VISIBILITY OF NAVIGATIONAL LIGHTS

In a letter recently received, the Hydrographer, Navy Department, Washington, emphasises the need for a uniform method of determining the visibilities of navigational lights as stated in the Light Lists and on the Charts. He points out that in that class of lights not sufficiently powerful to be seen their full "geographic range" there is an evident lack of consistent relation between assigned candlepower and visibility, a light of low candlepower often being stated to have a visibility greater than that of a light of more power; also that in that class of lights of sufficient power to be seen their full geographic range there is a lack of uniformity in the tables and formulas used in assigning the distance to which their visibility is limited from a height of eye of 15 feet above the sea.

Attached to his letter is the following provisional table of "Limits of Visibility" formulated in the U.S.A. Hydrographic Office:

LIMITS OF VISIBILITY

TO BE APPLIED TO NEW OR CHANGED LIGHTS

(Provisional Table)

(*A*) *Height in feet of focal plane.*	(B) *Visibility in nautical miles (geographic limit 15-foot height of eye).*		(*C*) *Minimum candlepower (English candles) essential to visibility.*
	(A)	(B)	(C)
	1	5	20
	2-4	6	30
	5-8	7	50
	9-14	8	80
	15-21	9	120
	22-30	10	210
	31-40	11	300
	41-52	12	490
	53-66	13	670
	67-80	14	900
	81-97	15	1300
	98-115	16	1700
	116-134	17	2200
	135-155	18	3200
	156-178	19	4500
	179-202	20	6400
	203-227	21	8900
	228-254	22	12000
	255-283	23	16000
	284-313	24	21000
	314-344	25	28000
	345-377	26	37000
	378-412	27	49000
	413-448	28	65000
	449-485	29	85000
	486-524	30	110000

USE (*) OF TABLE

(*a*) The officially presented visibility of a light should not be increased.

(*b*) The visibility of a light should be reduced to that corresponding to its height and, where the difference is *substantial*, to that corresponding to its candlepower.

(*c*) Before entering the table with a fractional height the fraction should be disposed of according to the conventional system, by which 0.5 is either discarded or increased to make an even, rather than an odd, number.

(*) Provisional use in Hydrographic Office.

SOURCE OF TABLE.

(*a*) The visibility corresponding to each of the limiting heights has been computed from the formula $V = 1.15\sqrt{Ht.}$ to as many decimal places as necessary, the limiting fraction being accepted as 0.8 (0.8 mile is discarded and over 0.8 is increased to 1). There is a consequent lack of exact agreement with visibility Tables in which fractions have been handled differently and with Tables based on formulas using a slightly different constant.

(*b*) Candlepower limits are from a Lighthouse Bureau Table for miles 5 to 20, extended by formula to 30 miles, and adjusted in this office so as to produce an approximately smooth graph.

From this it will be seen that the formula used for columns *A* and *B* agrees with those referred to in Special Publication No. 7 of August 1925 issued by the International Hydrographic Bureau. That used for column *C* is described later.

In accordance with the Resolution under Section III *D* of the International Hydrographic Conference, London 1919, the question of the Visibility of Lights was studied by the International Hydrographic Bureau and the results published in Special Publications No. 2 of March 1924 and No. 7 of August 1925. This question was again discussed at the 1926 Conference (See Report of Proceedings, pages 445 and 470) and the *Hydrographic Review*, Vol. VIII No. 1, page 144, and Vol. VIII No. 2, page 200, contains the results of further observations made by various countries.

The above investigations carried out by the International Hydrographic Bureau showed that although most countries use practically the same formula for calculating the "Geographical Range" (see page 27 of Special Publication No. 7, August 1925), which agrees with that used for columns *A* and *B* in the above-mentioned table formulated in the U.S.A. Hydrographic Office, it appeared impossible to adopt a universal formula for calculating the "Candle-power Range" owing to the different meteorological conditions existing in the various countries and even during different seasons and at different places in each country.

The following remarks received from the U. S. Hydrographer respecting column *C* of the above table are therefore of special interest:–

"……

"The first part of Column *C* — miles 5 to 20 — was furnished the Hydrographic Office by the U. S. Bureau of Lighthouses.

"The part of the table covering — miles 21 to 30 — was furnished by the Naval Research Laboratory, and was developed by a method described in the memorandum enclosed herewith.

……"

"Memorandum referred to : Extension of Visibility Table by Formula.

"A portion of the working table of the Bureau of Lighthouses is reproduced in Table 1. The values in Table 1 are found to accord with equation (1), and equation (1) is used to calculate Table 2. It is concluded that the values of Table 1 are consistent with each other, bearing in mind that the ranges are given to the nearest whole number of miles, and it is believed that Table 2 can be used as a trustworthy basis for practice in the 20 to 30 mile range.

"It is assumed that light passing through the atmosphere is degraded in intensity inversely as the square of the distance and by exponential absorption. Or, denoting by I_r and I_o the intensities, i. e. candlepower, at distances x_r and x_o nautical miles respectively,

$$I_r = I_o \frac{x_o^2}{x_r^2} \, 10^{-B(x_r - x_o)} \qquad (1)$$

"This is the commonsense physical law which one would expect the values of Table 1 to obey.

"The range x_r is defined to be the distance at which the intensity is reduced to a constant small value I_r.

"Whence, from (1)

$$log_{10} \frac{I_o}{x_r^2} = B x_r \text{ plus } A \qquad (2)$$

where $A = log_{10} \frac{I_r}{x_o^2} - B x_o$, and A is a constant.

"It is seen from (2) that plotting $log_{10} \frac{I_o}{x_r^2}$ against x_r should give a straight line. This has been done with I_r and x_r from Table 1, and it is seen that points lie pretty well along a straight line. From this straight line B comes out to be 0.088, and with this value in (1), Table 2 was calculated.

"We do not know how the values of Table 1 were obtained but may presume that they are experimental. However, the suspicion arises, due to the fact that the values conform so well to equation (1), that the original experimental values were smoothed and made to fall in with the equation. If this is so, all that we have done is to reproduce equation (1) again and to derive the same constants which the unknown formulator of Table 1 has derived. If, on the other hand, Table 1 is based solely on experiment, the agreement with equation (1) is extraordinarily close.

"The value $B = 0.088$ for ranges in nautical miles means that visible light passing through a normally clear atmosphere is degraded by absorption to 1/10 of its original value in $1/0.088 = 11.4$ miles. Thus, at ranges beyond, say 10 miles the absorption of the clear atmosphere is much more important in reducing the intensity of the light than is the inverse square law. For example, if a 240 candlepower light is good for 10 miles, at 30 miles one would calculate from the inverse square law that a light of $9 \times 240 = 2160$ candlepower would be satisfactory. But actually, because of absorption, a light of 52 times this brilliancy of 112,000 candlepower is required.

TABLE 1.

WORKING TABLE OF BUREAU OF LIGHTHOUSES.

I_r	x_r	I_r	x_r
10 candlepower.	4 nautical miles.	320 candlepower.	11 nautical miles.
20 "	5 "	350 "	11 "
30 "	6 "	360 "	11 "
35 "	6 "	490 "	12 "
40 "	6 "	540 "	12 "
50 "	7 "	670 "	13 "
60 "	7 "	900 "	13 "
70 "	7 "	950 "	14 "
80 "	8 "	1300 "	15 "
100 "	8 "	1400 "	15 "
120 "	9 "	1700 "	16 "
150 "	9 "	2200 "	17 "
160 "	9 "	4000 "	18 "
240 "	10 "	5000 "	19 "
300 "	11 "	6000 "	20 "

TABLE 2.

EXTRAPOLATION OF TABLE I BY MEANS OF EQUATION (1).

I_r	x_r
8870 candlepower.	21 nautical miles.
11900 "	22 "
16000 "	23 "
21300 "	24 "
28200 "	25 "
37500 "	26 "
49400 "	27 "
65000 "	28 "
85000 "	29 "
112000 "	30 "

At the 1932 Conference the Bureau suggested that the individual Lighthouse Authorities were best competent to deal with this question and this suggestion was adopted (see Report of Proceedings 1932 Conference, pages 42, 167 and 181) since which date the Bureau has discontinued this work, but still receives from time to time further reports on the Visibility of Lights from certain countries and holds them available for study by the Authorities concerned.

The question is now being studied by the Technical Committee of the Lighthouse Authorities; a report of the work of this Committee made at the Conference on Maritime Signals held at Paris in 1933 appears in *Hydrographic Review* Vol. XI No. 2, pages 123 to 128.

J. D. N.