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THE USE OF REMOTE SENSING TO OBTAIN DATA FOR DESCRIBING THE LARGE RIVER

Interim Report

THE USE OF REMOTE SENSING TO OBTAIN DATA FOR DESCRIBING THE LARGE RIVER

INTERIM REPORT

Submitted to:

Potamology Section
River Stabilization Branch
Department of the Army
Vicksburg District, Corps of Engineers
Vicksburg, Mississippi

Prepared by

Civil Engineering Department
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INTRODUCTION

The control of river systems for the benefit of mankind represents one of the most challenging tasks facing the engineer today. Rivers are in a constant state of dynamic readjustment to meet varying constraints imposed by either man or nature. One of the main characteristics of a river is that it is constantly changing and in some instances may be changing very rapidly. Man's effort to impose control and direction to a river may produce totally unpredicted behavioral trends both upstream and downstream from such man-made activities.

Man's ability to understand the behavior of a river depends both on a good basic theoretical approach as well as long-term, real, practical experience with the performance of a given river system. The behavior of a river is the result of the complex interaction of many individual flow phenomena related to the fluid and the boundary. Adequate theory is not yet available to account for this complex interaction in order to accurately predict the behavior of a river. Consequently, the river engineer must rely very heavily on his own personal experience with a river system and continually strive to develop a practical understanding based on general observations and measured parameters at key locations.

General visual observations by man are dependent upon the reflectance characteristics of the scene within the visible portion of the spectrum and obviously limits the amount of information that a person may obtain. Additional understanding of the behavior of a river can be obtained by looking in portions of the spectrum other than just the visible. In addition it would be most helpful if an image (or a picture) could be developed for the invisible portion which would give an overall view of the particular scene in some form of a workable format.

Photography and imagery obtained in the visible and the invisible regions of the electromagnetic spectrum provide an unique, quasi-synoptic record of the scene of interest. This media of data recording represents a continuum of information rather than point information. In addition the synoptic character of a particular phenomenon at a particular instant of time can be recorded in a variety of ways. This characteristic of data collection is not practical with conventional point sampling procedures. A much improved data collection process can be achieved by combining aerial photography and imagery with conventional point sampling.

OBJECTIVE

The general objective of this project was to obtain photographic and imagery coverage of selected reaches of the Mississippi River in the Vicksburg district using precision mapping camera photography, multiband photography, and thermal infrared imagery; and to interpret and extract useful information from such records. Qualitative **interpretation** of the three forms of record were intended to relate to the following characteristics: flow patterns, suspended sediment distribution, surficial sediment deposits and erosion patterns, potential earthslide areas along the banks, vegetation (type and extent), soil type and moisture content on the flood plain and banks and in the levees, water depth effects, bedform effects, effect of man-made structures on the flow and the sedimentation patterns, temperature patterns at the surface of the water, direct water-depth determinations and sediment concentration (suspended sediment concentration) measurements, and the general ecology of the study reaches.

In conjunction with actual measurements from the precision mapping camera photography, the study was to include a limited analysis of the ability to use modern analytical **photogrammetry** techniques pertaining to the shape of certain features: radius of bends, shape of middle, point, and alternate bars, shape of bank erosion and volume estimates of erosion and sedimentation processes, water-surface flow patterns, slope of water surface (along the banks and the middle bars), flow velocities from floating debris in the channel, areal size and distribution of the eddies and boils, channel widths, height and spacing of standing waves related to structures, and the dimensions of surface flow patterns induced by river control structures.

Due to the tremendous variation in flow characteristics present in the river depending on the stage of the river, two flights were planned: one during low-water and one during high-water stage. Provided that the first flight illustrated the practical application of remote sensing, a second flight would be performed over the same two test sections. An interim period between these two flights would be necessary, however, in order to judge the effectiveness of the data from the first flights and the potential for performing a second flight during high water. In this regard, a meeting was scheduled to be held at Colorado State University as soon as some objective results were available from the first flight data.

PROCEDURE

The Potamology Section of the Vicksburg district selected two test sites in the vicinity of Vicksburg. These sites were: 1.) "The north site"; extending from approximately mile 476.0 to mile 494.0; and, 2.) "The south site"; extending from approximately mile 417.0 to mile 407.0. In addition, over a section of the north site, (from approximately mile 486.0 to mile 488.0), control surveys were accomplished and targeted points provided for use in subsequent analytical photogrammetry procedures.

An onsite visit was accomplished prior to the flights by the project co-directors and by certain members of the Potamology Section of the Vicksburg district involved in the remote sensing project. At this time coordination efforts were made for flight planning and routine sampling on the study reaches. The plan was to overfly the test sites concurrently with onsite sampling, thus providing relevant ground truth for use in interpreting the photography and imagery.

The following members comprised the Vicksburg Remote Sensing Committee:

1. Brien R. Winkley, Chief, Potamology Section, Vicksburg District;

2. Patrick C. Harris, Potomology Section, Vicksburg District;
3. Omega H. Shamblin, Chief, Survey Branch, Vicksburg District;
4. Ernest B. Lipscomb, Chief, Potamology Research Branch, Mississippi River Commission;
5. William K. Dornbusch, Jr., Geology Branch, Waterways Experiment Station.

The Survey Branch and Potamology Section of the Vicksburg District planned and collected the ground control and ground truth information.

An advisory team at Colorado State University was formed at the time of the initiation of this work and the advisory team was convened several times during the conduct of the interpretation. Three members of the Vicksburg Remote Sensing Committee and the CSU advisory team met at Colorado State University to discuss the results. The CSU advisory team and the Vicksburg Remote Sensing Committee also reviewed and made comments on this report.

The Colorado State University Advisory team members for the Vicksburg study were:

1. D. B. Simons and M. M. Skinner, Project co-directors;
2. J. F. Ruff, multiband photography and thermal infrared imagery;
3. A. H. Barnes, Photogrammetry;
4. E. V. Richardson, River mechanics;
5. C. F. Nordin, River mechanics;
6. S. A. Schumm, Geomorphology;
7. H. W. Shen, River mechanics;
8. M. A. Stevens, River mechanics;
9. J. E. Cermak, Fluid mechanics.

Ground control and ground truth

The ground control that was established over a selected portion of the "north site" is shown in Appendix A. First order accuracy was established in the survey for both the vertical and horizontal control. Mr. Shamblin's office of the Survey Branch placed the targets and provided the survey results. Four-feet-square panels with a maltese cross painted in the panel and three-legged streamers were used. The streamers were 20 feet long by 2 feet wide. The maltese crosses were a beige color on a black background and showed up as white on black in the color infrared photography.

Ground truth information taken only at selected ranges consisted of near-surface water temperatures, near-surface suspended sediment concentrations, velocities and depths. This ground truth information is given in Appendix B. Hydrographic Survey maps were also available (surveys of 23 July - 2 August 1971).

Data collection and preparation

Four remote sensing systems were used to collect data over the two Mississippi River test sites. The four systems were: 1.) a Wild RC-8 precision mapping camera; 2.) an International Imaging Systems Mark I multiband camera; 3.) an AGA Thermovision; and, 4.) a Bendix LN-2 thermal infrared line scanner.

The Wild RC-8 precision mapping camera was equipped with a 6-inch Universal Aviogon lens. It produced a 9 x 9-inch photograph with minimum distortion and high resolution. Two types of film were used in the RC-8 camera: Kodak Aerochrome Infrared Film 2443, estar base, specification 981, exposed through a .5μm cutoff yellow, 2.2 antivignetting filter; and, Kodak Aerocolor Negative Film 2445, estar base, specification 981, exposed without a filter. The filter was removed because of the poor lighting conditions due to excessive cloud cover.

The International Imaging Systems Mark I multiband camera was a modified K-22 camera body and mechanism. The camera was equipped with a matched set of four Schneider Xenotar lenses with 150 mm focal lengths. The 150 mm lens was purposely selected to match the scale of the photography taken with the Wild RC-8 camera. Filters used on the multiband camera were Wratten #47 B (blue), Wratten #57A (green), Wratten #25 (red), Wratten #88 A(infrared).Infrared blocking filters were also included in the optical train with the #47 B, #57 A, and #25 filters to produce photography in essentially the four spectral bands of blue, green, red, and photographic infrared. Four images, nominally 3.5 inches x 3.5 inches, were exposed on a 9-inch x 9-inch masked film format. The focal plane shutter had a transit time between optical axes of orthogonal sets of frames of approximately 50 milliseconds. The film used in the multiband camera was Kodak Infrared Aerographic Film 2424, estar base, specification 949.

An AGA Thermovision system 680 was used for the preliminary reconnaisance flights. The system consisted of an infrared camera and a connected display unit. The AGA Infrared 134 mm, f/1.8, $10^\circ \times 10^\circ$ standard lens was used on the camera head. The detector was indium antimonide (InSb) photovoltaic, sensitive in the spectral range from 2 micrometers — 5.6 micrometers. Liquid nitrogen was used to cool the detector. The display unit consisted of an AGA manufactured enlarged view television monitor tube which provided a picture size of 3.5 inch x 3.5 inch. Sixteen frames per second are displayed on the unit. The AGA thermovision unit can be used to observe in real time; or the output can be recorded on film; or on magnetic tape for later playback and analysis. The purpose for the unit used for these studies was only for real-time viewing on the television monitor; the objective use being to get some feeling for the overall river temperatures and to locate any temperature anomalies for later recording with the line scanner.

The Bendix LN-2 thermal line scanner had an instantaneous field of view of 2.5 milliradians. The lateral scan angle was nominally 120°, however, when installed in the CSU Aero-Commander the usable field of view was reduced to about 90°. The unit was equipped with a mercury-cadmium-telluride detector, sensitive in the spectral region from 8-14μm, and cooled with liquid nitrogen. The signal from the detector was used to modulate a glow tube which in turn produced imagery recorded on Kodak 70 mm film, RAR 2498, estar-AH base, specification 475.

The Kodak Aerochrome Infrared Film 2443, exposed in the Wild RC-8 precision mapping camera, was processed to a positive transparency. A duplicate positive transparency was made of each of the original rolls of film.

The Kodak Aerocolor Negative Film 2445, exposed in the RC-8 precision mapping camera, was processed to a negative transparency and control prints were made.

The Kodak Infrared Aerographic Film 2424, exposed in the multiband camera, has a spectral sensitivity from about .4 micrometers to about .9 micrometers. Due to the extremely poor lighting conditions encountered during the photographic missions, the correct exposures could not be maintained in some cases. The following shutter speeds and aperture openings were most commonly used:

Band No.	Filter No.	Shutter Speed	Aperture
(1)	No. 47B (Blue)	1/400 second	f/5.6
(2)	No. 57A (Green)	1/400 second	f/4
(3)	No. 25 (Red)	1/400 second	f/3.5
(4)	No. 88A (Infrared)	1/400 second	f/11

The 2424 film, exposed in the multiband camera, was processed to a negative transparency, and a positive transparency was then duplicated for use on the Mini-Adcol viewer.

The Kodak 70 mm film, exposed in the thermal line scanner, was processed to a negative; black and white positive prints enlarged 4X times were made from the negative. Each print overlapped the adjoining prints so a mosaic of each flight line could be constructed.

Duplicate copies of the positive transparencies and positive prints were transmitted to the Corps of Engineers, River Stabilization Branch, Vicksburg, Mississippi. The River Stabilization Branch furnished Colorado State University with copies of the ground control data and ground truth information.

Interpretation

Conventional manual interpretation procedures were used to study the various prints and transparencies of the photography and imagery. Color prints of the Kodak 2445 film were analyzed using a large magnifying glass and a mirror stereoscope. The Kodak 2424 positive transparencies were viewed in an International Imaging Systems Mini-Adcol viewer. The thermal infrared imagery film transparency was viewed on a light table and the positive enlarged prints from the film were made up into a mosaic and observed by the unaided eye. The color infrared positive transparencies were viewed on a light table with a large magnifying glass and a Bausch and Lomb Zoom 240 Stereoscope; and on a Wild STK-1 Precision Stereocomparator.

Color enhancement was tried with the Color Infrared positive transparencies, but the results indicated no distinct advantage over what one could observe directly from the transparency viewed on a light table.

An economic and effective way of interpreting color infrared positive transparency photography is the use of a magnifying glass in conjunction with a light table. Not only is considerable magnification possible, depending on the choice of magnifying glass, but a pseudo-stereo effect is produced which can be quite helpful in interpretation. This pseduo-stereo effect is possible using a magnifying glass with only one picture; a stereo-pair of pictures is not necessary. Pseudo-stereo effects developed in this manner, however, can give a false impression and some basic mistakes can be made if one does not recognize the appearance of certain features. For example, two patches of green vegetation of the same height may appear to have a different height depending on the vigor of growth; green grass may appear to be much higher than nearby trees. However, this pseudo-stereo effect can be used to advantage in many cases. This is particularly appealing since the cost of the magnifying glass is insignificant compared to the cost for a suitable stereo-viewing system for transparencies in a roll format.

Photogrammetry

All measurements in conjunction with the analytical photogrammetry procedures were made on a Wild STK-1 precision stereocomparator. Several computer programs for reducing the photo image measurements to space positions on the ground were utilized, including the modified Coast and Geodetic Survey programs. A CDC 6400 high speed digital computer was used. In the practical application of analytical photogrammetry a monocomparator may suffice, but in the case where position information is required for unmarked points (that is, neither targeted points, pugged points, nor sharply contrasting picture points), a stereocomparator is required.

RESULTS

The specific objectives listed previously under the interpretation and photogrammetry categories have been grouped under three general classifications: 1.) water and sediment, 2.) river banks and flood plain, and 3.) river geometry. The results of the interpretation and photogrammetry are discussed in the following sections.

As a necessary adjunct to this interim report, one copy of all photography and imagery obtained in the study have been provided to the Potamology Section of the River Stabilization Branch, Vicksburg, Mississippi.

INTERPRETATION (SPECTRAL CHARACTERISTICS)

I. WATER AND SEDIMENT

FLOW PATTERNS

The basic flow patterns that are discussed are those that are found in the bends and cut-offs, in the straight reaches, and in the crossings and in the long reaches including the bends; flow patterns related to local disturbances such as structures, scallops, and bank failure areas are also mentioned. Flow patterns related to mixing processes (that is, for example, in the vicinity of the inflow of the Big Black River, the confluence of divided flows, and mixing processes in conjunction with vortices and shear flows) are also identified.

Selected photographs and sketches are included in this report, but in general this part of the text is written so that the reader can follow along in an ordered sequence on the rolls of duplicate color infrared positive transparencies.

In the vicinity of the guide vanes near the Lake Providence area the flow patterns on the surface of the water are indicative of the effectiveness of the guide vanes; the flow pattern is well illustrated on the color infrared transparency 3534. Also, the surface turbulence phenomenon is indicated by the foaming action and the eddies around the nose of the guide vanes as shown on transparency 3535. The transverse flow pattern between two guide vanes is illustrated on 4198*. Long term observations could be used to effectively monitor the stability of these structures. In general, it will become more and more necessary with time to evaluate the real worth of such structures as these on the control and behavior of the Mississippi River. Based upon our evaluation from the photographs, the impact level of such structures on the overall river behavior is rather minor and we are firmly convinced that a theoretical treatment of the effects of these dikes can be presented which will indicate the restricted value of such structures for the present and the future.

Shallow water waves are evident on 4007*; "flat water" and shallow water waves are indirect indications of the effectiveness of structures for encouraging the deposition of sediment for closing of channels and redirecting the main flow.

In general these dike structures may be very effective in helping to maintain a desirable low water channel and they help establish channel control. But, it should be realized that they may have very limited beneficial effect from the viewpoint of deteriorating or closing chute channels.

Flow patterns from dredge spoil in the vicinity of the Ben Lomond Chute are evident on 3555; shear zones in the chute are evidence of a higher velocity flow component.

On 3565 there are surface patterns (both circulation and boils) which are relatively violent in the vicinity of the bank and along through the targeted region. These are similar to the circulation cells that develop in the vicinity of the scallops that form immediately downstream from bank protection works.

On 3599*, and several adjacent transparencies a very dramatic flow pattern occurs where the chute flow recombines with the flow that comes around the bend. Figure 1, an enhanced rendition taken from photo 3595, portrays the symmetrical circulations pattern.. This occurs in the vicinity of the large bend near Point Pleasant. The flow that is coming across the chute is considerably faster than the flow that is coming around the bend; and consequently the circulations are in a clockwise direction which nicely illustrates this relative flow field. Possibly the magnitude of these surface circulations, that is the diameters, and the spacing, can be related to the relative velocity fields on the two sides of the shear line. It is anticipated that beneath this shear line there would be considerable scouring activity. The axes of these circulation cells may be inclined; that is, in some direction other than vertical, and the maximum scouring activity along the bottom may be occurring at a somewhat displaced position other than immediately below the shear line that is obvious at the surface.

The tone of the water representing the two flows, that is across the chute and the one coming around the bend, is considerably different indicating that there is a variation in suspended sediment concentration between these two flows. The lighter color on the chute flow indicates that there is higher suspended sediment concentration in that flow as compared to the flow that is coming around the bend.

The variation in suspended sediment concentration near the confluence where these two flows recombine is probably due to the increased scouring activity through the chute which in turn is producing higher concentrations of suspended sediments that are manifesting this color difference in the shear zone vicinity.

Referring to 3598*, one can see the position of the major flow areas in the bend itself. This is illustrated by the darker color with the lighter blue color on either side. The surface flow pattern through this constriction near the mouth of Palmyra Lake shows that the major flow was occurring in approximately half of the channel width.

On 3599*, the little embayment area off the downstream end of the island illustrates the variation in suspended sediment concentration and the familiar process of filling in the mouth of such embayments. These openings along the banks provide an opportunity for an eddy or eddies to form that effectively transport sediment from the main stream into the mouths of such embayments; the sediment experiences a reduced velocity and falls out of suspension contributing to the closure of the embayment. Such photography could be used to study the mechanics of deposition in the entrance to such embayments, including harbors.

On 3602, as one looks on downstream from the confluence of the chute flow and bend flow one can still distinguish the results of the shear flow, that is, the circulation cells, but at this position they have dissipated to a considerable degree. However, it is still possible to see the division of the major flow due to the considerable variation in the suspended sediment concentration across the channel.

**Photograph numbers marked with an asterisk are arranged in numerical order in Appendix E.*

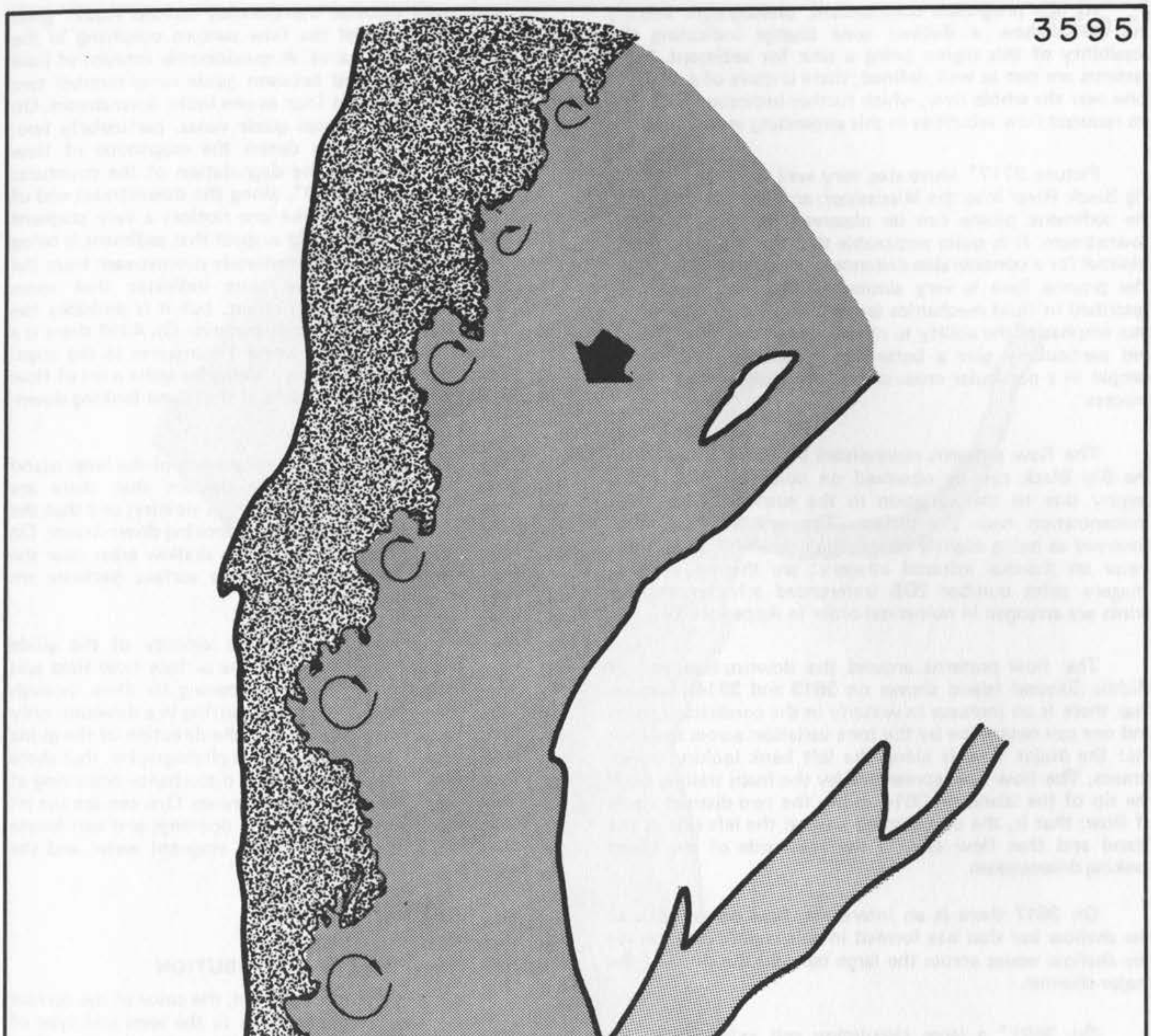


Figure 1. Circulations in the vicinity of the large bend at Point Pleasant.

As one progresses downstream, photographs 3611*, and 3612 show a distinct tone change indicating the possibility of this region being a sink for sediment. Flow patterns are not as well defined; there is more of a uniform tone over the whole river, which further indicates that there are reduced flow velocities in this expanding section.

Picture 3717* illustrates very well the inflow of the Big Black River into the Mississippi; and the persistence of the sediment plume can be observed for some distance downstream. It is quite noticeable that the lateral mixing is minimal for a considerable distance downstream (see Fig.2). The process here is very similar to the classical wall jet described in fluid mechanics texts. The photographs in this area emphasize the ability to observe these mixing processes and particularly give a better understanding of where to sample in a particular cross-section to describe this mixing process.

The flow patterns represented by the inflow such as the Big Black can be observed on color infrared photography due to the variation in the suspended sediment concentration near the surface. The inflow can also be observed as being slightly cooler than the Mississippi River water on thermal infrared imagery: see thermal infrared imagery print number 2D5 (referenced infrared imagery prints are arranged in numerical order in Appendix D).

The flow patterns around the downstream end of Middle Ground Island shown on 3613 and 3614 illustrate that there is an increase in velocity in the constricted reach and one can determine by the tone variation across the river that the major flow is along the left bank looking downstream. The flow line represented by the foam trailing from the tip of the island on 3614 shows the two distinct zones of flow; that is, the one coming around the left side of the island and that flow around the right side of the island looking downstream.

On 3617 there is an interesting flow pattern due to the shallow bar that has formed in this region. One can see the shallow waves across the large bar and the limit of the major channel.

On 3691* a large circulation cell exists along the bank in the vicinity of one of the large bank failure areas, (see also Fig.3). The variation in sediment concentration can be observed in the circulation cell. Of particular interest is the eye of the cell which is a lighter blue tone representing a lower sediment concentration. The centrifugal force develops a radial sediment concentration gradient which increases from the center of rotation.

Photographs 3737 and 3738 illustrate the development of secondary circulation cells occurring in the vicinity of this bend. Enhanced by the collection of foam and debris into a line, one can follow the path and the position of individual cell circulation across the channel. The location of these cells may play an important role in determining the location of hydraulic structures for the control of channel alignment. In bendways, the lines of foam and debris appear to be positioned over the deeper parts of the channel.

The color infrared transparency number 4007* gives a good overall view of the flow pattern occurring in the vicinity of the guide vanes. A considerable amount of flow is going to the left and between guide vanes number two and three and three and four as one looks downstream. On the upstream nose of these guide vanes, particularly two, three and four, one can detect the magnitude of flow impingement, and detect the degradation of the structures along their noses. On 4019*, along the downstream end of the upstream transverse dike one notices a very stagnant area and consequently would suspect that sediment is being deposited in this region. Immediately downstream from the transverse dike, the blue tone indicates that some suspended sediment is still present, but it is probably the very fine silt and colloidal size material. On 4016 there is a distinct overall velocity component transverse to the alignment of the guide vanes which indicates quite a lot of flow proceeding around the left side of the island looking downstream.

On 4021*, along the upstream end of the large island one can see from the surface pattern that there are relatively shallow water depths in this vicinity; and that the major flow is along the right bank looking downstream. On 4115 and 4116, one can detect the shallow areas near the middle portion of the river. These surface patterns are enhanced by the sun reflections.

Transparency 4198*, in the vicinity of the guide vanes, gives a very nice view of the surface flow field and one can estimate the effective opening for flow through these guide vanes. The flow is occurring in a direction only slightly less than perpendicular to the direction of the guide vanes. Also, it is obvious from this photography, that there is a considerable amount of flow disturbance occurring at the upstream noses of these guide vanes. One can see the jet of water accelerating through the openings and can locate the shear zone between the more stagnant water and the main currents.

SURFACE INDICATIONS OF SUSPENDED SEDIMENT DISTRIBUTION

Using the color infrared film, the color of the surface of the water is an excellent index to the level and type of suspended sediment transport taking place in any given cross-section at any particular time. In the case of essentially clear water with little suspended sediment, the water has a relatively dark-blue color; the color becomes a lighter blue with larger quantities of sediment in suspension near the surface. Consequently, by considering the color of the surface of the stream, one obtains understanding as to where the major transport activity is occurring in the cross-section. If one can observe the position of the line of maximum transport, this locates the thalweg of the channel and the position in the cross-section where the velocity has a maximum value. More specifically, by viewing the change in color tone across the channel, one can infer where the position of the deepest, most active part of the channel occurs; and where the shallower regions with lower velocity exist. Other constituents in the water, such as algae, also have an effect upon the color infrared photography of water bodies, but color changes may still be used to infer suspended sediment concentration differences.

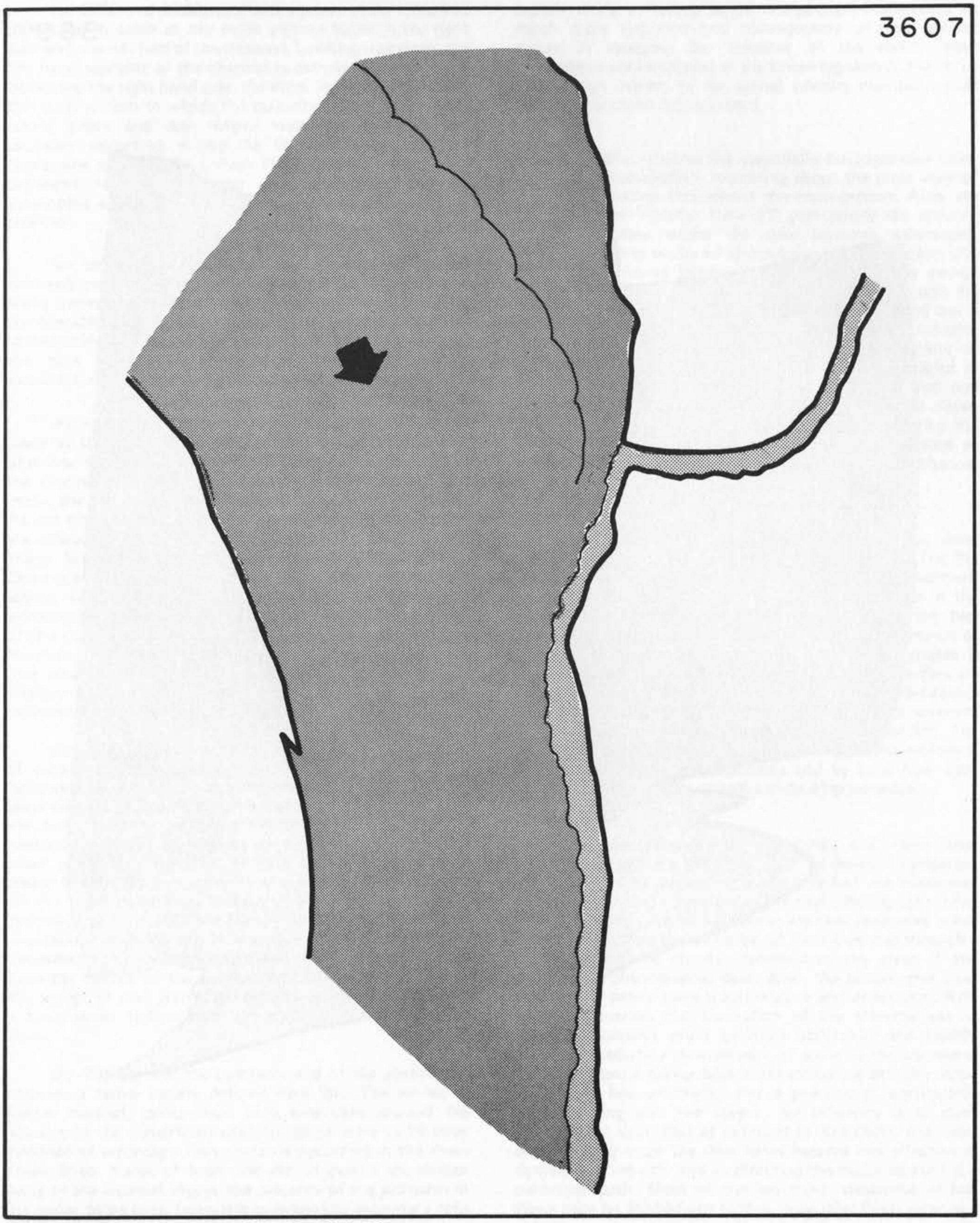


Figure 2. The inflow pattern of the Big Black River.

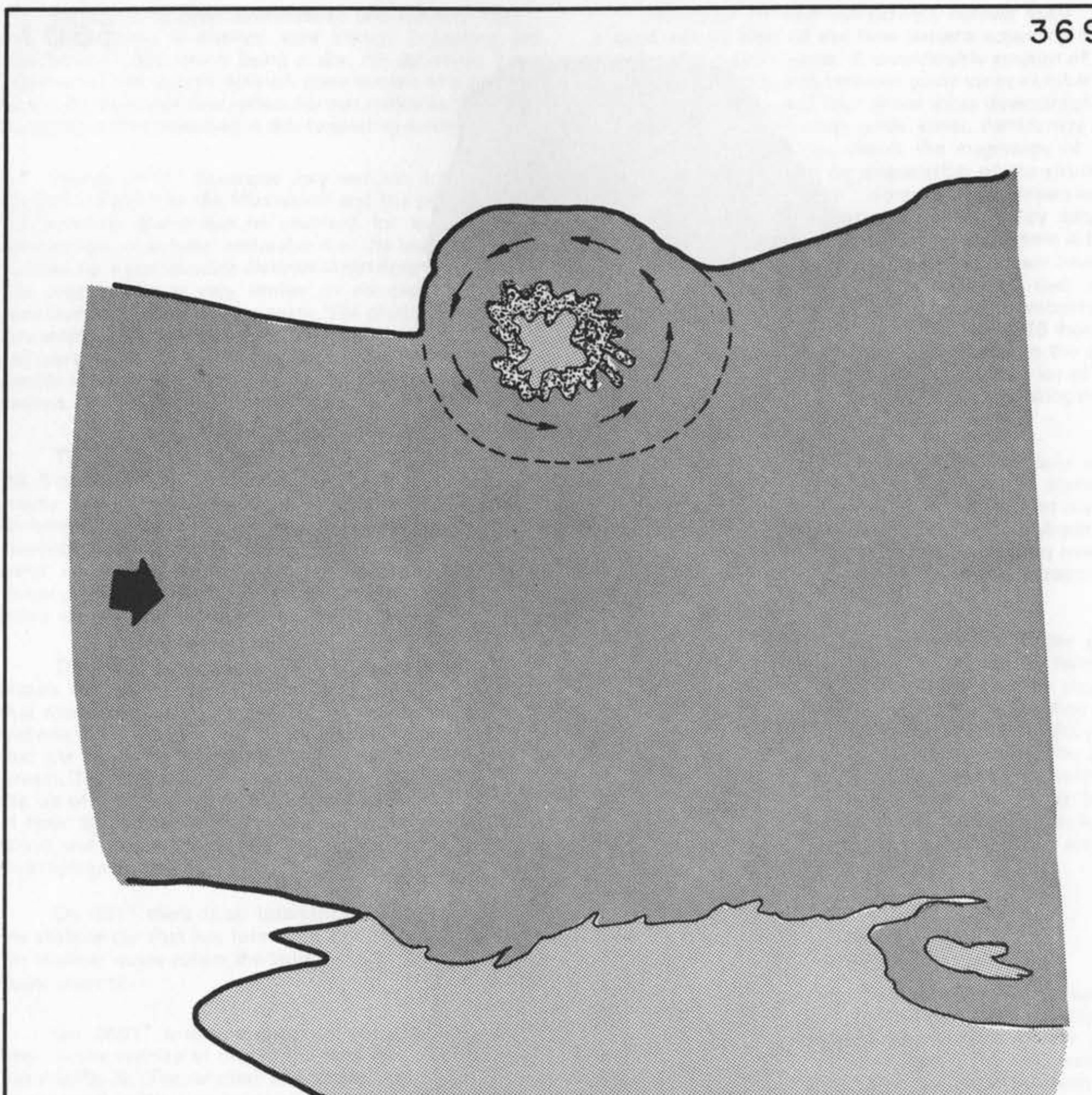


Figure 3. An example of the large circulation in a bank failure area.

In 3582 and 3583, one can observe quite a marked difference in color at the water surface between the right half and the left half of the channel. Looking upstream, the left hand segment of the channel is carrying less sediment. Observing the right hand side, the color indicates the area in the cross-section in which the majority of the transport is taking place and also where maximum velocities are probably occurring. Along the line between these two flows, one can observe a shear flow; in other words, one segment is flowing slower than the other segment developing a line of small vortices near the center of the channel.

In photograph 3584 the flow passes through a relatively narrow section and then rapidly expands. As one looks upstream on the left hand side, it is possible to see considerable difference in the color due to sediment immediately downstream of the narrow section, indicating the zone of separation on the left hand side, slower velocities, and reduced ability to transport sediment.

An extremely important aspect of deducing sediment loads by the color of the water surface is the identification of source and sink areas relative to sediment transport along the channel as a system. In regions where scour is taking place, the color of the water surface clearly indicates this. As the flow expands into wider sections and the velocities are reduced, the color tone changes and indicates that in these broader sections rapid deposition is occurring. Consequently, as one works along the river one can see source and sink areas and this knowledge can be of tremendous value in planning the long term improvement of the river system. For example, constricting a section of the river may release very large quantities of sediment from that area which will be dumped at the next wide, slow-velocity section – the next sink area, which the water-sediment mixture encounters.

On 3598*, in the very tight bend, is a classic example of variation in transport across the cross-section. In the narrowest section of the channel, the main action is taking place near the center, but somewhat towards the outside of the bend. On the inside of the bend the velocities are relatively small as indicated by the bluer tone, indicative of lesser scour and transport. In this same photograph the wedge of blue water forcing its way into the main channel on the right hand side, looking downstream, gives us an indication of how different flows interact. One obtains the impression, studying this blue wedge of water, that it acts somewhat as a dike helping to divert the main current away from the outside of the bend. Immediately downstream of this wedge of blue water, the heavier sediment-laden water is being swept back towards the bank by strong secondary flows.

On 3598*, near the upstream end of the photo, one observes a rather clearly defined flow line. The white, or lighter colored, continuous lines extending around the island into the constricted channel below seem to be clear evidence of secondary flow patterns occurring in the river. These linear traces of foam and debris overlie the deeper parts of the channel. Again, the presence of the sediment in the water helps to differentiate between the secondary cells formed in this region of the river. It is assumed that at rapidly rising or falling stages this phenomenon would be much more apparent and consequently of even greater value in assessing the behavior of the river. These phenomena are illustrated in the following sketch, Fig. 4. In addition an overlay of the actual velocity distributions at two cross-sections are indicated.

On 3604, observe the essentially homogeneous color across the cross-section, indicating about the same level of energy dissipation throughout the cross-section. Also, see the flow over Yucatan Dike #2; particularly the concentration of flow where the dike becomes submerged. However, as one works on downstream around the left side of Middle Ground Island, it is obvious that the energy gradient is steeper through this segment than through the other. As these flows rejoin downstream of the island one is obviously carrying more sediment and has higher velocity than the other segment. This type of information, in studying existing chute channels, will be very helpful in determining methods of helping to obtain control and perhaps partial closures of chute channels. Also the photo techniques may help provide a means of identifying the most likely places where chute channels may develop so that remedial work may be undertaken before the channel develops.

Photograph 3717* and adjacent photographs show the Big Black River joining the Mississippi River. The Big Black River is carrying a large quantity of sediment (probably a different type of fine sediment than in the Mississippi). The differential in color between the two streams is very marked and consequently the presence of different quantities and/or qualities of sediment makes it possible to use color infrared photography to trace the rate and degree of mixing occurring between these two rivers. With our present strong interest in the ecology and environmental impact, water quality is extremely important. The ability, through color differences resulting from sediment, to identify inflowing components and to trace how they combine with the main stream can be of great value.

The performance of dike fields that have been installed to redirect the flow, help to develop navigation channels, and to improve the alignment of the Mississippi can be evaluated using color infrared photography. For example, using such techniques as we have illustrated it has been verified that the direction of flow over and through a dike field can be clearly identified at any stage if one gathers the photographic data. Also, the photos give clear evidence of where there is active scour and deposition. With such information the evaluation of the effectiveness of control structures could be more accurately and readily made. Immediately downstream of some of the transverse dikes, one sees a darker blue water indicating that the water is carrying less sediment. For a given stage, particularly during falling and low stages, the tendency is to store considerable quantities of sediment in dike fields. However, on the rising stage the dike fields become less effective in slowing the velocity and in directing the major current in a particular path. Most of the sediment deposited at low flows may be flushed out so that these dike fields serve as a sediment source during periods of high flow.

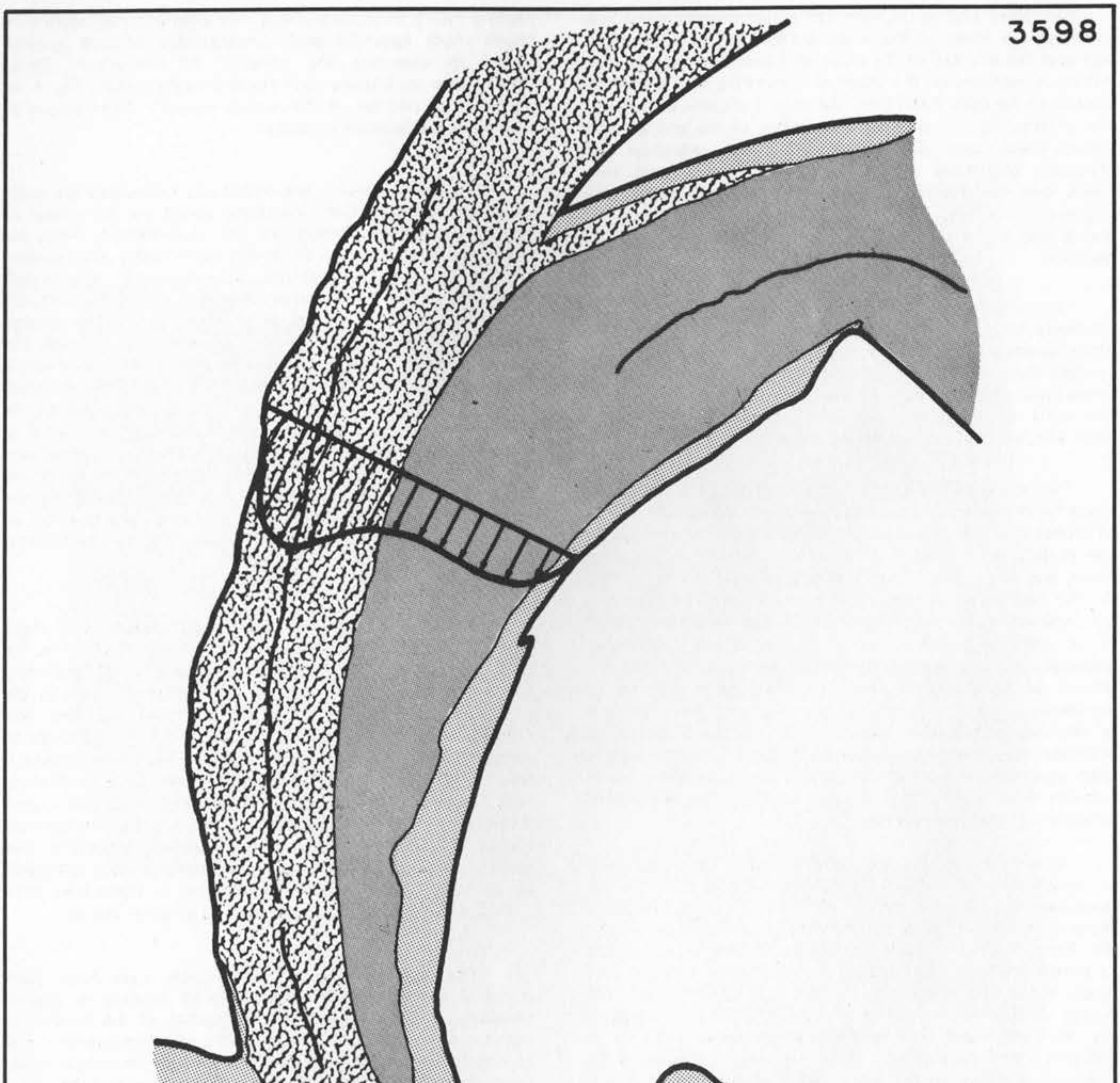


Figure 4. Superimposed velocity distributions (not to scale).

On 3659, two flows rejoin downstream of the bendway and first chute at Point Pleasant. In this instance we do not see the strong vortices dividing the two flows where they rejoin. Here we see essentially a continuous white line of foam or debris. This type of surface phenomenon indicates these two streams are coming together with approximately the same velocity. Also notice that the color throughout the cross-section is quite homogeneous. In other words, the sediment transport in each of the two streams that are rejoining is essentially the same – which is as it should be.

On 3687 and adjacent photographs, rather great surface color differentials occur as one works from one side of the river to the other. In this instance, one can observe that on the right-hand side, looking upstream, considerably more transport occurs, indicating higher velocities and more channel action. To the left, the water has a bluer color indicative of lesser transport and slower velocities. One can also observe that large bars have developed along the left side confirming other evidence in the photograph. The mottled surface effect at the surface, on the right, where the transport is heavier, is indicative of large boils probably associated with large bars with superposed dunes in that segment of the channel.

On 4007* we see the four longitudinal dikes. The water surface level is approximately at dike height. These dikes are forcing the flow to some degree to go around them, but the presence of sediment in the water, makes it possible to observe some flow through the dike field. The enhanced surface phenomena defines the direction of flow, the manner of attack on the dikes, and to some degree, the effectiveness of these dikes. However, to clearly relate what goes on in this view to the total system, it is necessary to study the photography both upstream and downstream of this particular region.

On 4010, there is a large transverse dike extending from the left bank. Immediately downstream of this dike it is obvious from differences in color across the water cross-section that the suspended sediment concentration is lower and velocities are slower. Working on downstream, to the next dike, one observes that on its upstream side the color of the water is a greyer-green, indicating more activity in terms of velocity and transport. Again, by comparison of colors in the cross-section, it is obvious that the main channel is generally towards the right bank.

On photograph 4001, a small tributary is evident on the right bank. At first glance, one wonders what is happening to the flow entering at that point ... it is not clearly obvious, based upon a superficial scan of the photograph. On the other hand, if one looks carefully, there is, in fact, a very small amount of flow entering from this channel and it is combining with the Mississippi in a conventional way. Here is another item that is of considerable interest to the individual working with the mechanics of rivers. One can gain an estimate of the magnitude of the inflow from side channels based upon its appearance and its mixing process after it has joined the mainstream. Currently, this type of detail is not possible except through the use of IR transparencies.

Throughout the complete set of photographs, one occasionally has the opportunity to observe ox-bow lakes and back-water areas. In these bodies of water, generally the amount of suspended sediment is relatively small. All of these have a very different color than the water in the main channel. The very dark-colored bodies of water on the flood plain are relatively quiet and undisturbed with little sediment in suspension. Conversely, when we see these bodies of water that have the blue, blue-grey, or grey-green color we know that some mechanism must be present locally to either suspend sediment in the water or discharge sediment into the body of water. These observations can be useful in determining the activity occurring on the flood plain and potential sources of pollution for the main river. Nutrient enriched water/water plant life may also be identified on color infrared photography.

On 4052*, an excellent example of the different tone in the inland bodies of water with essentially zero velocity is shown. Considerable tone difference exists between individual ponds of water, indicating different levels of suspended sediment, dissolved material, and algae growth. At present, it is not possible to interpret exactly the respective degree of cause in the differences in color. However, with adequate ground-truth information, this could be a rapid and reliable way of checking the quality of water in ox-bow lakes, fish ponds, back water areas, and in tributary flows to the main stem. The presence of minute color tone changes in water bodies taken with color infrared photography may be one of the most valuable indexes for evaluating environmental and ecological impact.

DETERMINATION OF SUSPENDED SEDIMENT CONCENTRATION

The color infrared photography for these two sites clearly demonstrates a variation in tone in the river somehow related to either the dissolved and/or suspended material in the water. The possibility to relate the color of the water to the suspended or dissolved material (or the combination) directly from a good quality color infrared transparency is an interesting potential application. The photometric characteristics of a photograph, however, are often the result of a very complex interaction of many photographic processes. For example, the tone of a given body of water may be considerably altered by simply varying the exposure or film processing.

In spite of this complex photographic process interaction involved in photographing any scene, one can establish and apply certain basic concepts. On a given exposure, for color infrared photography, clear water of sufficient depth appears to be very dark. On the other hand, water containing a considerable amount of suspended material takes on a very light blue tone. Consequently this range of tones of blue between very dark blue and light blue, in effect, represents a suspended sediment concentration ranging from a low concentration to a high concentration, respectively.

BED FORM EFFECTS

In alluvial channels a variety of bed forms results from the interaction between the flow and the alluvium. These bed forms have a very significant effect on channel geometry, resistance to flow, transport, and channel alignment. The bed forms fall in two categories: (1) the bars which include point bars, alternate bars, and middle bars; and, (2) the bed forms themselves which include ripples, ripples on dunes, dunes, transitional regions where the dunes are tending to vanish in favor of a plain bed and in extreme flow conditions it is possible to achieve upper regime conditions with plain bed. In smaller streams, standing waves and antidunes also form, but they are not a common phenomenon on the Mississippi River. Another type of bed form is sand bars that are formed by dredging spoils.

Color infrared photography can be used to identify the exposed bars and the forms of bed roughnesses that occur on them. These bars and bed forms define the general direction of flow. The bed forms superimposed on the bars give a very detailed picture of the direction of flow and actually the flow conditions over the bar at the time these roughness elements were formed. Consequently, observing these bed forms and understanding them enables us to discuss the type of channel; that is whether it is meandering or braided, the general direction of the flow and the detailed direction of overbank flow where residual dunes and other roughnesses are exposed for observation.

At this point we will refer to a few of the specific photographs and other interesting aspects of bar and bed formation in the Mississippi. On 3594, near Point Pleasant, one sees a classic example of a typical point bar. These bars generally form on the inside of the bend, but are not completely stationary. Their geometry changes with flow and with time. In many instances in extreme cases, chute channels ultimately develop across these point bars. Because of the importance of chute channels in deteriorating the major navigational channels, study of these point bars in greater detail is warranted. With more knowledge about point bars and how chute channels develop, perhaps remedial steps can be taken before this disadvantageous flow condition develops.

Photograph 3611* shows a typical middle bar that has been in existence for a very long period of time. This is apparent because of the status of growth of vegetation upon it.

VELOCITY FIELDS IN THE STREAM CROSS SECTION

The best parameters for determining velocity distribution at any cross section is the width-depth-discharge relationships coupled with the differential in color (on color infrared photography) in the cross section resulting from a difference in sediment transport across the width of the river. Several aspects of the velocity field are important: 1.) the velocity distribution at any cross section, 2.) the identification of secondary cells of water flowing side by side, 3.) the difference in the velocity distribution where the divided flows recombine, and 4.) the identification of large vortices formed by channel geometry and bank alignment structures. It is possible to obtain excellent information regarding velocities in all of these categories by utilizing the color infrared film.

From 3599* and adjacent photographs, as stated in earlier paragraphs, one will be able to relate the size and spacing of these vortices through the fundamentals of fluid mechanics to the difference in average velocities between the two segments of flow as they recombine downstream of the island. We have not had an opportunity to do this in a quantitative fashion at this particular point in time. On the other hand, we have taken the liberty of discussing this phenomenon with such knowledgeable individuals as Rouse (Iowa City), Roshko (California Institute of Technology) and our own faculty. All are greatly intrigued by this phenomenon made observable through the color infrared photography. We would strongly recommend that specific field data be collected in these regions at the time of the second flights. It could be tremendously rewarding toward interpreting this phenomenon in a more quantitative manner.

In order to exploit this information it would be necessary to make velocity and depth traverses normal to the direction of flow in the joining channels and across the line of vortices formed by the joining of the two flows. This would make it possible to calculate the coefficients in equations that relate vortex size and spacing to velocity. Thereafter, a useful estimate of the difference between the velocities in the two joining flows could be made. This information should, in turn, be useful to evaluate methods of controlling flow in the divided channels.

As discussed earlier on 3598*, we see two segments of the flow combining downstream of the island. In this instance the shear flow does not form the large vortices. Also the surface color pattern throughout the cross section near the upstream end of the photograph is quite uniform. This would indicate that the two flows coming around the island carry about the same amount of sediment and have approximately the same velocity. In order to fully understand the importance of the continuous white lines, which we have claimed to indicate secondary flows, it would be necessary again to gather additional field data as described above. With a limited amount of field data, improved interpretation of such phenomena would be possible.

Velocity distributions in channels such as the Mississippi, are very complex and difficult to deduce. Even with extensive field data collected by direct measurement it would be impossible to identify these types of phenomena that one observes by looking at the color infrared photographs. Having carefully analyzed these photographs and having asked for the evaluation of many other competent individuals in the field, all enthusiastically agree that with a limited amount of observations related to velocity used in conjunction with color infrared photography that a great deal can in fact be said about the velocity distribution in such channels as the Mississippi. By combining the fundamentals of fluid mechanics and field measurements with remotely sensed data an increased understanding can be developed about the Mississippi River. It should be kept in mind the information we are presenting here is again purely qualitative. A careful inspection of the photographs indicates that it simply requires time and effort to go from the qualitative to a more quantitative stage.

Another important aspect pertaining to velocity distribution is that one can take a series of photographs and develop a mosaic of a reach of river including straight reaches, bends, chute channels, and divided flow areas. Using the techniques previously described that relate to the sediment distribution and the velocity distribution in the cross section one can talk about the longitudinal variation in velocity and suspended sediment concentration along the river in a very meaningful manner. In those regions of the river where there are large amounts of sediment activity the energy gradient must be relatively high. On the other hand, in the wider, more uniformly colored cross sections we can rest assured that we have sink areas capable of storing large quantities of sediment. A more effective approach must incorporate this concept in control and development of rivers.

Of great interest is the phenomenon such as one observes on 3617. In this particular photograph a large submerged bar can be identified along the right bank. Although it is not always possible to identify these bars or the bed roughnesses superimposed on the bar as clearly as in this particular case, we can locate enough of these when we look at long reaches of the river so that we have excellent details about submerged bar formations. In fact with knowledge of the position of a few of these by observation and with our knowledge of river mechanics it is entirely possible to deduce where other bars exist. Furthermore, we should be able to predict the occurrence of such bars and their geometry at different stages of flow. As we gain more knowledge of the application of remote sensing techniques to river mechanics, it will be practical to simultaneously consider sediment distribution in the cross section, the velocity distributions (both lateral and longitudinal), zones of separation, the occurrence of large submerged bars, and the occurrence of point bars, alternate bars, and middle bars. With such background information the selection of appropriate channel alignments to strive for in the future could be more accurately made.

As more knowledge is gained in the use of remote sensing applied to rivers over well documented reaches, the interpretation may be readily applied to other areas of the same river or to other rivers where little or no "ground truth" exists. For example, knowing the conditions that existed in the "north" and "south" study sites, the interpretation can be reliably extended to the intervening section between the two sites. Likewise these interpretation keys can be extended for use in totally undeveloped reaches of the river for planning the appropriate river control structures.

Referring to photograph 3647, we see a small part of the channel and a large part of an exposed sand bar deposited by the flow at higher stages. This photograph clearly illustrates the occurrence of dunes on the large bars. The direction of these bars can be identified and that the flow traversed these bars essentially at right angles to their axes. By studying such overbank areas over a long reach of river one gains considerable insight as to how the direction of flow and how the thalweg in the channel shifts as we go from high to lower stages. If one desired to determine the actual dimensions of such bed roughnesses on this bar, it would be a simple matter to determine spacings, lengths, and amplitudes using analytical photogrammetric techniques.

Another easily discernable characteristic of the sand bars is their relative age. Where the bars are old, advanced stages of vegetation growth are evidenced. Conversely, the more recent deposits are basically free of vegetation, and if dry, they are snowy-white in color. As one studies the older bars in relationship to the newer bars, considering a considerable length of the river, its quite easy to document how the characteristics of the channel have changed with time. In other words, an assessment can be made as to what the alignment of the flow was a decade ago in comparison with its current alignment. Subsequently an evaluation can be made as to how effective the control and alignment structures have been over a long time period. This type of information can be extremely useful in planning future control structures for improving alignment for navigation and flood control in the Mississippi River. One can effectively visualize what channel alignment has produced the most stable long-term situation; or conversely what reaches have been aggravated by imposed river control.

A good example of a recent point bar with a chute channel is illustrated in photograph 3738. As implied before, note that at the present stage one can quite precisely determine the directions of flow, gain some insight to the velocity distribution, and also have some knowledge of the sediment distribution in the cross section in the channels on either side of the bar. Looking closely at the surface of the bar one observes the superimposed bed forms and their orientation. By studying their orientation one can see how the direction of the flow changed with changing stage and how at higher stages the main current may be in a different location impinging on the bank in some different manner. By utilizing extensions of these concepts in conjunction with other information such as type of soils forming the bank, (such as the existence of old clay plugs), a more suitable channel alignment can be developed over the long haul which will better serve basic interests from all viewpoints.

In the case of relatively broad sections of the river, the intricate details of the bed forms are not exposed and the color of the water surface is essentially uniform throughout the cross section illustrating basically uniform velocity distribution and a uniform concentration of sediment. It is extremely difficult to know what the bed forms are or to predict what bed forms will result at other stages looking at a single photograph. On the other hand if one studies a whole series of photographs for a considerable length of river one can formulate with reasonable accuracy the type of bed forms that occur in these reaches and how these bed forms and resistance to flow may change with stage. We also may deduce how these may serve as sinks or storage areas for sediment. Sinks result in steepening of the channel in these vicinities and ultimately may cause further deterioration unless remedial measures are taken.

Photograph 3656* clearly illustrates a very complex flow phenomenon as the channel converges, just upstream from the bar mentioned in the above paragraph, also see Fig. 5. We see shear flows near the center of the channel and color differences indicating zones of separation. We see very active surface phenomenon along the banks. There is no way of visualizing the highly complex flow patterns one experiences in a river that will compare with this pictorial

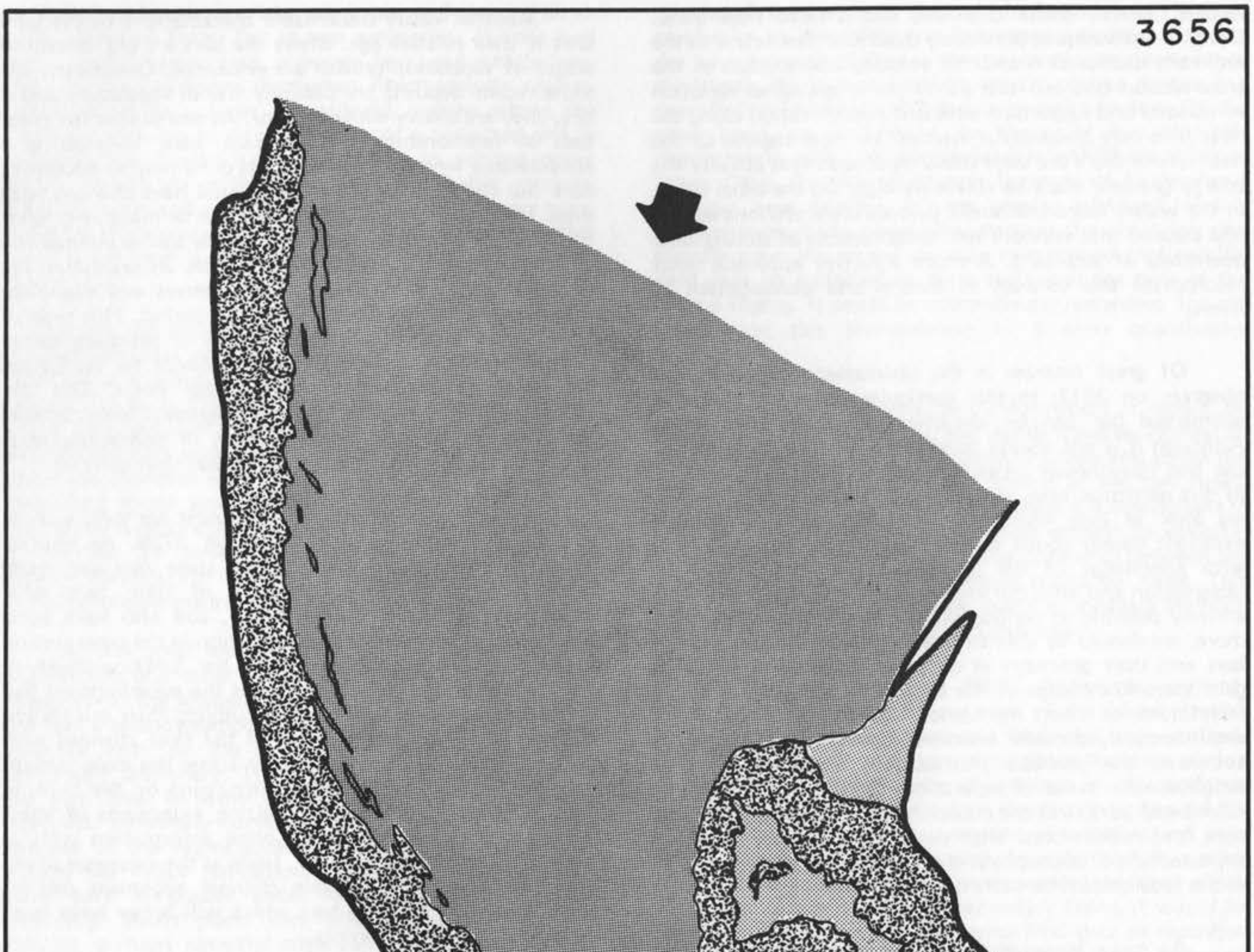


Figure 5. Flow patterns in the vicinity of a converging channel.

presentation obtained by color infrared photography. By a more careful and more detailed study of these individual phenomenon it is entirely possible to learn to interpret them in a reasonable quantitative way resulting in a greatly improved understanding of the complex science of river mechanics.

Another example of how one might deduce velocity distribution, zones of separation and the position of thalweg is shown in photograph 3662. In this instance we see that on the right hand side of the channel looking upstream the big point bar extends down into the flow, the water is a darker blue, the velocities are slower, and the transport is relatively small. Working from the left hand bank to the right as we approach the center of the channel the surface color indicates much higher velocities and larger concentration of sediment. Working on to the right hand bank one observes the intrusion of dark blue water, which is relatively stagnant compared with the main river flow. Again there is no way of gaining the degree of insight into the flow field in this complex region that is comparable to what can be obtained by simply studying the phenomena observable in this photograph.

Many other photos such as these could be sighted as we discuss velocity distribution in the cross section, formation of vortices, flow separation, etc. However, the object of this study was not to come up with quantitative answers, but to illustrate in a qualitative way the tremendous value of using color infrared photography and other sensing methods. With that thought in mind we believe that the utility is clearly demonstrated in the case of velocity distributions and does not warrant further detailed discussion at this point.

TEMPERATURE PATTERNS

There are many features about the thermal infrared imagery obtained in this study that one can interpret and use to some degree of practical application. This section will entail a very general interpretation of all the thermal infrared imagery obtained on the flights. We will indicate certain important features of the thermal infrared imagery and in turn interpret what these selected images represent.

The surficial sediment deposits that are relatively dry and devoid of vegetation provide a relatively high radiometric temperature, consequently they appear quite light or white on the print. An example of this is on thermal infrared imagery 2A2. Note in connection with this imagery that areas covered with vegetation have a very low radiometric temperature, and consequently look very dark. Intermediate grey zones indicate areas of partial vegetative cover or very low vegetative cover having a total radiometric temperature somewhere between the very light sand and the cold vegetative areas.

Thermal infrared imagery 2A3 illustrates the effect of the thermal inertia in shallow areas versus the deeper areas; that is, the shallow area between the bank and the long, vegetated bar is somewhat warmer due to the fact that this shallow mass of water heated up quicker than the larger mass of deep water. This differentiation of water depth can be enhanced by obtaining thermal infrared imagery at the appropriate time during any twenty-four-hour period; that is when the thermal gradients are highest between the slower moving, shallow water and the faster moving, deeper water sections. Water surface temperature gradients were generally very small during this series of flights; onsite temperature measurements across a given section of river often varied less than one degree centigrade.

The determination of the proper time to obtain thermal imagery for enhancing temperature gradients in water bodies can best be established from experience with a given area. The authors have found that at least two times during the day are generally good; (1) very early morning, and (2) late evening. In order for the navigator to maintain visual ground contact, the early morning flights should not be attempted until at least the river outline is visible; and the evening flight should terminate before complete darkness. During the period of direct sunlight on the river and flood plain, very dynamic temperature variations can develop – particularly immediately after sunrise.

Riprap conditions are evident on thermal infrared imagery 2A5; one can detect the presence of areas of riprap where vegetation is growing through.

The variation in vegetative cover, unimproved roadways, levees, and a variation in temperature in both of the two ponds are imaged on 2B4.

The location of inflow areas such as depicted on 2D5 where the Big Black River flows into the Mississippi may be readily identified on thermal infrared imagery. The mixing process in connection with these types of inflows can generally be readily identified and evaluated. However, where cooler waters are flowing into a warmer-water body, the density effect causes the cooler water to sink. This rapidly inhibits the observation of the surface mixing process. Conversely, warm water inflows will be readily identifiable for long distances downstream where they are flowing into cooler bodies of water.

The exposed bars along the near shore are identifiable on 2N3. Notice the detection of moisture content increase in the surficial sediment deposit near the water line. Also just offshore of this surficial sediment deposit notice the grey-tone change due to apparent depth effects.

Likewise, hydraulic structures such as transverse dikes on 2N6 image quite well on thermal infrared imagery primarily because they have a slightly higher radiometric temperature than the background water.

The stratification of old alluvial deposits along the bank is enhanced on 2N14.

As an aside, it is of interest to note that on thermal infrared imagery 2011 that the aluminum roofs on the survey boats appear very cold (black). Since aluminum is almost a perfect reflector over many wave lengths the apparent cold temperature of the roof is the direct result of the material having a very low emissivity (or low absorptance). This points out the ability to detect differences in terrestrial scenes having similar temperature, but slightly different emissivities.

High altitude thermal infrared imagery can be very useful for obtaining a thermal imagery mosaic of the overall scene. This is illustrated on thermal imagery 2Q1. Fairly good resolution is still available at the higher altitudes, but often times the attenuation due to the atmosphere can be very significant especially in areas of high humidity. This strip of imagery, however, is very informative in that it helps determine the interrelationship of a larger reach of the river.

II. RIVER BANKS AND FLOOD PLAIN

SURFICIAL SEDIMENT DEPOSITS AND EROSION PATTERNS

Photograph 3529 illustrates the application of color infrared photography, although taken under poor lighting conditions, for enhancing sediment deposits. Dry sand characteristically has a very white, snowy appearance; slight moisture content change drastically alters this white color. An excellent example of the effect of moisture content on color infrared photography of a surficial sediment deposit is shown in picture 3555. In this area near Lake Providence, where some dredging was going on at the time of the flights, the moist sand is quite evident on the small alluvial fan developing on the dredging spoil bank on the far side of the island.

Photograph 3570 is an example of a surficial sediment deposit. A very pronounced dune pattern is superimposed upon this bar which gives some indication of the direction of the flow at the time that the bar was formed. Notice particularly the variation in the moisture content and the resulting enhancement of the dune pattern.

Photograph 3583 illustrates a relatively large bar that has been deposited along the near bank. On the opposite bank to the bar formation are the characteristic C-shaped zones where the materials have eroded out or have slipped into the river. These erosion patterns were evident on all film-filter combinations as well as the thermal imagery. However, again color infrared photography can be used to distinguish zones along the bank that are moist versus those areas that are relatively dry. Moist, clayey soils identify a relatively high resistance to erosion; clay materials, since they retain considerable moisture in the vicinity of a river bank, generally have a characteristic darker tone.

Stereo observation of the bank can verify if slumping or a slip-failure tendency exists. Clay materials have a very steep angle of repose and often exhibit a honeycombed effect; more easily erodible materials may also have a steep angle of repose, but they have a smoother texture and generally exhibit a lighter tone corresponding to a lower moisture content.

On 3599* the large island has some dry sandy material which appears snowy white; those surficial deposits that have some vegetation growing on them exhibit the characteristic red tone on color infrared or if the vegetation is dead it exhibits a green tone. The appearance of either live or dead vegetation on surficial sediment deposits gives some indication of the age and the recent water stage history over such surficial sediment deposits.

Middle bars are characteristically shaped with rounded noses upstream and sharp streamlined tails downstream. This determines in some cases the direction of flow of the stream, the alignment of the velocity field in the vicinity of the bar, and gives some indication of the velocity distribution at the time the island was developing. A very symmetrical middle bar (vegetated part) is shown on 4021; at high flow stages the velocity distribution is similar around either side.

On 3598*, the bar remaining near the outside of the bend is relatively narrow, indicating that there are relatively high velocities around either side of the bar. The bar has a very sharp downstream tail; and one can tell that the outside boundary of the bar is steeper which identifies more erosive action on that side of the bar.

Photograph 3598* also illustrates an ability to interpret where the active erosion is as opposed to the more stagnant areas. Stagnant or slow velocity areas are characteristically identified by boundaries of bars having irregular shapes; whereas the stream bank that is eroding actively has a very smooth, steep boundary. In addition the steeper side of the island generally represents the side having the deeper nearshore portion.

On 3603 there is a string of surficial sediment deposits along the left bank looking downstream which is probably the result of some dredging operations. One would expect the flow to deposit sediment in this area of an expanding cross section.

On 3717* immediately downstream of the area where the Big Black River flows into the Mississippi one can infer some very high velocities and erosion along this area. The characteristic signatures that evidence this phenomenon are: a very steep bank line, very irregular shape (serrated edges) along this bank indicating the presence of a relatively cohesive material, and fresh trees laying in the stream immediately adjacent to the bank. This very active erosion area probably results from the effect of the inflow from the Big Black as well as the fact that the main channel of the Mississippi impinges on the bank in this vicinity.

On 3673 the large failure downstream of the end of the riprap section has a sharper corner upstream and a rounded corner downstream; a very common shape on many of the pictures. On picture 3686, again a large surficial sediment deposit exists where the dry areas appear white and the high moisture areas near the bank line are a darker color.

On 4005, over along the right bank, one notices a lot of vegetation laying in the near vicinity of the bank indicating relatively active erosion. The trees still have some red appearance which means that they have been recently eroded.

On 4009 the surficial sediment deposit moved on down across the lower transverse dike indicating that there had been a considerable velocity component normal to the dikes in this region transporting the bed-load material. On picture 4010 the exposed bar upstream of the first transverse dike indicates an entirely different flow direction at this lower stage; there is some down-channel velocity component along that part of the bar that is exposed to the outer main channel, but the tail of this middle bar points out into the main channel indicating that there is a new velocity component at this stage.

On 4014* the absence of the sharp tail on the downstream end of the middle bar indicates that there is low velocity along the vicinity of the bar in this area.

On 4021* the middle bar is vegetated with green vegetation and has almost a perfect, symmetrical air-foil shape. At low stages, the flow field changed direction so that deposits occurred in an asymmetrical pattern with more deposit along the left channel looking downstream.

On picture 4027* there is a rapid change from a large cross section in a boundary to a narrower cross section; flow impinges along the left bank with a resultant sediment deposit occurring along the point bar and very active erosion occurring along the outer bank.

Photograph 4096* illustrates a phenomenon that is obvious throughout much of the study reaches. The surficial sediment deposits occur in aligned steps depending on the stage and the flow field at the time of deposition. These surficial sediment depositions can probably be dated by the height of the vegetation, the kind of vegetation, and the elevation of the deposit.

EARTHSLIDE AREAS

On 3583, along the left bank, there have been many cases of bank failure, and one would suspect that even with maintainence more of these types of failures will occur. The relative size of these failure zones may be a complex interrelationship between the depth and velocity of the water adjacent to the particular bank area, height of the bank above the water line, the kind of bank material present, and moisture content in the bank material. Potential earthslide areas associated with high moisture content in bank material should be recognizable on thermal infrared imagery if vegetative cover is not masking the radiometric temperature difference. The incidence of earthslides in the bank material can also be increased by ponded water on the bank. On 3640, since there are relatively shallow depths adjacent to the bank and there is little evidence of historical slip failure here, one would not anticipate failures in the future in this area.

Looking at photograph 3645, along the bank line immediately downstream from where the Big Black flows into the river, there is a considerable amount of eroding action along this bank. There is undoubtedly a relatively deep channel just off the bank, but the bank material appears to be a very tough, clay material and apparently has experienced very few slip failures.

EVALUATION OF RIPRAP

Both color infrared photography and thermal infrared imagery can be used to determine the conditions of riprapped sections. Color infrared photography is particularly useful for noting the type and age of the riprap or the source of riprap material. In addition, the presence of deterioration of bank paving caused by "blowouts" or in areas where vegetation is growing through can be readily identified. Also the presence of vegetation or deteriorated sections can be identified on thermal infrared imagery. This gives a very quick way to evaluate the condition of riprap along the bank lines. In some cases, however, vegetation growing in the stone riprap may be beneficial.

More detailed examination of riprap may be made by observing stereo pairs of color infrared photography with a magnifying stereoscope. In the case of sufficient magnification, resolution was adequate on the precision mapping camera photography to identify small stones (6-inches in diameter) from photography taken at an altitude up to about 2000 feet above the ground.

VEGETATION: TYPE AND EXTENT

Color infrared photography is well suited for identifying vegetation. As a matter of fact, the original purpose for this particular film type was for camouflage detection. Since there is a very high reflectance from green vegetation in the photographic infrared region, one may color code this particular reflectance region as red and use this sensitive portion of the spectrum to identify vegetation type and vegetation growth and vigor.

Information may be obtained from such photography under moderate adverse light conditions such as that shown on picture 3588. The exposure may be increased to compensate for light level conditions and a fairly good quality picture of vegetation type and extent may be obtained.

In addition it should be emphasized that color infrared photography is particularly useful for hazy sky conditions. Due to the relatively long wave lengths being used, good penetration is achieved through particulates present in the atmosphere.

The photography is particularly useful for identifying open or cut sections in heavily forested areas such as shown in 3621*. One can make area determinations directly from such stereo pairs of pictures with either conventional analog or analytical photogrammetry procedures.

Another important application of color infrared photography is the identification of water surfaces having algae blooms such as shown in 3596. This can be used in conjunction with water quality determinations.

Cropping patterns are readily identifiable on color infrared photography. For example, on 3596 one can identify fields that are under cultivation and even identify those areas of the field that are suffering from some type of plant stress. Utilizing analytical photogrammetry procedures, in a precision comparator, (either a monocomparator or stereocomparator), one can determine height of vegetation. For example, the tree heights shown on picture 3598* could readily be determined with a considerable amount of precision. In conjunction with the tree height determinations, counting the trees of a certain variety of species may be done expeditiously from color infrared photography. Photograph 3607 shows a wide variety of vegetation type and conditions — low grass cover, trees, and both live and dead vegetation cover.

Vegetation species associated with certain soil types, altitude of soil types, or historical deposition processes may be identified on color infrared photography; as an example, see picture 3619. Bare soil areas are indicated by the grey tone as shown in this picture.

Photograph 3649 shows the difference in age and species for at least three distinct regions: one near the water, a species-age combination in the lower middle part of the picture, and another species-age combination in the lower right hand corner of the picture. These can possibly be related back to the soil type and historical deposition process of the flood plain. Regions of soil type anomalies such as found on photograph 3681 along the right bank can be readily identifiable; this anomaly can be the result of a clay plug or back filling operations in an old failure area.

Vegetation, as discussed earlier, can be used as an indirect measurement of scouring activity along banks. That is vegetation that is recently eroded still retains some of its red color on color infrared photography. Of course vegetation actively growing in the riprapped areas is readily identifiable.

SOIL TYPE AND MOISTURE CONTENT

Soil type and moisture content is a very difficult set of parameters to determine from either the color infrared photography or the thermal infrared imagery. In those areas where vegetation covers the ground it is practically impossible to differentiate moisture content differences or establish soil type without having more detailed information about plant species and soil classification. In addition, the effect of high moisture availability at the time these pictures were taken makes it difficult to detect any type of plant stress that might be associated with variation in soil type or moisture content. The determination of soil type and moisture content on bare fields is also difficult since heavy rainfall occurred in these areas immediately prior to the time the photography was taken. If a period had existed following rainfall where the soils had a chance to dry out, possibly some differentiation could have been obtained. From an over-all standpoint about all one is able to determine is the difference between sandy surficial deposits and the wetter bank and flood plain materials. Some discussion however will be made in conjunction with certain of the photographs.

As an example, on 3617 along the left bank-flood plain, a variation in the tone of the vegetation apparently of the same type indicates probably a high moisture area or a different soil type. On 4090*, the bare field is exhibiting a variety of tones of green and grey. This may result from a combination of soil-moisture/soil-type.

On 4022 and 4023 some bare soil areas exist and there is a variation in tone that might be related to the character of the soil. Ideally, if these bare fields had had a chance to dry out, one should be able to see the difference between surface areas that have coarse material versus those surface areas that have more clay content. In general the wetter soil areas should appear darker and the dryer soil areas should appear lighter.

Picture 4185* is a relatively large scale representation of the near bank flood plain and the open field shown in this picture illustrates some variation in color. The light red tone indicates growing vegetation; the lighter tones in the soil infer a dryer material of a certain character; whereas, the darker, green tones (resembling buried channels) indicate a tighter more clayey material with a higher moisture content.

Photograph 4090* illustrates the effect with moisture standing on the field. In some cases, the specular reflection off of the wet areas makes it appear white or very light even though there is just a film of water on top of the ground. A slightly different view angle in relation to the sun removes this specular reflectance property and the area simply looks a little darker color. There is a cultural feature noticed on this field, apparently a pipeline crossing, and one can see the location of this form from the apparent difference in moisture content and/or soil type at the surface of the ground.

On 4125 and 4126 the bare field shows very sandy-white dry material near the surface of the ground in contact with a soil of a higher moisture content.

In 4227, the levees appear to have a very uniform vegetative cover with a very uniform red tone, but a slightly different shade of red than in the adjacent areas at the toe of the fill.

III. RIVER GEOMETRY

The river geometry, to a large degree, dictates the type of flow conditions that result therein. For example in narrow, deep sections of the river, the velocity is relatively swift and is capable of carrying large quantities of sediment. In the broad, more shallow sections, the velocities are smaller; the direction of the main thalweg may divide and whether undivided or not may be very difficult to control. At one stage the thalweg may be in one position in the river; at a slightly different stage perhaps in an altogether different position in the river. The basic methods of controlling alignment are bank stabilization techniques and a variety of dike structures.

ALIGNMENT

Using any type of photographic record, particularly the color infrared, one can quite precisely determine the alignment of the river at that particular stage when the photographs were taken. In fact using analytical photogrammetric techniques not only the plan view of alignment can be precisely determined, but also height of banks, bank slopes and related elevation information is readily available.

In striving for a desirable alignment, knowledge of many of the foregoing factors must be considered such as the present position of the main thalweg of the stream where active scour and deposition is occurring, what the type of bank materials are (where resisting segments of the river bank occur such as old clay plugs), and where a readily erodible section of the bank may be exposed. Infrared photography helps not only to define the current alignment of a river, but significantly helps to guide the overall plan toward a more workable and stable alignment in the future.

WIDTH OF CHANNEL

At any section, the river width can be precisely determined from the photographic evidence collected. The width is an integral part of the geometry and ties in closely with alignment. When widths are excessive, the velocities and ability to transport sediment are reduced; the position of the thalweg is unpredictable and it may attack the bank at any location at any time. Consequently, it is essential to understand the mechanics of flow in relationship to appropriate width and depth of channel. As a result of detailed studies made on the river geometry in the preceding years by Colorado State University and others, the most suitable width-depth relationships have been established. For example, the work reported by Hannan (see footnote reference) gave considerable insight to this problem. These have been established with a considerable degree of accuracy and reliability. Consequently, knowing what depth one wishes to strive for, one can use the remotely sensed data to select an alignment and consequently a width corresponding to that alignment to achieve the goals best suited to the objectives.

DEPTH OF CHANNEL

As with the width, good relationships exist between depth, discharge and other variables for river systems. When the river is wide, depths are shallow and depths vary markedly with time. As the thalweg shifts, of course, the line of principal depth shifts with it. In order to achieve appropriate depths in a river system it is necessary to control both alignment and width. Once we have established alignment and width, we know that middle bars will not form dividing the flow, and we can predict with a reasonable degree of accuracy the variation in depths that will result for a given discharge. Where we get into difficulty with alignment, width, and depth is when changes occur so rapidly that it is impossible to fix the river with the desired alignment, width, and depth. One may plan on doing so, but due to the high rate of change in channel conditions with time and because of high cost the objective may be impossible to achieve.

Another way of look at it is that the river has a tremendous capacity for change. Concurrently it is very difficult to make major changes in the river; that is in its alignment, width, and depth. Man's effects are relatively slowly imposed on river characteristics whereas the river action itself may be tremendously fast. This simply implies the necessity to use all of the tools available to us as we select an alignment, width, depth in relationship to time and construction capabilities.

INDIRECT DEPTH DETERMINATION

As implied above we have good knowledge of the relationships between depth of flow, discharge, channel width and other strongly related variables. By looking at the velocity distributions and the sediment in the cross-section as indicated previously; and, knowing width, and knowing the discharge we can utilize geomorphic parameters developed for the river in question to make good indirect depth determinations. Again, our ability to work with depth is quite qualitative at this time, but if we have the will to put forth the effort there is strong evidence as a result of this study that we could couple all of our resources to make some significant gains in this direction.

Hannan, Abdul, "Study of Mississippi River Bends," Ph.D. Dissertation, Colorado State University, 1969.

THE EFFECT OF STRUCTURES

We utilize structures in our river systems to improve alignment, to control width, and to improve depth. A variety of structures are used to help achieve these goals. Unfortunately, we only have limited information regarding the effectiveness of these structures. Infrared photography and other remotely sensed information gives us an ideal method of showing the effect of the structures on the velocity and sediment distribution patterns. Also, we can time lapse the effect of these structures to determine something about their long term effects. In many instances we have constructed structures on river systems without an adequate understanding of the flow situation at that point. It is strongly recommended that remote sensing techniques be utilized to help establish the appropriate design of the structure, the appropriate placement of the structure; and coupled with this, an evaluation of the structure over a long period of time can be made in order to gain better insight as to whether or not the proper choice was made. Periodic remote sensing flights over a total river system coupled with interpretation that we are gaining from this study can help achieve the above goals.

PHOTOGRAMMETRY (SPATIAL CHARACTERISTICS)

There are two basic procedures commonly employed to determine the spatial position of ground points from an aerial photograph. One may be entitled an analog approach and the other an analytical approach. The analog approach depends upon an optical projection of the transparent positive. The spatial optical model formed from this projection is in turn mapped directly to its orthographic projections.

The analytical approach depends upon the measurement of coordinates of the images from the transparencies. A computer program transforms these image positions to ground spatial coordinates. The selection of either of these two basic procedures depends upon the accuracy which one desires in the end product. For mapping purposes with contour intervals of 1-10 feet, the analog procedure is the preferable approach. For the precise location of points to less than a foot in the x,y,z coordinates, the analytical approach is the preferable approach.

The analytical approach depends upon measurement of photographic coordinates to accuracies on the order of plus or minus a few micrometers. A subsequent computer program depends upon a detailed knowledge of the lens characteristics of the taking camera and atmospheric refraction. The computations permit the use of more than a sufficient number of ground control points for determining the position and orientation of the camera at the time of the exposure. This procedure is done through a least squares analysis of the data. Once the position and orientation of each of the exposure stations is computed from the ground coordinates, the location of the ground coordinates appearing on successive overlapping photographs may be computed and adjusted. This adjustment is also done through a least squares fit.

The first application of the analytical approach to the available photography of the Baleshed Landing Dike Field Reach was to demonstrate the application of this procedure. The information available consisted of the known position of well marked targets along both banks as well as vertical control targets a short distance back from the left bank. The goal for this initial part of the study was to compare the computed position of a selected number of these points to the furnished coordinates.

The photography used for this initial phase was at a scale of approximately 1:12,000 (taken at an altitude of approximately 6,000 feet above the mean terrain). Three photographs covered the entire area; these photographs had 60% overlap in the direction of flight. Measurements were made of the coordinates of four fiducial marks and all of the targets utilizing a Wild STK-1 Precision Stereocomparator. Four to five observations were made of the coordinates and parallax of each of the selected target points. The expected standard error in the measurement of these coordinates is between 2 and 5 micrometers. With these measured coordinates, the characteristics of the camera system and the furnished ground control coordinates of a selected number of targets, the computation of space coordinates of the ground control was then performed. A comparison between the computed and observed ground elevations of the ground control points was made. The differences in elevations between the surveyed elevations and calculated elevations ranged to a maximum of 3.58 feet; the root-mean-square error was 1.51 feet.

A ratio of the error in the computed elevation to the mean altitude of the flight is a measure of the accuracy of the procedure. One might expect that this error ratio would apply for a wide range of flying heights. In this case it would appear that this ratio is on the order of approximately 1 to 4000. The comparable figure for any analog situation would be expected to be in the range of 1:1,000 to 1:1,500. Work has not been completed on the photography taken at 3,000 and 1,500 feet above the targets but the authors expect accuracies on the order of 1:10,000

These initial results, however, indicate that it will be possible to determine water surface elevations to within approximately 0.25 of a foot for flying heights of about 1,000 feet above the mean terrain. Actually the authors expect to be able to do better than this because of the increased resolution of the photographic diapositive.

The horizontal position of arbitrary ground points would be expected to be determined with a comparable order of accuracy. It should be pointed out, however, that much of the horizontal geometry of the river is not as critical as the elevation information for describing river geometry. For example, the radius of a bend in the river is not well defined either on the ground or by the interpreter, and hence the measurements for this purpose need not be as accurate as that for elevation. It is convenient and desirable to also determine the horizontal geometry of the river with the stereocomparator since the information is digitized at the time of observation and readily available for subsequent computer analysis.

The final report for this project will discuss in detail the results of the analytical photogrammetry procedures. This interim report will deal only in a very superficial way with the results to date.

The results to date are encouraging; however, continuing efforts need to be made to improve the results. It is believed that this can be done through optimizing the number of control points necessary for photographic control. More than sufficient points were utilized in the previous analysis. The question to be answered is; could fewer points have been used to achieve comparable accuracy? It is believed that this could be done. Future work will be devoted to answering this question.

Accuracy may also be improved by utilizing diapositives of higher resolution. For this study, black and white transparencies were made from color negatives. It was discovered that the images on the black and white transparencies were not as sharp or well defined as one might expect had they been made from black and white negatives. Another alternative is to utilize original color infrared transparencies.

Greater accuracy could also be obtained by utilizing glass plate diapositives rather than Estar film base. The glass plates have greater dimensional stability as influenced by temperature and humidity than does the Estar base film. The dimensional changes of the film were essentially evaluated by the measurement of coordinates of the fiducial points compared with the calibrated position of these same four points. However, there may be local discrepancies not detectable by the use of only four fiducial marks.

It has been demonstrated that the analytical solution of the determination of the spatial position of photographic images measured with a stereocomparator can be applied to the determination of elevations of selected ground control targets. Improvements to the procedure can be made which will increase the accuracy as well as decrease the time for ground control surveys and photographic measurements.

The Wild RC-8 precision mapping camera photography and the I^2S multiband camera photography are listed in Appendix C.

I. WATER AND SEDIMENT

SURFACE FLOW PATTERNS

Analytical photogrammetry can be applied to the spatial determination of the shape of practically all types of flow patterns that are enhanced to the degree where the comparator operator can distinguish boundaries. In the case where the flow pattern is translating in a downstream direction additional refinements to the present computer program must be made in order to handle the additional parallax introduced into the stereo model. The authors feel that a computer program particularly suited to a specific type of water surface flow pattern could be developed.

However, in most cases one photograph illustrating the entire flow pattern can be used to make the basic x,y coordinate measurements and describe the shape of the flow pattern in two dimension. The three dimensional characteristics of a translating flow pattern, such as very large eddies having a significant radial energy gradient, will have to be developed from a specialized computer program adapted to stereocomparator measurements.

One photograph may describe a particular flow pattern for a given instant; in some cases, additional benefit could be derived by overflying the same area over a selected period to time-lapse the flow pattern configuration and movement. The transient characteristics of some particular flow patterns may be very important in the process of evaluating what the ongoing fluvial process amounts to.

It should be emphasized that some high altitude NASA color photographs were available. The usefulness of these photos were limited by scale. Most photos available for reference were taken at an altitude of about 40,000 ft. In future efforts NASA has agreed that they would be interested in cooperation. Colorado State University presently has a cooperative working agreement with NASA whereby both organizations are striving to improve the application of remote sensing to practical hydrologic, hydraulic and fluvial-geomorphic problems.

WATER SURFACE SLOPES

Water surface elevations along bank lines and along middle bars can be determined with a high degree of reliability using the stereocomparator. This would not be practical using a monocomparator, however. In addition, one is limited to determining water surface elevations adjacent to some fixed boundary such as a structure or bank or surficial sediment deposit. A trial made along one of the banks in the vicinity of the targeted region demonstrated that the water surface slope could be well duplicated by two operators working individually.

Water surface slopes out in the vicinity of the open river, where no fixed reference shape lies adjacent to the water, is very difficult to obtain; there is a parallax introduced into a stereo pair by the movement of the water surface during the interval between adjacent exposures and, in addition, the water surface is often indefinite to the stereocomparator operator.

FLOW VELOCITIES FROM DEBRIS

Velocity vectors can be determined for adjacent photographs (stereo pairs) from descrete measurements of displacements of pieces of debris in a stream. This, however, has limited application unless there is a considerable amount of debris to represent a sufficient number of points within the river cross section. Particularly at low stage, the presence of debris may be almost negligible. From observing the photographs obtained in this study taken at about 1500 feet above the water's surface, debris is evident if it has enough contrast – that is in size and color – with the background water. It is the feeling of the authors that the flow velocity at any selected point may be determined by measuring the apparent parallax of the water surface. This procedure would require a special computer program and trial demonstration.

SIZE OF THE EDDIES

The diameters of individual circulations, manifested at the surface of the water, may be determined by simply making x,y coordinate measurements from one photograph. In addition, stereo pairs of a particular circulation may be utilized in a stereocomparator to determine the vertical component in some cases. Again, the apparent parallax introduced by downstream movement of the total circulation pattern may obscure the true vertical component of a particular point.

The basic information observable on the infrared photos could be related, as previously stated, to the rate of energy dissipation in the channel, the velocity of the flow and sediment transport at least in a qualitative manner. With additional experience we should be able to make the results much more quantitative.

STANDING WAVES

The shape of stationary standing waves can be defined quite well using stereo pairs of photography. Again, however, the stereocomparator provides the most accurate way to define the shape of a standing wave. The stereocomparator operator has no difficulty recognizing the profile of a standing wave if the texture of the water surface is sufficient. Generally in the case of rivers like the Mississippi where the water is very heavily sediment-laden, this provides enough texture so that the stereocomparator operator can place the floating dot on the surface of the water.

RIVER CONTROL STRUCTURES

Structures such as transverse dikes and guide vanes oftentimes create a drop in the water surface in the immediate vicinity of such structures. Preliminary investigations using the stereocomparator on such photography illustrated that this differential in elevation can be very accurately described. With accurate parallax measurements, the difference in elevation for two points within a very localized area can be described by very simple mathematical relationship. Trials made on some of the photography in the vicinity of the guide vanes illustrated that several operators could accurately describe this difference in drop across the structure and repeat these determinations with minimum variation.

II. RIVER BANKS AND FLOOD PLAIN

SHAPE OF BANK EROSION

Bank failure zones can be accurately described as far as their planimetric shape. In addition, using a very simple relationship the difference in elevation in the immediate vicinity of a localized bank erosion feature may be determined. Subsequently, volume estimates can be made as to the amount of material that has been eroded from such failure zones. No direct measurement, however, of volume estimates can be made that are beneath the surface of the water.

VOLUME ESTIMATES OF SURFICIAL SEDIMENT DEPOSITS

Using a stereocomparator, with the analytical photogrammetry program, very accurate determinations can be made of volumes of material deposited above water surface levels. There are several programs to determine this volume of material quite accurately. In addition, time lapse stereo pairs of a particular deposit would provide a change measure in this volume of material being deposited.

III. RIVER GEOMETRY

RADIUS OF BENDS

The radius of bends can be determined from a single, near-vertical photograph or more accurately in a stereo pair using a precision stereocomparator. Likewise, the planimetric shape of middle, point, and alternate bars can be described from a single, near vertical photograph; a stereo pair of these bar formations can be used to accurately describe the spatial shape of such bars.

CHANNEL WIDTH

Channel widths can be determined very accurately from precision photography using either a monocomparator or a stereocomparator. This width determination can be related to velocities and depths as discussed earlier in the text of this report.

Specific examples of the use of analytical photogrammetry for describing many of the phenomena discussed above under the **Photogrammetry** section will be presented in the final report.

SUMMARY

Of the three remote sensing systems used in this study, the Wild RC-8 Precision Mapping Camera with color infrared film was the most useful. Not only is a tremendous amount of interpretation possible from the color infrared photography, but the positive color infrared transparency may be placed directly into a comparator or a plotter for determining spatial information about the scene. Initial study of the use of analytical photogrammetry techniques, involving a Wild STK-1 Precision Stereocomparator, demonstrated the practicality of measuring water surface elevations along bank lines and adjacent to structures and in determining change in water-surface elevations across structures. Slopes of banks, width of channel, and volume determinations of sediment deposits above water level are feasible.

Thermal infrared imagery is also a very valuable form of data. The temperature gradients across the Mississippi River were very low at the time of the study (that is, temperature differences at a cross section generally varied less than 0.1 degree centigrade). However, in backwater areas or in the area of certain inflows, temperature gradients greater than 2^{o} or 3^{o} centigrade provided imagery that was quite useful for interpreting mixing processes and for indirect determination of depth of channel. Thermal infrared imagery of the banks and floodplain area was quite useful for delineating vegetation, bare soil areas, surficial sediment deposits, and areas of riprap.

The miltiband photography did not provide any additional information over that which was contained on the color infrared photography. In addition, there were some limitations in both the collection and interpretation of the multiband photography that the authors felt was quite critical. The extremely variable lighting conditions due to the cloud cover and high humidity made the proper exposure settings difficult to maintain. The extremely hazy atmospheric conditions rendered channel one (the blue band) almost useless for photographs taken above 2500 feet; at 1500 feet there was sufficient reflected energy to distinguish ground features reasonably well. The degree of haze penetration increased with the longer wave lengths of channel two (green), channel three (red), and channel four (near photographic infrared).

The most useful aspect of the multiband interpretation is the tonal differences obtained by the additive color; and the variable colors available from the different filters and the adjustable lamp intensities. Even those photographs having poor quality (those with improper exposure) provided information from the color tone differences such as indications of suspended sediment concentration differences similar to those obtained with the 2443 (color infrared) film. However, the interpretation was very subjective and was dependent upon prior knowledge of the scene by the interpreter.

Clear water penetration and surface disturbances were most easily detected by the channel one photographs under the best conditions of exposure and lower altitude photography. The targets and streamers placed in the Lake Providence reach were most easily detected on channel one even when the film was poorly exposed and most other ground features were unidentifiable. River control structures were readily detected in all of the three visible channels.

Channel four is most useful in vegetation identification and the ability to vary the lamp intensity in the viewer aids in enhancing the different types of vegetation through tone differences. The boundaries between different types of vegetation may go unnoticed unless the back lighting is varied. This band also is good for identifying clear water ponds and waterways because of the high absorption in clear water of the energy at this wavelength.

The multiband camera and viewer system has certain advantages and disadvantages over other camera systems. The advantages are:

1) Several film-filter combinations may be obtained at essentially the same time.

2) Numerous real, false color, and individual color representations can be obtained through the filter combinations available in the viewer. Variable lamp intensities provide an additional advantage to distinguish tonal differences.

The disadvantages are:

1) Because of the small field of view, the photographs should be taken at relatively high altitudes to obtain sufficient coverage to assist in interpretation. The high humidity and haze make band one almost useless at this higher altitude due to severe scattering of these wavelengths.

2) Reconstruction of the color depends upon the judgment of individual interpreters.

3) Registration of all areas of the photo cannot be achieved simultaneously and thus a portion of the photo may be out of focus when observed on the viewer.

One of the most useful applications of the color infrared photography taken with the Precision Mapping camera was in the identification of flow patterns manifested by suspended material in the water. In addition, foam and debris at the surface of the water provided flow lines, particularly in the bend ways that were indicative of the position of the maximum depth of the channel. The enhanced flow lines also help evaluate the direction of flow in the vicinity of structures. In areas where flows are recombining, for example below a bend and a chute, the relative velocities of the two combining flows are indicated by the size of the vortices created along the shear line. In the case where photography is available over any sizeable length of river the source and sink areas may be established by the relative tone of the water surface as well as the inherent feeling that an interpreter gains by noting the constrictions and expansions of the river cross section.

The use of color infrared photography for enhancing the near-bank and over-bank areas as well as the total floodplain is vitally important. Vegetation, old meander patterns deposition patterns indicated by vegetation, recent surficial sediment deposits, age of bars, and the general cultural and ecological features of the total system may be evaluated.

The use of two basic systems flown simultaneously over extended reaches of the river can prove most beneficial. These two systems are: a precision mapping camera with color infrared film and a thermal infrared imaging device with both tape and film output (with roll compensation). High altitude flights, that is, at heights on the order of 10,000' above the land surface will be quite useful for looking at the total system. On the other hand, to obtain high resolution, particularly temperature resolution in the case of the thermal infrared imaging device, altitudes on the order of 2,000 feet above the land surface, particularly flown along bank lines will be very useful. Considerable attenuation of the thermal infrared band may occur at elevations in excess of a few thousand feet above the land surface. Early morning flights as well as the late evening flights are particularly useful in the case of the thermal infrared imagery. The color infrared photography should be accomplished as soon as light conditions permit and before the sun angle becomes so high that excessive specular reflection exists on the water surface; ideally the color infrared photography should be accomplished shortly after mid-morning. Generally at this time the cloud cover is at a minimum and the air is quite stable. Late afternoon flights are permissible, but generally, the cloud cover begins to increase and has an adverse effect upon the quality of the infrared photography.

CONCLUSIONS

The major purpose of this study was to verify the work of remote sensing, improve knowledge in river mechanics and provide a new step towards streamlining the future data collection program for river training and development for navigation and flood control. Furthermore, the techniques in remote sensing should enable one to achieve the foregoing in a manner that would be compatible with current environmental concepts. An analyses of the remote sensing data was discussed in the body of the text. It has been demonstrated in a general, qualitative way that the long-range potential of the existing techniques needs to be developed further.

The principal phenomena detectable from the remote sensing data were: the basic flow patterns in the river, the transverse and longitudinal distribution in suspended sediment concentration, the velocity field, and the bed-form effects. In instances where a sufficient temperature gradient existed, depth effects could be identified.

In connection with the river banks and the flood plain, the remotely sensed data helped to identify and classify surficial sediment deposits and erosional patterns, potential earth slide areas, and the vegetative types that exist and their extent and implication.

Similarly, the river geometry in many instances can be specifically described. A sequence of photographs along the river precisely defines the alignment of the channel. The width of any channel for any stage can be precisely measured. The depth of flow can be deduced indirectly from discharge and width relationships, using regime type relationships.

The effect of hydraulic structures in the river can be evaluated. One can observe the flow patterns around the structures; how the sediment is deposited in the structure field during a particular interval of time; and predict in a qualitative way the long term effect of the structures on flow patterns and depositional patterns.

The remote sensing techniques, also, have very great advantages in terms of determining environmental factors and the background information related to ecology. The remote sensing techniques would have favorable impact when considering water use, the possible degradation or improvement of water quality, the extent and quality of wild-life habitat, the proximity of the water table and how it may fluctuate with time, vegetation – its classification and change with time, livestock inventories, and land utilization in the area. Also, such an approach would be extremely useful in evaluating ethnic cultures, identifying historic sites, and geologic sites. Consequently, the question is not one of the value of remote sensing, but the development of remote sensing for specific uses in the evaluation of river systems in particular watersheds.

Referring back to the major topic of river mechanics and the development of rivers for efficient utilization, the full impact of potential for remote sensing can best be illustrated by considering not just the individual photographs, but the photographs arranged in a sequence or mosaic so that it is possible to look at long stretches of the river in a continuous, homogeneous manner. With the mosaic to look at, it is possible to determine how the transport of sediment varies not only in the cross section but along the river. One can clearly identify where the material is being derived from; and where the transport rates are relatively heavy as well as sink areas where material being derived from an upstream reach of the river may tend to drop out.

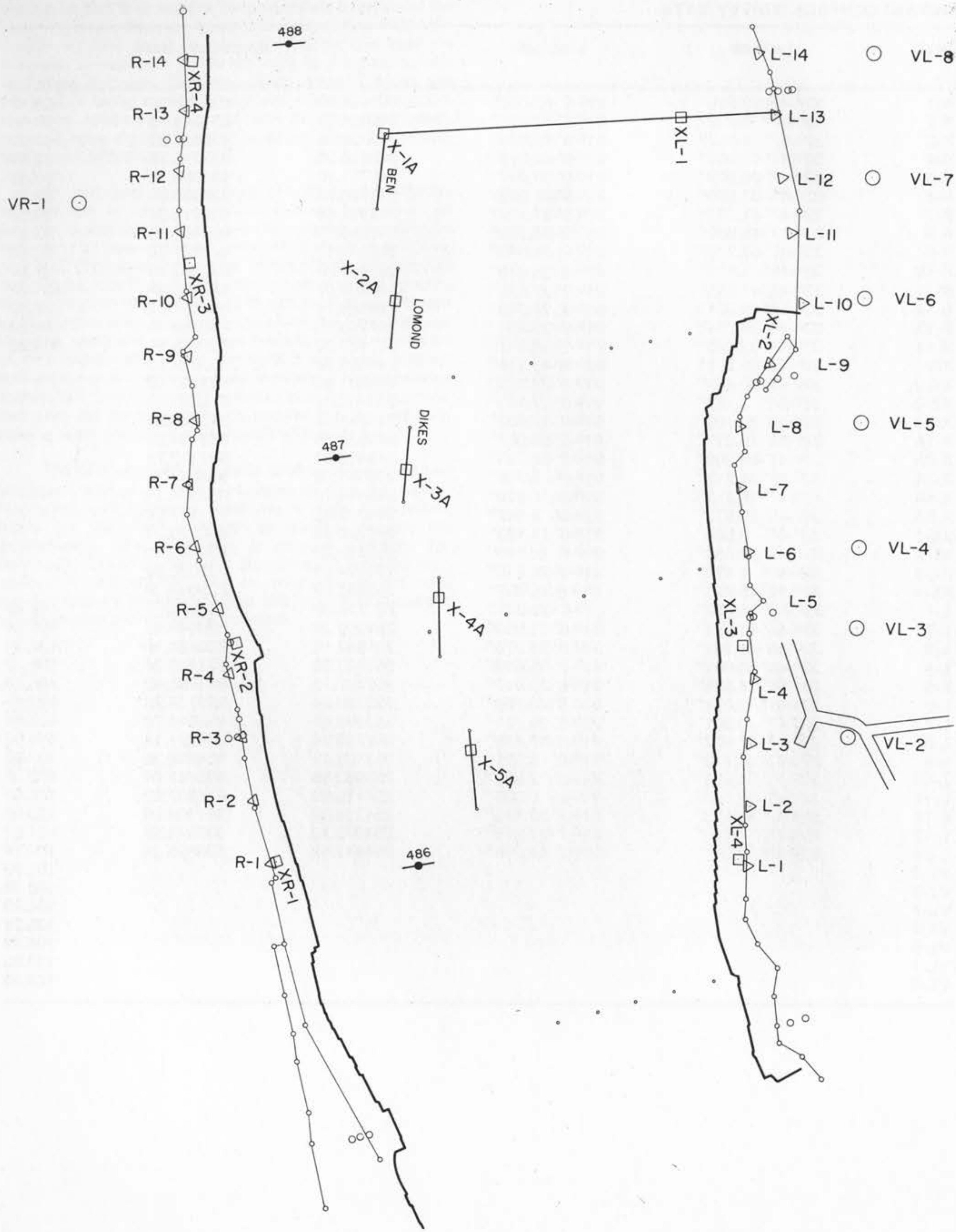
In the same manner, one can study the velocity distributions in the river. Qualitative information on velocity is available that indicates the reaches of maximum velocity; and how the flow divides when chute channels are involved. With some knowledge of the effects of bends and major bars, it is likewise possible to rather clearly identify the position of the thalweg of the channel at a particular stage. By the same token, one can study the bank lines and identify, using soil classification techniques and vegetation as an indicator where the river bank is apt to be toughest and where it is apt to be most erodible. This knowledge enables the river engineer to select an alignment of the river and plan his work in order to stablize the river when it reaches some pre-selected, preferable alignment.

The data obtained by remote sensing, coupled with an intelligent utilization of the concepts of river mechanics, hydraulics, and hydraulic structures provide an excellent basis for the river engineer to greatly improve his procedures. The possibility is greatly improved for developing a river channel that is optimal for flood control, navigation, and stability; over-all utilization of the total water resource is maximized while still keeping with current environmental and ecological concepts.

APPENDIX A

GROUND CONTROL SURVEY DATA

Target	Latitude	Longitude	Coordinates (feet) x	y	z
R-1	32°-46'-52.816"	91°-9'-42.052"	245406.06	830827.05	99.12
R-2	32°-47'- 0.928"	91°-9'-41.882"	245426.92	831646.73	98.06
R-3	32°-47'- 8.912"	91°-9'-40.745"	245530.36	832452.88	99.61
R-4	32°-47'-17.060"	91°-9'-39.814"	245616.30	833275.76	92.84
R-5	32°-47'-25.209"	91°-9'-38.307"	245751.40	834098.28	90.65
R-6	32°-47'-33.520"	91°-9'-38.926"	245705.08	834938.68	96.75
R-7	32°-47'-41.193"	91°-9'-37.117"	245865.54	835712.94	95.66
R-8	32°-47'-48.689"	91°-9'-33.323"	246195.39	836467.93	97.31
R-9	32°-47'-56.712"	91°-9'-31.643"	246345.11	837277.63	91.22
R-10	32°-48'- 3.612"	91°-9'-28.933"	246581.84	837973.19	97.57
R-11	32°-48'-11.895"	91°-9'-27.005"	246752.97	838808.99	101.31
R-12	32°-48'-19.321"	91°-9'-24.346"	246985.74	839557.72	98.87
R-13	32°-48'-26.274"	91°-9'-20.842"	247290.29	840258.14	92.34
R-14	32°-48'-32.598"	91°-9'-18.841"	247466.09	840895.91	115.02
XR-1	32°-46'-52.792"	91°-9'-41.319"	245468.58	830824.15	
XR-2	32°-47'-20.463"	91°-9'-37.326"	245831.40	833617.98	
XR-3	32°-48'- 7.762"	91°-9'-27.123"	246739.61	838391.38	
XR-4	32°-48'-32.180"	91°-9'-17.832"	247551.90	840853.03	
X-1A	32°-48'-15.927"	91°-8'-54.007"	249572.75	839194.65	
X-2A	32°-47'-55.398"	91°-8'-59.713"	249069.62	837123.72	
X-3A	32°-47'-34.818"	91°-9'- 5.706"	248541.99	835047.79	
X-4A	32°-47'-18.252"	91°-9'- 6.670"	248446.79	833374.14	
X-5A	32°-46'-58.877"	91°-9'- 8.945"	248237.40	831417.60	
XL-1	32°-48'- 6.561"	91°-8'-11.183"	253220.78	838220.21	
XL-2	32°-47'-34.062"	91°-8'-10.596"	253246.00	834935.30	
XL-3	32°-47'- 1.170"	91°-8'-25.778"	251924.58	831620.98	
XL-4	32°-46'-35.598"	91°-8-35.760"	251052.53	829043.09	
L-1	32°-46'-34.633"	91°-8'-35.025"	251114.59	828945.09	105.75
L-2	32°-46'-41.623"	91°-8'-31.859"	251390.28	829649.49	106.24
L-3	32°-46'-49.109"	91°-8'-28.976"	251642.18	830404.18	106.56
L-4	32°-46'-56.699"	91°-8'-25.588"	251937.36	831169.04	106.12
L-5	32°-47'- 4.523"	91°-8'-23.511"	252120.70	831958.42	106.78
L-6	32°-47'-12.021"	91°-8'-20.769"	252360.58	832714.33	102.97
L-7	32°-47'-19.951"	91°-8'-19.171"	252503.06	833514.76	103.48
L-8	32°-47'-27.452"	91°-8'-16.478"	252738.74	834271.14	102.82
L-9	32°-47'-33.742"	91°-8'- 9.631"	253328.12	834902.36	107.27
L-10	32°-47'-39.824"	91°-8'- 2.006"	253983.69	835512.04	102.25
L-11	32°-47'-48.595"	91°-8'- 0.535"	254115.95	836397.60	106.07
L-12	32°-47'-55.593"	91°-7'-59.383"	254219.63	837104.08	103.58
L-13	32°-48'- 3.400"	91°-7'-57.666"	254372.13	837891.95	101.62
L-14	32°-48'-11.351"	91°-7'-57.254"	254413.42	838695.24	102.74
VL-2					101.23
VL-3					100.28
VL-4					104.73
VL-5					105.22
VL-6					104.24
VL-7					104.03
VL-8					103.58


488
487
486
R-14
R-13
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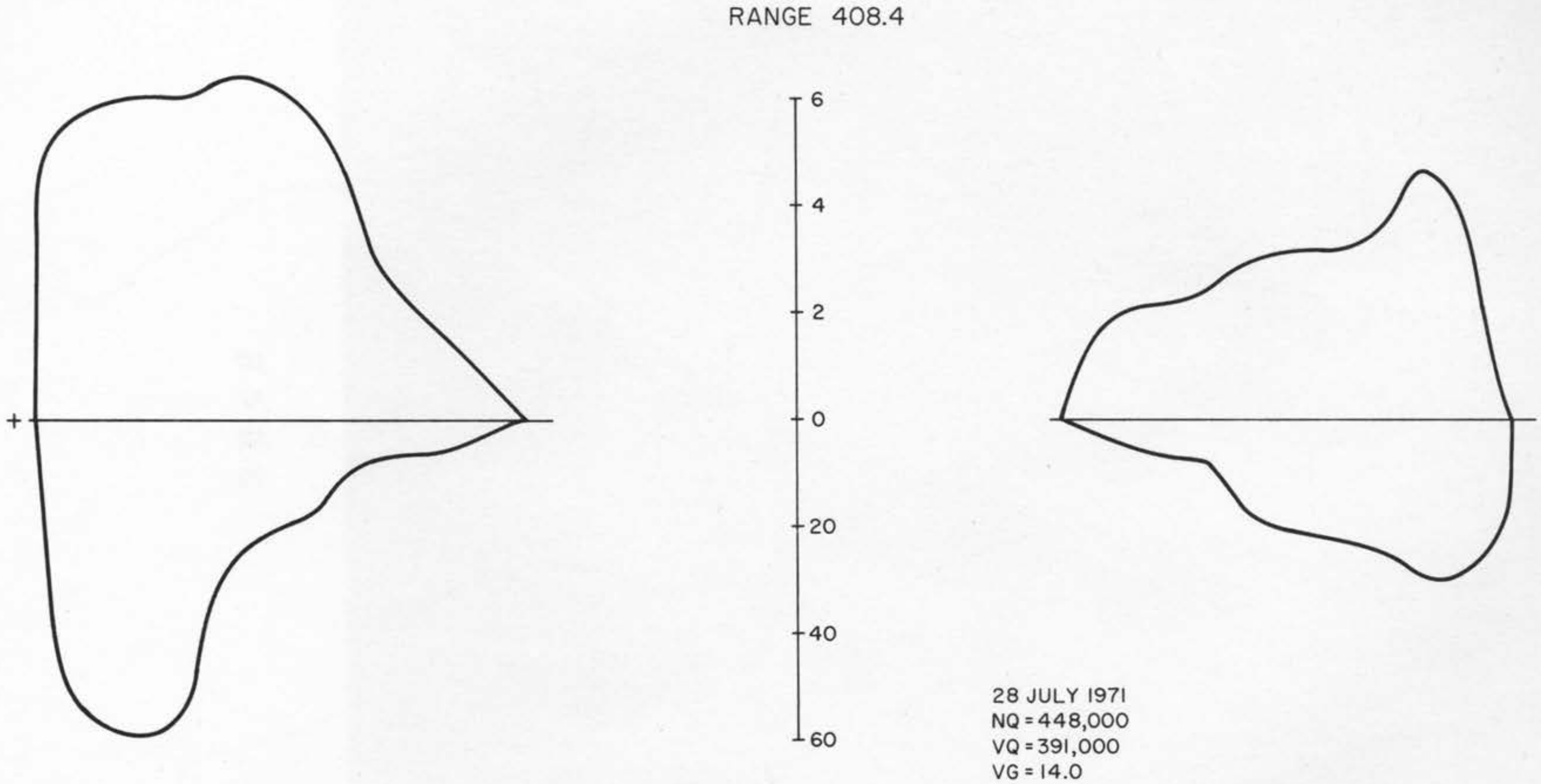
R-3
R-2
R-1
XR-4
XR-3
XR-2
XR-1
VR-1
X-1A
X-2A
X-3A
X-4A
X-5A
BEN
LOMOND
DIKES
XL-1
XL-2
XL-3
XL-4
L-14
L-13
L-12
L-11
L-10
L-9
L-8
L-7
L-6
L-5
L-4
L-3
L-2
L-1
VL-8
VL-7
VL-6
VL-5
VL-4
VL-3
VL-2

3 6 4 5


RANGE 408.4
6
4
2
0
20
40
60
+
28 JULY 1971
NQ = 448,000
VQ = 391,000
VG = 14.0

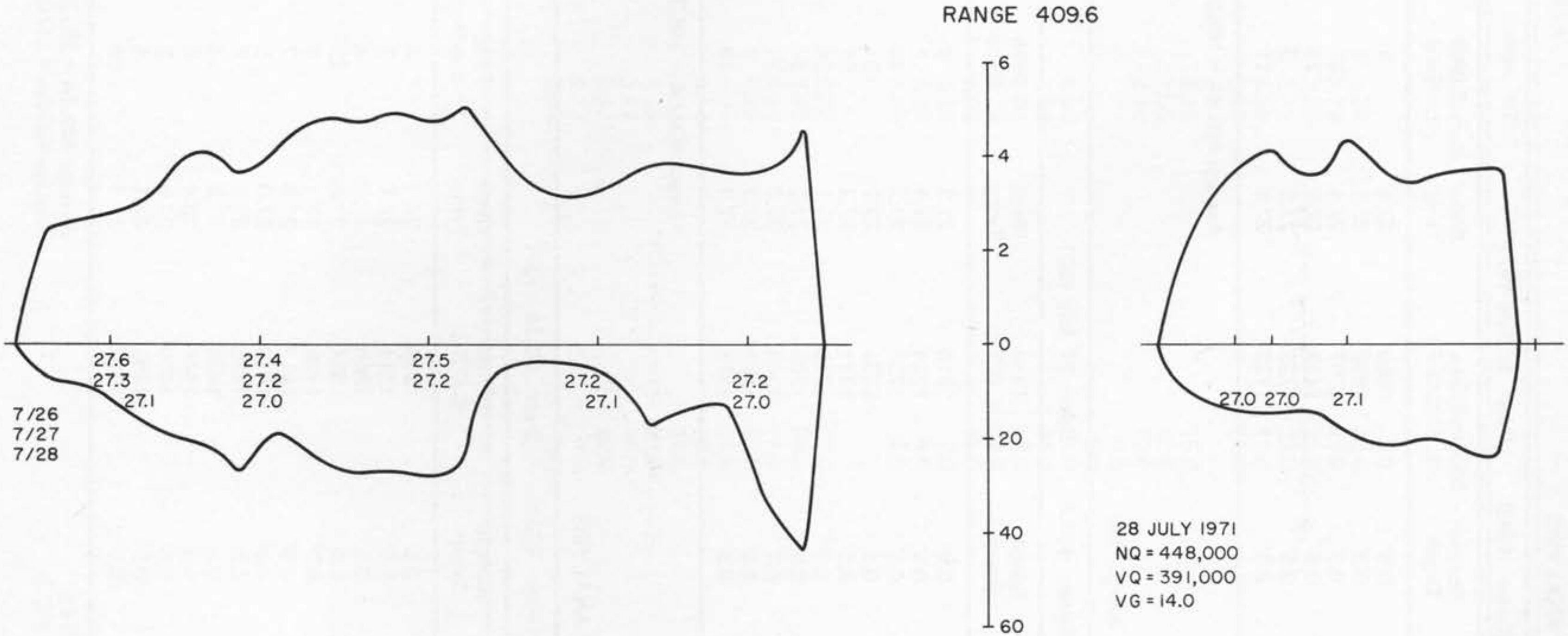
VELOCITY AND DEPTH DATA

Location: Point Pleasant **Range:** 408.4 **Date:** 28 July 1971

Station*	Near Surface Velocity	Sounded Depth	Near Surface Sediment (-230 in PPM)
7031		0.0	
7000	1.73	18.0	
6800	4.18	28.5	
6600	4.64	30.0	
6400	3.43	25.0	
6200	3.16	23.0	
6000	3.13	21.0	
5800	2.92	18.0	
5600	2.52	8.0	
5400	2.16	7.0	
5200	1.98	5.0	
5100	.49	4.0	
4900		0.0	
100		0.0	
200	5.02	45.0	
400	5.90	57.0	
600	6.05	59.0	
800	5.94	53.0	
1000	6.39	28.0	
1200	6.35	21.0	
1400	5.72	18.0	
1600	4.13	9.0	
1800	2.41	7.0	
2000	1.53	6.5	
2200	1.40	3.0	
2400		0.0	

**Measured from left bank IPQ 408.4A*

3 6 1 1


RANGE 409.6
6
4
2
0
20
40
60
27.6
27.3
27.1
27.4
27.2
27.0
27.5
27.2
27.2
27.1
27.2
27.0
7/26
7/27
7/28
27.0 27.0 27.1
28 JULY 1971
NQ = 448,000
VQ = 391,000
VG = 14.0

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 409.6 **Date:** 26 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
21	4+00	0.5′	1653	27.6	5	181	186
22A	4+00	0.5′	1656	27.4	5	183	188
23	12+00	0.5′	1707	27.4	27	194	221
24A	12+00	0.5′	1712	27.5	23	166	189
25	21+00	0.5′	1722	27.5	3	165	168
26A	21+00	0.5′	1728	27.5	11	168	179

Average 409.6 = 191.7 Average 409.6A = 185.3

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 409.6 **Date:** 27 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
21	4+00	0.5′	1218	27.3	8	200	208
22A	4+00	0.5′	1224	27.4	7	231	238
23	12+00	0.5′	1231	27.2	16	222	238
24A	12+00	0.5′	1236	27.2	34	226	260
25	21+00	0.5′	1311	27.2	64	238	302
26A	21+00	0.5′	1315	27.1	24	218	242
27	30+00	0.5′	1300	27.2	27	209	236
28A	30+00	0.5′	1305	27.2	24	241	265
29	38+00	0.5′	1323	27.2	8	227	235
30A	38+00	0.5′	1328	27.3	15	206	221

Average 409.6 = 243.8 Average 409.6A = 245.2

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 409.6 **Date:** 28 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
21	4+00	0.5′	1335	27.1	4	270	274
22A	4+00	0.5′	1341	27.1	7	272	279
23	12+00	0.5′	1348	27.0	4	284	288
24A	12+00	0.5′	1354	27.0	23	334	357
25	30+00	0.5′	1406	27.1	9	281	290
26A	30+00	0.5′	1411	27.0	3	249	252
27	38+00	0.5′	1419	27.0	5	241	246
28A	38+00	0.5′	1425	27.1	4	241	245
29	74+00	0.5′	1439	27.0	14	246	260
30A	74+00	0.5′	1444	26.9	5	236	241
31	77+00	0.5′	1450	27.0	5	252	257
32A	77+00	0.5′	1455	27.1	4	250	254
33	80+00	0.5′	1500	27.1	4	251	255

Left Channel Average 409.6 = 274.5 Average 409.6A = 283.3
Right Channel Average 409.6 = 257.3 Average 409.6A = 247.5

VELOCITY AND DEPTH DATA

Location: Point Pleasant **Range:** 409.6 **Date:** 28 July 1971

Station*	Near Surface Velocity	Sounded Depth	Near Surface Sediment (-230 in PPM)
8930		0.0	
8800	3.76	23.0	
8600	3.79	22.0	
8400	3.50	20.0	
8200	3.77	22.0	
8000	4.35	19.0	
7800	3.60	14.0	
7700			
7600	4.15	15.0	
7400	3.54	13.5	
7200	2.76	12.0	
7000		0.0	
297		0.0	
400	4.44	44.0	
600	3.58	34.0	
800	3.60	13.0	
1000	3.72	14.0	
1200	3.85	17.0	
1400	3.43	7.0	
1600	3.15	4.0	
2000	3.97	5.0	
2100			
2100			
2200	5.07	23.0	
2400	4.72	28.0	
2600	4.91	27.0	
2800	4.71	27.0	
3000	4.77	24.0	
3200	4.13	19.0	
3400	3.65	26.5	
3600	4.15	21.0	
3800	3.52	19.0	
4000	2.92	15.0	
4200	2.73	9.0	
4400	2.50	8.0	
4600		0.0	

**Measured from left bank IPQ 409.6A*

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 409.6 **Date:** 29 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
21	4+00	0.5′	1328	26.9	13	261	274
22	4+00	0.5′	1333	26.8	16	208	224
23	12+00	0.5′	1341	26.9	17	272	289
24	12+00	0.5′	1346	26.8	22	298	320
25	21+00	0.5′	1358	26.7	13	292	305
26	21+00	0.5′	1403	26.8	11	265	276
27	30+00	0.5′	1409	26.9	17	283	300
28	30+00	0.5′	1414	26.9	24	274	298
29	38+00	0.5′	1419	26.9	11	247	258
30	38+00	0.5′	1425	27.0	13	220	233
31	74+00	0.5′	1441	27.0	13	255	268
32	74+00	0.5′	1446	26.9	5	242	247
33	77+00	0.5′	1451	26.9	15	247	262
34	77+00	0.5′	1456	26.9	15	238	253
35	80+00	0.5′	1501	26.8	15	219	234
36	80+00	0.5′	1506	26.9	10	235	245
37	83+00	0.5′	1511	27.0	14	245	259
38	83+00	0.5′	1516	27.0	11	223	234
39	87+00	0.5′	1522	26.9	16	217	233
40	87+00	0.5′	1528	27.0	16	221	237

Left Channel Average 409.6 = 285.2 Average 409.6A = 270.2
Right Channel Average 409.6 = 251.2 Average 409.6A = 243.2

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 413.2 **Date:** 26 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
11	38+00	0.5′	1424	27.6	6	171	177
12	38+00	0.5′	1428	27.5	3	182	185
13	43+00	0.5′	1435	27.7	5	189	194
14	43+00	0.5′	1440	27.4	5	174	179
15	49+00	0.5′	1446	27.4	9	181	190
16	49+00	0.5′	1451	27.3	7	188	195
17	55+00	0.5′	1458	27.6	3	156	159
18	55+00	0.5′	1504	27.9	4	144	148
19	60+00	0.5′	1510	27.4	6	175	181
20	60+00	0.5′	1515	27.3	5	121	126

Average 413.2 = 180.2 Average 413.2A = 166.6

3 6 2 9

RANGE 413.2

7/26	27.6	27.7	27.4	27.6	27.4
7/27	27.0	26.9	27.0	27.1	27.1
7/28	26.9	27.0	26.7	26.9	27.1

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 413.2 **Date:** 27 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
11	38+00	0.5′	0947	27.0	6	205	211
12	38+00	0.5′	0952	26.9	7	193	200
13	43+00	0.5′	0957	26.9	15	209	224
14	43+00	0.5′	1002	27.0	18	202	220
15	49+00	0.5′	1007	27.0	24	216	240
16	49+00	0.5′	1012	27.0	39	222	261
17	55+00	0.5′	1017	27.1	11	160	171
18	55+00	0.5′	1022	27.1	16	173	188
19	60+00	0.5′	1027	27.1	15	171	186
20	60+00	0.5′	1032	27.1	9	175	184

Average 413.2 = 206.4 Average 413.2A = 210.6

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 413.2 **Date:** 28 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
11	38+00	0.5′	1012	26.9	8	291	299
12	38+00	0.5′	1017	26.9	12	291	303
13	43+00	0.5′	1025	27.0	11	301	312
14	43+00	0.5′	1030	26.9	13	298	301
15	49+00	0.5′	1152	26.7	29	304	333
16	49+00	0.5′	1157	16.9	9	288	297
17	55+00	0.5′	1204	16.9	9	233	242
18	55+00	0.5′	1209	27.0	5	186	191
19	60+00	0.5′	1215	27.1	8	147	155
20	60+00	0.5′	1220	26.9	8	210	218

Average 413.2 = 268.2 Average 413.2A = 262.0

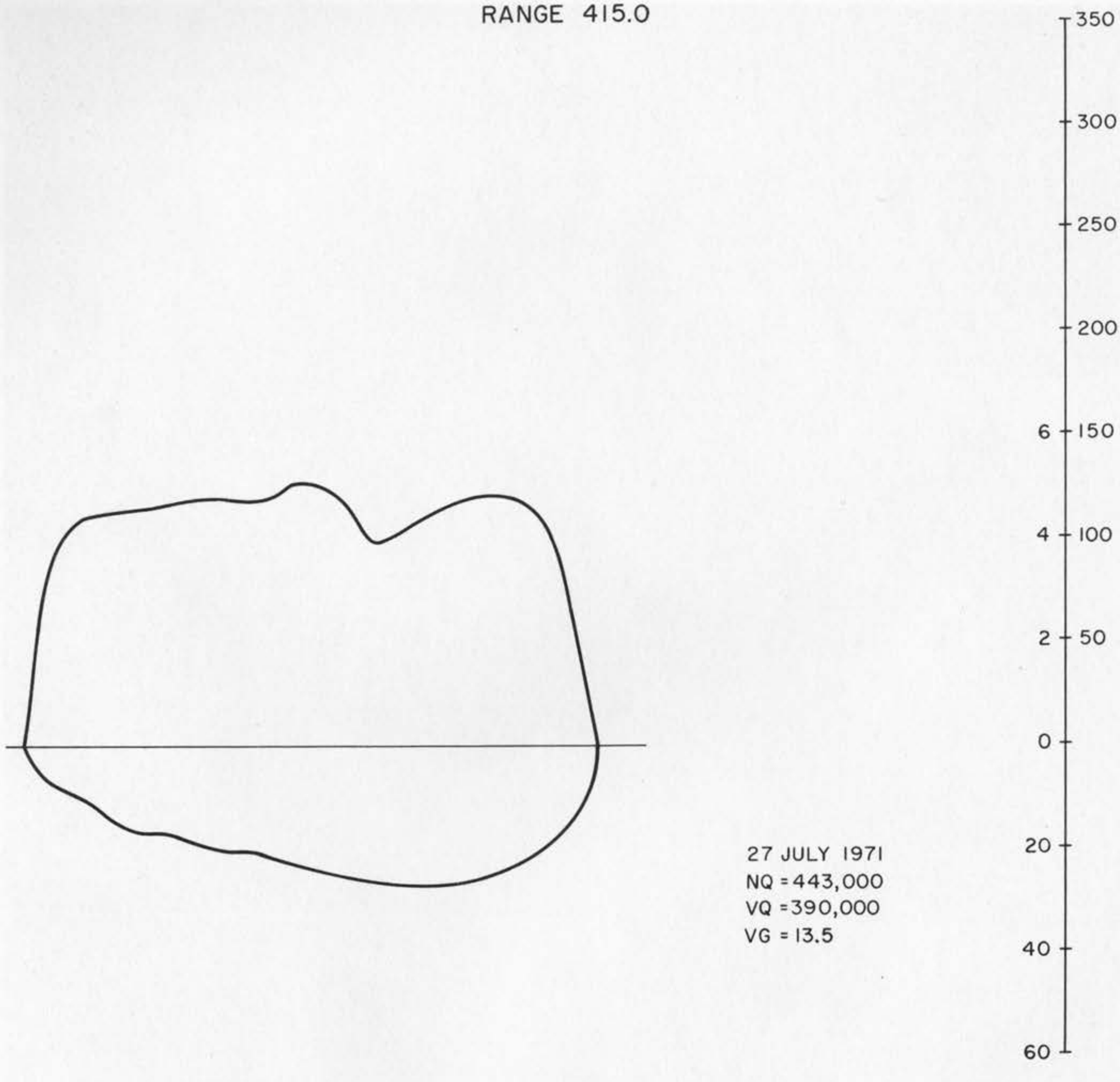
TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 413.2 **Date:** 29 July 1971

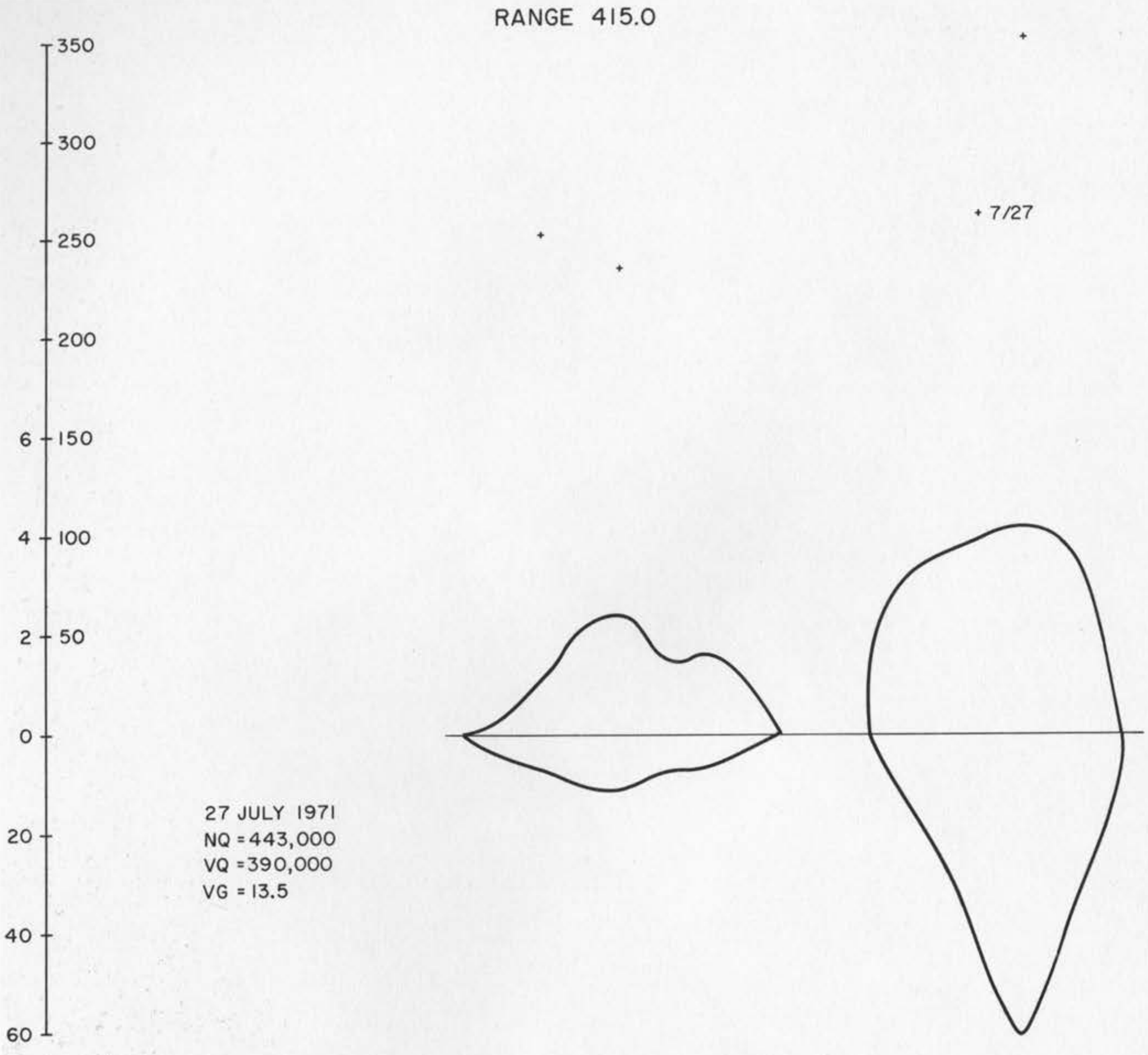
Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
11	38+00	0.5′	1133	26.7	12	273	285
12	38+00	0.5′	1138	26.7	8	267	275
13	43+00	0.5′	1144	26.7	11	258	269
14	43+00	0.5′	1151	26.7	11	292	303
15	49+00	0.5′	1156	26.8	16	278	294
16	49+00	0.5′	1202	26.8	10	265	275
17	55+00	0.5′	1207	26.8	10	156	166
18	55+00	0.5′	1212	26.8	8	134	142
19	60+00	0.5′	1217	26.8	9	117	126
20	60+00	0.5′	1222	26.9	12	240	252

Average 413.2 = 228.0 Average 413.2A = 249.4

3599


RANGE 415.0
350
300
250
200
6 150
4 100
2 50
0
20
40
60
27 JULY 1971
NQ = 443,000
VQ = 390,000
VG = 13.5

3699


RANGE 415.0
350
300
250
200
6 150
4 100
2 50
0
20
40
60
7/27
27 JULY 1971
NQ = 443,000
VQ = 390,000
VG = 13.5

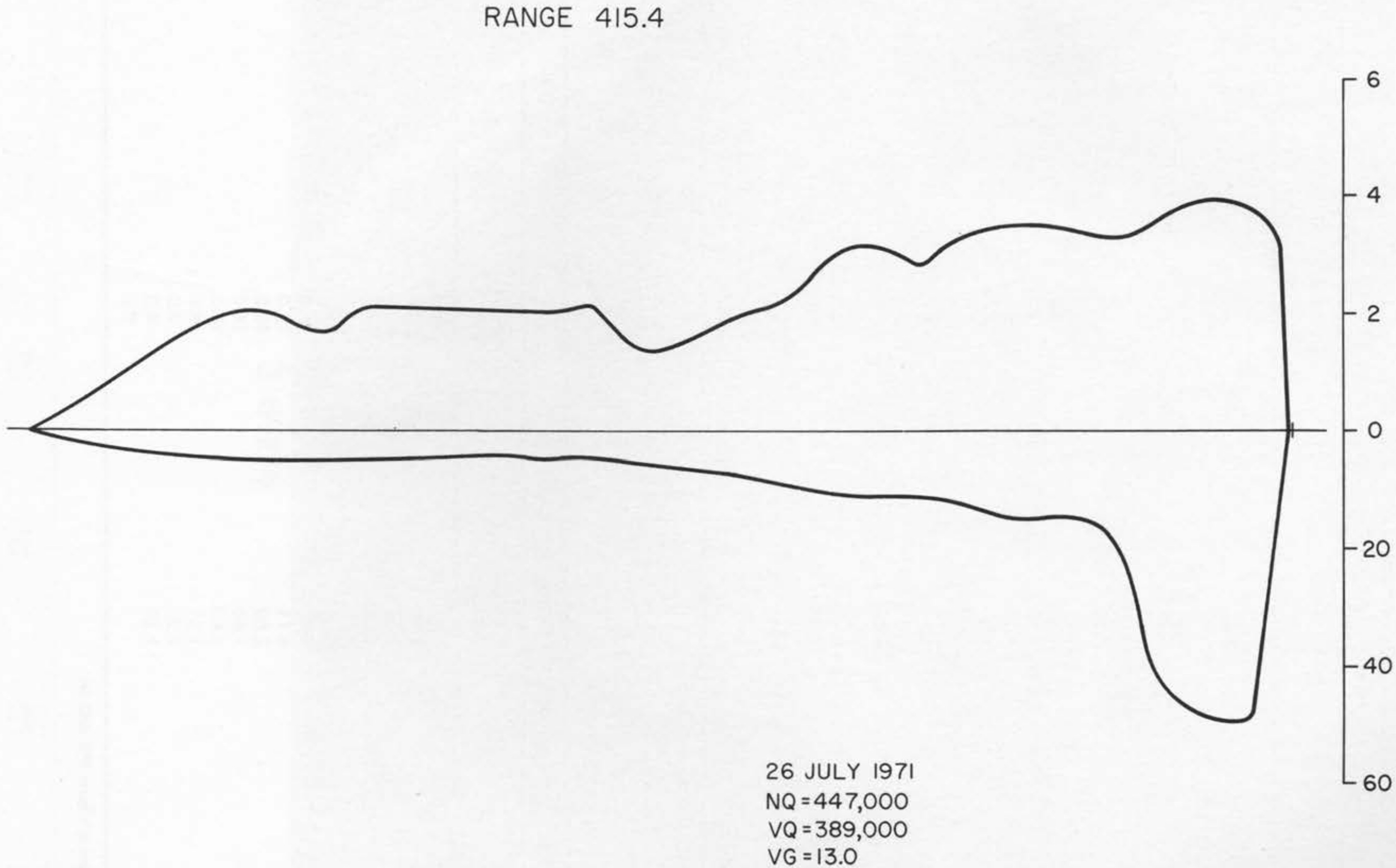
VELOCITY AND DEPTH DATA

Location: Point Pleasant **Range:** 415.0 **Date:** 27 July 1971

Station*	Near Surface Velocity	Sounded Depth	Near Surface Sediment (-230 in PPM)
11869		0.0	
11800	0.87	20.0	
11600	3.89	39.0	
11400	4.28	61.0	351
11200	3.92	47.0	263
11000	3.56	26.0	
10800	3.00	14.0	
10640	1.50	0.0	
10200		0.0	
10000	1.12	4.0	
9800	1.60	7.0	
9600	1.58	8.0	
9400	2.41	11.0	235
9200	2.17	10.5	
9000	1.08	7.0	251
8800	0.58	2.0	
8600		0.0	
4250		0.0	
4200	1.48	9.0	
4000	4.18	21.0	
3800	4.80	24.0	
3600	4.67	27.0	
3400	4.26	27.0	
3200	3.96	26.5	248
3000	4.80	26.0	
2800	5.00	24.0	
2600	4.69	21.0	
2400	4.71	20.0	233
2200	4.63	17.5	
2000	4.58	16.5	
1800	4.44	11.0	
1600	3.13	7.0	
1500		0.0	

**Measured from left bank IP 415.0A*

3621


RANGE 415.4
6
4
2
0
20
40
60
26 JULY 1971
NQ=447,000
VQ=389,000
VG=13.0

VELOCITY AND DEPTH DATA

Location: Point Pleasant **Range:** 415.4 **Date:** 26 July 1971

Station*	Near Surface Velocity	Sounded Depth	Near Surface Sediment (-230 in PPM)
6988		0.0	
6800	3.90	50.0	
6600	3.92	48.0	
6400	3.59	41.0	
6200	3.25	17.0	
6000	3.45	15.0	
5800	3.40	12.0	
5600	3.29	13.0	
5400	2.84	12.0	
5200	3.13	11.5	
5000	2.88	10.8	
4800	2.14	9.0	
4600	1.85	7.5	
4400	1.53	7.0	
4200	1.42	6.0	
4000	2.10	5.0	
3800	2.07	5.0	
3600	2.08	4.5	
3400	2.09	4.5	
3200	2.12	4.5	
3000	2.03	5.0	
2800	1.72	5.0	
2600	2.01	5.0	
2400	1.90	5.0	
1600		0.0	

**Measured from Middle Bar IPQ 415.4A*

VELOCITY AND DEPTH DATA

Location: Ajax **Range:** 480.1 **Date:** 29 July 1971

Station*	Near Surface Velocity	Sounded Depth	Near Surface Sediment (-230 in PPM)
4228		0.0	
4000	2.39	46.0	
3800	3.68	55.0	
3600	5.32	62.0	266
3400	5.50	64.0	
3200	5.81	72.5	219
3000	4.78	71.0	
2800	4.11	70.0	205
2600	2.69	45.0	
2400	1.45	14.0	
2200	1.43	10.0	166
2000	1.41	6.5	
1800	1.23	7.0	
1600	1.19	4.0	
1400		0.0	

**Measured from left bank IPQ 480.1A*

3 6 2 6

RANGE 416.4

7/26	27.3	27.2	27.1	27.1	27.6
7/27	27.0	26.4	26.8	26.9	27.0
7/28	27.0	26.7	26.9	26.7	26.7
7/29					

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 416.4 **Date:** 26 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
1	21+50	0.5′	1232	27.3	7	176	183
2	21+50	0.5′	1238	27.5	12	172	184
3	34+00	0.5′	1248	27.2	11	193	204
4	34+00	0.5′	1253	27.2	5	189	194
5	46+00	0.5′	1300	27.1	5	171	176
6	46+00	0.5′	1306	27.3	14	178	192
7	58+00	0.5′	1319	27.1	7	197	204
8	58+00	0.5′	1329	27.2	9	176	185
9	69+00	0.5′	1337	27.6	8	147	155
10	69+00	0.5′	1345	27.7	3	146	149

Average 416.4 = 184.4 Average 416.4A = 180.8

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 416.4 **Date:** 27 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
1	21+50	0.5′	0806	27.0	11	210	221
2	21+50	0.5′	0813	27.0	11	200	211
3	34+00	0.5′	0822	26.9	6	189	195
4	34+00	0.5′	0828	27.0	5	217	222
5	46+00	0.5′	0834	26.8	8	210	218
6	46+00	0.5′	0840	27.0	12	205	217
7	58+00	0.5′	0846	26.9	5	189	194
8	58+00	0.5′	0853	26.9	12	193	205
9	69+00	0.5′	0859	27.0	13	147	160
10	69+00	0.5′	0906	26.9	10	109	119

Average 416.4 = 197.6 Average 410.4A = 194.8

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 416.4 **Date:** 28 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
1	21+50		0823	27.0	14	304	318
2	21+50		0829	26.8	14	288	302
3	34+00		0836	26.7	7	294	301
4	34+00		0842	26.7	17	303	320
5	46+00		0848	26.9	16	261	277
6	46+00		0854	26.8	14	255	269
7	58+00		0902	26.8	10	258	268
8	58+00		0909	26.7	10	193	203
9	69+00		0914	26.7	14	111	125
10	69+00		0920	27.0	6	98	104

Average 416.4 = 257.8 Average 416.4A = 239.6

TABULATION OF SEDIMENT ANALYSIS

Location: Point Pleasant **Range:** 416.4 **Date:** 29 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
1	21+50		0848	26.7	8	253	261
2	21+50		0854	26.6	11	294	305
3	34+00		1039	26.8	12	255	267
4	34+00		1045	26.8	11	296	307
5	46+00		1052	26.7	15	262	277
6	46+00		1057	26.8	6	275	281
7	58+00		1104	26.7	8	145	153
8	58+00		1109	26.8	7	189	196
9	69+00		1114	26.7	8	173	181
10	69+00		1120	26.8	6	82	88

Average 416.4 = 227.8 Average 416.4A = 235.4

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax Cottonwood **Range:** 473.6 **Date:** 28 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
101	7+00	0.5′	1555	26.9	14	184	198
102A	7+00	0.5′	1559	26.9	17	194	211
103	12+00	0.5′	1605	26.9	10	177	187
104A	12+00	0.5′	1609	26.8	9	182	191
105	17+00	0.5′	1614	26.8	16	183	199
106A	17+00	0.5′	1618	26.9	31	192	223
107	22+00	0.5′	1622	27.0	22	199	221
108A	22+00	0.5′	1626	27.0	10	178	188
109	28+00	0.5′	1630	27.1	13	172	185
110A	28+00	0.5′	1634	27.0	15	180	195

Average 473.6 = 198.0 Average 473.6A = 201.6

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax Cottonwood **Range:** 473.6 **Date:** 29 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
151	7+00	0.5′	1649	27.0	19	177	196
152A	7+00	0.5′	1653	27.0	17	173	196
153	12+00	0.5′	1657	26.9	16	182	198
154A	12+00	0.5′	1700	27.0	19	185	204
155	17+00	0.5′	1704	27.0	20	175	195
156A	17+00	0.5′	1708	27.0	13	187	200
157	22+00	0.5′	1712	27.0	18	178	196
158A	22+00	0.5′	1716	27.1	27	192	219
159	28+00	0.5′	1720	27.1	23	182	205
160A	28+00	0.5′	1724	27.2	10	182	192

Average 473.6 = 198.0 Average 473.6A = 202.2

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax Cottonwood **Range:** 473.6 **Date:** 30 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
201	7+00	0.5′			12	175	187
202A	7+00	0.5′			9	177	186
203	12+00	0.5′			10	185	195
204A	12+00	0.5′			12	180	192
205	17+00	0.5′			9	192	201
206A	17+00	0.5′			21	184	205
207	22+00	0.5′			11	184	195
208A	22+00	0.5′			9	181	190
209	28+00	0.5′			8	186	194
210A	28+00	0.5′			13	184	197

Average 473.6 = 194.4 Average 473.6A = 194.0

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax Cottonwood **Range:** 473.6 **Date:** 31 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
241	7+00	0.5′	1534	26.6	8	160	168
242A	7+00	0.5′	1538	26.6	7	159	166
243	12+00	0.5′	1542	26.6	9	154	163
244A	12+00	0.5′	1546	26.5	7	171	178
245	17+00	0.5′	1550	26.6	8	167	175
246A	17+00	0.5′	1554	26.6	6	186	192
147	22+00	0.5′	1559	26.7	9	171	180
248A	22+00	0.5′	1603	26.6	7	200	207
249	28+00	0.5′	1607	26.7	7	168	175
250A	28+00	0.5′	1611	26.7	8	185	193

Average 473.6 = 172.2 Average 473.6A = 187.2

4027

RANGE 477.2

7/29 26.9 26.9 27.0 27.0 27.0

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax **Range:** 477.2 **Date:** 28 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
91	19+00	0.5′	1422	26.9	18	173	191
92A	19+00	0.5′	1427	26.9	6	166	172
93	30+00	0.5′	1434	26.9	8	188	196
94A	30+00	0.5′	1438	27.0	5	186	191
95	42+00	0.5′	1444	27.0	7	174	181
96A	42+00	0.5′	1448	26.9	6	183	189
97	56+00	0.5′	1455	26.9	9	181	190
98A	56+00	0.5′	1459	26.8	7	187	194
99	75+00	0.5′	1508	26.8	5	186	191
100A	75+00	0.5′	1514	26.9	6	190	196

Average 477.2 = 189.8 Average 477.2A = 188.4

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax **Range:** 477.2 **Date:** 29 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
141	19+00	0.5′	1507	26.9	8	174	182
142A	19+00	0.5′	1513	27.0	5	167	172
143	31+00	0.5′	1525	26.9	7	191	198
144A	31+00	0.5′	1528	26.9	7	186	193
145	42+00	0.5′	1535	27.0	12	195	207
146A	42+00	0.5′	1539	27.0	8	191	199
147	56+00	0.5′	1548	27.0	8	192	200
148A	56+00	0.5′	1552	26.9	10	186	196
149	65+00	0.5′	1557	27.0	14	194	208
150A	65+00	0.5′	1601	26.9	8	194	202

Average 477.2 = 199.0 Average 477.2A = 192.4

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax Cottonwood **Range:** 477.2 **Date:** 30 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
191	19+00	0.5′	1352	26.9	10	153	163
192A	19+00	0.5′	1356	26.8	13	164	177
193	31+00	0.5′	1402	26.8	14	189	203
194A	31+00	0.5′	1407	26.8	13	183	196
195	42+00	0.5′	1411	26.9	5	179	184
196A	42+00	0.5′	1415	27.0	11	188	199
197	56+00	0.5′	1420	26.0	15	180	195
198A	56+00	0.5′	1425	26.8	9	185	194
199	65+00	0.5′	1430	26.8	14	194	208
200A	65+00	0.5′	1434	26.8	7	195	202

Average 477.2 = 190.6 Average 477.2A = 193.6

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax Cottonwood **Range:** 477.2 **Date:** 30 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Observed Velocity	PPM Sand	PPM -230	PPM Sediment
1	A-4000	3.7		3.89	8	150	158
2		11.3			60		
3		20.0			17		
4		29.4			29		
5		34.0			31		
1	B-4400	3.7		5.40	5		209
2		11.3			69	204	273
3		20.0			54		
4		29.4			94		
5		34.0			95		
1	C-5000	2.8		5.18	5		213
2		8.4			241		
3		14.8			31	208	239
4		21.8			62		
5		25.0			240		
1	D-5800	1.3		3.34	7		215
2		4.0			12		
3		7.1			366		
4		10.5			35	208	243
5		11.5			26		

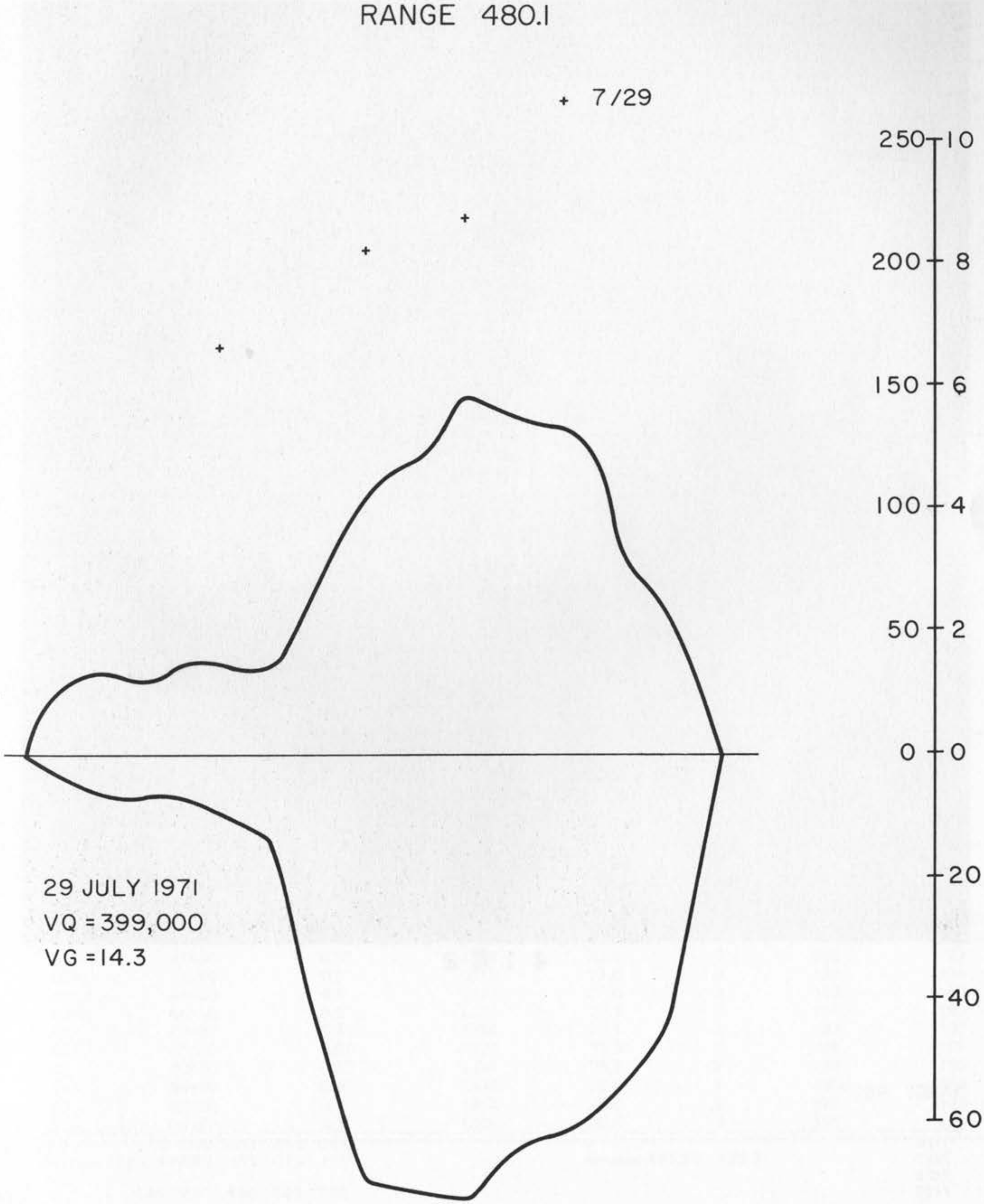
TABULATION OF SEDIMENT ANALYSIS

Location: Ajax Cottonwood **Range:** 477.2 **Date:** 31 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
231	19+00	0.5′	1422	26.7	6	170	176
232A	19+00	0.5′	1426	26.7	3	168	171
233	30+00	0.5′	1430	26.7	11	182	193
234A	30+00	0.5′	1434	26.7	7	162	169
235	42+00	0.5′	1439	26.8	4	168	172
236A	42+00	0.5′	1443	26.7	6	182	188
237	56+00	0.5′	1447	26.7	4	175	179
238A	56+00	0.5′	1451	26.7	4	174	178
239	65+00	0.5′	1455	26.7	6	181	187
240A	65+00	0.5′	1459	26.7	6	179	185

Average 477.2 = 181.4 Average 477.2A = 178.2

4 0 3 2


RANGE 480.1
+ 7/29
250 10
200 8
150 6
100 4
50 2
0 0
20
40
60
29 JULY 1971
VQ = 399,000
VG = 14.3

4148

RANGE 481.1

7/26	27.0	26.9	27.0	27.0	27.1
7/27	27.1	27.0	27.1	27.1	27.0
7/28					
7/29	26.7	26.9	26.9	26.9	26.9

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax **Range:** 481.1 **Date:** 26 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
21	41+00	0.5′	1613	27.0	4	213	217
22A	41+00	0.5′	1618	27.0	2	201	203
23	44+00	0.5′	1623	26.9	4	191	195
24A	44+00	0.5′	1628	27.0	3	205	208
25	47+00	0.5′	1633	27.0	7	195	202
26A	47+00	0.5′	1638	27.0	9	206	215
27	50+00	0.5′	1642	27.0	7	208	215
28A	50+00	0.5′	1646	27.1	7	198	205
29	53+00	0.5′	1650	27.1	8	201	209
30A	53+00	0.5′	1654	26.8	16	207	223

Average 481.1 = 207.6 Average 481.1A = 210.8

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax **Range:** 481.1 **Date:** 27 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
51	41+00	0.5′	1320	27.1	7	198	205
52A	41+00	0.5′	1324	27.3	5	195	200
53	44+00	0.5′	1329	27.0	9	205	214
54A	44+00	0.5′	1333	27.1	2	202	204
55	47+00	0.5′	1342	27.1	3	213	216
56A	47+00	0.5′	1349	27.2	5	187	192
57	50+00	0.5′	1351	27.1	10	191	201
58A	50+00	0.5′	1356	27.1	13	212	225
59	53+00	0.5′	1402	27.0	7	212	219
60A	53+00	0.5′	1407	27.0	8	203	211

Average 481.1 = 211.0 Average 481.1A = 206.4

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax **Range:** 481.1 **Date:** 28 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
81	41+00	0.5′	1309	27.0	9	188	197
82A	41+00	0.5′	1313	27.0	8	186	194
83	44+00	0.5′	1317	27.0	3	183	186
84A	44+00	0.5′	1321	27.1	6	186	192
85	47+00	0.5′	1326	27.1	5	192	197
86A	47+00	0.5′	1329	26.9	9	186	195
87	50+00	0.5′	1334	26.9	9	184	193
88A	50+00	0.5′	1338	26.9	5	180	185
89	53+00	0.5′	1342	26.8	8	185	193
90A	53+00	0.5′	1346	26.8	9	186	195

Average 481.1 = 193.2 Average 481.1A - 192.2

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax **Range:** 481.1 **Date:** 29 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
131	41+00	0.5′	1412	26.7	7	183	190
132A	41+00	0.5′	1417	26.9	9	175	184
133	44+00	0.5′	1423	26.9	9	167	176
134A	44+00	0.5′	1427	26.9	7	172	179
135	47+00	0.5′	1435	26.9	8	175	183
136A	47+00	0.5′	1439	26.9	9	182	191
137	50+00	0.5′	1444	26.9	14	182	196
138A	50+00	0.5′	1448	26.9	13	186	199
139	53+00	0.5′	1452	26.9	16	184	200
140A	53+00	0.5′	1455	26.9	9	184	193

Average 481.1 = 189.0 Average 481.1A = 189.2

TABULATION OF SEDIMENT ANALYSIS

Location: Ajax **Range:** 481.1 **Date:** 30 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
181	41+00	0.5′	1301	26.5	5	184	189
182A	41+00	0.5′	1305	26.5	4	190	194
183	44+00	0.5′	1310	26.7	7	175	182
184A	44+00	0.5′	1314	26.9	6	182	188
185	47+00	0.5′	1318	26.9	6	182	188
186A	47+00	0.5′	1322	27.0	5	173	178
187	50+00	0.5′	1327	27.0	10	185	195
188A	50+00	0.5′	1331	26.9	5	185	190
189	53+00	0.5′	1335	26.8	7	195	202
190A	53+00	0.5′	1339	26.8	7	190	197

Average 481.1 = 191.2 Average 481.1A = 189.4

TABULATION OF SEDIMENT ANALYSIS

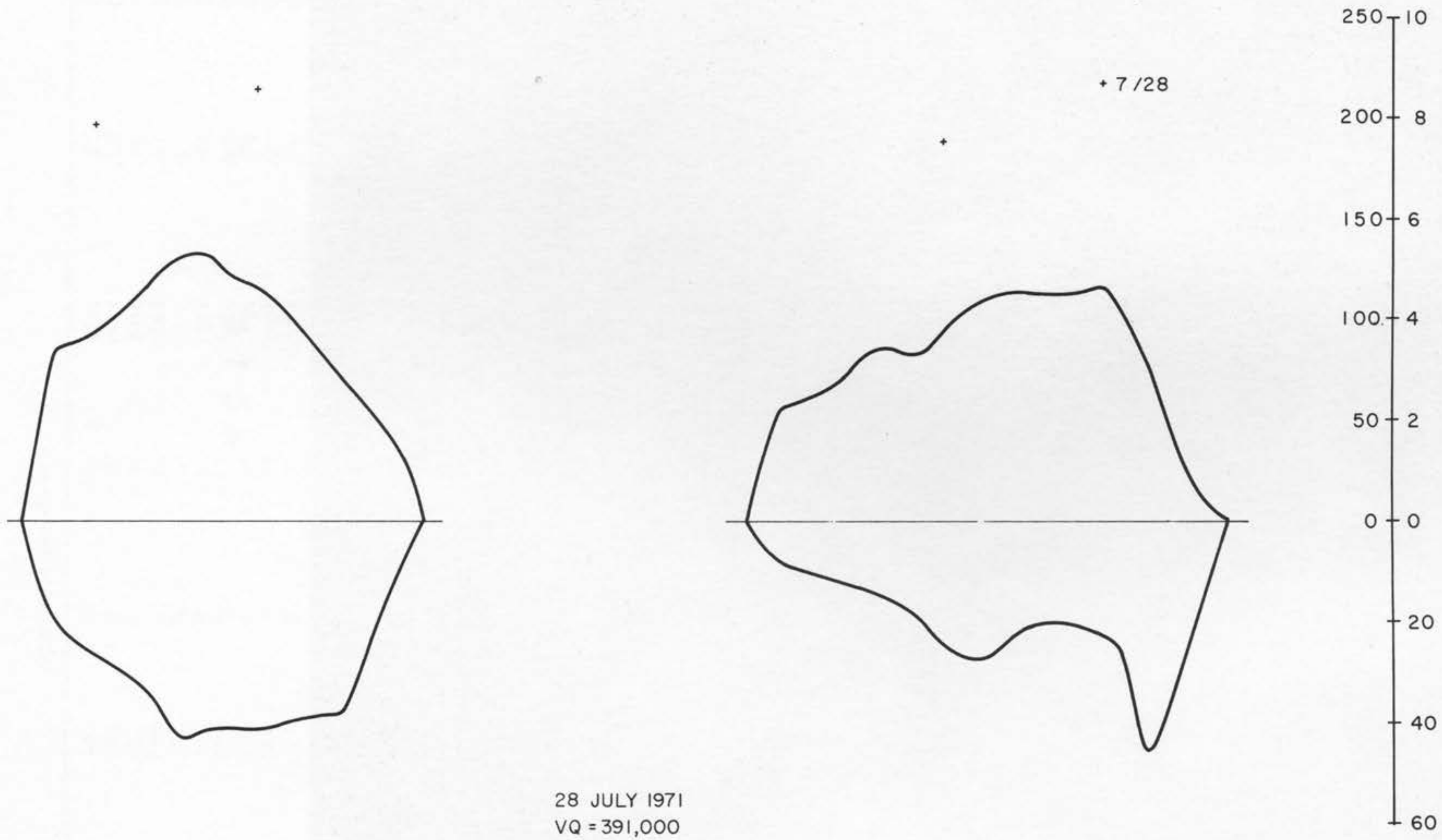
Location: Ajax **Range:** 481.1 **Date:** 31 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
221	41+00	0.5′	1332	26.9	6	170	176
222A	41+00	0.5′	1336	26.0	7	165	172
223	44+00	0.5′	1341	26.8	9	168	177
224A	44+00	0.5′	1346	26.7	10	163	173
225	47+00	0.5′	1351	26.7	6	175	181
226A	47+00	0.5′	1355	26.7	5	167	172
227	50+00	0.5′	1400	26.7	7	183	190
228A	50+00	0.5′	1404	26.7	9	186	195
229	53+00	0.5′	1409	26.7	8	192	200
230A	53+00	0.5′	1413	26.7	10	181	191

Average 481.1 = 184.8 Average 481.1A = 180.6

4014

RANGE 484.8



28 JULY 1971
VQ = 391,000
VG = 14.0

VELOCITY AND DEPTH DATA

Location: Ajax **Range:** 484.8 **Date:** 28 July 1971

Station*	Near Surface Velocity	Sounded Depth	Near Surface Sediment (-230 in PPM)
1200		0.0	
1400	3.40	21.5	
1600	3.77	27.0	195
1800	4.39	33.5	
2000	5.25	43.0	
2200	5.00	41.0	
2400	4.64	41.0	213
2600	3.69	39.0	
2800	2.83	28.0	
3000	1.87	15.5	
3200		0.0	
4800		0.0	
5000	2.22	9.0	
5200	2.69	11.5	
5400	3.14	14.5	
5600	3.32	17.5	
5800	3.82	25.5	187
6000	4.05	27.0	
6200	4.42	21.0	
6400	4.45	21.0	
6600	4.54	23.5	216
6800	3.22	46.0	
7000	.90	20.0	
7200		0.0	

**Measured from left bank IPQ 484.8A*

VELOCITY AND DEPTH DATA

Location: Baleshed **Range:** 486.4 **Date:** 27 July 1971

Station*	Near Surface Velocity	Sounded Depth	Near Surface Sediment (-230 in PPM)
391		0.0	
550			178
			181
			178
			163
			171
			165
600	1.38	25.0	
800	1.76	18.0	
1000	2.53	11.5	
1200	2.71	9.5	
1400	3.03	10.0	
1600	2.61	11.5	
1800	2.22	18.0	
2000	2.36	13.5	200
2050			220
			209
			194
			190
			193
			183

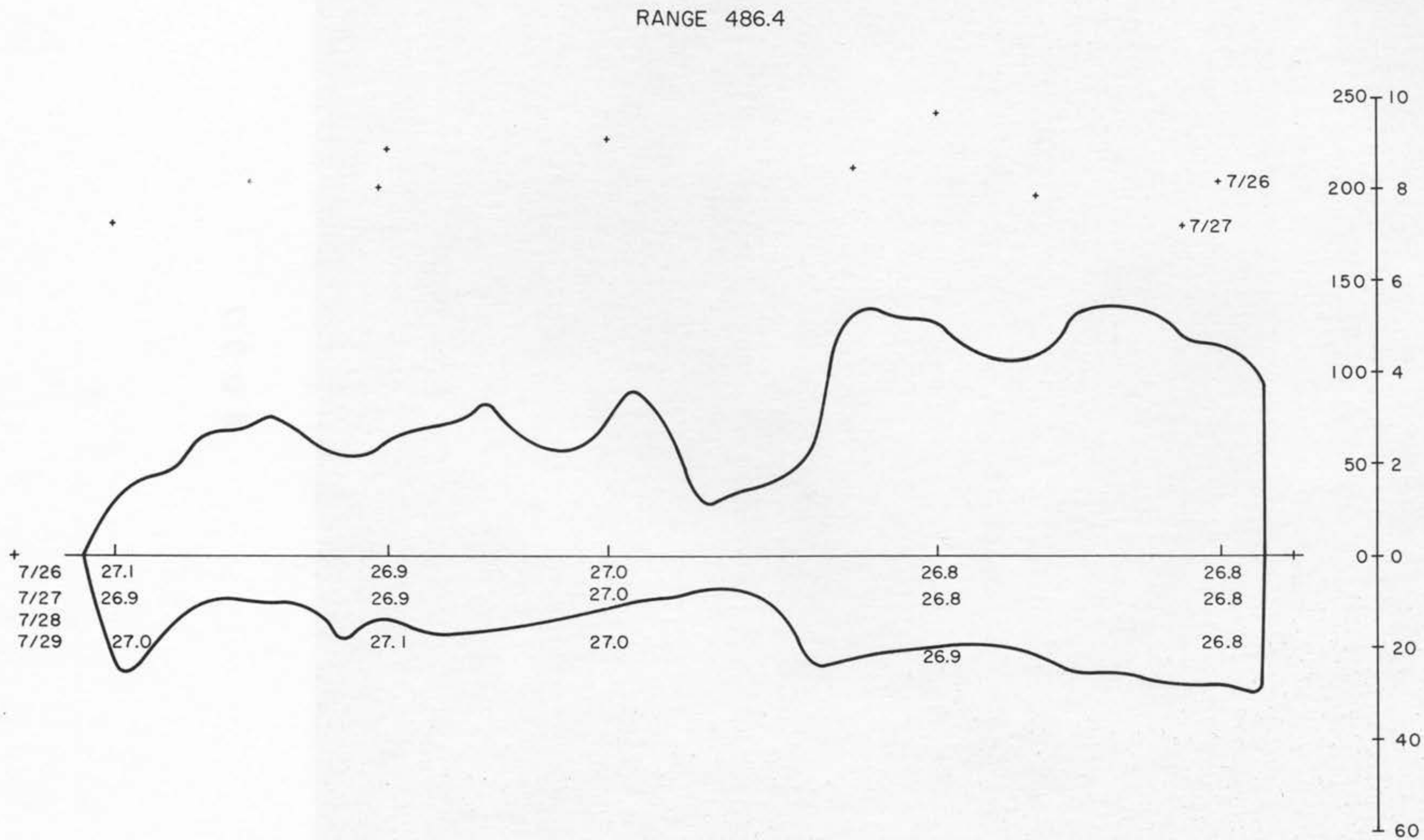
(continued on next page)

Location: Baleshed **Range:** 486.4 **Date:** 27 July 1971

Station*	Near Surface Velocity	Sounded Depth	Near Surface Sediment (-230 in PPM)
2200	2.71	16.5	
2400	2.92	17.0	
2600	3.33	16.0	
2800	2.57	15.0	
3000	2.25	13.5	
3200	2.71	12.0	
3250			225
			212
			200
			192
			186
3400	3.58	9.5	
3500			200
3600	2.33	9.0	
3800	1.09	7.0	
4000	1.42	8.0	
4200	1.70	13.0	
4400	2.71	24.0	
4600	5.32	22.0	211
4800	5.19	21.0	
5000	5.16	20.0	
5050			240
			214
			211
			198
			204
			182
5200	4.44	19.0	
5400	4.32	19.5	
5600	4.35	22.0	196
5800	5.32	25.0	
6000	5.28	25.0	
6200	5.32	27.0	
6400	4.72	28.0	180
6600	4.59	28.0	204
			216
			180
			212
			218
			186
6800	3.65	29.5	
6839		0.0	

**Measured from left bank IPQ 486.4A*

4007


RANGE 486.4
250
200
150
100
50
0
10
8
6
4
2
0
20
40
60
+7/26
+7/27
7/26
7/27
7/28
7/29
27.1
26.9
27.0
26.9
26.9
27.1
27.0
27.0
27.0
26.8
26.8
26.9
26.8
26.8
26.8

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 486.4 **Date:** 26 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
11	5+50	0.5′	223	27.1	7	173	180
12A	5+50	0.5′	230	27.2	6	170	176
13	20+50	0.5′	240	26.9	8	206	214
14A	20+50	0.5′	250	26.9	14	211	225
15	32+50	0.5′	256	27.0	15	221	236
16A	32+50	0.5′	300	27.5	8	206	214
17	50+50	0.5′	310	26.8	30	221	251
18A	50+50	0.5′	315	26.2	15	214	229
19	66+00	0.5′	328	26.8	39	214	253
20A	66+00	0.5′	333	26.8	6	150	156

Average 486.4 = 226.8 Average 486.4A = 200.0

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 486.4 **Date:** 27 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
41	5+50	0.5′	1126	26.9	16	154	170
42A	5+50	0.5′	1130	26.9	6	186	192
43	20+50	0.5′	1135	26.9	4	204	208
44A	20+50	0.5′	1139	27.0	6	204	210
45	32+50	0.5′	1150	27.0	9	205	214
46A	32+50	0.5′	1152	27.0	9	202	211
47	50+50	0.5′	1203	26.8	8	212	220
48A	50+50	0.5′	1208	26.8	2	207	209
49	66+00	0.5′	1217	26.8	8	200	208
50A	66+00	0.5′	1221	26.8	7	196	203

Average 486.4 = 204.0 Average 486.4A = 205.0

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 486.4 **Date:** 27 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Observed Velocity	PPM Sand	PPM -230	PPM Sediment
1	A-2000	1.4		2.52	16	184	200
2		4.4			61		
3		7.7			22		
4		11.3			31		
5		12.5			59		
1	B-4600	2.4		5.70	8		
2		7.1			77	203	280
3		12.5			124		
4		18.4			157		
5		21.0			445		
1	C-5600	2.4		4.65	6		
2		7.1			64		
3		12.5			73	190	263
4		18.4			109		
5		21.0			154		
1	D-6400	3.0		5.06	1		
2		9.0			55		
3		16.0			98		
4		23.5			157	179	336
5		27.0			157		

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 486.4 **Date:** 28 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
71	5+50	0.5′	1050	26.7	6	195	201
72A	5+50	0.5′	1054	26.7	4	152	156
73	20+50	0.5′	1059	26.8	3	197	200
74A	20+50	0.5′	1103	26.8	5	183	188
75	32+50	0.5′	1111	26.9	0	199	199
76A	32+50	0.5′	1116	26.9	4	196	200
77	50+50	0.5′	1124	26.9	6	202	208
78A	50+50	0.5′	1128	26.8	13	201	214
79	66+00	0.5′	1136	26.8	9	171	180
80	66+00	0.5′	1140	26.8	2	179	181

Average 486.4 = 197.6 Average 486.4A = 187.8

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 486.4 **Date:** 29 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
121A	5+50	0.5′	1523	27.1	5	149	154
122A	5+50	0.5′	1527	27.1	6	166	173
123A	20+50	0.5′	1534	27.3	8	191	199
124A	20+50	0.5′	1540	27.2	6	175	181
125A	32+50	0.5′	1546	27.1	11	183	194
126A	32+50	0.5′	1550	27.1	9	182	191
127A	50+50	0.5′	1603	27.0	4	195	199
128A	50+50	0.5′	1608	27.0	6	190	196
129A	66+00	0.5′	1618	16.9	11	196	207
130A	66+00	0.5′	1623	27.0	13	205	218

Average 486.4 = 190.6 Average 486.4A = 191.8

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 486.4 **Date:** 30 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
171	5+50	0.5′	1257	26.8	7	162	169
172A	5+50	0.5′	1302	26.8	8	165	173
173	20+50	0.5′	1307	26.8	5	188	193
174A	20+50	0.5′	1311	26.9	11	182	193
175	35+00	0.5′	1317	26.8	18	172	191
176A	35+00	0.5′	1322	26.7	11	201	212
177	50+50	0.5′	1331	26.6	16	181	197
178A	50+50	0.5′	1336	26.6	8	204	212
179	66+00	0.5′	1343	26.7	11	212	223
180A	66+00	0.5′	1348	26.6	11	202	213

Average 486.4 = 194.6 Average 486.4A = 200.6

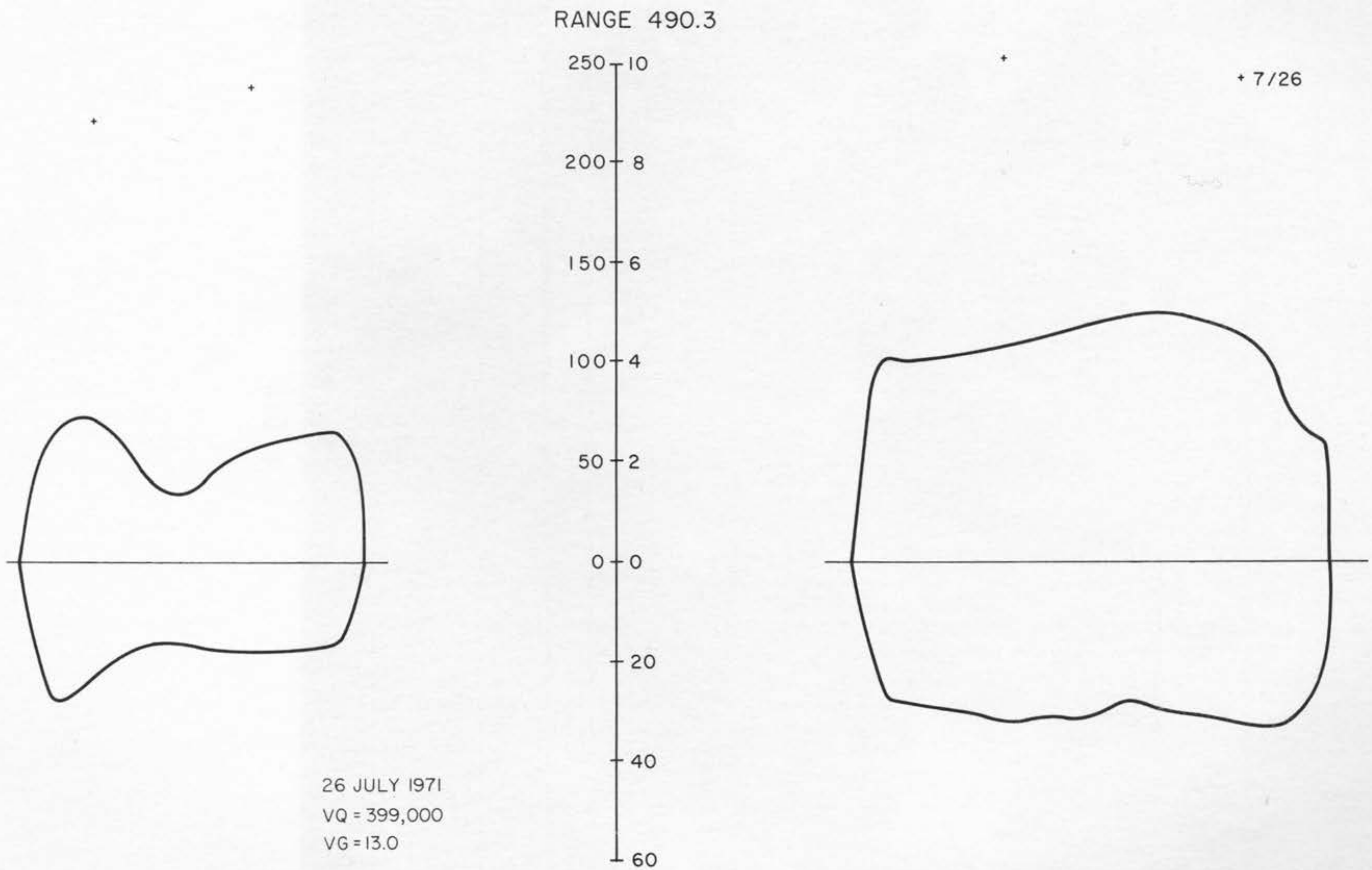
TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 486.4 **Date:** 31 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
211	5+50	0.5′	1028	25.9	5	156	161
212A	5+50	0.5′	1036	25.9	5	163	168
213	20+50	0.5′	1028	26.4	4	175	179
214A	20+50	0.5′	1036	26.3	5	182	187
215	32+50	0.5′	1028	26.0	4	182	186
216A	32+50	0.5′	1036	26.1	13	174	187
217	50+50	0.5′	1028	26.5	8	168	176
218A	50+50	0.5′	1036	26.5	11	175	186
219	66+00	0.5′	1028	26.5	5	180	185
220A	66+00	0.5′	1036	26.5	6	181	187

Average 486.4 = 177.4 Average 486.4A = 183.0

4 0 2 1


RANGE 490.3
250
10
200
8
150
6
100
4
50
2
0
0
20
40
60
7/26
26 JULY 1971
VQ = 399,000
VG = 13.0

VELOCITY AND DEPTH DATA

Location: Baleshed **Range:** 490.3 **Date:** 26 July 1971

Station*	Near Surface Velocity	Sounded Depth	Near Surface Sediment (-230 in PPM)
7282		0.0	
7200	2.39	17.5	
7000	3.37	32.0	
6800	4.44	32.5	243
6600	4.76	31.0	
6400	5.04	30.0	
6200	4.88	27.5	
6000	4.72	31.0	
5800	4.56	31.0	
5600	4.36	32.0	253
5400	4.20	30.0	
5200	4.08	29.0	
5000	4.12	27.5	
4800		0.0	
2200	2.64	16.8	
2000	2.47	18.0	
1800	2.25	18.0	239
1600	1.84	18.0	
1400	1.35	17.0	
1200	2.08	17.5	
1000	2.81	22.8	221
800	2.64	28.0	
600		0.0	

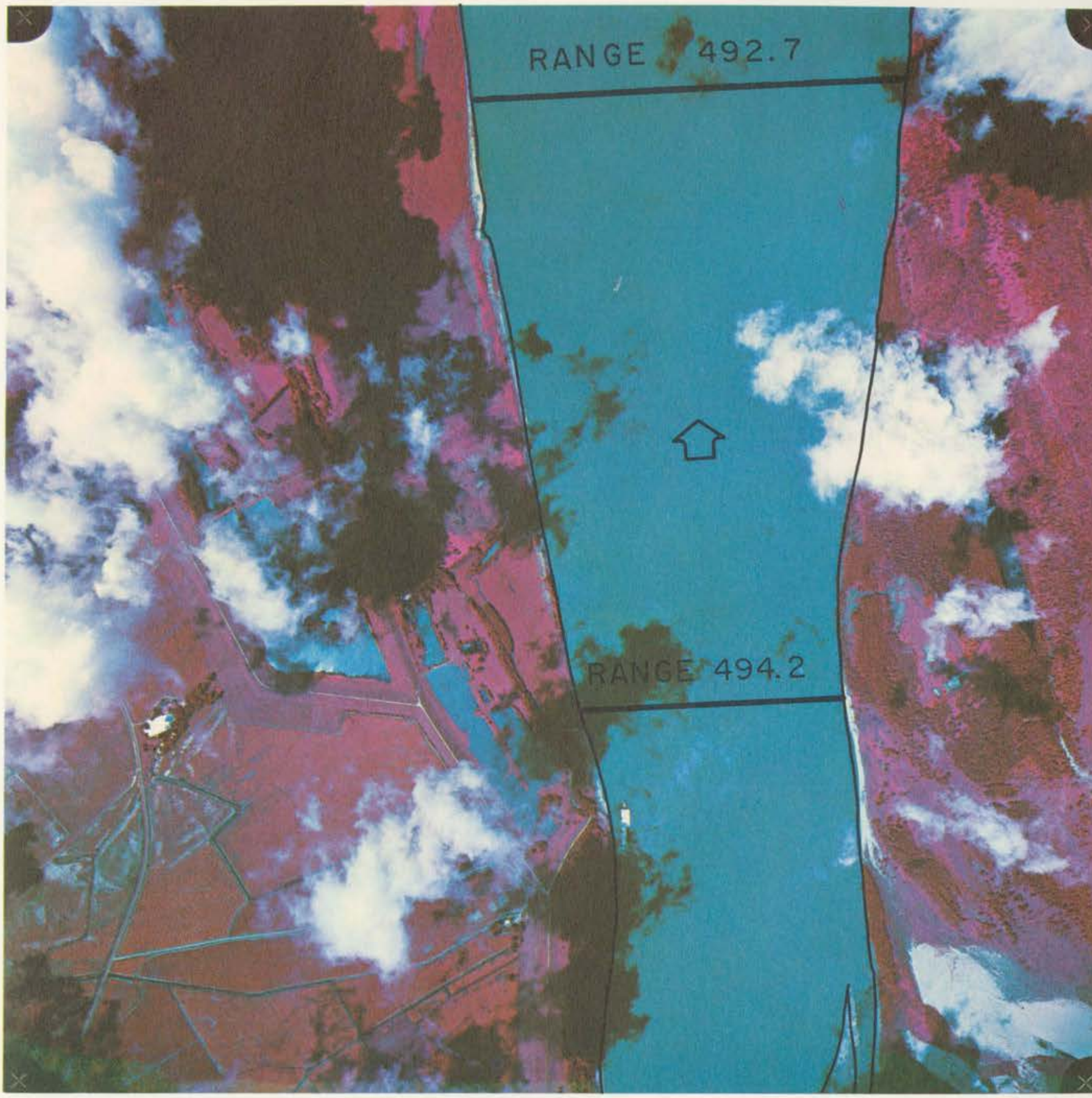
**Measured from left bank IPQ 490.3A*

VELOCITY AND DEPTH DATA

Location: Baleshed **Range:** 494.2 **Date:**

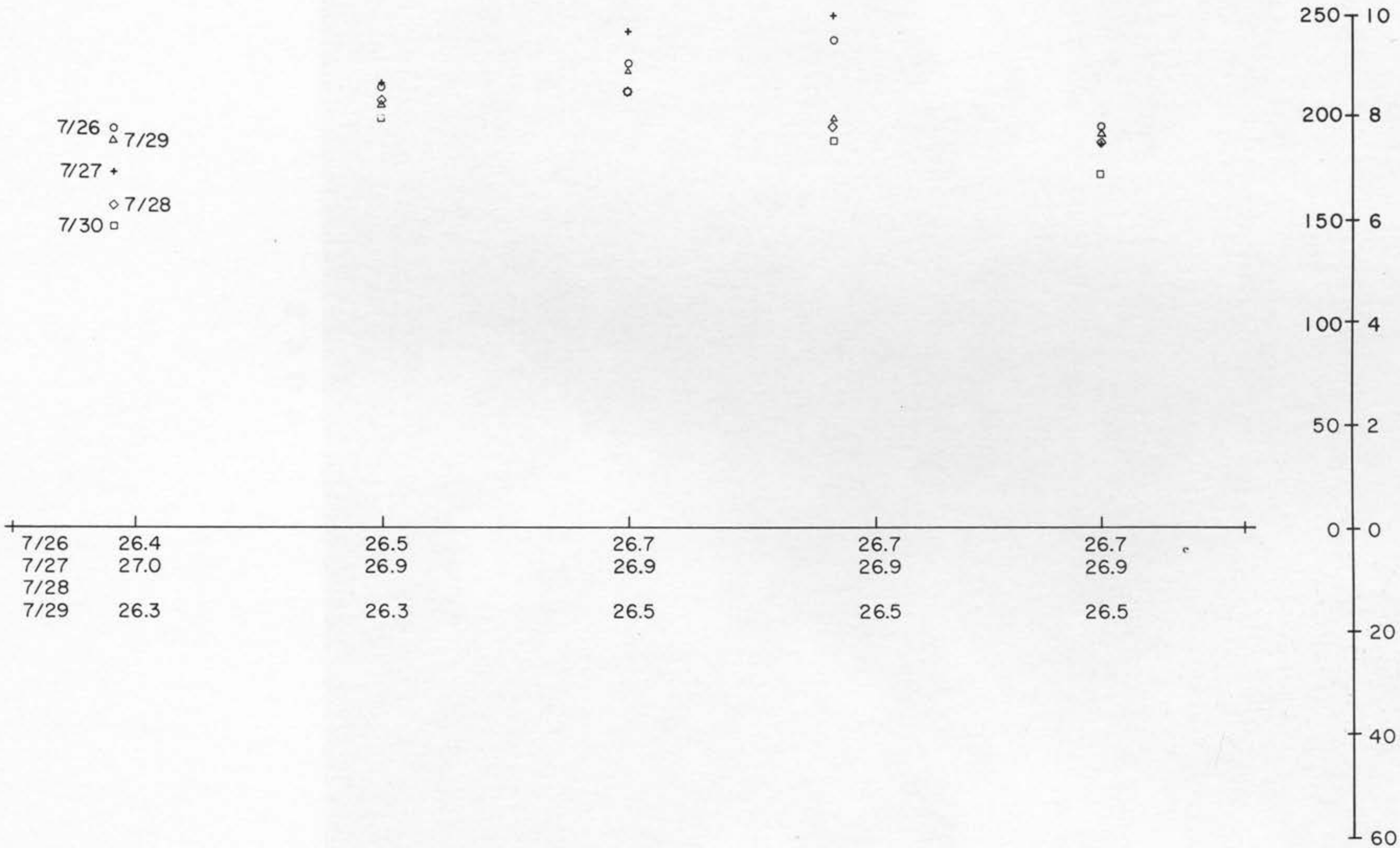
Station*	Near Surface Velocity	Sounded Depth	Near Surface Sediment (-230 in PPM)
1000		46.0	199
1600		52.5	255
2200		45.5	229
2800		32.0	208

**Measured from*

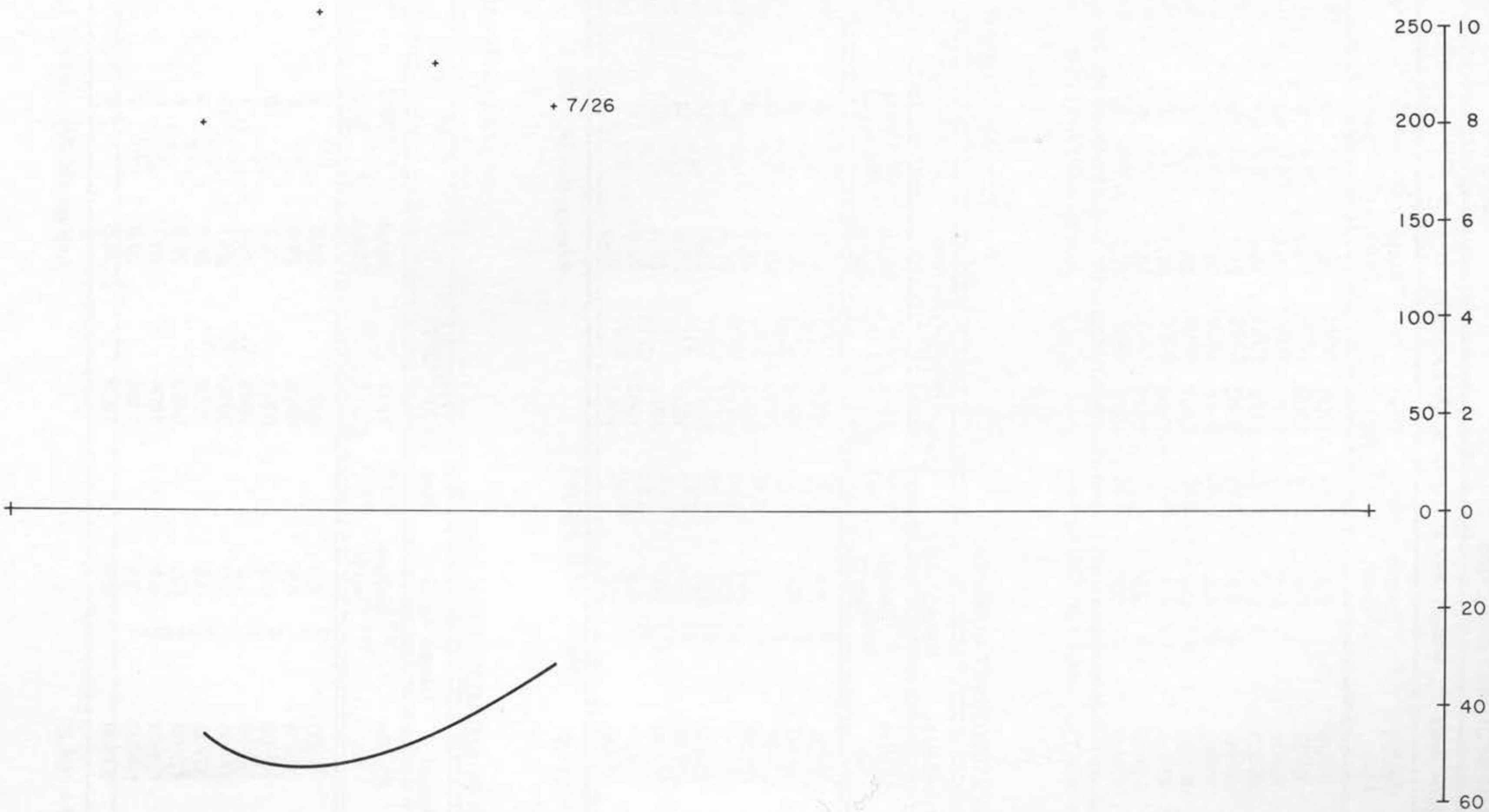


4048

RANGE 492.7


7/26
7/29
7/27
7/28
7/30
250
200
150
100
50
0
10
8
6
4
2
0
20
40
60
7/26 26.4 26.5 26.7 26.7 26.7
7/27 27.0 26.9 26.9 26.9 26.9
7/28
7/29 26.3 26.3 26.5 26.5 26.5

RANGE 494.2



TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed Area **Range:** 492.7 **Date:** 26 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
1	6+00	0.5′	1100	26.4	0	165	165
2A	6+00	0.5′	1109	26.2	6	217	223
3	18+00	0.5′	1120	26.5	10	214	224
4A	18+00	0.5′	1128	26.6	11	193	204
5	30+00	0.5′	1140	26.7	10	212	222
6A	30+00	0.5′	1146	26.7	3	225	228
7	42+00	0.5′	1151	26.7	11	219	230
8A	42+00	0.5′	1156	26.8	18	226	244
9	53+00	0.5′	1204	26.7	5	186	191
10A	53+00	0.5′	1210	26.7	8	193	201

Average 492.7 = 206.4 Average 492.7A = 220.0

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed Area **Range:** 492.7 **Date:** 27 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
31	6+00	0.5′	1002	27.0	5	176	181
32A	6+00	0.5′	1006	27.0	5	161	166
33	18+00	0.5′	1013	26.9	6	216	222
34A	18+00	0.5′	1017	26.9	8	200	208
35	30+00	0.5′	1022	26.9	20	218	238
36A	30+00	0.5′	1027	26.9	17	226	243
37	42+00	0.5′	1033	26.9	14	210	224
38A	42+00	0.5′	1037	26.8	51	223	274
39	53+00	0.5′	1042	26.9	12	182	194
40A	53+00	0.5′	1047	26.8	5	179	184

Average 492.7 = 211.8 Average 492.7A = 215.0

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 492.7 **Date:** 28 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
61	6+00	0.5′	0929	26.8	3	188	191
62A	6+00	0.5′	0934	26.8	6	179	185
63	18+00	0.5′	0941	26.7	9	198	207
64A	18+00	0.5′	0945	26.5	7	197	204
65	30+00	0.5′	0950	26.7	13	204	217
66A	30+00	0.5′	0955	26.7	9	197	206
67	42+00	0.5′	0959	26.8	5	183	189
68A	42+00	0.5′	1004	26.7	6	182	188
69	53+00	0.5′	1009	26.8	7	160	167
70A	53+00	0.5′	1014	26.8	6	169	175

Average 492.7 = 194.2 Average 492.7A = 191.6

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 492.7 **Date:** 29 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
111	6+00	0.5′	0846	26.3	2	121	123
112A	6+00	0.5′	0851	26.5	5	185	190
113	18+00	0.5′	0901	26.3	22	199	221
114A	18+00	0.5′	0905	26.6	17	172	189
115	30+00	0.5′	0918	26.5	18	212	230
116A	30+00	0.5′	0922	26.6	23	191	214
117	42+00	0.5′	0959	26.5	11	193	204
118A	42+00	0.5′	1003	26.5	10	184	194
119	53+00	0.5′	1011	26.5	8	194	202
120A	53+00	0.5′	1015	26.5	10	174	184

Average 492.7 = 196.0 Average 492.7A = 194.2

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 492.7 **Date:** 30 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
161	6+00	0.5′	1033	26.9	8	131	139
162A	6+00	0.5′	1038	26.8	13	140	153
163	18+00	0.5′	1046	26.8	5	177	192
164A	18+00	0.5′	1051	26.9	17	198	215
165	30+00	0.5′	1059	26.8	19	200	219
166A	30+00	0.5′	1104	26.8	15	188	203
167	42+00	0.5′	1109	26.8	15	186	201
168A	42+00	0.5′	1114	26.7	17	172	189
169	53+00	0.5′	1119	26.8	16	165	181
170A	53+00	0.5′	1123	26.7	10	183	193

Average 492.7 = 186.4 Average 492.7A = 190.6

TABULATION OF SEDIMENT ANALYSIS

Location: Baleshed **Range:** 492.7 **Date:** 31 July 1971

Sample No.	Station No.	Sample Depth	Time (C.D.T.)	Water Temp.	PPM Sand	PPM -230	PPM Sediment
1A		0.5′			6	168	174
2A		0.5′			6	181	187
3A		0.5′			8	169	177
4A		0.5′			14	181	195
5A		0.5′			7	181	188
6A		0.5′			6	190	196
7A		0.5′			8	174	182
9A		0.5′			6	174	180
10A		0.5′			7	175	182

APPENDIX C

KODAK AEROCHROME INFRARED FILM 2443

DATE: July 27 and 29, 1971
WEATHER: Overcast/Haze

Strip No.	Heading	Altitude	Exposure Number start	end
July 27, 1971				
A	North	3,100	3523	3548
B	North	3,100	3549	3573
July 29, 1971				
C	290°	6,100	3581	3588
D	209°	6,100	3589	3596
E	150°	6,100	3597	3608
F	180°	6,100	3609	3615
G	290°	6,200	3616	3623
H	210°	6,300	3624	3629
I	150°	6,200	3630	3639
J	180°	6,200	3640	3646

ROLL No. 18 PROCESS No. D10473

KODAK INFRARED AEROGRAPHIC FILM 2424

DATE: July 27 and 29, 1971
WEATHER: Overcast/Haze

Strip No.	Heading	Altitude	Exposure Number start	end
July 27, 1971				
A	North	3,100		
B	North	3,100		
July 29, 1971 – Point Pleasant				
G	290°	6,200		
H	210°	6,300		
I	150°	6,200		
J	180°	6,200		
K	290°	3,100		
L	180°	3,100		
M	150°	3,200		

ROLL No. MB4 PROCESS No. D10475

KODAK AEROCHROME INFRARED FILM 2443

DATE: July 29, 1971
WEATHER: Partly cloudy

Strip No.	Heading	Altitude	Exposure Number start	end
K	290°	3,100	3647	3657
L	170°	3,100	3658	3664
M	150°	3,200	3665	3684
N	280°	3,100	3685	3699
O	180°	3,100	3700	3704
P	140°	3,100	3705	3714
Q	190°	3,100	3715	3724
R	330°	3,200	3725	3731
S	330°	3,200	3732	3735
T	330°	3,200	3736	3739
U	30°	3,100	3740	3744
V	40°	3,300	3745	3752
W	220°	3,400		

ROLL No. 18 PROCESS No. D10473

KODAK AEROCOLOR NEGATIVE FILM 2445

DATE: July 29, 1971
WEATHER: Partly cloudy/shadows

Strip No.	Heading	Altitude	Exposure Number start	end
A	270°	1,300	3879	3894
B	270°	1,300	3895	3908
C	270°	1,300	3909	3924
D	270°	1,300	3925	3939
E	270°	1,400	3940	3952
F	0°	2,200	3953	3966
G	0°	2,200	3967	3980
H	0°	2,100	3981	3991
I	180°	6,200	3992	3995

ROLL No. 17 PROCESS No. D10472

KODAK INFRARED AEROGRAPHIC FILM 2424

DATE: July 29 and 31, 1971
WEATHER: Partly cloudy/shadows

Strip No.	Heading	Altitude	Exposure Number start	end
July 29, 1971				
J	10°	1,300		
K		1.300		
L		1,300		
F		1,300		
F		2,100		
G		2,100		
July 31, 1971 - Lake Providence				
A	North	6,100		
B	North	6,100		
C	North	9,100		
D	280°	9,100		
Lake Providence Harbor				
E	20°	9,100		
F	50°	9,100		
Catfish Ponds				
G		9,100		
	290°	2,800		

ROLL No. MB5 Positive PROCESS No. D10476

KODAK AEROCHROME INFRARED FILM 2443

DATE: July 31, 1971
WEATHER: Partly cloudy

Strip .No.	Heading	Altitude	Exposure Number start	end
A	North	6,100	4002	4012
B	North	6,100	4013	4023
C	North	9,100	4024	4028
D	280°	9,100	4029	4036
E	20°	9,100	4037	4044
F	50°	9,100	4045	4049
G		9,100	4050	4052

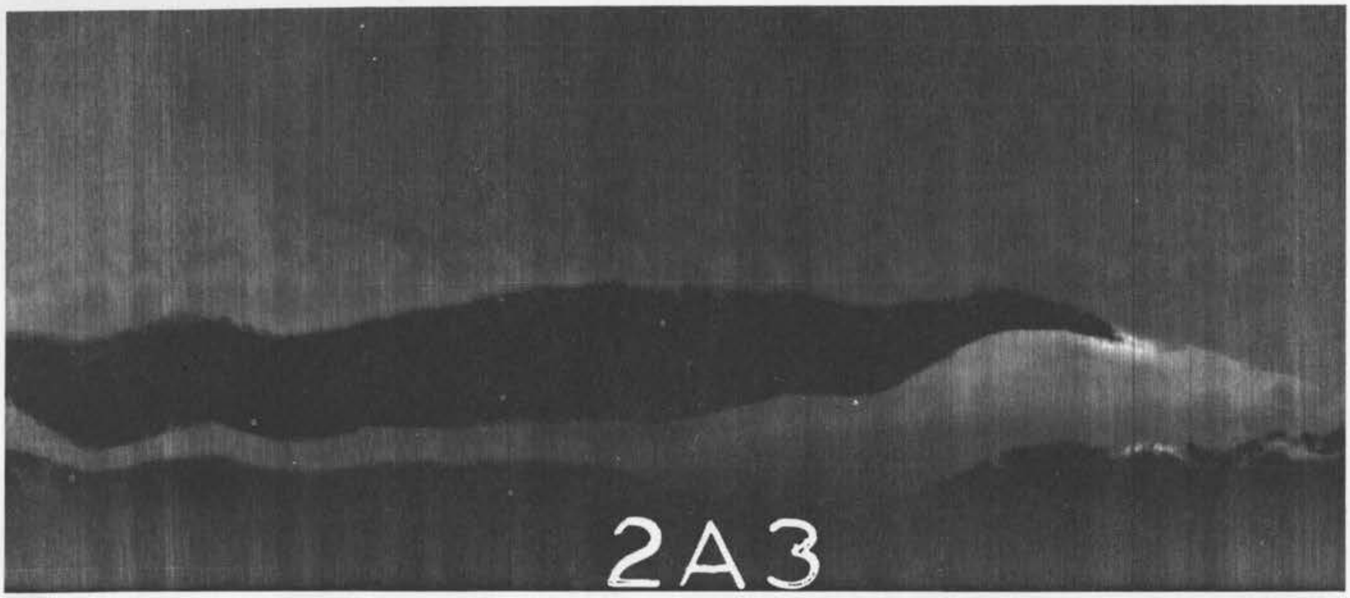
ROLL No. 19 PROCESS No. D10474

KODAK AEROCHROME INFRARED FILM 2443

DATE: July 31, 1971
WEATHER: Scattered clouds

Strip No.	Heading	Altitude	Exposure Number start	end
A'	30°	2,800	4053	4061
B'	290°	2,800	4062	4076
C'	North	2,800	4077	4082
D'	20°	2,800	4083	4098
E'	30°	2,800	4099	4108
F'	220°	2,800	4109	4123
G'	190°	2,800	4124	4134
H'	170°	2,800	4135	4143
I'	90°	2,800	4144	4158
J'	170°	2,800	4159	4165
K'	20°	2,800	4166	4176
L'	North	1,600	4177	4193
M'	20°	1,600	4194	4207
N'	West	1,600	4208	4217
O'	West	2,800	4218	4226
P'	West	2,800	4227	4235

ROLL No. 19 PROCESS No. D10474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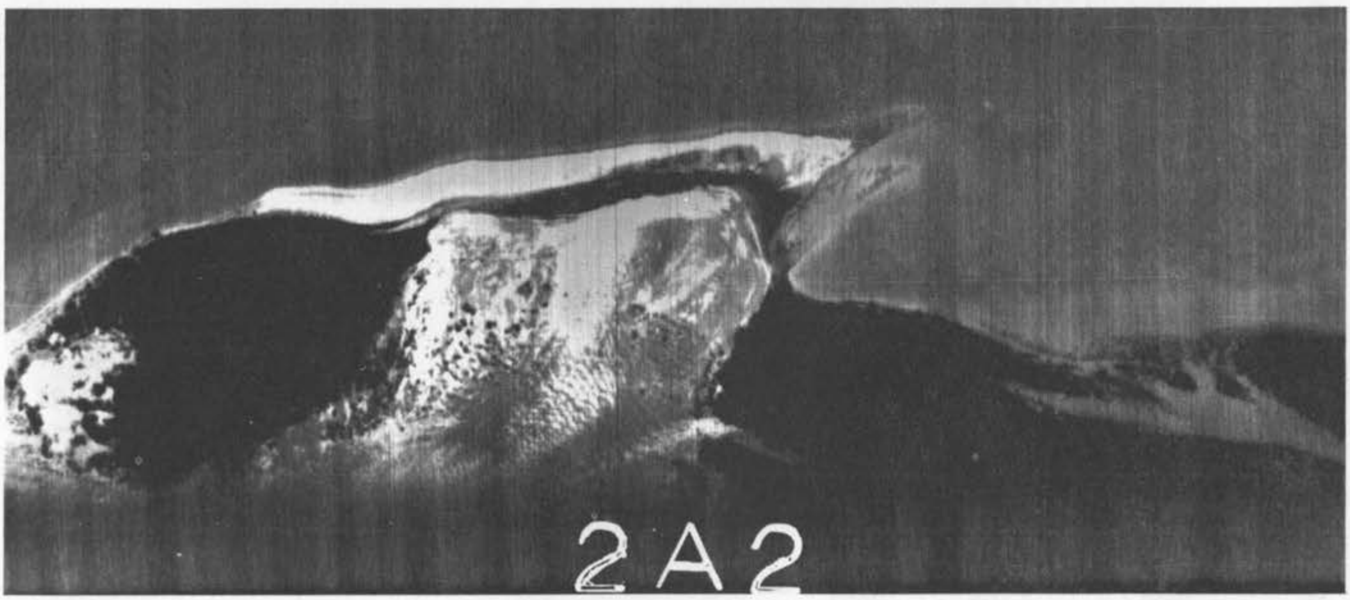
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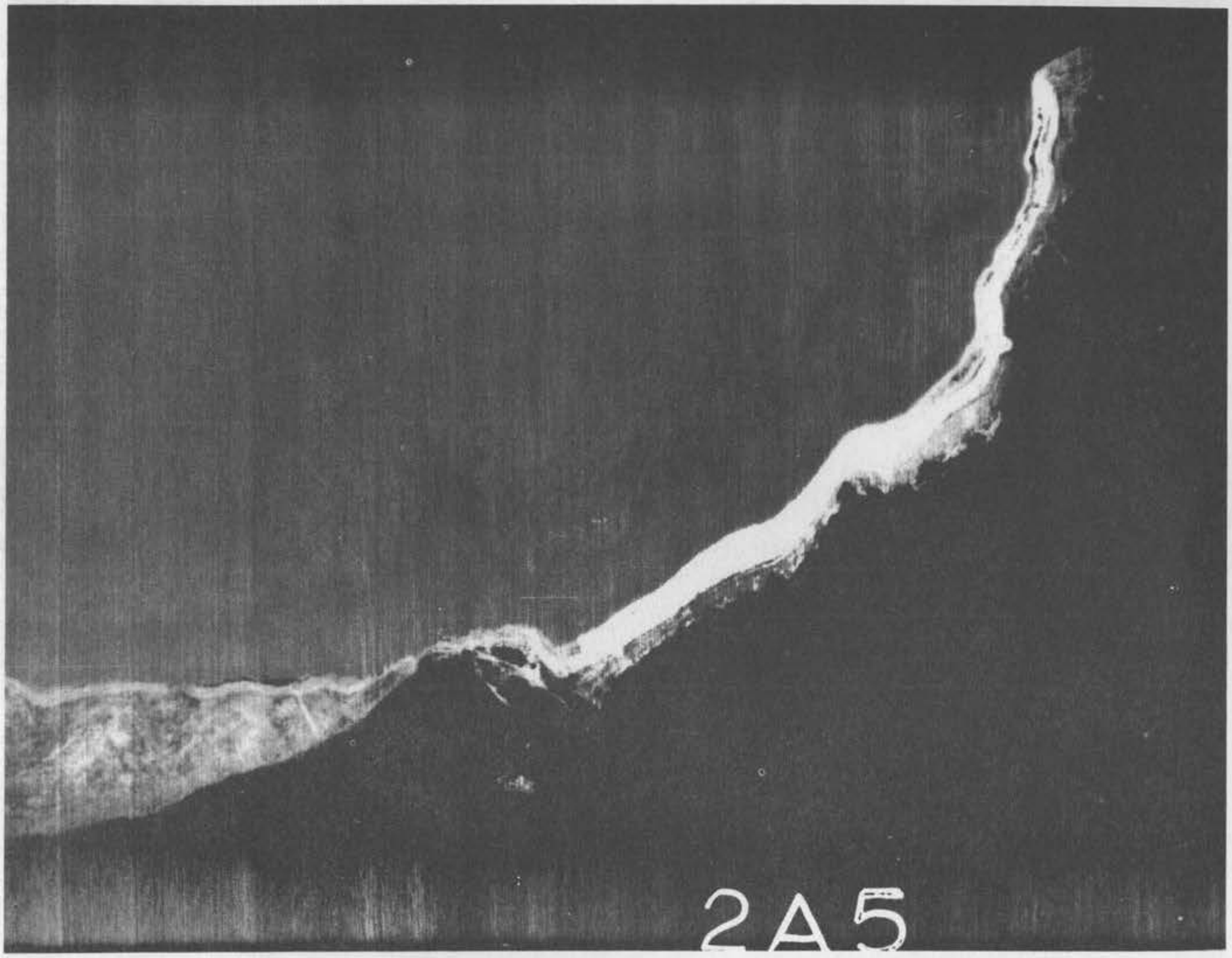
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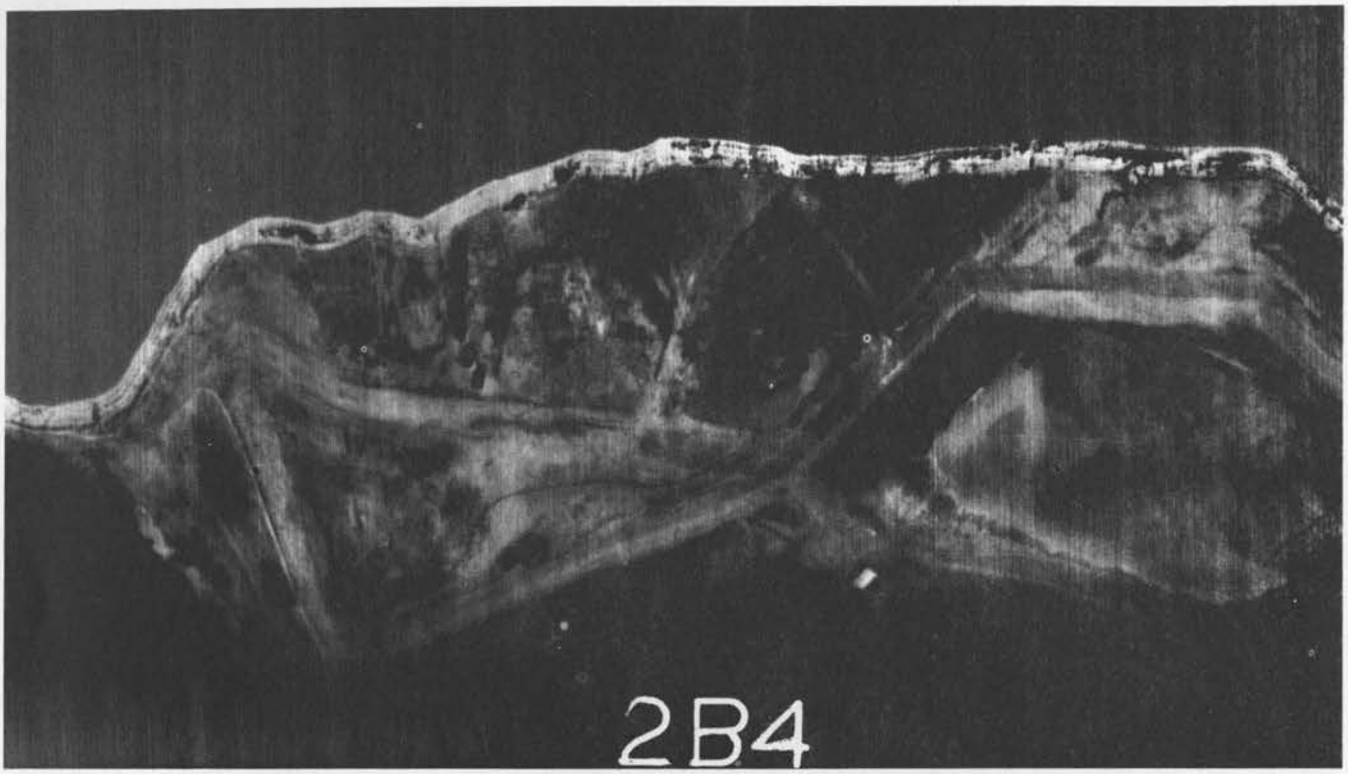
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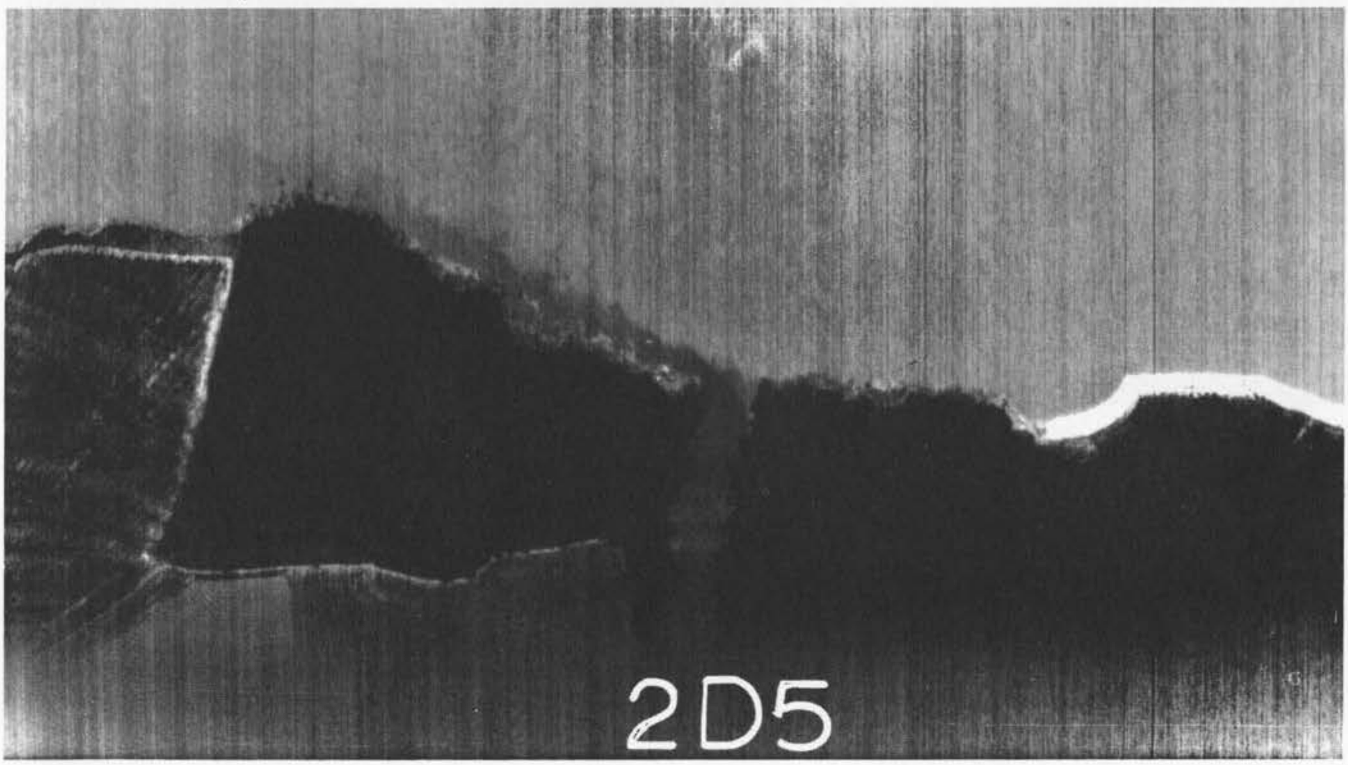
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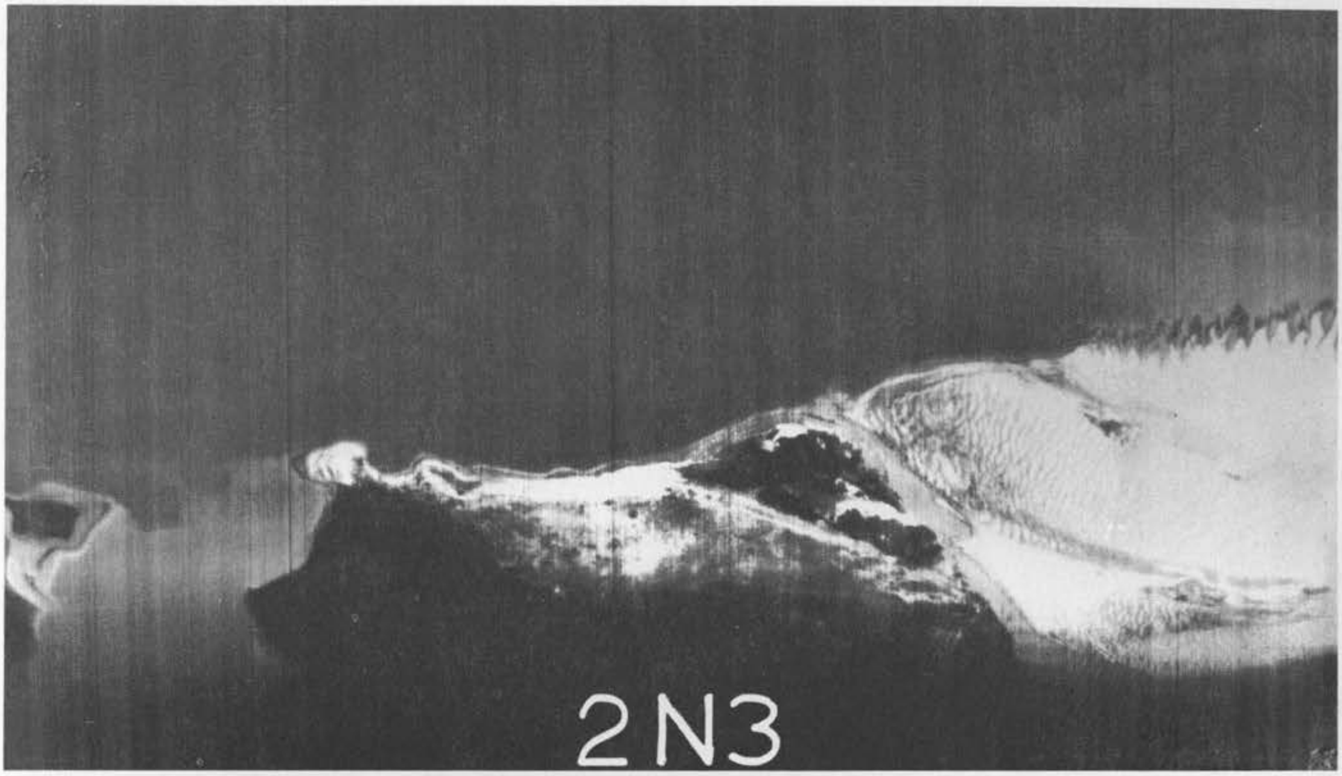
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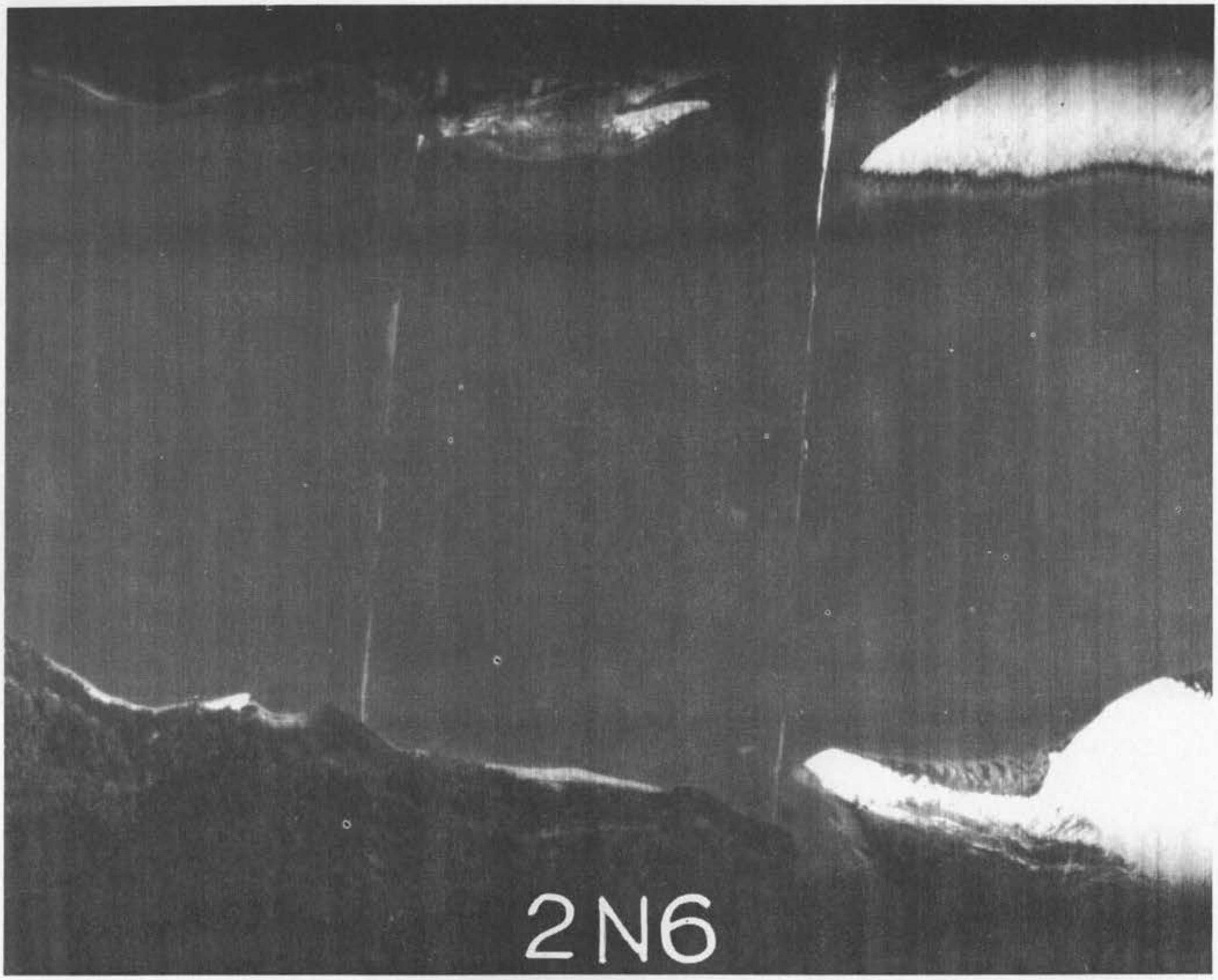
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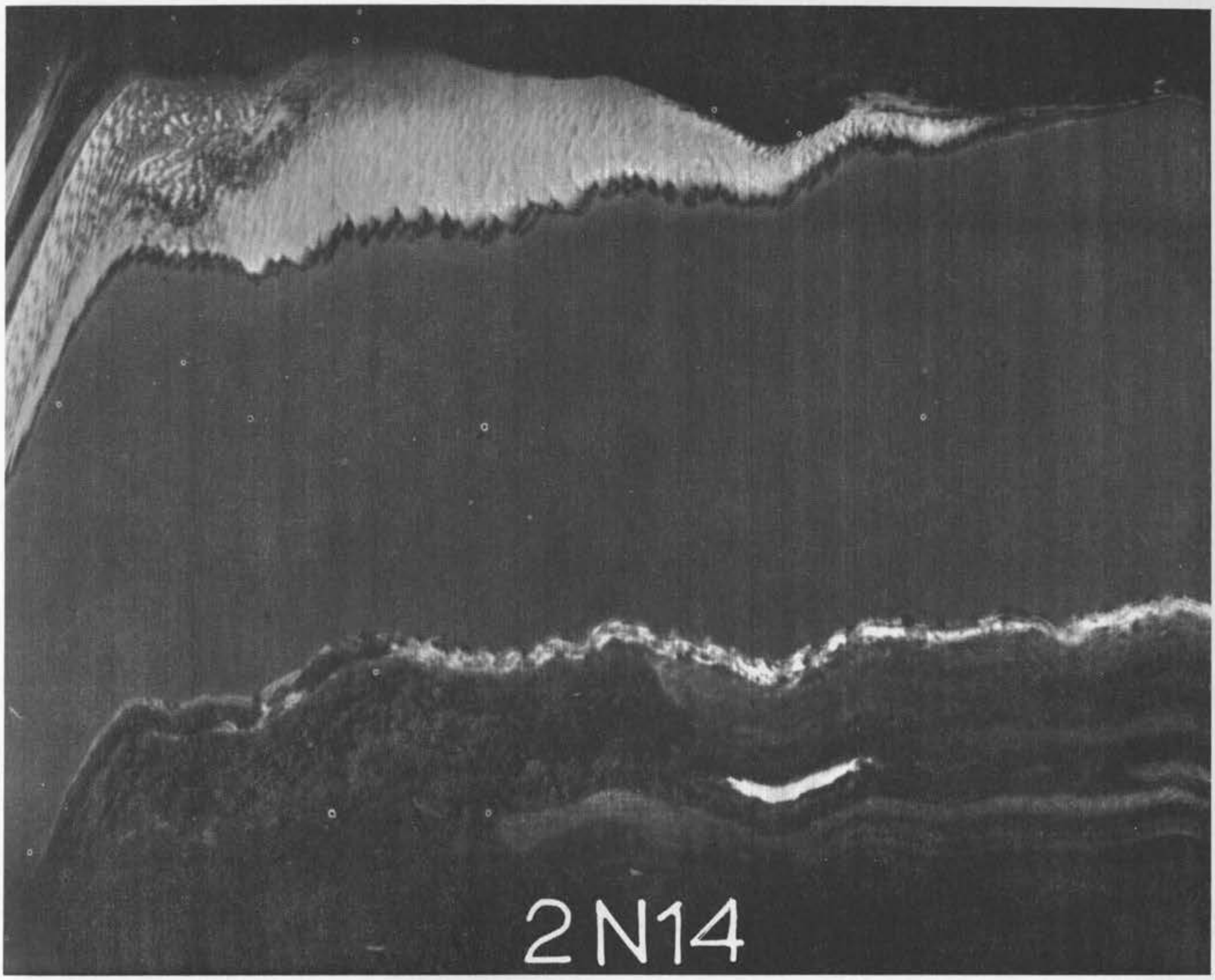
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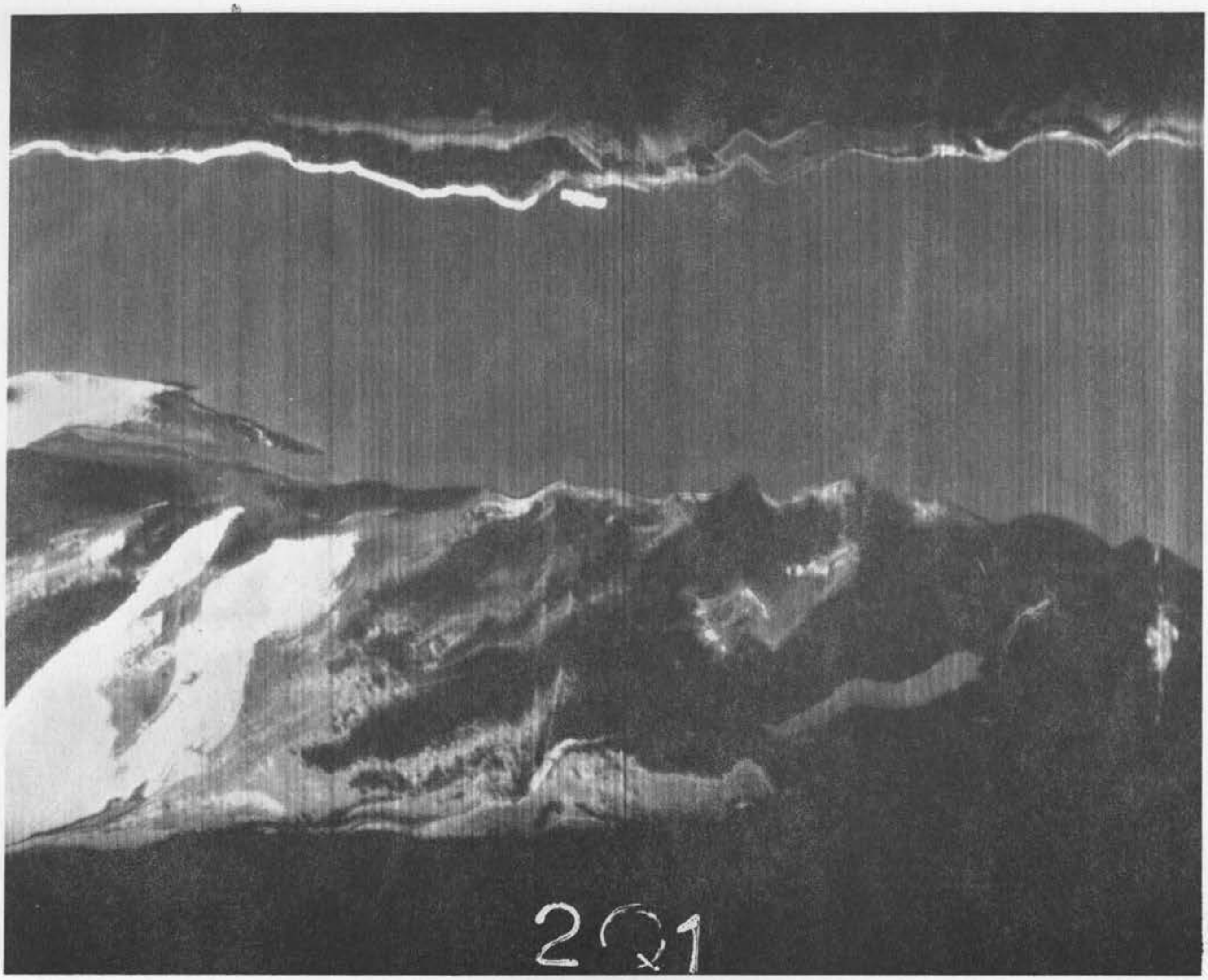

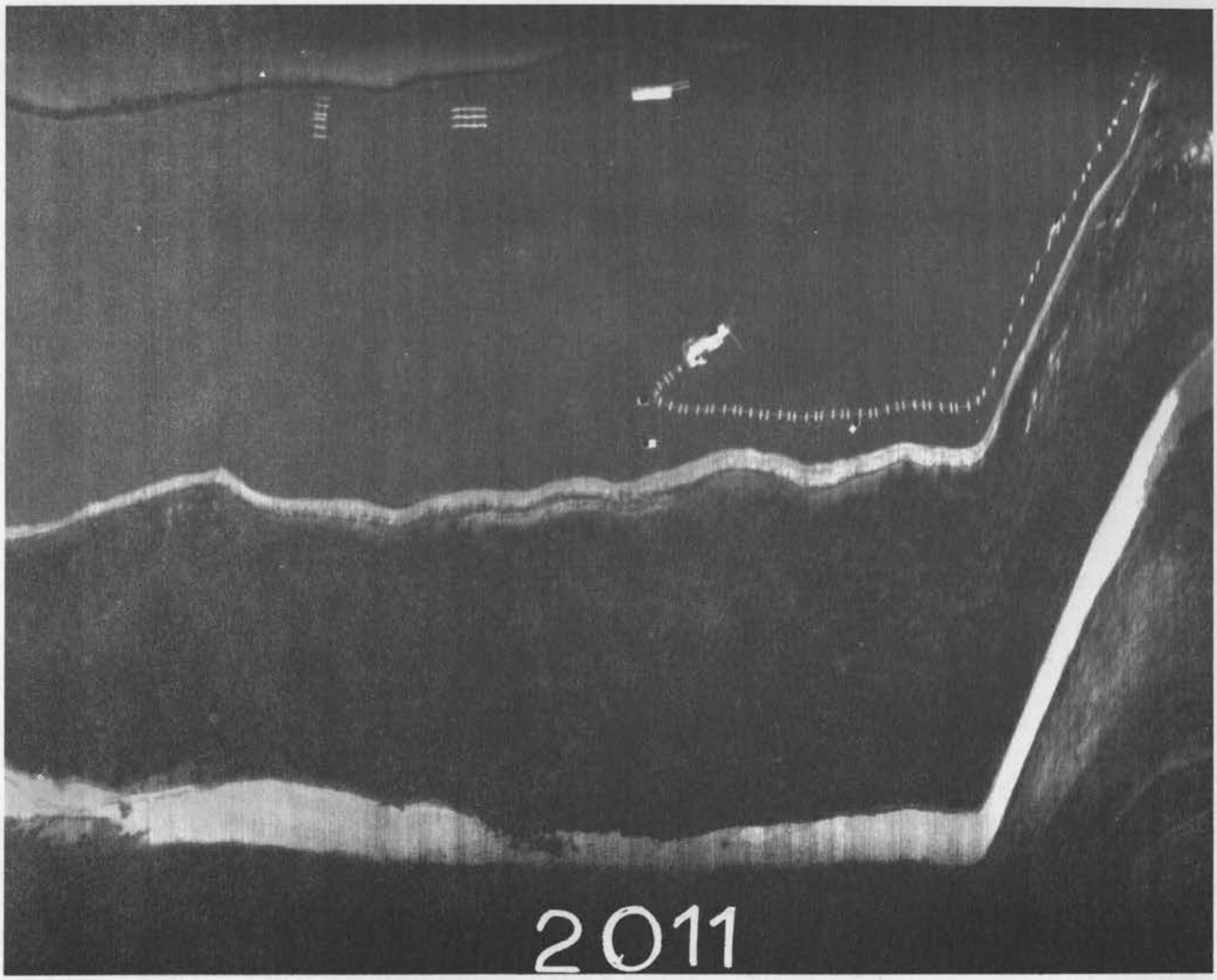
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3598

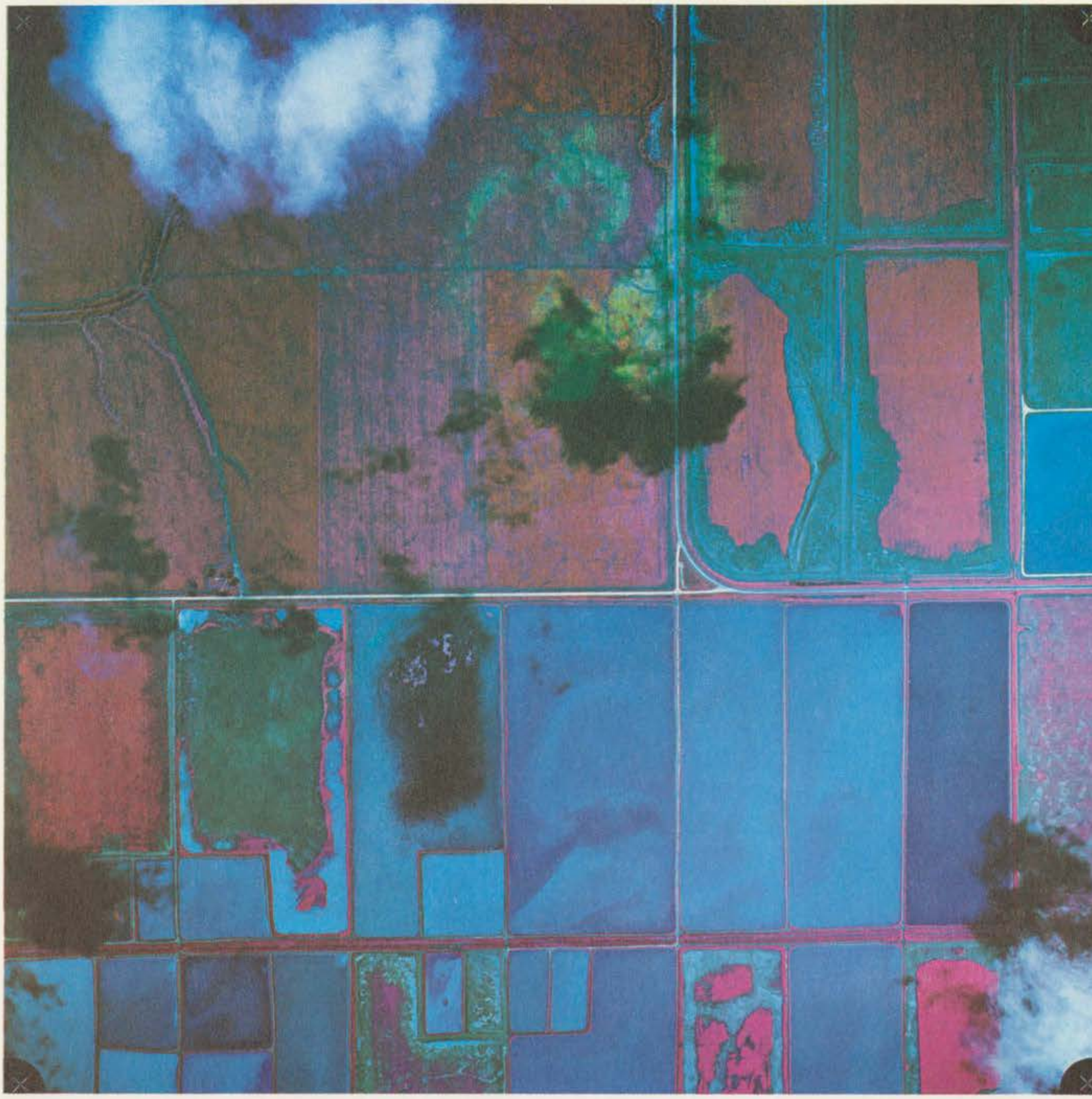
3600

3656

3 6 9 1

3 7 1 7

4019



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4090

4 0 9 6

4185

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