VISIBLE REGION REMOTE SPECTROSCOPY OF POLLUTED WATER

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INTRODUCTION

The data described in this report was taken in order to see if correlations could be obtained between airborne and surface measurements of subsurface pollutants. Figure 1 illustrates some of the problems associated in making this type of measurement. In the right hand column the electro-magnetic spectrum from ultra-violet through infrared is displayed. In the adjacent column, the areas in which the atmosphere interferes with observations are shown. At the shorter wavelengths, atmospheric particles scatter radiation to the extent that the back-scattered light effectively obscures the signal from the target. At the longer wavelengths, the atmosphere effectively absorbs all the useful measureable signal. The middle column shows a similar effect due to the water itself. At the short wavelengths, water molecules scatter radiation received from above much as the atmosphere did in the previous case. At wavelengths greater than .7 microns, the absorption coefficient of water is so high that effectively, any signal from beneath the surface never reaches the surface. Therefore, the only region of the spectrum which is useful in making measurements of pollutants beneath the surface of the water is within the approximate range of .38 to .7 microns. Pollutants at, or near, the surface of the water can be detected and measured over a considerably larger portion of the spectrum as is shown in the left-hand column of Figure 1.

TEST PROCEDURES

Our tests involved the flight of an airborne spectrometer flown in a Cessna 180 aircraft at 1,000 ft. altitude over a flight path slightly more than 2 nmi. long located in Los Angeles Harbor. Surface truth measurements were taken from a small boat in the harbor, along the same path.

Figure 2 shows the northern portion of the flight path during the tests. The lines indicated on the photograph are the path traced out during individual spectral scans by the spectrometer in the aircraft. The circles are areas in which water samples and surface measurements were made from the boat. Notice that at the top of the photograph, a large sewage outfall is seen on the right. This outfall is used by the City of Los Angeles to discharge sewage after primary treatment. On the left a smaller outfall can be seen which is associated with a fish cannery in the area, and another cannery outfall is located somewhat below this, but just out of the left-hand edge of the picture, and is not visible.

While taking measurements, experimenters on the boat noticed that in the immediate vicinity of the sewage outfall, the water was substantially warmer. This prompted us, on a subsequent date, to fly an 8 to 13 micron infrared linescanner to obtain a thermal image of the scene. This is shown in Figure 3. Notice that the two outfalls seen in the preceding Figure 2 are both visible and that their flow patterns show up in a very similar manner.

Some typical spectral reflectance signatures, obtained by the spectrometer, are shown in Figure 4. Notice the large differences between the three signatures shown, even though their locations are not too distant from one another.

The upper curve is typical of water near the sewage outfall. The lower curve is typical of water some distance away, and water that prevailed all the way out to the Los Angeles breakwall and even beyond.

Figure 5 is a photograph taken from 8,000 feet altitude showing the complete flight path of the aircraft. Every tic mark along the line represents a point at which a spectral signature was obtained. Water measurements on the surface were made along the same line.

The sewage outfalls mentioned previously are visible near the upper part of the picture, and in the lower portion, indications of a plankton known as gonyaulax sometimes referred to as "Red Tide" may be seen. Some recent research has indicated that plankton concentrations are frequently higher in regions adjacent to sewage outfalls.

Figure 6 is a map of the same area showing more accurately the areas measured by the spectrometer as small rectangles and the points at which all water samples and ground measurements were made, shown as dots.

DATA ANALYSIS

Certain characteristics of the spectral signatures obtained were noted. Referring back to Figure 4, we see that the area in the immediate vicinity of the outfall shows a very distinct increase in reflectivity between 4000 and 5000Å. In all cases in which sewage was present in the water, this rise in reflectivity was noted in this region and in addition, it was noted that the slope of the reflectance curve here appeared to change as a function of the sewage content in the water. On the other hand, in the areas of the harbor which contain plankton, this same portion of the reflectance curve had a slope in the other direction, as shown by the lower curve. In this case, regardless of the plankton content of the water, the slope remained fairly constant. In order to see if these observations were indeed real, the parameter K_1, shown in Figure 7 was devised. K_1 is the difference in reflectivity between 5250 and 4000Å with the total quantity normalized by dividing by the reflectance at 5700Å. K_1 is plotted against Secchi depth, which is a measure of the clarity of the water. The higher the Secchi depth, the clearer the water.

The sewage points on the curve show a very definite relationship between K_1 and the Secchi depth. This is consistent with our observation of the change in slope of the reflectance curve with sewage content of the water.

On the other hand, no trend is noticed when K_1 for algae is plotted against Secchi depth. Once again, this is in agreement with our observation of no change in the slope of the reflectance curve from 4000 to 5250Å.

The plankton or algae under observation was a type known as gonyaulax which contains a pigment called pycobilin. Pycobilin absorbs radiation in the region of 5250Å. This absorption shows up in the lower curve in Figure 4 and was very characteristic of all spectral curves obtained over waters containing this algae. Therefore, Figure 8 is a plot of a parameter K_2. K_2 is an attempt to determine the concentration of pycobilin pigment and hence algae, in the water. K_2 is defined as the difference in reflectance between 5700 and 5250Å, once again normalized by dividing by 5700Å. In other words, K_2 is a measure of the depth of the pycobilin absorption. In this case, as shown in Figure 8, we have indeed developed a relationship between K_2 and the Secchi depth for the algae. As the depth of the pycobilin absorption increases, K_2 becomes larger and the Secchi depth or the clarity of the water decreases. Perhaps surprisingly, another relationship between K_2 and Secchi depth seems to be apparent for water containing sewage, although this is not as strongly marked as was K_1.

Another feature of water containing algae is an absorption due to chlorophyll-α at 6700Å. This too, can be seen in Figure 4, and in the case of Figure 9, we have plotted parameter K_3 which attempts to measure the absorption at 6700Å. Once again, we have developed a relationship that seems to hold for concentration of algae and again, a different relationship for concentration of sewage, when plotted against Secchi depth.

In the case of Figures 7, 8, and 9, the clear water values of K are indicated from data obtained previously and this, of course, is the value that K would have at a Secchi depth of the order of perhaps 50 feet. It serves as an indication of the direction in which the curve shown will tend. Figure 10 shows reflectance curves from two areas containing algae; in the one case, a fairly high concentration, shown as the dashed curve, in which the Secchi depth was only 8.3 feet, and in the other case a lesser concentration in which the Secchi depth was 15.5 feet. The algae counts shown on the curve represent the number of cells of algae counted in a given area on a microscope slide and show correlation with the Secchi depths as might be expected.

One of the most striking features of Figure 10 is the sharp drop in reflectance at wavelengths higher than 5700Å. In order to see if there was meaning to this observed phenomena, Figure 11 shows a parameter K_4 which is a measure of that drop. It is the difference in reflectance between 5700 and 6100Å divided by the reflectance at 5700Å. In this case also, a relationship develops between K_4 and the Secchi depth. The point of inflection in the curve near the right hand side is due to the fact that the value of K_4 for clear water is somewhat less than .30.

CONCLUSIONS

The significance of the preceding results is that they show that some form of quantitative measurement may be made from an airplane of phenomena associated with subsurface pollutants. There is definite evidence that some measure of the concentration of sewage may be obtained remotely and a measure of associated algae growths. Both measurements may be made independently of one another.

The scatter shown in the curves is probably primarily due to the non-homogeniety of the water and, in addition, to an uncertainty of the location of the boat during the time the measurements were made. The location of the boat was known to probably 150 feet on the surface, whereas the spectral reflectance curves made by the spectrometer from the air were known to within 50 feet.

It is reasonable to expect that with more careful and accurate ground truth measurements, particularly particle size distributions to a depth of 10 or 20 feet, and with more accurate navigation data, that the scatter shown in these curves will be substantially reduced and that, in addition, new relationships not at present apparent will be seen.

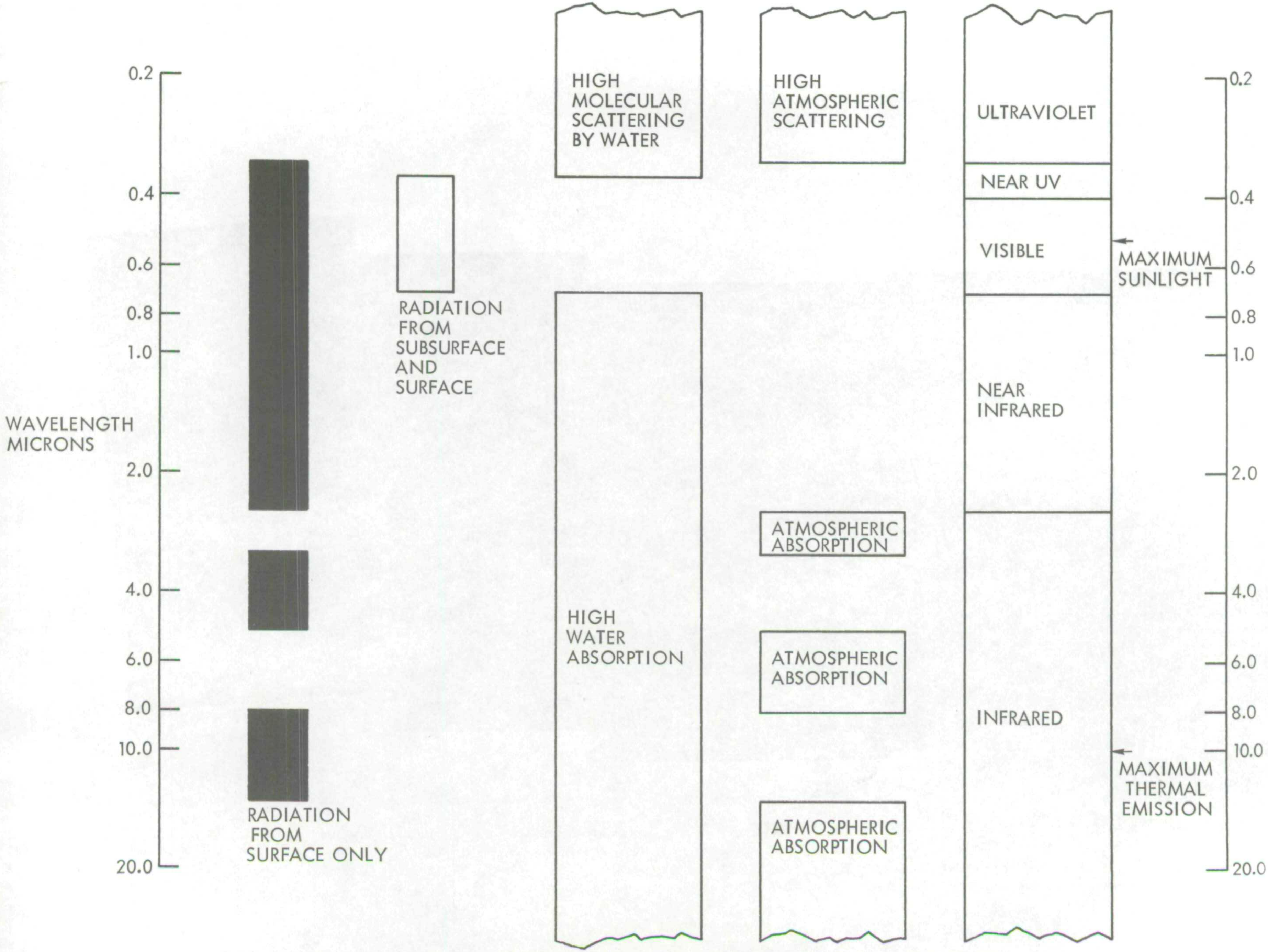

Figure 1 - Spectral regions suitable for remote polluted measurements.

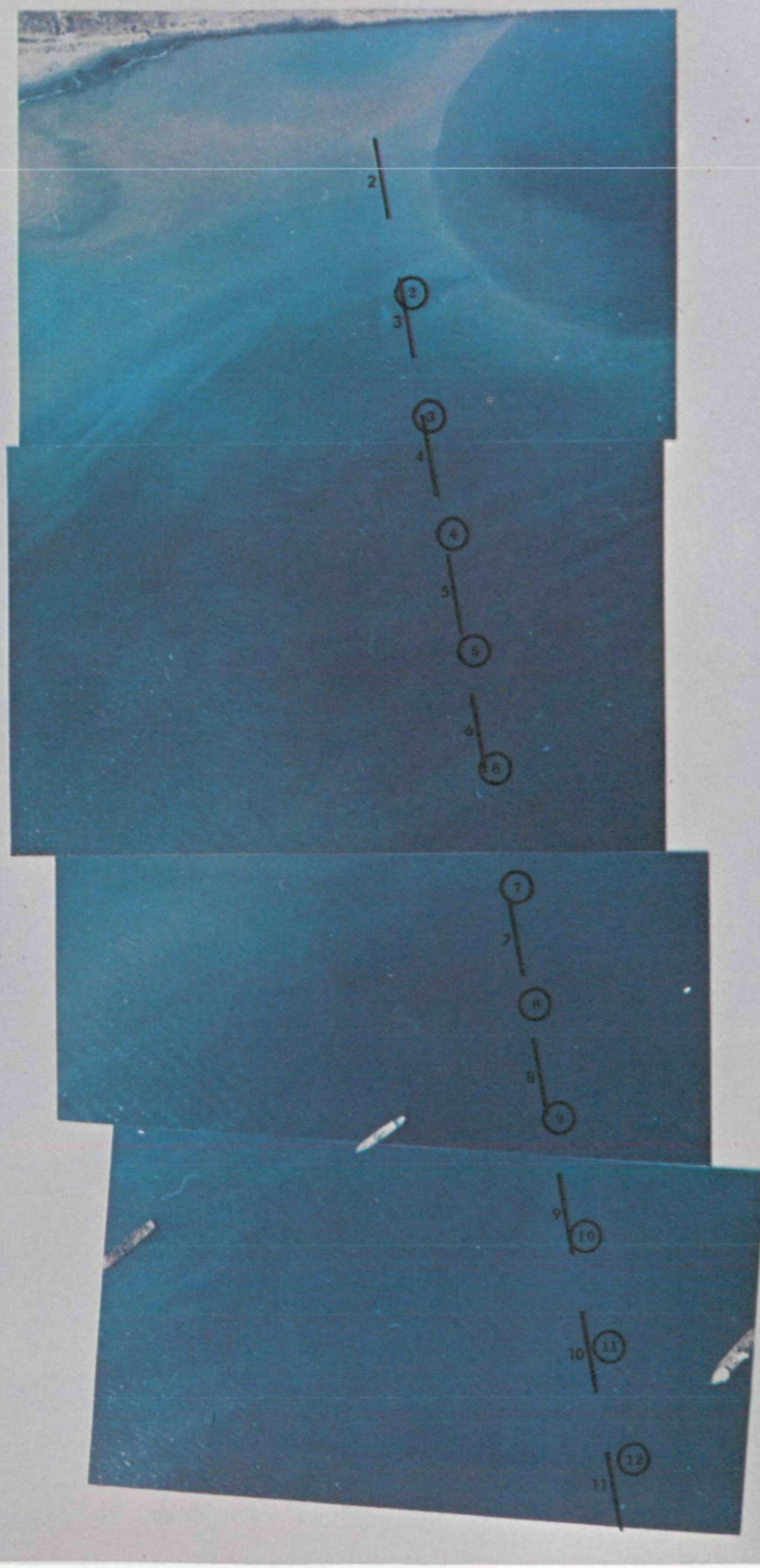

Figure 2 - Northern Portion of test area showing spectrometer scan locations and surface truth points.

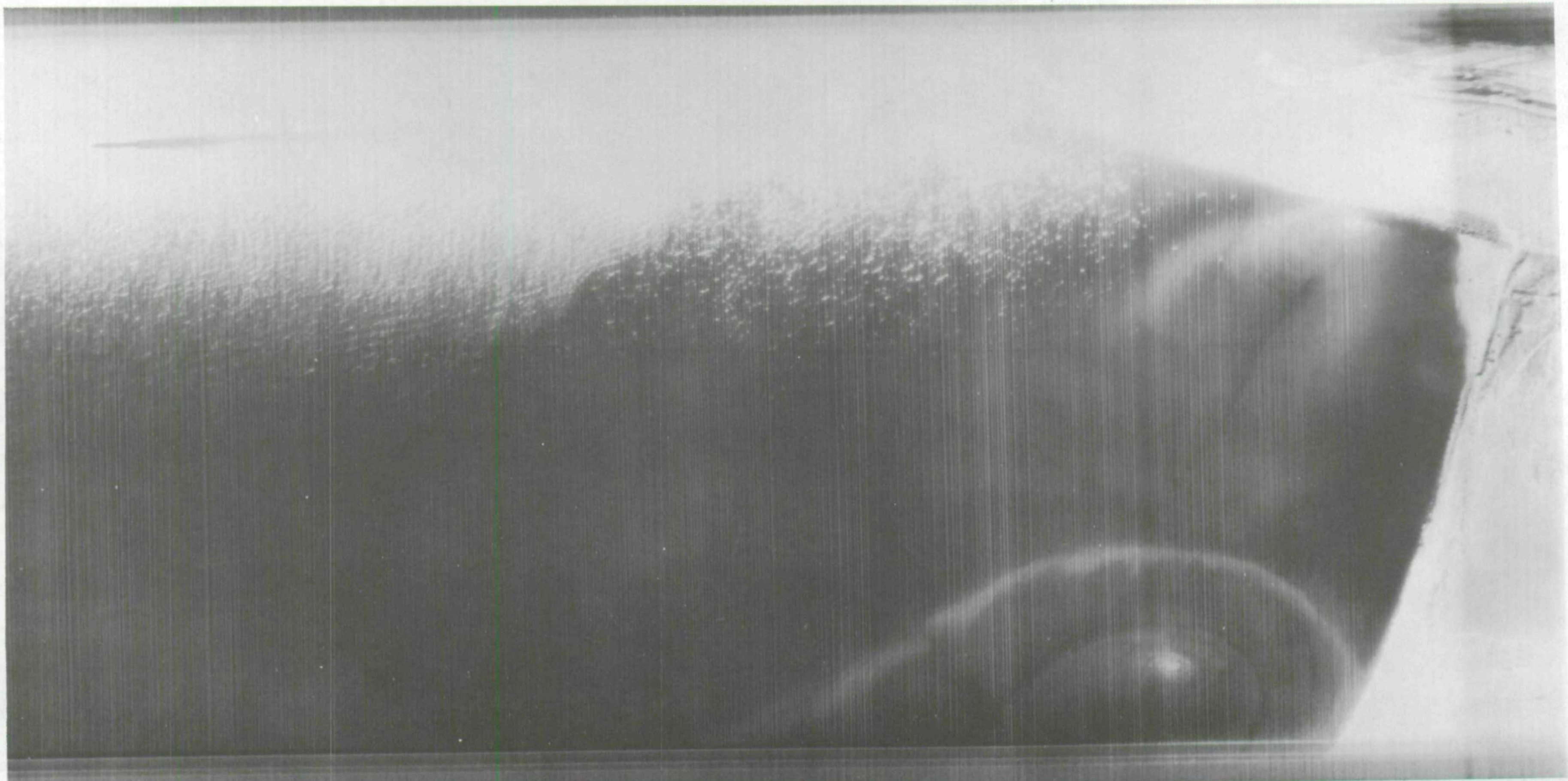

Figure 3 - Thermal image of northern portion of test area.

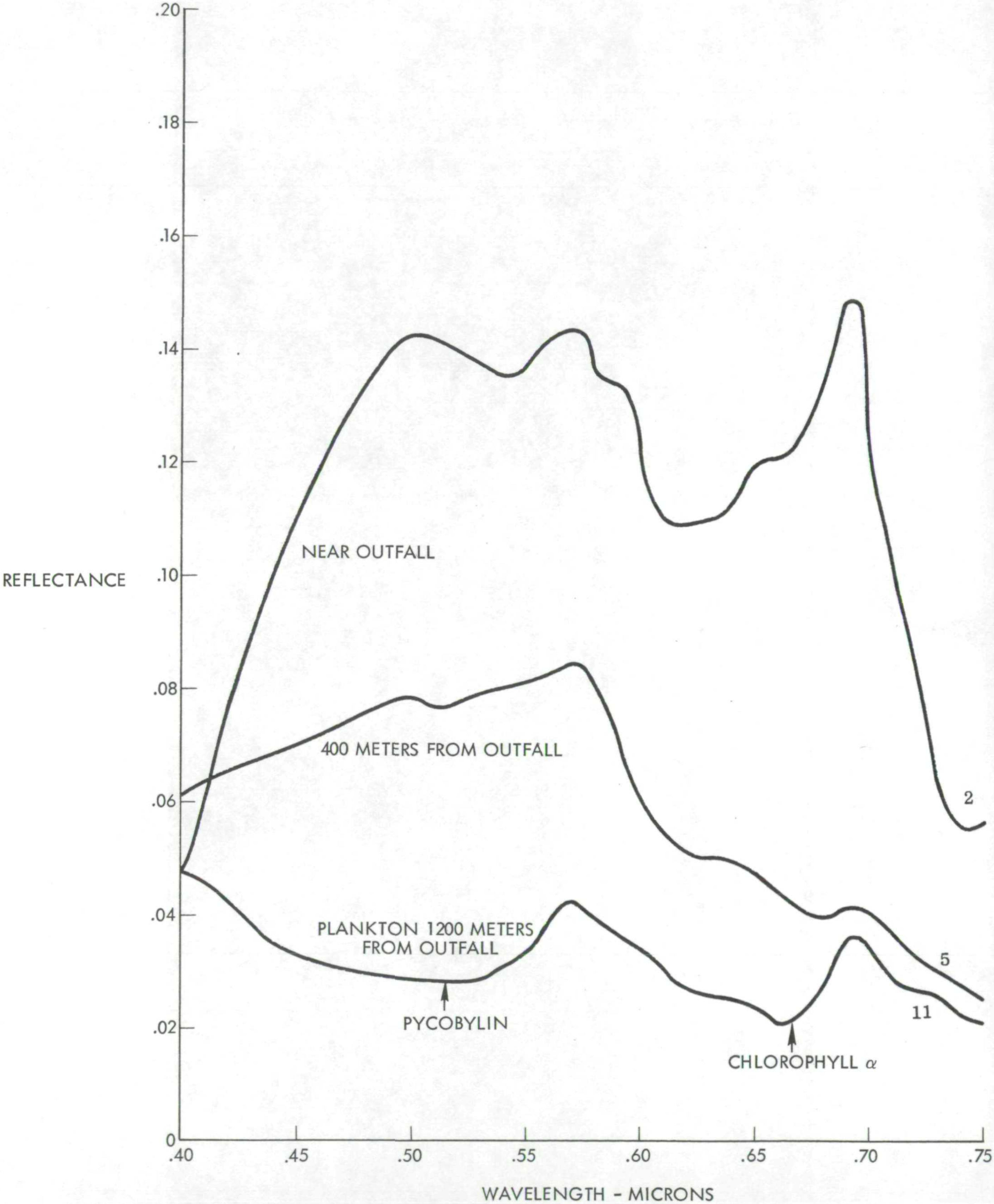

Figure 4 - Typical spectral reflectance signatures.

LOCATION OF SPECTROMETER SCANS IN LOS ANGELES HARBOR 10/18/70

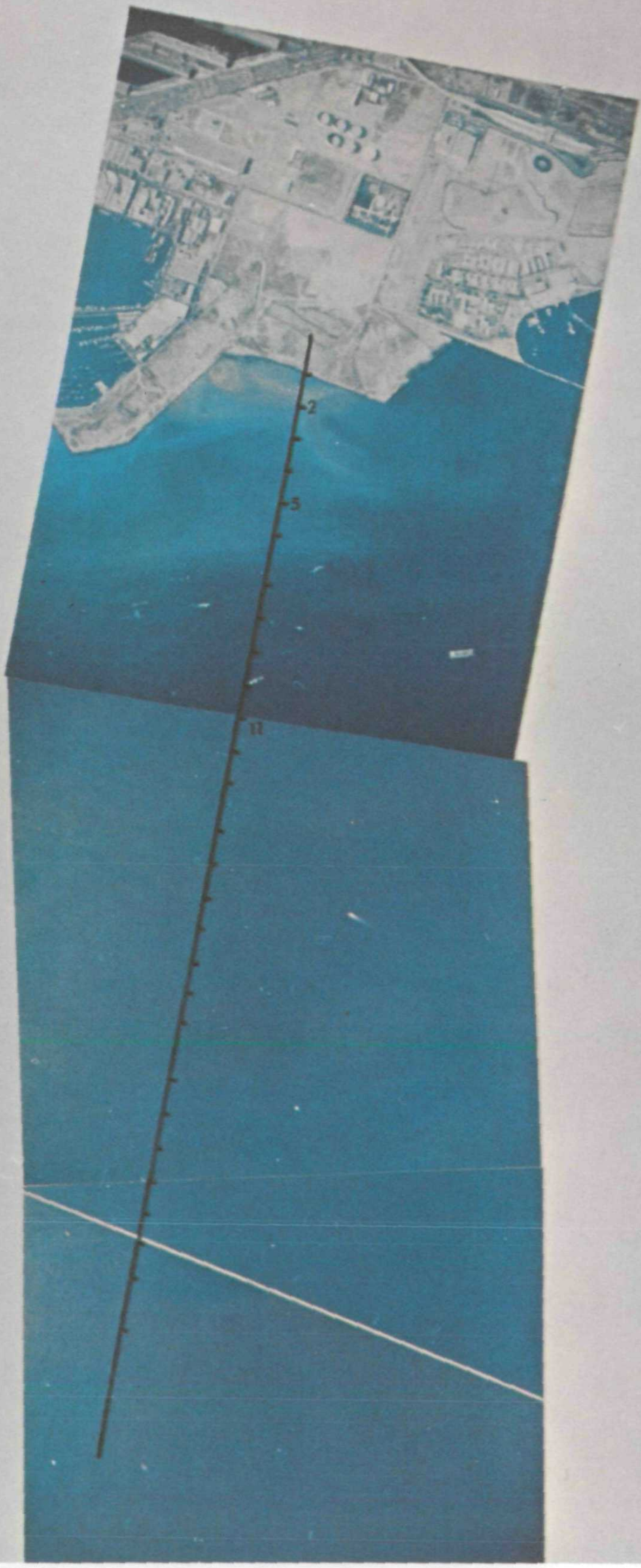

Figure 5 - Complete test area.

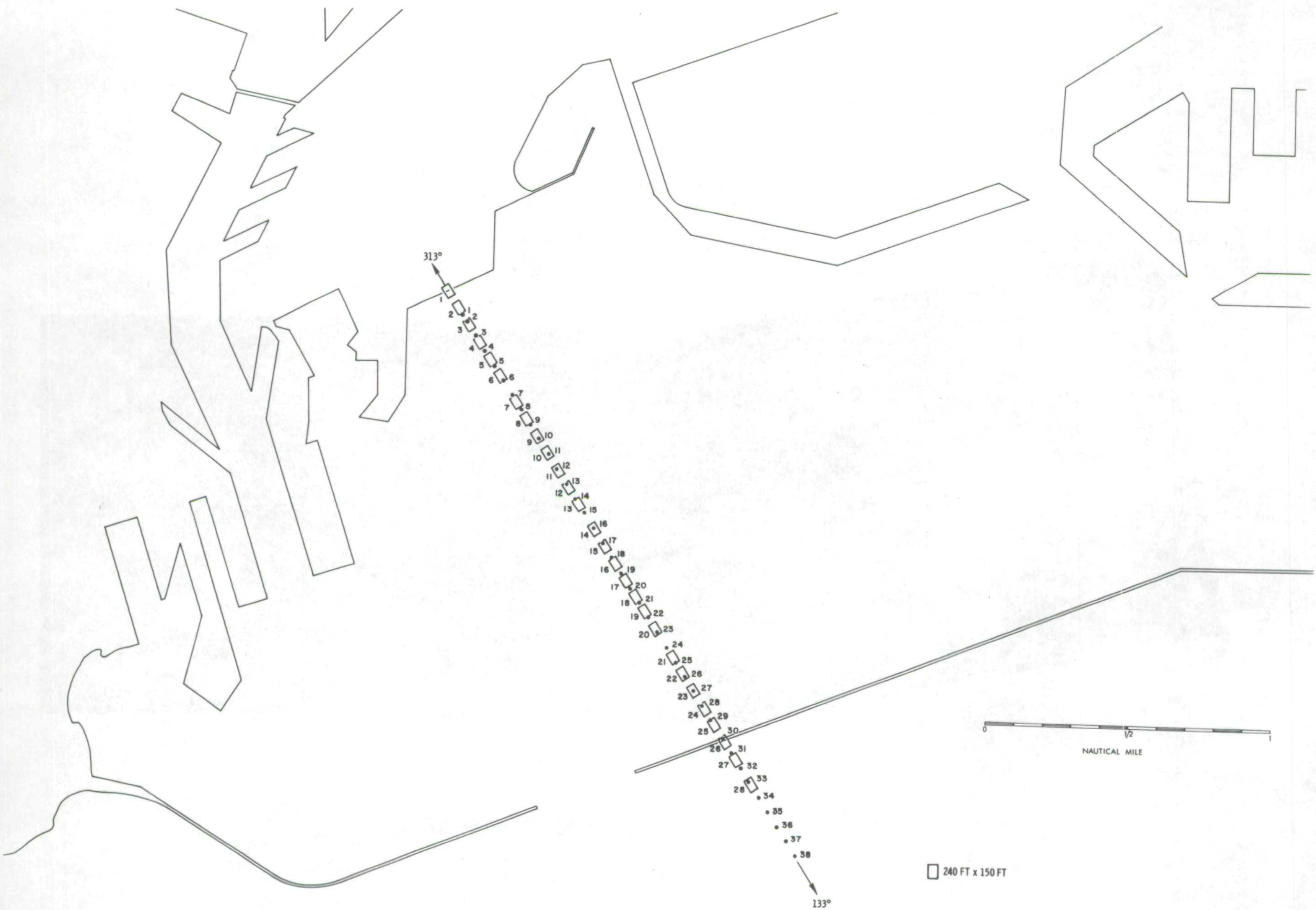

Figure 6 - Map of test area showing measurement locations

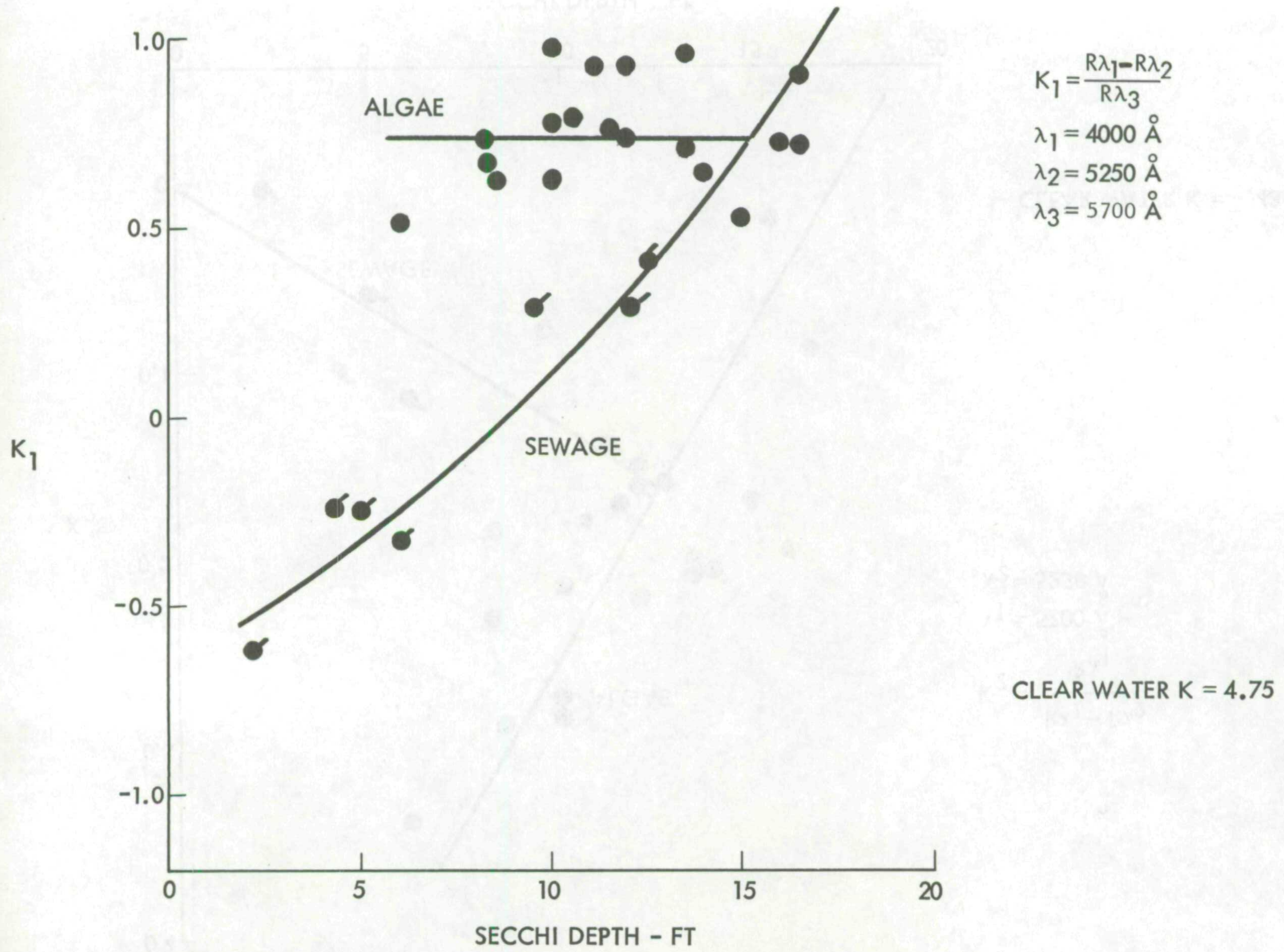

Figure 7 - Parameter K_1 vs. Secchi depth.

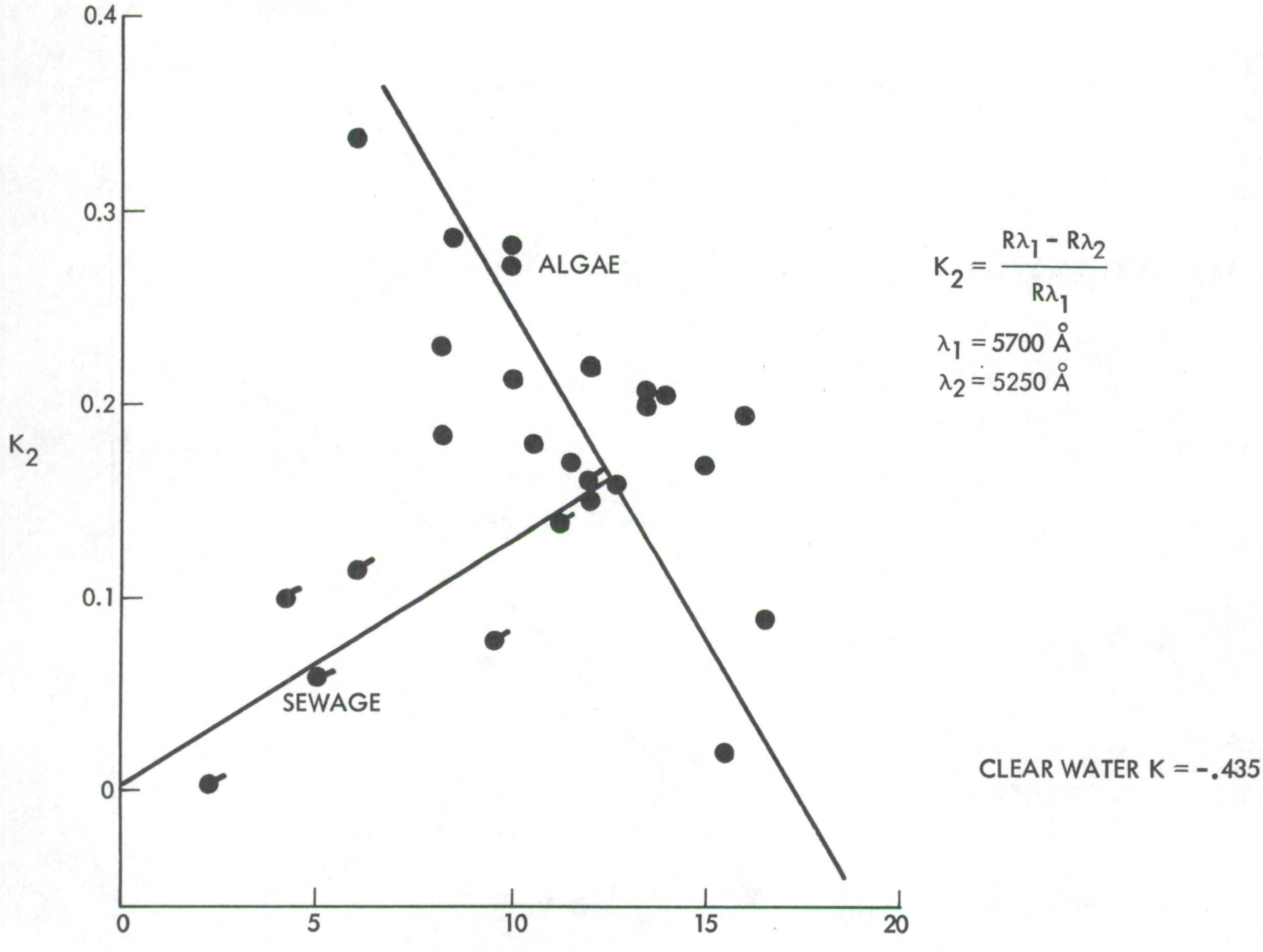

Figure 8 - Parameter K_2 vs. Secchi depth.

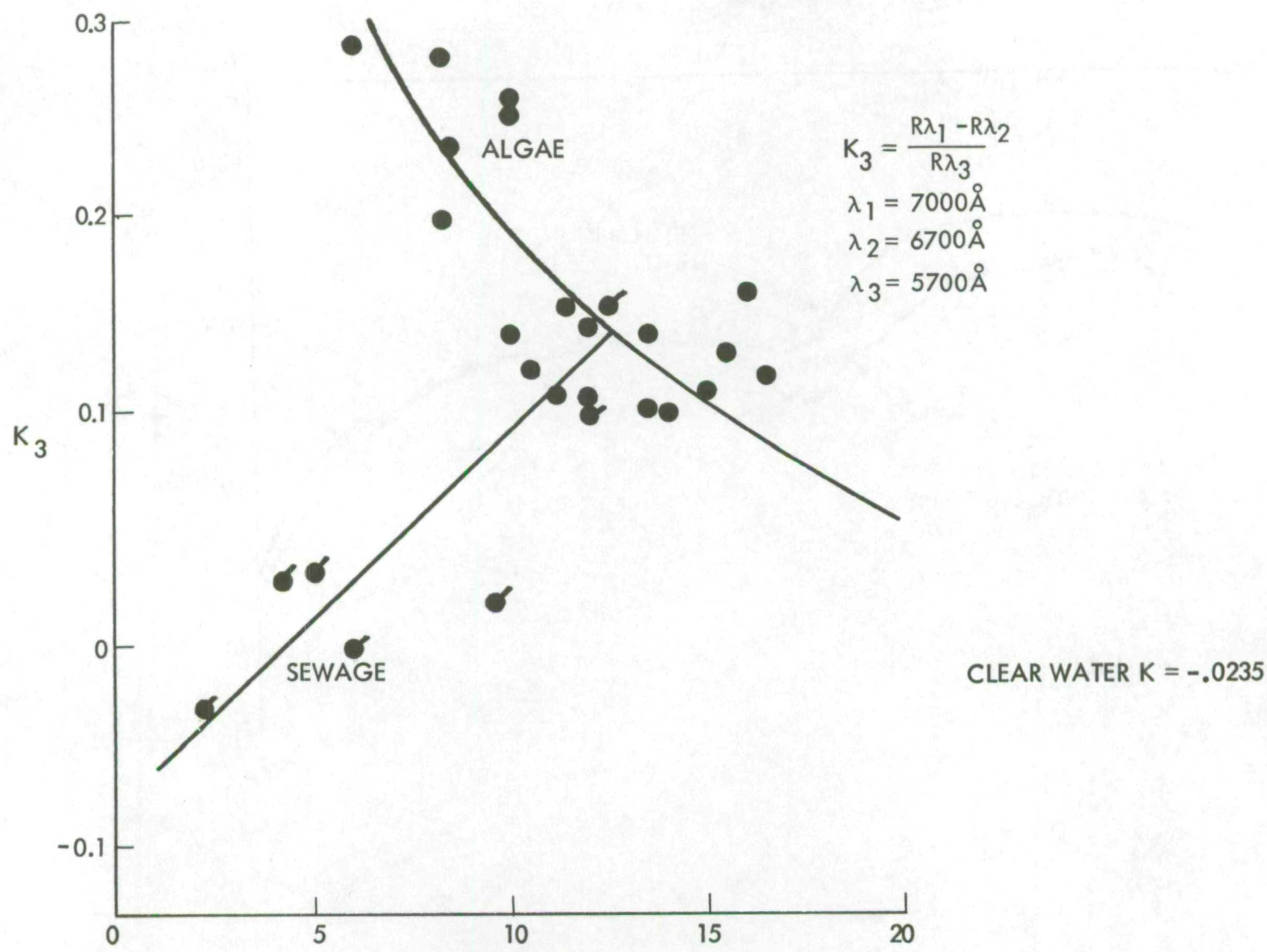

Figure 9 - Parameter K_3 vs. Secchi depth.

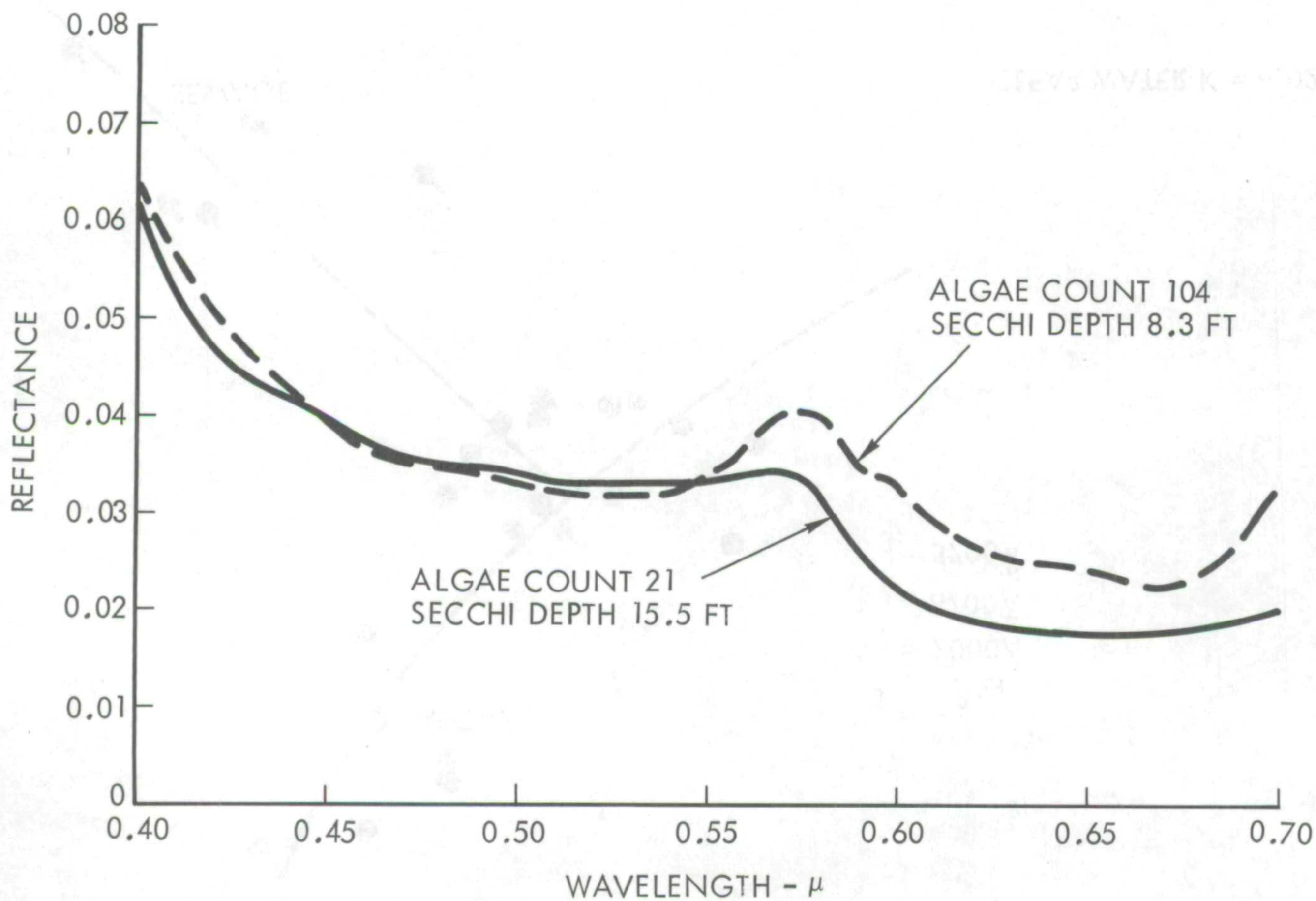

Figure 10 - Spectral reflectance of water containing two concentrations of algae.

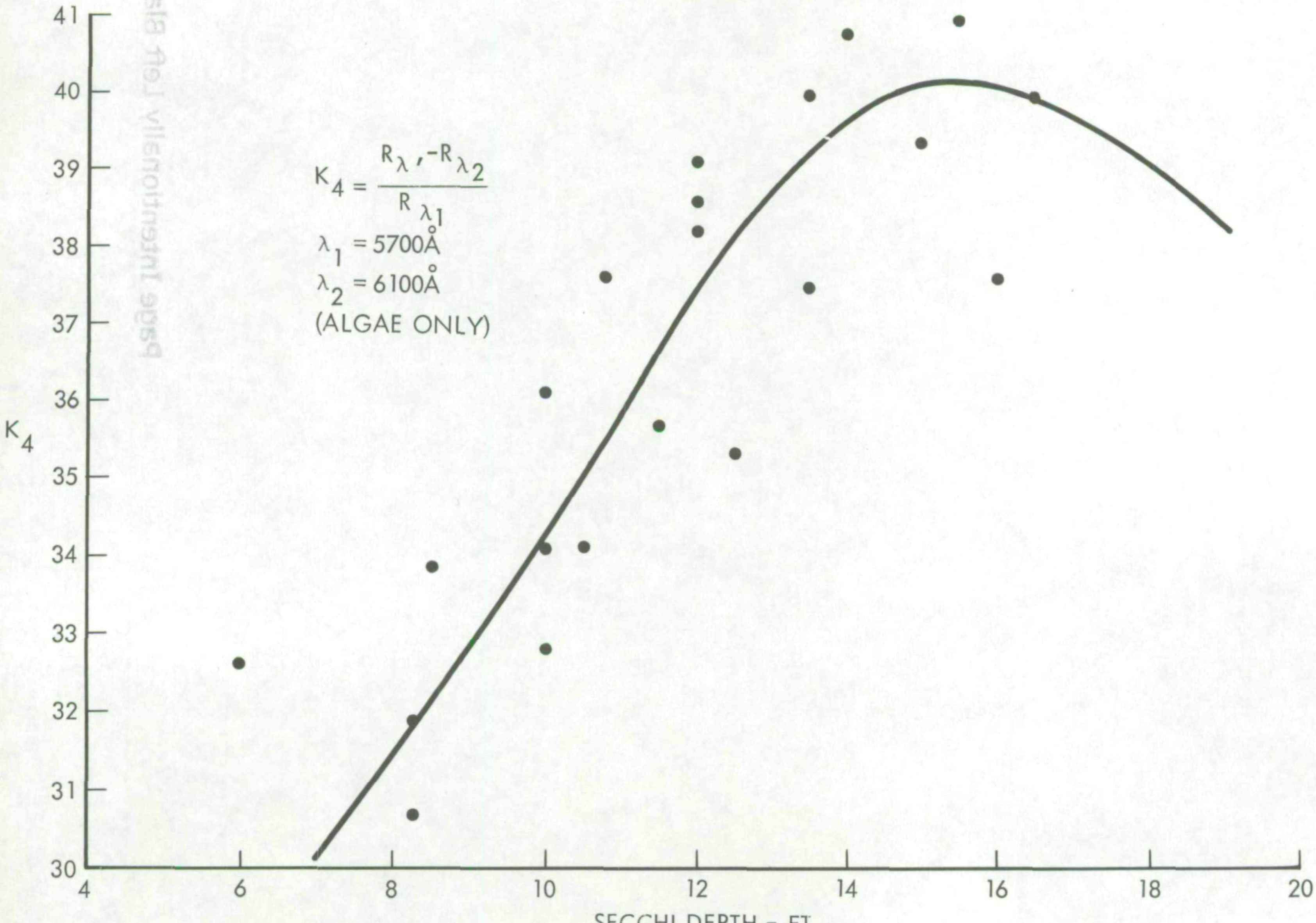

Figure 11 - Parameter K_4 vs. Secchi depth.