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BROADBAND SPECTRAL PHOTOGRAPHY

OF THE JAMES RIVER

BY Walter E. Bressette

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16. Abstract

On May 28, 1974, a photographic mission from 5.3 kilometers altitude was flown over the James River from Norfolk to Hopewell. During the mission 252 photographs were exposed over the river. The photographs are divided into four simultaneously exposed groups with each group exposed through a different broadband optical filter. The four filters isolated blue-green, green, yellow, and near-infrared radiation from the water body. The document summarizes the mission photography in relation to flight altitude, sunglint, and photographic exposure.

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OF THE JAMES RIVER

By

Walter E. Bressette

INTRODUCTION

The NASA Langley Research Center is working with the Environmental Protection Agency, Office of Monitoring, in a joint program to develop the capability to determine synoptic pollution levels and distributions of biodegradable pollutants through the use of a chlorophyll detection system. The objectives of the program are: first, to determine if the spatial and temporal changes of the chlorophyll a produced by the growth of phytoplankton (algae) can be measured remotely; and second, to determine if these measurements can be combined with in situ data to provide an index of the stress on the ecosystem caused by biodegradable pollution (ref. 1). In an early report (ref. 2) from this program, it has been shown that chlorophyll a produced by growth of blue-green phytoplankton can be remotely mapped with a near-infrared detector when the concentration of chlorophyll a is greater than 34 μg/ℓ--a condition commonly referred to as a phytoplankton "bloom." However, as pointed out in reference 1, a "bloom" is a critical biodegradable condition where additional energy input above the "bloom" level becomes a stress, and the system becomes poisoned by "too much of a good thing." Therefore, it is necessary to detect and monitor phytoplankton growth that produces chlorophyll a concentration below 34 μg/ℓ in order to provide remote "prebloom" biodegradable pollution monitoring. In a later report (ref. 3), it was also shown that the backscattered radiance relative to water from blue-green phytoplankton (algae) between the chlorophyll a concentration of 34 and 1000 μg/ℓ depends upon the spectral variation of the ratio of backscattering to absorption of the phytoplankton; shows that the backscattered radiance below the concentration of 34 μg/ℓ is combined in the backscattered radiance from the total suspensoids; and identifies an optical filtering system for separating the backscattered radiance of chlorophyll a from the total backscattered radiance.

On May 28, 1974, a remote sensing mission was flown over the James River from Norfolk to Hopewell, Virginia. The major objective of the photographic portion of the mission was to determine the effectiveness of the optical filtering system proposed in reference 3 for separating the radiance from phytoplankton and suspended solids in a body of water. Other important objectives were proper synoptic view of the river, elimination of sunglint, and suitable photographic exposure.

The purpose of this report is to summarize the impact of operational factors on mission photography in relation to flight altitude, sunglint and photographic exposure.

EXPERIMENTAL AREA

The photographic mission was flown between the hours 09:37 and 11:50 a.m. EDT, from 5.3 kilometers altitude by an NASA, Wallops Flight Center, C-54 aircraft. The flight lines are shown in figure 1. Table 1 shows the duration and time of each flight line. The mission began at Norfolk, flew several flight lines up the river, as shown in figure 1, to Hopewell, and then returned to Norfolk. The weather was clear with high, thin, broken clouds in places. There was a moderate haze. The wind speed at 5.3 kilometers was 60 kts from 320° and the air temperature was -12° C.

EXPERIMENTAL METHOD

The Wallops aircraft contained a bank of four Hasselblad cameras. Pertinent information concerning cameras, film, filters, and exposures is listed in Table 2. The four Hasselblad cameras were equipped with different optical filters. The spectral transmittance (T) of each filter is shown in figure 2, where T, which is the fraction of the total incident light that is transmitted through the filter, is plotted on the vertical scale against the wavelength of incident light in nanometers on the horizontal scale. The two narrow-band optical filters centered at 525 nanometers (blue-green wavelength) and at 554 nanometers (green wavelength) are Baird-atomic filters, type B-3 (ref. 4). The number 12 (yellow) filter, which is a Wratten filter (ref. 5), transmits reflected sunlight under the curve in the blue-green-yellow-orange-red region with the cutoff in the red determined by the response of the film used (Table 2). The number 89B (near-infrared) filter, is also a Wratten filter (ref. 5) that transmits reflected sunlight under the curve in the near-infrared region. Black and white film was used with all four filters.

The bandwidth and location of the filters were selected based on the following:

The narrow-band filter centered at 525 nanometers in figure 2 integrates the radiance around the central wavelength where, as shown in reference 6, the backscattering to absorption characteristics of both chlorophyll a and water are equal. It is also shown (ref. 6) that for wavelengths less than this central wavelength the backscattering to absorption ratio of chlorophyll a is less than the ratio for water. Above the central wavelength the ratio is greater. Thus, it is expected that the radiance integrating narrow-band filter centered at 525 nanometers will not detect radiance variations from chlorophyll a in water. Therefore, it is assumed that it can be used to detect variations in radiance from suspended solids.

It is further shown in reference 6 that the backscattering radiance at 560 nanometers from chlorophyll a concentrations between 1 and 30 μg/ℓ is always greater than the radiance from water. The narrow-band filter with the central wavelength located at 554 nanometers should be close enough to the wavelength of 560 nanometers to be able to detect the changing radiance from varying concentrations of chlorophyll a below the concentration of 30 μg/ℓ. However, as shown in reference 3, the radiance from the chlorophyll a would be combined with the radiance from other suspensoids in the water and must be separated. Therefore, it is surmised that the chlorophyll a radiance below the concentration of 34 μg/ℓ can be obtained by subtraction of the radiance detected through the two narrow-band filters shown in figure 2. Prior to subtracting the detected radiance between the two narrow-band filters, the radiance will require processing for other variables such as uneven incident light, atmospheric backscattering, camera-lens anomalies, and exposure-development difference between the two filter systems.

The 89B near-infrared filter in figure 2 must be flown simultaneously with the two narrow-band filters to determine if the water area under surveillance is phytoplankton "bloomed," because, as shown in reference 3, the two narrow-band filter systems can only be useful for "unbloomed" phytoplankton water. In the "bloomed" water areas the concentrations of chlorophyll a would be determined from the near-infrared system (ref. 2).

The 12 yellow filter in figure 2 has two purposes. It has potential for identifying phytoplankton color groups in phytoplankton "bloomed" water, as it did in reference 3 for blue-green phytoplankton, and the 12 yellow filter along with the 89B near-infrared filter system has a potential for detecting radiance in "nonbloomed" phytoplankton water from large particulates.

Increasing concentrations of large particulates are expected to increase radiance from "nonbloomed" phytoplankton water in the yellow, red, and near-infrared light region, depending upon their location under the surface of the water. This increased radiance from large particulates is shown theoretically in reference 7 and is believed to be seen through the 12 yellow filter in photography over the Potomac River.

RESULTS AND DISCUSSION

Presented in figure 3 are 252 positive prints of photographs that were taken with Hasselblad cameras over the James River from 5.3 kilometer altitudes on May 28, 1974. The negatives of these prints are retained at the Chesapeake Bay Ecological Program Data Center, National Aeronautics and Space Administration, Wallops Flight Center, Wallops Island, Virginia, 23377. The negatives are stored in four separate containers, each container numbered with one of the following numbers: W2760101, W2760102, W2760103, and W2760104. The last number in each of the number series is consistent with the camera system number in Table 2. The photographs are divided into four groups, (a) those taken through the 5250 (blue-green) central wavelength B-3 Baird-Atomic optical filter, (b) those taken through the 5540 (green) central wavelength B-3 Baird-atomic optical filter, (c) those taken through the 12 (yellow) Wratten optical filter and (d) those taken through the 89B (near-infrared) Wratten optical filter.

The four nearly simultaneous pictures through each of the filter systems are further grouped and given a number from 1 to 63. Photographic spectral groups from 1 to 14 and 59 to 63 are from the Norfolk area where, as shown in figure 1, ground test area number 1 was located. Photographic spectral groups 15 to 35, 39 to 42, and 48 to 54, are between Norfolk and Hopewell with spectral groups 22, 23, and 24 from the location of ground test area number 2 (fig. 1). Photographic spectral groups 36 to 38, 43 to 47, and 55 to 58 are from the Hopewell area where ground test area number 3 was located (fig. 1).

Mission altitude.- The altitude of the mission was determined by operating requirements of the Multi-Color Ocean Scanner, a remote sensing instrument also flown in the aircraft. Normally, the best altitude would be one in which approximately 90 percent of each picture is over the water area. A small percentage of shoreline is required in every picture for referencing the photographs between filter systems and for location of radiances from ground truth data areas.

For most tidal rivers, such as the James, where the lower reach is much wider than the upper reach, two flight altitudes would be required. A high altitude being more favorable for the lower reach as can be seen in spectral groups 15 to 21 of figure 3. The same altitude, however, is not so favorable in the upper reach near Hopewell as can be seen in spectral groups 43 to 47. In these spectral groups, the water area is less than 50 percent of the photographs and in most cases the water data will require extensive off-axis corrections.

Mission Time.- To minimize sunglint into the 40 mm wide-angle lens flown (72°) on this mission, while at the same time maintaining enough light for exposure of the photographic film, it was necessary to fly between the hours of 8:00 and 10:00 a.m. or 2:00 and 4:00 p.m. EDT. The 8:00 a.m. and 4:00 p.m. EDT limits were dictated by the minimum altitude of the sun for illumination of the photographic film on May 28, 1974, and the 10:00 a.m. and 2:00 p.m. EDT limits were dictated by the maximum altitude of the sun in order to restrict the reflectance of the sun off the water surface to less than 25 percent of the photographs.

It is difficult to eliminate sunglint because the image of the sun reflected off the water is large in area and will become more extensive from increased water surface roughness caused by wind (ref. 8). Therefore, it is more practical to fly at a time when the expected sunglint would be contained in less than 25 percent of the photographs and program the photography for 50 percent overlap--thus assuring complete photographic coverage without sunglint.

The photographic mission on May 28, 1974, over the James was flown between the time of 09:37 and 11:50 a.m. EDT, thus bracketing the 10:00 a.m. EDT limiting time for less than 25 percent sunglint in the photograph. The surface wind conditions during the mission were also severe, being reported as 20 knots over the lower reach.

The photographs through the 89B near-infrared Wratten optical filter over deep water are the best photographs for detecting sunglint because the sunglint which reflects off the surface of the water shows very high contrast relative to the highly absorbed radiance from thewater body at these wavelengths. A good example of this is photograph 13(d) in figure 3, taken before 10:00 a.m. EDT, where the sunglint is confined to the upper right quadrant. However, the sunglint appears along the upper border to be near the center point on that border. Nevertheless, 50 percent overlapping photography before 10:00 a.m. EDT assures complete water coverage without sunglint. This might not be the case after 10:00 a.m. EDT as shown by photograph 59(d) of essentially the same water area taken at 11:50 a.m. EDT. In 59(d) the sunglint is over two-thirds of the photograph and would require 75 percent overlapping photography to assure complete water coverage without sunglint.

Exposure-Development.- It is shown in reference 2 that the detection and mapping of phytoplankton "blooms" can be accomplished remotely with photography by using an optical filter that passes only near-infrared radiation. It is also shown, because of the strong absorption of light by water at the near-infrared wavelength, that the photographic exposure and positive development time must be greater than is required for aerial surveillance of land features in the near-infrared. Thus, it is shown in table 2 that the f-number for the near-infrared camera system, number 4 in table 2, is 5.6. This f-number is two stops greater than the typical f-number recommended by the Eastman Kodak Company in reference 9 for near-infrared aerial photography.

The selection of an f-number two stops greater than for normal near-infrared aerial photography for this mission was somewhat arbitrary since in reference 2 it was shown that the threshold for detecting phytoplankton "blooms" was obtained with the camera only one stop greater. However, it is important to determine if the threshold for detecting phytoplankton "blooms" would occur at a lower phytoplankton concentration than obtained in reference 2. Therefore, the increased f-number would establish for subsequent missions whether or not the concentration threshold for detecting phytoplankton "blooms" as established in reference 2 was camera-film sensitivity limited or due to the phytoplankton light absorption characteristics in water.

Observation of the near-infrared photographs in figure 3 (d) shows a great deal of radiance coming from the water areas. Much of the radiance is reflected sunlight off the water surface because of the time of day the mission was flown. However, due to the 50 percent overlapping photographs, there is a great deal of area over the length of the river flown that can be analyzed for radiance from phytoplankton "blooms," river bottom, or suspended solids. At present, the river bottom is highly suspected since observation of marine maps shows the bottom as only one to two feet deep in areas where the radiance is high.

In reference 3, it is shown that the number 12 (yellow) Wratten filter could detect the absorption pigment of blue-green algae in phytoplankton "bloomed" water. For that photographic mission, the f-number and speed of the camera was the same as shown in table 2. The exposure numbers shown in table 2 are recommended for standard aerial photography by Eastman Kodak Company in reference 9. Observation of the photographs taken through the number 12 (yellow) Wratten optical filter in figure 3(c) appears satisfactory for further data analyses in water areas not affected by sunglint.

The bright areas in the center of all the photographs through these B-3 Baird-atomic optical filters in figure 3 (a) and (b) are not caused by sunglint. While sunglint can enhance the bright areas, as seen by comparing photographs 13(a) and 13(b) with 59(a) and 59(b), the bright center areas are the result of over-exposure and development of the center portion of the photographs.

It is shown (ref. 10) from densitometer traces over photographs exposed from 3 kilometers altitude through two of the Hasselblad cameras used in this photographic mission that the center of photographs are exposed to a higher degree than the edge. This effect is normal in photography and is caused by camera-lens, off-axis, falloff which in some camera systems can be as high as $\cos^{12}\theta$ where θ is the angle off the principle axis of the lens (ref. 11). The off-axis falloff in photography is not normally noticed by the human eye when the resultant maximum and minimum exposures are on the linear portion of the characteristic curve of a photographic emulsion and remains so during subsequent development.

Evidently, the f-4 number for the two narrow-band filters in this mission (table 2) resulted in the center portion of the photographs being exposed to a value greater than the upper limit of the linear portion of the characteristic curve for the emulsion during development. The center portion of the negative is very dark and appears very bright in the positive transparencies and prints from the negatives as seen in figure 3 (a) and (b).

When the overexposed center portion of each photograph is above the linear portion of the characteristic curve, that portion of each photograph cannot be used for quantitative remote sensing measurements. Therefore, in future missions an f-number of 5.6 is recommended for the two narrow-band B-3 Baird atomic optical filter systems.

CONCLUDING REMARKS

In general, the May 28, 1974, photographic mission from 5.3 kilometers altitude, over the James River from Norfolk to Hopewell, can be considered successful from the mission preplanning standpoint, although final analysis of the radiance in the photographs versus the ground truth data is yet to be accomplished.

Results to date are as follows:

1. The mission altitude was very satisfactory for the lower reach, Hampton Roads area, with approximately 90 percent of each photograph over water.

2. The mission altitude was too high for the upper reach, Hopewell area, where only approximately 50 percent of each photograph contained water.

3. Many photographs of the ground truth data test areas were obtained, some of which are reasonably close to the times ground truth data were taken.

4. There is a great deal of sunglint in the photographs since the mission was flown prior to and after the sunglint cut-off time. However, the 50 percent overlapping pictures resulted in sunglint free radiance information for nearly the complete river area overflown.

5. The 89B Wratten optical-filter camera system detected heavy radiance in many water areas. At the present time, it isn't known whether the radiance is from phytoplankton "bloom," large particulates, or from the bottom of the river. In many places the bottom is the chief suspect since the marine maps show the bottom as one to two feet deep.

6. The f-4 number for the two B-3 Baird-Atomic optic-filter camera systems resulted in over-exposure of the center portion of each photograph. The negatives are black in the center portion, and the corresponding positives white. It is recommended that an f-5.6 number be used in all subsequent photographic missions with these filter systems.

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Table 1.- Duration and Time of Each Flight Line

Flight Line	Time EDT
1	0937 - 0940
2/1	0945 - 0948
3	0955 - 1008
4	1011 - 1018
5	1024 - 1030
6/1	1035 - 1036
7/1	1040 - 1042
8	1049 - 1053
9	1056 - 1100
6/2	1113 - 1114
7/2	1119 - 1120
10	1126 - 1130
2/2	1147 - 1150

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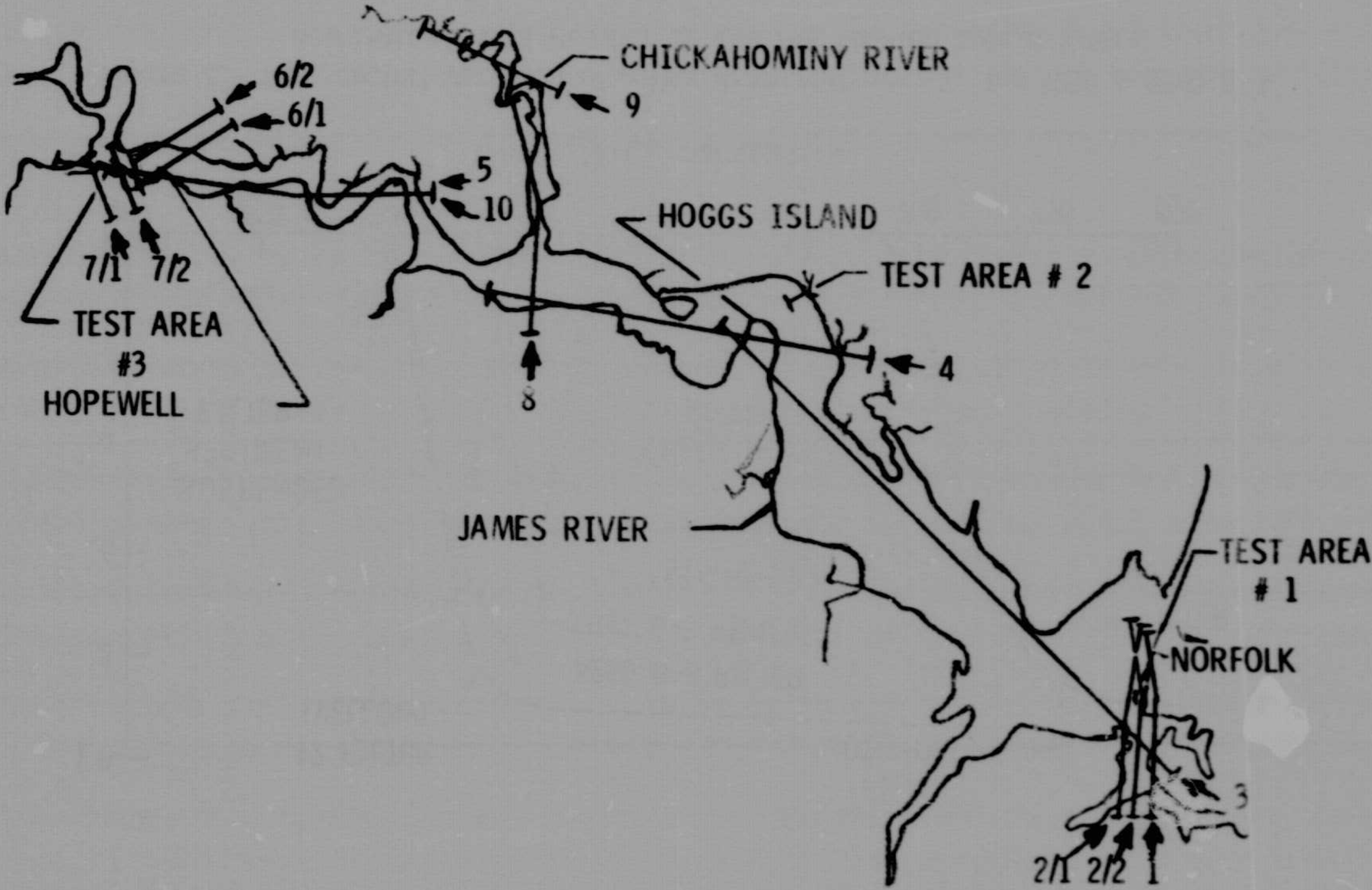
Table 2.- Sensor Complement and Camera Settings

Camera	Focal Length (mm)	Filter	Film Format (mm)	Film Type[3]	Speed (Sec)	F Number
1. Hasselblad	40	5540 (green)[1]	70	2402 Black & White	1/250	4
2. Hasselblad	40	5250 (blue green)[1]	70	2402 Black & White	1/250	4
3. Hasselblad	40	12 (yellow)[2]	70	2402 Black & White	1/250	11
4. Hasselblad	40	89B (NIR)[2]	70	2424 Black & White	1/250	5.6

1. Baird-atomic B-3 optical filter with central wavelength of 5540 and 5250 anstroms
2. Kodak Wratten optical filter number
3. Kodak film number


CHICKAHOMINY RIVER
9
6/2
6/1
5
10
7/1
7/2
TEST AREA
#3
HOPEWELL
HOGGS ISLAND
TEST AREA # 2
4
8
JAMES RIVER
TEST AREA
1
NORFOLK
3
2/1
2/2
1

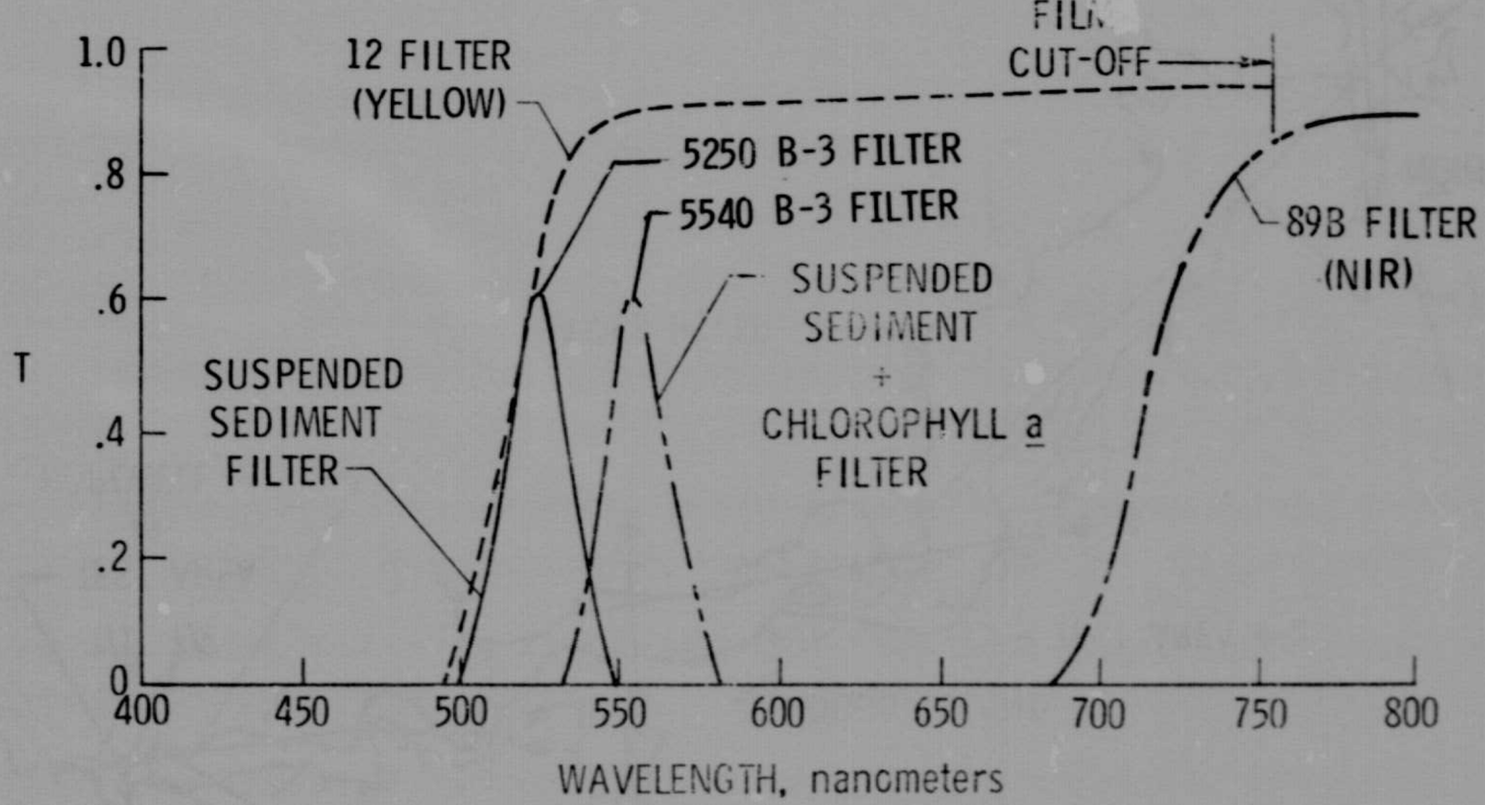
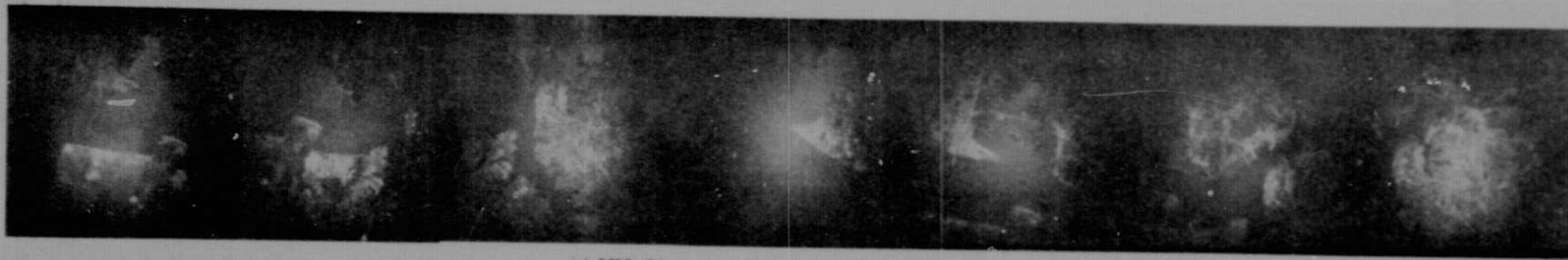
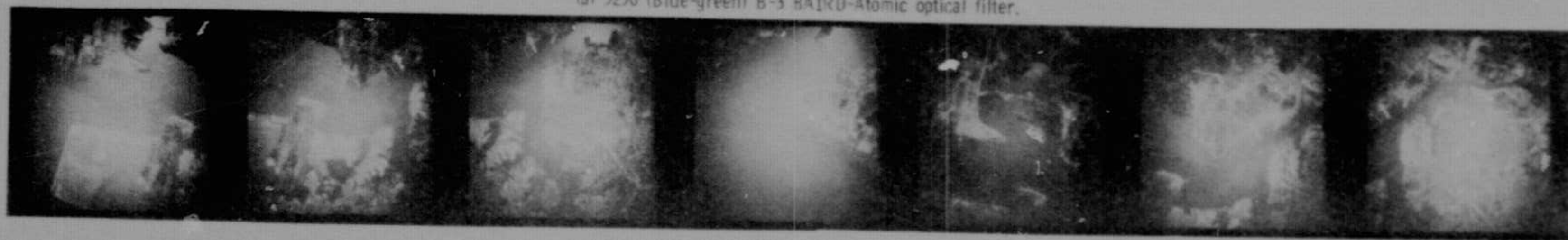


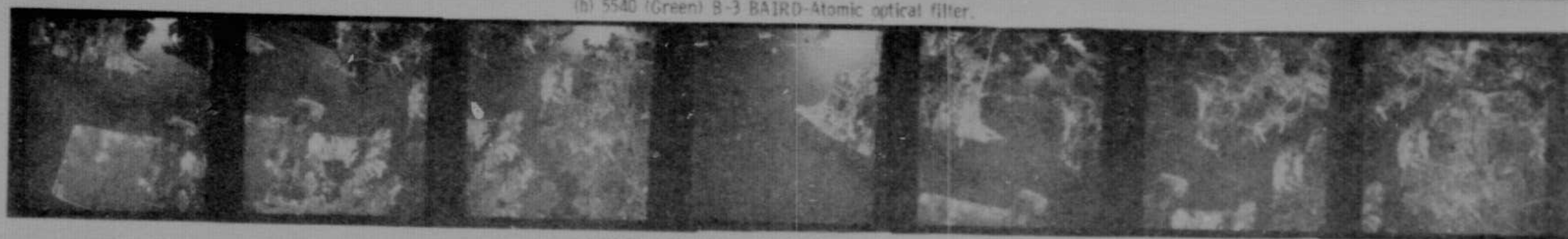
Figure 2. - The spectral variation of optical transmittance, T, for 5250 & 5540 B-3 Baird-Atomic and number 12 and 89B Wratten optical filters.



(a) 5250 (Blue-green) B-3 BAIRD-Atomic optical filter.



(b) 5540 (Green) B-3 BAIRD-Atomic optical filter.



(c) (Yellow) Wratten optical filter.

1 2 3 4 5 6 7

(d) 89B (near-infrared) Wratten optical filter.

Figure 3. - Photographs of the James River from 5.3 kilometers altitude on May 28, 1974. In photographs 1 to 3 is the Norfolk Harbor Reach from Sewells Point to Lamberts Point. In photograph 4 is Hampton Roads and in photographs 5 to 7 is the Norfolk Harbor Reach from Craney Island Disposal Area to the Elizabeth River. The time of the photographs was between 0937 and 0946 Eastern daylight time.

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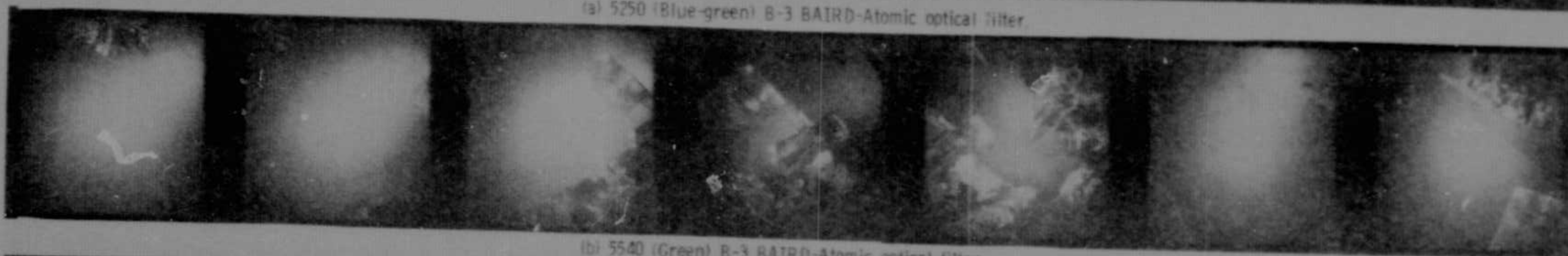
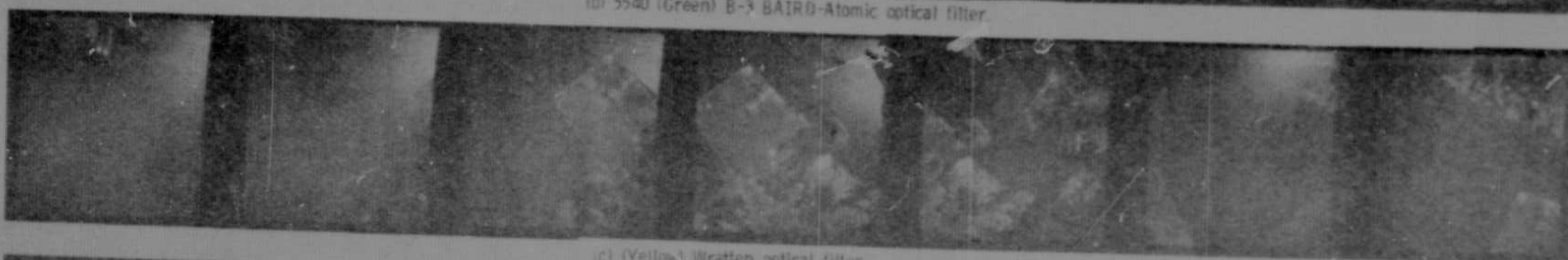
(a) 5250 (Blue-green) B-3 BAIRD-Atomic optical filter.



(b) 5540 (Green) B-3 BAIRD-Atomic optical filter.

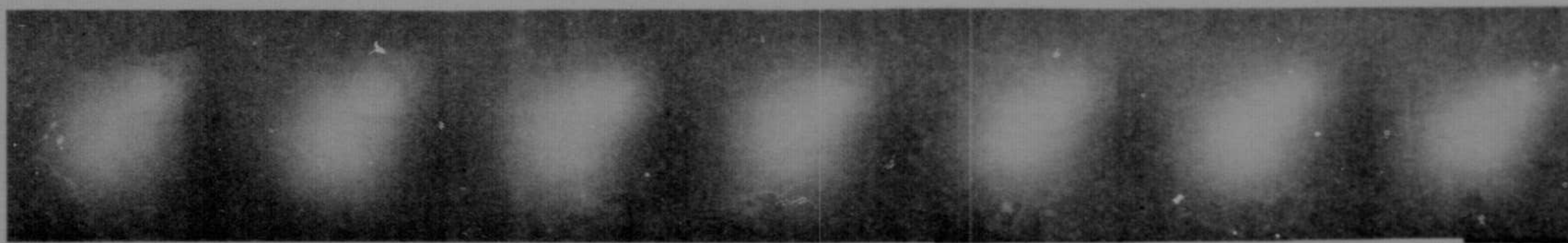


(c) (Yellow) Wratten optical filter.

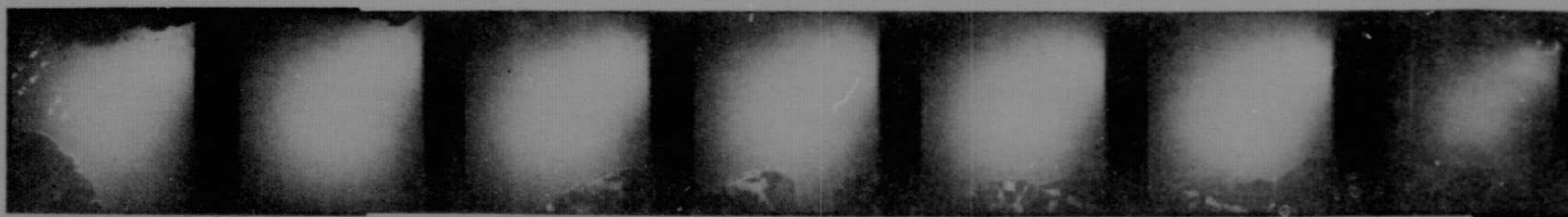
8 9 10 11 12 13 14

(d) 898 (near-infrared) Wratten optical filter.

Figure 3. -Continued. Photographs of the James River from 5.3 kilometers altitude on May 28, 1974. In photographs 8 to 12 is Hampton Roads from Newport News Point to Lamberts Point and in photographs 13 to 14 is Hampton Roads from Hampton Flats to Craney Island Disposal Area. The time of the photographs was between 0947 and 0958 Eastern daylight saving time.



(a) 5250 (Blue-green) B-3 BAIRD-Atomic optical filter.



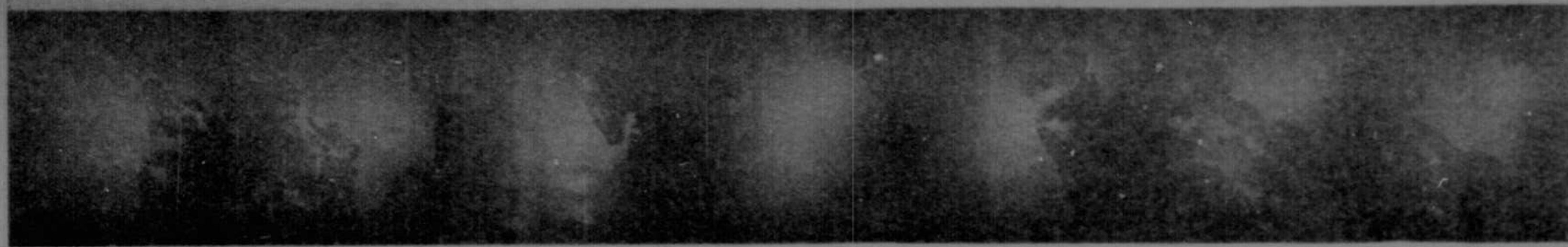
(b) 5540 (Green) B-3 BAIRD-Atomic optical filter.

(c) 12 (Yellow) Wratten optical filter.

15 16 17 18 19 20 21

(d) 89B (near-infrared) Wratten optical filter.

Figure 3. -Continued. - Photographs of the James River from 5.3 kilometers altitude on May 28, 1974. In photographs 15 to 21 is the lower James from Mulberry Point to Newport News. The time of the photographs was between 0958 and 10:04 Eastern daylight saving time.



(a) 5250 (Blue-green) B-3 BAIRD-Atomic optical filter.

(b) 5540 (Green) B-3 BAIRD-Atomic optical filter.

(c) 12 (Yellow) Wratten optical filter.

(d) 89B (near-infrared) Wratten optical filter.

Figure 3 continued. - Photographs of the James River from 5.3 kilometers altitude on May 28, 1974. In photographs 22 to 24 is the Hoggs Island area from Jamestown Island to Fort Eustis, and in photographs 25 to 28 the Hoggs Island area from Jamestown Island to Mulberry Point. The time of the photographs was between 10.05 and 10.13 Eastern daylight saving time.

(a) 5250 (Blue-green) B-3 BAIRD-Atomic optical filter.

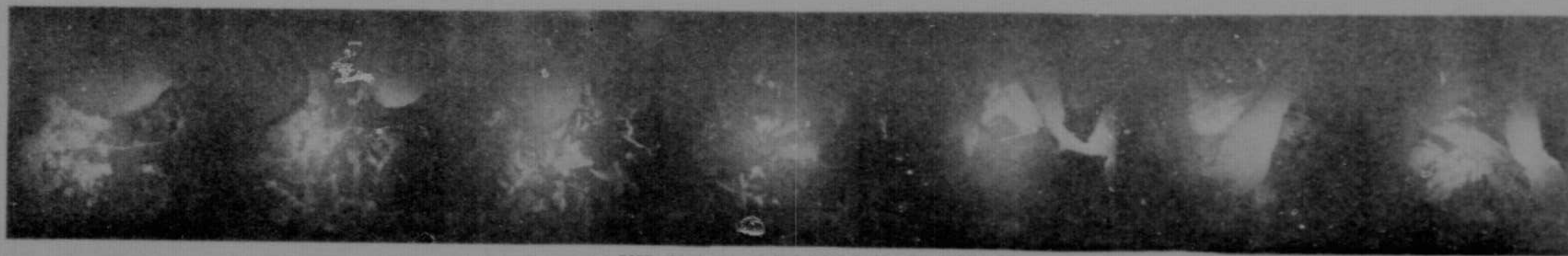
(b) 5540 (Green) B-3 BAIRD-Atomic optical filter.

(c) 12 (Yellow) Wratten optical filter.

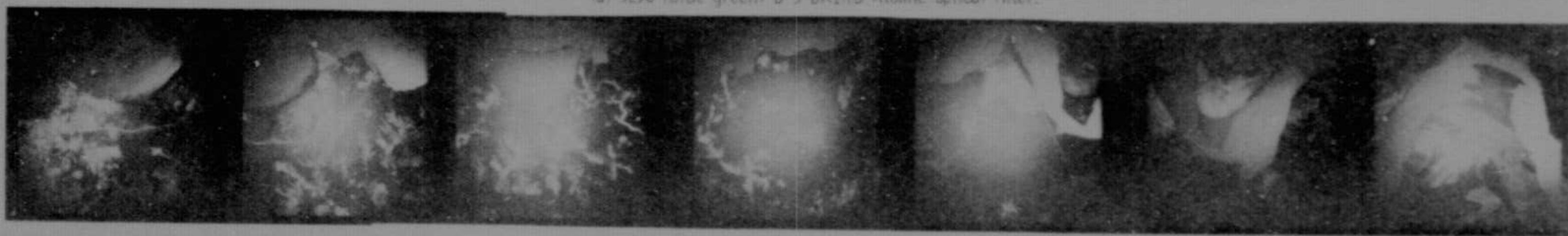
29 30 31 32 33 34 35

(d) 89B (near-infrared) Wratten optical filter.

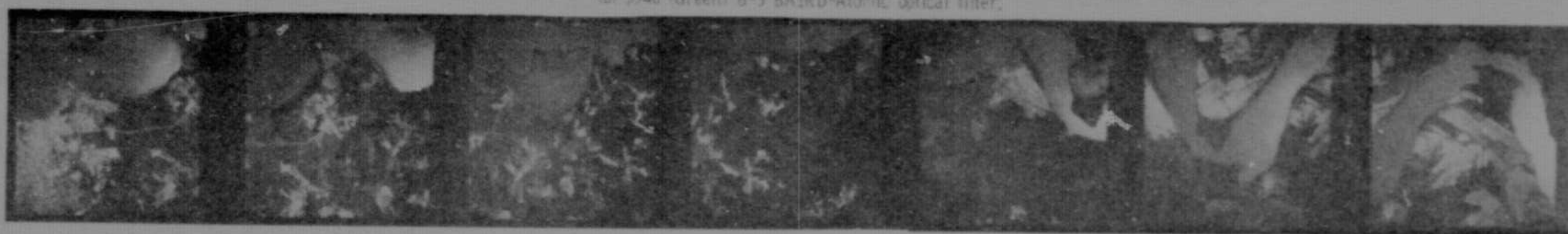
Figure 3 continued. - Photographs of the James River from 5.3 kilometers altitude on May 28, 1974. In photographs 29 to 35 is shown the river from Kerron Marsh to Jamestown Island. The time of the photographs was between 10:13 and 10:24 Eastern daylight saving time.



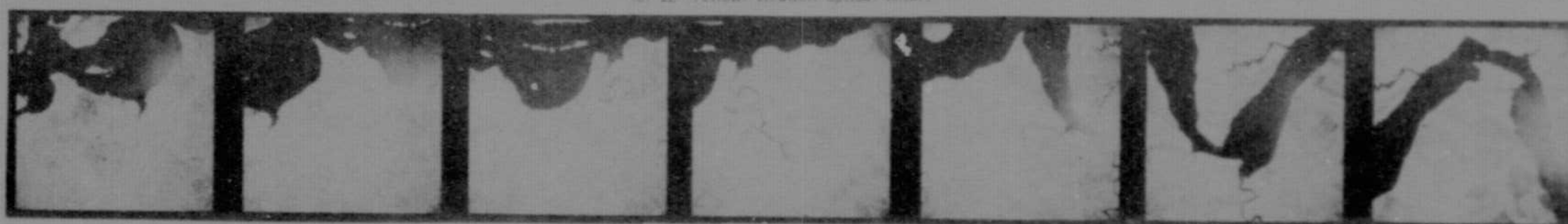
(a) 5250 (Blue-green) B-3 BAIRD-Atomic optical filter.



(b) 5540 (Green) B-3 BAIRD-Atomic optical filter.



(c) 12 (Yellow) Wratten optical filter.



36 37 38 39 40 41 42

(d) 89B (near-infrared) Wratten optical filter.

Figure 3 continued. - Photographs of the James River from 5.3 kilometers altitude on May 28, 1974. In photographs 36 to 42 is shown the river from City Point (Hopewell) to Kerron Marsh. The time of the photographs is between 10:25 and 10:30 Eastern daylight saving time.

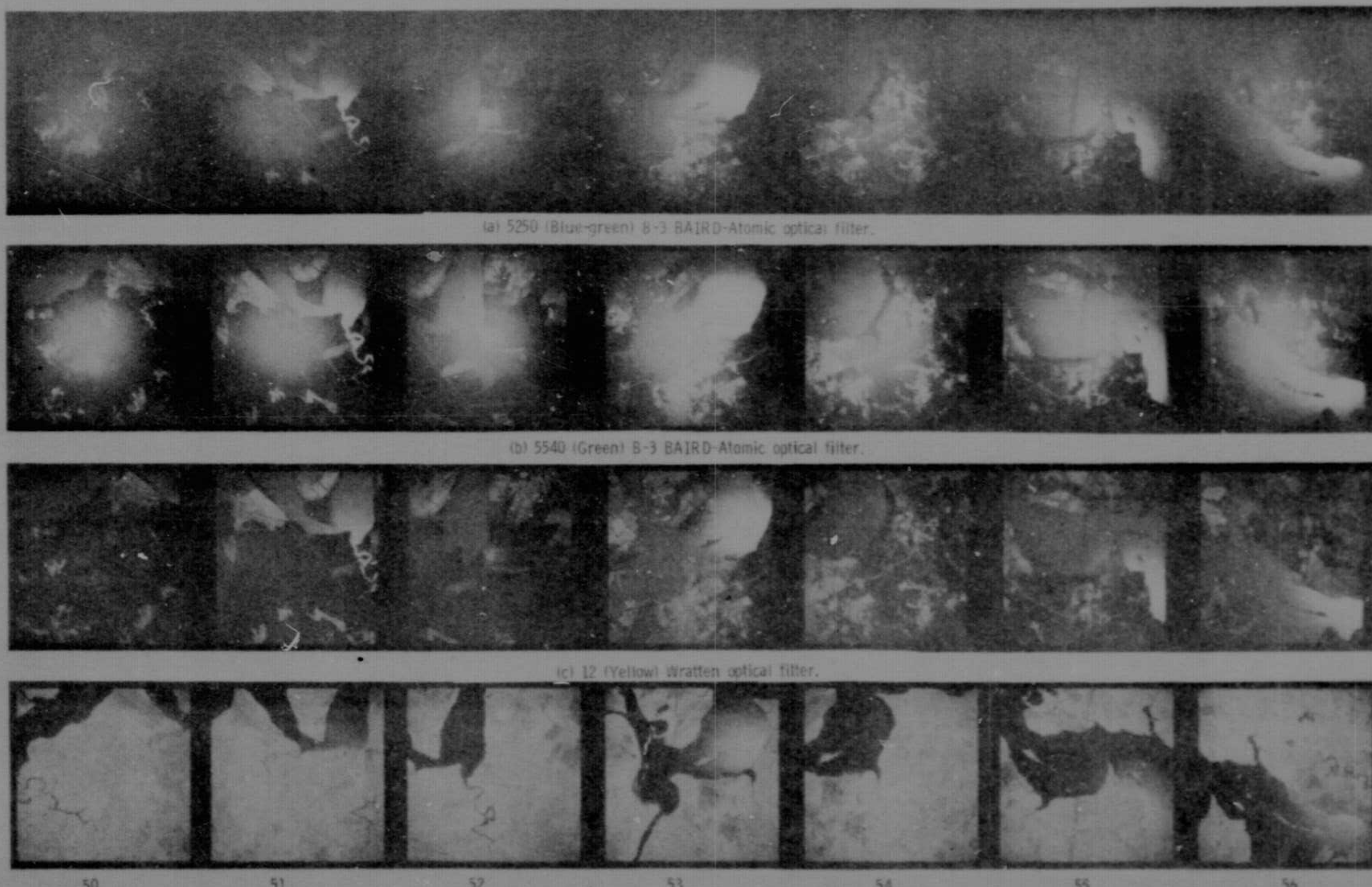
(a) 5250 (Blue-green) B-3 BAIRD-Atomic optical filter.

(b) 5540 (Green) B-3 BAIRD-Atomic optical filter.

(c) 12 (Yellow) Wratten optical filter.

(d) 89B (near-infrared) Wratten optical filter.

Figure 3 continued. - Photographs of the James River from 5.3 kilometers altitude on May 28, 1974. In photographs 43 to 46 is shown the Hopewell area from City Point to Maycock Point. In photograph 47 is shown City Point again and in 48 and 49 is shown the James at the mouth of the Chickahominy River. The time of the photographs is between 1035 and 1050 Eastern daylight saving time.



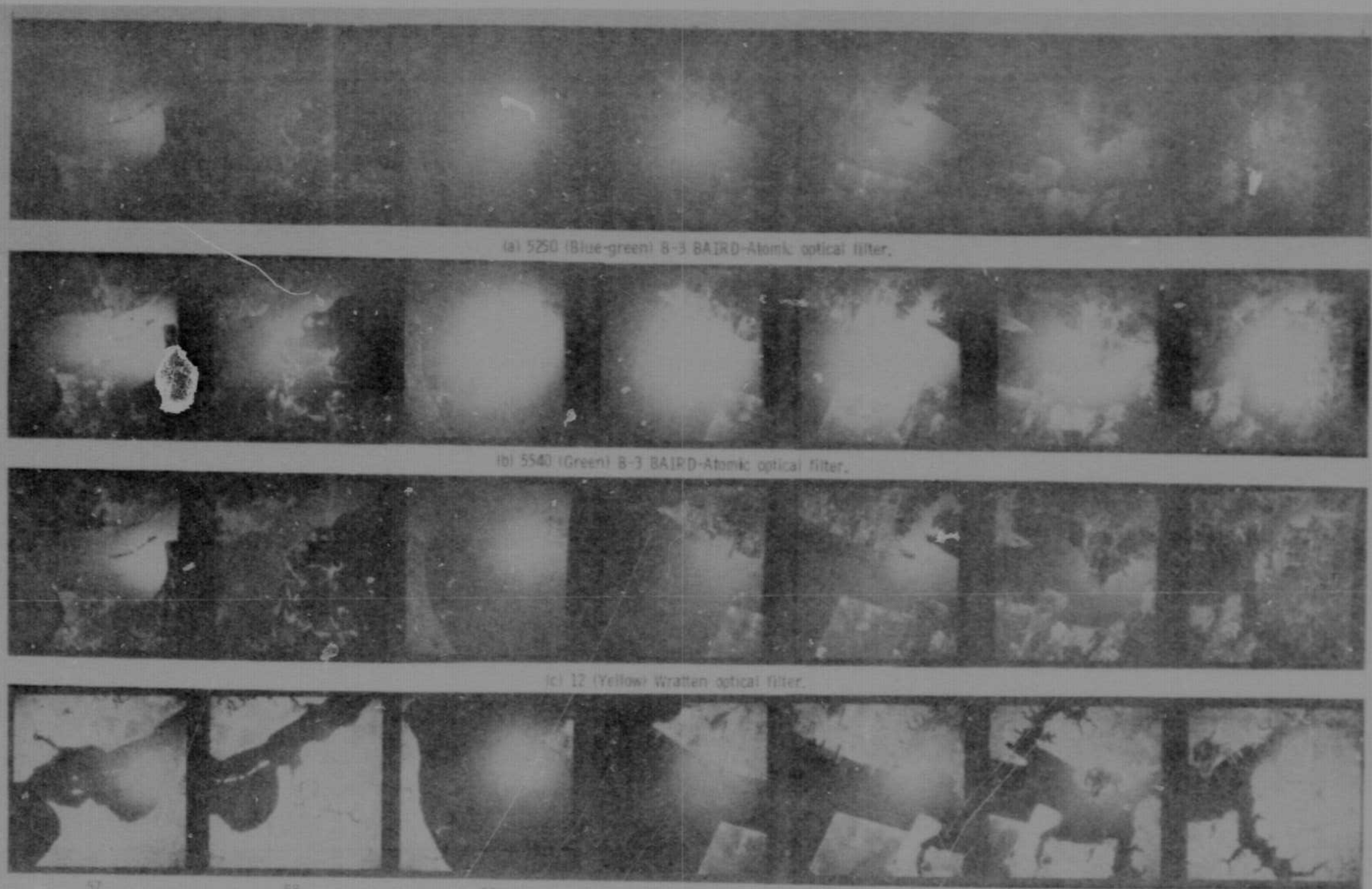
(a) 5250 (Blue-green) B-3 BAIRD-Atomic optical filter.

(b) 5540 (Green) B-3 BAIRD-Atomic optical filter.

(c) 12 (Yellow) Wratten optical filter.

(d) 89B (near-infrared) Wratten optical filter.

Figure 3 continued. - Photographs of the James River from 5.3 kilometers altitude on May 28, 1974. In photographs 50 to 52 is shown the river from Maycocks Point to Ward Creek and in photographs 53 to 56 is the Hopewell area from City Point to Maycocks Point. The time of the photographs is between 11:13 and 11:28 Eastern daylight saving time.



(a) 5250 (Blue-green) B-3 BAIRD-Atomic optical filter.

(b) 5540 (Green) B-3 BAIRD-Atomic optical filter.

(c) 12 (Yellow) Wratten optical filter.

57 58 59 60 61 62 63

(d) 89B (near-infrared) Wratten optical filter.

Figure 3 concluded. - Photographs of the James River from 5.3 kilometers altitude on May 28, 1974. In photographs 57 and 58 is the Hopewell area from Jordan Point to Herring Creek

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