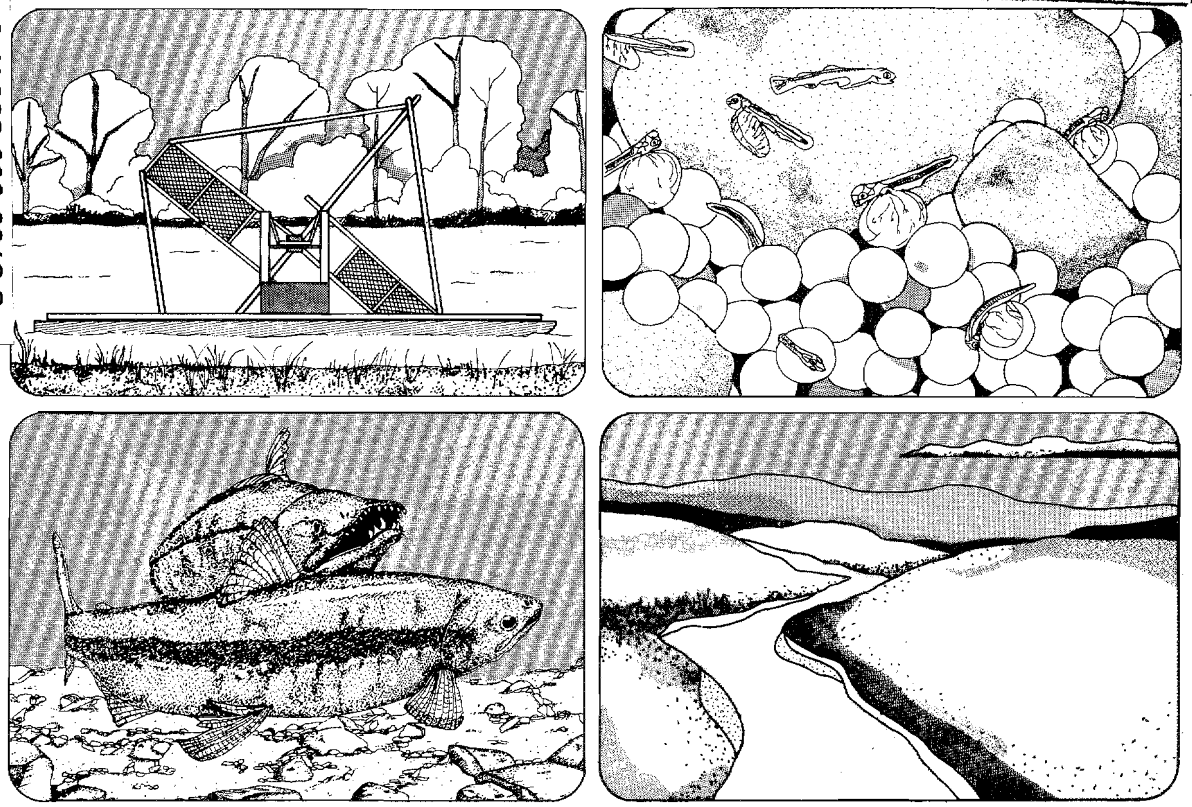

REPORT NO. 3

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

Chapter 10: Evaluations of the Effectiveness of Applying Infrared Thermal Imagery Techniques to Detect Upwelling Groundwater

ALASKA DEPARTMENT OF FISH AND GAME
SUSITNA HYDRO AQUATIC STUDIES REPORT SERIES

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Chapter 10: Evaluations of the Effectiveness of Applying Infrared Thermal Imagery Techniques to Detect Upwelling Groundwater

Edited by:

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Prepared for:

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PREFACE

This report is one of a series of reports prepared for the Alaska Power Authority (APA) by the Alaska Department of Fish and Game (ADF&G) to provide information to be used in evaluating the feasibility of the proposed Susitna Hydroelectric Project. The ADF&G Susitna Hydro Aquatic Studies program was initiated in November 1980. The five year study program was divided into three study sections: Adult Anadromous Fish Studies (AA), Resident and Juvenile Anadromous Studies (RJ), and Aquatic Habitat and Instream Flow Studies (AH). Reports prepared by the ADF&G prior to 1983 on this subject are available from the APA.

The information in this report summarizes the findings of the 1983 open water field season investigations. Beginning with the 1983 reports, all reports were sequentially numbered as part of the Alaska Department of Fish and Game Susitna Hydro Aquatic Studies Report Series.

TITLES IN THE 1983 SERIES

Report Number	Title	Publication Date
1	Adult Anadromous Fish Investigations: May - October 1983	April 1984
2	Resident and Juvenile Anadromous Fish Investigations: May - October 1983	July 1984
3	Aquatic Habitat and Instream Flow Investigations: May - October 1983	1984
4	Access and Transmission Corridor Aquatic Investigations: May - October 1983	1984

This report, "Aquatic Habitat and Instream Flow Investigations" is divided into two parts. Part I, the "Hydrologic and Water Quality Investigations", is a compilation of the physical and chemical data collected by th ADF&G Su Hydro Aquatic Studies team during 1983. These data are arranged by individual variables and geographic location for ease of access to user agencies. The combined data set represents the available physical habitat of the study area within the Cook Inlet to Oshetna River reach of the Susitna River. Part II, the "Adult Anadromous Fish Habitat Investigations", describes the subset of available habitat compiled in Part 1 that is utilized by adult anadromous fish studied in the middle and lower Susitna River (Cook Inlet to Devil Canyon) study area. The studies primarily emphasize the utilization of side slough and side channel habitats of the middle reach of the Susitna River for spawning (Figure A). It represents the first stage of development for an instream flow relationships analysis report which will be prepared by E.W. Trihey and Associates.

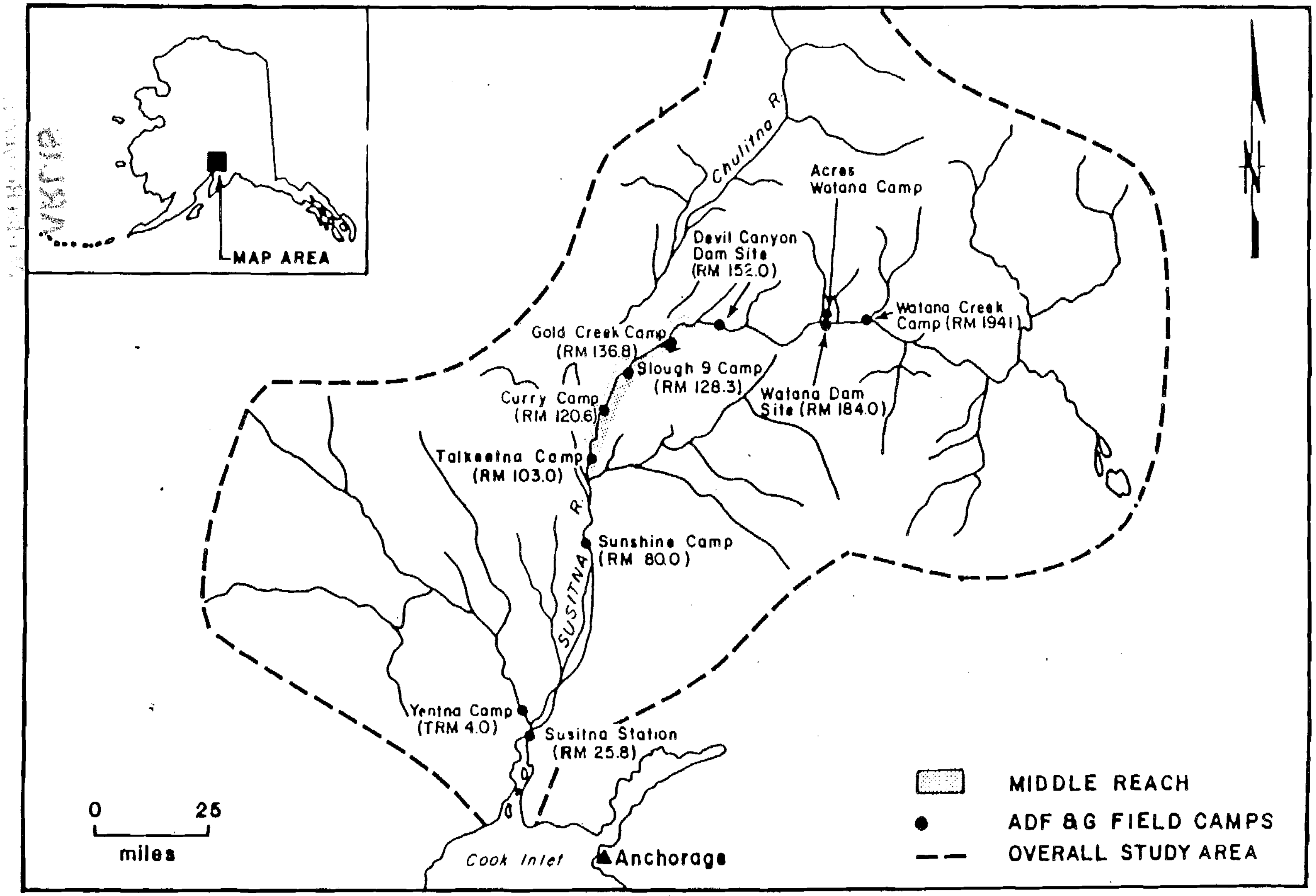

Figure A. Susitna River drainage basin.

CONTENTS OF REPORT NO. 3

Part One

Questions concerning this and prior reports should be directed to:

Alaska Power Authority
334 W. 5th Avenue
Anchorage, Alaska 99501
Telephone (907) 276-0001

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

1984 Report No. 3, Chapter 10

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ABSTRACT

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 chum salmon spawning in the middle reach of the Susitna River (ADF&G 1983). Three infrared heat sensing devices (Hughes Probeye, Xedar Pyroscan, and AGA Thermovision) were tested to evaluate the feasibility of using infrared thermal imagery as a remote sensing technique for detecting and quantifying the amount of upwelling groundwater in slough habitats of the Susitna River. Results of these investigations indicate that the application of infrared heat sensing devices for locating upwelling is contingent on a host of environmental conditions and the level of detail desired. Areas of upwelling groundwater and their relative magnitude were identified using these techniques; however, some areas known to have upwelling based on ground truthing surveys were not detected. This inconsistency is due to the wide variety of environmental conditions that occur within the Susitna River combined with the physical limitations of the technology. For these reasons, it is doubtful whether this technique can be applied on a large scale for the detection and quantification of upwelling areas.

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1.0 INTRODUCTION

This chapter presents an evaluation of whether thermal infrared imagery techniques can be employed to successfully detect and quantify upwelling groundwater in slough habitats of the Susitna River.

Upwelling groundwater is a principal variable influencing the suitability of slough habitats for spawning by chum salmon in the Talkeetna to Devil Canyon reach of the Susitna River system (ADF&G 1983; Chapter 7 of this report). 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 upwelling groundwater areas in the sloughs and side channels of the Susitna River to date have been conducted by 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. Often times, the vented groundwater was expelled under pressure so that, in relatively shallow water, a disturbance was visible at the surface of the substrate. Success of visual detection of upwelling groundwater in Susitna River sloughs, however, was found to vary with the particle size of the streambed substrate. Groundwater upwelling vents were easily discernible in silt and sand streambed substrates but were difficult to detect when larger streambed substrate particle sizes predominated.

Infrared thermal imagery was considered as a possible tool for improving the detection of upwelling groundwater since previous applications of this technique have allowed hydrologists to identify numerous hydrologic phenomena such as natural dispersion and circulation patters (Whipple 1972), dispersion of heated effluent (Whipple 1972; Pluhowski 1972), dispersion of sewage outfall, ice cover (Pluhowski 1972), and groundwater discharge into large bodies of water (Robinove 1965; Pluhowski 1972; Boettcher et al. 1976; Boettcher and Haralick 1977).

Boettcher et. al. (1976) and Boettcher and Haralick (1977) in their groundwater investigations along the Kootenai and Clarkfork Rivers quantified surface water infrared radiation using thermal infrared imagery. With the aid of computer techniques, the infrared imagery 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 portions of these rivers directly influenced groundwater inflows, and to detect circulation and dispersion patterns of the ground water into the larger body of water at the surface.

Because of the success of the technique of using thermal imagery for detecting ground water upwelling in these river systems, this technique was evaluated as a potential quick, sensitive, and accurate method to detect areas of upwelling groundwater venting into sloughs of the Susitna River system

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 (radiant energy from the object) determines the brightness of the images which appears on a 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 is related to the temperature and emissivity of the object. Emissivity is the ratio of actual energy radiated from the body to the maximum possible energy radiated from a black-body radiator at a given temperature. The emissivity of water is independent of temperature and concentration of dissolved solids and is estimated to be 0.97. 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 (Pluhowski 1977; 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 portion of the 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). 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 of infrared radiation occurs within this region (Shield 1977). Since infrared radiation exists in the absence of visible light, detecting operations in this spectrum region can be performed day or night. Imagers 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).

Upwelling groundwater vented into the sloughs and side channels 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 and warmer waters (greater than 4°C) will rise to the surface. Vented groundwater is usually warmer in winter and cooler in summer than slough surface water temperatures and therefore tends to remain near the bottom of the slough. Occasionally, during the fall and spring when atmospheric conditions are right, the temperature related density gradient diminishes allowing free mixing of the groundwater and slough water. It is during these periods when upwelling groundwaters can be detected using thermal infrared scanning techniques.

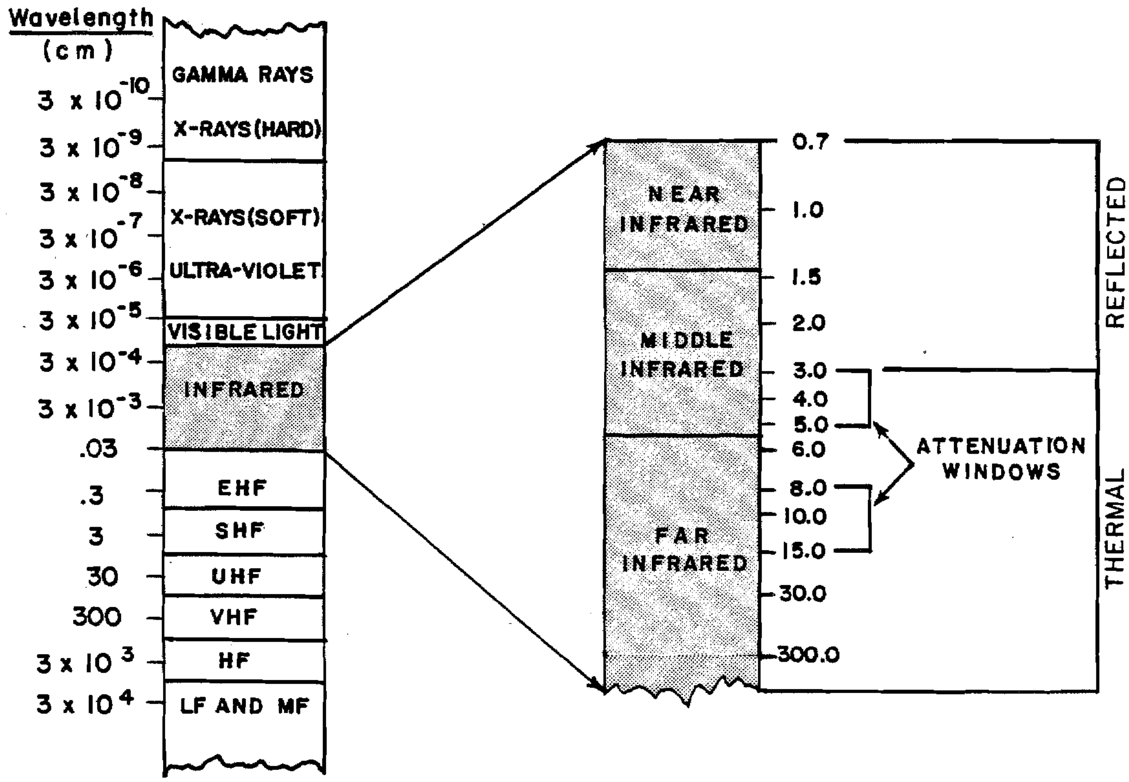

Figure 10-1. Infrared portion of the electromagnetic spectrum.

2.0 METHODS

2.1 Site Selection

Four sloughs (8A, 9A, 10, and 11) in the Talkeetna to Devil Canyon reach of the Susitna River were selected for evaluation in this pilot study (Figure 10-2). These sloughs were selected as study sites based on the presence of strong upwelling groundwater in each slough and because of their proximity for study.

2.2 Analytical Approach and Field Data Collection

Three infrared thermal imagers (Hughes Probeye, Xedar Pyroscan, and AGA Thermovision 750) were tested to evaluate their capabilities as remote sensing devices for locating the surface water areas known to be 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 eyepiece of the observer. 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.

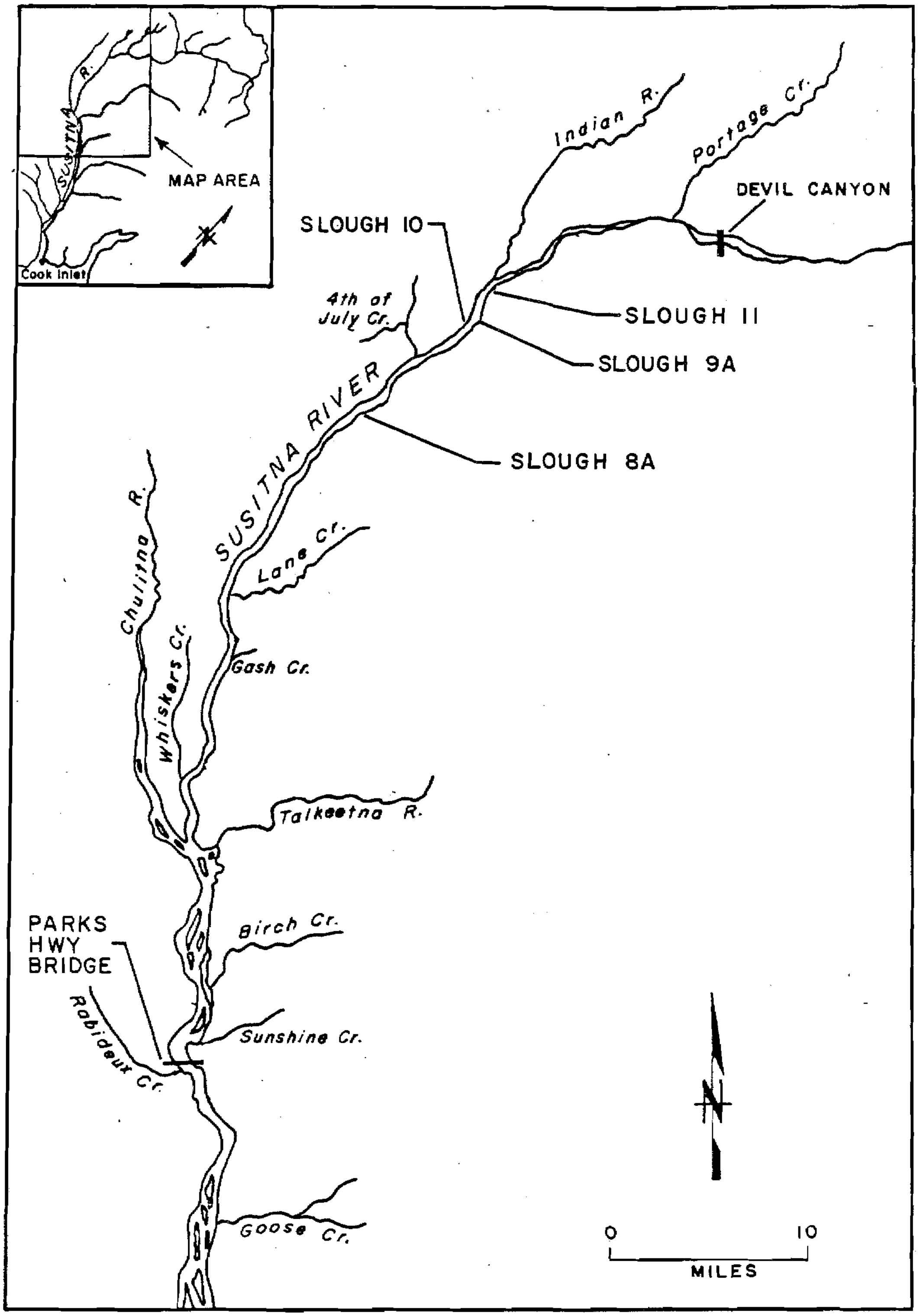

Figure 10-2. Infrared thermal imagery study sites.

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[1] at ?	33 mm	525 line video screen or video	Battery	10 lbs.	hand-operated

[1]/no temperature specified.

Three separate field trips were conducted under varied environmental and experimental conditions 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 the respective operating manuals. Infrared scanning operations were conducted conducted primarily from a helicopter hovering low 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 on August 8, 1983. These evaluations were conducted during bright daylight conditions and a Susitna River 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 the ground. The ground survey in Slough 8A centered around a visible upwelling groundwater vent.

On October 24, 1983, the Hughes Probeye and the AGA Thermovision were evaluated. These evaluations were conducted during the evening hours in order to minimize the thermal interference of sunlight reflecting off the water. Slough 10 and 11 were scanned during this field trip at a Susitna River discharge of 5,800 cfs. All infrared scans on October 24, 1983 were conducted from a helicopter platform.

A final field trip was undertaken on November 15, 1983 for evaluating the AGA Thermovision system exclusively. Infrared scans were conducted at night at Susitna River discharge of approximately 4,000 cfs. Water levels in the study sloughs were very low with some ice cover. Infrared

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 = 3,000 cfs. (approx.)	Slough 10 and Slough 9A

scans were conducted from a helicopter capable of night flying. Sloughs 10 and 9A were scanned during this period.

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 tested it was found that a more complex methodology was needed. It was determined that site specific measurements of surface water temperature of areas surveyed with the imagers were needed in order to compare infrared detected upwelling areas recorded on video tape to in site surface water temperatures of the sloughs.

Because of the evolutionary nature of the methodology, surface water temperatures of slough areas surveyed were only ground truthed on the last evaluation field trip. Surface water temperatures of Slough 10 were determined immediately prior to the thermal infrared scan. Surface water temperatures of Slough 9A could not be ground truthed until two days after the infrared scanning flight. Surface water temperature measurements were recorded at two foot intervals along transects in a 1500 foot reach of the slough divided into 100 transects. Temperatures were measured using a Digi-sense temperature probe at a depth of approximately 10 inches using procedures listed in the manufacturers operating manual. These data were then reduced into isothermal maps to facilitate analysis of data collected.

3.0 RESULTS

Three field trips were conducted under varied environmental and experimental conditions to evaluate whether thermal infrared imagers could be used to successfully detect and quantify the amount of upwelling groundwater in slough habitats of the Susitna River. During these field trips, three thermal infrared imagers were tested and evaluated (Hughes Probeye, Xedar Pryoscan, AGA Thermovision 750).

Because specific gear types were not tested under the same conditions, the relative ability of specific gear types tested could only be evaluated under the specific conditions that each gear type was tested under. For this reason, statements made in this report concerning the relative abilities of specific gear types tested must be viewed with caution and not taken as any type of product endorsement.

The Hughes Probeye was tested on the August 9th and October 24th field trips under different light (i.e. bright sunshine vs. dark) and mainstem discharge conditions (26,000 vs. 5,800 cfs) at three different sloughs (Sloughs 8A, 10 and 11). Based on the results from these tests, the Hughes Probeye could not detect thermal differences between upwelling and surface water when used from an aerial platform, but could detect a thermal difference when used on the ground. Resolution of visual images were poor; and the outline of water bodies were not readily distinguishable from the adjacent shoreline. Based on these findings, it was decided to suspend further testing of this equipment after the October 24th field trip.

The Xedar Pyroscan was only evaluated on the August 9th field trip. For this reason, it was difficult to ascertain the relative performance of this gear type under a varied range of environmental conditions. Under the limited conditions evaluated, the Xedar Pyroscan provided a relatively clear resolution of visually different images such as vegetation, shoreline, and surface water. The different shades of gray on the viewing screen, indicating differences in surface water temperatures, however, were extremely difficult to distinguish. Based on these findings, it was decided to suspend further testing of this equipment after the August 9th field trip.

The AGA Thermovision 750 was tested during the October 24th and November 15th field trips. Bright sky conditions were present at dusk during the October field trip. This hampered the effectiveness of this infrared scanner to detect subtle surface water temperature differences. In spite of this, upwelling groundwater areas were detected relatively easily using this system in the two sloughs evaluated (10 and 9A). On the November 15th trip, numerous areas of suspected groundwater upwelling in Slough 9A were identified using the AGA system (Plates 10-1 through 10-3). Based on ground-truthing measurements of surface water temperatures obtained at this slough two days after the scanning of the slough[1], it was found that the areas of suspected groundwater upwelling had higher surface water temperatures than nearby areas without suspected groundwater upwelling, indicating that upwelling was occuring (Figures 10-3 and 10-4). It was further found that a surface water

[1]Ground trouthing could not be performed on the day of survey due to logistic problems.

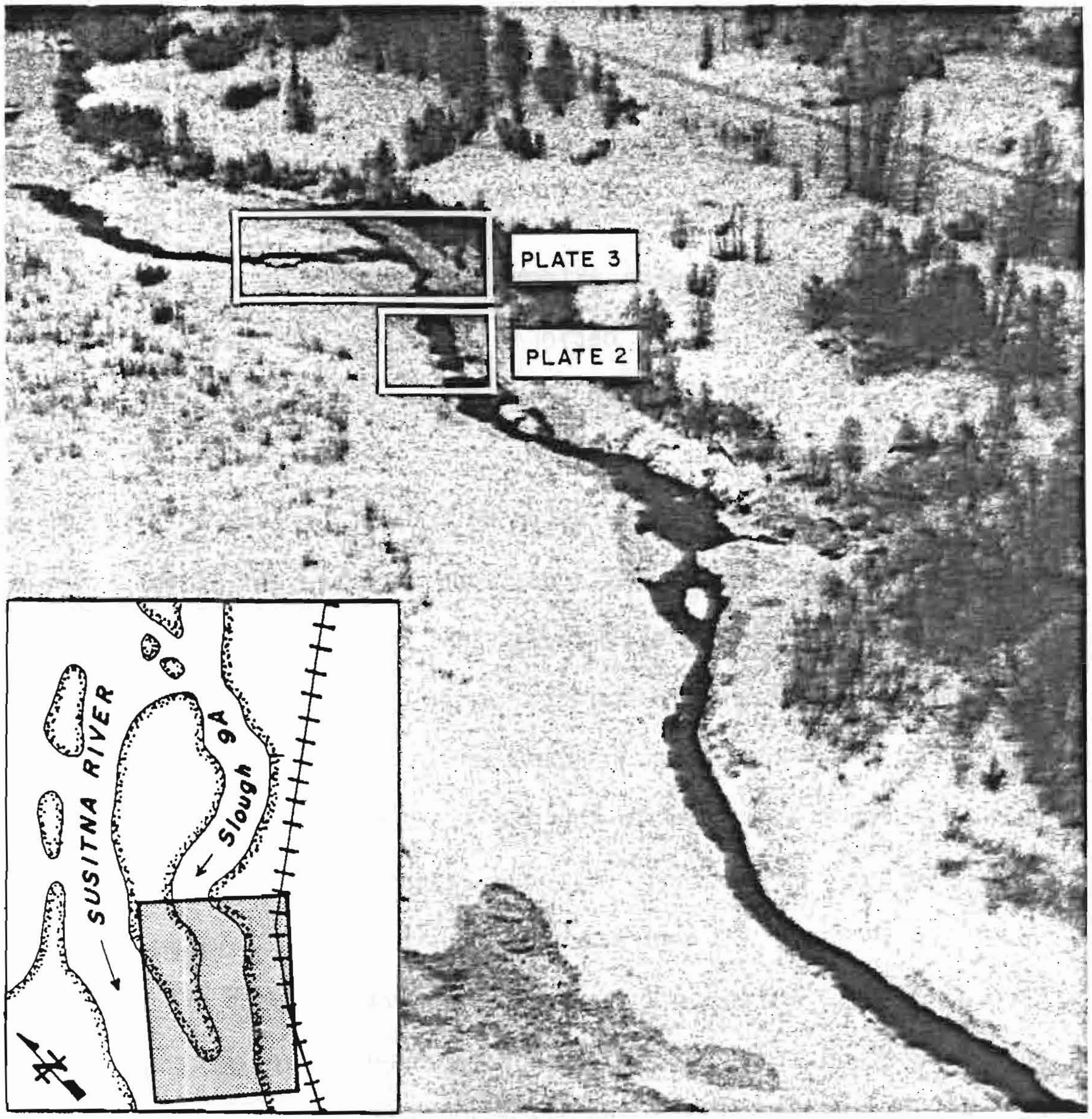

Plate 10-1. Aerial photo of Slough 9A: November 15, 1983. Thermal scans of outlined areas are presented in Plates 10-2 through 10-3.

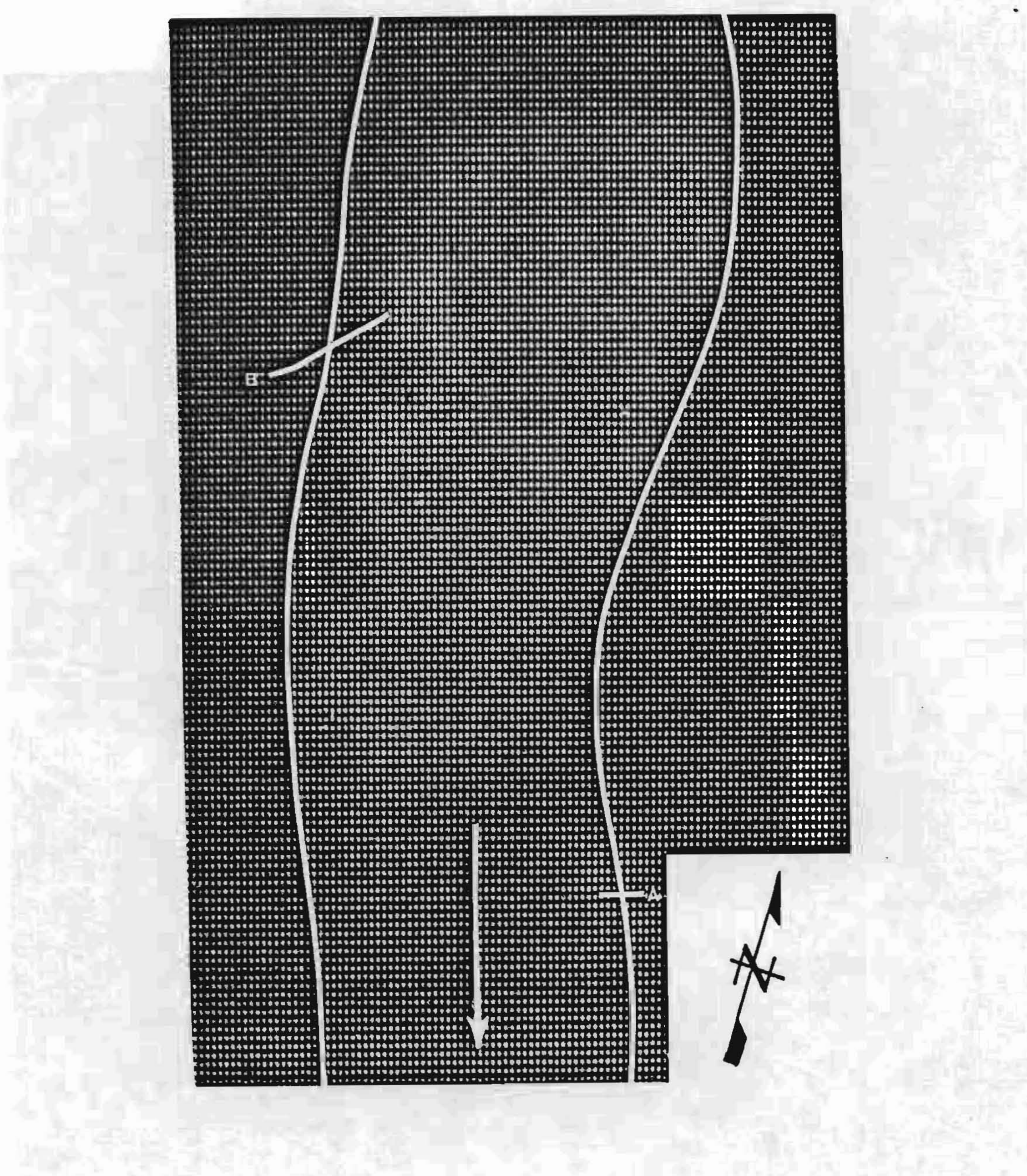

Plate 10-2. Thermal scan of a portion of Slough 9A (see Plate 10-1): November 15, 1983.

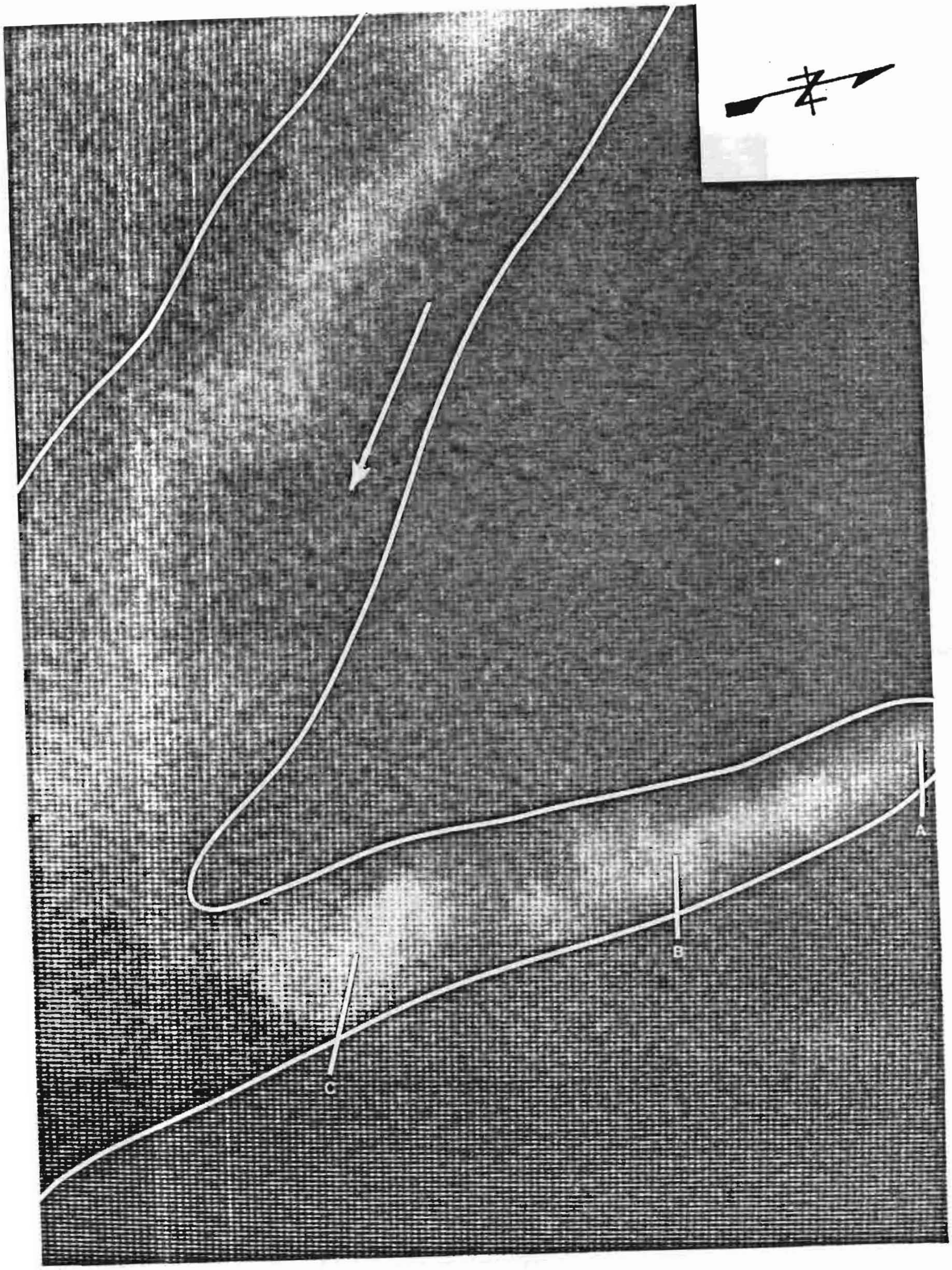

Plate 10-3. Thermal scan of a portion of Slough 9A (See Plate 10-1): November 15, 1983.

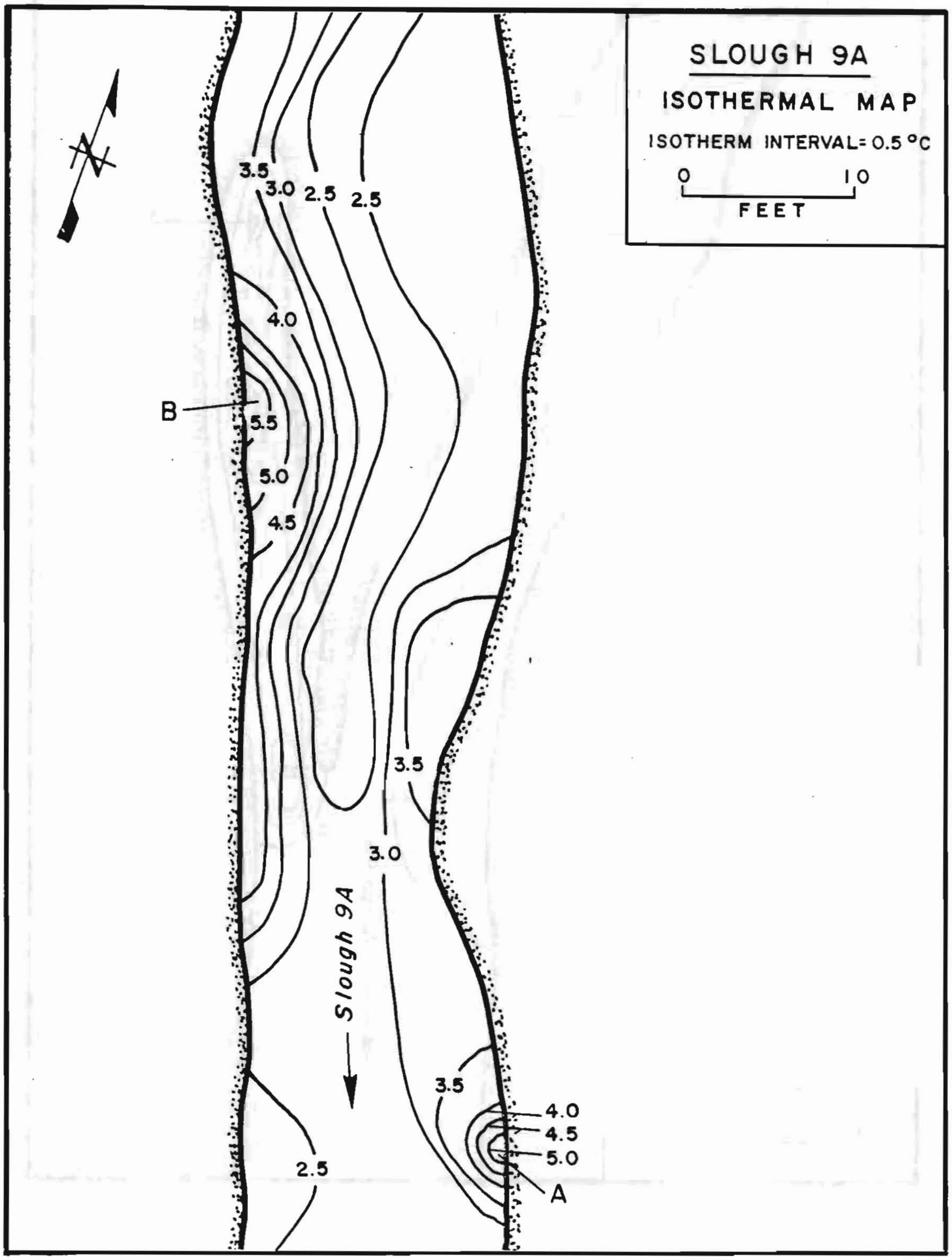

Figure 10-3. Isothermal map of a portion of Slough 9A corresponding to the thermal scan in Plate 10-2 developed from ground-truthing data collected November 17, 1983.

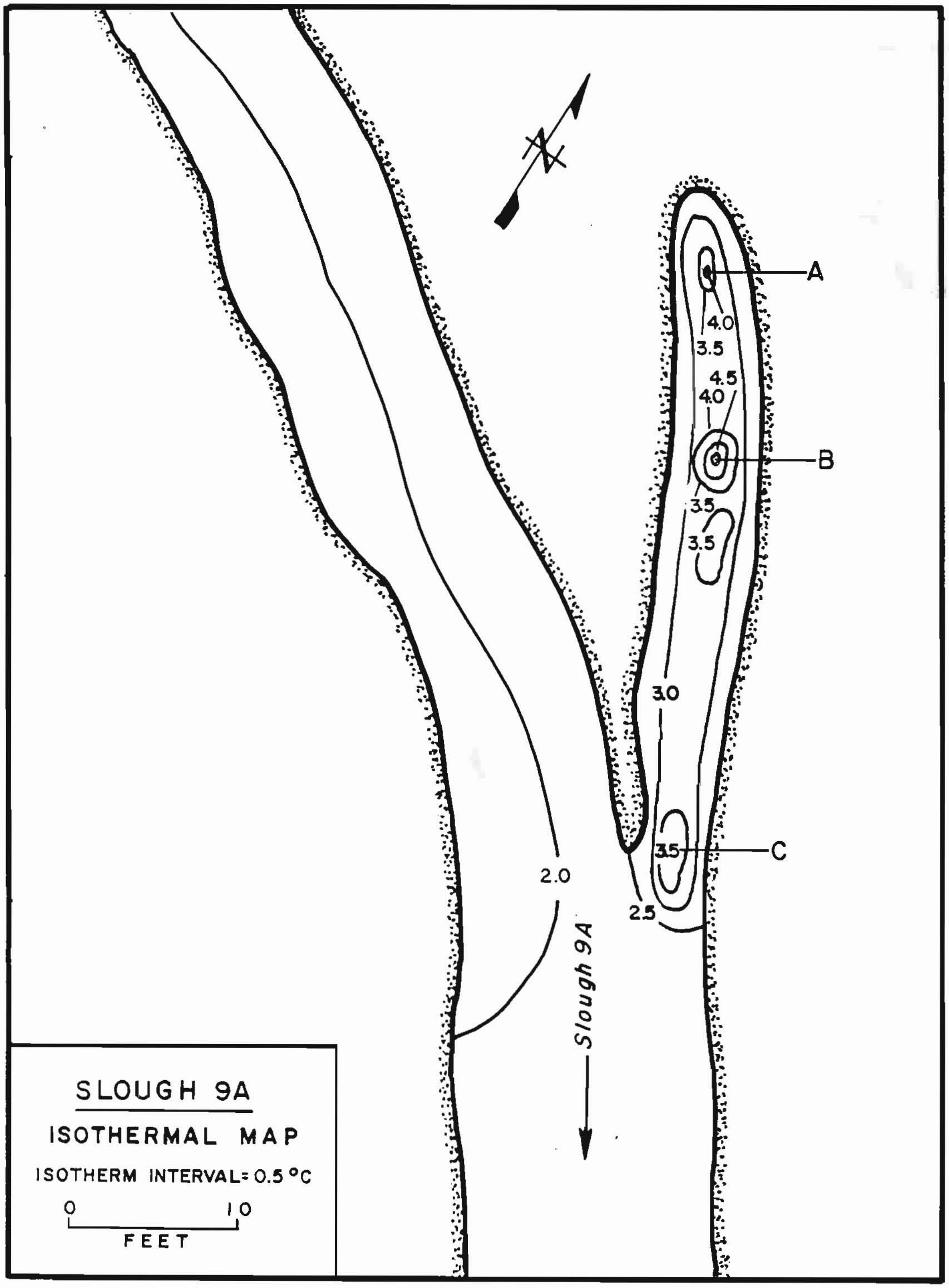

Figure 10-4. Isothermal map of a portion of Slough 9A corresponding to the thermal scan in Plate 10-3 developed from ground-truthing data collected Nov. 17, 1983.

temperature difference ranging from 1.5 to 2.0°C was necessary for differentiating between areas with and without upwelling groundwater.

The thermal infrared imagery of the AGA system, however, failed to locate numerous known upwelling groundwater vents in Slough 10. This was due to the fact that upwelling temperatures at many of these known vents in this slough were not detectable on the surface of the slough at the time of scanning as verified by ground truthed measurements. Based on ground truthed temperature measurements at groundwater upwelling areas located by the infrared imagery at this slough, it was determined that a temperature difference of 1.5°C in slough surface water temperature was necessary for detection of upwelling areas. It was also determined that the depth of flow or water velocity over the vent had to be small in order to make a detectable temperature difference in surface water temperatures caused by upwelling.

4.0 DISCUSSION

In order to maximize the efficiency of the thermal infrared imagery for detecting upwelling groundwater, environmental conditions must be ideal for detection. Based on the finding of this study, infrared thermal imagery can best be used to detect surface water temperature anomalies caused by upwelling groundwater within sloughs when the following environmental conditions are met:

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

(2) Infrared thermal scanning is conducted during the lowest possible, ice free, water levels in order to maximize the chances that upwelling groundwaters will reach the surface of the water body without significant deviation from their point source (i.e., shallow water depths and lower velocities are present); 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.

Based on findings of these studies, however, even when these conditions are optimal, the use of thermal infrared imagery techniques to detect areas of upwelling groundwater probably will not provide a quantitative assessment of upwelling locations in sloughs and side channels. For reasons previously stated, upwelling groundwater may not reach the surface in all cases or may not cause a decernable thermal difference in the surface waters. Thermal imagery, however, is a useful tool in determing the locations of upwelling groundwater vents in the vicinity of detectable surface water temperature anomalies in sloughs. Because of water depth and velocities in the Susitna River mainstem, side channels, and tributaries, it is very unlikely that small to moderate upwelling groundwater areas could be detected in these habitats using infrared thermal scanning.

In summary, infrared imagery has been used successfully in this study to detect upwelling groundwater vents in selected sloughs; however, it is doubtful whether this technique can be employed on a large scale for site specific evaluations of upwelling source in the variety of habitats and conditions present in the Susitna River. As a result, other types of evaluations providing more detailed and precise measurements will be required for determining the presence of upwelling as a function of flow and mainstem discharge in sloughs and side channels.

5.0 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 obtaining corroborating measurements of a variable at the site.

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.

Micron (um) - 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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7.0 ACKNOWLEDGEMENTS

The authors express their appreciation to the following for their assistance in preparing this report.

- The other ADF&G Su Hydro Aquatic Studies Program staff who provided their support to this report.

- Richard Town of Infrared Technology, Inc. who provided the AGA Thermovision equipment and the time and expertise to operate it.

- Kathy Barker of United States Department of Interior, Bureau of Land Management, who provided and operated the Hughes Probeye.

- Alaska Department of Natural Resources who provided the Pyroscan.

- E. Woody Trihey of E. Woody Trihey Consultants, for hIs review of this document.

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