BIOLOGICAL ASPECTS OF TURBIDITY AND OTHER OPTICAL PROPERTIES OF WATER

By G. Chris Holdren, U.S. Bureau of Reclamation, Denver, CO

ABSTRACT

Introduction: Water clarity and light penetration have significant effects on both ecology and recreational water use. Visual water clarity and light penetration are closely related, with both depending on the absorption and scattering of light. Suspended particles are the dominant influence on light penetration in most natural waters (Davies-Colley and Smith (2001), with the exception of highly colored waters where absorption can be more significant.

Light penetration is of great ecological significance because of its impact on photosynthesis. Visual clarity impacts the behavior of aquatic organisms that rely on sight to catch their prey, and also influences human perception of water quality.

Limnologists have long used the Secchi disk to measure water clarity. It is often argued that Secchi depth measurements are highly subjective, with the implication that they are not as reliable as other instrumental measurements. In a recent review, Davies-Colley and Smith (2001) assessed methods for measuring turbidity, suspended sediment, and water clarity, as measured with a Secchi disk, is a true scientific measurement that can be measured with better precision than either turbidity or suspended sediment concentrations.

History: Carlson (1995; 1997) performed extensive research on the origins and use of the Secchi disk. Sailors have long reported sighting of various objects as a means of determining water clarity. Based on reports of some of these earlier observations, Commander Cialdi, head of the papal navy, used disks of white clay and canvas stretched over circular iron frames to measure transparency in the Mediterranean Sea. He enlisted the help of Fr. Peitro Angelo Secchi, an astronomer and the scientific advisor to the Pope, to test the utility of the disks. Beginning on April 20, 1865, Secchi initiated a series of seven experiments over a six-week period using disks of various sizes and colors, on the sunny and shady sides of the ship, on bright and cloudy days, and at different times of the day. The result was the selection of an all-white disk that was very similar to the modern Secchi disk.

G.C. Whipple modified the white Secchi disk by adding alternating balck and white quadrants to improve contrast in 1899. Whipple also viewed the disk through a tube, the forerunner to today’s viewscopes.

The first recorded Secchi disk reading was probably made in 1804, 8 years before Secchi was born, when someone on the U.S. Navy frigate President lowered a white china plate on a log line. That plate was observed at a depth of 45 m (148’) off the southern Mediterranean coast of Spain. The first recorded Secchi depth measurements in

freshwater were recorded on August 28 and September 6, 1873. He lowered a white dinner plate, 9.5 " in diameter, into lake Tahoe and was able to see the plate at a depth of 33 m (108.27'). The deepest Secchi depth is 80 m, recorded on October 13, 1986, in the Weddell Sea near Antarctica.

Theory of Operation: The Secchi disk measures the depth of visibility in water. This depth depends on both absorption due to dissolved substances and scattering by suspended particles. While an all-white disk is still commonly used in oceanography, most limnoligists use a disk with alternating black and white quadrants. There is a scientific basis for this difference. The Secchi disk acts as a contrast instrument, disappearing when there is no longer any contrast between the disk and its background. A white disk would remain visible at the greatest depth when viewed against a completely black background. The background color in the deep ocean, as well as in deep lakes, would be black. In contrast, light can be reflected off the bottom in shallow lakes, or off suspended particles in turbid lakes. In these cases, a white disk disappears sooner than would be the case if the background was black. The black quadrants may help provide the standard black background.

The apparent difference in brightness between the disk and surrounding water is represented by the following equation, presented by Hutchinson (1957):

$(I_o d_1 d_2 r_d - I_u) / (I_u + I_u' + I_R)$,

where I_o = the light penetrating the surface, I_u = the light scattered upward from below the level of the disk, I_u' = the light scattered upward between the disk and the surface, I_R = the light reflected from the lake surface, d_1 = the loss in intensity of the light passing from the surface to the disk, d_2 = the loss in the intensity of light passing from the disk to the eye, and rd = the reflectivity of the disk. In general, the human eye can perceive a difference in intensity of the quantity defined by the above equation of not less than 1/133.

In those cases where light transmission depends only on absorption, only d_1d_2 is decreased. If the loss in transmission if affected by scattering both I_u and I_u' increase. Because of these variables, correlations between Secchi depth and light penetration are limited. However, when a relatively homogeneous group of lakes is compared the can be a high correlation between Secchi depth and light transmission. For example, the Indiana Lake Enhancement Program requires measurement of both Secchi depth and the depth of 1% light penetration, as measured with a photometer. Jones (2002) reported the relationship:

1% light depth (m) = 1.73 x Secchi depth (m), with r2 = 0.52 (n = 681).

Scheffer (1998) also reported that the euphotic depth can be estimated as 1.7 times the Secchi depth. In contrast, measurements the Salton Sea, California, a highly saline body of water, found the 1% light depth = 4 x Secchi depth (Holdren, unpublished).

Application: The use of the Secchi disk to measure water clarity is an extremely valuable tool for limnologists. The Secchi disk is inexpensive, durable, easy to use, and produces readings that are directly related to key ecological variables and human perceptions of water quality. Applications and examples of readings with different styles of disks will be discussed.

REFERENCES

Carlson, R. E., 1995, The Secchi Disk and the Volunteer Monitor. LakeLine 15(1), 28-29, 35-37.

Carlson, R. E., 1997, The Secchi Disk in Black and White. LakeLine 17: 14-15, 58-59.

Davies-Colley, R. J., and D. G. Smith, 2001, Turbidity, Suspended Sediment, and Water Clarity: A Review. Jour. Amer. Water Resour. Assoc. 37:1085-1101.

Hutchinson, G. E., 1957, A Treatise on Limnology, Volume 1, Geography, Physics, and Chemistry. John Wiley and Sons, Inc., New York.

Jones, W. W., 2002, Personal communication between William Jones, Indiana University and G. Chris Holdren, U.S. Bureau of Reclamation.

Scheffer, M., 1998. Ecology of Shallow Lakes. Klluwer Academic Publishers, Dordrecht.