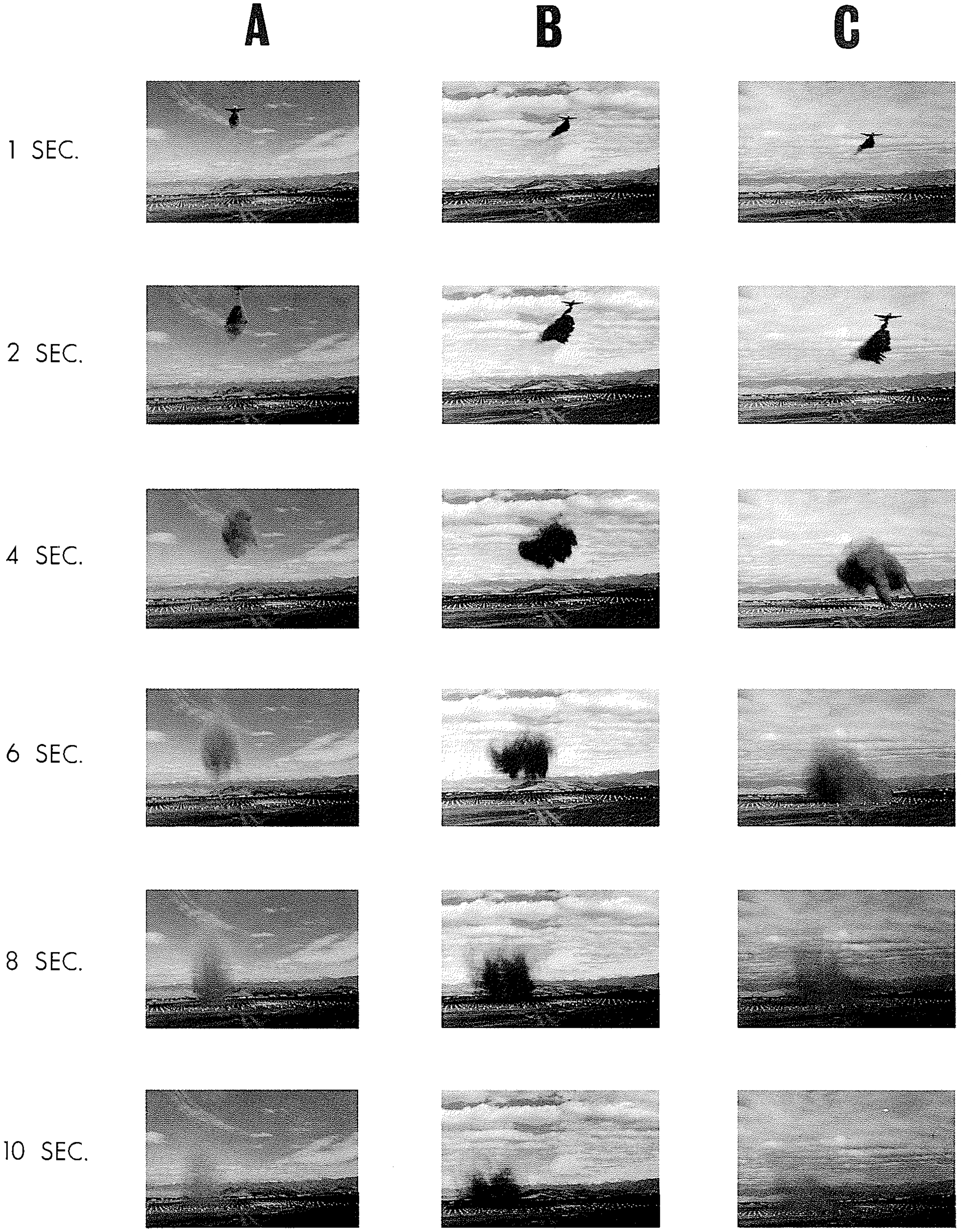


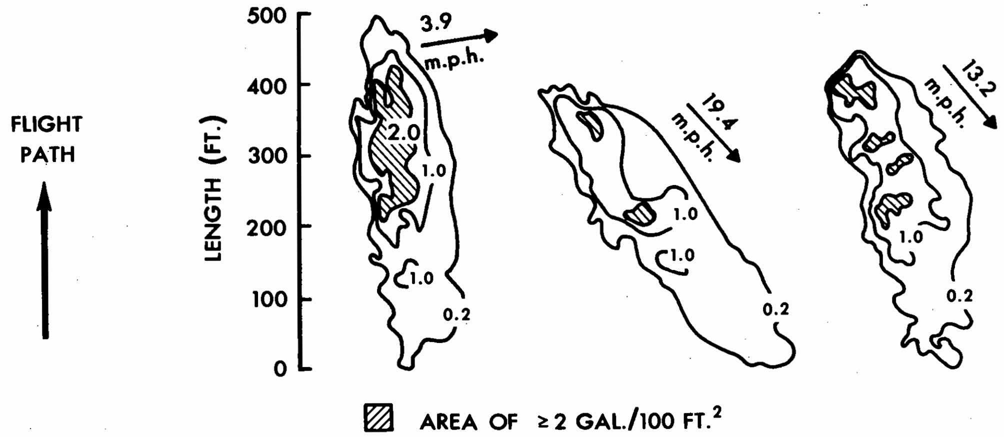
Figure 16.--The general effects of drop height and windspeed on retardant erosion and drift as shown by sequential photographs of three retardant drops.

Drop Conditions

Drop	A	B	C
Height (ft.)	237	234	154
Groundspeed (knots)	102	97	103

Drop Pattern Responses

Drop patterns (0.2, 1.0, AND 2.0 GAL./100 FT.^{2} CONTOURS)



	A	B	C
Recovery (percent)	86	50	68
Coverage (ft.^{2}) (AREA ≥ 2 GAL./100 FT.^{2})	6976	1800	3375

Figure 17.--The general effects of drop height and windspeed on recovery and coverage for three retardant drops.

Within the ≥ 2 gallons coverage area, the length of areas decreased as the drop height and wind increased. The patterns for Fire-Trol 100, Fire-Trol 931, and Phos-Chek XA generally ranged from little to no decrease in length at drop heights from 50 to 150 feet but these patterns decreased rapidly between drop heights of 150 and 350 feet. The pattern for water showed a flat sigmoidal decrease between 50 and 350 feet drop height.

For average winds of about 4 m.p.h., the length of ≥ 2 gallons/100 feet^2 area for Fire-Trol 100 and Fire-Trol 931 decreased from about 210 to 30 feet; Phos-Chek decreased from 230 to 80 feet, and water decreased from 220 to 40 feet over the range of drop heights. Thus, as with coverage, these gross trends indicate that Phos-Chek's greater cohesiveness tends to be reflected in greater lengths (≥ 2 gallons/100 feet^2). This holds for either the maximum lengths of ≥ 2 gallons/100 feet^2 coverage, the length of coverage ≥ 5 feet wide, or the length of coverage ≥ 10 feet wide.

TESTS FOR DIFFERENCES BETWEEN LINEAR MODELS OF EFFECTIVE RETARDANT COVERAGE AND RECOVERY*

Effective Coverage (Area of ≥ 2 Gal./100 Ft.^{2})

	Retardant	*Significance level** percent*
Generally decreasing area ↓	Phos-Chek XA	
		99
	Fire-Trol 100	
		95
	Fire-Trol 931	
		NS
	Water	

Recovery (Total Retardant Reaching the Ground)

	Retardant	*Significance level** percent*
Generally decreasing retardant ↓	Phos-Chek XA	
		99
	Fire-Trol 100	
		NS
	Fire-Trol 931	
		95
	Water	

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*In the linear equations, the primary ground responses for each retardant were expressed as a function of drop height and windspeed. Aircraft speed within the data range was not significant.

**The significance level indicates the probability level at which the difference between retardants may be regarded as real, i.e., not due to chance. "NS" means no significance between products existed for that particular response.

MODEL FOR THE AREA OF 2 GAL./100 FT.^{2} COVERAGE

$$\text{Area} = YP \left\{ \frac{e^{-\left|\frac{\frac{D}{DP} - 1}{1 - I}\right|^N} - e^{-\left|\frac{1}{1 - I}\right|^N}}{1 - e^{-\left|\frac{1}{1 - I}\right|^N}} \right\}$$

Phos-Chek XA

$$\begin{aligned} \text{where:}\quad YP &= 0.9985\left(8{,}450 + 1.205 \times 10^{-4}\ (20\text{-}W)^{5.6}\right) \\ DP &= 1{,}164 - 8.956 \times 10^{-5}\ (20\text{-}W)^{4.8} \\ I &= 0.866 - (1.024 \times 10^{-6})\ (20\text{-}W)^{4.2} \\ N &= 2 \\ {}^{*}R^2 &= 0.21 \\ {}^{**}s_{y \cdot x_i} &= 1{,}106 \end{aligned}$$

Fire-Trol 100

$$\begin{aligned} \text{where:}\quad YP &= 0.9959\left(7{,}600 + 1.506 \times 10^{-4}\ (15\text{-}W)^{6}\right) \\ DP &= 1{,}185 - 3.203 \times 10^{-3}\ (15\text{-}W)^{4.1} \\ I &= 4{,}937 + 0.4063e^{-\left|\left((W/15) - 1\right)/.7\right|^4} \\ N &= 1.5 \\ R^2 &= 0.88 \\ s_{y \cdot x_i} &= 835 \end{aligned}$$

Fire-Trol 931

$$\begin{aligned} \text{where:}\quad YP &= 0.9738\left(6{,}600 + 4.732 \times 10^{-11}(25\text{-}W)^{10}\right) \\ DP &= 1{,}154 - (7.445 \times 10^{-15})\ (25\text{-}W)^{11.8} \\ I &= 0.90 - (2.681 \times 10^{-15})\ (25\text{-}W)^{10} \\ N &= 2 \\ R^2 &= 0.81 \\ s_{y \cdot x_i} &= 1{,}638 \end{aligned}$$

Water

$$\begin{aligned} \text{where:}\quad YP &= 0.9660\left(6{,}100 + 1.112 \times 10^{-2}\ (15\text{-}W)^{4.6}\right) \\ DP &= 1{,}185 - 3.365 \times 10^{-4}\ (15\text{-}W)^{4} \\ I &= 0.90 - 0.00133\ (15\text{-}W)^{1.65} \\ N &= 1.75 \\ R^2 &= 0.80 \\ s_{y \cdot x_i} &= 939 \end{aligned}$$

NOTE: W = windspeed (m.p.h.) $0 \leq W \leq 15$; D = 1,250 - DH; DH = drop height (feet) $50 \leq DH \leq 350$.

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*R^2 is the coefficient of multiple determination.

**$s_{y \cdot x_i}$ is the standard error of the estimate.

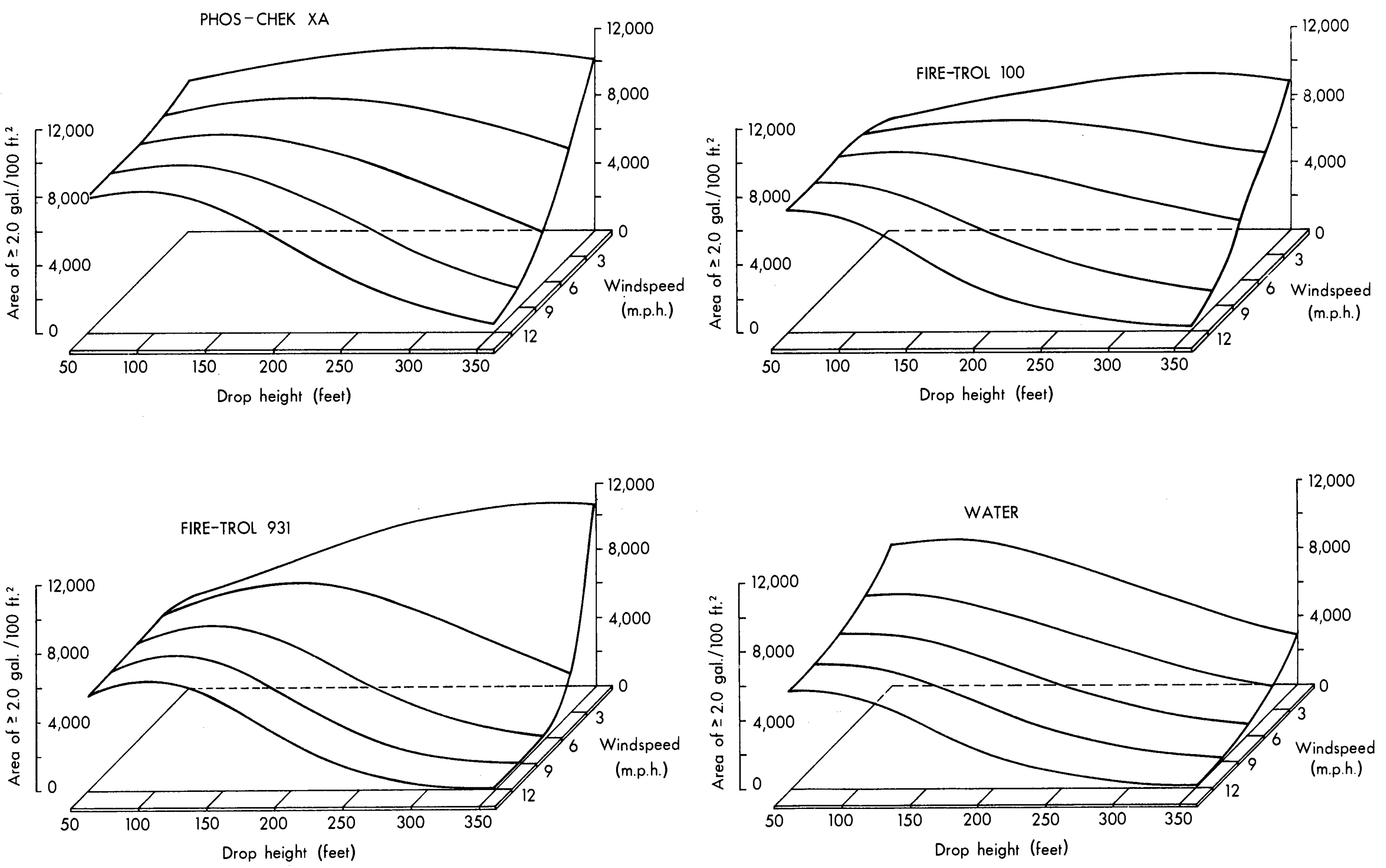


Figure 18.--Graphic forms of the models for predicting the area of effective pattern concentration ($\geq$2 gallons/100 feet^2).

TABLE 2.--A COMPARISON OF PREDICTED VALUES OF AREA COVERED BY ≥2 GAL./100 FT.^{2} AND RETARDANT RECOVERED AT DROP HEIGHTS OF 100, 200, and 300 FEET, BASED ON TEST DROPS USING PHOS-CHEK XA (PC), FIRE-TROL 100 (FT 100), FIRE-TROL 931 (FT 931), AND WATER

Windspeed	100 feet				200 feet				300 feet			
(m.p.h.)	PC	FT 100	FT 931	Water	PC	FT 100	FT 931	Water	PC	FT 100	FT 931	Water
						AREA COVERED (FT.^{2})						
0	9,649	7,325	6,633	8,571	10,654	8,669	9,264	6,643	10,580	9,180	10,736	3,988
3	9,051	7,739	7,180	6,686	9,205	7,741	7,083	4,555	7,611	6,678	3,986	2,216
6	8,718	7,612	6,700	5,843	7,602	6,225	4,044	3,368	4,510	4,424	792	1,230
9	8,513	7,017	6,474	5,489	6,121	3,799	3,059	2,563	2,419	1,493	349	645
						RETARDANT RECOVERED (GAL.)						
0	579	528	550	481	577	524	550	462	569	512	546	412
3	559	499	477	453	548	491	471	429	493	464	442	371
6	539	478	426	423	523	465	408	376	440	424	357	275
9	519	470	393	386	500	454	366	271	403	403	299	104

Retardant Recovered

The method of analysis used for analyzing the areas of effective concentration was used for examining the amount of retardant reaching the ground (e.g., the amount recovered). As in the analysis of the effective concentration areas, the covariance analysis suggested that real differences existed between Phos-Chek XA and the remaining retardants. The tests of differences between the linear models were given on page 25. An algebraic portrayal of the model interation was then developed for each retardant and was adjusted to the data by least squares. Final algebraic models are given on page 30. The models in their graphic form are shown in figure 19. Appendix tables 18 and 19 show the predicted values of retardant and volume recovered as a function of drop height and windspeed. The data points lie within the boxed areas of these tables. As suggested earlier, most dependence should be placed on predicted values within the general surface area wherein data points are concentrated (boxed areas of the tables). An abbreviated set of these predictions was given in table 2.

Variable Concentration, Area Coverage Model

In order to predict areas of coverage other than at the ≥ 2 gallons/100 feet^2 concentration level, a general model was developed by incorporating concentration (Appendix tables 12 through 15) as an independent variable along with drop height and windspeed. The algebraic models for each retardant material are given on pages 59 and 60 in the form of Fortran IV statements, for simplicity; these models are more complex than previous models. Note that the basic drop height effect in all equations is bell-shaped and is of the form:

$$\text{Area covered} = YP \left\{ \frac{e^{-\left|\frac{\frac{1250-DH}{XP}}{1-I}\right|^{N}} - e^{-\left|\frac{1}{1-1}\right|^{N}}}{1 - e^{-\left|\frac{1}{1-I}\right|^{N}}} \right\}$$

where, YP (scalar), I (inflection point), and N (exponent) are specified as various functions of windspeed and coverage concentration. DH is drop height. Predictions of areas of coverage for various levels of concentration for each retardant are given in Appendix tables 20 through 23. Appendix table 24 gives the R^2 and $s_{y \cdot x_i}$ for various levels of coverage within each of the retardant models.

Smoothing over the concentration level has caused some weakening of estimates at the $\geq$2-gallon level for all retardants. This is evident when the R^2 and $s_{y \cdot x_i}$ for the previous, fixed concentration (≥ 2 gallons/100 feet^2) models are compared to those for the variable concentration models. When predictive decision is crucial at the $\geq$2-gallon level, it is suggested that fixed concentration models be used. Note that the latter are only provided for the $\geq$2-gallon level (see p. 26).

The importance of the model containing concentration-level as an independent variable is in its utilization in future studies concerning cost-effectiveness trade-offs between retardant solution salt content, volume of solution, and area of coverage. It is necessary to deliver a given quantity of salt per unit area for a particular situation. The model will permit estimation of the optimum solution salt concentration to obtain maximum effective coverage.

MODELS FOR THE TOTAL GALLONS OF RETARDANT RECOVERED

Phos-Chek XA

$$\text{Total gallons recovered} = 1.00309\left(A - 6.3988 \times 10^{-12} \times SD \times (DH)^{4.4}\right)$$

where: $A = 577 - 6.5\ (W)$
$SD = 252 - 0.001456\ (20\text{-}W)^{4}$

$*R^2 = 0.07$
$**s_{y \cdot x_i} = 39$

Fire-Trol 100

$$\text{Total gallons recovered} = 1.00425\left(A - 4.02324 \times 10^{-9} \times SD \times (DH)^{3.3}\right)$$

where: $A = 468 + 58 \times e^{-\left|\frac{\frac{20-W}{20} - 1}{0.2}\right|^{1.5}}$

$$SD = 27 + 105\left\{\frac{e^{-\left|\frac{\frac{W}{20} - 1}{0.99}\right|^{3.6}} - 0.35457}{0.64543}\right\}$$

$R^2 = 0.01$
$s_{y \cdot x_i} = 43$

Fire-Trol 931

$$\text{Total gallons recovered} = A - (SD/350^{N})\ (DH)^{N}$$

where: $A = 373 + 0.010475\ (20\text{-}W)^{3.25}$
$SD = 210 - 0.49\ (20\text{-}W)^{2}$
$N = 2.65 + 3.7477 \times 10^{-9}\ (20\text{-}W)^{7}$

$R^2 = 0.59$
$s_{y \cdot x_i} = 55$

Water

$$\text{Total gallons recovered} = 1.0078 \times SD \times e^{-\left|\frac{\frac{1,250-DH}{1,250} - 1}{1 - I}\right|^{3}}$$

where: $SD = 343 + 2.0743\ (20\text{-}W)^{1.4}$

$$I = 0.56 + 0.29\left\{\frac{e^{-\left|\frac{\frac{W}{20} - 1}{0.73}\right|^{4.8}} - 0.01079}{0.98921}\right\}$$

$R^2 = 0.78$
$s_{y \cdot x_i} = 43$

NOTE: W = windspeed (m.p.h.) $0 \le W \le 15$; DH = drop height (feet) $50 \le DH \le 350$.

$*R^2$ is the coefficient of multiple determination.
$**s_{y \cdot x_i}$ is the standard error of the estimate.

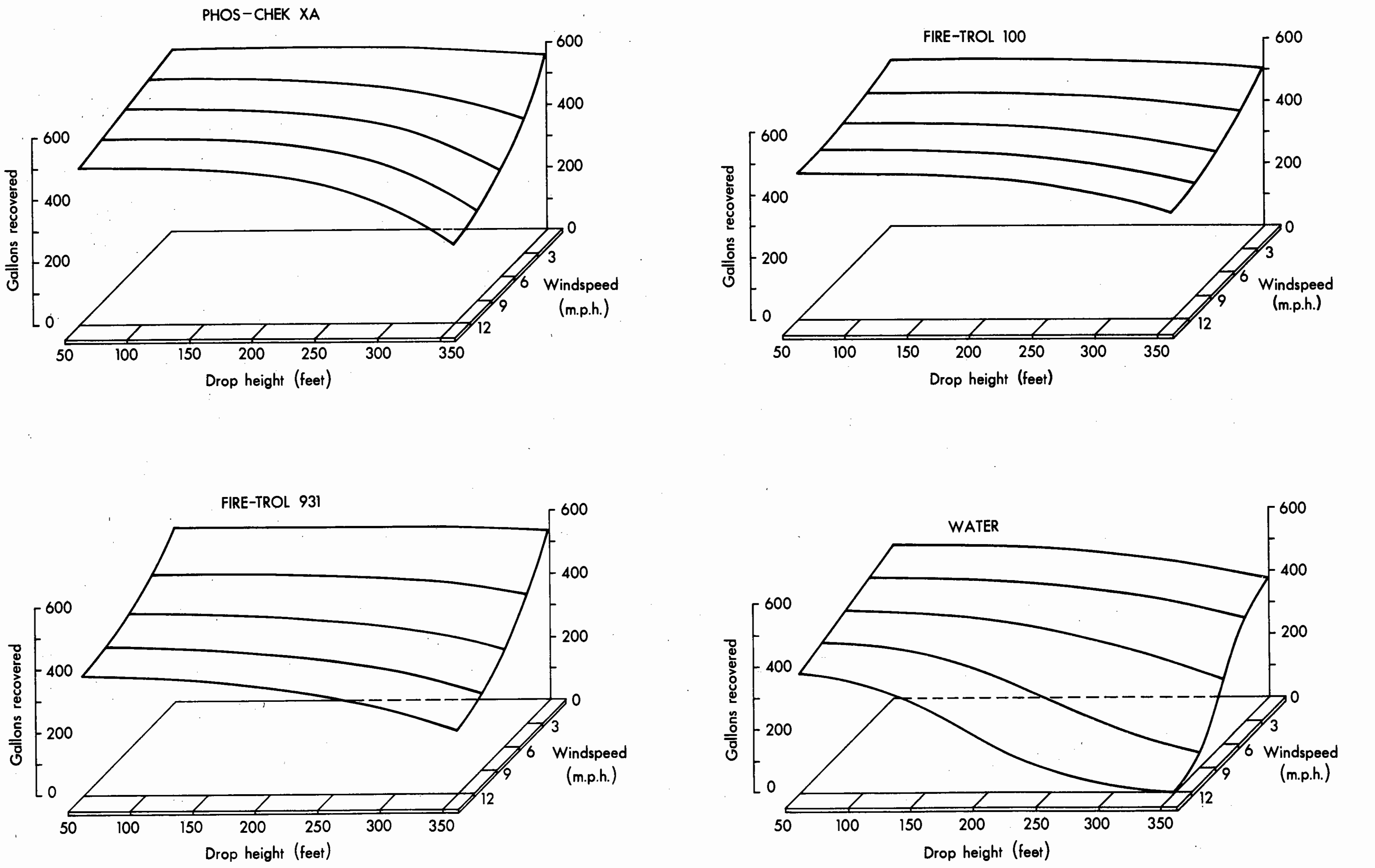


Figure 19.--Graphic forms of the models for predicting the retardant within the pattern.

Vertical Retardant Distribution

Data were obtained from the vertical distribution arrays (both wooden and aluminum) during nine retardant drops. Because the number of variables affecting retention by the arrays is large and the number of measurements limited, a large variation within the retention data was encountered. These retention data were calculated and expressed in relation to the surface area of the array. Appendix table 25 provides a summary of the array data. The retention of retardant solution by the wooden and aluminum arrays was plotted as a function of the total retardant impinging on the array (fig. 20). Although the wooden array appears generally to have greater retention values, covariance analysis indicated that for the limited data, no real difference existed between the retention by the wooden array and the aluminum array. A comparison of the total percent retention by the arrays using a *"t"* test indicated a significantly higher retention for the wood array. Although a much more comprehensive study would be needed to establish whether differences existed between retardants, this analysis will provide some general quantative values for volume retention for a given fuel surface area and as a function of the retardant coverage.

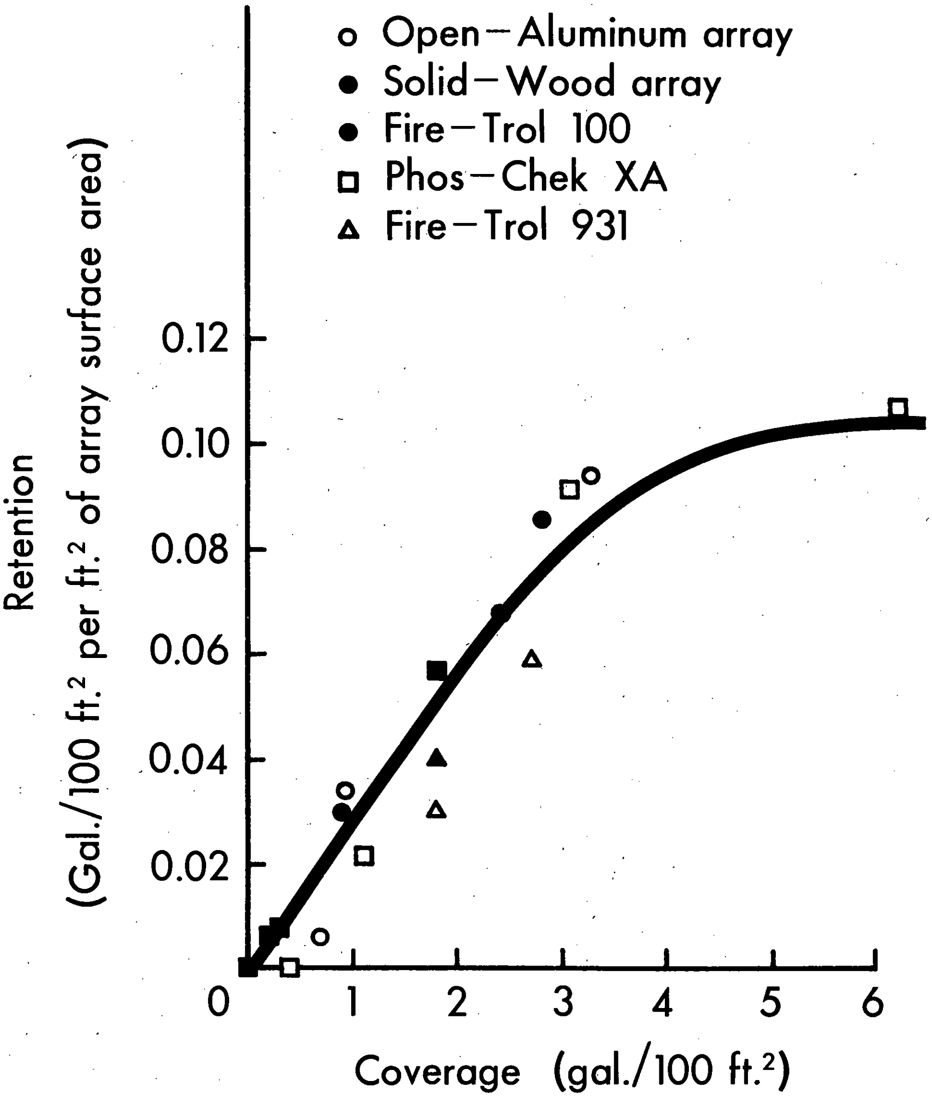


Figure 20.--Retention of retardant by the vertical distribution arrays.

Other Drop Responses

Retardant Exit Time

The exit time of each retardant from the tank (Appendix tables 8 through 11) was studied as a function of drop speed, windspeed, and wind direction. Covariance analysis suggested that no real differences in terms of retardant exit time existed for the four products. The average exit time for all retardant drops was 1.56 seconds ($S = \pm 0.16$, $S_m = \pm 0.03$). If there are real differences in exit times due to drop conditions or retardant properties, they are fairly small (<0.2 second) and measurement of them will likely require added sophistication. Variability in the speed of gate opening and photographic measuring ability are probably the cause of an equal amount of variation. Figure 21 shows a drop profile of a retardant at 0.5- and 1.0-second intervals. Comparing this drop profile and the ground distribution pattern and cross section (fig. 22), notice that the core of the drop or the area of >2 gallons/100 feet^2 concentration begins nearly 250 feet down range from the point of gate opening. The low concentration over the first 250 feet probably indicates poor tank venting or slow opening gates. The retardant within the beginning portion of the drop pattern is the retardant exiting the tank during the first 0.5 second. These first, highly eroded droplets reach terminal velocity almost instantaneously and fall essentially vertical if not influenced by wind.

Drop Time and Trajectory

The time required for a retardant to reach the ground is a function of the erosion process or droplet-size history which is determined by the tank and gate design, retardant exit time, aircraft speed, windspeed and direction, aircraft altitude and attitude, and retardant rheological properties. This drop time (appendix tables 8 through 11) was studied as a function of drop height, windspeed and direction, and aircraft speed. Covariance analysis indicated that the drop height was the primary factor governing the drop time and inclusion of the other variables did not contribute materially to a linear model in terms of improvement of curve fit. This does not mean, however, that the deleted variables do not actually affect the drop time but rather that we were unable to identify their effects by reason of uncontrolled variation in the data. Testing the pooled versus the unpooled model for each retardant indicated that no significant difference in drop times existed between the three formulated retardants. Drop times for water were significantly different from drop times for Phos-Chek XA and Fire-Trol 931, but no significant difference between water and Fire-Trol 100 was found. Although these differences are statistically real, they may not be meaningful because the magnitude of such differences is rather small (≤1.5 seconds for a drop height of 300 feet). It does, however, indicate that differences in droplet size exist and that Phos-Chek XA forms the larger droplets. The drop time as a function of drop height for each of the retardants is shown in figure 23. The equations, their fit, and significance level differences are given in Appendix table 26.

The drop trajectory was quantified by measuring the horizontal and vertical distance the retardant core traveled (from the release point) prior to reaching the terminal velocity. When the leading edge of the retardant became stationary it was assumed that terminal velocity had been reached. A comparison of the drop trajectories indicated a great deal of variation within different drops of the same type retardant. Visual observation as well as measurement indicated that the trajectory was greatly affected by aircraft attitude; however, it was impossible to reliably determine this. Nevertheless, for the tank and gating design and for the particular aircraft used in the tests, the mean drop trajectories may be useful. The forward horizontal distances varied between 305 and 670 feet; the mean of all drops was 487 feet ($S = \pm 63$, $S_m = \pm 9.5$). The vertical distance to terminal velocity ranged from 48 to 144 feet; the mean was 84 feet ($S = \pm 21$, $S_m = \pm 3.3$). The vertical distances to terminal velocity should give some indication of safe drop heights for a 600-gallon drop from an aircraft in a horizontal attitude.

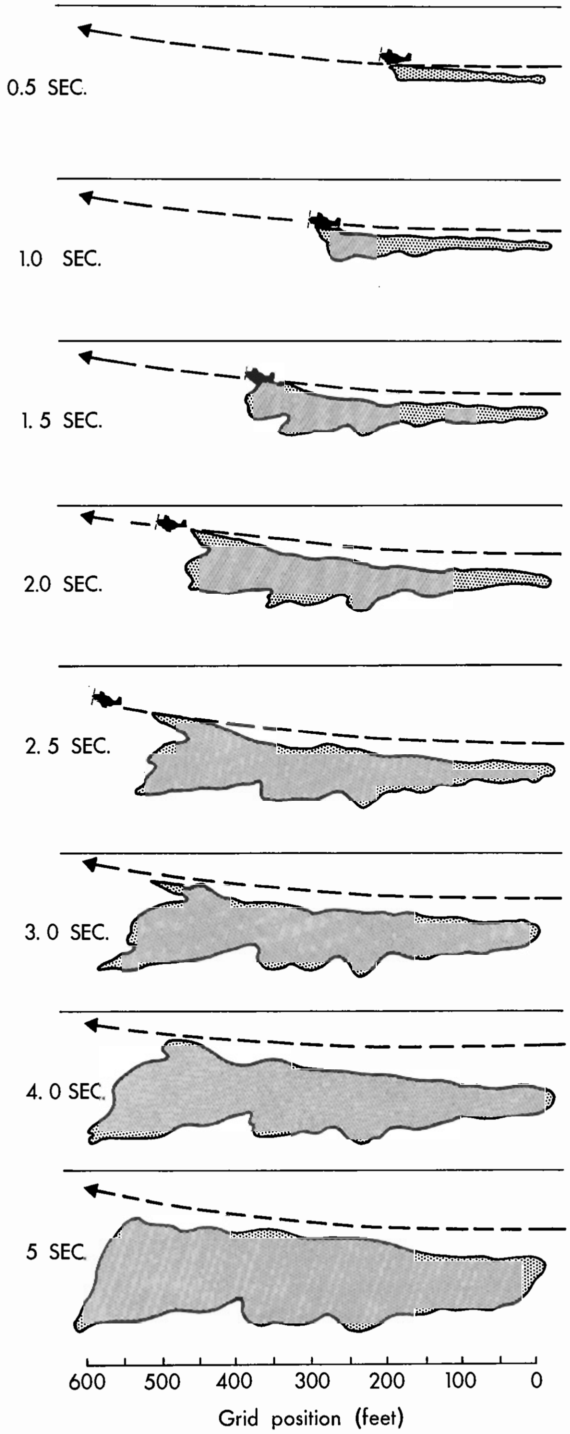


Figure 21.--Retardant drop profile during a release and fall.

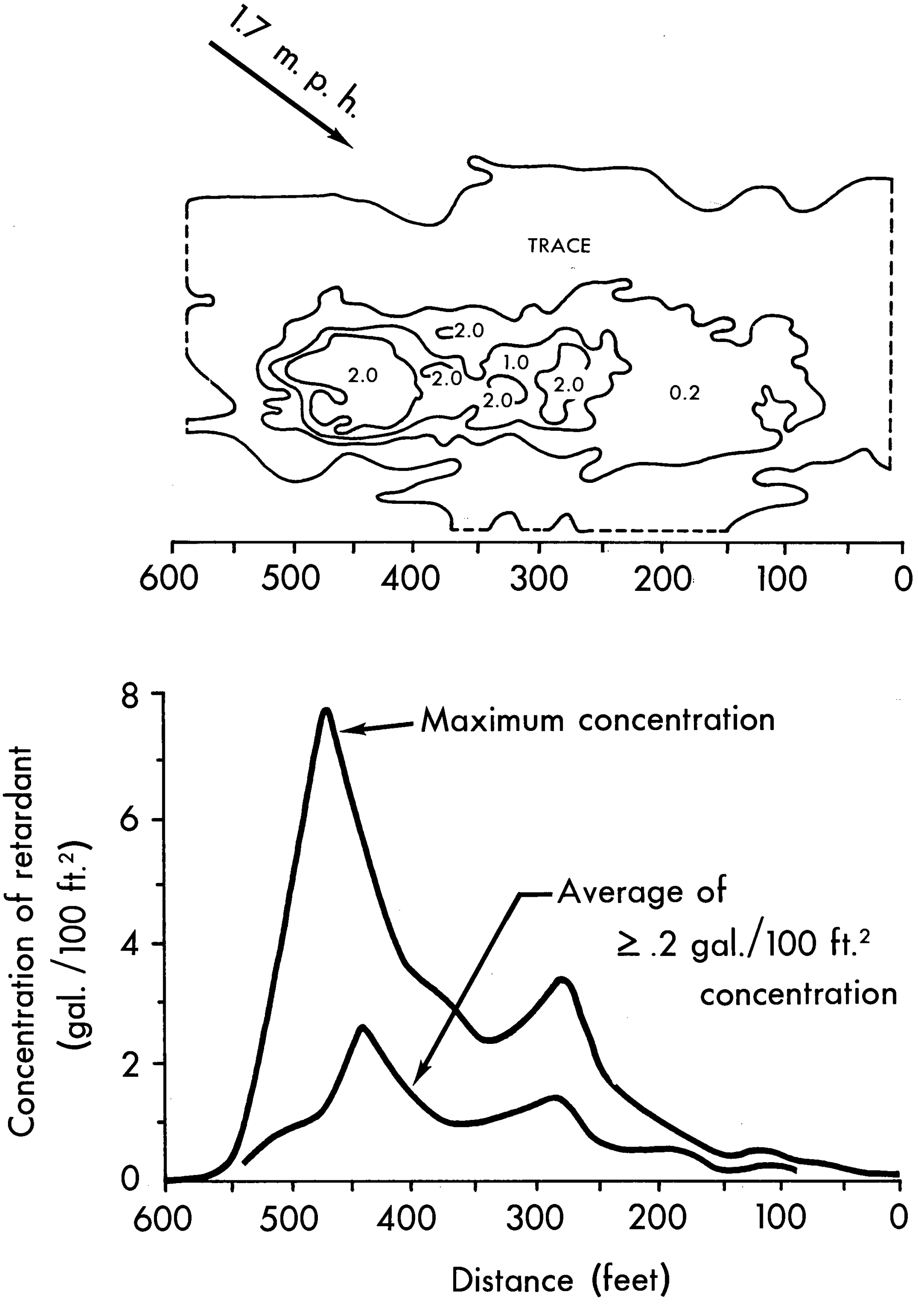


Figure 22.--Ground distribution pattern and average concentration profile for drop shown in figure 21.

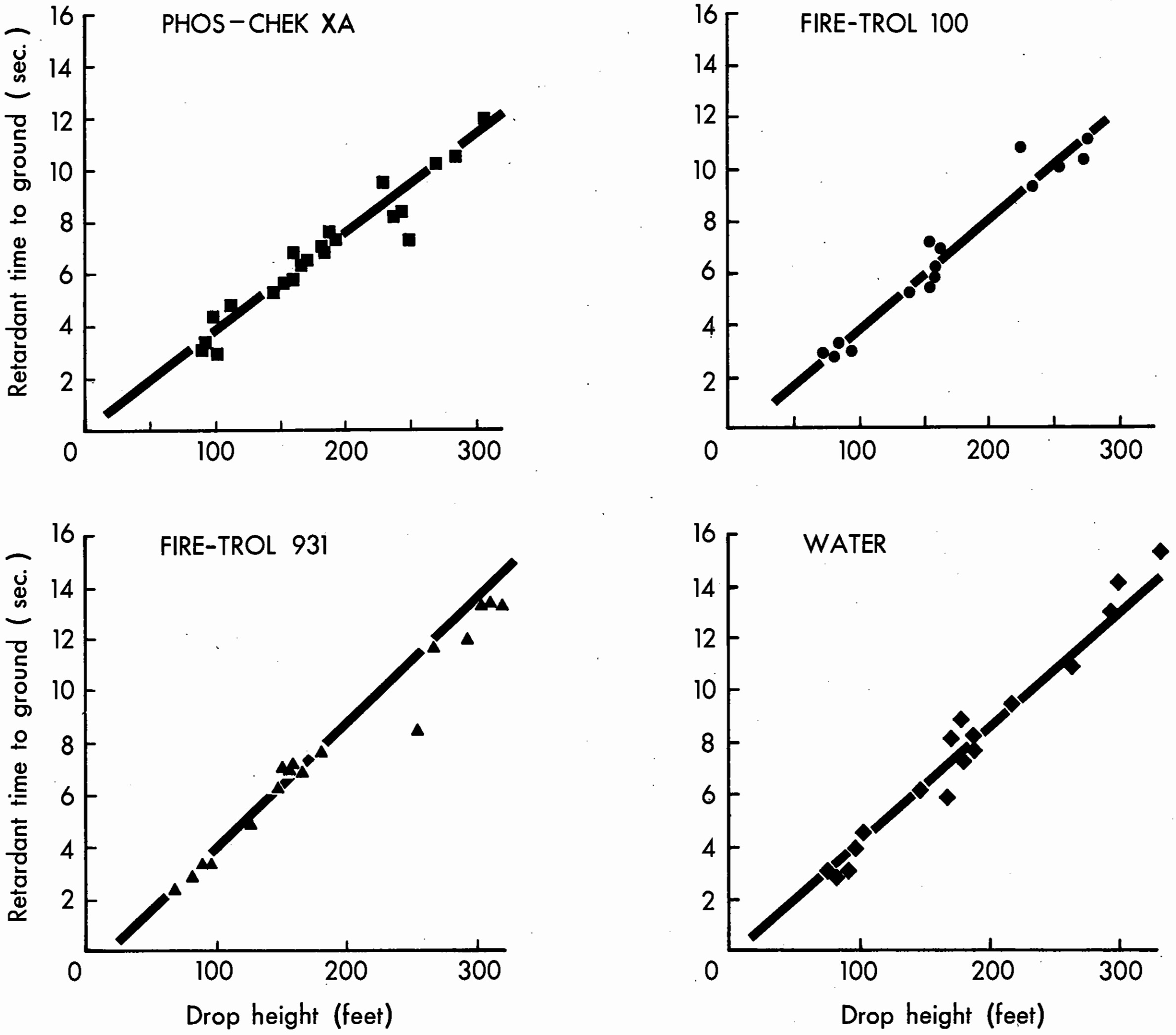
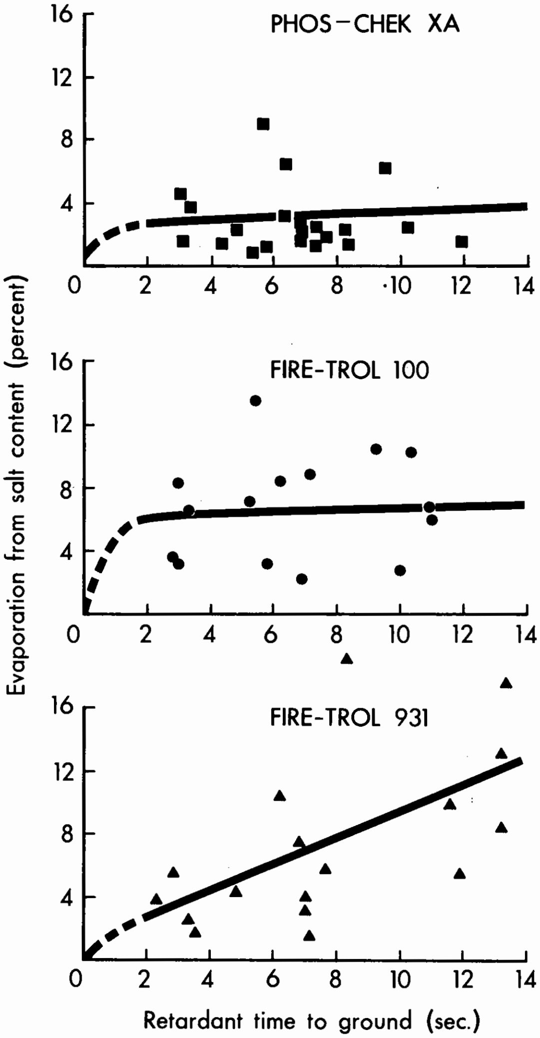


Figure 23.--Time required for the retardants to reach the ground as a function of drop height.

Figure 24.--Evaporation losses as a function of drop time.



Evaporation Losses

The retardant volume that was dropped but not accounted for in the grid measurements was lost because of drift or evaporation during the drop. Determination of the retardant salt content prior to and following the drop allowed calculation of how much water evaporated during the drop (Appendix tables 4 through 6). The quantity of water lost by evaporation during the drop is related to temperature, relative humidity, droplet-size history or surface area of the droplets, and the time of exposure to the atmosphere. The percent of the total drop lost due to evaporation was plotted as a function of the time required for the retardant to reach the ground (the latter previously correlated to drop height) and is shown in figure 24.

Covariance analysis of the percent of drop loss due to evaporation and the time required for the retardant to reach the ground suggests that again real differences (not due to chance) exist between Phos-Chek XA and the remaining retardants. The Phos-Chek drops showed less evaporation for any given drop time or height. The percent of the drop lost by evaporation for Phos-Chek was nearly constant for any condition and less than 4 percent, or 24 gallons. Both Fire-Trol 100 and Fire-Trol 931 had increasing losses as drop time increased and maximum losses of near 12 percent, or 72 gallons. Volume losses above these percentages can be attributed to drift and can be sizable when drop heights and wind increase. The equations for retardant loss by evaporation, their fit, and significance are given in Appendix table 26.

DISCUSSION

The primary objective of the evaluation of drop characteristics and ground distribution patterns of forest fire retardants was to determine the effect of thickening agents on drop characteristics under various drop conditions by quantifying the area of various concentrations, the total area, and the amount of retardant reaching the ground. In this evaluation, both drop height and windspeed were found to be consistently strong variables, for all retardants, in models used for predicting area coverage and gallons recovered. Covariance analysis of the drop height-windspeed models (see page 25) suggested that the greatest real differences existed between Phos-Chek XA and the remaining retardants. The effective area of coverage and retardant recovery tended to decrease for Fire-Trol 100, Fire-Trol 931, and water in that order. Predicted values for the area of effective concentration (≥ 2 gallons/100 feet^2) and the total retardant reaching the ground for various drop heights (50 to 350 feet) and winds (0 to 12 m.p.h.) are given in Appendix tables 16 through 19. Similar predicted values for various levels of concentration are given in Appendix tables 20 through 23.

Although significant differences existed between the thickened retardants (Phos-Chek XA and Fire-Trol 100) and the unthickened retardants (Fire-Trol 931 and water), the largest difference was found between the gum-thickened Phos-Chek XA and all other retardants. The gum-thickened retardant apparently has a cohesiveness that reduces the rate of erosion and maintains a larger minimum droplet size. This characteristic is not adequately quantified by viscosity, or other commonly measured physical properties. Although clay-thickened Fire-Trol 100 exhibits some improvement in drop characteristics over the unthickened materials, it does not exhibit the cohesiveness that the gum-thickened retardants maintain when under high shearing forces. This phenomenon is also reflected in the lower drop times and lower evaporation losses obtained when the gum-thickened retardant (Appendix tables 4 through 6, 8 through 11, and fig. 24) is used.

In addition to providing larger areas of effective coverage and less retardant losses through drift and evaporation, the gum-thickened retardant produced slightly longer effective pattern lengths.

The effect of aircraft speed on drop pattern characteristics, within the limits tested (93 to 127 knots) was small and quantitatively fell within uncontrolled variations in the data. The maximum effective drop speed for the particular tank and gating system used during these tests is probably less than the maximum safe drop speed of 145 knots for the TBM (USDA Forest Service and U.S. Army 1962). The maximum effective drop heights obviously depend on the particular use, fuel, fire intensity, etc. For a given desired concentration and required area, however, the drop height-windspeed models can provide an estimate of maximum heights and winds allowable for a particular retardant drop (see pages 26 and 30 and tables 20 through 23). For example, in a fire situation where winds are about 10 m.p.h., 1,000 square feet of 2 gallons/100 feet^2 coverage might be necessary for desired effectiveness. Under these conditions, a maximum drop height of 250 feet would be effective for a water or Fire-Trol 931 drop. However, Fire-Trol 100 could be delivered from nearly 300 feet and Phos-Chek from as high as 350 feet. Considering this aspect alone, it appears that gum-thickened retardants can be used to permit both higher and safer drops without decreasing the effectiveness.

It should be emphasized that the effectiveness of a delivered retardant depends on the concentration and type of active salt and the coverage of the fuel surface area. Thus there is both an optimum salt content and optimum solution volume which can provide maximum fuel surface coverage while depositing the required concentration of salt. The retardant retention and coverage within the fuel complex are of utmost importance. The variable concentration, area coverage model (tables 20 through 23) will allow us to make studies as to the trade-offs between salt content and volume in relation to effective coverages. Obviously under easy drop conditions (low drop height ≤ 150 feet and low winds ≤ 6 m.p.h.) it may be more economical to adjust the salt content to achieve effectiveness rather than through the use of thickening agents. In other instances, where high drops are necessary (≥ 200 feet) due to canopy heights and topography and in the presence of relatively high winds (≥ 10 m.p.h.), it is necessary to use thickened retardants. In some cases, thickened retardants may also be required to provide an adequate coating of salt on aerial fuel.

Improving retardant drop patterns by manipulation of retardant rheological or physical properties as well as improving retardant release mechanisms should be given considerable attention and will hopefully result in increased retardant effectiveness and air tanker safety.

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APPENDIX

TABLE 3.--COMPOSITION OF THE FIRE RETARDANTS EVALUATED

	Composition	Approximate percent in dry product or concentrate
Thickened Products		
Phos-Chek® XA	Diammonium phosphate (21-53-0)	89
	Guar gum (thickening agent)	8
	Iron oxide (coloring agent)	1
	Corrosion and spoilage inhibitors	2
Fire-Trol® 100	Ammonium sulfate $(NH_4)_2SO_4$	62
	Attapulgite clay (thickening agent)	36
	Iron oxide (coloring agent)	1
	Corrosion inhibitor	1
[1] Unthickened Products		
Fire-Trol® 931 (LC)	[2] Arcadian Poly-N 10-34-0	93
	Iron oxide (coloring agent)	2
	Corrosion inhibitor	1
	Attapulgite clay (to prevent separation in the concentrate)	4

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[1] Although the concentrate is thickened, the mixed product has a low viscosity and can be considered an unthickened product.

[2] Arcadian Poly-N 10-34-0 is a product of Allied Chemical Company.

TABLE 4.--RETARDANT CHARACTERISTICS BEFORE AND AFTER EACH TEST DROP OF PHOS-CHEK XA

Drop No.	Characteristics before drop			Characteristics after drop		Increase in salt content	Water loss during drop[1]	
	Viscosity	Density	Salt content	Density	Salt content			
	Centipoise	G./cc.	Percent $(NH_4)_2HPO_4$	G./cc.	Percent $(NH_4)_2HPO_4$	Percent	Gallons	Percent
2	2,160	1.071	9.77	1.076	10.40	6.4	38.3	6.4
5	2,030	1.071	10.06	1.079	11.00	9.3	55.1	9.2
10	1,793	1.071	10.13	1.072	10.44	3.1	36.7	6.1
13	1,700	1.071	10.04	1.073	10.29	2.5	15.4	2.6
18	1,600	1.071	9.89	1.071	10.04	1.5	10.0	1.7
20	1,580	1.067	9.67	1.070	10.04	3.8	23.5	3.9
29	1,550	1.067	9.52	1.068	9.78	2.7	16.6	2.8
34	1,500	1.067	9.56	1.068	10.09	1.9	11.4	1.9
37	1,550	1.067	9.61	1.176	9.74	1.4	9.1	1.5
39	1,500	1.067	9.51	1.070	9.81	3.2	19.8	3.3
41	1,520	1.067	9.48	1.069	9.71	2.4	15.3	2.6
43	1,350	1.067	10.00	1.069	10.22	2.2	14.3	2.4
46	1,490	1.067	10.19	1.069	10.28	.9	6.1	1.0
52	1,445	1.067	9.94	1.068	10.24	3.0	20.3	3.4
59	1,500	1.067	9.90	1.068	10.07	1.7	10.7	1.8
62	1,430	1.067	10.05	1.068	10.23	1.8	11.8	2.0
64	1,430	1.067	10.11	1.068	10.26	1.5	9.5	1.6
66	1,460	1.067	9.90	1.068	10.11	2.1	13.6	2.3
67	1,400	1.067	9.83	1.064	9.55	1.4	9.3	1.6
68	1,450	1.067	9.79	1.067	10.26	4.8	28.0	4.7
69	1,370	1.067	10.09	1.068	10.22	1.3	8.5	1.4
Mean	1,562	1.068	9.86	1.075	10.13	3.2	18.3	3.1

[1] The water loss during the drop is calculated from the increase in the salt content of the retardant reaching the ground. Percent values shown represent percent loss based on a 600-gal. load.

TABLE 5.--RETARDANT CHARACTERISTICS BEFORE AND AFTER EACH TEST DROP OF FIRE-TROL 100

Drop No.	Characteristics before drop			Characteristics after drop		Increase in salt content	Water loss during drop[1]	
	Viscosity	Density	Salt content	Density	Salt content			
	Centipoise	G./cc.	Percent $(NH_4)_2SO_4$	G./cc.	Percent $(NH_4)_2SO_4$	Percent	Gallons	Percent
3	4,465	1.139	13.34	1.156	14.37	7.7	51.0	8.5
7	2,160	1.146	13.15	1.149	13.56	3.1	19.8	3.3
9	2,240	1.144	13.96	1.158	14.82	6.2	41.4	6.9
14	3,830	1.176	16.23	1.186	17.14	5.6	36.6	6.1
16	2,560	1.165	15.10	1.171	15.60	3.3	22.2	3.7
21	3,290	1.167	15.05	1.171	16.37	8.8	50.4	8.4
24	1,940	1.154	14.73	1.157	16.12	9.4	53.4	8.9
30	2,360	1.152	14.82	1.159	15.16	2.3	17.4	2.9
32	1,880	1.155	14.33	1.164	15.33	6.9	43.2	7.2
38	2,850	1.174	15.85	1.176	16.29	2.8	17.4	2.9
45	2,500	1.158	16.38	1.186	18.48	12.8	80.7	13.5
47	2,520	1.163	16.40	1.181	18.05	10.1	63.0	10.5
51	2,900	1.170	16.98	1.171	17.54	3.3	19.8	3.3
56	2,250	1.149	15.36	1.166	16.21	5.5	39.6	6.6
58	2,260	1.156	15.87	1.173	17.43	9.8	61.8	10.3
60	2,410	1.157	15.20	1.159	15.53	2.3	13.8	2.3
Mean	2,651	1.158	15.17	1.168	16.13	6.2	39.5	6.6

[1] The water loss during the drop is calculated from the increase in the salt content of the retardant reaching the ground. Percent values shown represent percent loss based on a 600-gal. load.

TABLE 6.--RETARDANT CHARACTERISTICS BEFORE AND AFTER EACH TEST DROP OF FIRE-TROL 931

Drop No.	Characteristics before drop: Viscosity	Characteristics before drop: Density	Characteristics before drop: Salt content	Characteristics after drop: Density	Characteristics after drop: Salt content	Increase in salt content	Water loss during drop[1]	
	Centipoise	*G./cc.*	*Percent* P_2O_5	*G./cc.*	*Percent* P_2O_5	*Percent*	*Gallons*	*Percent*
1	226	1.122	8.60	1.138	10.40	10.5	62.4	10.4
6	154	1.122	9.92	1.128	10.28	3.6	24.0	4.0
11	70	1.122	9.40	1.144	11.18	18.9	105.6	17.6
15	75	1.122	9.43	1.122	9.73	3.2	18.6	3.1
17	140	1.122	9.42	1.126	9.76	3.6	23.4	3.9
22	140	1.122	9.98	1.131	10.47	4.9	33.0	5.5
25	78	1.101	7.84	1.108	7.93	1.1	9.6	1.6
26	80	1.101	7.81	1.112	8.60	10.1	59.4	9.9
28	68	1.101	7.95	1.105	8.19	3.0	19.2	3.2
31	72	1.101	7.98	1.106	8.28	3.8	24.0	4.0
36	160	1.103	8.03	1.111	8.71	8.5	51.0	8.5
40	140	1.103	7.86	1.108	8.33	6.0	34.8	5.8
44	440	1.101	7.68	1.124	9.60	25.0	127.8	21.3
49	250	1.103	10.04	1.138	11.40	13.5	79.2	13.2
53	60	1.103	8.45	1.104	8.66	2.5	15.6	2.6
54	120	1.103	8.41	1.105	8.55	1.7	10.8	1.8
61	160	1.103	8.44	1.109	9.07	7.5	45.0	7.5
65	30	1.103	8.67	1.109	9.12	5.2	33.0	5.5
Mean	137	1.109	8.66	1.118	9.35	7.5	43.1	7.2

[1] The water loss during the drop is calculated from the increase in the salt content of the retardant reaching the ground. Percent values shown represent percent loss based on a 600-gal. load.

TABLE 7.--ENVIRONMENTAL CONDITIONS DURING EACH TEST DROP OF WATER AND CHEMICAL RETARDANTS

Drop No.	Air temperature	Relative humidity	Windspeed	Wind direction[1]	Drop No.	Air temperature	Relative humidity	Windspeed	Wind direction[1]
	°F.	*Percent*	*M.p.h.*	*Degrees*		°F.	*Percent*	*M.p.h.*	*Degrees*
		PHOS-CHEK XA					FIRE-TROL 100		
2	68	27	2.2	111 L	3	70	25	4.3	138 R
5	60	47	3.4	123 L	7	68	38	3.6	174 R
10	59	50	5.3	144 L	9	54	53	2.0	135 L
13	65	48	2.3	151 L	14	65	48	.7	73 L
18	67	38	2.5	108 R	16	65	44	2.6	139 R
20	63	45	2.7	138 L	21	67	38	4.8	175 R
29	56	67	3.3	135 R	24	59	47	1.7	145 L
34	63	58	3.4	140 L	30	60	63	2.8	38 R
37	57	65	3.8	65 L	32	57	65	2.4	76 R
39	57	55	5.0	105 L	38	61	64	10.4	68 L
41	58	51	3.9	162 L	45	67	41	13.2	110 L
43	64	46	3.9	85 L	47	67	41	8.4	94 L
46	68	40	13.0	113 L	51	55	78	6.4	162 R
52	58	65	.2	136 L	56	57	66	4.3	42 L
59	61	58	.3	37 R	58	61	55	.3	29 R
62	59	51	4.2	152 R	60	57	58	3.4	128 L
64	56	55	.1	94 R					
66	56	54	1.9	81 R					
67	58	48	3.3	120 R					
68	58	49	1.5	152 R					
69	54	61	4.9	102 L					
		FIRE-TROL 931					WATER[2]		
1	61	34	4.9	156 L	4	70	25	2.1	153 L
6	64	43	1.6	156 L	8	68	37	5.9	177 R
11	60	51	3.0	140 L	12	62	50	5.0	159 L
15	65	48	5.4	150 L	19	66	39	2.0	100 R
17	68	40	2.4	14 R	23	69	35	4.0	58 R
22	69	37	3.8	127 R	27	67	37	3.2	170 L
25	63	42	2.5	129 L	33	63	58	3.2	102 R
26	68	37	5.7	166 L	35	64	55	3.9	157 L
28	51	76	2.5	119 L	42	59	49	2.4	91 L
31	63	58	1.1	38 R	50	54	82	7.7	110 L
36	59	65	5.5	48 L	55	59	63	.2	175 R
40	58	51	1.3	135 L	57	59	62	.9	163 L
44	67	42	19.4	126 L	63	57	56	5.3	150 L
49	65	43	5.0	142 L	70	56	59	5.5	115 L
53	59	62	.2	154 L	71	61	46	.3	169 R
54	59	61	.8	167 L	72	62	42	3.8	143 L
61	58	54	5.4	177 L	73	63	43	2.6	32 L
65	56	54	4.4	138 R	74	63	42	2.4	91 L

[1] The wind direction is given in degrees left or right of grid center (0° = tailwind, 180° = headwind).

[2] At a viscosity of 1.0 centipoise and a density of 1.0 grams/cubic centimeter.

TABLE 8.--AIRCRAFT HEIGHT AND SPEED, AND DROP HISTORY AND TRAJECTORY FOR PHOS-CHEK XA[1]

Drop No.	Drop speed	Drop height	Drop history			Drop trajectory	
			Time to exit tank	Time to reach ground	Time to settle	Horizontal	Vertical
	Knots	*Feet*	- - - - - - - *Seconds* - - - - - - -			- - - - *Feet* - - - -	
2	115	168	1.67	6.50	12.63	--	--
5	96	152	1.61	5.63	8.67	--	--
10	111	228	--	9.48	13.04	--	--
13	97	269	--	10.21	14.48	--	--
18	98	90	--	3.10	6.46	--	--
20	117	91	1.35	3.33	7.71	--	--
29	116	182	1.52	6.79	12.29	495	59
34	108	182	1.35	6.85	11.90	549	81
37	124	248	--	7.33	--	393	77
39	122	166	1.26	6.25	11.25	491	69
41	98	191	--	7.29	11.60	447	73
43	102	237	--	8.15	13.15	482	83
46	103	145	--	5.27	9.46	494	87
52	113	111	--	4.79	8.27	540	62
59	122	305	--	11.88	16.35	--	--
62	113	187	1.45	7.58	14.00	--	--
64	110	242	--	8.33	12.71	485	126
66	112	159	1.39	6.77	12.29	442	114
67	107	98	1.63	4.27	8.85	455	61
68	101	98	1.56	3.00	7.40	520	76
69	100	159	--	5.73	9.69	517	77
Mean	109	177	1.48	6.60	11.11	485	80

[1] Available data depended on movie coverage. Where data are lacking, the drop release or empty point was out of the camera's view.

TABLE 9.--AIRCRAFT HEIGHT AND SPEED, AND DROP HISTORY AND TRAJECTORY FOR FIRE-TROL 100[1]

Drop No.	Drop speed	Drop height	Drop history			Drop trajectory	
			Time to exit tank	Time to reach ground	Time to settle	Horizontal	Vertical
	Knots	*Feet*	- - - - - - - *Seconds* - - - - - - -			- - - - *Feet* - - - -	
3	116	157	1.66	6.17	13.71	--	--
7	103	157	--	5.75	11.83	--	--
9	114	223	--	10.83	18.81	--	--
14	97	275	--	11.04	--	--	--
16	96	79	1.56	2.77	9.04	--	--
21	109	72	1.56	2.90	10.17	--	--
24	114	153	--	7.08	15.31	507	82
30	120	149	1.65	--	--	546	64
32	99	137	--	5.21	13.75	466	89
38	127	253	--	10.04	--	670	144
45	103	154	1.65	5.40	12.90	517	90
47	107	232	1.84	9.19	17.92	516	96
51	95	92	1.65	3.02	9.33	305	48
56	125	83	--	3.27	11.50	507	--
58	105	272	--	10.33	19.08	--	--
60	104	161	--	6.88	15.48	--	--
Mean	108	166	1.65	6.66	13.76	504	88

[1] Available data depended on movie coverage. Where data are lacking, the drop release or empty point was out of the camera's view.

TABLE 10.--AIRCRAFT HEIGHT AND SPEED, AND DROP HISTORY AND TRAJECTORY FOR FIRE-TROL 931[1]

Drop No.	Drop speed	Drop height	Drop history			Drop trajectory	
			Time to exit tank	Time to reach ground	Time to settle	Horizontal	Vertical
	Knots	*Feet*	- - - - - - - *Seconds* - - - - - - -			- - - - -*Feet* - - - -	
1	113	146	1.42	6.17	12.10	--	--
6	104	125	--	4.83	11.63	--	--
11	113	289	1.35	13.25	--	--	--
15	97	325	--	--	--	--	--
17	99	67	1.74	2.33	8.02	--	--
22	117	80	1.33	2.75	10.83	--	--
25	97	158	--	7.08	15.03	522	119
26	93	246	--	11.63	--	421	90
28	116	150	--	6.98	18.96	520	69
31	106	157	1.49	6.96	--	523	112
36	124	298	--	13.15	--	612	67
40	95	180	--	7.75	15.00	468	106
44	97	234	--	8.35	17.42	407	91
49	97	283	--	13.15	25.53	535	73
53	94	88	--	3.31	--	462	--
54	115	95	--	3.31	--	543	59
61	101	165	--	6.77	13.50	--	--
65	105	272	--	11.88	18.23	493	91
Mean	105	186	1.47	7.63	15.11	501	88

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[1] Available data depended on movie coverage. Where data are lacking, the drop release or empty point was out of the camera's view.

TABLE 11.--AIRCRAFT HEIGHT AND SPEED, AND DROP HISTORY AND TRAJECTORY FOR WATER[1]

Drop No.	Drop speed	Drop height	Drop history			Drop trajectory	
			Time to exit tank	Time to reach ground	Time to settle	Horizontal	Vertical
	Knots	*Feet*	- - - - - - - *Seconds* - - - - - - -			- - - - -*Feet* - - - -	
4	116	171	1.61	8.02	19.06	--	--
8	108	178	--	8.79	12.21	--	--
12	110	295	--	12.92	20.79	--	--
19	95	75	1.66	3.02	10.00	--	--
23	119	80	1.59	2.77	12.02	--	--
27	104	300	--	13.96	--	--	--
33	108	164	1.35	--	--	385	78
35	103	188	--	7.73	17.00	417	69
42	104	188	--	8.15	14.77	498	73
50	114	332	1.83	15.23	--	491	59
55	99	103	--	4.48	11.85	428	76
57	100	218	--	9.40	26.69	373	110
63	111	180	--	7.23	20.63	--	--
70	97	91	--	3.02	10.42	504	77
71	98	264	--	10.79	18.31	457	97
72	111	97	1.68	3.92	13.40	506	67
73	98	147	1.89	6.10	15.83	499	94
74	110	167	--	5.75	16.63	540	127
Mean	106	180	1.66	7.72	15.97	463	84

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[1] Available data depended on movie coverage. Where data are lacking, the drop release or empty point was out of the camera's view.

TABLE 12A.--PHOS-CHEK XA RECOVERY BY CONCENTRATION CLASS AND TOTAL RECOVERY

Drop No.	Concentration class							Total retardant recovered	Drop recovered
	<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0		
	Gallons							*Gallons*	*Percent*
2	15.9	97.1	82.2	94.0	86.1	54.2	62.1	492	82.0
5	13.1	90.3	93.6	118.1	90.8	52.3	62.0	520	86.7
10	13.4	103.5	127.3	145.5	42.5	45.0	22.8	500	83.3
13	23.2	70.7	148.2	136.3	73.6	38.9	6.3	497	82.9
18	18.2	57.1	62.3	65.4	39.0	61.1	177.9	481	80.2
20	17.6	82.9	93.6	110.1	119.1	45.8	90.3	559	93.2
29	22.3	113.6	144.8	78.0	98.3	38.3	43.1	538	89.7
34	15.0	95.3	119.4	77.1	124.6	78.7	35.3	545	90.8
37	34.2	166.8	136.1	149.3	62.7	29.3	11.8	590	98.3
39	48.6	128.9	129.5	107.2	90.0	20.7	59.2	584	97.3
41	14.3	88.5	146.0	116.8	104.0	60.4	61.8	592	98.7
43	21.3	119.5	146.7	86.4	77.3	29.9	32.0	513	85.5
46	20.2	107.6	143.7	115.7	50.6	30.0	23.9	492	81.9
52	34.3	97.0	97.7	71.8	154.1	73.7	43.8	572	95.4
59	20.7	89.4	171.0	187.4	67.6	19.4	0	556	92.7
62	28.4	146.2	158.5	134.7	46.1	29.6	12.7	556	92.7
64	20.6	95.2	122.1	164.2	86.9	66.0	18.5	574	95.6
66	39.7	93.1	140.0	147.0	63.3	47.9	24.6	556	92.6
67	36.9	89.7	102.0	102.4	88.0	65.5	112.3	597	99.5
68	43.9	70.7	93.1	72.8	77.8	60.7	164.4	583	97.2
69	26.4	105.5	92.1	148.5	134.6	62.5	20.6	590	98.4

TABLE 12B.--PHOS-CHEK XA COVERAGE BY CONCENTRATION CLASS AND EFFECTIVE PATTERN DIMENSIONS

Drop No.	Concentration class							Total area	Dimensions of 2 gal./100 ft.^{2} coverage			
									Length			Maximum width
	<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0		Maximum	>5.0	>10.0	
	Square feet							*Square feet*	*Feet*			
2	37,800	19,125	5,963	3,825	2,476	1,238	1,240	71,438	184	181	180	78
5	40,050	16,200	7,200	4,613	2,588	1,238	901	72,788	201	197	193	69
10	20,588	21,166	8,550	5,963	1,238	1,013	388	58,853	217	205	191	79
13	49,050	15,075	9,900	5,625	2,138	900	113	82,800	144	138	133	64
18	53,100	12,038	4,163	2,588	1,125	1,350	2,477	76,838	206	202	178	56
20	42,975	15,638	6,188	4,275	3,375	1,013	1,126	74,588	266	259	252	64
29	74,700	20,700	9,788	3,263	2,813	901	675	112,838	200	195	170	82
34	40,725	18,964	8,438	3,263	3,488	1,800	563	77,239	203	197	191	69
37	33,413	34,334	9,338	6,075	1,913	675	225	85,972	196	189	184	75
39	45,563	25,875	8,663	4,388	2,588	450	1,014	88,538	193	185	170	79
41	16,763	16,525	9,563	4,725	3,038	1,350	1,013	52,975	149	146	142	60
43	34,538	22,838	10,013	3,488	2,250	675	563	74,363	218	212	205	57
46	37,575	23,063	10,125	4,725	1,463	675	450	78,075	237	236	236	59
52	46,913	21,263	6,863	2,925	4,388	1,688	676	84,713	281	275	273	50
59	65,363	17,663	11,130	7,650	2,025	450	0	104,288	245	218	219	75
62	56,588	28,125	10,800	5,625	1,350	675	226	103,388	263	228	186	40
64	33,076	17,550	8,213	6,413	2,588	1,463	338	69,641	259	256	249	62
66	64,688	18,563	9,675	5,850	1,913	1,125	450	102,263	240	232	223	61
67	49,950	18,900	7,425	4,163	2,588	1,463	1,801	86,288	292	267	254	58
68	55,575	12,938	6,525	2,925	2,250	1,350	2,139	83,700	201	197	197	66
69	36,338	20,363	6,638	5,850	3,938	1,463	338	74,925	256	255	214	61

TABLE 13A.--FIRE-TROL 100 RECOVERY BY CONCENTRATION CLASS AND TOTAL RECOVERY

Drop No.	Concentration class							Total retardant recovered	Drop recovered
	<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0		
	Gallons							*Gallons*	*Percent*
3	28.9	84.1	113.8	167.3	11.5	23.1	0	429	71.5
7	19.4	83.2	76.6	116.2	54.7	35.4	81.4	467	77.8
9	20.1	113.7	140.0	164.2	37.3	4.5	0	480	80.0
14	23.1	109.8	144.8	140.0	87.5	15.5	0	521	86.8
16	26.5	71.3	66.4	72.8	68.7	54.8	135.8	496	82.7
21	27.1	79.2	81.7	101.6	55.1	41.4	90.7	477	79.5
24	32.8	115.4	127.2	76.4	82.8	29.5	28.5	493	82.1
30	34.7	111.9	187.6	123.6	64.0	24.2	0	546	91.0
32	23.5	103.2	87.5	73.2	80.2	59.9	51.2	479	79.8
38	24.5	278.9	187.4	16.6	0	0	0	507	84.5
45	41.7	104.7	172.6	61.8	24.1	0	0	405	67.5
47	42.9	151.7	188.9	70.3	3.4	0	0	457	76.2
51	42.5	78.5	76.8	96.3	70.1	44.1	134.5	543	90.5
56	33.4	81.7	99.4	68.8	40.1	24.2	91.5	439	73.2
58	23.7	89.7	134.1	172.5	40.2	13.7	18.8	493	82.1
60	23.5	103.8	111.4	150.8	69.9	28.9	29.7	518	86.3

TABLE 13B.--FIRE-TROL 100 COVERAGE BY CONCENTRATION CLASS AND EFFECTIVE PATTERN DIMENSIONS

Drop No.	Concentration class							Total area	Dimensions of 2 gal./100 ft.^{2} coverage			
									Length			Maximum width
	<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0		Maximum	>5.0	>10.0	
	Square feet							*Square feet*	*Feet*			
3	75,150	19,269	7,875	6,975	338	563	0	110,169	224	222	219	55
7	64,575	17,775	5,400	4,725	1,575	788	1,576	96,413	199	196	185	68
9	47,813	23,738	9,225	6,638	1,125	113	0	88,650	213	205	197	57
14	66,488	23,175	9,675	5,963	2,588	338	0	108,225	182	165	162	73
16	83,363	14,400	4,613	2,925	2,025	900	1,802	110,025	204	201	198	58
21	82,125	16,614	5,738	3,938	1,688	900	1,463	112,464	229	225	219	60
24	10,163	23,850	8,663	3,150	2,363	675	451	140,513	210	174	153	37
30	84,938	21,600	13,275	5,063	1,913	563	0	127,350	257	248	225	54
32	56,475	18,225	6,188	3,038	2,363	1.350	1,239	88,875	201	197	194	62
38	28,575	58,499	13,838	788	0	0	0	101,699	191	187	185	80
45	68,625	21,150	12,038	2,700	675	0	0	105,188	53	46	39	25
47	61,650	30,713	13,275	3,038	113	0	0	108,788	152	127	97	20
51	51,300	16,763	5,400	3,825	2,025	1,013	1,802	82,125	212	210	206	58
56	79,650	16,650	7,200	2,813	1,125	563	1,464	109,463	221	196	183	60
58	80,100	18,113	9,000	7,088	1,125	338	338	116,100	209	188	176	51
60	44,325	20,813	7,763	6,188	2,025	675	563	82,350	244	239	239	66

TABLE 14A.--FIRE-TROL 931 RECOVERY BY CONCENTRATION CLASS AND TOTAL RECOVERY

Drop No.	Concentration class							Total retardant recovered	Drop recovered
	<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0		
	Gallons							*Gallons*	*Percent*
1	20.5	112.8	107.5	50.7	62.1	41.1	34.7	429	71.5
6	10.1	65.7	72.4	68.6	77.7	39.9	74.7	409	68.2
11	45.3	164.9	216.6	28.5	0	0	0	455	75.9
15	6.2	56.2	184.8	63.6	3.5	0	0	314	52.3
17	36.7	70.0	60.0	59.4	61.7	24.8	82.5	395	65.8
22	28.6	86.2	110.5	105.7	38.5	35.6	48.3	453	75.6
25	34.4	104.6	130.3	81.1	51.6	40.9	26.7	469	78.2
26	19.2	101.5	126.1	68.9	26.9	14.5	5.9	363	60.5
28	21.0	111.1	96.5	125.0	74.2	49.2	35.2	512	85.4
31	57.1	123.9	151.4	103.4	79.6	49.6	6.2	571	95.2
36	52.1	176.8	178.6	65.2	19.5	0	0	492	82.0
40	26.2	116.4	122.7	163.2	75.4	14.6	6.4	525	87.5
44	30.0	91.2	128.2	32.9	17.3	0	0	300	50.0
49	18.4	166.8	181.2	7.5	0	0	0	374	62.3
53	56.9	108.1	75.6	65.0	75.4	80.1	92.5	554	92.3
54	55.2	109.1	78.3	60.8	78.5	24.9	150.6	557	92.9
61	13.5	113.5	129.6	106.8	65.9	15.6	34.5	479	79.9
65	8.4	132.6	184.9	97.4	15.8	4.6	0	444	74.0

TABLE 14B.--FIRE-TROL 931 COVERAGE BY CONCENTRATION CLASS AND EFFECTIVE PATTERN DIMENSIONS

Drop No.	Concentration class							Total area	Dimensions of 2 gal./ 100 ft.^{2} coverage			
									Length			Maximum width
	<0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0		Maximum	>5.0	>10.0	
	Square feet							*Square feet*	*Feet*			
1	40,613	22,613	7,425	2,025	1,800	900	563	75,938	222	221	220	47
6	37,575	12,060	4,950	2,925	2,250	900	1,238	62,898	186	179	176	62
11	69,638	31,476	15,075	1,238	0	0	0	117,426	57	48	40	26
15	15,188	13,888	12,600	2,813	113	0	0	44,601	114	104	88	47
17	109,575	15,525	4,275	2,363	1,800	563	1,350	135,450	232	217	208	41
22	75,938	17,100	7,538	4,388	1,125	788	789	107,663	216	197	195	47
25	86,625	19,463	9,563	3,375	1,463	900	450	121,838	224	201	190	50
26	32,963	19,350	8,325	2,925	788	338	113	64,800	127	122	117	60
28	60,975	21,488	6,750	5,063	2,138	1,125	563	98,100	189	185	180	79
31	75,600	26,888	10,800	4,388	2,363	1,125	113	121,275	245	227	218	49
36	61,538	40,496	11,925	2,813	563	0	0	117,334	146	81	54	36
40	31,725	22,950	8,775	6,750	2,138	338	113	72,788	248	246	214	69
44	7,313	29,821	9,592	1,350	450	0	0	51,219	32	30	27	39
49	19,800	35,339	13,500	338	0	0	0	68,976	27	19	0	10
53	79,313	24,247	5,288	2,588	2,138	1,800	1,239	116,610	245	235	227	53
54	63,450	26,073	5,513	2,588	2,250	563	2,139	102,573	188	172	172	74
61	40,613	21,825	8,775	4,388	1,913	338	563	78,413	233	222	195	20
65	11,925	27,516	13,500	4,050	450	113	0	57,556	168	166	156	48

TABLE 15A.--WATER RECOVERY BY CONCENTRATION CLASS AND TOTAL RECOVERY

Drop No.	Concentration class <0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0	Total retardant recovered	Drop recovered
	-Gallons-							*Gallons*	*Percent*
4	29.2	115.8	119.1	72.2	34.5	9.3	5.9	386	64.3
8	17.5	108.2	145.6	74.9	32.3	9.6	0	388	64.7
12	26.9	133.6	164.1	56.5	0	0	0	381	63.5
19	18.0	86.6	62.4	87.6	66.7	39.7	99.6	461	76.8
23	20.3	114.1	112.4	75.4	65.7	36.3	39.7	464	77.3
27	26.7	149.4	98.7	42.0	3.4	0	0	320	53.4
33	26.6	132.4	125.6	70.3	60.7	24.4	7.1	447	74.5
35	10.8	74.2	140.1	113.5	44.3	4.8	0	388	64.6
42	21.2	180.2	129.0	94.8	64.9	33.4	0	524	87.2
50	19.4	65.4	31.8	19.7	0	0	0	136	22.7
55	22.1	126.3	102.4	102.3	59.6	63.4	54.7	531	88.5
57	18.6	111.4	109.0	106.6	53.2	5.4	0	404	67.3
63	29.1	172.1	131.8	57.6	22.8	26.3	19.0	459	76.5
70	19.6	90.1	55.5	74.1	55.5	43.1	96.5	434	72.3
71	28.6	117.6	149.4	72.1	19.7	15.3	0	403	67.5
72	31.2	105.9	103.3	71.2	63.5	50.3	0	425	70.9
73	25.3	103.8	104.9	66.4	40.1	45.6	40.3	426	71.1
74	36.7	112.2	185.5	71.1	15.7	13.7	0	435	72.5

TABLE 15B.--WATER COVERAGE BY CONCENTRATION CLASS AND EFFECTIVE PATTERN DIMENSIONS

Drop No.	Concentration class <0.2	0.2-0.99	1.0-1.99	2.0-2.99	3.0-3.99	4.0-4.99	≥5.0	Total area	Dimensions of 2 gal./100 ft.^{2} coverage: Length Maximum	>5.0	>10.0	Maximum width
	Square feet							*Square feet*	*-Feet-*			
4	47,700	23,288	8,662	3,038	1,013	225	113	84,038	130	131	126	50
8	34,425	23,728	10,237	3,038	900	225	0	72,453	86	79	69	112
12	29,925	57,000	12,038	2,588	0	0	0	71,550	74	69	69	65
19	35,550	18,226	4,500	3,600	1,913	900	1,465	66,150	211	206	200	75
23	23,963	22,163	8,100	3,038	1,913	788	563	60,525	207	214	211	64
27	24,975	32,625	6,975	1,800	113	0	0	66,488	68	62	61	32
33	31,275	26,775	9,113	2,813	1,800	563	113	72,450	89	83	79	112
35	11,138	14,225	9,450	4,500	1,238	113	0	40,663	185	184	180	59
42	18,900	40,950	9,450	3,938	1,913	788	0	76,056	171	164	150	59
50	21,825	14,625	2,138	788	0	0	0	39,375	56	38	18	14
55	44,663	26,775	7,200	4,275	1,800	1,463	901	87,075	262	251	249	56
57	23,288	24,976	7,763	4,500	1,575	113	0	62,213	146	138	130	63
63	27,000	35,412	9,900	2,475	675	563	338	76,262	117	112	103	60
70	29,138	20,138	3,938	2,925	1,688	1,013	1,127	60,188	226	213	187	62
71	40,050	25,200	10,125	3,150	563	338	0	79,425	115	98	79	62
72	41,850	24,525	7,313	2,925	1,800	1,125	0	79,538	184	172	165	54
73	30,488	23,850	7,313	2,700	1,238	1,013	676	67,275	182	177	173	44
74	36,900	25,650	13,388	2,925	450	338	0	79,650	126	120	103	34

TABLE 16.--PREDICTIONS OF THE AREA COVERED (IN SQUARE FEET) BY 2 GAL./100 FT.^{2} FOR PHOS-CHEK XA AND FIRE-TROL 100[1]

Windspeed (m.p.h.)	Drop height (feet) 50	75	100	125	150	175	200	225	250	275	300	325	350
						PHOS-CHEK XA							
0	8,823	9,257	[2]9,649*	9,990	10,274	10,497	10,654	10,742	10,759*	10,705	10,580*	10,388	10,132
1	8,619	9,045	9,414	9,718	9,950	10,104	10,176	10,164	10,069	9,894	9,642	9,319	8,933
2	8,443	8,866	9,214*	9,478	9,649*	9,723*	9,697	9,571	9,350	9,041*	8,652	8,195	7,682
3	8,305	8,726	9,051*	9,267	9,366*	9,345*	9,205	8,949	8,590	8,138	7,611	7,027	6,405
4	8,202	8,622	8,918	9,077	9,092	8,960*	8,690*	8,293*	7,787*	7,195	6,542	5,853	5,153
5	8,129	8,547	8,810	8,901	8,818	8,563*	8,151	7,608	6,960	6,243	5,489	4,732	3,999
6	8,081	8,495	8,718	8,734	8,542	8,156	7,602	6,917	6,144	5,328	4,510	3,727	3,007
7	8,050	8,459	8,639	8,574	8,270	7,752	7,062	6,253	5,380	4,499	3,656	2,887	2,216
8	8,031	8,435	8,570	8,425	8,012	7,371	6,561	5,650	4,706	3,793	2,957	2,231	1,628
9	8,020	8,419	8,513	8,292	7,780	7,031	6,121	5,134	4,147	3,227	2,419	1,746	1,215
10	8,013	8,408	8,466	8,179	7,583	6,746	5,759	4,717	3,707	2,796	2,024	1,405	936
11	8,009	8,402	8,430	8,091	7,427	6,521	5,477	4,399	3,380	2,484	1,746	1,174	755
12	8,006	8,398	8,405	8,026	7,312*	6,356	5,271	4,171	3,149	2,268	1,559	1,022	639
						FIRE-TROL 100							
0	6,576	6,952	7,325	7,688	8,037	8,367	8,669	8,933	9,145	9,274*	9,180	8,982	8,727
1	6,982	7,307	7,619	7,912	8,179	8,412	8,595	8,698	8,598	8,415*	8,183	7,917	7,624
2	7,175	7,459	7,721	7,954*	8,145*	8,275	8,240	8,085*	7,878	7,635	7,364	7,073	6,768
3	7,256	7,514*	7,739	7,917	8,017*	7,919	7,741	7,517	7,259	6,977	6,678	6,366	6,047
4	7,285	7,532*	7,727	7,834	7,722*	7,525	7,277	6,993	6,686	6,361	6,025	5,684	5,342
5	7,292	7,543*	7,706	7,626	7,407	7,122	6,796	6,441	6,068	5,685	5,301	4,919	4,544
6	7,291	7,559	7,612*	7,381	7,048	6,655	6,225	5,776	5,320	4,867	4,424	3,998	3,593
7	7,286	7,579	7,455	7,078	6,600	6,068	5,511	4,952	4,407	3,886	3,399	2,949	2,540
8	7,278	7,585	7,254	6,698	6,045	5,353	4,665	4,006*	3,396	2,843	2,354	1,927	1,562
9	7,268	7,536	7,017	6,265	5,429	4,590	3,799	3,085	2,461	1,932	1,493	1,138	855
10	7,256	7,477	6,784	5,851	4,864	3,922	3,080	2,360	1,770*	1,300	937	663	461
11	7,246	7,429	6,603	5,542	4,458	3,461	2,606	1,908	1,361	949	647	431	282
12	7,239	7,400	6,499	5,367	4,234*	3,215	2,361	1,682	1,166	788	519	335	211

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[1] Values within outlines are those upon which most confidence should be placed.

[2] Asterisk (*) denotes actual data points.

TABLE 17.--PREDICTIONS OF THE AREA COVERED (IN SQUARE FEET) BY 2 GAL./100 FT.^{2} FOR FIRE-TROL 931 AND WATER[1]

Windspeed (m.p.h.)	Drop height (feet) 50	75	100	125	150	175	200	225	250	275	300	325	350
							FIRE-TROL 931						
0	5,233	5,926	[2]6,633*	7,338	8,024	8,672	9,264	9,781	10,208	10,530	10,736	10,820	10,777
1	5,753	6,482	7,182*	7,825	8,384*	8,832*	9,149	9,320	9,336	9,196	8,907	8,483	7,945
2	5,876	6,619*	7,273	7,798*	8,157*	8,325	8,289	8,053	7,633	7,058	6,368	5,605	4,814
3	5,857	6,599	7,180	7,542	7,650	7,491	7,083	6,466	5,699	4,850	3,986*	3,162	2,422
4	5,792	6,528*	7,017	7,195	7,038	6,567	5,844	4,961	4,017	3,103*	2,286	1,607	1,077
5	5,720	6,446	6,846	6,850	6,458*	5,737*	4,802	3,787	2,814	1,971*	1,300	808*	473
6	5,654	6,375	6,700	6,562	5,991	5,098	4,044	2,990	2,060*	1,323	792*	442	230
7	5,600	6,320	6,591	6,353	5,659	4,659	3,545	2,493	1,620	973	540	277	131
8	5,559	6,281	6,519	6,216	5,444	4,381	3,238	2,199	1,372	786	414	200	89
9	5,530	6,255	6,474	6,132	5,315	4,215	3,059	2,032	1,235	687	349	163	69
10	5,510	6,239	6,448	6,084	5,241	4,121	2,959	1,939	1,160	634	316	144	60
11	5,498	6,229	6,434	6,058	5,201	4,071	2,905	1,890	1,121	606	299	134	55
12	5,491	6,223	6,426	6,045	5,181	4,045	2,877	1,864	1,101	592	290	129	53
							WATER						
0	8,424	8,639	8,571*	8,273	7,825	7,270	6,643	5,976	5,296	4,628*	3,988	3,391	2,846
1	7,721	7,900	7,782	7,455	6,988	6,423	5,798	5,146*	4,492	3,861	3,269	2,727	2,242
2	7,172	7,323*	7,164	6,809	6,319	5,741*	5,114*	4,470	3,838	3,239	2,688	2,195	1,765
3	6,754	6,878	6,686	6,301	5,786*	5,190*	4,555	3,916	3,300	2,729	2,216*	1,767	1,385
4	6,441	6,546*	6,322*	5,904	5,359	4,741	4,093*	3,454	2,852	2,306	1,827	1,419	1,081
5	6,214	6,303	6,048	5,594	5,014	4,367*	3,704	3,063	2,472	1,949	1,502*	1,133	836
6	6,053	6,130	5,843*	5,349	4,729	4,051*	3,368	2,724	2,144	1,644	1,230	898	640
7	5,943	6,012	5,691	5,152	4,488	3,774	3,072	2,424	1,856	1,381	1,000	704	483
8	5,870	5,934	5,577	4,989	4,277	3,528	2,806	2,156	1,603	1,154	806	546*	359
9	5,822	5,885	5,489	4,850	4,089	3,303	2,563	1,915	1,379	959	645	419	264
10	5,792	5,855	5,420	4,728	3,918	3,097	2,343	1,699	1,184	794	513	319	192
11	5,771	5,838	5,364	4,619	3,761	2,909	2,144	1,510	1,018	658	408	243	140
12	5,758	5,827	5,317	4,523	3,621	2,742	1,972	1,349	881	549	328	198	103

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[1] Values within outlines are those upon which most confidence should be placed.

[2] Asterisk (*) denotes actual data points.

TABLE 18.--PREDICTIONS OF THE TOTAL RETARDANT (IN GALLONS) REACHING THE GROUND FOR PHOS-CHEK XA AND FIRE-TROL 100[1]

Windspeed (m.p.h.)	Drop height (feet) 50	75	100	125	150	175	200	225	250	275	300	325	350
							PHOS-CHEK XA						
0	579	579	[2] 579*	578	578	578	577	576	574*	572	569	565	560
1	572	572	572	572	571	569	567	562	558	551	541	527	510
2	566	566	565*	565	563*	561*	557	552	543	531*	515	494	466
3	559	559	559*	558	556*	553*	548	541	529	514	493	465	428
4	553	553	552	551	549	545*	539*	530*	517*	498	473	439	396
5	546	546	545	544	542*	538*	531	521*	505	484	455	417	367
6	540	539	539	538	535	530	523	512	495	472	440	398	343
7	533	533	532	531	528	523	515	503	485	460	426	381	322
8	527	526	526	524	521	516	508	495	476	450	414	366	304
9	520	520	519	518	515	509	500	487	467	440	403	353	289
10	514	513	513	511	508	502	493	479	459	431	393	342	275
11	507	507	506	504	501	496	486	472	452	423	384	332	264
12	500	500	500	598	495*	489	478	465	444	415	375	322	254
							FIRE-TROL 100						
0	528	528	528	527	527	525	524	522	519	516*	512	507	501
1	521	521	521	520	519	518	515	513	509	504*	498	491	483
2	511	511	510	509*	508*	506	503	499*	495	489	481	472	461
3	500	500*	499	498	497*	494	491	486	480	473	464	453	440
4	491	491*	490	489	487*	484	480	475	468	459	448	435	420
5	484	484*	483	482	479	476	471	465	457	447	435	420	402
6	479	479	478*	476	474	470	465	458	449	438	424	407	387
7	476	475	474	472	470	466	460	452	443	430	415	397	375
8	473	473	472	470	467	462	456	448*	438	425	409	389	366
9	472	471	470	468	465	460	454	445	434	421	403	383	358
10	471	470	469	467	464	459	452	443	432*	417	399	378	352
11	470	470	469	466	463	458	451	442	430	415	396	374	347
12	470	470	468	466	463*	457	450	441	429	413	394	371	344

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[1] Values within outlines are those upon which most confidence should be placed.

[2] Asterisk (*) denotes actual data points.

TABLE 19.--PREDICTIONS OF THE TOTAL RETARDANT (IN GALLONS) REACHING THE GROUND FOR FIRE-TROL 931 AND WATER[1]

Windspeed (m.p.h.)	Drop height (feet) 50	75	100	125	150	175	200	225	250	275	300	325	350
							FIRE-TROL 931						
0	550	550	[2] 550*	550	550	550	550	550	549	548	546	542	536
1	523	523	523*	523	523*	522*	522	521	519	515	510	502	490
2	499	499*	499	499*	498*	497	496	493	489	483	475	463	448
3	477	477	477	477	476	474	471	467	461	453	442*	427	409
4	459	459*	458	457	455	452	448	442	434	424*	411	394	374
5	442	442	441	439	436*	432*	427	419	410	397*	383	364*	343
6	428	428	426	424	420	415	408	399	388*	374	357*	338	315
7	416	415	413	410	406	399	391	381	369	353	335	314	290
8	406	405	402	399	394	386	377	366	352	335	316	293	267
9	398	396	393	389	383	376	366	353	338	320	299	275	248
10	391	389	386	382	375	367	356	343	326	307	285	260	231
11	385	383	380	375	368	359	348	334	317	297	273	246	216
12	381	379	376	370	363	354	342	327	309	288	263	235	203
							WATER						
0	484	483	481*	479	475	469	462	452	441	427*	412	394	374
1	474	473	472	469	465	459	452	442*	431	417	401	383	363
2	465	464*	462	459	455	449*	441*	431	419	405	388	369	349
3	456	455	453	449	444*	438*	429	418	405	389	371	351	329
4	446	445*	443*	439	433	425	415*	402	387	369	348	325	301
5	438	436	433	428	421	411*	398	382	363	341	317*	290	262
6	429	427	423	416	406	393*	376	356	332	304	275	243	211
7	420	417	412	402	389	371	348	321	290	257	221	186	151
8	412	407	395	386	367	343	313	278	239	200	161	125*	92
9	403	397	386	368	342	309	271	228	184	142	104	72	47
10	395	387	371	347	314	273	227	179	133	93	60	36	20
11	387	376	357	327	287	239	188	138	93	58	33	17	8
12	379	366	343	309	263	211	157	107	67	37	19	8	3

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[1] Values within outlines are those upon which most confidence should be placed.

[2] Asterisk (*) denotes actual data points.

TABLE 20.--AREAS (IN SQUARE FEET) OF VARIOUS CONCENTRATIONS AS A FUNCTION OF WINDSPEED AND HEIGHT FOR PHOS-CHEK XA

Windspeed	Drop height (feet)												
(m.p.h.)	50	75	100	125	150	175	200	225	250	275	300	325	350
0.2 GAL./100 FT.^{2}													
0	27,341	29,926	32,322	34,451	36,316	37,889	39,169	40,168	40,907	41,418	41,728	41,911	41,981
3	27,212	29,814	32,218	34,376	36,258	37,846	39,139	40,148	40,895	41,411	41,735	41,910	41,980
6	27,138	29,750	32,164	34,333	36,224	37,821	39,122	40,137	40,888	41,408	41,734	41,909	41,980
9	27,135	29,748	32,162	34,331	36,223	37,821	39,121	40,137	40,888	41,408	41,734	41,909	41,980
12	27,135	29,748	32,162	34,331	36,223	37,821	39,121	40,127	40,888	41,408	41,734	41,909	41,980
0.5 GAL./100 FT.^{2}													
0	21,741	23,884	25,919	27,793	29,458	30,873	32,007	32,842	33,374	33,619	33,631	33,417	32,919
3	17,936	19,894	21,769	23,508	25,061	26,386	27,451	28,234	28,731	28,956	28,961	28,749	28,266
6	15,780	17,609	19,371	21,011	22,482	23,740	24,752	25,496	25,967	26,178	26,178	25,969	25,500
9	14,949	16,682	18,351	19,904	21,296	22,486	23,442	24,144	24,588	24,784	24,783	24,581	24,133
12	14,662	16,360	17,994	19,515	20,979	22,042	22,977	23,664	24,097	24,288	24,285	24,087	23,646
1.0 GAL./100 FT.^{2}													
0	13,674	14,860	16,002	17,076	18,057	18,922	19,650	20,222	20,624	20,847	20,886	20,740	20,413
3	13,425	14,736	15,930	16,960	17,783	18,365	18,681	18,721	18,483	17,975	17,218	16,243	15,092
6	12,049	13,634	15,050	16,207	17,029	17,460	17,472	17,066	16,265	15,125	13,722	12,144	10,484
9	12,065	13,573	14,891	15,834	16,631	16,934	16,826	16,312	15,425	14,227	12,798	11,227	9,605
12	12,004	13,488	14,780	15,798	16,471	16,753	16,630	16,106	15,217	14,022	12,603	11,048	9,444
1.5 GAL./100 FT.^{2}													
0	10,226	10,895	11,531	12,122	12,659	13,133	13,534	13,854	14,089	14,233	14,283	14,239	14,101
3	11,131	11,813	12,372	12,786	13,039	13,123	13,033	12,773	12,353	11,790	11,104	10,320	9,465
6	10,475	11,512	12,215	12,514	12,378	11,822	10,901	9,705	8,342	6,923	5,547	4,291	3,205
9	10,674	11,602	12,149	12,255	11,910	11,150	10,056	8,738	7,313	5,897	4,581	3,428	2,471
12	10,684	11,584	12,101	12,179	11,809	11,032	9,929	8,610	7,193	5,789	4,489	3,354	2,414
2.0 GAL./100 FT.^{2}													
0	8,703	9,171	9,601	9,983	10,312	10,581	10,784	10,918	10,980	10,970	10,886	10,731	10,508
3	8,694	9,085	9,386	9,587	9,682	9,667	8,544	9,315	8,988	8,576	8,089	7,544	6,956
6	8,145	8,719	8,998	8,950	8,582	7,933	7,068	6,071	5,026	4,011	3,086	2,288	1,636
9	8,253	8,677	8,697	8,310	7,569	6,573	5,442	4,295	3,231	2,318	1,585	1,033	642
12	8,299	8,639	8,573	8,108	7,310	6,282	5,146	4,018	2,990	2,121	1,434	925	568
2.5 GAL./100 FT.^{2}													
0	8,577	8,762	8,872	8,903	8,856	8,731	8,531	8,263	7,932	7,546	7,116	6,651	6,162
3	7,149	7,322	7,406	7,400	7,302	7,117	6,851	6,513	6,116	5,673	5,197	4,702	4,201
6	6,215	6,484	6,571	6,471	6,190	5,753	5,194	4,556	3,883	3,215	2,586	2,021	1,534
9	5,815	6,133	6,138	5,828	5,250	4,488	3,639	2,800	2,044	1,416	931	580	343
12	5,837	6,047	5,896	5,411	4,673	3,799	2,907	2,093	1,419	905	543	307	163
3.0 GAL./100 FT.^{2}													
0	7,170	7,166	7,037	6,791	6,440	6,001	5,494	4,943	4,371	3,797	3,241	2,719	2,241
3	5,728	5,724	5,602	5,369	5,040	4,633	4,171	3,678	3,176	2,685	2,224	1,804	1,433
6	4,864	4,859	4,693	4,382	3,957	3,455	2,917	2,382	1,879	1,434	1,058	755	521
9	4,425	4,417	4,171	3,728	3,153	2,524	1,912	1,370	929	596	362	208	113
12	4,265	4,254	3,945	3,401	2,727	2,032	1,408	907	544	303	157	75	34
3.5 GAL./100 FT.^{2}													
0	5,539	5,524	5,361	5,062	4,650	4,156	3,614	3,058	2,517	2,016	1,571	1,191	878
3	4,386	4,372	4,220	3,944	3,568	3,126	2,651	2,177	1,731	1,332	993	716	500
6	3,726	3,709	3,510	3,158	2,702	2,198	1,701	1,251	875	582	368	221	126
9	3,411	3,386	3,105	2,631	2,059	1,490	995	615	351	185	90	40	17
12	3,305	3,274	2,930	2,369	1,731	1,143	682	367	179	79	31	11	4
4.0 GAL./100 FT.^{2}													
0	3,904	3,890	3,738	3,463	3,095	2,667	2,217	1,777	1,373	1,023	736	510	341
3	3,394	3,377	3,202	2,893	2,490	2,042	1,595	1,187	842	569	366	225	131
6	3,142	3,113	2,808	2,306	1,724	1,174	728	411	211	99	42	16	6
9	3,041	2,998	2,560	1,893	1,213	673	323	135	49	15	4	1	0
12	3,017	2,969	2,491	1,783	1,087	556	251	95	31	8	2	0	0

TABLE 21.--AREAS (IN SQUARE FEET) OF VARIOUS CONCENTRATIONS AS A FUNCTION OF WINDSPEED AND HEIGHT FOR FIRE-TROL 100

Windspeed (m.p.h.)	Drop height (feet)												
	50	75	100	125	150	175	200	225	250	275	300	325	350
0.2 GAL./100 FT.^{2}													
0	25,957	28,597	31,280	33,979	36,665	39,305	41,867	44,317	46,622	48,747	50,663	52,340	53,751
3	25,941	28,582	31,266	33,967	36,654	39,297	41,861	44,313	46,620	48,748	50,665	52,342	53,754
6	25,924	28,566	31,252	33,945	36,644	39,288	42,855	44,310	46,618	48,748	50,667	52,345	53,757
9	25,907	28,550	31,237	33,942	36,633	39,280	41,849	44,306	46,617	48,748	50,668	52,348	53,761
12	25,980	28,534	31,223	33,929	36,623	39,272	41,843	44,302	46,615	48,748	50,670	52,351	53,764
0.5 GAL./100 FT.^{2}													
0	16,678	18,607	20,557	22,491	24,369	26,146	27,781	29,233	30,462	31,435	32,125	32,513	32,586
3	16,019	17,991	19,995	21,990	23,936	25,773	27,466	28,965	30,228	31,218	31,903	32,264	32,290
6	15,838	17,818	19,831	21,836	23,785	25,632	27,327	28,822	30,075	31,046	31,707	32,035	32,021
9	15,824	17,799	19,804	21,798	23,735	25,567	27,243	28,718	29,947	30,893	31,526	31,827	31,786
12	15,833	17,798	19,792	21,772	23,693	25,507	27,164	28,617	29,826	30,752	31,365	31,648	31,590
1.0 GAL./100 FT.^{2}													
0	12,147	13,333	14,475	15,544	16,511	17,346	18,026	15,828	18,837	18,943	18,842	18,537	18,040
3	11,543	13,037	14,432	15,657	16,648	17,350	17,722	17,741	17,406	16,738	15,776	14,572	13,193
6	12,302	13,649	14,841	15,817	16,521	16,914	16,971	16,690	16,086	15,197	14,070	12,768	11,356
9	12,337	13,602	14,701	15,576	16,179	16,475	16,445	16,093	15,438	14,519	13,385	12,098	10,719
12	12,218	13,453	14,522	15,368	15,944	16,217	16,170	15,808	15,150	14,235	13,112	11,841	10,483
1.5 GAL./100 FT.^{2}													
0	9,133	9,807	10,453	11,059	11,615	12,108	12,530	12,871	13,124	13,284	13,347	13,312	13,179
3	8,095	8,225	10,208	10,969	11,446	11,598	11,412	10,904	10,117	9,115	7,975	6,776	5,590
6	9,439	10,226	10,724	10,884	10,693	10,167	9,357	8,335	7,186	5,996	4,843	3,483	2,865
9	9,757	10,346	10,625	10,567	10,178	9,494	8,577	7,504	6,359	5,218	4,147	3,192	2,380
12	9,808	10,348	10,576	10,470	10,040	9,327	8,392	7,315	6,176	5,051	4,002	3,071	2,283
2.0 GAL./100 FT.^{2}													
0	7,161	7,567	7,948	8,299	8,613	8,887	9,116	9,295	9,422	9,494	9,510	9,471	9,376
3	7,037	7,426	7,723	7,915	7,995	7,958	7,806	7,546	7,189	6,749	6,245	5,694	5,117
6	7,167	7,475	7,563	7,423	7,069	6,530	5,852	5,088	4,292	3,512	2,788	2,148	1,605
9	7,273	7,467	7,340	6,908	6,226	5,372	4,438	3,510	2,658	1,928	1,388	890	566
12	7,308	7,453	7,242	6,703	5,911	4,966	3,975	3,031	2,202	1,524	1,004	631	377
2.5 GAL./100 FT.^{2}													
0	4,729	5,082	5,413	5,713	5,976	6,195	6,363	6,477	6,534	6,534	6,471	6,353	6,181
3	3,834	4,620	5,245	5,611	5,655	5,370	4,805	4,051	3,218	2,408	1,698	1,128	706
6	4,951	5,334	5,342	4,973	4,305	3,464	2,591	1,802	1,165	700	391	203	98
9	5,204	5,296	5,017	4,425	3,634	2,778	1,977	1,310	808	464	248	123	57
12	5,241	5,251	4,901	4,261	3,451	2,604	1,830	1,198	731	415	220	108	50
3.0 GAL./100 FT.^{2}													
0	3,676	3,984	4,222	4,375	4,434	4,394	4,258	4,036	3,741	3,390	3,005	2,605	2,208
3	3,485	3,952	4,111	3,921	3,430	2,752	2,024	1,366	845	480	250	119	52
6	3,769	3,930	3,738	3,244	2,568	1,854	1,221	734	402	201	92	38	15
9	3,787	3,807	3,496	2,932	2,247	1,572	1,005	587	313	152	68	28	10
12	3,772	3,750	3,407	2,829	2,146	1,488	943	546	289	140	62	25	9
3.5 GAL./100 FT.^{2}													
0	2,820	3,028	3,115	3,040	2,823	2,496	2,100	1,681	1,282	930	642	422	264
3	2,850	3,032	2,917	2,536	1,994	1,417	911	529	278	132	57	22	8
6	2,899	2,951	2,709	2,243	1,675	1,128	685	375	185	82	33	12	4
9	2,880	2,874	2,589	2,105	1,544	1,023	611	330	160	70	28	10	3
12	2,849	2,825	2,529	2,043	1,490	981	583	313	152	66	26	9	3
4.0 GAL./100 FT.^{2}													
0	2,239	2,372	2,389	2,287	2,082	1,801	1,481	1,158	861	608	409	261	158
3	2,261	2,380	2,255	1,922	1,475	1,018	633	354	178	81	33	12	4
6	2,312	2,347	2,138	1,747	1,281	843	497	263	125	53	20	7	2
9	2,320	2,314	2,073	1,667	1,203	779	453	237	111	47	18	6	2
12	2,312	2,292	2,040	1,630	1,170	754	436	227	106	44	17	6	2

TABLE 22.--AREAS (IN SQUARE FEET) OF VARIOUS CONCENTRATIONS AS A FUNCTION OF WINDSPEED AND HEIGHT FOR FIRE-TROL 931

Windspeed (m.p.h.)	Drop height (feet)												
	50	75	100	125	150	175	200	225	250	275	300	325	350
0.2 GAL./100 FT.^{2}													
0	31,138	33,956	36,785	39,593	43,346	45,007	47,541	49,912	52,084	54,024	55,703	57,092	58,169
3	26,969	29,369	31,758	34,102	36,367	38,516	40,514	42,324	43,914	45,255	46,322	47,093	47,553
6	25,222	27,476	29,704	31,870	33,936	35,864	37,617	39,160	40,461	41,492	42,231	42,661	42,774
9	24,833	27,052	29,235	31,343	33,334	35,171	36,814	38,227	39,381	40,248	40,808	41,048	40,962
12	24,914	27,133	29,307	31,398	33,363	35,162	36,757	38,112	39,196	39,983	40,455	40,600	40,414
0.5 GAL./100 FT.^{2}													
0	22,346	23,595	24,765	25,836	26,792	27,617	28,297	28,821	29,179	29,365	29,376	29,212	28,876
3	19,341	20,448	21,471	22,392	23,192	23,858	24,376	24,735	24,929	24,953	24,808	24,495	24,022
6	17,978	19,003	19,934	20,755	21,448	21,997	22,391	22,622	22,684	22,575	22,299	21,861	21,271
9	17,590	18,561	19,430	20,177	20,786	21,243	21,538	21,622	21,615	21,395	21,010	20,467	19,780
12	17,681	18,611	19,428	20,116	20,657	21,039	21,253	21,293	21,159	20,853	20,383	19,761	19,000
1.0 GAL./100 FT.^{2}													
0	11,673	12,991	14,262	15,446	16,504	17,397	18,094	18,570	18,808	18,805	18,561	18,079	17,377
3	11,682	12,811	13,850	14,762	15,511	16,071	16,420	16,547	16,453	16,137	15,608	14,885	13,995
6	11,589	12,572	13,432	14,134	14,651	14,961	15,055	14,935	14,599	14,059	13,336	12,459	11,464
9	11,524	12,410	13,145	13,697	14,042	14,167	14,073	13,758	13,234	12,523	11,655	10,669	9,605
12	11,512	12,350	13,011	13,463	13,684	13,673	13,428	12,954	12,275	11,421	10,434	9,359	8,242
1.5 GAL./100 FT.^{2}													
0	5,917	6,388	6,886	7,413	7,971	8,562	9,851	10,553	11,297	11,297	12,086	12,924	13,817
3	6,487	7,513	8,546	9,531	10,396	11,038	11,212	10,721	9,942	9,001	7,982	6,947	5,943
6	7,443	8,615	9,467	9,891	9,862	9,377	8,476	7,273	5,918	4,563	3,332	2,304	1,507
9	8,004	8,900	9,355	9,437	9,236	8,614	7,566	6,205	4,719	3,309	2,129	1,250	668
12	8,165	8,931	9,259	9,294	9,105	8,514	7,475	6,085	4,539	3,073	1,871	1,016	488
2.0 GAL./100 FT.^{2}													
0	6,551	6,935	7,317	7,693	8,061	8,417	8,759	9,083	9,384	9,658	9,899	10,100	10,251
3	6,482	7,079	7,438	7,593	7,618	7,581	7,400	7,008	6,377	5,527	4,529	3,481	2,493
6	6,333	6,527	6,551	6,537	6,381	5,886	4,914	3,537	2,081	945	312	70	10
9	6,115	6,201	6,206	6,186	6,017	5,475	4,389	2,875	1,407	464	92	10	0
12	6,053	6,120	6,123	6,107	5,958	5,446	4,370	2,822	1,316	390	63	5	0
2.5 GAL./100 FT.^{2}													
0	6,482	6,718	6,899	7,024	7,098	7,129	7,130	7,103	7,034	6,913	6,738	6,508	6,223
3	5,078	5,089	5,090	5,088	5,075	5,030	4,932	4,758	4,487	4,108	3,626	3,060	2,449
6	4,231	4,233	4,232	4,224	4,182	4,054	3,777	3,295	2,606	1,794	1,026	461	153
9	3,931	3,932	3,932	3,918	3,832	3,560	2,972	2,052	1,048	341	59	4	0
12	3,851	3,853	3,852	3,832	3,705	3,291	2,428	1,273	381	48	2	0	0
3.0 GAL./100 FT.^{2}													
0	4,615	4,622	4,558	4,362	4,006	3,499	2,884	2,228	1,602	1,066	652	365	186
3	3,599	3,599	3,589	3,528	3,350	2,990	2,428	1,726	1,028	489	176	45	8
6	2,963	2,963	2,960	2,929	2,812	2,523	2,001	1,301	630	201	37	3	0
9	2,606	2,606	2,604	2,582	2,482	2,208	1,682	979	372	75	6	0	0
12	2,434	2,434	2,433	2,411	2,308	2,013	1,446	732	210	25	1	0	0
3.5 GAL./100 FT.^{2}													
0	3,221	3,211	3,099	2,827	2,395	1,856	1,298	810	445	214	89	32	9
3	2,525	2,524	2,499	2,384	2,098	1,611	1,009	475	155	32	4	0	0
6	2,062	2,062	2,052	1,989	1,786	1,367	791	295	57	5	0	0	0
9	1,781	1,781	1,775	1,730	1,564	1,186	643	197	25	1	0	0	0
12	1,632	1,632	1,628	1,589	1,435	1,072	548	144	13	0	0	0	0
4.0 GAL./100 FT.^{2}													
0	2,659	2,643	2,531	2,278	1,891	1,427	965	577	302	136	53	17	5
3	1,876	1,875	1,850	1,744	1,498	1,101	643	273	77	13	1	0	0
6	1,496	1,496	1,486	1,427	1,249	905	474	149	22	1	0	0	0
9	1,338	1,338	1,332	1,287	1,133	808	387	95	8	0	0	0	0
12	1,286	1,286	1,281	1,240	1,089	760	337	68	4	0	0	0	0

TABLE 23.--AREAS (IN SQUARE FEET) OF VARIOUS CONCENTRATIONS AS A FUNCTION OF WINDSPEED AND HEIGHT FOR WATER

Windspeed	Drop height (feet)												
(m.p.h.)	50	75	100	125	150	175	200	225	250	275	300	325	350
						0.2 GAL./100 FT.^{2}							
0	32,057	35,157	37,996	40,441	42,344	43,544	43,748	42,842	41,139	38,857	36,133	33,105	29,903
3	30,769	33,745	36,472	38,819	40,646	41,797	41,995	41,111	39,489	37,298	34,682	31,775	28,700
6	29,480	32,333	34,947	37,197	38,949	40,025	40,242	39,395	37,840	35,739	33,232	30,445	27,498
9	28,192	30,921	33,422	35,575	37,252	38,307	38,488	37,678	36,190	34,181	31,781	29,115	26,295
12	26,904	29,510	31,898	33,954	35,554	36,562	36,735	35,961	34,541	32,622	30,331	27,785	25,094
						0.5 GAL./100 FT.^{2}							
0	21,488	23,858	26,040	27,917	29,359	30,220	30,234	29,390	27,962	26,095	23,919	21,553	19,105
3	20,221	22,459	24,521	26,294	27,657	28,472	28,484	27,687	26,337	24,573	22,517	20,282	17,971
6	18,957	21,063	23,004	24,637	25,956	26,723	26,735	25,984	24,713	23,052	21,117	19,015	16,841
9	17,696	19,669	21,487	23,052	24,255	24,975	24,986	24,282	23,090	21,533	19,720	17,750	15,714
12	16,438	18,277	19,973	21,433	22,555	23,226	23,237	22,580	21,468	20,016	18,324	16,488	14,591
						1.0 GAL./100 FT.^{2}							
0	13,570	14,962	16,148	17,032	17,500	17,347	16,672	15,638	14,346	12,890	11,354	9,812	8,325
3	12,085	13,378	14,483	15,309	15,747	15,603	14,972	14,007	12,805	11,455	10,039	8,624	7,268
6	10,622	11,808	12,826	13,588	13,994	13,861	13,278	12,387	11,282	10,046	8,756	7,475	6,255
9	9,183	10,255	11,178	11,871	12,241	12,119	11,588	10,779	9,779	8,665	7,508	6,367	5,288
12	7,771	8,719	9,540	10,158	10,488	10,379	9,905	9,185	8,297	7,314	6,298	5,302	4,368
						1.5 GAL./100 FT.^{2}							
0	10,623	11,174	11,460	11,352	10,920	10,261	9,439	8,511	7,530	6,540	5,581	4,681	3,861
3	8,859	9,421	9,716	9,604	9,161	8,494	7,673	6,766	5,829	4,912	4,050	3,270	2,587
6	7,106	7,672	7,972	7,858	7,409	6,742	5,941	5,079	4,219	3,408	3,680	2,053	1,533
9	5,375	5,928	6,288	6,114	5,669	5,022	4,269	3,491	2,750	2,019	1,536	1,091	750
12	3,681	4,199	4,484	4,375	3,954	3,363	2,706	2,067	1,503	1,042	689	436	264
						2.0 GAL./100 FT.^{2}							
0	8,457	8,566	8,408	8,065	7,585	7,005	6,538	5,677	4,988	4,316	3,678	3,089	2,558
3	6,745	6,879	6,684	6,271	5,708	5,051	4,353	3,658	3,000	2,402	1,880	1,438	1,076
6	5,015	5,191	4,936	4,413	3,740	3,018	2,325	1,713	1,209	818	532	332	200
9	3,238	3,502	3,122	2,419	1,659	1,017	561	280	126	52	19	7	2
12	1,241	1,806	1,044	309	51	5	0	0	0	0	0	0	0
						2.5 GAL./100 FT.^{2}							
0	6,835	6,801	6,556	6,168	5,676	5,116	4,522	3,921	3,339	2,793	2,296	1,856	1,475
3	5,319	5,277	4,974	4,507	3,941	3,333	2,731	2,170	1,674	1,255	915	649	448
6	3,799	3,741	3,339	2,763	2,134	1,546	1,054	677	411	236	129	66	33
9	2,263	2,167	1,572	921	444	179	61	17	4	1	0	0	0
12	538	277	2	0	0	0	0	0	0	0	0	0	0
						3.0 GAL./100 FT.^{2}							
0	5,381	5,289	4,941	4,432	3,832	3,200	2,586	2,024	1,526	1,132	810	563	380
3	4,232	4,135	3,776	3,268	2,692	2,117	1,594	1,150	760	530	339	209	124
6	3,083	2,984	2,626	2,142	1,630	1,163	780	492	293	165	88	45	21
9	1,953	1,841	1,515	1,110	732	437	237	118	53	22	9	3	1
12	789	742	516	300	146	59	21	6	2	0	0	0	0
						3.5 GAL./100 FT.^{2}							
0	3,972	3,873	3,533	3,055	2,516	1,979	1,490	1,076	745	496	318	196	117
3	3,255	3,147	2,786	2,297	1,774	1,290	884	574	352	205	114	60	30
6	2,538	2,421	2,041	1,557	1,084	693	408	223	112	53	23	9	4
9	1,821	1,659	1,308	868	501	254	114	45	16	5	1	0	0
12	1,104	977	625	309	120	37	9	2	0	0	0	0	0
						4.0 GAL./100 FT.^{2}							
0	2,848	2,750	2,422	1,982	1,516	1,088	735	469	283	161	87	45	22
3	2,368	2,260	1,911	1,465	1,028	663	395	218	111	53	24	10	4
6	1,887	1,768	1,400	967	590	321	156	68	27	10	3	1	0
9	1,405	1,275	898	516	246	98	33	10	2	1	0	0	0
12	924	784	434	170	49	10	2	0	0	0	0	0	0

TABLE 24.--COEFFICIENT OF MULTIPLE DETERMINATION AND STANDARD ERROR OF THE ESTIMATE AND LIMITATIONS FOR EACH GENERAL RETARDANT MODEL

Retardant	Wind limits[1]	Level of coverage	R^2	$s_{y \cdot x_i}$
	M.p.h.	*Gal./100 ft.*^{2}		
Phos-Chek XA	$0 \leq W \leq 15$	0.2	[2]0.36	[3]5,175
		1.0	.38	1,708
		2.0	.06	1,245
		3.0	.59	946
		4.0	.56	637
Fire-Trol 100	$0 \leq W \leq 20$	.2	.43	9,147
		1.0	.52	1,738
		2.0	.80	1,241
		3.0	.68	1,070
		4.0	.69	669
Fire-Trol 931	$0 \leq W \leq 20$	.2	.39	6,815
		1.0	.48	1,972
		2.0	.62	1,837
		3.0	.94	448
		4.0	.94	313
Water	$0 \leq W \leq 20$	.2	.33	7,476
		1.0	.57	2,317
		2.0	.71	1,185
		3.0	.79	703
		4.0	.77	434

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[1] The limits on coverage for all models are from 0.2 to 4.0 gal./100 ft.^{2} and the limits on drop height are from 50 to 350 feet.

[2] R^2 is the coefficient of multiple determination and is a measure of how well the regression fits the data.

[3] $s_{y \cdot x_i}$ is the standard error of the estimate.

TABLE 25.--VERTICAL ARRAY RETENTION DATA

Drop No.	Retardant	Retention by each level[1]										Average retention each level	Retardant penetrating array (pan)	
		1 (top)		2		3		4		5 (bottom)				
		Grams	*Percent*	*Grams*	*Percent*	*Grams*	*Percent*	*Grams*	*Percent*	*Grams*	*Percent*	*Percent*	*Grams*	*Gal./ 100 ft.^{2}*
						ALUMINUM TOWER								
1	FT 931	18	4.7	23	6.3	25	7.3	19	6.0	16	5.3	5.9	284	1.33
2	PC XA	74	5.8	71	6.0	70	6.2	69	6.6	60	6.0	6.1	921	4.54
5	PC XA	14	6.3	14	3.3	20	5.0	10	2.6	10	2.6	4.0	154	.76
7	FT 100	1	6.3	1	6.7	1	7.1	0	0	0	0	4.0	13	.06
14	FT 100	37	17.7	30	17.4	26	17.8	13	12.6	12	13.5	15.8	91	.41
16	FT 100	60	8.3	64	9.7	72	12.8	73	12.4	77	17.0	11.9	376	1.71
20	PC XA	53	8.5	57	10.0	59	11.5	54	11.9	56	14.0	11.2	343	1.70
25	FT 931	32	5.6	38	7.1	41	8.3	38	8.3	42	10.0	7.9	378	1.81
Average			7.0		8.9		9.4		7.6		8.6	8.4		
						WOODEN TOWER								
2	PC XA	7	15.5	4	10.5	5	14.7	4	13.7	2	8.0	12.5	23	.11
7	FT 100	52	9.9	45	9.5	49	11.4	44	11.6	42	12.5	11.0	293	1.35
10	PC XA	36	9.7	41	12.3	43	14.6	31	12.4	31	14.6	12.7	188	.93
14	FT 100	24	12.1	26	14.9	24	16.1	16	12.8	16	14.7	14.1	93	.42
16	FT 100	65	10.5	60	10.8	59	12.0	59	13.6	56	14.9	12.4	319	1.45
20	PC XA	7	13.2	5	10.9	5	12.2	4	11.1	5	15.6	12.6	27	.13
25	FT 931	23	6.1	30	8.5	31	9.6	25	8.5	24	9.0	8.3	244	1.17
Average			11.0		11.1		11.3		12.0		12.8	11.6		

Drop No.	Total retardant impinging on array		Retardant retained by array			
	Grams	*Gal./ 100 ft.^{2}*	*Grams*	*Gal./ 100 ft.^{2}*	*Gal./100 ft.^{2} per square foot surface*	*Percent*
			ALUMINUM TOWER			
1	385	1.81	101	0.48	0.031	26.5
2	1,265	6.23	304	1.70	.108	27.2
5	222	1.10	68	.34	.022	30.6
7	16	.07	3	.01	.00064	18.8
14	209	.94	118	.53	.034	56.5
16	722	3.28	346	1.57	.100	47.9
20	622	3.13	279	1.43	.091	44.9
25	569	2.73	191	.92	.059	33.6
Average						35.8
			WOODEN TOWER			
2	45	.22	22	.11	.007	48.9
7	525	2.42	232	1.07	.068	44.2
10	370	1.83	182	.90	.057	49.2
14	199	.89	106	.48	.031	53.3
16	618	2.80	299	1.36	.087	48.4
20	53	.26	26	.13	.0083	49.1
25	377	1.80	133	.64	.041	35.5
Average						46.9

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[1] The percent retention by each level is calculated as a percent of the total retardant less any retention by any above levels.

TABLE 26.--EQUATIONS AND SIGNIFICANCE FOR RETARDANT DROP TIME AND WATER LOST BY EVAPORATION

	n	R^2	Equation	Significance level[1]
				Percent
RETARDANT TIME TO GROUND = *f* (DROP HEIGHT)				
Phos-Chek XA	20	[2]0.95	0.0379H + 0.0067	
Fire-Trol 100	13	.93	.0429H - .454	
Fire-Trol 931	11	.95	.0461H - .698	
Water	15	.96	.045H - .546	
Phos-Chek XA + Fire-Trol 100 (pooled)	33	.94	.039H - .124	NS
Fire-Trol 100 and 931 (pooled)	24	.94	.0245H - .625	NS
Fire-Trol 931 + water (pooled)	26	.96	.0456H - .613	99
Phos-Chek XA + water (pooled)	35	.93	.041H - .218	99
Fire-Trol 100 + water (pooled)	28	.94	.044H - .537	NS
PERCENT LOST BY EVAPORATION = *f* (RETARDANT TIME TO GROUND)				
Phos-Chek XA	22	.04	2.44 + .076T	
Fire-Trol 100	15	.05	5.82 + .091T	
Fire-Trol 931	17	.29	.960 + .846T	
Phos-Chek XA + Fire-Trol 100 (pooled)	37	.03	4.32 + .054T	99
Fire-Trol 100 and 931 (pooled)	32	.17	2.83 + .601T	NS
Phos-Chek XA and Fire-Trol 931 (pooled)	39	.18	.391 + .660T	99

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[1] The significance level indicates the probability level at which the difference between retardants may be regarded as real, i.e., not due to chance. NS means no significant difference between products existed for that particular response (and the pooled model should be used for predictions) e.g., Phos-Chek XA + Fire-Trol 100 pooled at a significance level of 99 percent means that the models for the two retardants should be kept separate and the individual equations used.

[2] R^2 is the coefficient of multiple determination and is a measure of how well the regression fits the data.

ALGEBRAIC MODELS FOR GENERAL GROUND PATTERN RESPONSES FOR PHOS-CHEK XA AND FIRE-TROL 100

Phos-Chek XA

```
 G=X(1)
 DH=X(2)
 W=X(3)
 REAL I,IREDG,ISD,IEI,N
 IEI=.81-.285*EXP(-(ABS((G/3.25-1.)/.3)**2))
 ISD=.305*EXP(-(ABS(((G+1.)/2.75-1.)/.338)**3))+.0922*EXP(-(ABS((
*G/3.-1.)/.16)**2))
1 +.0809*EXP(-(ABS((G/4.-1.)/.165)**4))
 IREDG=.926-.0315*(4.-G)-1.1684E-6*(4.2-G)**9
 I=IREDG-ISD*(EXP(-(ABS(((15.-W)/14.8-1.)/(1.-IEI))**2))-
1             EXP(-(ABS((                1.)/(1.-IEI))**2)))/(1-
2             EXP(-(ABS((                1.)/(1.-IEI))**2)))
 XN=1.+4.2*EXP(-(ABS(((G+2.)/3.33-1.)/.2495)**4))
 XSD=172.*EXP(-(ABS(((G+1.)/2.67-1.)/.3)**4))
 XREDG=1190.-.7179*(4.2-G)**4.4
 XP=XREDG-(XSD/14.8**XN)*(15-W)**XN
 N=2.+2.537E-12*(4.-G)**20
 YN=3.07+.584*EXP(-(ABS(((G+1.)/2.75-1.)/.27)**3.5))+.93*EXP(-(ABS(
*(G/4.-1.)/.1)**2))
 YLEDG=16200.-3100.*G+25670.*EXP(-(ABS(((G+4.)/4.2-1.)/.159)**1.3))
 YREDG=3000.+1201.8*(4.-G)**2.195+5.0385E-11*(4.-G)**25
 YP=YREDG+((YLEDG-YREDG)/14.8**YN)*(15.-W)**YN
 SQFTCV=YP*((EXP(-(ABS(((1250.-DH)/XP-1.)/(1.-I))**N))-
1            EXP(-(ABS((                 1.)/(1.-I))**N)))/(1.-
2            EXP(-(ABS((                 1.)/(1.-I))**N))))
 X(1)=SQFTCV
 RETURN
 END
```

Fire-Trol 100

```
 REAL N,I,IRED,ISD
 G=X(1)
 DH=X(2)
 W=X(3)
 R=19.-13.*EXP(-(ABS((G/2.-1.)/.2)**2))-18.*EXP(-(ABS(((G+5.)/5.2-
+1.)/.08)**3))
 ISD=.35*((EXP(-(ABS((G/2.-1.)/.472)**2))-.01124)/.98876)+
+.045*EXP(-(ABS((G/4.-1.)/.15)**1.5))
 IRED=.91-5.8613E-04*(5.-G)**3.95-5.0293E-15*(5.-G)**20
 I=IRED-(ISD/(20.**R))*(20.W)**R
 T=7.6-.75*G-6.45*EXP(-(ABS(((G+4.)/4.2-1.)/.1)**3))
 XPSD=223.*((EXP(-(ABS((G/2.-1.)/.520)**3))-.00082)/.99918)
++31.*EXP(-(ABS((G/4.-1.)/.20)**6))
 XPREG=720.+470.*(EXP(-(ABS((G/4.-1.)/.99)**6))-.34571)/.65429
 XP=XPREG-(XPSD/(20.**T))*(20.-W)**T
 N=1.+7.27*EXP(-(ABS(((G+2.)/4.1-1.)/.247)**2))
 YPT=2000.+336.33*(5.-G)**2.75+1.52339E-08*(5.-G)**18
 YPB=2000.+247.61*(5.-G)**2.78+1.05124E-06*(5.-G)**15.42
 YP=YPB+((YPT-YPB)/(19.5**N))*(20.-W)**N
 SQFTCV=YP*((EXP(-(ABS(((1250.-DH)/XP-1.)/(1.-I)) **2))-
1            EXP(-(ABS((                 1.)/(1.-I)) **2)))/(1.-
2            EXP(-(ABS((                 1.)/(1.-I)) **2))))
 X(1)=SQFTCV
 RETURN
 END
```

ALGEBRAIC MODELS FOR GENERAL GROUND PATTERN RESPONSES FOR FIRE-TROL 931 AND WATER

Fire-Trol 931

```
 FUNCTION F(G,DH,W)
 REAL N,NREDG,NSD,NN,I,IREDG,ISD,IN
 IN=1.+13.71*EXP(-(ABS(((G+1.)/2.875-1.)/.19)**3))+3.1*EXP(-(ABS((
*(G+4.)/4.2-1.)/.1)**3))
 ISD=.279-.189*EXP(-(ABS(((G+4.)/4.7-1.)/.17)**4))-.269*EXP(-(ABS((
*G/4.-1.)/.368)**6))
 IREDG=.87+.005*G-.291*EXP(-(ABS(((4.2-G)/4.-1.)/.18)**2))
 I=IREDG-(ISD/(19.**IN))*(20.-W)**IN
 XN=10.3-8.5*EXP(-(ABS(((G+4.)/4.7-1.)/.17)**3))
 XSD=170.*EXP(-(ABS(((G+1.)/2.7-1.)/.3)**4))+80.*EXP(-(ABS(((G+4.)/
*4.2-1.)/.15)**4))
 XREDG=1195.-6.9649*(4.2-G)**2.2-1.0732E-10*(4.2-G)**20
 XP=XREDG-(XSD/(19.**XN))*(20.-W)**XN
 YN=6.35-3.05*EXP(-(ABS(((G+4.)/4.9-1.)/.1)**2))
--3.05*EXP(-(ABS((G/3.35-1.)/.2)**3))
 YSD=986.+676.05*(4.2-G)**1.4+7.1996E-12*(4.2-G)**25
 YREDG=1250.+697.22*(4.2-G)**2.45+1.6105E-11*(4.2-G)**25
 YP=YREDG+(YSD/(19.**YN))*(20.-W)**YN
 NN=1.+2.76*EXP(-(ABS((G/4.-1.)/.67)**15))
 NSD=2.*EXP(-(ABS((G/4.-1.)/.67)**15))
 NREDG=2.+3.*EXP(-(ABS((G/4.-1.)/.58)**6))
 N=NREDG-(NSD/(19.**NN))*(20.-W)**NN
 SQFTCV=YP*((EXP(-(ABS(((1250.-DH)/XP-1.)/(1.-I))**N))-
1            EXP(-(ABS((              1.)/(1.-I))**N)))/(1.-
2            EXP(-(ABS((              1.)/(1.-I))**N))))
 F=SQFTCV*1.007969
 END
```

Water

```
 REAL I
 8=.01647*((EXP(-(ABS((G/2.25-1.)/.36)**2))-.00045)/.99955)+
1   .00476*EXP(-(ABS((G/4.-1.)/.196)**6))
 I=.793+.031*G-.0001024*(5.-G)**4
++B*(W-3.93)
 XP=1058.+137.*((EXP(-(ABS((G/5.-1.)/.77)**8))-.00031)/.99969)
 YP=(.6+1.6*(5.-G)+.00018589*(5.-G)**7.7)*1000.
 WE=500.+1500.*EXP(-(ABS(((5.-G)/5.-1.)/.65)**6))
 YPW=YP+(WE/3.46*(3.93-W))
 SQFTCV=YPW*(((EXP(-(ABS(((1250.-DH)/XP-1.)/(1.-I))**1.8))-
1              EXP(-(ABS((              1.)/(1.-I))**1.8)))/(1.-
2              EXP(-(ABS((              1.)/(1.-I))**1.8)))))
 F=SQFTCV*1.012951
 END
```

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GEORGE, CHARLES W., and AYLMER D. BLAKELY

1973. An evaluation of the drop characteristics and ground distribution patterns of forest fire retardants. USDA For. Serv. Res. Pap. INT-134, 60 p., illus. (Intermountain For. and Range Exp. Stn., Ogden, Utah 84401.)

Presently used fire retardants were dropped from a TBM aircraft to determine the effect of several variables on drop characteristics and patterns. Parameters having the greatest effect were drop height and windspeed. The largest differences in drop characteristics were found between the gum-thickened retardants and others; these differences were attributed to its greater cohesiveness. Mathematical models were developed for predicting the effect of drop height and windspeed on recovery, effective coverage, and concentration.

OXFORD: 432.3:843.1. KEY WORDS: aerial fire suppression, fire-retardant chemicals, models, predictions, ground distribution patterns, drop heights, air tankers.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)