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AERIAL PHOTOGRAPHIC-INTERPRETATION TECHNIQUES FOR WATER-QUALITY ANALYSIS

by

[redacted] 25X1

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ABSTRACT

Aerial photographic interpreters are in a unique position to act as "water pollution detectives." As a professional group, we probably study more land area than do members of any other profession.

While there are literally thousands of different kinds of water pollutants, they can be grouped into a restricted number of categories based on type of source, nature of pollutant, ecological effect on the receiving water, damage which is done, or change in the appearance of the receiving water itself.

This paper sets forth two existing partially-overlapping pollutant classification systems, defines some of the terminology which is used in water quality analysis, outlines and illustrates some of the "signatures" of different types of pollutants, and spells out some of the basic "ground truths."

TABLE OF CONTENTS

LIST OF FIGURES

17.- Red appearance of algae, imaged in "false" color infrared film.

18.- Urban land-drainage wastes polluting lake in Western Minnesota.

19.- Mass of dead fish resulting from hugh fish kill in Potomac River, summer 1963.

20.- Dense mass of algae choking surface of Clear Lake, Lake County, California.

25X1 21.- [redacted] nine-lens multiband panel illustrating appearance of pond in different portions of the spectrum.

22.- Subsurface rooted vegetation imaged in reddish tones as shown in "false" color infrared film using Kodak Wratten 2A filter.

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AERIAL PHOTOGRAPHIC-INTERPRETATION TECHNIQUES FOR WATER-QUALITY ANALYSES

1. INTRODUCTION

Water pollution is America's shame. Figure 1 shows one of the hundreds of noxious outfalls which discharge~~s~~ into ~~an~~ American stream$. Some rivers are so seriously polluted that they are totally unfit for many legitimate uses. The consequences of water pollution include:[1]

(1) Disease transmission through infection.
(2) Poisoning of man and animals.
(3) Detrimental effects on aquatic life.
(4) Creation of objectionable odors or unsightliness.
(5) Cause of unsatisfactory quality of treated water.
(6) Impairment of shellfish culture (disease transmission).
(7) Excess mineralization.
(8) Destruction of aesthetic values.

As an example of a seriously polluted river, the Anacostia, not far from here, occasionally goes septic. This occurs because raw sewage is occasionally bypassed from the Washington Suburban Sanitary Commission's sewer lines, and discharged raw into the Anacostia, rather than being routed into the District of Columbia's Blue Plains Sewage Treatment Plant.

A few years ago, New York City was described as being "an island entirely surrounded by sewage."[2] Fortunately, some of this mess has been cleaned up.

Many of these problems exist because of lack of general public awareness of conditions - and in many instances, because the sources of pollution are unknown, or because the consequences of pollution are not appreciated by those whom we elect or appoint to take care of such things.

I suggest that we, as specialists in the field of aerial reconnaissance, can perform a potentially life-saving service, and that the lives we save may be our own. In our profession, we probably study more land area than any other professional group. I suggest that we extend our studies so that they include detecting and reporting potentially dangerous water pollution conditions which may exist along streams in areas which we may be studying for other purposes. I suggest, then, that we act as "water pollution detectives."

Aerial photographic-interpretation techniques can serve a valuable role in helping to protect our national water resources. A vast amount of aquatic ecological information can be imaged photographically. Perhaps in no other way can large water areas be examined, and the interactions which occur in them be studied as thoroughly.

Aerial photographic-interpretation techniques add to, but do not replace, existing field and laboratory analysis methods. Laboratory methods, which depend on the use of test tubes, water sample bottles and microscopes, are made even more valuable. Critical areas which require field work can be located more rapidly. Both time and money can be saved by reducing field work, leaving more time and money for confirming laboratory analyses, and more important, more for taking corrective action.

If aerial photographic-interpretation techniques are to be used effectively for water quality analyses, it is wise first to review the terminology which is used to define certain water-quality conditions, and review the extent and causes of some of the more serious water-quality problems which exist in the United States. Water-quality analyses depend upon recognition of amorphous images. Minor tone differences may indicate significant differences in water quality. Both the capabilities and the shortcomings of photographic methods of collecting water-quality data, which in turn requires a review of the selective spectral-energy absorbtion and transmission regions of water, should be reviewed.

Last, we have to know to whom water-pollution observations should be reported so that effective remedial action can be taken.

The term "water quality" refers to the physical, chemical, and biological characteristics of water. The physical characteristics of water include temperature, density, viscosity, color, clarity, and similar data. Chemical water-quality characteristics include the presence and amount (if present) of organic and inorganic substances in solution, and the way that these substances are bonded or dispersed within the molecular structure of water. Biological water-quality characteristics include the types and numbers of organisms which are present.

Physical, chemical, and biological characteristics interact. Even slight changes in one characteristic may induce a chain reaction of synergistic or antagonistic responses which will alter water quality. An example is the chain of reactions which take place when the temperature of water is raised.

Biological activity is accelerated, which in turn speeds up removal of dissolved oxygen, nutrient chemicals, and other substances which are required for aerobic life processes. If biological processes continue until the dissolved oxygen is exhausted, aerobic organisms may be replaced by anaerobic types. Organisms in bottom mud may stimulate thermogenesis, adding more heat to the water.

"Water pollution" and "contamination" have rather restricted water-quality definitions. Water pollution is defined as the "adding to water of any substance, or the changing of water's physical characteristics in any way which interferes with its use for any legitimate purpose."[3] "Contamination" has a more serious definition. Polluted water which is contaminated is toxic to higher mammals, including humans.

Natural waters are frequently referred to as being "hard" or "soft." Hard waters are waters which are richer in nutrients, and have more lime dissolved in them. Such waters are termed "eutrophic." Soft waters are referred to as being "oligotropic." These waters are usually clearer, and usually support different types of organisms. Lakes and streams in which the water is clear and brown are termed dyastrophic, or "underfed."

Many water-quality problems stem from the fact that water must be reused. As long ago as 1960, all of the water consumed by the 118 million persons then served by municipal water systems, which were dependent on surface water resources, was reported to have been "used" at least once before arrival in homes for drinking. During droughts, some cities, Ottumwa, Iowa, and Chanute, Kansas, for example, have been forced to use "closed" systems.[4] A closed system is one in which sewage effluent is routed into the city water works with little or no dilution. Fortunately, these two examples represent unusual conditions.

Few, if any, effluents can be treated so as to render them completely innocuous; even the most satisfactory effluent is not of the same quality as the river (or other) source from which it was drawn.[5]

Five principal types of effects may stem from different kinds of polluting effluents.[6] These effects are: (1) contaminating, toxic, or poisonous effects; (2) addition of suspended solids; (3) de-oxygenation (removal of dissolved oxygen); (4) addition of non-toxic salts; and (5) heating of the water. Pollutants have been classified into 8 general type categories[7] and into 11 general, partially overlapping, type and source categories[8] by the U. S. Senate.

Chart No. 1 has been prepared to list pollutants as classified by both systems, and to illustrate how these classification methods overlap.

Many different types of pollutants may issue from a given type source, and some pollutants may cause more than a single type of undesirable effect when released in water resources. Sanitary engineers are confronted with the problem of providing safe treatment methods for handling more than 400 new kinds of wastes each year, as a consequence of our technological capability to produce almost 10,000 new products each year.[9] Note in Chart No. 1 that one of the major non-consumptive uses of water (cooling) did not seem to fit any of the categories, and that the author has taken the liberty of adding "other" to the Senate Public Works Committee listings.

2. SAPOBRIC ZONATION OF STREAMS

Let us examine a typical oligotropic stream into which an effluent is discharged, and see what sort of water-quality changes occur downstream.

Figure 2 illustrates an underwater outfall from which a mixture of treated domestic and industrial wastes are discharged into a stream in New York state. Figure 3 is a diagram which illustrates how the water quality downstream from such an outfall is affected. Using the German "saprobeinsystem", the zone immediately downstream from such an outfall is usually grossly polluted, and is termed the "polysaprobic" zone. Further downstream, settleable solids sink to the bottom, and dissolved oxygen begins to return to the water. Oxygen is added by contact with the air, aided by currents and turbulence in the stream, and by the photosynthetic activity of green plants and algae. As the dissolved oxygen content increases, the types of organisms which are present in the water are replaced by other types. If the zone immediately downstream from the outfall was septic, anaerobic organisms probably existed in the polysaprobic zone. As oxygen levels increase, these types are replaced by aerobic populations. The reach of the river in which these changes take place is termed the "zone of recovery," or "mesosaprobic" zone. The mesosaprobic zone downstream from the outfall illustrated in Figure 2 is shown in Figure 4.

The mesosaprobic zone is normally divided into an upper, or alpha zone, and a lower, or beta zone. In the alpha zone, many bacteria and often fungi, simple animals, but very few algae are found. Further downstream, in the beta zone, mineralization has proceeded further, and conditions are more favorable for aquatic life. Many of the simpler algal populations, some of the more tolerant animals, and some rooted plants may occur. The conditions illustrated in Figure 4 are in the lower, or beta zone of the stream, evident from the heavy growth of green algae in the water.

The zone in which complete recovery occurs, if it occurs at all, is termed the "oligosaprobic" zone. Mineralization has normally been completed, and dissolved oxygen levels are back to the saturation level. A wide range of aquatic plants and animals have become re-established. This does not mean that the stream is again oligotropic. The added minerals may have changed the character of the stream so that it is now a eutropic, or hard water stream.

By careful photo-interpretation analysis, it is frequently possible to identify polysaprobic, mesosaprobic, and oligosaprobic zones, from the ecological changes in the water and along the banks. Classic zonation may not occur, of course. Several outfalls spaced along a stream may extend a polysaprobic zone from the zone below the first outfall all the way to the mouth of the stream, or may repollute waters from a mesosaprobic zone back to a polysaprobic zone.

3. TYPES OF WATER POLLUTANTS

Referring again to Chart No. 1, most of the listed types of pollutants create identifiable "signature" conditions in water, or alter the aquatic environment in special ways so that the presence of specific kinds of pollutants is indicated.

4. MUNICIPAL WASTES

Municipal outfalls may be of several different types. They range from outfalls from modern sewage treatment plants which provide almost complete reduction of wastes, to outfalls from which raw, untreated sewage is discharged.

Effluents may range from clear water, to effluents which are brightly colored, as shown in Figure 1. The effluents may also be almost the same color as the water into which they are being discharged. Figure 5 illustrates the appearance of raw sewage being discharged into the Potomac River at a time when sewage lines were being repaired. Note the number of seagulls which are present. The gulls have been attracted by the small fish which in turn were attracted by the added food supply. Figure 6 shows the appearance of another outfall as seen in pan-minus-blue aerial photography, during this same sewage repair project. Note that while the raw sewage appeared to be the same color as the river water, a much different tone is apparent in the pan-minus-blue coverage.

Outfalls from sewage-treatment plants are frequently located on the bottoms of the streams into which effluents are discharged. The effluent is frequently warmer than the receiving water, and usually tends to rise to the surface. This is particularly true if the effluents are clear. Clear waters usually photograph black or at least in dark tones in pan-minus-blue aerial photography, because the longer wavelengths of visible light are absorbed.

The effluent from the Blue Plains Sewage Treatment Plant in the District of Columbia is an excellent example. The outfall is located on the bottom of the usually muddy Potomac almost across the river from Washington National Airport. The effluent is usually quite clear, and being warmer, rises to the surface. Figure 7 illustrates the typical appearance of the effluents from this outfall. Blue Plains is reputed to be one of the best treatment plants in the country. The most seriously polluted section of the Potomac, however, is just below this outfall, and, on one of my field trips in this area, vast numbers of an extremely rugged type of snail were found dead. The presence of dead organisms is an indicator of the severity of pollution.

Sometimes a very obvious polysaprobic zone develops below an outfall. Figure 8 illustrates a particularly nasty polysaprobic condition below the outfall of the sewage treatment plant serving a community on the shore of San Francisco Bay within the Approach Control zone for the San Francisco International Airport. Note the oily-gray appearance of the grossly polluted water.

Extensive white streaks and patches are sometimes seen in the water below municipal treatment plant outfalls. Depending upon the film and filter combination which was used to obtain the aerial photography, these streaks and patches may be caused by large populations of sewage fungus, or by lime which may have been added to the water.

Effluents from municipal treatment plants may be very rich in nutrient materials, and may stimulate the growth of several Phyla of algae. This was shown in Figure 3.

Many water-pollution problems which stem from sewage treatment plants in the United States exist because the facilities are overloaded. For example, if a forward looking community of 10,000 persons installs a treatment plant which is 90-percent effective, the effluent which is discharged contains about the same amount of wastes as if 1,000 persons discharged raw sewage into the receiving stream. If the population later rises to 100,000 persons, and the treatment facilities are not enlarged proportionately, the effluents which are discharged contain as much waste material as if treatment facilities had not been installed in the first place. Conditions are probably worse, in fact, because the partially treated wastes frequently have greater nutrient value than do untreated wastes.

Some very interesting observations have been made using Kodak Ektachrome Infrared Aero Film, Type 8443, an improved type of "camouflage detection" film. It has been observed that the trickling filters of some treatment facilities, particularly those which are overloaded, reflect a considerable amount of infrared, as shown in Figure 9, while trickling filters which are operating more efficiently do not, as shown in Figure 10.

5. POLLUTION FROM COMBINED SEWAGE SYSTEMS

Combined sewage systems are those in which storm drains are connected with sanitary sewers. If all of the wastes are routed to sewage-treatment facilities, few problems can be anticipated. Unfortunately, complete treatment is rarely provided.

In earlier times, sanitary wastes were discharged directly into lakes and rivers without treatment. With the development of sanitary engineering, community progress may have followed one of two lines. Bypasses may have been installed so that, under normal flow conditions, all wastes were routed to treatment plants, but when rainfall exceeded certain limits, the excess flow was discharged through stormdrain outfalls, without treatment. The second line of development was, of course, installation of separate sewage lines for sanitary wastes. These separate systems are not subject to overflow in the same way as are the systems in which bypasses are installed.

During the transition period, sewer lines may have become "lost," however, so that in some cities, in spite of the existence of modern treatment facilities some wastes may still be discharged "raw."

Most of the major cities which are still served by combined systems have taken steps to route all wastes into treatment facilities. In most of these cases, improvement has not been voluntary on the part of the City Fathers. In the Federal Water Pollution Control Act of 1956 as amended in 1961, the Congress has provided for some rather severe punishment if an Enforcement Action is lodged.

Washington, D. C., for example, as of a few years ago had 71 combination outfalls, including one which discharged into the Tidal Basin. Figure 11 illustrates the appearance of one of these outfalls discharging effluent into the Anacostia adjacent to the Naval Gun Factory. An Enforcement Action was averted by the District, by initiating "Project C" to route all wastes to

Blue Plains. This project, in my opinion, is under very capable guidance, and should be completed by 1966. An Enforcement Action, however, may be warranted if the project is not completed by 1966. If this is necessary, the Public Health Service and the District's 435 member "city council" will be in a very odd position, to say the least.

Many of the signature clues for the detection and identification of combined sewage outfalls are the same as for municipal outfalls. A difficulty in locating many of them exists, however, because they flow heaviest during bad weather, when photography cannot be obtained.

6. ORGANIC INDUSTRIAL WASTES

Organic industrial wastes include wastes from meat-packing plants, pulp and paper mills, animal wastes from stockyards and feedlots, and similar sources.

Identification of sources of wastes in this category depends on identification of the type of industry or facility. When this has been done and the outfalls have been located, the search should be extended downstream for evidence of saprobic zonation. Organic industrial wastes usually place an additional biological oxygen demand on the receiving waters, and create effects much like those caused by raw sewage.

At this point, let me state that most industries try to prevent adding wastes to waters which create adverse conditions. Most industries try to keep toxic wastes out of waters on moral grounds. Others, I'm afraid, only because they feel that the most permanent way of losing downstream customers is to kill them, or because they fear legal action. In spite of the best of efforts, however, accidental spills have been known to happen.

Wastes from cattle feedlots, which belong in this category, were reported to me as being one of the most serious pollutants of streams in Kansas. Photo interpreters who are studying areas in Kansas who locate sources of feedlot pollution are urged to report their observations to:

The Kansas State Board of Health
Division of Sanitation
Topeka, Kansas

Salmon packing wastes are considered to be one of the more serious types of pollutants in this category which degrade Alaskan rivers and coastal waters. Photo interpreters who are studying Alaskan terrain are urged to report observations of such wastes in recent aerial photographic coverage to:

Department of Health and Welfare
Division of Public Health
Alaska Office Building
Juneau, Alaska

The volume of wastes from the pulp and paper industry is staggering. Until installation of a clarification system to remove fiber and clay wastes a few years ago, the West Virginia Pulp and Paper Company plant at Luke, Maryland, discharged 22-1/2 tons of wastes into the North Branch of the Potomac every day.

Pulp and paper wastes are considered to be one of the most serious sources of pollution to waters in Maine and Wisconsin. Photo interpreters who are studying areas in Maine or Wisconsin are urged to report observations of pulp and paper mill wastes to:

Maine: Department of Health and Welfare
Water Improvement Commission
State of Maine
Augusta, Maine

Wisconsin: Director, Committee on Water Pollution
State Office Building
Madison, Wisconsin

7. INORGANIC INDUSTRIAL WASTES

Wastes in this category again include some from the pulp and paper industry. They also include sediments from hydraulic mining, salts, such as those which are contained in connate waters which may be released in oil drilling operations, metallic wastes from plating and refining operations, acid mine drainage, and wastes from similar operations.

Bleaching agents are used in the manufacture of paper to produce paper of uniform color. After use, these bleaches are usually discharged directly into streams, without treatment. Figure 12 illustrates waste bleach being discharged in the Mississippi River at Grand Rapids, Minnesota, from the Blandin Paper Company plant in the summer of 1961. At that time, the wastes turned the entire Upper Mississippi a sickly green for several miles downstream. The normal color of the Mississippi in that region is about the color of strong black tea, a color which is characteristic of dyastrophic waters.

Salt pollution from oil drilling operations has been cited as one of the more serious pollutants of streams in Arkansas, and the category which appears to have been the subject of more litigation, from the number of cases which appear in legal records concerning water pollution in the United States, than any other type of industrial pollution.

Petroleum photogeologists who observe salt pollution from drilling operations entering streams are urged to report their observations to the oil companies. Oil companies, in general, do try to do what is morally right about correcting water pollution problems. They have also been among the heaviest losers in legal actions.

Connate waters usually carry an extremely heavy load of salt, which may leave a white encrustation along streams.

Metallic wastes pose many serious problems. Chromium wastes, for example, when discharged into sewage treatment plants, kill the bacteria upon which these systems depend for biological reduction of wastes.

No signature clues have been developed by this investigator for identification of chromium toxicity on trickling filters, but perhaps other members of the photo-interpretation community will give some thought to the problem. An answer may lie in the appearance of trickling filter beds as imaged using infrared or camouflage detection film.

Acid mine drainage is one of the most serious pollutants in the eastern half of the United States. An estimated 10 MILLION tons of sulfuric acid oozes from strip mines and from abandoned shaft and tunnel mines each year in the region extending from New York State to Alabama, and west to include parts of Missouri and Illinois. Figure 13 illustrates drainage from an abandoned mine in Preston County, West Virginia. Figure 14 illustrates a ventilation hole from a nearby abandoned shaft mine as it appeared in March 1963. The total acidity of the stream into which these wastes discharged measured between pH3 and 4, much too acid to sustain a healthy aquatic population.

An interesting signature clue for identification of sources of acid mine drainage is evident in Figure 14. The acid appears to accelerate the decomposition of overburden, creating very fertile soil. The only sources of lush, green stream bank and aquatic vegetation observed on this flight were near the sources of acid drainage.

Two additional clues which sometimes indicate sulfuric-acid drainage are (1) yellow or reddish-yellow stains on stream bottoms. These are iron stains which remain after the biochemical decomposition of pyrite and/or marcasite; and (2) the water sometimes appears greenish. The greenish coloration was probably caused by a green algae, probably a minute form belonging to the Phylon Chlorophyta. Green algal forms predominate in waters which are chemically neutral, of course, so this clue must be used with caution.

8. NEW CHEMICAL WASTES

Most of the estimated 400 new wastes with which sanitary engineers must learn to cope each year are in this category. As photo interpreters, it is suggested that the best we can hope to do is to examine areas downstream from chemical manufacturing and processing plants, and report ecological changes which we may detect. Since these wastes are new, many of the ecological changes which they may induce are unknown, and reports of unusual effects which are observed may aid in developing methods for their treatment.

9. LAND DRAINAGE WASTES

Land drainage wastes may include leaves and trash which are washed into streams, and whose biological reduction by natural processes may induce de-oxygenation. Organic chemical exotics in the form of pesticides, fertilizers, weed killers, agricultural lime, and sediments are included in this category. Millions of tons of top soil are washed away each year, clogging navigational channels, smothering organisms which live on the bottoms of streams, and blocking the penetration of light into waters. When sunlight is blocked so that it cannot reach green aquatic vegetation, photosynthetic action, which helps replenish the supply of dissolved oxygen is stopped.

Figure 15 illustrates a typical outfall from which land drainage wastes are being pumped. This outfall discharges into San Francisco Bay from a land filling project. Marshy tidal lands are being filled to make room for the next generations' houses.

Most land drainage wastes enter streams from creeks which flow through farm land. Figure 16 illustrates topsoil being carried downstream along both sides of the Potomac above Washington, D. C. Sediments are considered to be the most serious pollutant in the Potomac, and stem largely from this source and from sloppy land-development practices by builders.

10. IRRIGATION RETURN FLOWS

Irrigation return flows may contain fertilizers, pesticides, insecticides, salts which are leached from the soil, and sediments. Fields which are being irrigated are quite easy to identify, of course, and interpreters may do well to note where these flows are entering streams. Since those flows frequently contain highly nutritious substances, rank growths of algae and aquatic vegetation may be present.

Algae and other growths in water can be imaged very distinctively using Kodak Ektachrome Infrared Aero Film, Type 8443. Figure 17 shows a characteristic infrared response in water from this type of source.

11. URBAN LAND DRAINAGE

Harry, the Happy Home Owner, probably uses more fertilizer per square foot of cultivated area (lawn) than any farmer does for a marketable crop. The excess fertilizer which Harry puts on his lawn washes away, is added to the residue left by city litter bugs, and pollutes streams which it enters via storm sewers. That portion which enters combined sewage systems may receive some treatment, but the majority of the wastes are carried directly into streams or lakes.

Storm drains through which considerable volumes of nutrient rich water are discharged may have luxurient growths of algae and aquatic vegetation adjacent to them. Figure 18 illustrates these effects near such an outfall close to a swimming beach on the shores of Big Stone Lake, at Ortonville, Minnesota.

12. AGRICULTURAL PESTICIDES

Agricultural pesticides may be found in land drainage wastes, irrigation return flows, and in urban land drainage. Pesticides are toxic substances. One type, Endrin, which is used to kill field mice, is deadly to fish in quantities as dilute as one part in three billion.

Pesticides have been blamed for virtual extinction of commercial fishing in the lower Mississippi River.[10] Evidence partially confirming that Endrin was responsible has recently come to light. A chemical manufacturer - Velsicol Chemical Corporation in Memphis, Tennessee - changed its techniques for disposing of Endrin wastes so that residue no longer enters the river. No fish kills have occurred since this was done.

Detection of masses of dead fish in the water may be accepted as initial evidence that toxic substances are present in the water, or at least, that something is seriously wrong.

Figure 19 illustrates a portion of the huge fish kill which occurred in the Potomac Estuary in the summer of 1963. Since the dead fish are usually very small, they will rarely be seen, except in large-scale photography which has been obtained using extreme resolution films and high-resolution camera systems.

Fish kills which may be detected should be reported immediately to cognizant health authorities, and to department of fish and game personnel. These groups will take necessary action to determine cause, and, if necessary, warn water-treatment plant operators downstream so that remedial action, if possible, can be taken.

Fish kills provide one of the better indicators of the possible presence of toxic substances in the water.

13. AGRICULTURAL FERTILIZERS

Agricultural fertilizers in limited quantities may accelerate productivity of natural waters, stimulating natural purification. Green algal growths and green aquatic vegetation release oxygen by photosynthetic processes. Problems arise, however, when excessive growths develop. Photosynthetic activity may continue through most of the night, followed by a period before dawn when the green aquatic growths remove, rather than add oxygen to the water. If this occurs, and the dissolved oxygen levels become too low to support desired biological organisms for even a few minutes during a period of several months, the ecology of the stream may be altered. Most types of fish, for example, will die very rapidly if the dissolved oxygen level of the water drops below about four parts per million. Serious continuing damage to the fish population may develop if the dissolved oxygen level is lowered to the point where the fish are "uncomfortable." For comparison, we humans live in an atmosphere which is about 21 percent oxygen. We can normally survive in an atmosphere in which the oxygen content is as low as 18 percent, but with difficulty. While acclimatization is possible, we will "migrate" out of such an atmosphere as rapidly as possible, as will fish, when the dissolved oxygen level in water drops below about seven parts per million. Trout, which can exist only in oligotropic waters, require even more oxygen, and are almost always found in water colder than 70° F which is saturated with oxygen.

Excessive growths of algae and aquatic vegetation may cause additional long term effects on streams. When they die, additional oxygen is required for their decomposition.

Aerial photographic-interpretation techniques may be quite successfully used to map out places where runoff from fields is entering lakes and streams, and for mapping areas where dense growths of vegetation and algae have developed. Figure 20 illustrates how dense green algal growths may become. Note that speed boats have cut paths through the algae which look much like ski trails in new snow.

14. POLLUTION RESULTING FROM RECREATION AND NAVIGATION

Outboard motor exhaust may introduce complex chemical substances into water which are much like those which create smog and other air pollution problems. These substances have an adverse effect on fish life.[11] This is one of the reasons why the use of outboard motors is prohibited on some lakes, particularly if the lakes are also sources of municipal water supply.

Oil spillage from large vessels may be a very serious pollutant. The seriousness of oil pollution is internationally recognized, and has stimulated adoption of an international treaty, to which the United States is signatory, prohibiting the discharge of oil at sea.

Oil on the surface of the lower Detroit River during the months of March and April 1960, contributed to the death of more than 12,000 canvasback, redhead, and blue bill ducks. A film of oil only 0.00008-inch thick will cause ducks to drown. The oil penetrates through the outer layer of feathers, and causes the inner layer of down to mat, so that the ducks loose buoyancy. A layer of oil this thick is quite visible as an iridescent layer on water.

In studies which were made in 1946 and 1948, it was disclosed that 16,280 gallons of oil were being discharged into the lower Detroit River each day.[12]

This amount of oil is sufficient to create a film 0.00008-inch thick over 12.21 square miles of water surface.

In the winter of 1962, while participating in a Civil Air Patrol training exercise, the author observed four swans which were trapped in an oil slick on the Potomac River below the Baltimore and Ohio Railroad repair facilities at Brunswick, Maryland. This was duly reported, but what action was taken to rescue the birds is not known. It is suspected that no action was taken, because once waterfowl become trapped in an oil slick, little can be done to save them. Most of the ducks which were rescued from the lower Detroit River, for example, later died when efforts were made to wash the oil from them.

Oil on the water is quite easy to identify by visual aerial observation, but may be misinterpreted as a natural slick in aerial photography, unless it is observed to extend from an outfall or from a ship.

Observations of oil being discharged from ships should be reported to the U. S. Coast Guard, in view of our treaty obligations. Outfalls from which oil is being discharged should be reported to cognizant water-pollution control authorities.

15. OTHER SPECIAL TYPES AND SOURCES OF POLLUTION

As stated, this category was added to the established classification systems to define better specific types of pollutants. One of the major types of water demand in this category is water for cooling. The heating of water and subsequently returning it to a stream may be beneficial, at least under certain circumstances. Warming of water may prevent ice from forming, creating an air-water interface so that oxygen can be taken up by otherwise oxygen deficient ice-locked waters during winter months.

Mild warming of waters may stimulate natural purification, by accelerating biological activity. Warm water will hold less dissolved oxygen in solution, however, and since biological activity is accelerated, oxygen is consumed faster. This may cause streams to go septic.

Some types of fish cannot survive at all in warm water, both because they are intolerant of heat, and because they require certain organisms for food which are even more intolerant of heat. Brook trout, for example, cannot exist in a stream in which the water rises to 80° F for just 1 day out of a year.[13]

Heated coolant water which is being discharged from outfalls may be identified in aerial photography because of the physical and perhaps the biological effects which it has on the water downstream. Heated coolant water may appear as a light-toned area in an otherwise dark-toned stream. This appears to be a reliable indicator in pan-minus-blue aerial photography. The anomolous light tonal indicator is much more evident in coverage which has been obtained using special filter combinations, however. It is frequently very vivid, for example, in coverage which is obtained using a filter which transmits only that portion of the spectrum longer than 650 millimicrons, using a panchromatic film.

The physical conditions in water which permit this anomoulous appearance probably stem from higher reflection from the interface between denser subsurface water and the warmer, less-dense surface layer. Heated coolant water will ride on the surface of a stream. Since the warm water is less dense than the cooler water, more light will penetrate into it. The light will be refracted less while passing through the warmer layer. Phytoplanktonic organisms, usually transparent species, concentrate along the interface. These organisms, together with, perhaps, a denser layer of colloidal particles in suspension, cause some of the light to be scattered and reflected back up toward the camera. Bioluminescence may be a contributing factor, also.

A different form of surface wave may develop in the less-dense surface layer. Wavelets which are formed are usually smaller, wave fronts may advance at a slightly different angle, and wave slopes may be different. As a result, surface glitter patterns may be suppressed (or accentuated) in the heated water, but not in the receiving water.

16. PHOTO REQUIREMENTS FOR WATER-QUALITY ANALYSIS

Much valuable water-quality information can be obtained from the analysis of normal pan-minus-blue aerial photography but, for most types of analysis, large-scale coverage which has been obtained using special film and filter combinations is desirable. Figure 21 is a multiband panel which was obtained using the Itek Multiband Camera which illustrates tone differences in a pond. The tonal differences in this instance are probably caused by different phyla of algae, primarily Blue-Greens and Yellow-Greens.

Visible light, as it passes through water, is both absorbed and scattered. If the type of analysis to be performed requires that imagery of subsurface objects be obtained, a filter which transmits only the green, yellow, and orange portions of the spectrum is recommended, for use with black-and-white panchromatic films. Best results, however, have been obtained using aerial color film with a Kodak Wratten 2A filter (or equivalent) with a polarizing filter.

Some excellent examples of aerial color photography from which much valuable water-quality data might be obtained have been published in Photogrammetric Engineering (November 1963 and September 1964).

Very unusual and quite spectacular results have been obtained using Kodak Ektachrome Infrared Aero Film, Type 8443. Some illustrations of the results which can be obtained using this film have been shown. When this film is exposed through a Kodak Wratten 2A filter, which transmits the violet and blue light which is excluded by the Kodak Wratten 12 and 15 filters which are normally used, reddish and magenta responses are imaged from sessile vegetation and algae to some depth below the surface. This is illustrated in Figure 22, and was shown in Figure 17.

Fish kill analyses require large-scale coverage using extreme resolution films and camera systems. Panoramic cameras are recommended. This recommendation is made because of the small size of the images which must be identified. A fish kill survey is much like counting cigarettes, scattered on the water, from perhaps several thousand feet in the air.

An interesting observation was made in the course of the survey which was conducted of the fish kill in the Potomac Estuary in the summer of 1963. In coverage which was obtained using Kodak Ektachrome Infrared Aero Film, Type 8443, some of the dead fish which were imaged had a reddish tinge, while most of them were bluish. It is suspected that the difference in color indicated differences in state of decay, which, of course, might be an indication of time since death, from which the rate of mortality might be determined.

An estimate of the extent of this fish kill was made using a technique about which comments from the photo-interpretation community will be appreciated.

Dead fish and floating debris on a water surface will collect in confluences which are created by wind, currents, and convection movements. Individual fish in a mass which may be several hundred yards long and several feet wide can rarely be counted accurately, obviously. The technique used by this invetigator was to photograph as many areas as could be sighted in which the dead fish were still dispersed on the surface, determine the average distance between them, from this calculate the average number of dead fish per acre, and assume that the total number of dead fish approximated this number times the number of acres in the area in which dead fish were sighted. Comments on the validity of this technique will be appreciated.

While large-scale coverage is preferred for most types of water-quality analysis, some interesting information can be obtained from extremely small-scale coverage, obtained using extreme resolution films. Current patterns, for example, are sometimes easier to map in coverage at scales smaller than 1/100,000, 20 times smaller than the scale preferred by this investigator for analysis of mortality distribution in fish kills, for example.

17. REPORTING WATER-QUALITY INFORMATION

The names and addresses of a few of the persons to whom observed indications of water pollution should be reported have been given. Complete listings of state and interstate water pollution control authorities in the United States may be obtained from the Division of Water Supply and Pollution Control, U. S. Public Health Service.

Water-quality reports should contain as much information as possible. Ground data, if possible, should be obtained. Critical ground-truth data include, as a minimum:

(1) Water temperature

(2) Amount of dissolved oxygen

(3) Acidity (pH)

(4) Relative turbidity between effluent and receiving waters.

If possible, bacteriological data, including standard 5-day BOD data, and total bacteriological and chemical analysis data should be obtained. If dead fish and/or dead snails in large quantities are observed, these should be reported, as should odor, presence of trash, debris, foam, oil, and discoloration. The bottoms of some streams which are very low in dissolved oxygen may have a reddish color which will disappear when one stamps on the bank or throws a stone into the water. These may be bloodworms, busily cleaning up stream bottom wastes. If present, they should be reported.

If water samples are collected, care must be taken not to further contaminate them. Narrow-mouthed, glass-stoppered bottles, 250 to 300 milliliter capacity should be used. Bottles should be held completely underwater while filling them, so that no bubbles of air enter. Air bubbles can cause errors in dissolved oxygen measurements. A preservative solution consisting of 0.7 milliliter concentrated sulfuric acid (H_2SO_4) and 1.0 milliliter sodium azide (NaN_3) should be added to the samples to arrest biological activity. Sample bottles should be packed in ice, if possible, and gotten to a laboratory within 8 hours.

For most purposes, water samples should be representative of average conditions; however, a few samples of the water which appears to be most polluted may aid in identification of substances whose presence in extremely dilute quantities is harmful.

18. SUMMARY

Aerial water-quality reconnaissance methods can help protect out national water resources by speeding up, reducing the cost of, and making field work more productive. Investigators who examine water in test tubes or by the drop on microscope slides cannot "see" whole rivers and lakes, nor can investigators studying aerial photography taxinomically classify the aquatic organisms which are present, or conduct qualitative and quantitative chemical analyses. The two investigators can work together as a team, however, to their mutual benefit.

I suggest that we, as potential "aerial water-pollution detectives" volunteer to be members of such teams.

19. ACKNOWLEDGMENTS

Much of the research contributing to this paper was supported by Research Grant WP-181, and by Demonstration Grant WPD 20-01-1963, from the Division of Water Supply and Pollution Control, Public Health Service. Additional support has been obtained from the Vidya Division, Itek Corporation, Palo Alto, California, from the Congress of the United States, and from the many state and interstate water-pollution control groups who have assisted in collection of data.

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POLLUTION CLASSIFICATION CHART

SENATE COMMITTEE ON PUBLIC WORKS, 1ST SESSION, 88TH CONGRESS

SENATE SELECT COMMITTEE ON NATIONAL WATER RESOURCES, 2ND SESSION, 86TH CONGRESS

	MUNICIPAL WASTE	POLLUTION FROM COMBINED SEWAGE SYSTEMS	ORGANIC INDUSTRIAL WASTES	INORGANIC INDUSTRIAL WASTES	NEW CHEMICAL WASTES	LAND DRAINAGE WASTES	IRRIGATION RETURN FLOWS	URBAN LAND DRAINAGE	AGRICULTURAL PESTICIDES	AGRICULTURAL FERTILIZERS	POLLUTANTS RESULTING FROM RECREATION AND NAVIGATION	OTHER SPECIAL TYPES AND SOURCES OF POLLUTION
SEWAGE AND OTHER OXYGEN DEMANDING WASTES	X	X	X		X	X		X		X	X	
INFECTIOUS AGENTS	X	X									X	
ORGANIC CHEMICAL EXOTICS	X		X		X	X	X	X	X	X		
OTHER MINERAL AND CHEMICAL SUBSTANCES	X	X		X	X	X	X	X	X	X	X	
SEDIMENTS	X	X	X	X		X	X	X				
RADIOACTIVE SUBSTANCES				X	X							
HEAT	X	X				X	X	X				COOLANT WATER

CHART NUMBER 1

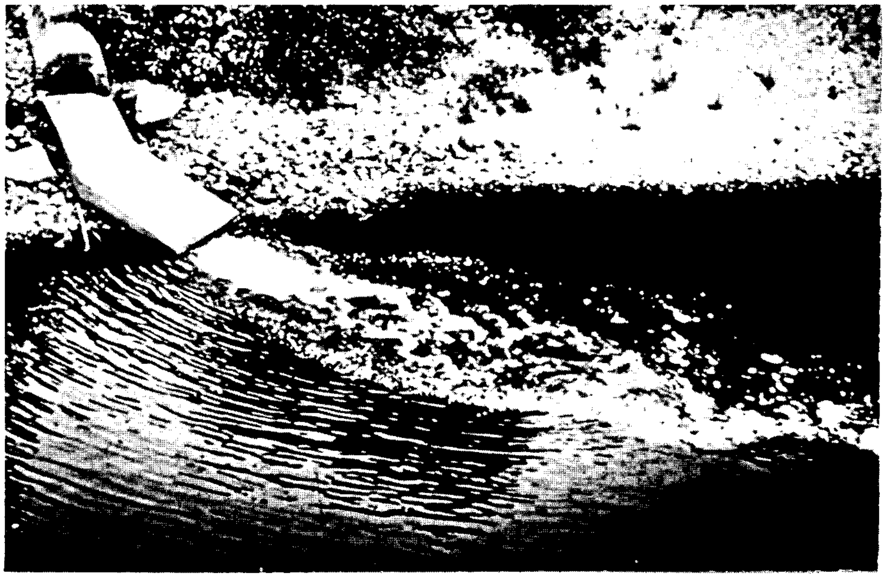


Figure 1.- One of the hundreds of outfalls which discharge into American streams. The effluent from this outfall is blood-red, and is probably a metallic waste. No chemical or biological data are available.

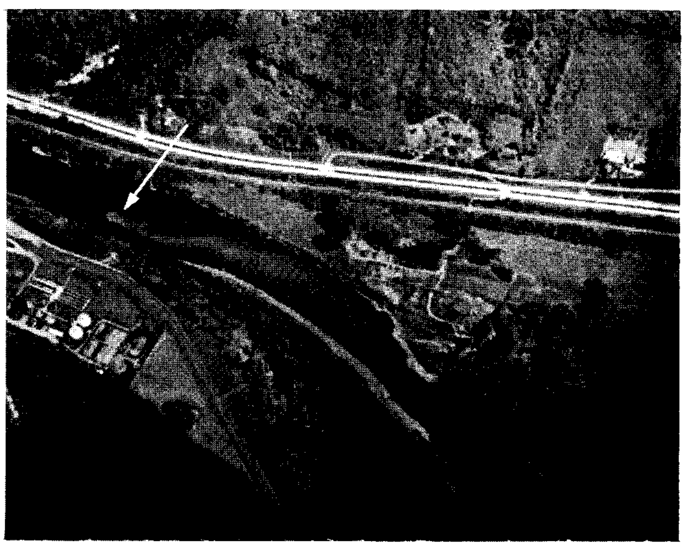
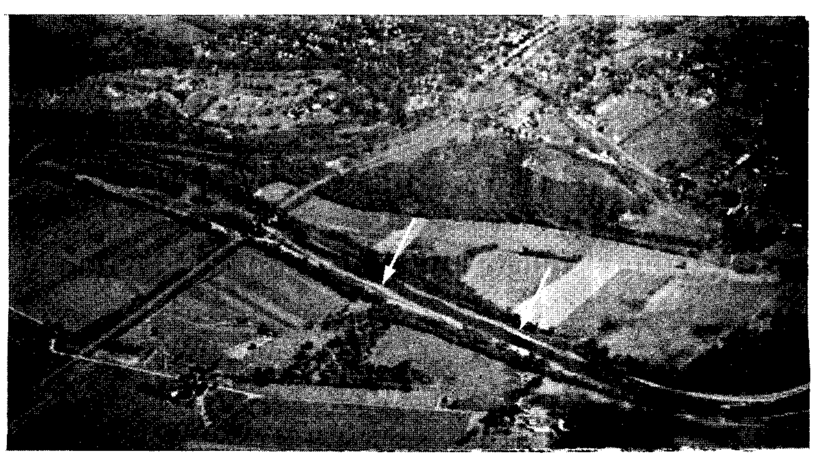


Figure 2.- Treated mixed domestic and industrial wastes entering a stream in New York State. Note that the nasty discoloration extends for a considerable distance downstream in a relatively intact plume.

Figure 4.- Section of the beta Mesosaprobic Zone downstream from the outfall shown in Figure 2. Arrows point to masses of green algae.



SAPROBIC ZONATION

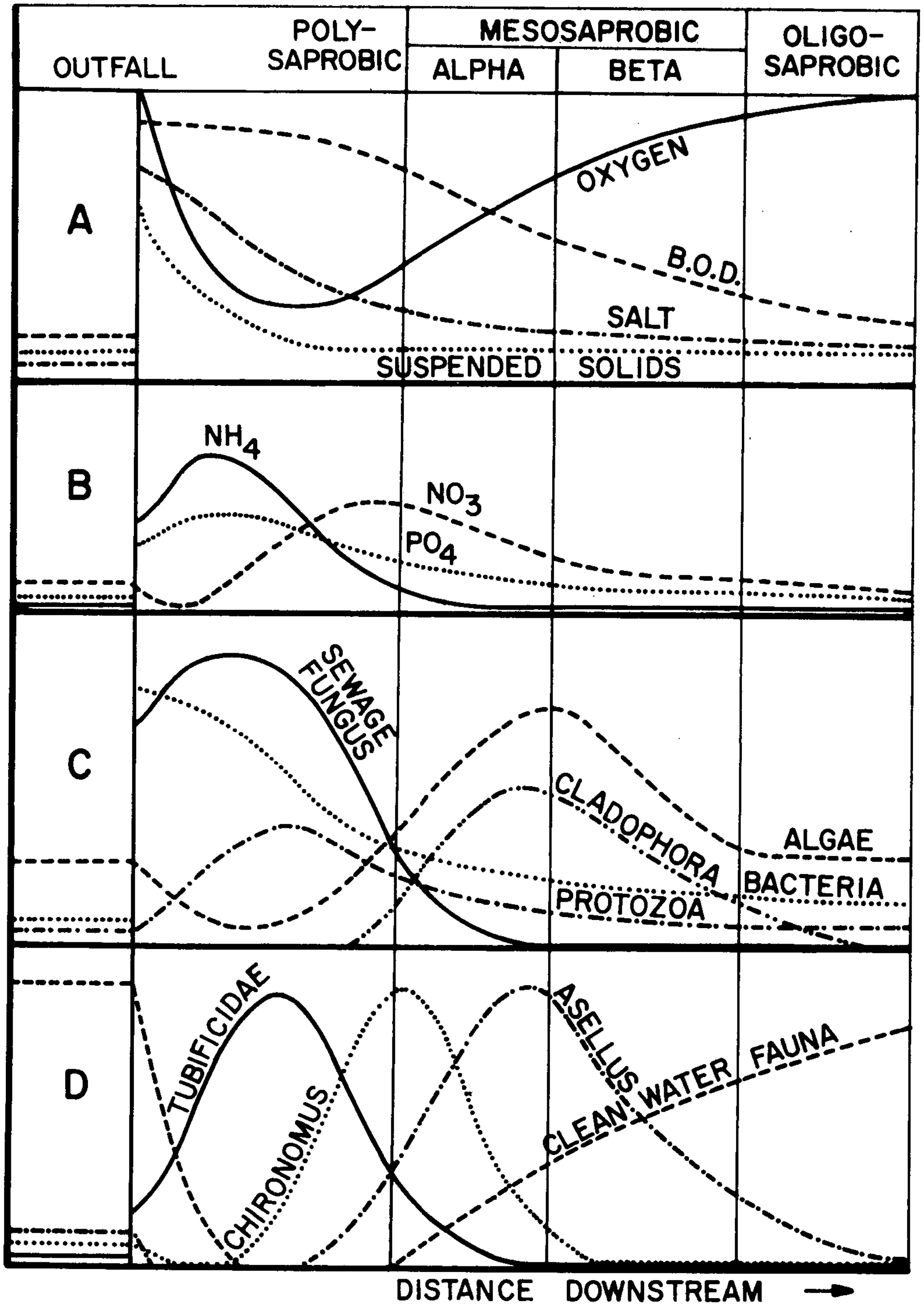


FIGURE 3.- DIAGRAMMATIC PRESENTATION OF THE EFFECTS OF AN ORGANIC EFFLUENT ON A RIVER AND THE CHANGES AS ONE PASSES DOWNSTREAM FROM THE OUTFALL: A & B PHYSICAL AND CHEMICAL CHANGES, C CHANGES IN MICRO-ORGANISMS, D CHANGES IN LARGER ANIMALS.

NOTE: ADAPTED FROM HYNES, BIOLOGY OF POLLUTED WATERS.

Figure 5.- Raw sewage being discharged into the Potomac River just upstream from the Lincoln Memorial in Washington, D.C. During 1963, raw sewage was discharged from this and 70 other outfalls along the Potomac and Anacostia Rivers an average of 5 days each month, as cited in a report issued by the Senate Public Works Committee.

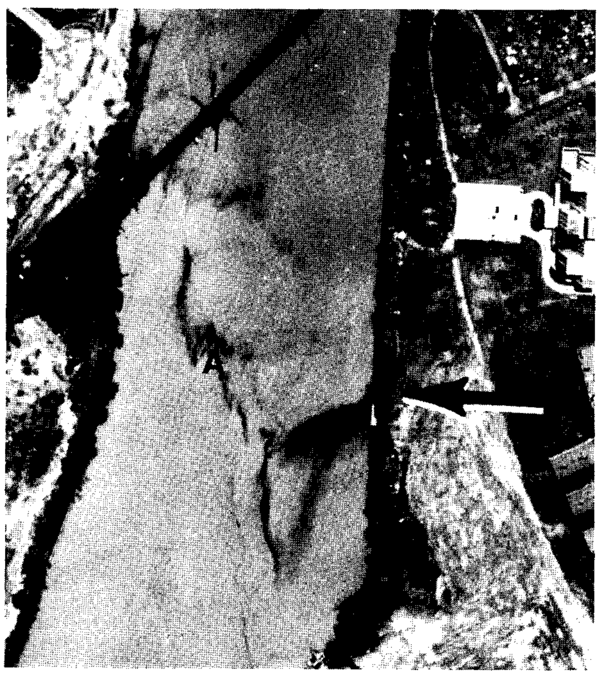


Figure 6.- Bypassed raw sewage being discharged into the Anacostia River from the lines of the Washington Suburban Sanitary Commission, as pictured in pan-minus-blue aerial photography. Note also the filthy scum of oil at A. Less than a month after this picture was taken, the Anacostia went septic.

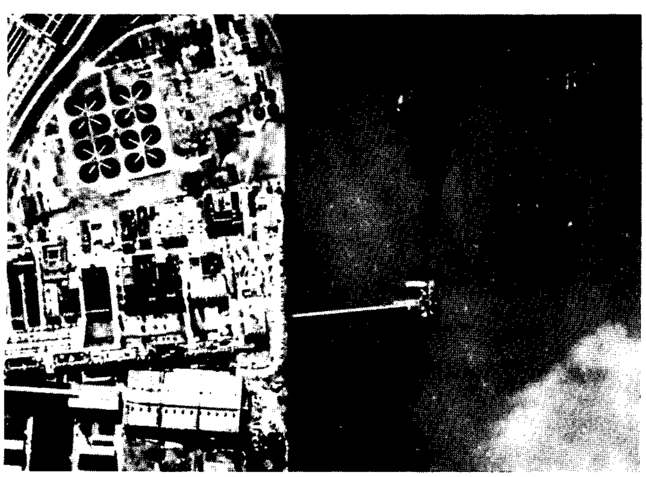


Figure 7.- Effluent from the Washington, D.C.,(Blue Plains) sewage treatment plant. Blue Plains provides perhaps the best treatment possible within the current state-of-the-art, yet the Interstate Commission on the Potomac River Basin reports that the section of the river just downstream from this outfall (into which the Washington Suburban Sanitary Commission plans to discharge additional sewage effluent) is the most polluted section of the entire 386-mile length of the Potomac.

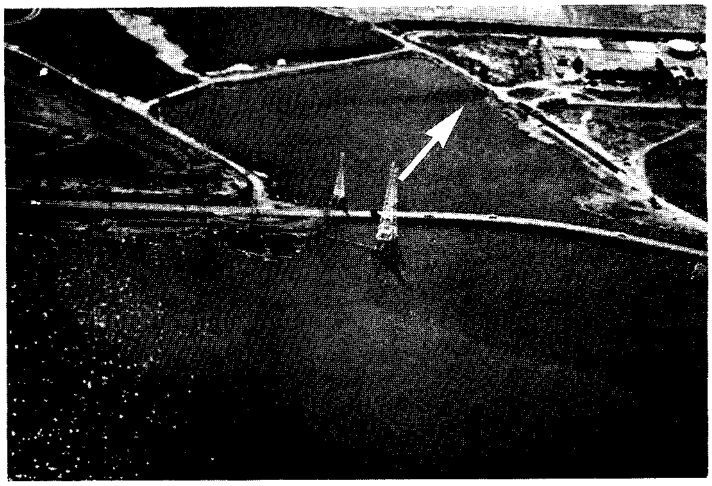


Figure 8.- Sewage treatment plant which discharges into the San Francisco Bay. Mildly stated, this plant has a serious odor problem during warm weather. The tone and color of the receiving waters is an oily gray, an appearance which is characteristic of some badly polluted waters, particularly turbid waters which are low in dissolved oxygen.

Figure 9.- Beds of trickling filters of overloaded treatment plants, especially those with serious odor problems like this one near Milpitas, California, reflect considerable amounts of infrared energy. The cause of this condition is not known to this investigator - yet. (Note: This condition is quite vivid in imagery obtained using Kodak Ektachrome Infrared Aero Film, Type 8443, from which this illustration was copied.)

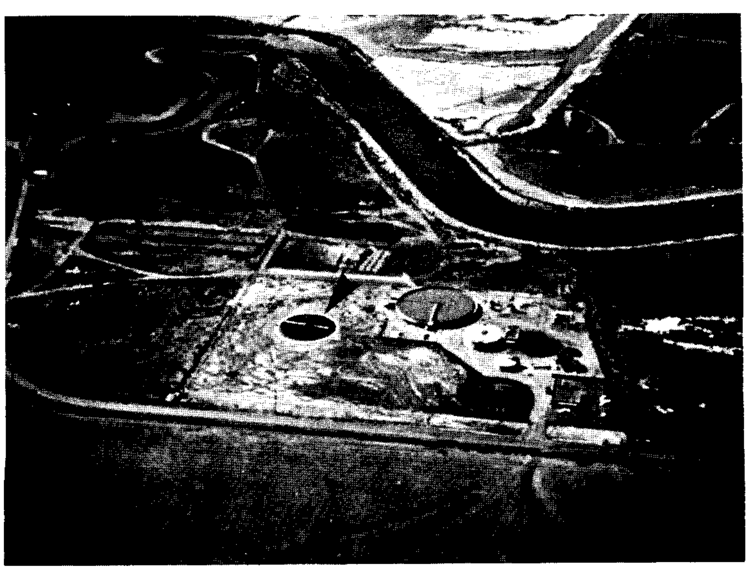


Figure 10.- Union Sanitary District sewage treatment plant near Fremont, California. This plant has no appreciable odor problem - and no infrared reflectance from the bed of the trickling filter. (Original photograph obtained using Kodak Ektachrome Infrared Aero Film, Type 8443.)

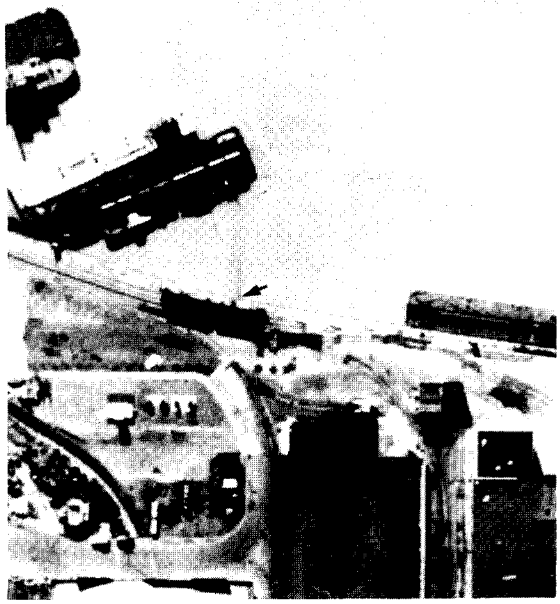


Figure 11.- Outfall near the Naval Gun Factory (a combined outfall) discharging into the Anacostia River.

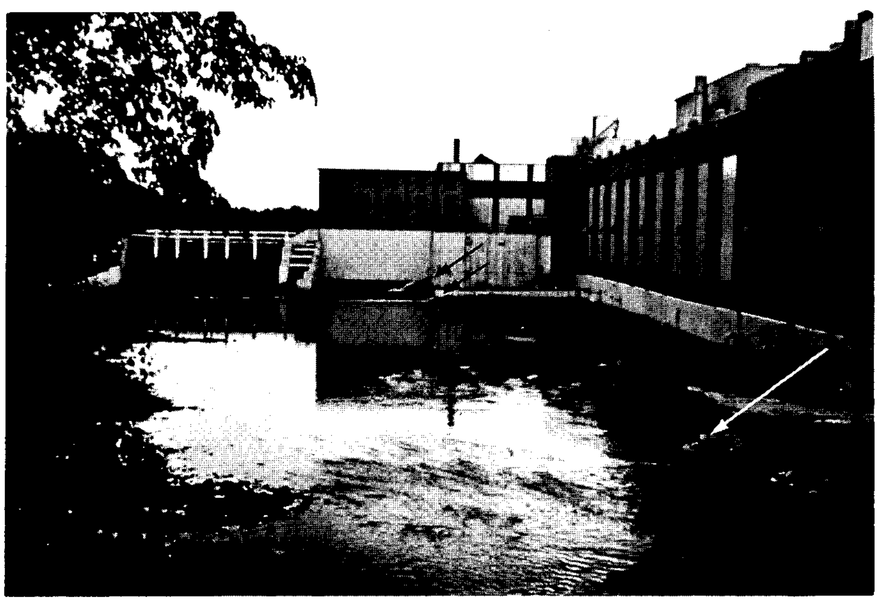


Figure 12.- Spent sulphite wastes from the Blandin Paper Company plant at Grand Rapids, Minnesota being discharged into the Upper Mississippi River. Sickly green sulphite wastes and scummy paper fiber discolored the entire river for several miles downstream when this picture was taken in the summer of 1961.

Figure 13.- Mouth of an abandoned tunnel mine in Preston County, West Virginia, from which sulfuric acid is draining. Bottom of stream has characteristic yellow iron stain.

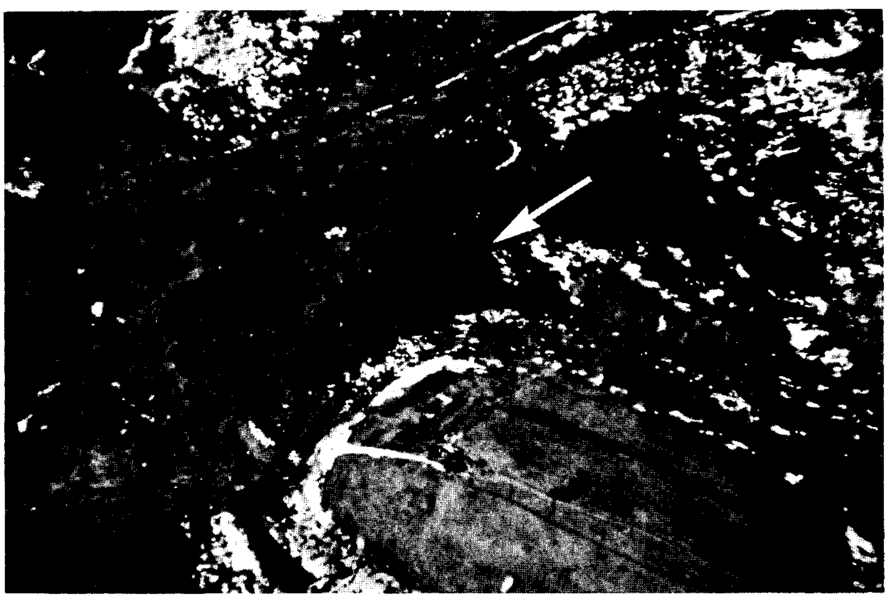


Figure 14.- Flooded vent from abandoned shaft coal mine in Garrett County, Maryland. Vegetation near mine entrances and in strongly acid waters, frequently appears brilliant green, even during cold weather. Area at head of arrow is brilliant green in original color photograph. This photograph was obtained during March 1963. Note snow on ground.

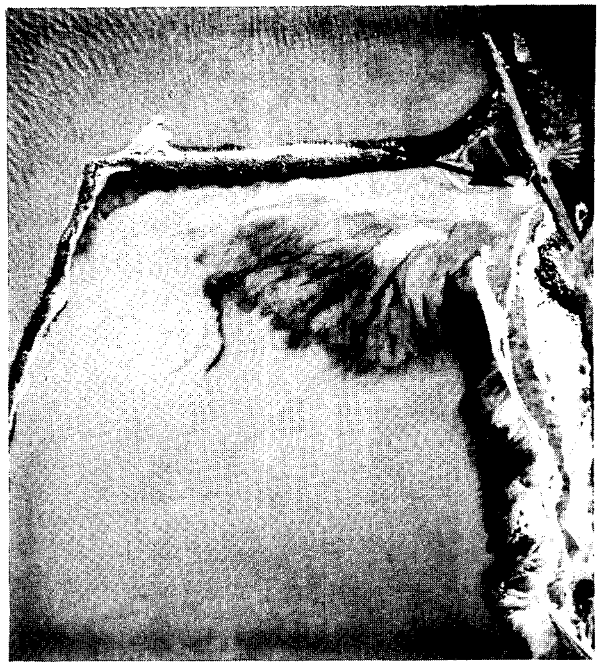


Figure 15.- Arrow points to drainage from hydraulic dredge filling in tidal marsh near Foster City, California. Note sediment pollution.

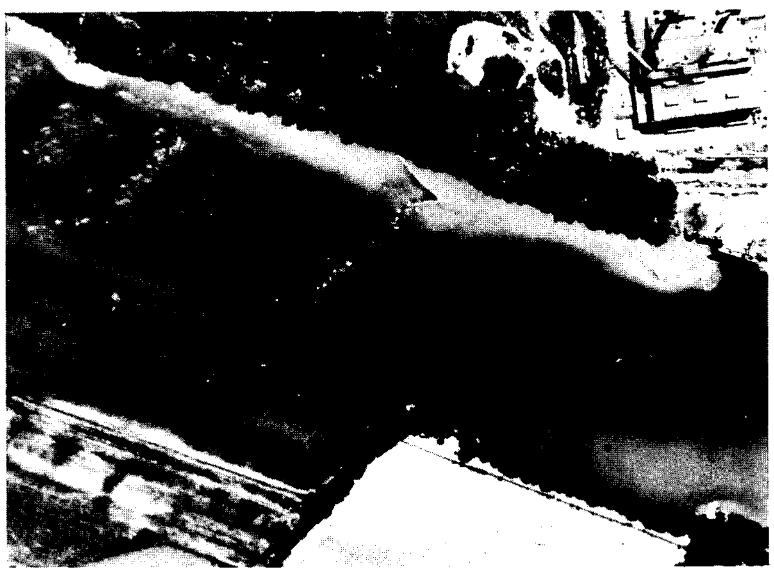


Figure 16.- Sediment pollution from sloppy soil conservation practices along both shores of Potomac River above Washington, D.C. Sediment pollution is considered to be the most serious pollutant in the Potomac. Note that almost all of the silt-laden water along the north bank enters the coolant water intake of the thermal electric generating station (Dickerson, Potomac Electric Power Company). Whether the grinding effects of this silt reduce the life of generating equipment - and indirectly raise the cost of electricity - is not known.

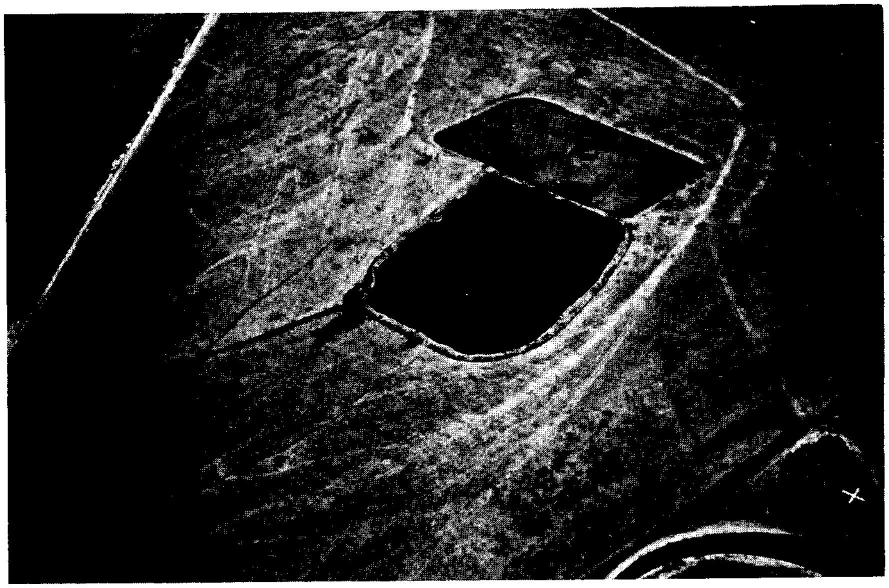


Figure 17.- Algae in stock watering pond reflecting characteristic infrared reflectance, as pictured using Kodak Ektachrome Infrared Aero Film, Type 8443.

Figure 18.- Drainage of clear, fertilizer-rich water from storm drain into muddy Big Stone Lake, Ortonville, Minnesota. Note the mats of floating green vegetation.

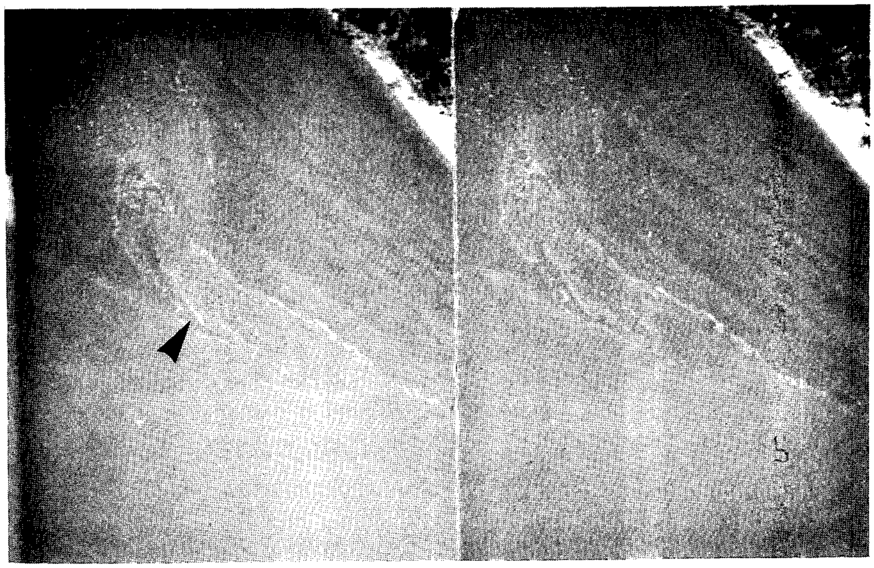


Figure 19.- A portion of the evidence in the huge fish kill which occurred in the Potomac Estuary in the summer of 1963. An estimated 78,000,000 fish, 90 percent of which were 3-year-old female white perch, littered the surface of the Potomac for 80 miles downstream from Washington, D. C.

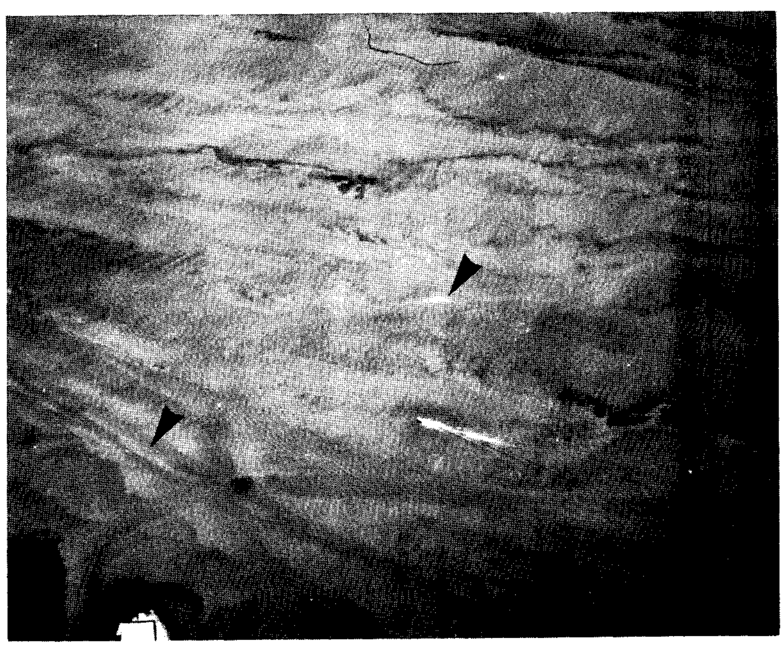


Figure 20.- Heavy bloom of green algae choking the surface of Clear Lake, Lake County, California. The algae in Clear Lake has gotten out of hand because of drainage from faulty septic systems and fertilizer-rich runoff from fields and orchards. Note that the algae is so heavy that boat wakes look much like ski trails in new snow. A Kodak Wratten 61 (green) filter was used with Kodak High Definition Aerial Film, Type 3404 (Estar thin base), to accentuate the appearance of the green algae in the water.

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Figure 21.- Note the tone changes in pond A. The lighter the tone, the greater the reflectance in the portion of the spectrum. Tone changes in this instance probably indicate different algal phylon, ranging from blue-greens through reds. Note also the tone reversals in different bands near points B, C, D, and E.

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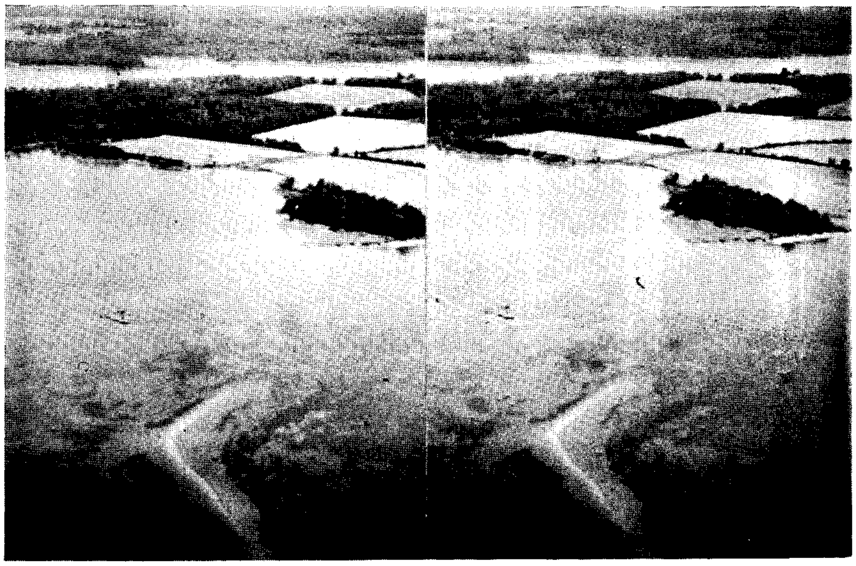

Figure 22.- Healthy green sessile vegetation in brackish water images in slightly reddish or magenta tones in Kodak Ektachrome Infrared Aero Film, Type 8443, when it is exposed using a Kodak Wratten 2A filter. This capability is helpful for detecting and mapping out that vegetation which contributes to the oxygen budget in streams and lakes. It may also contribute to better understanding of the effects of impoundment on water quality. The enhancement of the vegetation is helpful in detecting possible sources of nutrient-rich polluting substances.