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AQUATIC HABITAT AND INSTREAM FLOW INVESTIGATIONS (MAY-OCTOBER 1983)

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EVALUATIONS OF THE EFFECTIVENESS OF APPLYING INFRARED THERMAL IMAGERY TECHNIQUES TO DETECT UPWELLING GROUNDWATER

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ABSTRACT

Three infrared heat sensing devices (Hughes Probeye, Xedar Pyroscan, and AGA Thermovision) were tested to evaluate their feasibility as remote sensing devices for locating and quantifying the surface area of Susitna River slough habitat influenced by groundwater upwelling.

Studies by the Alaska Department of Fish and Game Susitna Hydroelectric Aquatic Studies Team suggest that upwelling groundwater is one of the principal variables influencing the suitability of habitat for spawning by chum salmon in sloughs and side channels.

This pilot evaluation indicates that the application of remote sensing for locating upwelling is contingent upon the environmental conditions, level of detail desired, and the equipment utilized. Of the three thermal infrared imagers evaluated, the AGA thermovision proved to be the overall best suited imager for discerning upwelling groundwater areas within the sampled sloughs of the Susitna River.

GLOSSARY

Emissivity - the ratio of actual energy of thermal radiation emitted from an object to the actual energy of thermal radiation emitted from a black-box radiator at the same temperature.

Glow Tube - a viewing screen, i.e. cathode ray tube.

Ground-Truthing - the process of determining actual measurements of variable on the ground.

Imager - an electronic device which is sensitive to emitted thermal infrared radiation and produces and electric signal proportional to the incident infrared radiation received.

Infrared Radiation - electromagnetic radiation just beyond the red end of the visible spectrum which is radiated from all objects whose temperature is above absolute zero.

μm - a millionth of a meter.

Thermal Infrared Imagery - the process by which thermal images are obtained through the use of thermal infrared sensors (imagers); the tone of the image or picture is directly related to the infrared radiation emitted from the object imaged.

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1.0 INTRODUCTION

This chapter presents an evaluation of thermal infrared imagery for locating upwelling groundwaters in selected sloughs of the Susitna River. The specific objectives of the study are:

1) to determine if upwelling groundwaters in selected side sloughs of the Susitna River can be detected using thermal infrared imagers; and

2) to evaluate the ability of different thermal infrared imagers to detect upwelling groundwaters in the side sloughs of the Susitna River.

Upwelling groundwater is a principal variable influencing the suitability of habitat for spawning by chum salmon in the Talkeetna to Devil Canyon reach of the Susitna River system (ADF&G 1983; Chapter 7). Other investigators have also associated chum salmon spawning habitat with upwelling groundwater elsewhere in Alaska (Kogl 1965, Francisco 1977, Wilson et al. 1981).

Preliminary evaluations of the upwelling groundwater areas in the selected sloughs of the Susitna River were conducted by on-the-ground visual inspections of slough substrate (ADF&G 1983: Appendix C). Upwelling groundwater was detected by observing the movement of small streambed particles as the groundwater was vented from the streambed. Oftentimes, the vented groundwater was expelled under pressure so that, in relatively shallow water, a disturbance was visible at the surface.

Success of detecting upwelling groundwater vents in Susitna River sloughs varied with the particle size of the streambed substrate. Vents were easily discernible in silt and sand streambed substrates but were difficult to detect when larger streambed substrate particle sizes predominated. This information is required to support studies to model the availability of spawning habitat in sloughs as a function of flow. Therefore, a means of improving the data base was desired.

Infrared thermal imagery was considered as a possible tool for improving the upwelling data base. This assumption was based on recent applications of thermal infrared imagery as a tool to detect synoptic surface water temperatures over a large area. These applications have allowed hydrologists to identify numerous hydrologic phenomena such as natural dispersion and circulation patterns (Whipple 1972), dispersion of heated effluent (Whipple 1972; Pluhowski 1972), dispersion of sewage outfall, ice cover (Pluhowski 1972) and ground water discharge into large bodies of water (Robinove 1965; Pluhowski 1972; Boettcher et al. 1976; Boettcher and Haralick 1977).

Infrared radiation is created by atomic or molecular energy and is radiated from all matter (Shields 1977). Thermal infrared imagery uses electronic devices (imagers) which are sensitive to emitted infrared radiation. The imagers convert the radiant energy received to an electrical signal which is amplified and either recorded on magnetic tape or, transmitted to a glow tube. Signal strength determines the brightness to which an area appears on the viewing screen. The resulting gray tones represent the thermal emissions of the object (Robinove and Anderson 1969).

The amount of infrared radiation emitted from a body depends upon the emissivity of the object, that is, its ratio of actual energy radiated from the body to the maximum possible energy radiated from a black-box radiator at a given temperature (Pluhowski 1977). The emissivity of water regardless of its temperature and concentration of dissolved solids is estimated to be 0.97 (Anderson 1954). Therefore, differences in the amount of infrared radiation emitted at various places from a water body are directly related to differences in the surface water temperature (Robinove 1965). Infrared imagery only detects energy radiated from the surface of a body of water. Thermal radiation below the surface cannot be detected (Boettcher et. al. 1976).

The full infrared electromagnetic spectrum (Figure 10-1) ranges from 0.7 to 300 um. This range can be further broken down to include reflected infrared radiation (from 0.7 - 3 um) and emissive or thermal infrared radiation (3.0 um - 14.0 um). Infrared photography operates in the reflected region from 0.7 to 0.9 um. Water vapor, carbon dioxide, ozone, and particulates in the atmosphere attenuates the amount of infrared energy received by absorption or scattering. There exists areas or "windows" in the spectrum however, where attenuation is minimized (Figure 10-1). These "windows" which occur in the regions of 3 to 5 m and 8 to 13 m are used by infrared imagers (Pluhowski 1972). Systems which operate in the 8 to 13 um region of the spectrum are best suited for detailed terrain analyses because natural earth emissions occur of infrared radiation within this region (Sheild 1977). Since infrared radiation occurs in the absence of light, detecting operations in this spectrum region can be performed day or night. Imagers

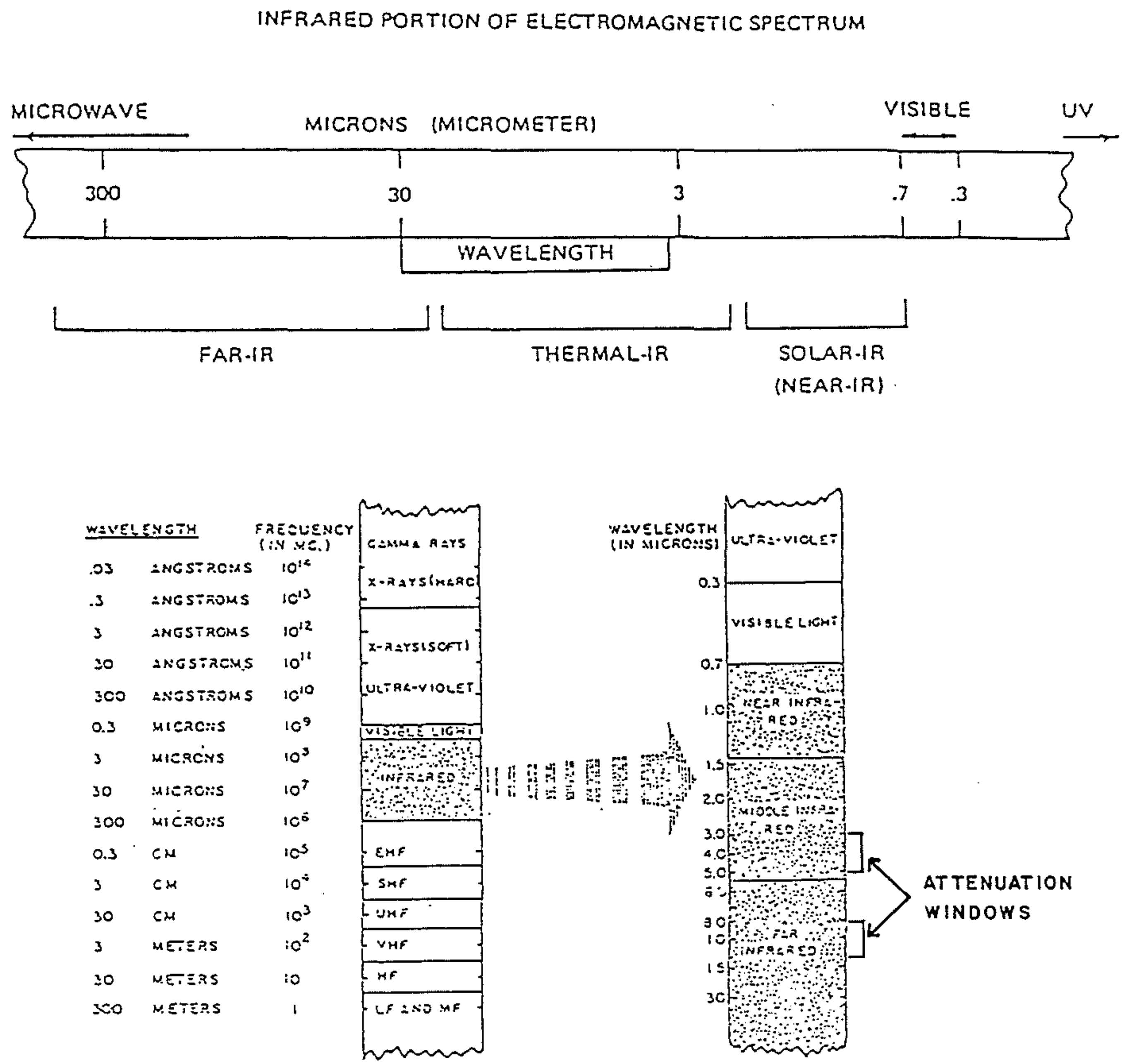

Figure 10-1 Infrared portion of the electromagnetic spectrum.

operating in the 3 to 5 um region provide excellent discrimination at the sacrifice of background detail, but solar-reflected energy can interfere with the images on bright, sunny days. Generally, as systems move into the longer wave length portions of the spectrum (earth temperatures) sophistication and price increase, performance and resolution is improved, and versatility is gained (Shields 1977).

Boettcher et. al. (1976) and Boettcher and Haralick (1977) in their groundwater investigations using thermal infrared imagery, quantified surface water infrared radiation. With the aid of computer techniques, the infrared was transformed into a spatial-temperature map having an isotherm spacing of 0.5°C. This computer generated isothermal map allowed the investigators to pin-point surface water temperature influenced groundwater inflows, and to detect circulation and dispersion patterns of the ground water into the larger body of water at the surface. The technique of using thermal imagery for detecting ground water inflows may provide a quick, sensitive and accurate method to detect areas of upwelling groundwater venting into the sloughs of the Susitna River system.

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2.0 METHODS

2.1 Site Selection

Sloughs with known major upwelling groundwater areas within the Talkeetna to Devil Canyon reach of the Susitna River were selected for this pilot study (Figure 10-2). Specifically, sloughs 9A, 10 and 11 were chosen as study sites for this investigation. On one occasion Slough 8A was used as a study site because of its proximity to base camp and easily detected upwelling ground water vents.

2.2 Field Data Collection

Three infrared thermal imagers, a Hughes Probeye, Xedar Pyroscan and AGA Thermovision 750, were tested to evaluate their capabilities as remote sensing devices for locating the surface water areas of selected slough habitats influenced by upwelling groundwater. The AGA Thermovision 750 and the Xedar Pyroscan units are infrared camera systems capable of being interfaced with video recording equipment. The Hughes Probeye is an infrared imager which presents a thermal picture in the observers eyepiece. The Hughes Probeye does not have recording capabilities. Only the AGA Thermovision 750 can magnify the thermogram by the use of interchangeable camera lenses having different focal lengths. Camera lenses are fixed in the other two systems. All systems are portable and lightweight and can be operated by one person. Because of the magnification capabilities of the AGA Thermovision 750, this system must be operated from a stable platform to insure camera stability. Table 10-1 summarizes the technical specifications of each system.

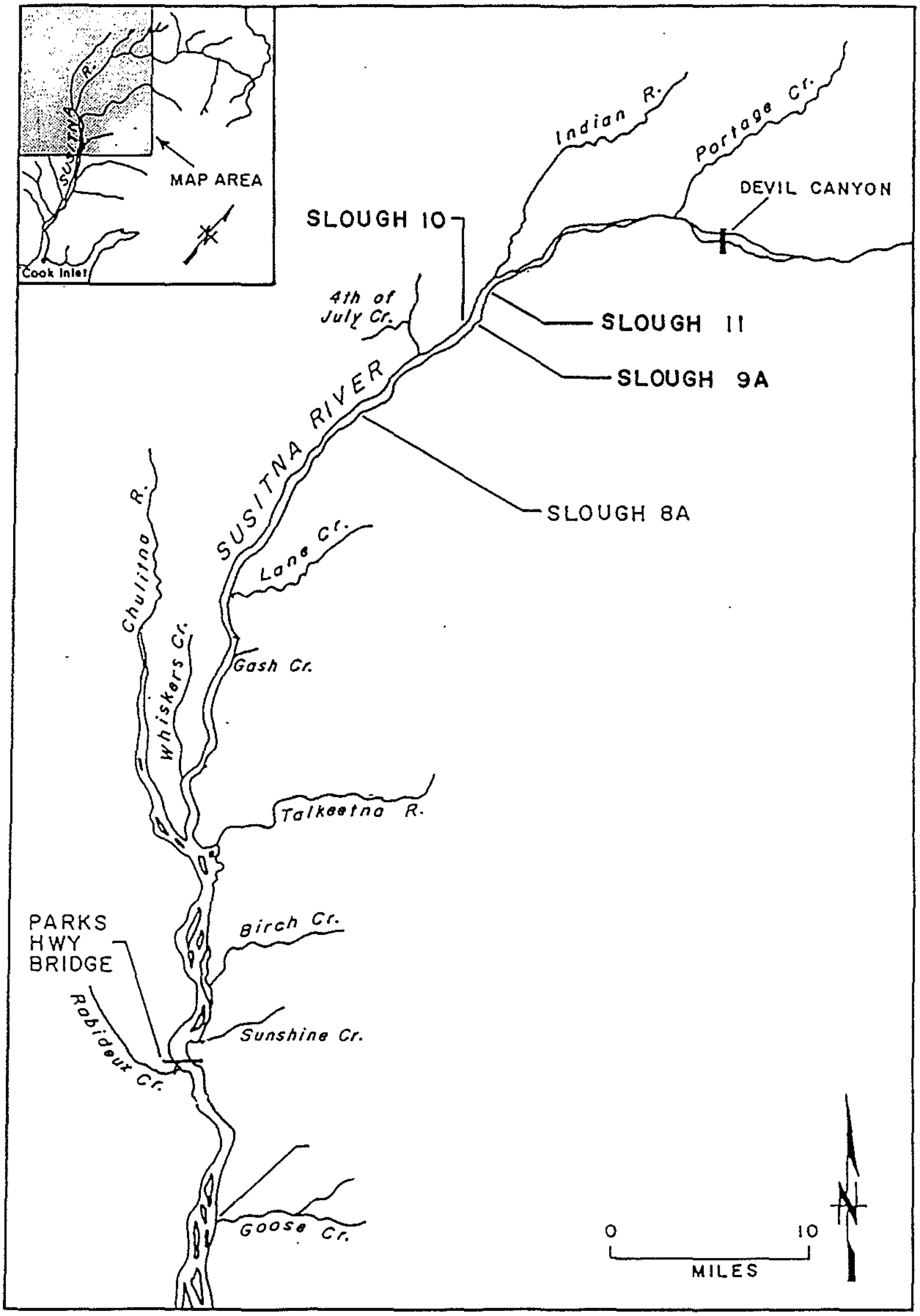

Figure 10-2 Infrared thermal imagery study sites.

Table 10-1. Technical specifications of the thermal imagers evaluated.

System	Spectral Region	Resolution	Lens Focal Length	Display Type	Support	Weight	How used
AGA Thermovision	2.5-6 um	0.2° C at 30° C	100 mm	CRT or Video	Battery Pack and Liquid Nitrogen for cooling	21 lbs.	portable
Hughes Probeye	3-5.4 um	0.1° C at 22° C	38 mm	60 line LED display	Battery; Bottled Argon for coding	7 lbs.	hand-operated
Xedar Pyroscan	8-14 um	0.2° C at ?	33 mm	525 line video screen or video	Battery	10 lbs.	hand-operated

Three separate field trips were necessary to evaluate the thermal infrared imagers used in this study (Table 10-2). Each imager was operated by a trained operator according to procedures outlined in this respective operating manuals. Infrared scanning operations were conducted primarily from a helicopter flying at a near hover over the study area. Altitude ranged from 100 to 300 feet above the water surface. During the initial field evaluation, thermal scans were also conducted on foot.

The Hughes Probeye and the Xedar Pyroscan were evaluated and compared on August 8, 1983. These evaluations were conducted during bright daylight conditions and under a high mainstem discharge of 26,000 cfs. Infrared scans of known upwelling groundwater areas in Slough 8A and Slough 11 were conducted from a helicopter and on foot. The foot survey in Slough 8A focused on an upwelling groundwater vent visible to the unaided eye.

On October 24, 1983, the Hughes Probeye and the AGA Thermovision were evaluated and compared. These evaluations were conducted during the evening hours in order to minimize the thermal interference of sunlight reflecting off the water (the Pyroscan operates in a wave length range which is not influenced by sunlight). Sloughs 10 and 11 were scanned during this field trip. Susitna River discharge was 5,800 cfs. All infrared scans on October 24, 1983 were conducted from a helicopter platform.

Table 10-2. Field testing conditions and locations.

DATE	SYSTEMS	FIELD CONDITIONS	STUDY SITES
830809	Hughes Probeye Xedar Pyroscan	Bright; daylight Susitna River Q = 29,900 cfs.	Slough 11 and Slough 8A
831024	Hughes Probeye AGA Thermovision 750	Bright; dusk Susitna River Q = 5850 cfs.	Slough 10 and Slough 11
831115	AGA Thermovision 750	Dark; night Susitna River Q = 3,000 cfs. (approx.)	Slough 10 and Slough 9A

A final field trip was taken on November 15, 1983 for evaluating the AGA Thermovision system exclusively. Infrared scans were conducted at night during the very low, early winter discharge conditions of the Susitna River (approximately 4,000 cfs). Water levels in the study sloughs were very low with some ice cover. Infrared scans were conducted from a helicopter capable of night flying. Sloughs 10 and 9A were scanned during this period.

Ground-truthed measurements of slough surface water temperatures were collected only on the last evaluation field trip. Surface water temperatures of Slough 10 were determined immediately prior to the thermal infrared scan. Slough 9A surface water temperatures were ground truthed two days after the infrared scanning flight. A 1500 foot reach of the slough was divided into 100 transects. Surface water temperature measurements were recorded at two foot intervals every two feet along the transects. Temperatures were measured with a Digi-sense temperature probe.

2.3 Analytical Approach

Initially, the approach to this study appeared to be simple. Thermal infrared imagers were to be evaluated under field conditions to assess their capability in detecting thermally different upwelling groundwaters. After becoming familiar with the capabilities and limitations of the equipment the approach evolved into a more complex methodology. Eventually, specific surface water temperature ground truthed data was obtained in order to compare infrared detected upwelling areas recorded on video tape to actual measured surface water temperatures of the sloughs. Surface water temperature data collected along transects for each slough were reduced into rough isothermal maps which facilitated the analysis.

3.0 RESULTS

Hughes Probeye

The Hughes Probeye was tested during two imager evaluation field trips. This system was evaluated under different light (e.g. bright, sunny, dark, etc) and mainstem discharge conditions at three different sloughs (Sloughs 8A, 10, and 11). The Hughes Probeye could not detect thermal differences of water when used from an aerial platform but could detect the thermal difference of an upwelling groundwater vent when used from the ground. Resolution of all visual images were poor. Outline of water bodies could not be readily distinguished. After the last field trip, it was decided to suspend further testing of this system. The Hughes Probeye was deemed incompatible with achievement of the primary objective of the study.

Xedar Pyroscan

The Xedar Pyroscan was evaluated on the first field trip. Although the image resolution was much better than the Hughes Probeye, the Xedar Pyroscan did not perform as well as the Hughes Probeye in distinguishing surface water temperature differences. The different shades of gray on the viewing screen, indicating differences in surface water temperature, were extremely difficult to discern. Since sunlight does not affect the operation of this imager because it operates in the 8-14 um wave length "window", it was considered unnecessary to further consider the Xedar Pyroscan as a possible candidate for detecting upwelling groundwater in sloughs.

AGA Thermovision 750

The AGA Thermovision 750 was tested during the last two field trips on October 24 and November 15, 1983. Upwelling groundwaters were detected influencing the surface water of Sloughs 10 and 9A, respectively, during these flights. Although the bright sky conditions present at dusk during the October field trip hampered the effectiveness of the infrared scanner to detect the subtle surface water temperature differences of the slough, more upwelling areas were detected as the sky grew darker. Infrared scanning operations were suspended prior to nightfall because of low helicopter fuel levels. The video data collected during the October field trip was very poor in quality.

Although the AGA Thermovision 750 system was capable of detecting areas of thermally different waters on the surface of the slough, a definitive evaluation was not made because of the poor quality of the video tape caused by the bright sky conditions. A second field trip was scheduled for November.

Before the final field evaluation of the AGA Thermovision 750 system on November 15, 1983, the following additional procedures were included in the methods:

1) Only Slough 10 would be infrared scanned in order to maximize effort in an area with a known high degree of upwelling.

2) Ground truthing of surface water temperatures would be completed immediately prior to the thermal scan; and

3) the thermal infrared scan of the slough would commence after dark to avoid the bright sky conditions which hampered the effectiveness of the system initially.

Thermal infrared imagery of the AGA thermovision 750 system failed to locate the numerous known upwelling groundwater vents in Slough 10 because of the homogeneous nature of the surface water temperature of the slough. Homogeneous surface water temperture was verified by ground truthed measurements. Only one groundwater upwelling area was located by the infrared imagery. At this point there was only a 1.4^{0} C difference in slough surface water temperature and the temperature of the upwelling groundwater reaching the surface.

Because of the negative results (very few detectable surface anamolies) gained during the infrared thermal scan of Slough 10, it was immediately decided to scan Slough 9A during the same night. Ground truthing measurements of surface water temperatures of Slough 9A were completed two days later. The scan of Slough 9A detected numerous and varying degrees of surface water temperature anomolies. The scan of Slough 9A was recorded on video tape. Photographs of the site (Plate 10-1) and the video display of the scan and the corresponding rough isothermal maps are displayed in Plates 10-2 through 10-4 and Figures 10-3 through 10-5, respectively.

After comparing the results of the infrared scans with the rough isothermal map constructed from the ground truthed surface water temperature of Slough 9A, it became apparent that the AGA Thermovision 750 system was able to detect the thermally different waters at the surface of Sloughs 10 and 9A. Because of the slow flowing nature of the slough and intensity of the bright spot on the film indicating warmer waters, exact position of upwelling groundwater vents could be pin-pointed. However, upwelling waters reaching the surface of the slough which differed less than 1.4°C in temperature could not be detected. Based upon the comparison of the infrared scan with the ground truthed isothermal maps, it is apparent that of the infrared thermal imagers tested, the AGA Thermovision 750 is the most applicable system for detecting upwelling groundwater in sloughs.

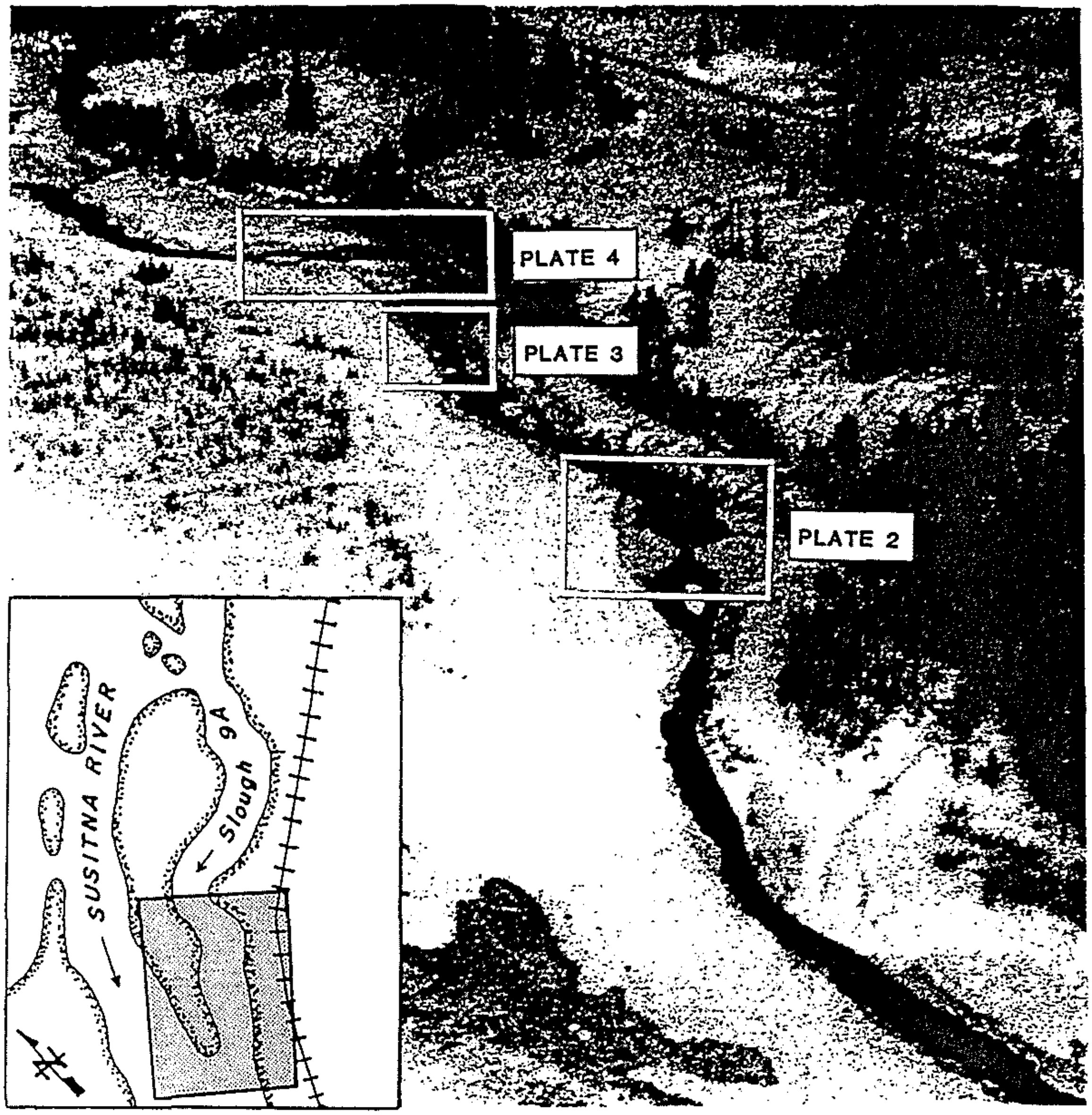

PLATE 10-1 Aerial photo of Slough 9A (November 15, 1983). Thermal scans of outlined areas are presented in Plates 10-2 through 10-4 as indicated.

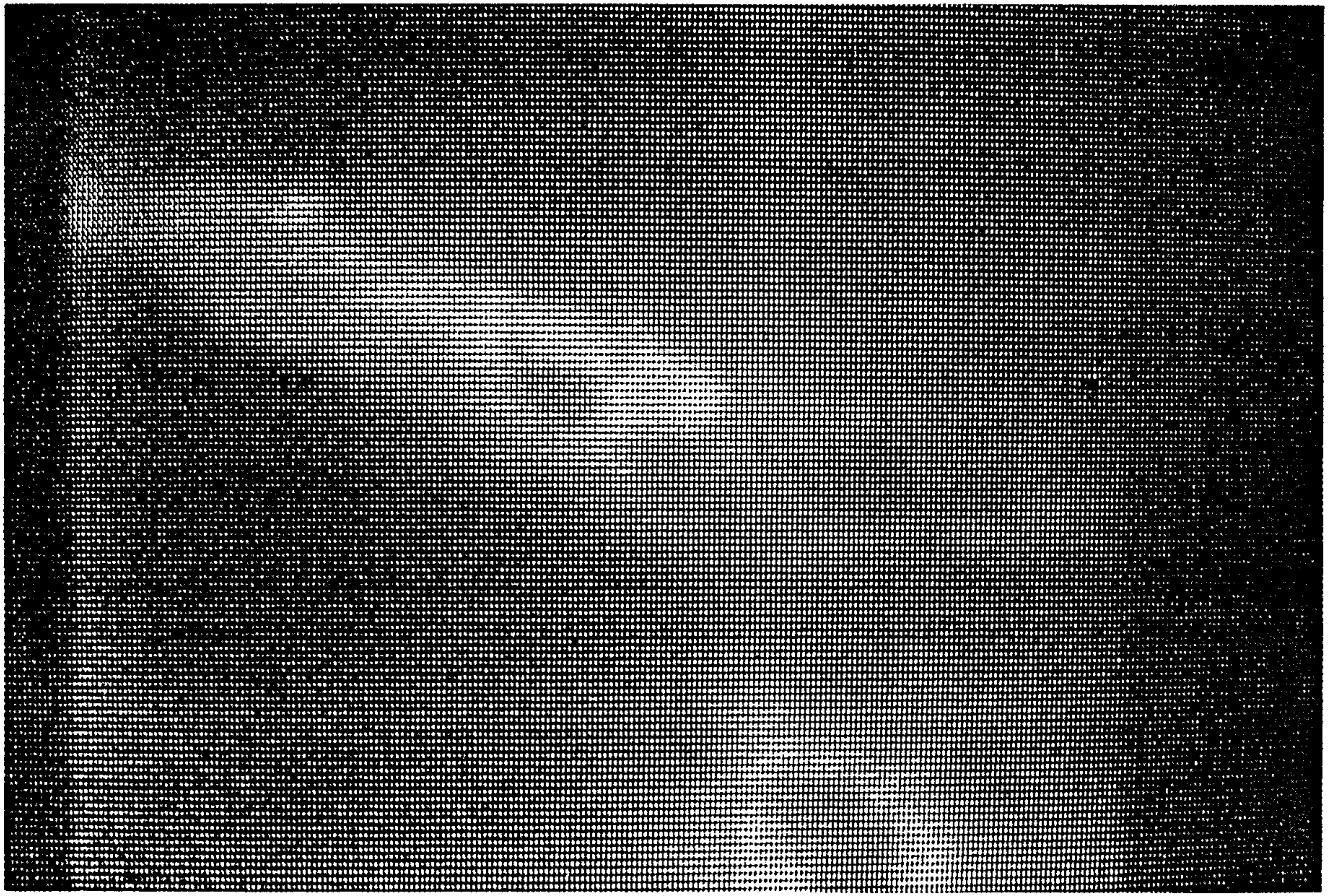

PLATE 10-2 Thermal scan of a portion of Slough 9A (see Plate 10-1), November 15, 1983.

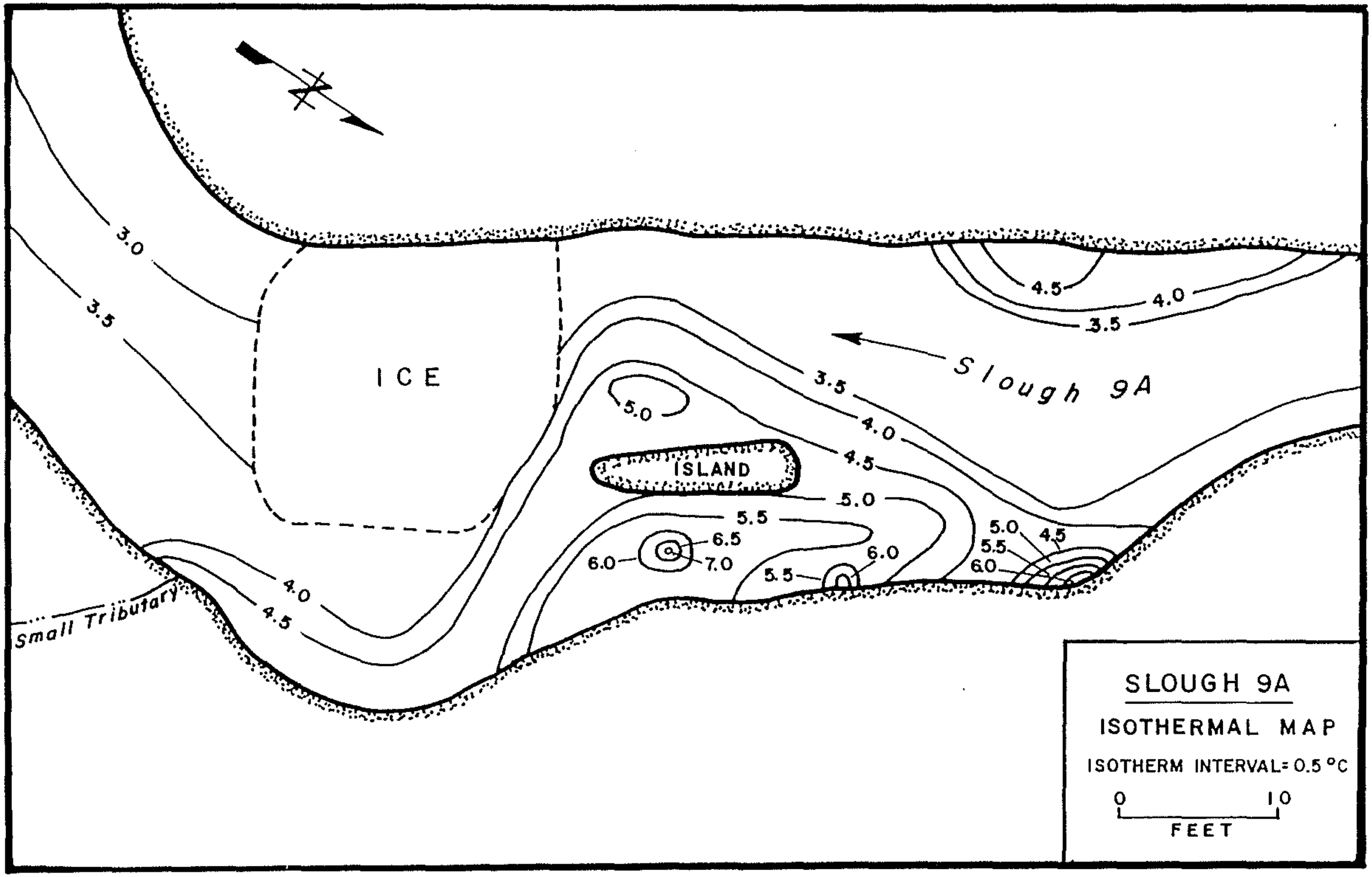

Figure 10-3 Isothermal map of a portion of Slough 9A developed from ground-truthing data collected Nov. 17, 1983. Corresponding thermal scan in Plate 10-2.

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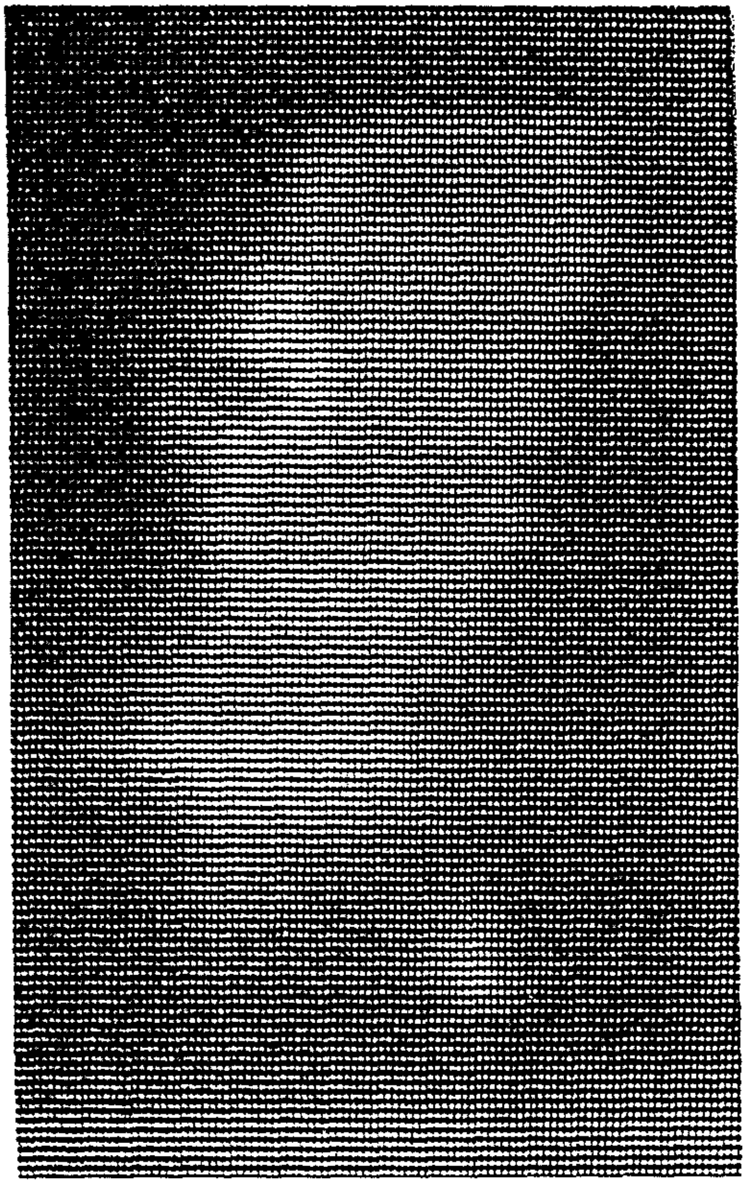

PLATE 10-3 Thermal scan of a portion of Slough 9A (see Plate 10-1), November 15, 1983.

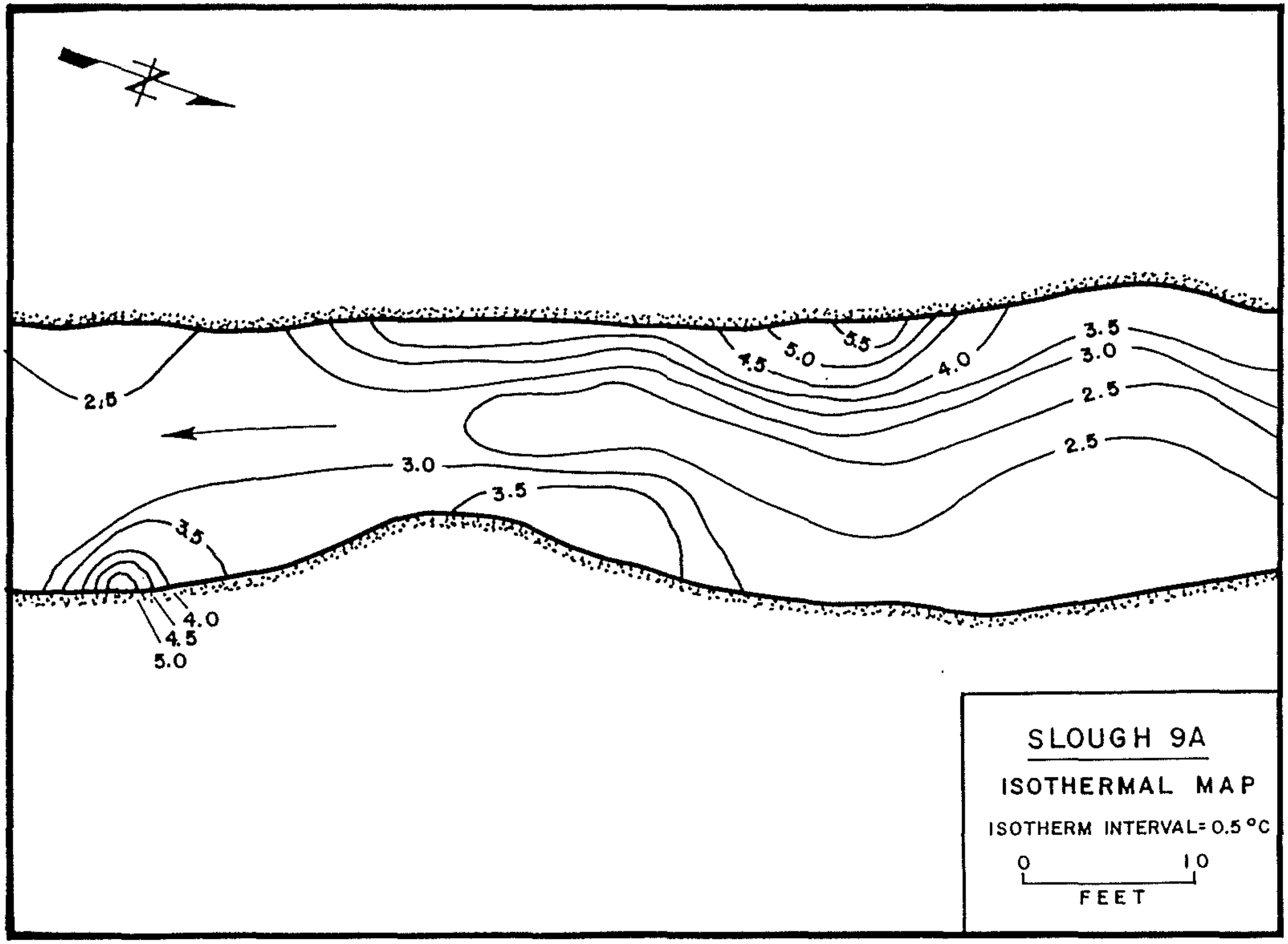

Figure 10-4 Isothermal map of a portion of Slough 9A developed from ground-truthing data collected Nov. 17, 1983. Corresponding thermal scan in Plate 10-3.

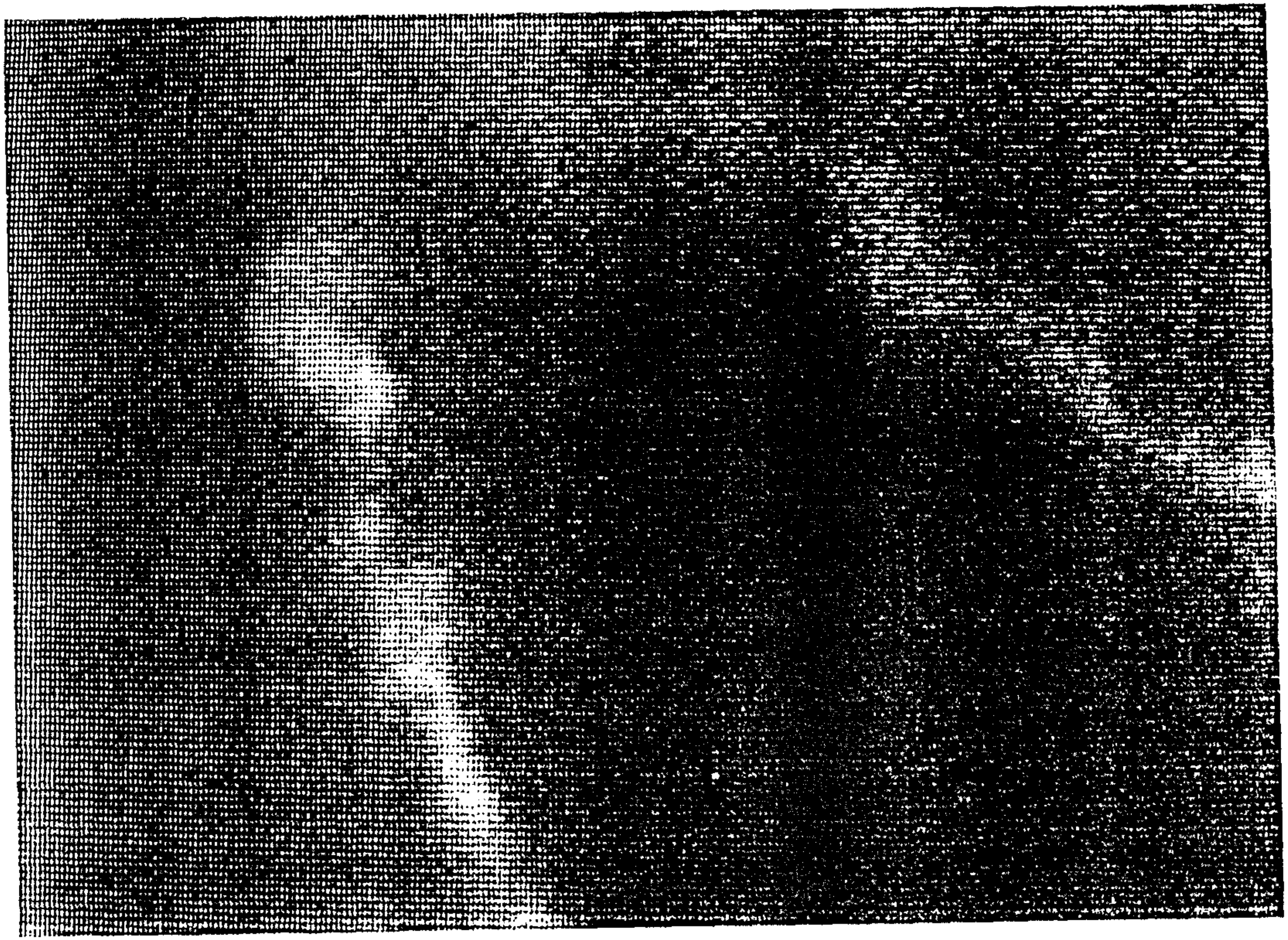

PLATE 10-4 Thermal scan of a portion of Slough 9A (see Plate 10-1), November 15, 1983.

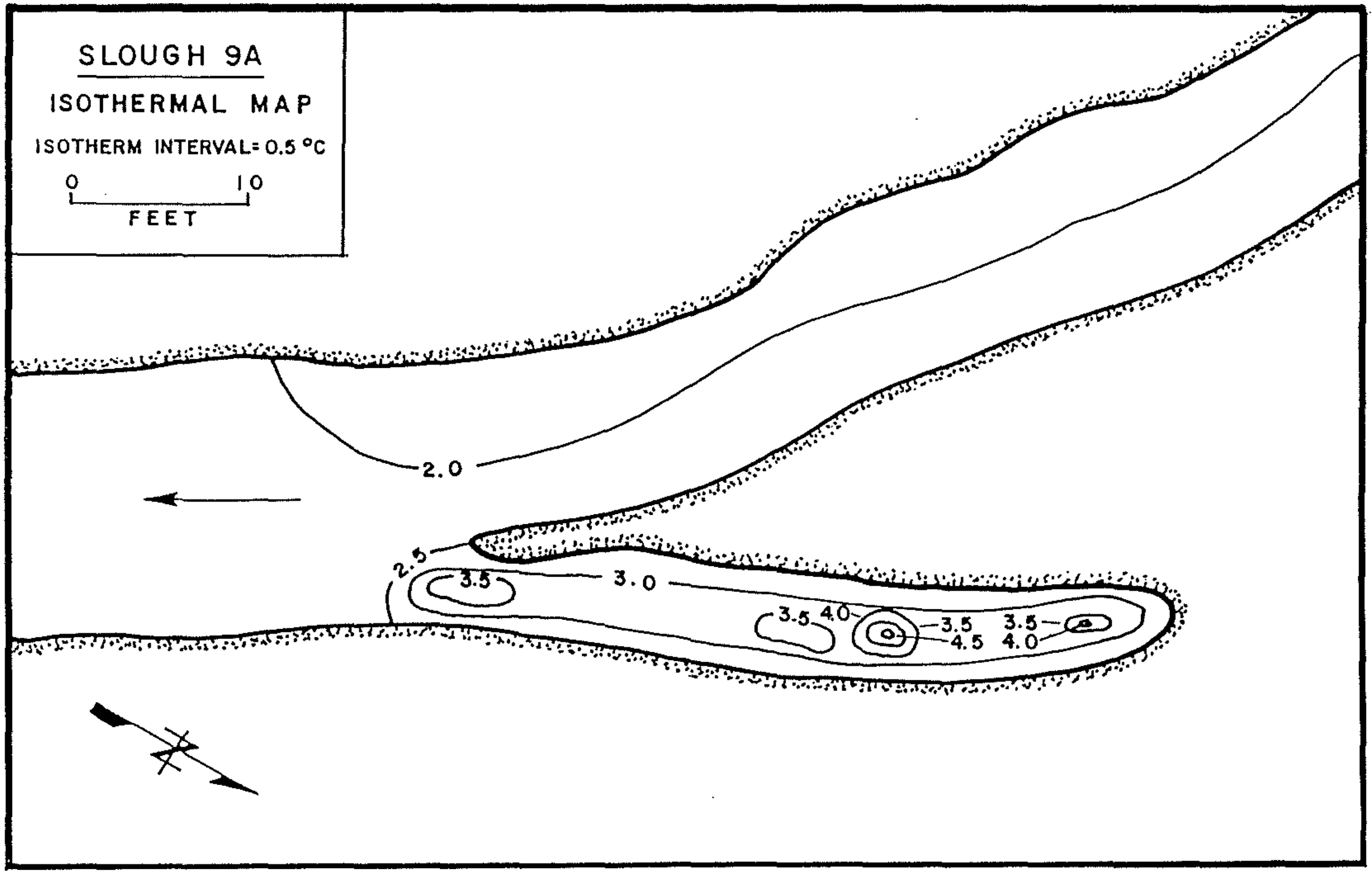

Figure 10-5 Isothermal map of a portion of Slough 9A developed from ground-truthing data collected Nov. 17, 1983. Corresponding thermal scan in Plate 10-4.

4.0 DISCUSSION

Infrared thermal imagery can be used to detect upwelling groundwaters within the sloughs of the Susitna River system when the proper environmental conditions exist. Of the infrared imagers evaluated, the AGA Thermovision 750 infrared camera system proved to be the best suited imager for detecting groundwater influenced surface water temperature anomalies. Although Slough 10 was know to contain numerous vigorous upwelling groundwater areas, the homogenous infrared thermal image of the slough indicated that upwelling groundwater areas were scarce. This obvious discrepancy has highlighted the limitations of applying remote sensing techniques to detect subsurface groundwater inflows in sloughs.

This study indicates that infrared thermal imagery can be used to detect upwelling groundwaters within a larger body of water only if:

(1) a temperature difference of at least 1.5°C - 2.0°C exists between the water bodies; and

(2) the upwelling groundwater reaches the surface of the receiving body.

Both conditions were violated during the infrared scan of Slough 10.

Although a few warmer groundwater inflows entered the slough from the substrate of Slough 10, these inflows failed to influence the surface water temperature above the vent.

A majority of the groundwater inflows were isothermal with the surface water. A few of these inflows were vented under pressure causing an obvious surface water disturbance with no detectable change in surface water temperature. The homogeneity of the slough surface water temperature caused by the isothermal conditions of the slough and groundwater sources masked the upwelling groundwater areas within the slough.

Groundwaters vented into the sloughs of the Susitna River generally tend to be more dense than the surface water. The temperature/density relationship of water dictates that water is most dense at 4°C. Because of this relationship, colder waters (less than 4°C) in winter and warmer waters (greater than 4°C) in summer rise to the surface. Vented groundwater is usually warmer in winter and cooler in summer than slough surface water temperatures. Therefore, these waters remain near the bottom of the slough because of their greater density than the overlying waters. Occasionally, when isothermal conditions exist between the water bodies, the temperature related density gradient diminishes allowing free mixing of the groundwater and slough water. In either case, (denser or isothermal groundwater) infrared imagery will not be able to assist in determining the location of the subsurface groundwater vents in larger bodies of water. Infrared imagery will aid in determining the location of groundwater vents only when the surface water temperature is influenced by thermally different groundwaters. Groundwater inflows in shallow water or groundwater releases under pressure are the two modes by which thermally different groundwaters can reach and affect the surface water of the slough.

In order to maximize the efficiency of the thermal infrared imagery in detecting slough surface water anomalies caused by upwelling groundwater, environmental conditions must be ideal for detection. The following is a list of the environmental conditions necessary to maximize efficiency:

(1) Infrared thermal scanning of the water body must be conducted during the dark night hours in order to minimize any interference from the sun or bright skies;

(2) Infrared thermal scanning must be done during the lowest possible, ice free, water levels of the water body in order to maximize the chances that groundwaters will reach the surface of the water body without significant deviation from point source; and

(3) Surface water temperatures and groundwater temperatures must vary sufficiently to cause a surface water temperature anomaly of at least 1.5° - 2.0°C in order to maximize detection.

From the above conditions it is apparent that the period for thermal infrared imagery scanning on the Susitna River is a dark night in early winter, immediately prior to freeze-up. Slough 9A was scanned during near optimal conditions. The infrared imagery detected many surface water temperature anomalies.

Even when conditions are optimal, infrared imagery probably will not be able to assist in determining the location of every upwelling groundwater vent in the slough. Upwelling groundwaters may not reach the surface in all cases, or may not be thermally different than surface waters. Thermal imagery will definitely aid in determining the locations of upwelling groundwater vents in the vicinity of detectable surface water temperature anomalies but will not be able to aid in the determination of vents beneath homogeneous surface water temperatures. Because of water depth and velocities in the Susitna River mainstem and tributaries, it is very unlikely that small to moderate upwelling groundwater areas could be detected using infrared thermal scanning. In order for groundwater to be detected in these water bodies, the magnitude of the groundwater inflow would have to be much greater. Infrared imagery used to detect upwelling groundwater vents in sloughs is an excellent prospecting tool capable of providing a good deal of positive results on a large scale. However, application of this technique for site specific evaluations of upwelling sources has not proven to be successful. As a result other types of evaluations will be required for determining the presence of upwelling as a function of flow and mainstem discharge in sloughs and side channels.

6.0 CONTRIBUTORS

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8.0 LITERATURE CITED

Alaska Department of Fish and Game, 1983. Susitna Hydro aquatic studies phase II report. Synopsis of the 1982 aquatic studies and analysis of fish and habitat relationships (2 parts). Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. Anchorage, Alaska.

Anderson, E. R. 1954. Energy budget studies, IN: Water-loss investigations - Lake Hefner Studies Technical Report: U. S. Geological Survey Prof. Paper 269:71-119.

Boettcher, A. J. and R. M. Haralick, 1977. Use of Thermal-infrared imagery in groundwater investigations, Montana: Proceedings of the Eleventh International Symposium on Remote Sensing of Environment. 1161-1170.

Boettcher, A. J., R. M. Haralick, C. A. Paul and N. Smothers. 1976. Use of 1976 Thermal-infrared imagery in groundwater investigations, Northwestern Montana. Jour. Research U. S. Geological Survey. 4(6)727-732.

Francisco K. 1977. Second interim report of the Commercial Fish - Technical Evaluation Study. Joint State/Federal Fish and Wildlife Advisory Team. Special Report No. 9, Anchorage, Alaska.

Kogl, D. R. 1965. Springs and groundwater as factors affecting survival of chum salmon spawn in a subarctic stream. M. S. thesis. University of Alaska. Fairbanks, Alaska.

Pluhowski, E. J. 1972. Hydrologic interpretations based on infrared imagery of Long Island, New York. U. S. Geological Survey. Water Supply Paper 2009-B. Washington, D.C.

Robinove, C. J. 1965. Infrared photography and imagery in water resources research: American Water Works Association Journal 57(7): 834-840.

Robinove, C. J. and D. G. Anderson 1969. Some guidelines for remote sensing in hydrology: Water Resources Bulletin, 5(2):10-19.

Shields, H. J. 1977. Infrared systems and their selection. Paper presented at the National Fire Generalship School, Marana, Arizona. December 7, 1977. Marana, Arizona.

Whipple, J. M. 1972. Remote sensing of New York lakes. U. S. Geological Survey. Professional Paper 800-C: 243-247. Washington, D.C.

Wilson, W. J., W. W. Trihey, J. E. Baldridge, C. D. Evans, J. G. Thiele and D. E. Triedgen. 1981. An assessment of environmental effects of construction and operation of the proposed Terror Lake hydroelectric facility, Kodiak, Alaska. Instream Flow Studies final report. Arctic Environmental Information and Data Center. University of Alaska. Anchorage, Alaska.