# Simulated Sunlight Duration Maps of Forest Openings[1]

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*Abstract*

A mathematical model has been developed that allows ecologists and silviculturists to simulate the movement of light and shadow through forest openings. This paper describes a computer program which facilitates the mapping of isopleths indicating the duration of solar radiation over selected time periods in forest openings. Examples that show the effect of opening size and aspect on the distribution of solar radiation in time and space are used to demonstrate the program. Several practical applications of the method and indicated needs for future research are discussed.

## Introduction

The light regime within small forest openings is influenced by many factors including the dimensions and orientation of the opening, height of timber surrounding the opening, slope and aspect of the forest floor, latitude, and time of year. Since the dimensions and orientation of artificial forest openings are subject to manipulation, it is theoretically possible to "design" small openings so that an approximation of some desired light regime is achieved. The physical mechanisms that relate the light factor to opening design are so complex, however, that it is difficult in practice for the designer to accomplish his desired objective. Mathematical simulation models have been suggested as a means by which he might simultaneously consider many of the variables that determine light regime and thus simplify the problem (1, 3). This paper describes a model that should be of considerable aid to silviculturists and others interested in vegetation manipulation.

## Background

A mathematical simulation model has recently been completed by the authors (1) which can provide *a priori* information about the movement of light and shadow in alternative opening designs. The model is implemented with a FORTRAN IV computer program which allows the user to specify size, shape and orientation of the opening to be simulated, height of the surrounding timber, slope and aspect of the opening floor, latitude, day of the year, and time of day.

The program's potential to simulate complex situations can be demonstrated with an example. The example simulates the shadow pattern at 10:00 AM on August 3, 1970, in a 400- by 75-foot east-west clearcut strip with adjacent timber 70 feet in height. The strip is located at 40° 26′ north latitude on a 30° slope with an aspect of south 34° east.

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The problem data is first coded and submitted to the computer. The computer output begins with a summary of the problem data which identifies the problem for future reference. This information is followed by a list of the rectangular coordinates of enough points on the shadow boundary to allow its location to be sketched on a map of the opening. Figure 1 depicts the opening upon which is superimposed the shadow pattern at the specified time. By simulating a time series of shadow pattern maps, it is possible to follow the movement of light and shadows through the opening.

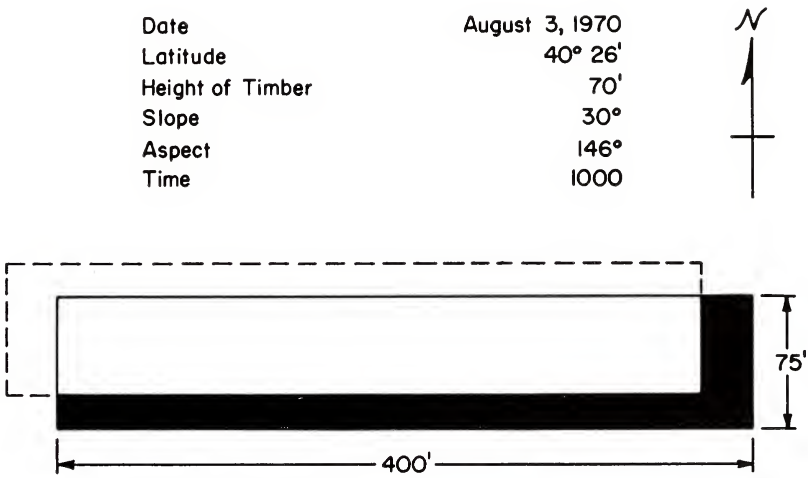


FIGURE 1. *A simulated forest opening shadow pattern. The solid line indicates the opening map. The darkened area is in shade at the simulated time. The dashed line borders an area on the forest floor outside the opening that is potentially in the sun.*

The simulation model is based on three assumptions about the physical characteristics of the opening. It is assumed 1) that the map of the opening can be approximated by a polygon, 2) that the timber surrounding the opening forms an opaque wall of uniform height, and 3) that the floor of the opening is a plane with given slope and aspect. Given these assumptions, the coordinates of a vector in the direction of the sun's rays at the specified time of day, date, and latitude, are computed. Each of the vertices of the top of the opening is then projected in the direction of this vector onto the plane used to simulate the floor of the opening.

## Simulated Sunlight Duration Maps

In addition to shadow pattern mapping, it is helpful in analyzing the light regime of small openings to map the spatial distribution of sunlight duration on the opening floor over specified time periods. Such a map provides information about sunlight duration on the opening floor in an easily interpreted form and a criterion for making comparisons between openings or opening designs based on a time summary of the shadow pattern data. The following procedure is used in a modified version of the shadow pattern simulation computer program to prepare "sunlight duration maps" of forest openings (2).

First, a sampling grid is superimposed on the opening to be simulated. The shadow pattern simulation model is then run at regular time intervals through some total selected time period. At each simulated point in time, each of the grid points is tested to see whether it is in the sun or in the shade. When a point is found to be in the sun, one time increment is added to the total sun time for that point. If it is in the shade, the sun-time total remains unchanged. At the end of the specified time period, *e.g.* from sunrise to sunset, the grand total associated with each grid point is plotted on a map of the opening. By interpolation, isopleths are drawn connecting those points that were in the sun for equal amounts of time. The completed map shows the distribution of sunlight within the opening for the time period in question.

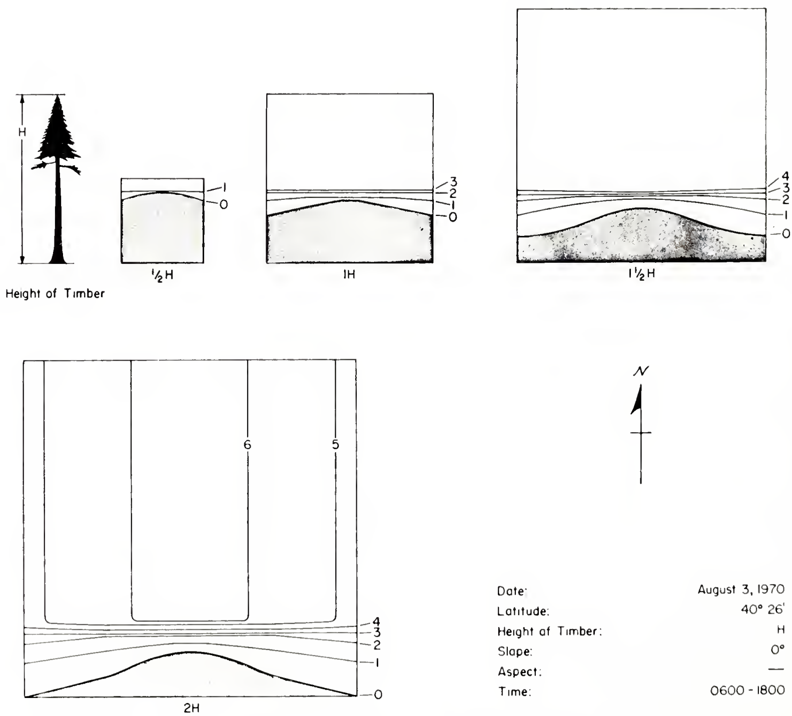


FIGURE 2. *The effect of size on sunlight duration patterns in square openings. Openings of ½ H, H, 1½ H and 2 H units on a side are surrounded by opaque walls H units in height. Other problem variables are given in the figure. The contour interval is one hour. The darkened areas represent those portions of the opening not receiving direct sunlight during the 12 hour time period.*

We find that sunlight duration maps are useful for illustrating the effects of changes in one or more of the problem variables on the light regime in the opening. Consider, for example, the effect of changes in the ratio of opening width to tree height (H) on the sunlight duration maps of square openings. Figure 2 shows maps of ½ H, 1 H, 1½ H, and 2 H openings; other variables remain the same as in the original example. Two trends are immediately apparent. The duration of sunlight on the opening floor and the percentage of the opening that receives direct sunlight both increase with increasing opening size. Although the direction of these trends is intuitively obvious, the details would be obscure without sunlight duration maps.

A second example illustrates the effect of aspect on the duration and spatial distribution of sunlight in forest openings. Figure 3 shows the sunlight duration maps of 1½ H square openings on a 30° slope and on north, east, south, and west aspects, other variables remaining the same as in the original example. The east and west aspect maps show that even in relatively simple situations the light factor can have an intricate spatial variation. These maps are mirror images and illustrate that the sunlight duration distribution on such aspects is asymmetrical.

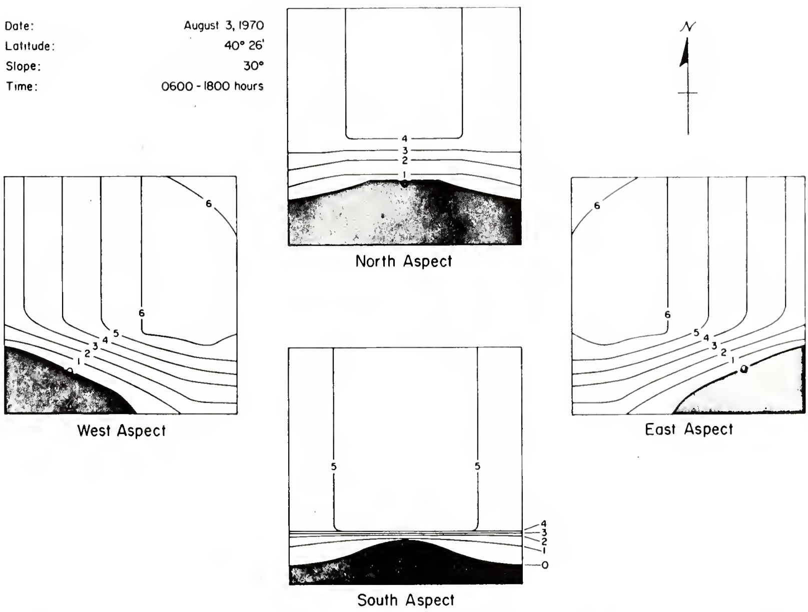


FIGURE 3. *The effect of aspect on sunlight duration patterns in 1½ H square openings. Other problem variables are given in the figure. The contour interval is one hour. The darkened areas represent those portions of the opening not receiving direct sunlight during the 12 hour time period.*

The north and south aspect maps indicate that the duration of sunlight is least, and the percentage of the opening floor in complete shade is greatest, on the north aspect. Since the ecological impact of the light factor depends in part on the angle at which solar radiation strikes the forest floor, the light regimes associated with the north and south aspects would, of course, be even more disparate than Figure 3 indicates.

## Discussion

Although originally developed as an aid to silviculturists, the authors feel that applications for this computer program exist in other fields. The model could aid studies of the spatial distribution of plants in natural forest openings. It could be used in the design of openings for campgrounds, picnic areas, and other recreational facilities. And the model could also be useful as a teaching aid for courses in silviculture and ecology where it could help students gain insight into the dynamics of forest microclimates and the effect on such microclimates of vegetation manipulation.

The model in its present form does not provide other than inferential information about the intensity or quality of solar radiation. It is obvious, of course, that these characteristics of solar radiation are as important in ecosystem energetics as are the duration and spatial distribution of sunlight. The authors suggest, therefore, that the inclusion of a mechanism that will allow estimates to be made of the intensity of solar radiation should be the next step in the evolution of this model.

## Literature Cited

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