*Analysis of Thermal Pollution from the Air**

CARL H. STRANDBERG,†
Principal Investigator,
U. S. Public Health Service Research Grant WP-181,
Sponsoring Institution,
General Research and Development, Inc.,
112-A Wayne St., Arlington, Va.

ABSTRACT: *Under U. S. Public Health Service Research Grant WP-181, extensive research and study is being conducted to gain a better understanding of the dispersion and diffusion of heated coolant water. Aerial photographic interpretation techniques are being used, for analyzation of heat-induced secondary effects in the aquatic environment.*

Preliminary studies have confirmed that, under certain circumstances, large areas within heated coolant water discharge zones extending from industrial outfalls exhibit distinctly different tonal characteristics. Correlation data examined to date indicates that the water in these areas is warmer than the surrounding water mass.

Studies have included extensive analysis of several of the factors which may contribute to the formation of photographically recorded "secondary" imagery, which can be recorded in the visible and near-infrared regions of the spectrum.

Analyses were also made of several types of infrared sensors which may prove suitable for analysis of temperature distribution within the aquatic environment.

A concept has been developed for the integration of a non-image-forming infrared sensor with a camera system, under which the infrared sensor will act as the "triggering" unit, activating cameras when preselected thermal limits sensed in a water mass. On completion of the "Integrated Aerial Sensor System," it is hoped that accurate isothermal maps may be rapidly compiled of surface waters.

THE THERMAL POLLUTION PROBLEM

AN ESTIMATED 40% of all of the water available in this country at any one time is used for industrial cooling.[1] Industrial expansion forecasted to take place between now and 1980 is expected to increase this demand 240%. As is recognized, thermal cooling is a largely non-consumptive use of water. Most of the surface water used for cooling is returned to the lake or stream from which it was taken, carrying with it the heat acquired in the course of its use.

The impact of heat on the aquatic environment induces many changes. Some of these may be desirable; some of them may be undesirable.

Thermal electric power plants are the largest single user of water for cooling. They are estimated to use 74.5%[2] of the total industrial coolant water demand. Their requirements in 1959 amounted to over 24 *TRILLION* gallons.[3] Thermal electric plants, on the average, heat the coolant water 12 to 13 degrees Fahrenheit, before returning it to the source from which it was withdrawn.

Extensive evaluation of thermal pollution has been made in previous studies, largely assessing of its effects from the standpoints of

* This paper was presented at the 17th Purdue Industrial Wastes Conference, Purdue Univer., West Lafayette, Ind., May 3, 1962

† Post Office Box 1553, Wheaton Sta., Silver Spring, Md.

EDITOR'S NOTE: For the privilege of publishing this paper thanks are extended to Purdue University, to the Conference for which the paper was prepared and at which it was presented, and particularly to Prof. Don E. Bloodgood, Chairman of the Conference.

conservation, natural stream purification, and water loss.

Analysis of the potential effects of heat on the aquatic environment indicate that there is an urgent need for more knowledge about the effects of thermal pollution.

It is, for instance, recognized that warming water increases its capacity for holding certain substances in solution. It is also recognized that certain kinds of fish and shellfish are natural concentrators of certain elements.[4] Some of these may be quite nutritious, others may be quite harmful.[5] It therefore logically follows that at least some of the edible marine life in heated coolant water discharge areas may become either more nutritious, or, perhaps, totally unfit for human consumption. Heated coolant water which will affect one of the areas in which it is hoped that studies can be conducted in the future, near Chalk Point, on the Patuxent River, in Maryland, will flow over three large oyster beds.[6] What effect, it is wondered, will the heated, possibly more mineralized water have on these oysters?

Several problems have been encountered in previous studies of thermal pollution. A need has been voiced for better differentiation of the boundaries of mixing zones, for instance.[7] Recent studies indicate that some of the more commonly used engineering formulas for forecasting the diffusion and dispersion of substances into flowing water, which have largely been derived following purely laboratory studies, may be in error by a factor of 6 to 10, when applied to natural streams.[8]

From the conservation standpoint, the potentially harmful effects of heat have been recognized for several years. In a paper presented before the 8th Purdue Industrial Wastes Conference, in 1953, Dr. Tarzwell, reporting on studies which started in 1931, stated that raising the temperature of a trout stream to too high a level in just one day out of the year rendered that stream unsuitable as a trout stream.[9]

In more recent studies, it has been found that other types of fish, notably small mouth bass, appear to thrive in warmer water. Studies which are still in progress indicate that fishing may be materially improved below heated coolant water outfalls. Findings to date, made with a special thermistorized fishing rod in the Potomac,[10] indicate that fish appear to prefer the heated water zone nine months out of the year. During two of the remaining months, they appear to prefer the cooler zone; and in the remaining month, they appear to have no preference. In studies conducted about 30 years ago in Iowa, Mr. Harlan, Conservation Consultant to the Division of Water Supply and Pollution Control, U. S. Public Health Service, found that certain species of game fish stopped eating entirely when stream temperatures dropped to less than 54 degrees Fahrenheit.

Apparently, the increased biotic activity induced by the warmer water increases the available food supply. This is indicated in studies which have been conducted below the Martin's Creek Pennsylvania Power and Light Company plant, on the Delaware River near Stroudsburg, Pennsylvania. These studies, being conducted by the Institute of Research, Lehigh University,[11] report that, on the average, fish taken from within the heated coolant water zone of the discharge area have been larger than those taken outside the coolant water discharge area.

From the standpoint of natural stream purification, the increase in induced biotic activity appears to speed up purification. On the other hand, in increasing the biotic activity, there is a tendency to more rapidly deplete the existing reduced supply of dissolved oxygen. In the winter time, however, heated coolant water may be very beneficial in natural stream purification. It may prevent ice from forming in a large section of an otherwise ice-locked body of water, providing an otherwise non-existent air-water surface for reoxygenation Figure 1 illustrates this beneficial situation. Heated coolant water from the Potomac Electric Power Company plant at Dickerson, Maryland, kept a stretch of water several miles long from freezing in the winter of 1960–1961, when the rest of the Potomac was frozen over for several weeks.

Several water loss investigations have been made, principally by the U. S. Geological Survey, and are well reported in the literature.[12–24]

In this investigation, efforts are being made to develop techniques which will facilitate isothermal mapping from the air. If these efforts are successful, significant savings in time and money may be realized.

In several engineering, topographic mapping, and geographic study applications, aerial photographic interpretation and aerial photogrammetric mapping regularly enable savings of 80% in time, and 40% in money.

Two types of measurement, both of which may be quite significant, may be made with extreme accuracy from the air. First, the physical size and shape of the area within the receiving waters which are subjected to increases in temperature, and second, the abso-

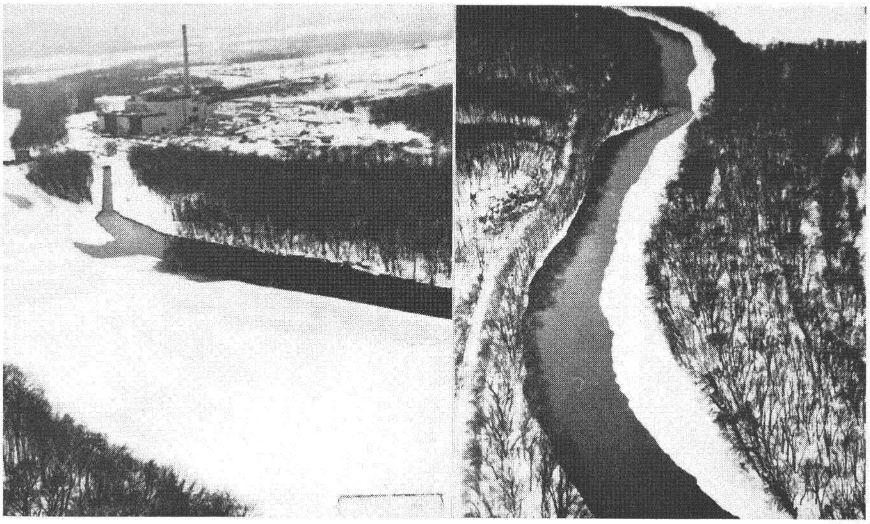

FIG. 1. Dickerson (Maryland) Thermal Electric Plant, Winter, 1960–1961 (Potomac Electric Power Company) (Potomac River).

lute and differential temperatures within the water mass.

Physical measurement of the area actually subjected to increases in temperature necessitates that, first, a distinct, measurable image must be formed. Aerial photography, or other forms of aerial sensors may be used. Aerial photography is preferred, because of greater geometric accuracy, and higher object resolution, considering the current state of the art. Special aerial photographic techniques appear necessary for picturing desired, meaningful imagery. The photogrammetric measuring techniques which may be used for actually making the necessary measurements themselves are only slightly different from those used in compilation of about 90% of the topographic maps which are now produced.

Previous improvements in the art-science of aerial photography, as they relate to picturing water masses, have largely been made in advancing the state of the art for aerial photogrammetric mapping. They have been directed either toward maximum penetration of a water mass, for more accurate analysis and mapping of the bottom, or have been directed toward minimum penetration of the water surface, for more accurate picturing of shorelines and location of inundated areas. The problem presented in this case, however, and in most of the Principal Investigator's continuing efforts to develop a rapid, efficient, economical aerial water quality reconnaissance system to augment ground methods, is to more accurately picture conditions within the water mass. Some of the earlier findings, particularly those directed toward maximum depth penetration, appear valuable in detecting and analyzing thermal boundaries.

Russian studies,[25] begun more than 20 years ago to develop methods for more accurate mapping of off-shore areas, point out several important elements. It must be remembered that the principal problem in all photography is to record differences in object brightness with maximum clarity.

Rays of light, which picture objects or conditions within a water mass, must travel through two different mediums, each having different refractive indexes, and different light absorption and light scattering characteristics.

It was found in the Russian studies that maximum penetration, that is, minimum absorption, of light in turbid water occurs in the yellow-orange sector of the visible spectrum, in which the wave-lengths of light lie between 576Mμ and 609Mμ.

The Russians also cited several important aerial photographic fundamentals relating to photography taken of water masses. Four factors are stressed which affect the relative brightness of underwater objects. Each should be given consideration when planning aerial photographic flights for the picturing of sub-surface imagery. These four factors are:

(1) *Brightness of the atmospheric haze*—the layer of atmosphere between the lens of the camera and the surface of the water.
(2) *Brightness of the water surface*, which, mirror like, reflects the sky.

(3) *Brightness of the water layer* above the object to be photographed.
(4) *Brightness of the underwater object.*

In addition, consideration must be given to three additional factors in overcoming brightness image degradation. These are:

(5) *Meteorological conditions*—state of the atmosphere, clouds and wind.
(6) *Height of the sun above the horizon*—time of day.
(7) *Flight height*—the altitude from which the photography is to be taken.

It has been demonstrated that, giving due consideration to all of these factors, best results, using panchromatic film, are usually obtained, when flights are made on:

(a) *relatively clear days*, under a high, thin cloud layer,
(b) from a *relatively low altitude*,
(c) using a *normal-angle lens aerial camera*, fitted with a yellow filter corresponding to a Wratten 16, preferably also fitted with a polarizing light filter to reduce the effect of surface wave reflections.

High shutter speeds should be used, with corresponding large relative aperture settings.

Flights should be made in the morning, when minimum haze conditions usually occur, when the sun is not less than 26 degrees, nor more then 50 degrees above the horizon, to reduce surface reflections.

The Photogrammetric Branch, U. S. Coast and Geodetic Survey, has been conducting several very significant studies[26] using aerial color film. Giving due considerations to the several factors previously cited—except that the photographic filter used was essentially minus-ultraviolet, rather than minus-blue—coverage has been taken which has permitted accurate photogrammetric mapping of the ocean floor to depths of 70 feet.

If the intent is to more accurately picture shore-lines, best results can normally be expected using infrared film and filter combinations. Infrared energy is normally completely absorbed in natural surface waters. There are exceptions, however. In preliminary tests conducted by the Principal Investigator, it was noted that light-toned patterns can sometimes be seen in water in which a great deal of algal activity is taking place. This has been noted twice in coverage taken of the Potomac River. One light toned streak detected in infrared photography was subsequently identified as a drain from the Chesapeake and Ohio Canal, which follows the Maryland shore of the Potomac above Washington, D. C.

Complete absorption of light in the 576–609Mμ region also appears to occur in water in which dissolved oxygen levels are low. Most of the outfalls, other than the outfalls associated with the heated coolant water for which search is being made under this Grant, have been detected by location of a dark streak in otherwise light-toned water. Light tones in the water appear to be caused primarily by oxygen-demanding biotic activity, based on correlation with National Water Quality data which has been examined of the areas studied. Sediment load and water color are, of course, also significant.

Heat, at the levels present in heated coolant water, or in the receiving discharge areas, will not create photographic imagery. Much higher temperatures are required. Photographic imagery can be quite successfully recorded in the spectral region extending from the ultra-violet to the near infrared, the upper limit being at approximately 1500Mμ. Emissivity from the temperature region 30 degrees Fahrenheit to 120 degrees Fahrenheit consists of electromagnetic energy extending from about 9.3 to 10.8 microns in wavelength, which is in the infrared region, well beyond that which can be photographically recorded.

If one is to analyze thermal patterns in photographic imagery, then, one must analyze secondary imagery. This is imagery induced by the heat, rather than actually picturing the heat itself.

As was stated, a photographic system is preferred, considering the current state of the art. Use of image-forming infrared sensors, while offering several significant advantages, including discrete picturing of a heated water mass because of its emissivity, offers many disadvantages. The most nearly insurmountable of these is Security Classification. In addition, most of the systems currently in use, with notable exceptions, exhibit considerable geometric distortion, and resolution well below that obtained in photography.

Studies to date support the hypothesis that thermal boundaries can be pictured by recording the significant secondary characteristics.

Some of the significant physical effects of heat on the aquatic environment are well known, but little previous effort appears to have been directed toward analyzation of these effects, from the standpoint of possible secondary photographic image formation.

The factors noted to date which appear to offer the greatest promise in photographically picturing desired meaningful imagery from the air include changes in the index of refraction, changes in density, changes in the saturation capacity for various chemical substances in solution, changes in sediment load transporting capability, and changes in biotic activity rates. In addition, alteration of capillary wave action below outfalls, and increases in evaporation rates, under certain circumstances, may aid in photographic image formation.

The index of refraction of water changes from 1.329 to 1.333 when the temperature is lowered from 120 degrees Fahrenheit to 38 degrees Fahrenheit. As the index of refraction is reduced, light of certain wavelengths will penetrate to greater depths.

The 70 foot depth obtained by the Coast and Geodetic Survey, for instance, was obtained in relatively clear water in the Caribbean, off Puerto Rico, where the average water temperature was above 70 degrees Fahrenheit.

Turbulent diffusion patterns have been noted several times to date, which appear to be caused by variations in the index of refraction of heated water in contact with cooler water. This is quite well illustrated in Figure 2. This photography was taken from 12,000 feet, of the Potomac Electric Power Company plant, at Buzzard's Point, on the Anacostia River, in Washington, D. C.

The density of water, of course, also changes with temperature. Water is at its maximum density at 4 degrees Centigrade, 39.2 degrees Fahrenheit. Its density decreases when its temperature is either raised or lowered from that level.

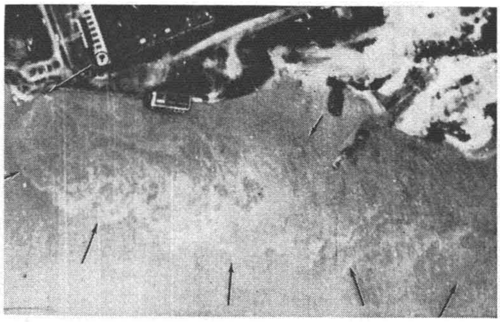

FIG. 2. Buzzard's Point Thermal Electric Plant, Washington, D. C. (Potomac Electric Power Company) (Anacostia River).

Density changes appear to account for a number of significant secondary effects, other than, of course, being the primary controlling factor in changes in index of refraction, which has already been discussed.

Density changes appear to account for variations in sediment transporting capacity. Studies currently in progress by the Geological Survey indicate that changes in temperature have a noticeable effect both on the amount of sediment transported, and on the size and type of particles.[27]

Changes in density may also cause the formation of a different form of surface wave, in certain instances. This may be the cause of the bright spectral pattern in the Connecticut River, extending from the coolant water outfall of the plant shown in Figure 3, and into Baltimore Harbor, from the thermal electric plant shown in Figure 4.

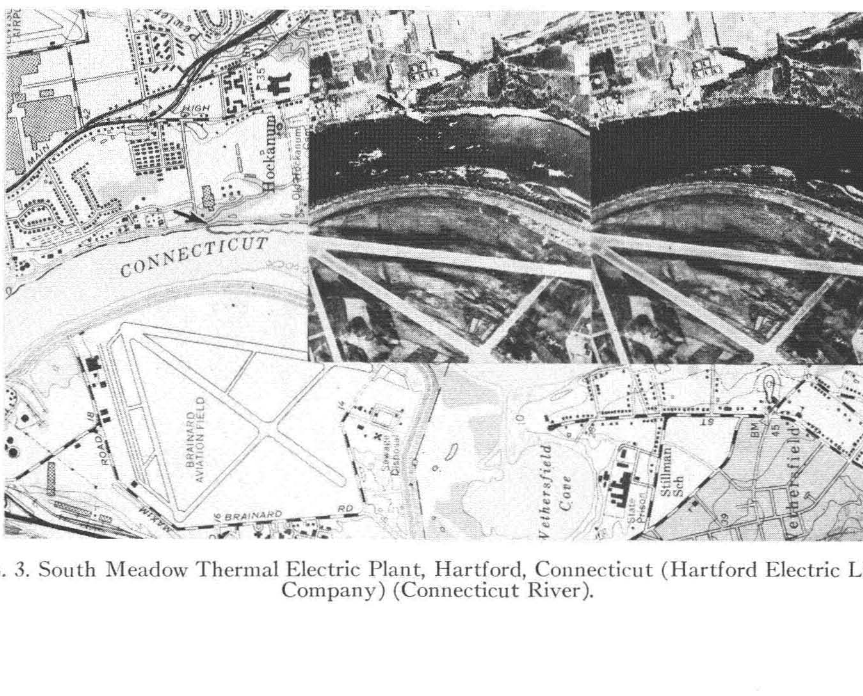

FIG. 3. South Meadow Thermal Electric Plant, Hartford, Connecticut (Hartford Electric Light Company) (Connecticut River).

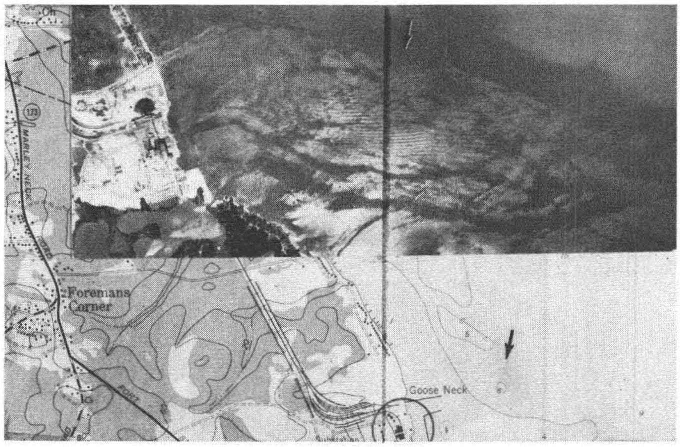

FIG. 4. Thermal Electric Plant, Baltimore Harbor, Baltimore, Maryland.

Answering the question "How do we apply these fundamentals to the detection of thermal boundaries by aerial photographic interpretation?" has been the major aim of research to date.

Aerial photographic interpretation is no "black art." It has been developed to a high state, primarily for military intelligence purposes. Essentially, when correctly applied, modern interpretive techniques permit an interpreter to study the equivalent of a precisely scaled, minutely detailed three dimensional model of the terrain. The view studied is somewhat analogous to the view a giant might get of the Earth, as shown in Figure 5. This is sometimes called the "giant eye-base" concept. Vertical elevations are usually exaggerated, as the interpreter sees them through a stereoscope. This aids identification, because low objects appear to leap out at the interpreter. This phenomenon is also potentially very important in current mapping. Differential velocities appear as changes in elevation, when viewed through the stereoscope. Extensive studies are currently in progress in Canada to develop this aspect.[28]

The basic "tools" of the photo interpreter are, as shown in Figure 6, the stereoscope, usually of two power magnification, sometimes more powerful; the "tube magnifier," a small transparent tube with a magnifying lens in one end, usually from 5 to 7 power, with a measuring reticule in the other end, and a "thousandths of a foot" scale; and perhaps other simple measuring devices.

The photo interpreter looks simultaneously at two slightly different views of the same area, through a stereoscope.

The human eye-brain combination fuses the two images, creating the impression of the precisely scaled, minutely detailed, three dimensional model referred to previously.

These are only the basic tools and funda-

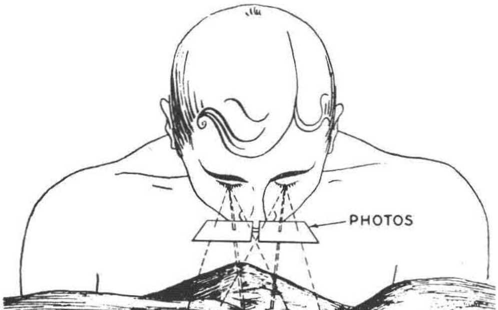

FIG. 5. "The Giant Eye-Base" Concept.

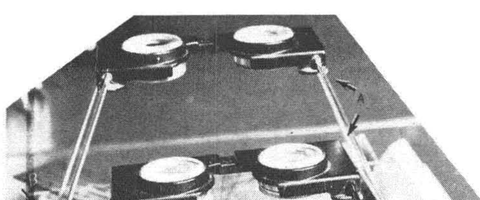

FIG. 6. The Basic Tools of Photointerpretation.

mentals, of course. Much more precise—and expensive—equipment (and techniques for its use) is available for special applications.

Images are recognized by recognition of their size, shape, shadow, tone, pattern, texture, and relationship with surrounding objects, or location.

As is generally known, aerial photographic coverage, at a scale of 1/20,000 is available of most of the United States, from the Department of Agriculture, the Geological Survey, and other sources within the Government.

In this study, preliminary aerial photographic analyses were made of several thermal electric plants, from a list of 30 provided by the Federal Power Commission, both for evaluation of the existing photography, and in further analysis of the previously listed fundamentals.

Light tonal anomalies, indicating that a greater amount of reflected light was reaching the film, were noted in a swath, extending from the outfalls of most of the plants analyzed. Most of the patterns, on initial entry into flowing streams, extend *upstream* a short distance, against the current. They then change direction, and flow downstream, hugging the bank for a considerable distance, until bank deflection elements force them away from shore. In only one instance noted did the light tonal anomaly, still in visible laminar form, just disappear.

These conditions are also illustrated in Figure 7, a current diagram prepared by the Maryland Water Pollution Control Commission, of flows from the Potomac Electric Power Company plant at Dickerson, Maryland, into the Potomac River. The Dickerson plant, rated capacity 350 MW, enters the river, rises to the surface, and hugs the Maryland shore for several miles. This condition is only marginally visible in the sediment-laden high water flows shown in Figure 8, taken early in April, 1962, from an altitude of 2,000 feet.

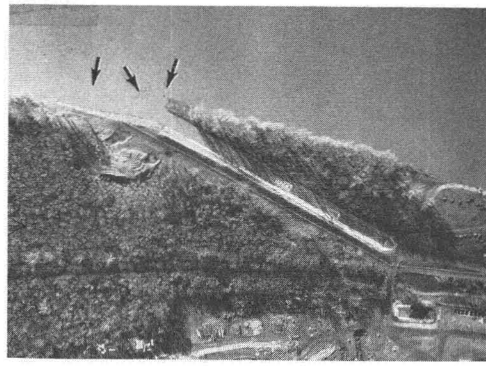

FIG. 8. Vertical Aerial Photograph, Heated Coolant Water Discharge Area, Dickerson (Maryland) Thermal Electric Plant.

As the water progresses downstream, the heated coolant water is deflected into the narrow channel between Mason Island and the Maryland shore. On leaving this channel, it encounters a small island. Turbulent flows are exhibited near the downstream end of this island.

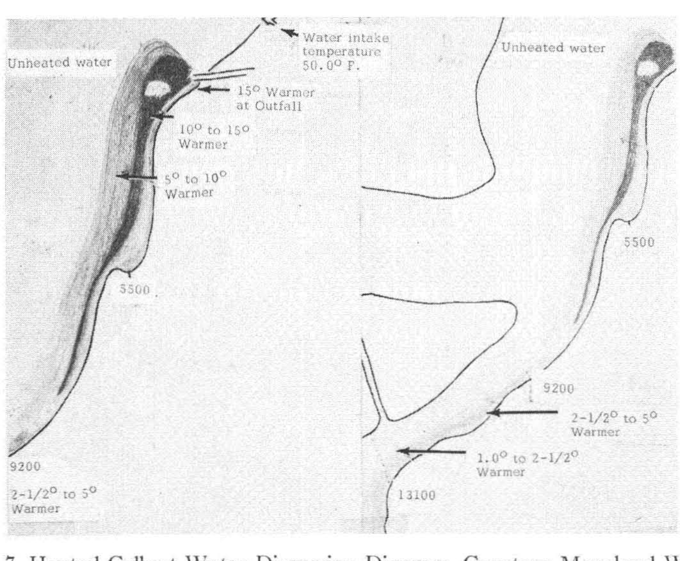

FIG. 7. Heated Collant Water Dispersion Diagram, Courtesy Maryland Water Pollution Control Commission.

FIG. 9. Raritan River Thermal Electric Plant Sayreville New Jersey (Jersey Central Power and Light Company) (Raritan River).

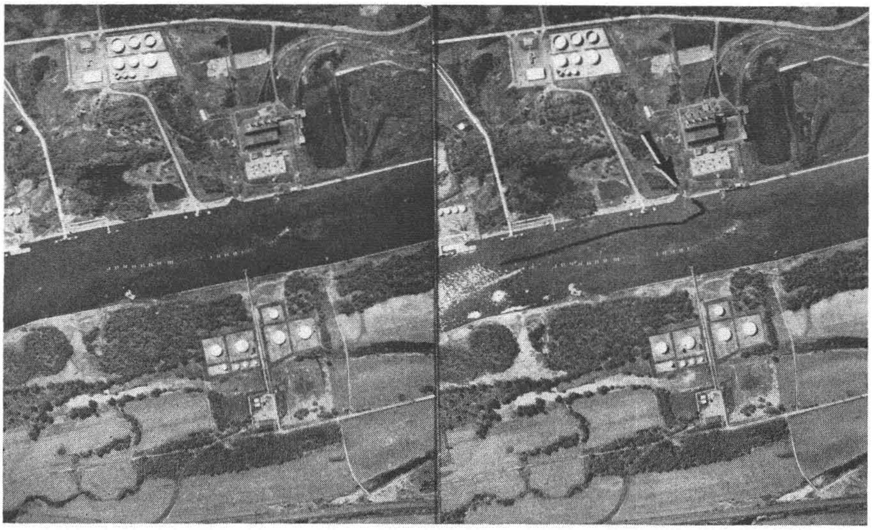

FIG. 10. Thermal Electric Plant, Albany, New York, Hudson River.

A similar "shore hugging" phenomenon appears to exist below the Raritan River Jersey Central Power and Light Company Plant on the Raritan River, near Sayersville, New Jersey, shown in Figure 9.

This condition is perhaps even more evident in flows below the Albany plant of the Niagara Mohawk Power Company, Albany, New York, on the Hudson River, shown in Figure 10. (Note: Plant identity unconfirmed.)

Only slightly different conditions were noted below the Martin's Creek Pennsylvania Power and Light Company plant, near Stroudsburg, Pennsylvania, on the Delaware River, illustrated in Figure 11. Here, Big Kaypush Rapids, and a series of groins constructed along the western shore of the river appear to force the heated coolant water out into the main channel soon after exit from the discharge canal. Subsurface water, however, appears to enter the river in considerable volume just above Big Kaypush Rapids, forcing the surface riding heated coolant water back along the western bank of the river. The heated collant water continues downstream along the western bank, past the railroad bridge, until complete diffusion occurs in Little Kaypush Rapids, further downstream.

This analysis, performed entirely by aerial photographic interpretation, agrees in detail with findings by the Institute of Research, Lehigh University, except for the probable entry of subsurface water above Big Kaypush Rapids. A probable current-induced spectral pattern extends from a trace on the east bank of the river which may mark the location of a crustal fracture trace.

Indications that the heated coolant water hugs the shore were noted below the Titus Metropolitan Edison plant, shown in Figure 12, and the Shawville Pennsylvania Electric Company plant, shown in Figure 13.

A slightly different condition was noted below the Sunbury Pennsylvania Power and Light Company plant near Shamokin Dam, Pennsylvania, as shown in Figure 14. Here, a bright, probably wave-induced spectral pattern originates near the outfall, and extends a considerable distance downstream.

The course of flow into the ocean appears to follow a different pattern.

The flow from the Salem plant, New England Power Company, at Salem, Massachusetts into Salem Harbor, is shown in Figure 15. Here, the flows appear to be initially vortical, when viewed stereoscopically. They subside to the right, around the end of the groin seen in the illustration, then rise to the surface, and extend far out to sea as a laminar flow. Essentially this same condition can be seen in flows from the Baltimore Harbor thermal electric plant illustrated in Figure 4. Here, the flows appear to be differentiated by the same type of spectral wave pattern previously illustrated in some of the flows entering streams.

Several problems have been encountered in analyses.

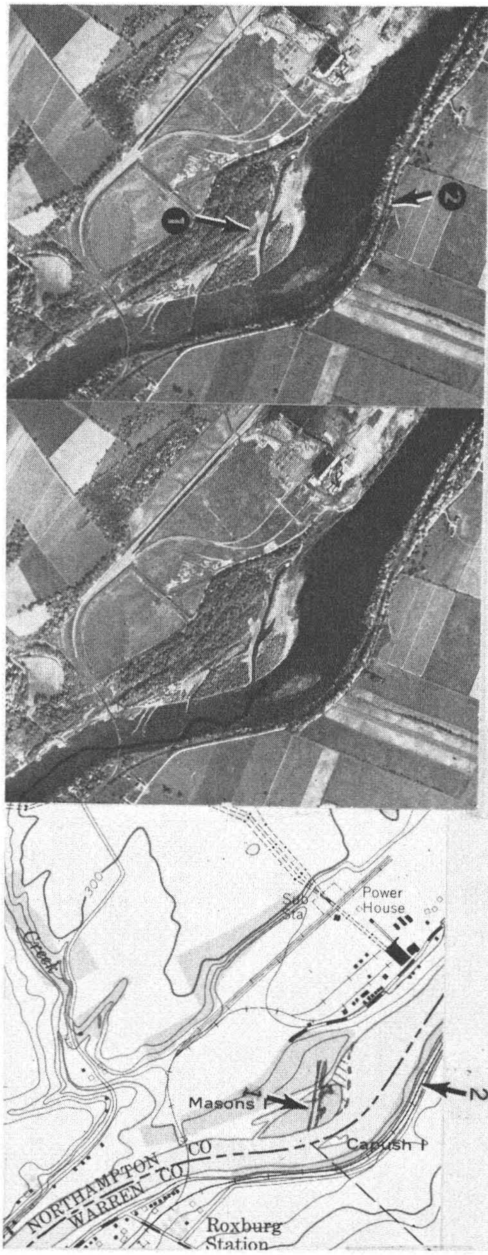

FIG. 11. Martin's Creek Thermal Electric Plant, near Stroudsburg, Pennsylvania (Pennsylvania Power and Light Company) (Delaware River).

First—insufficient base-line data, in most instances. It is axiomatic among photo interpreters that the more knowledge one takes to the photography, the more information one will extract from them. Additional desirable base-line data, it is felt, should include:

(1) Depth, width, and contour of stream channels.
(2) Location and deflection angle of bank deflection elements.
(3) Locations of obstructions of any sort in the stream channel, which may induce turbulence.
(4) Seasonal water temperature profiles.
(5) Types and amounts of flora and fauna present in the water, and induced turbidity values.
(6) Volume and velocity of seasonal flows.
(7) Location, volume and velocity of tributary streams.
(8) Location, volume and velocity of known entering subsurface flows.
(9) Composition of stream channel material, to include:
 (a) porosity
 (b) chemical composition
 (c) particulate types and sizes
 (d) specific weight of particles

It should be pointed out that many of these desirable elements can probably be determined in detailed analysis of large-scale, preferably multiband, aerial photography, including aerial color, and probably less expensively than by the type of detailed ground data collection program required. "Field checking," of course, must also be done, but this is simplified if it follows preliminary interpretation.

In addition to the listed items, of course, National Water Quality Summary data, and some of the additional data being collected by the U. S. Geological Survey, and published in the Water Supply Papers has proved very helpful in analysis.

Following the preliminary photographic analyses phases, a detailed survey was made of infrared equipment suitable for use from the air, which might prove valuable in analysis of the dispersion and diffusion of heated coolant water.

Infrared instruments suitable for monitoring heated coolant water must be passive systems which have a short time constant to respond to temperature changes in the water mass, and to the forward motion of the aircraft. The angle of view of the instrument must isolate critical water masses. If possible, the instrument should permit differentiation of boundary layers of heated to cooler water. The temperature response of the instrument must include the spectral region extending from 9.3 microns to 10.8 microns which corresponds to the critical temperature range.

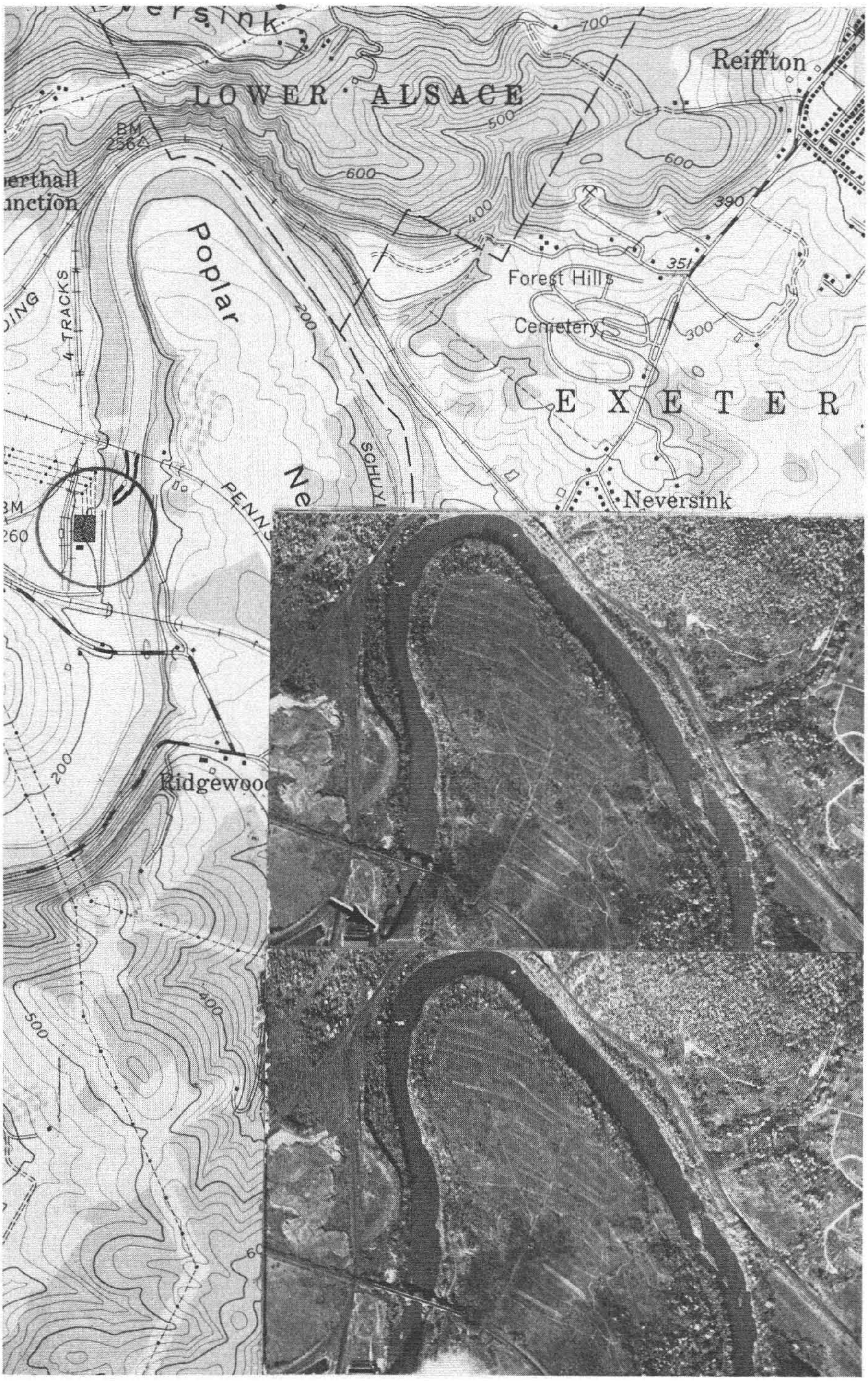

FIG. 12. Titus Thermal Electric Plant, Reading, Pennsylvania (Schuylkill River) (Metropolitan Edison Company).

FIG. 13. Shawville Thermal Electric Plant, Shawville, Pennsylvania (Susquehanna River) (Pennsylvania Electric Company).

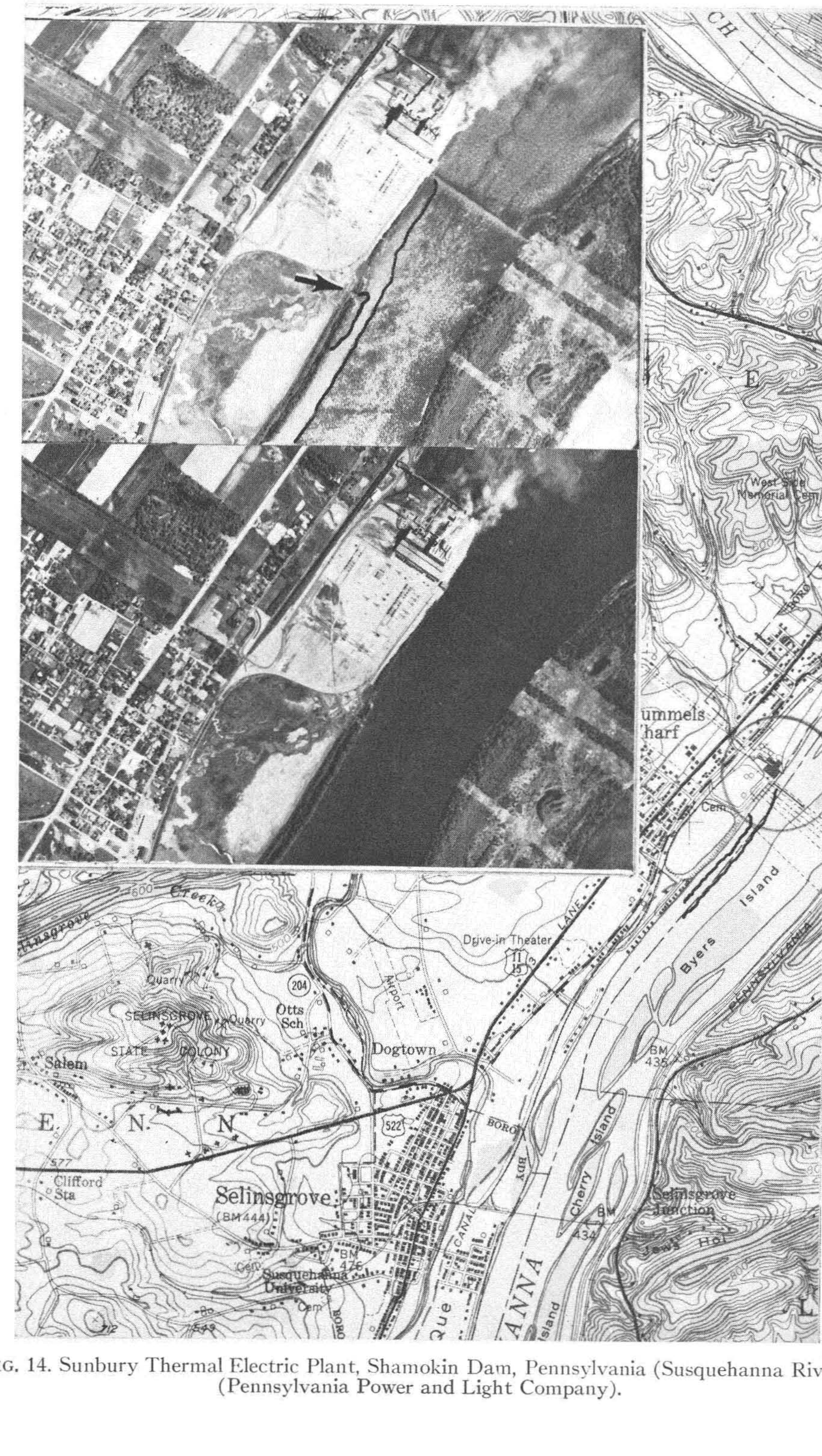

FIG. 14. Sunbury Thermal Electric Plant, Shamokin Dam, Pennsylvania (Susquehanna River) (Pennsylvania Power and Light Company).

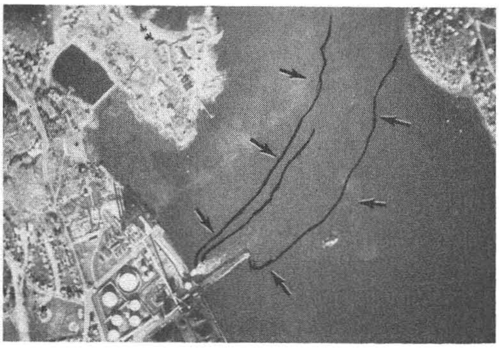

FIG. 15. Salem Thermal Electric Plant, Salem, Massachusetts (Salem Harbor) (New England Power Company.)

Physical size of the instrument, and its power requirements must correspond to the aircraft in which the instrument is to be mounted.

Remote temperature measurements can be made with extreme accuracy from the air, using various types of infrared sensors. One type of aerial infrared sensor, for instance, reportedly has an accuracy of .006 degree Centigrade, from an altitude of several thousand feet.

Letters of inquiry were sent to twenty-four manufacturers of infrared instrumentation which might prove suitable as the triggering element of an Integrated Aerial Sensor System. Analyses of the products of these companies led to the conclusion that two instruments were most suitable.

One of these is the Barnes Model 14-310 Portable Radiation Thermometer, manufactured by Barnes Engineering, 30 Commerce Road, Stamford, Connecticut.

The second instrument is the Block 14T, manufactured by Block Engineering, Cambridge, Massachusetts.

These two instruments are essentially noncompetitive. Each has unique capabilities for sensing conditions in the aquatic environment, which may well serve to greatly increase our knowledge.

Under the Integrated Sensor Concept, it is hoped that the infrared sensor can be used to trigger two 35 mm. cameras, in vertical mounts, when heated coolant water raises the average temperature of the receiving stream 1°F.

In operation, aerial data collection under this concept will follow this sequence:

1. On reaching a preselected point in a flight path approaching a thermal outfall, the aerial instrument operator (or pilot) turns on an infrared sensor for warm-up. Selection of this point depends on speed over the ground approaching target, and required instrument "warm-up" time.

2. On reaching a second preselected position, the aerial instrument operator (or pilot) turns on a single switch activating the infrared sensor recorder and a K-24 "base" cover camera.

3. When the infrared sensor senses that the average temperature of the receiving stream is raised 1°F. above a pre-set temperature (the temperature of the river above the plant intake) the sensor will activate the two 35 mm. cameras, each of which will probably be loaded with specially selected films and fitted with selected filters or filter combinations. This will permit collection of "multiband" coverage. Pictures taken with each camera will be spectrally different from those taken with the other cameras. All pictures will be taken at almost exactly the same time, optical axes vertical and parallel. Time variation is unavoidable between the K-24 and the 35 mm. cameras, if 60% overlap is maintained with the 35 mm. cameras, as is desired, because of differences in format shape and size. Fortunately, this variation is considered to be of only minor importance in subsequent analysis.

4. The 35 mm. cameras will cease operating when the infrared sensor detects that the average temperature of the stream has dropped to less than 1°F. above the pre-set temperature.

A map illustrating the type of coverage which it is hoped that this system will produce is shown as Figure 16.

It is planned that the Integrated Aerial Sensor Concept be developed and employed in subsequent phases of the investigation, if continuation of this program is authorized.

In conclusion, let me say that it is hoped that the knowledge that has been gained in the initial phase of this investigation is as valuable in furthering our knowledge about the aquatic environment, as the investigation has been fascinating to conduct.

BIBLIOGRAPHY

1. Woodward, D. R., "Availability of Water in the U. S. with Special Reference to Industrial Needs by 1980." Washington, D. C., 1957.
2. "Water Requirements of Electric Utility Steam-Electric Plants in 1959." Federal Power Commission.
3. "Steam-Electric Plant Construction Cost and Annual Production Expenses"—thirteenth Annual Supplement, 1960. Federal Power Commission.
4. Personal Communication, Dr. Richard H. Strain, Strong Memorial Hospital, Rochester, New York.
5. Proceedings—"Conference on Physiological Aspects of Water Quality." U. S. Public Health

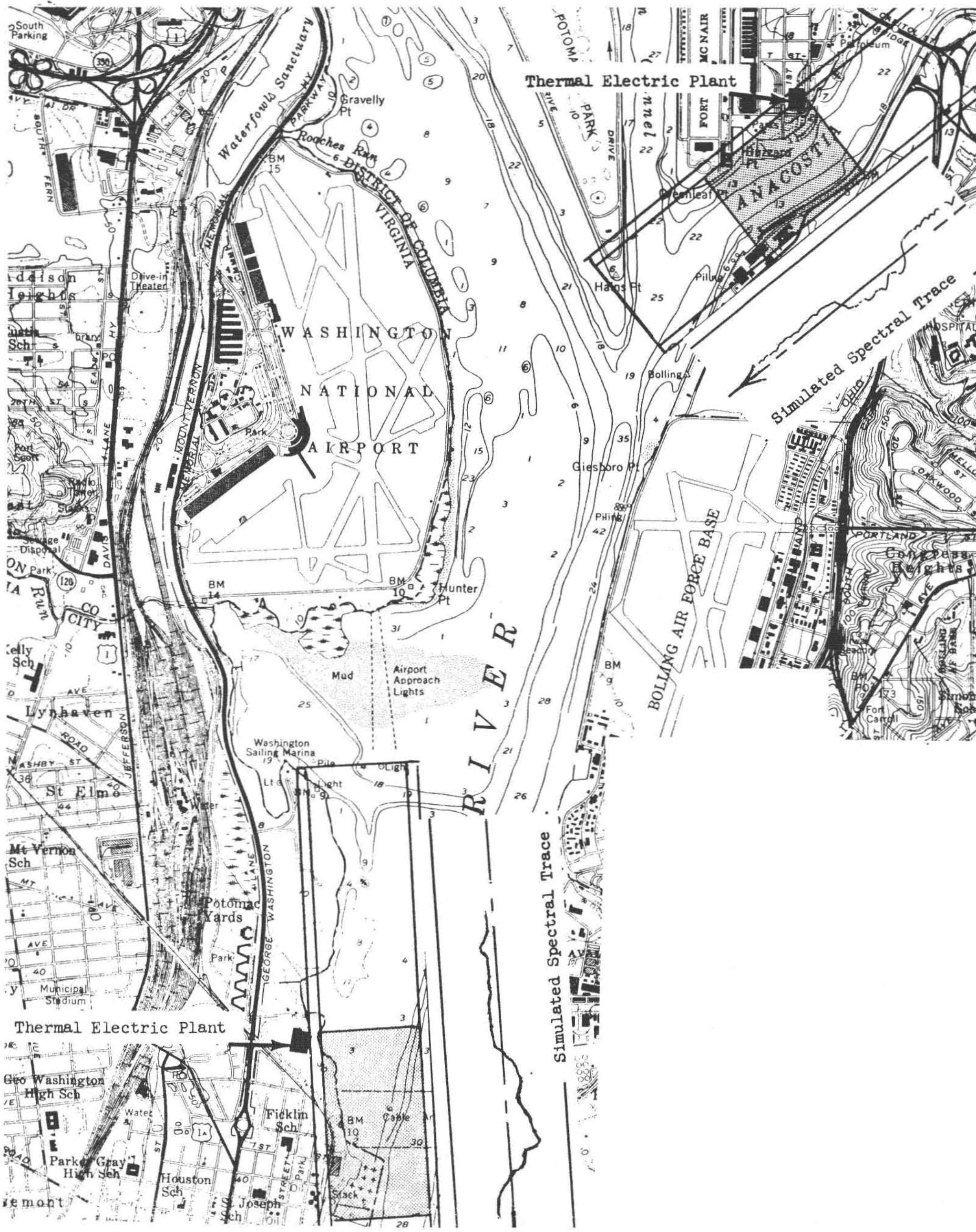

Fig. 16. Simulated Coverage Diagram—Integrated Aerial Sensor Systems

Service, Washington, D. C., September 8–9, 1960.

6. Personal Communication—Mr. Paul McKee, Chairman, Maryland Water Pollution Control Commission, Annapolis, Maryland.
7. "The Thermal Pollution Problem," Dr. Richard D. Hoak, Journal of the Water Pollution Control Federation. December, 1961.
8. Personal Communication—Mr. R. G. Godfrey U. S. Geological Survey, Director of Project Number 3254 "Dispersion in Natura Streams."
9. "Some Important Biological Effects of Pollution Often Disregarded in Stream Surveys." Purdue University Engineering Bulletin "Proceedings of the 8th Industrial Wastes Conference—May 4, 5, 6, 1953." Dr. Clarence M. Tarzwell.
10. Personal Communication—Mr. Harold Elser. Maryland Department of Game and Inland

Fisheries. Annapolis, Maryland.
11. "Research Project on Effects of Condenser Discharge Water on Aquatic Life." Progress Report 1956 to 1958. The Institute of Research, Lehigh University. October 1, 1959.
12. "Effect of Addition of Heat from a Power Plant on the Thermal Structure and Evaporation of Lake Colorado City, Texas." *U. S. Geological Survey Professional Paper* 272-B.
13. "The Use of Reservoirs and Lakes for the Dissipation of Heat." U. S. Geological Survey Circular 282.
14. "Water Loss Investigations: Lake Mead Studies." *U. S. Geological Survey Professional Paper* 298.
15. "Water Loss Investigation: Lake Hefner Studies." Technical Report. *U. S. Geological Survey Professional Paper* 269.
16. "Pond Cooling by Surface Evaporation." D. O. Lima, *Power*, Vol. 80 (1936), No. 3, pp. 142–144.
17. "How to Predict Lake Cooling Action." R. F. Thorne, *Power*, Vol. 95 (1961), No. 9, pp. 86–89.
18. "Cooling Ponds May Answer Your Water Cooling Problem." J. W. Langhear, *Chemical Engineering*, August 1953, pp. 194–198.
19. "The Use of Surface and Ground Water for Cooling Purposes for Steam Electric Generating Stations in Texas." M. G. Salzmann *ASCE Proceedings*, Vol. 82, August 1956, Paper No. 1044.
20. "Report on the Behavior of Power Station Cooling Ponds." N. Lamb, Assistant Engineer, Projects Division, Power Development Branch, The Electricity Commission of New South Wales, Australia.
21. "Forecasting Heat Loss in Ponds and Streams." C. J. Velz and J. J. Gannon *Journal of the Water Pollution Control Federation*, April 1960, p. 392.
22. "Cooling Pond Design in the South West." T. J. Cotter and A. W. Lotz, *Proceedings of the ASCE, Journal of Power Division*, PO 2, July 1961.
23. "Condensing Water—How Does It Affect the River?" Melvin D. Engle, *Mechanical Engineering*, Vol. 82, No. 1, January 1961.
24. "Heated Discharges—Their Effect on Streams." A Report by the Advisory Committee for the Control of Stream Temperatures to the Pennsylvania Sanitary Water Board, January 1962. Division of Sanitary Engineering, Bureau of Environmental Health, Pennsylvania Department of Health, Harrisburg, Pennsylvania.
25. "The Procurement of Aerial Photography of Underwater Objects. An Analysis of the Problem by Russian Scientists." Appendix C. Chapter 2, MANUAL OF PHOTOGRAPHIC INTERPRETATION, American Society of Photogrammetry, 1960. (Editor in Chief, Dr. Robert N. Colwell, Department of Forestry, University of California.)
26. Personal Communication—Mr. William D. Harris, Chief of Photogrammetric Research, U. S. Coast and Geodetic Survey, Washington, D. C.
27. Personal Communication—Mr. D. M. Culbertson, U. S.. Geological Survey, Lincoln, Nebraska. Director of Project Number 2701 "Sediment Transport Investigations."
28. Personal Communication—Professor H. L. Cameron, Nova Scotia Research Foundation, Halifax, Nova Scotia (Canada).

ACKNOWLEDGMENTS

A great number of persons, both professional photointerpreters and professional personnel in other arts and sciences have willingly assisted the Principal Investigator in this Research. So many, in fact, that it is difficult to name them. Particular gratitude is expressed to:

Mr. Harry Faber, Chief, Research and Training Grants Branch, Division of Water Supply and Pollution Control. USPHS.
Mr. James Coulter, Chief Water Projects Section, Technical Services Branch, Division of Water Supply and Pollution Control, USPHS.
Dr, Richard A. Geyer, Chief Oceanographer, Texas Instruments, Inc., Dallas, Texas.
Dr. D. W. Pritchard, Chesapeake Bay Institute, Johns Hopkins University.
Dr. William H. Strain, Strong Memorial Hospital, Rochester, New York.
Mr. S. V. Griffith, Bureau of the Budget, Washington, D. C.
Dr. Ralph Fuhrman, Water Pollution Control Federation, Washington, D. C.
Mr. Paul W. McKee, Director, Maryland Water Pollution Commission.
Mr. Sylvin Belkov, District Engineer, Maryland Water Pollution Control Commission.
Dr. Frank Schwartz, Chesapeake Biological Laboratory, Soloman's, Maryland.
Mr. Richard G. Godfrey, U. S. Geological Survey.
Mr. Harold Elser, Maryland Department of Game and Inland Fisheries.
Mr. William D. Harris, Chief, Photogrammetric Research, U. S. Coast and Geodetic Survey.
Mr. D. M. Culbertson, U. S. Geological Survey.
Professor Charles E. Olson, Jr., Chairman, Committee on Aerial Photography, University of Illinois.
Professor H. L. Cameron, Nova Scotia Research Foundation, Halifax, Nova Scotia, Canada.
(Mrs.) Malin Sundberg-Falkenmark, Royal Institute of Meteorology and Hydrology, Stockholm, Sweden.
Dr. Robert N. Colwell, University of California.
Dr. Myron Block, Block Engineering, Cambridge, Massachusetts.
Mr. Ansel Gere, Engineering Service Associates, Washington, D. C.
Mr. Wendell M. Smith, Barnes Engineering, Stamford, Connecticut.
Mr. O. L. Hooper, Chief Hydraulic Engineer, Stone and Webster Engineering Corporation, Boston, Massachusetts.
Mr. Page Truesdell, U. S. Naval Photographic Interpretation Center, Suitland, Maryland.
Mr. Charles G. Coleman, U. S. Naval Photographic Interpretation Center.
Mr. William Fischer, U. S. Geological Survey.
Dr. Jack Van Lopik, Texas Instruments Inc., Dallas, Texas.
Mr. Edward Tinsley, Chief, Geosciences Department, Science Services Division, Texas Instruments, Inc., Dallas, Texas.
Mr. Julian F. Arntz, Jr., U. S. Navy.
Dr. Robert H. L. Howe, West Lafayette, Indiana.
Dr. Don E. Bloodgood, Chairman of this Conference, and, of course,
My fellow employees at General Research and Development, Inc.