LIGHT

Application Notes for Underwater Light

Water is a medium with significant attenuance (which varies with depth and dissolved and suspended materials; e.g. transmission to 1m may be between 90 and $<10^{-4}$% of the surface irradiance) and a surface with a reflectance which varies with sun (and diffuse radiation) angle and distribution.

Incident and submerged irradiance varies enormously and rapidly; the attenuance is relatively constant. Given the % transmission T_2 (100% submerged surface at depth z) and absolute values at the surface, absolute values submerged can be readily calculated. Hence a laboratory studying light underwater usually has equipment for recording insolation and a meter with surface and underwater sensors to measure % transmission. Underwater recording is so difficult, because of the problems of maintaining a clean sensor, that it is only attempted when absolutely essential.

Mathematical analyses and models of light underwater usually use the vertical attenuation coefficient , which is derived from transmission. If I_o is the irradiance immediately under the water surface and I_2 is the irradiance at depth z then

$$= \frac{[\ \ln (I_o / I_2)\ ]}{z} \qquad {}_z \text{ is the attenuance of a stratum of z m}$$

Diffusion by scattering is much more important underwater than in air and in many situations the upwelling flux may be significant. However, aquatic organisms are not standard shapes and a facing global (4) collector is no nearer a standard shape than a horizontal upward facing surface, and may be much less convenient. The horizontal surface is widely accepted as a convenient standard. Checks on the upwelling component can be made by inverting the horizontal surface. If horizontal surfaces are used they must have a cosine response which is particularly important early and late in the day and in turbid waters.

The immersion of a collector has optical consequences which mean that a submerged sensor exposed to x W/m^2 does not give the same reading as an identical sensor in air exposed to x W/m^2. Within the first few centimetres (actually said to be when z <0.9 r, where r is the radius of the collector) there is an extra error due to multiple reflections between the water surface and the sensor. It is convenient therefore to avoid taking readings at less than 0.1 m. The observed difference between a surface and a submerged sensor at 0.1 m is due to optical effects at the collector-water interface (the true immersion error), reflection at the water-air surface and the attenuance of 0.1 m of water. In clean water the latter is small (of the order of a 1% decrease).

Various methods have been proposed to measure the true immersion effect. Berger (1961) used a blackened funnel with 0.9 r of water above the cell. Smith (1969) used a spectroradiometer under the

Application Notes for Underwater Light (cont)

collector, immersed to a series of depths, and illuminated by a collimated beam. Surface reflection was calculated from Fresnel's equation. He showed that the immersion error depended on wavelength (for his collector between 0.74 at 440nm to 0.80 at 700nm) so that ideally it is necessary to use a weighted factor for any particular spectral distribution. In practice a weighted factor for white light is used. Given this inaccuracy it is probably adequate to determine the weighted factor directly using the submerged sensor in a large tank of clean water (the Freshwater Biological Association used >3m diameter for readings down to 30 cm) exposed to daylight. A series of readings over depths greater than 0.1 m are taken.

In the field, take readings in open water on a calm day over a range of depths greater than 10cm. If the surface reading is I_o and the submerged readings without any correction are V_z, then plot apparent transmission V_z / I_o on a logarithmic scale against depth on a linear scale. Log (V_z / I_o) should be a straight line which can be extrapolated to zero depth. This intercept is the apparent sub-surface value V_o. If reflection R is determined from the sun angle and sky conditions (Anderson 1952, see Table 1) then :

V_o, the apparent value above the surface = $V_o / (1-R)$

The true immersion error $E = V_o / I_o$

A complete system to measure light underwater needs equipment to hold the sensors horizontally in known positions. The surface sensor is most conveniently mounted on a float that can be anchored to a bank or boat. Except in rough water this automatically keeps it horizontal. For oceanographic or rough weather on lakes it may be necessary to support the surface sensor on deck in gimbals, but these are not normally supplied as part of a system.

An underwater mount should hold the sensor at right angles to a vertical pole with a plumb line. A graduated line is helpful for measuring depth. A vane is also advantageous in moving waters. In deep, moving water is may be necessary to anchor the pole with a weight.

H = height of sun = above horizon

	Clear sky	**Low**	**cloud**	**<10,000ft**	**High**	**cloud**	**>10,000ft**
		1-5/10	6-9/10	10/10	1-5/10	6-9/10	10/10
a	1.18	2.17	0.78	0.20	2.20	1.14	0.51

Application Notes for Underwater Light (cont)

TABLE 1

Surface Reflectance for Calm Water

$$\underline{R} = a\underline{H}^{b}$$

$$\underline{R} = \text{reflectance} = \underline{I_o / I_o}$$

b	-0.77	-0.96	-0.68	-0.30	-0.98	-0.68	-0.58

REFERENCES

Berger F. Arch. Meteorol. Geophys. Biolklimatol. 1961. B Vol 11 pp224
Smith RC. J Mar Res. 1969. Vol 27 pp341
Anderson ER. Tech. Dept. Circ. U.S. Geol. Surv. 1952. Vol 229 pp71