DEVELOPMENT AND TESTING OF A LASER RAIN GAGE

by

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INTRODUCTION

Current catchment methods of measuring precipitation have several problems which affect their accuracy. The physical presence of the gage disturbs windflow patterns and reduces catch, as illustrated by wind tunnel measurements by Helliwell and Green (1974) and calculations assuming a Laws and Parson (1943) distribution (Fig. 1). Other errors of less significance arise from evaporation from the gage, wetting of the gage, and so forth.

Another problem with catchment gages is the difficulty in obtaining acceptable precipitation means for areas of irregular topography, such as encountered in mixed conifer forests in Arizona. A study of a 67-acre tract of this type indicated that 31 gages would be required for a statistically acceptable annual mean, and many more for monthly means (Rycroff 1949).

This paper describes a method of measuring precipitation by scattering light from a beam by waterdrops. The sampling medium is a collimated beam from a helium-neon laser. The amount of light scattered is a function of the number and size of drops intercepting the beam.

ATTENUATION OF LIGHT BEAM

Mathematically, the scattering of a light beam by raindrops is expressed as:

$$I_s = 1 - \mathrm{Exp}(-\frac{L}{2}\sum n_i d_i^2) \qquad i = 1,2,3,\ldots,\infty \qquad (1)$$

I_s is the fraction of the initial light that is scattered; L is the length of the beam; n_i is the number of drops with diameter d_i per unit volume.

Theoretical and empirical work by several people shows that drop-size distribution can best be represented by an exponential distribution given by:

$$N(d) = N_o e^{-\lambda d} \qquad o \leq d \leq \infty \qquad (2)$$

where $\lambda = 4.1\ R^{-0.21}$ and R is the rainfall rate. N_o was originally assumed to be constant, but has since been shown to be variable (Waldvogel, 1974). Using equation (2) to calculate n_i, a relationship between N_o, R, and $\sum n_i d_i^2$ was derived:

$$\sum n_i d_i^2 = .029\ N_o R^{.63} \qquad (3)$$

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The output of the laser rain gage is a measure of the scattered light. Combining equations (1) and (3) gives a relationship between rainfall rate, R, and scattered light, I_s:

$$R = \left[- \frac{19200}{N_o} \quad \ln(1-I_s) \right]^{1.587} \tag{4}$$

The constants in this equation are determined by the length of the beam and by the units of the rate, in this case they are 86.7 meters and millimeters per minute, respectively. The recorded output of the system is numerically integrated to obtain total rainfall.

INSTRUMENTATION

The laser is located in a weatherproof housing along with other system components. The beam out of the laser is approximately 2 millimeters in diameter. This thin beam is chopped into pulses, which provide for removal of ambient light effects, and directed into the eyepiece of a telescope. The telescope expands the beam to a diameter of approximately 10 centimeters. This enlarged beam then passes downrange to the signal detector. The chopper also provides light pulses to a reference detector which measures the laser output power. The measure of light arriving at the signal detector at the other end of the beam is subtracted electronically from this reference measure to obtain the light scattered by the rain. A heat exchanger regulates the laser temperature, minimizing power drift.

The laser rain gage was located on Thomas Creek in mixed conifer forest of the White Mountains of Arizona. The beam length from source to detector was 86.7 meters. The source was mounted on a reinforced concrete pillar for stability with adjustments provided for alignment purposes. A 13-centimeter lens at the signal end focuses the beam onto the signal detector. Four standard 8-inch gages were placed directly under the beam with their orifices 60 centimeters above ground surface to provide a basis for comparison. The catch in the gages was measured after each storm.

RESULTS

Data from three storms during September 1973, were recorded on strip charts as illustrated by a tracing of the strip chart record of the September 10 storm (Fig. 2). Fine structure of rainfall rate is easily seen. The high intensity peak represents an instantaneous rate of 2.97 millimeters per minute, or about 7.0 inches per hour.

The strip chart record of each storm was divided into 0.5-minute intervals and numerically integrated to give total rainfall. A comparison of this integrated output from the laser gage and the mean catch of the four standard gages is given in Table 1. The data from the September 10 storm was integrated several times, changing N_o each time. At N_o = 11200 the integrated value agreed with the gage catch. This value of N_o was then used to integrate the storms of September 6 and 9. The first storm was one of medium intensity reaching a peak rate of 22.10 millimeters per hour. The second was a low intensity storm with a peak of 6.23 millimeters per hour. The total catch during this storm approached the resolution of the scales used to weigh the standard gages.

An improved approach to obtaining a value of N_o would be to use a raindrop spectrometer. One described in the literature allows a value of N_o to be calculated for each minute of storm duration (Joss and Waldvogel, 1967). N_o does not change each minute, but can have several values during any one storm. Calculation of N_o using a spectrometer would allow calibration of the laser independent of the gages.

APPLICATIONS

Due to the complexity of the system, it will be difficult to make it an automatic, untended gage. However it does have some advantages for research purposes. The laser beam does not disturb windflow and, thus, does not disturb the fall paths of raindrops. Therefore, it would also be useful for measuring snowfall if calibration problems could be overcome.

Instantaneous rainfall rates are difficult to determine using mechanical gages. With a laser system, the rate can be resolved for much less than a second.

The laser system allows for an increased sample size. The area for a beam 10 centimeters in diameter and 100 meters long is equivalent to over 300 standard 8-inch gages. The beam length can be extended to 400 meters or the equivalent of 1200 gages. Such large sampling areas make it possible to measure rainfall on an entire watershed with two or three beams which would average topographic effects. Fraction of precipitation occurring as runoff from a watershed could then be obtained more readily than by current methods.

Comparison of beam attenuation above and below a forest canopy would give a measure of precipitation intercepted by the canopy, which could be particularly useful for snow interception measurements.

REFERENCES CITED

Helliwell, P., and M. J. Green. 1974. Raingauge performance studies. Natural Environment Research Council, Institute of Hydrology Research Report 1973-74. p. 44-45.

Joss, Von J., and A. Waldvogel. 1967. Ein Spektrograph fur Niederschlagstropfen mit automatischer Auswertung. Pure Applied Geophysics 68: 240-246.

Laws, J. O., and D. A. Parson. 1943. The relation of raindrop-size to intensity. Transactions, American Geophysical Union, Hydrology Papers p. 452-460.

Rycroff, H. B. 1949. Random sampling of rainfall. Journal of South African Forest Association 18: 71-81.

Waldvogel, A. 1974. The N_0 jump of raindrop spectra. Journal of the Atmospheric Sciences 31: 1067-1078.

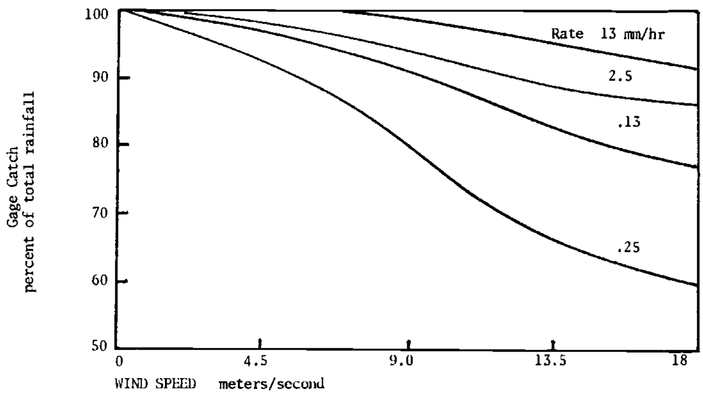

Fig. 1. Percent of catch versus wind speed at orifice height for various rainfall rates in inches per hour. Calculations were for a British Mk 2 gage using Laws and Parsons drop-size distribution versus rate.

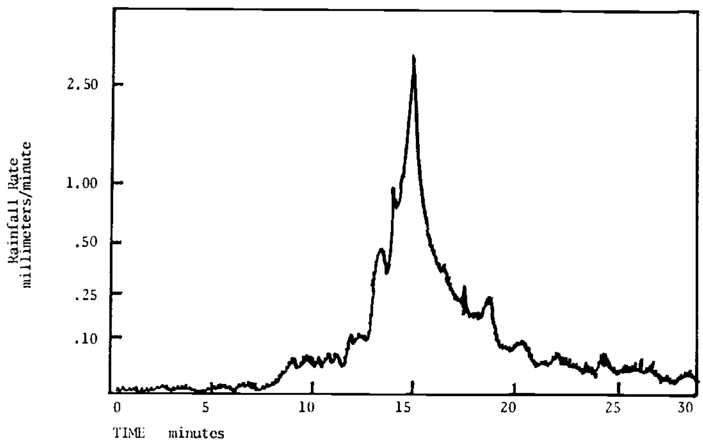

Fig. 2. Reproduction of strip chart recording of rainfall rate versus time for September 10, 1973 storm at Thomas Creek in White Mountains of Arizona. Precipitation rate is nonlinear because of relationship between rate and beam attenuation.

TABLE 1. Comparison of mean catch of four standard 8-inch gages and integrated output of laser system for three storms. The laser measurement for the September 10 storm was made to agree with the standard gage reading by choosing an appropriate value for a constant in the integration equation. The other two storms were integrated using this value.

Date 1973	Storm Duration	Mean rainfall catch Laser	Mean rainfall catch Gages
	hours	mm	mm
September 6	1.6	6.2	6.0
September 9	1.1	1.0	1.4
September 10	.5	3.8	3.8