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TURBID WATER MEASUREMENTS OF REMOTE SENSING PENETRATION DEPTH AT VISIBLE AND NEAR-INFRARED WAVELENGTH

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TURBID WATER MEASUREMENTS OF REMOTE SENSING PENETRATION DEPTH AT VISIBLE AND NEAR-INFRARED WAVELENGTHS

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INTRODUCTION

The quality of impounded water is subject to major changes due to the influx of sediments and dissolved substances from the surrounding land area. The use of remote sensing offers a unique potential for monitoring these individual water bodies on a regional basis and in a more timely manner than is possible with in situ techniques. Both multispectral scanners and photographic systems are presently being used for remote sensing of water quality. They record the reflected solar radiance from the water at visible and near-infrared wavelengths. The basis for their use is that changes in water quality are detectable by the changes in the solar radiance distribution of sunlight which has penetrated the water surface and is then scattered back toward the remote sensors. These signals are altered from that of clear water by their interaction with particulate and dissolved matter in the water. What is not well known, however, is the depth to which the remote sensors are able to detect these changes in water quality. It is often assumed that the depth of detection corresponds to the depth at which a Secchi disk will disappear from sight when lowered into the water, but previous investigation has indicated that this assumption is not always correct and may lead to erroneous interpretation of the remotely sensed data. The penetration depth of light into water as seen by a remote sensor is frequently less than that of the Secchi disk depth and can be highly wavelength dependent. An improved knowledge of the effect of water quality on the remote-sensing penetration depth will lead to more accurate interpretation of the remotely sensed data and to better correlation of those data with in situ measurements.

Over the past 2 years, the Marine Environments Branch at NASA-Langley has been examining the relationship between the reflected solar signal and water quality in both field test and laboratory experiments. An integral part of this work has been the determination of the depth to which the light received by a remote sensor penetrates the water and how this varies both with the wavelength and with water type. Results of three field experiments are presented here.

METHOD

Field measurements were made as illustrated in figure 1. Tests were made for two different types of light penetration. First, water samples were taken to obtain optical properties used in the determination of the remote-sensing penetration depth (RSPD) for water which is not depth limited (i.e., water in which light does not reach the bottom surface or the bottom surface has a very low reflectance level and does not affect the signal that is returned to the sensor). These water

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samples were analyzed in the laboratory for both water quality and optical parameters. The optical coefficients from these tests were then used to compute the RSPD by the method described in Gordon and McCluney (1975) from

$$Z_{90} = \frac{1}{K}$$

where Z_{90} is the depth above which 90 percent of the diffusely reflected radiance originates and K is the diffuse attenuation coefficient. The diffuse attenuation coefficient is defined by Gordon, Brown, and Jacobs (1975) as

$$K = \frac{a+b^*}{\cos\theta_0}$$

using the inherent water properties of absorption coefficient (a) and backscattering coefficient (b*) and the underwater solar zenith angle (θ_0).

The second type of measurement was designed to determine the apparent remote-sensing penetration depth (ARSPD). This is the depth to which the light will appear to penetrate when a highly reflective bottom material is present and the light reflecting back from this surface adds to the signal received by the remote sensor. This effect would bias the received signal. Determination of the ARSPD would define a minimum depth for receiving an unbiased signal in the presence of a highly reflective bottom. To simulate this condition, a rapid scanning spectrometer was used to record the reflected signal from a white plate as it was lowered into the water. Spectral signals were recorded for discrete depths from near the surface to a depth that was 20 to 40 cm beyond the depth at which the plate could no longer be seen by the eye. The recorded signals were then plotted versus depth for selected wavelengths and this figure was compared with the water spectrum for those same wavelengths. The depth at which the signal from the plate matched that of the water was then considered the ARSPD.

The third method was also used to measure penetration depth. A Secchi disk depth was recorded for each site for comparison with the RSPD and the ARSPD.

RESULTS AND DISCUSSION

Field tests have been conducted at a number of different sites in order to obtain data from various characteristic water types. The results of three of those tests are presented here. Their locations are shown in figure 2. Visually, each of these rivers had a distinctive water color. The Appomattox River in Hopewell, Virginia was the most turbid of the three rivers. The tests were conducted several days after heavy rains upstream of the test site and the river had a yellowish-brown, cloudy appearance. The test area on the Back River in Hampton, Virginia was at the mouth of the river, just before entering

Chesapeake Bay. This water had a blue-green appearance and was the clearest water tested. The Ogeechee River, near Savannah, Georgia, provides drainage for the swamps in that region and has a characteristic black but clear appearance. The optical and water quality parameters for each of these rivers are shown in the tables of figure 3. As anticipated from the general appearance of the rivers, the minimum Secchi depth, 51 cm, was in the Appomattox and the maximum was in the Back River at 137 cm. The Appomattox is characterized by a large attenuation coefficient which is almost 85 percent scattering. This agrees with the relatively large amount of total suspended solids which would be associated with high scattering coefficients. The Ogeechee River has the highest amount of dissolved organic carbon and a relatively low attenuation coefficient. Thirty-six percent of the attenuation in this river was due to absorption. The Back River had the highest level of chlorophyll a and total suspended solids and the lowest attenuation coefficient. The high level of suspended solids does not correlate well with the low attenuation coefficient.

The computed remote sensing penetration depths (Z_{90}) for light entering water which is not depth limited (i.e., an infinite water depth) are presented in figure 4 for each of the three tests. Each curve is characterized by a maximum penetration in the 600-to 700-nm range and an absorption peak near 750 nm. For the Appomattox River, the remote-sensing penetration depth is approximately half of the Secchi depth. For the Ogeechee, it is less than a third the depth. But for the Back River it is almost two-thirds the Secchi depth. In all cases, the penetration depths are less than that of the Secchi disk depth. The depths of penetration also vary with the wavelength and the Back River water appears to be the most highly wavelength dependent of the three test sites.

The ARSPD's (depth limited) are shown in figure 5 in comparison with the computed RSPD's (infinite depth) and the Secchi depths. In each case, the use of the white plate to simulate the effect of a highly reflective bottom material has extended the effective penetration depth of the light from that which was calculated (Z_{90}) for water which was not depth limited (i.e., assumes an infinite bottom depth). McCluney (1974) indicates that material with a reflectivity as low as 20 percent will greatly extend the apparent penetration depth. Each ARSPD curve also shows a maximum penetration in the 600-to 700-nm wavelength range. For the Back River, this extends from 500 to 700 nm.

These results imply that in the case of Landsat imagery, the results of each band might be valid for different depths. For example, the results of band 5 for the Appomattox River (with the same water quality as was tested) are representative of only the top 25 cm and not to the 50 cm depth read with the Secchi disk. Similarly, in situ samples taken to correspond with band 5 imagery would have to be taken from that top 25 cm layer to give valid results. This is only true if the band 5 imagery is used in regions where the water depth exceeds 80 cm. If it is less than this, the results will probably be influenced by bottom reflectance. The ARSPD curves essentially define a minimum bottom depth necessary for remotely sensed data, in order to be assured that the signal is unbiased by bottom reflectance.

CONCLUDING REMARKS

Remote sensing of water quality can be a valuable aid in monitoring and managing impounded water areas. The remotely sensed signal represents an integrated result over the water column that is viewed and to use this information accurately, the water depth through which the sunlight penetrates and returns to the sensor must be known. This remote sensing penetration depth is a function both of water type and wavelength. Results of three tests to help demonstrate the magnitude of this dependence have been presented.

The water depth to which the remote sensor data was valid was always less than that of the Secchi disk depth, although not always the same fraction of that depth. The penetration depths were wavelength dependent and showed the greatest variation for the water type with the largest Secchi depth. The presence of a reflective plate, simulating a reflective subsurface, increased the apparent depth of light penetration from that calculated for water of infinite depth.

Inferences from remote-sensing data should be limited to depths less than that of the Secchi disk depth and in situ data taken to correlate with remote sensing data should also be taken from water above this depth. Where the water depth is sufficiently shallow, the presence of a highly reflective bottom may bias the data. Where the depth is sufficient, a theoretical value of penetration depth may be used.

A knowledge of the penetration depth is required to best utilize remotely sensed data. The limited number of tests presented in this paper are insufficient to draw general conclusions between penetration depths and water type. Additional testing will be required.

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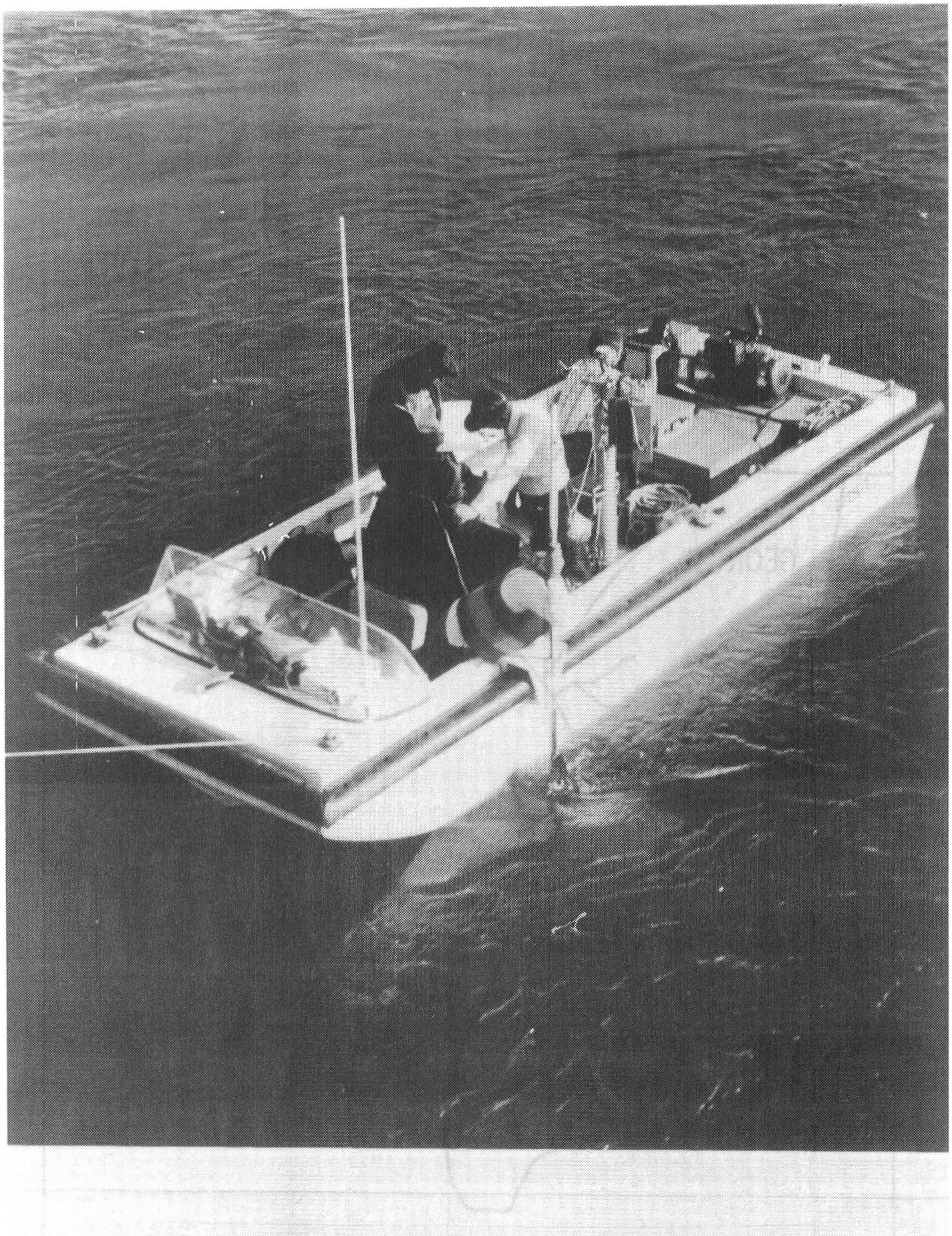

Figure 1.-Illustration of field measurements.

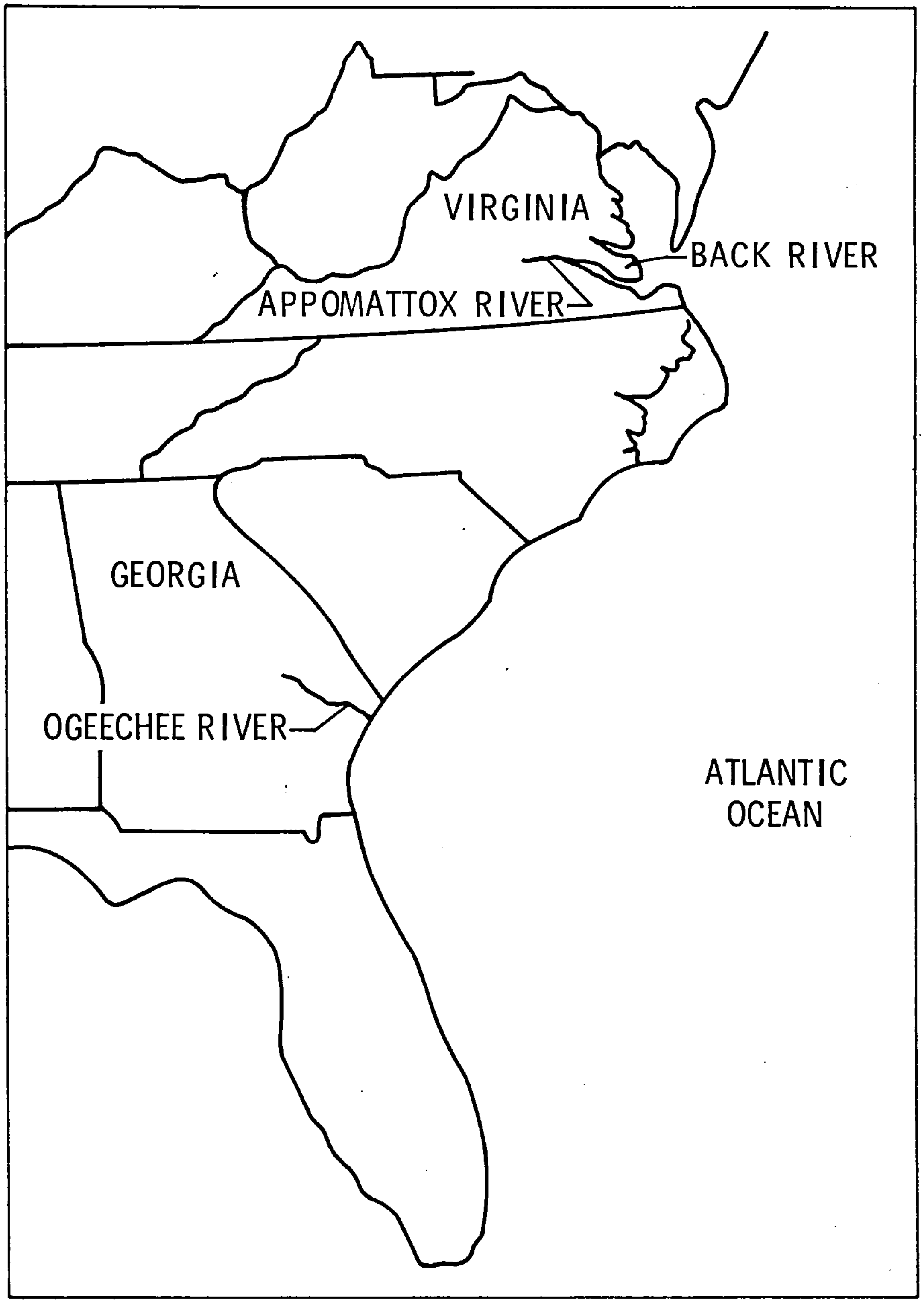

Figure 2.- Location of test sites for remote sensing penetration depth studies.

	Appomattox River	Ogeechee River	Back River
Secchi depth (cm)	51	95	137
Attenuation Coefficient (α) at 550 nm (m^{-1})	19	10	8.9
Scattering Coefficient(s) at 550 nm (m^{-1})	16.3	6.3	8.3
Absorption Coefficient (a) at 550 nm (m^{-1})	2.7	3.7	.6
Total Suspended Solids (mg/l)	18.6	11	22.8
Inorganic Suspended Solids (mg/l)	14.7	10	13.9
Volatile Suspended Solids (mg/l)	3.9	1	8.9
Dissolved Organic Carbon (mg/l)	<10	13	<10
Chlorophyll _a_ (μg/l)	10	4	13

Figure 3. Table of water quality and optical parameters

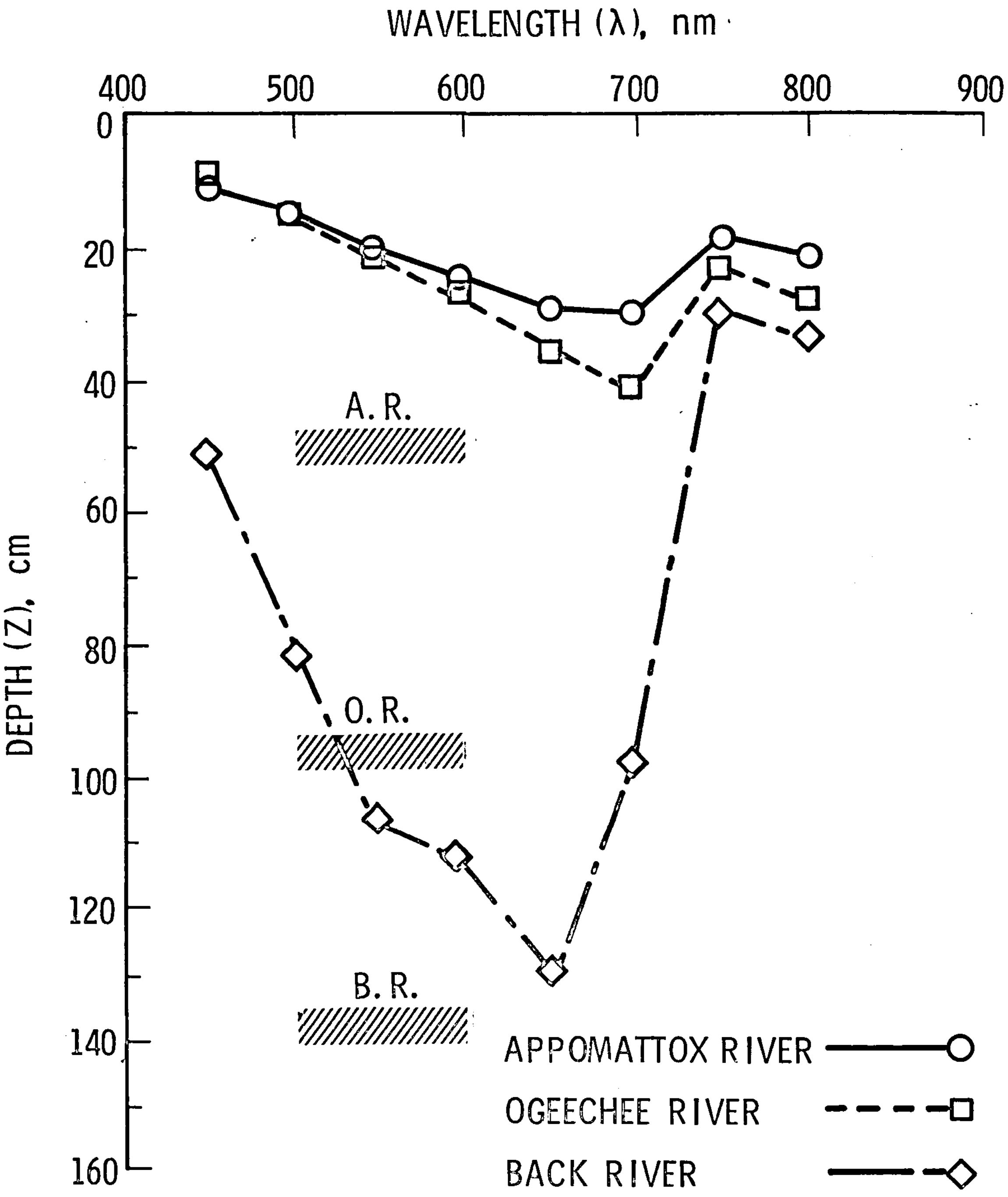

Figure 4. - Computed remote-sensing penetration depth as a function of wavelength for three test sites. Secchi depths are shown cross hatched for each river.

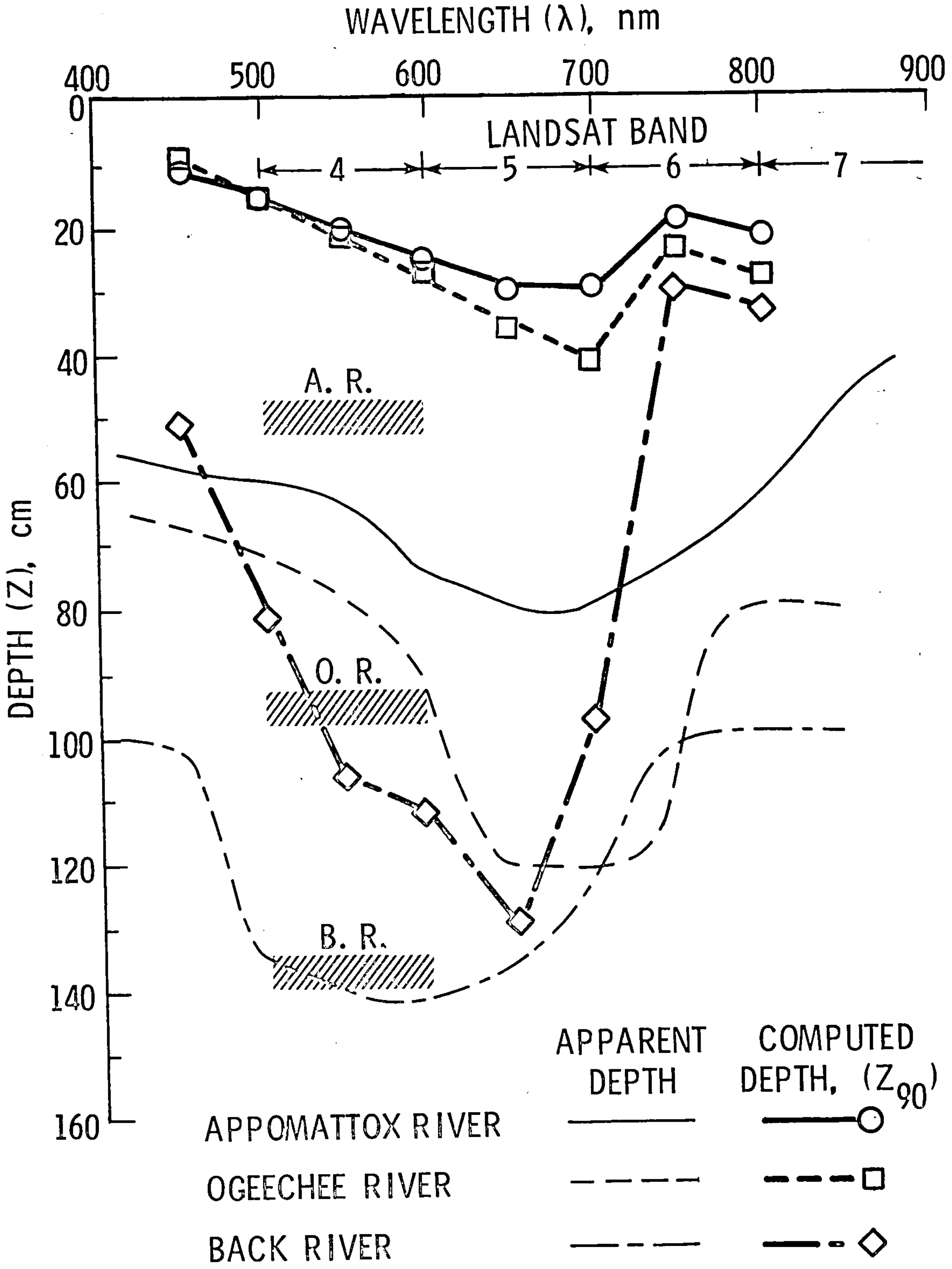

Figure 5. - Comparison of the apparent remote-sensing penetration depth (depth limited) with the remote-sensing penetration depth (infinite depth) and the Secchi depth (shown cross hatched).

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