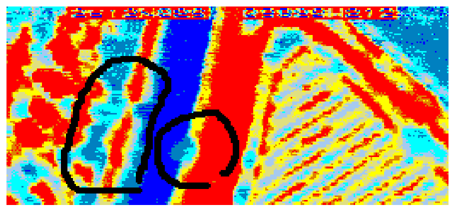
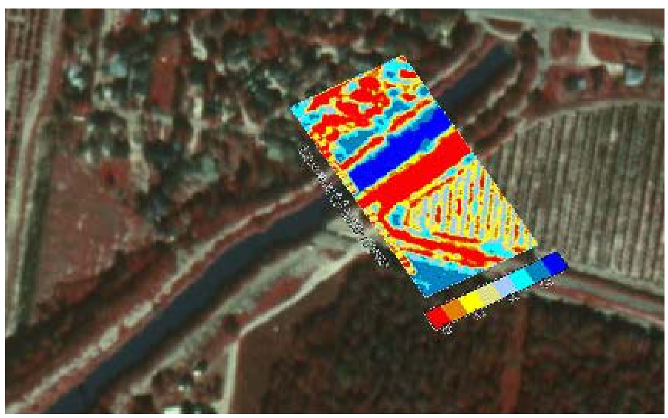
Thermal Imaging of Canals for

Remote Detection of Leaks:

Evaluation in the United Irrigation District[1]





by

Yanbo Huang and Guy Fipps, P.E.[2]

December 20, 2002

[1] A portion of this study was funded by Texas Cooperative Extension through the Rio Grande Basin Initiative administered by the Texas Water Resources Institute of the Texas A&M University System with funds provided through a grant from Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, under Agreement No. 2001-001-45049-01149

[2] Extension Associate, and Professor and Extension Agricultural Engineer, respectively, Biological and Agricultural Engineering, 2117 Texas A&M University, College Station, TX 77843-2117

Thermal Imaging of Canals for Remote Detection of Leaks: Evaluation in the United Irrigation District

Summary

This report summarizes our initial analysis of the potential of thermal imaging for detecting leaking canals and pipelines. Thermal imagery (video format) was obtained during a fly over of a portion of the main canal of United Irrigation District. The video was processed to produce individual images, and 45 potential sites were identified as having possible canal leakage problems (see Appendix I for all 45 thermal images).

District Management System Team personnel traveled to 11 of the 45 sites to determine if canal leakage was actually occurring. Of the 11 sites, 10 had leakage problems. Thus, thermal image analysis had a success rate of 91% for leak detection. Two sites had leaks classified as "severe" by the DMS Team.

This report also provides a detailed analysis of 4 sites, 3 with leaks and 1 without. For each site, photographs are included showing the source of the leak and/or condition of the canal segment. A literature review of thermal imagery for leak detection is included in Appendix II.

Our findings and recommendations are as following:

1) thermal imaging is a promising technique for evaluation of canal conditions and leak detection;
2) the district provide should provide personnel to help the DMS Team verify the remaining 34 sites; and
3) the district should consider correcting the problems identified at sites 7 and 8.

Procedures

A main canal in United Irrigation District was one of several canals which was flown over with an air-borne thermal imager in Fall of 2001. The section of canal analyzed in this report consists of a 6.6 mile unlined (earth) segment and an 11 mile concrete-lined segment (Figure 1).

The thermal imagery was processed and 45 sites were identified as having possible leaks. The DMS Team visited and evaluated 11 these sites using a Site Evaluation Rating Procedure. Photographs were also taken to document the cause of the leaks. Additional information on procedures is included below.

The thermal sensor was provided and operated by Dr. Steve Mass, USDA-ARS Scientist in Lubbock. The thermal imagery was recorded on a standard VHS video tape. The air plane was provided by the USDA-ARS Remote Sensing Lab in Weslaco. Image processing was done by the District Management System Team, Agricultural Engineering Department, Texas Cooperative Extension.

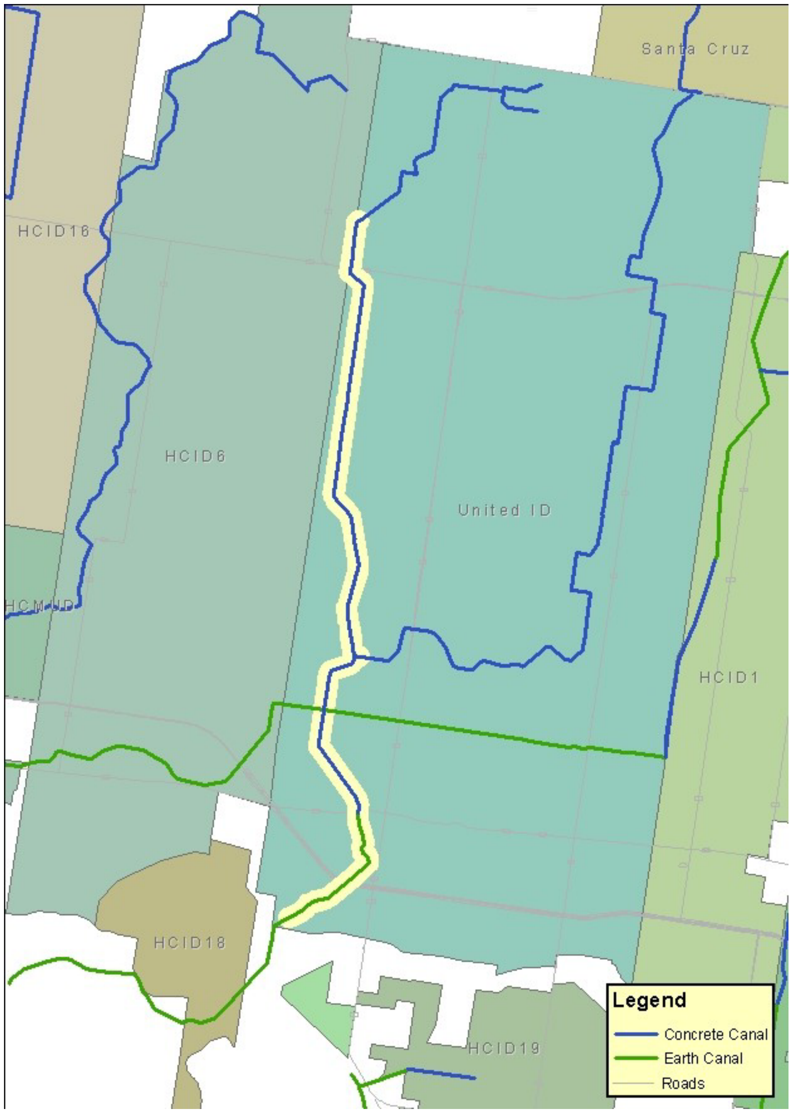


Figure 1. Map showing the main irrigation canal of United and areas for which thermal images were processed.

The study was conducted as follows:

1. Digitize the VHS video tape containing the thermal imagery;
2. Capture the frames of interest and enhance using image processing techniques;
3. Create a GIS map to locate each frame (or image) based on GPS coordinates;
4. Invert and overlay the processed images with DOQQ images to better identify the locations;
5. Go to the field with using the maps and overlaid DOQQ images as a guide;
6. Conduct field evaluation with pre-designed criteria (below); and
7. Complete the analysis.

The following criteria were developed and used to rate the conditions at each site:

- Wetness: 0. None visible 1. some 2. Strong
- Vegetation:
    - Grass – 0. None 1. some 2. Strong and thick
    - Trees – 0. None 1. some 2. Strong and big
    - Crops – 0. None 1. some 2. Strong
- Seepage: 0. None 1. Some 2. Severe
- Cracks: 0. None 1. some 2. Severe
- Holes: 0. None 1. some 2. Obvious and big

Results

Table 1 summarizes the results of the field evaluation performed for 11 of the 45 sites. Of the 11, 10 were found to have leakage problems. These results show that thermal imagery is very promising technology for remotely detecting leaks in canals.

Table 1. Field rating results of thermal imaging.

Site*	Type	Wetness	Grass	Trees	Crops	Seepage	Cracks	Holes	Total	Confirmed Leak
07	Earth	2	2	2	0	2	0	2	10	yes
08	Earth	2	2	2	0	2	0	2	10	yes
09	Concrete	0	2	0	0	1	1	0	4	yes
10	Concrete	0	0	0	0	1	1	0	2	no
11	Concrete	1	2	2	0	1	1	0	7	yes
12	Concrete	1	2	2	0	1	1	0	7	yes
13	Concrete	1	2	2	0	1	1	0	7	yes
40	Concrete	1	2	2	0	1	1	0	7	yes
43	Concrete	1	2	2	0	1	1	0	7	yes
44	Concrete	1	2	2	0	1	1	0	7	yes
45	Concrete	1	2	2	0	1	1	0	7	yes

* see Appendix I for coordinates of each site, and initial analysis of the thermal image. Shown on the images are areas that may be caused by leaks in the canal at that location. Detailed analysis of sites 7-10 are in the next section of this report.

Detailed Analysis - Examples

Site 1: an unlined (earth) canal segment

As seen in figure 2a, on one side of the canal (right side on the image) there is a wide strip which is likely a dirt road on the canal levee. On the same side beside the canal, an area showing the possibility of wetness or vegetation (mark circled on the right of the image). On the other side of the canal (left side on the image), there is another area of vegetation and/or wetness and a narrow dirt road (mark circled on the left of the image).

To help locate the site, the image was inverted and overlaid onto the DOQQ image (Fig. 2b). The results of the field rating were as follows:

- Wetness: 2
- Vegetation:
    - Grass – 2
    - Trees – 2
    - Crops – 0
- Seepage: 2
- Cracks: 0
- Holes: 2

Total: 10;

Photographs taken at this location show a large tree and the dirt road on the same side of the canal (Fig. 2c). Water appears to be flowing out of the canal through a large hole located near the tree. Figure 2d shows thick vegetation (grasses and bushes) with a narrow stripe of dirt road. The site evaluation matched very well our interpretation of the thermal imagery.

Conclusion: this canal segment has a severe seepage problem at this location caused by a hole in the canal..

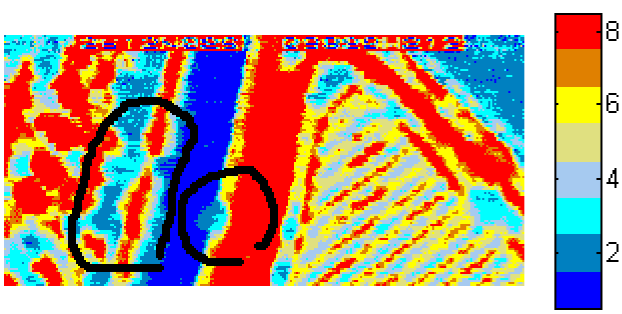


Figure 2a. Site 1 - Original processed image.

Figure 2b. Site 1 – Inverted image, overlaid onto the DOQQ.

Figure 2c. Photograph of Site 1 – an unlined canal segment with a hole in the embankment.

Figure 2d. Photograph showing dirt road on canal embankment at Site 1.

Site 2 - a lined (concrete) canal segment

As shown in Figure 3a, the thermal image shows two areas of wetness (mark circled on the image) on either side of the canal. Figure 3b shows the inverted image overlaid onto the DOQQ (figure 3b). The results of the field evaluation are as follows:

- Wetness: 1
- Vegetation:
    - Grass – 2
    - Trees – 2
    - Crops – 0
- Seepage: 1
- Cracks: 1
- Holes: 0

Total: 7

Site photographs (Fig. 3c-d) show a structure on the side of the canal which appears to be an abandoned gate through which water is flowing. As this is the only place along the canal with thick vegetation, the abandoned gate is likely the only source of the leak.

Conclusion: thermal imaging clearly identified the source of a significant leak being caused by an abandoned gate.

Figure 3a. Site 2 - Original processed image.

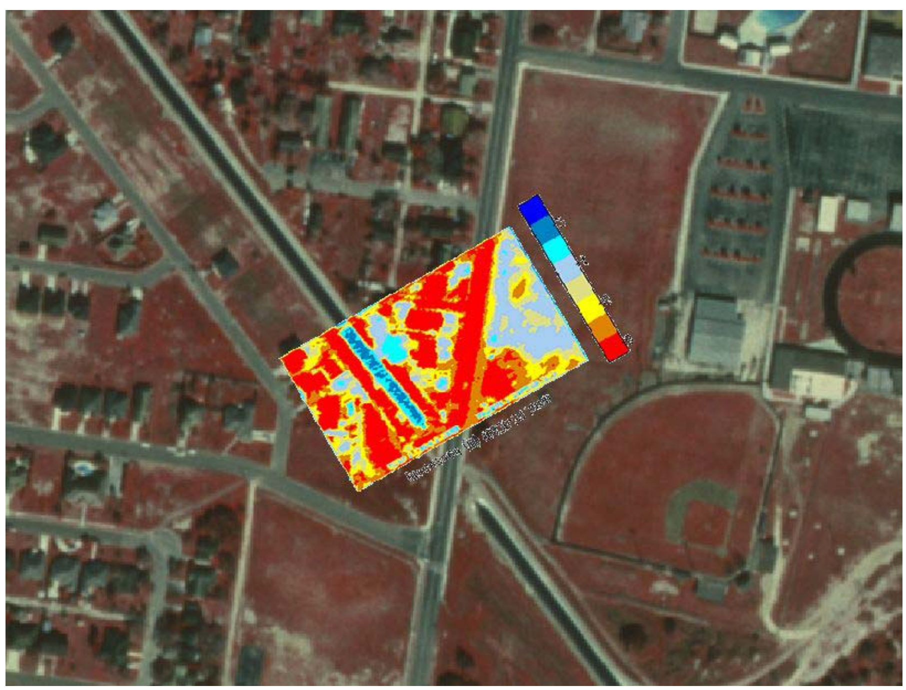


Figure 3b. Site 2 – thermal image inverted and overlaid onto the DOQQ.

Figure 3c. Site 2 – thick vegetation along the canal.

Figure 3d. Site 2 – an abandoned gate associated with the area of thick vegetation.

<u>Site 3 – a lined (concrete) canal segment with cracks</u>

As shown in figure 4a, there is likely a seepage area along one side of the canal (left side on the image). The rating of this site is as follows:

- Wetness: 0
- Vegetation:
    - Grass – 2
    - Trees – 2
    - Crops – 0
- Seepage: 0
- Cracks: 2
- Holes: 0

Total: 6

The field photograph (Fig. 4c) shows thick vegetation on the side of the canal having and many cracks. Some of the cracks are sealed but others are not. These unsealed cracks appear to be the cause of the seepage from this canal segment.

Conclusion: thermal imaging detected seepage caused by cracks in a canal.

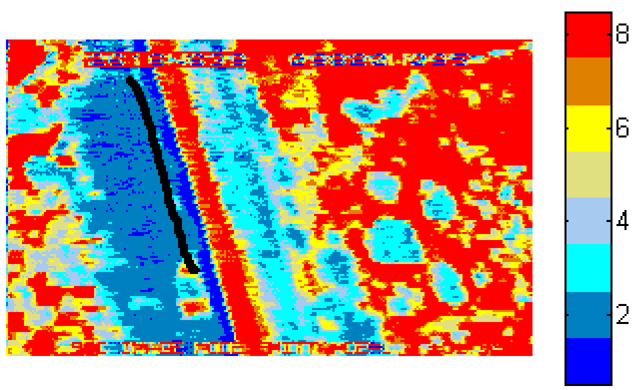


Figure 4a. Site 3 - Original processed image.

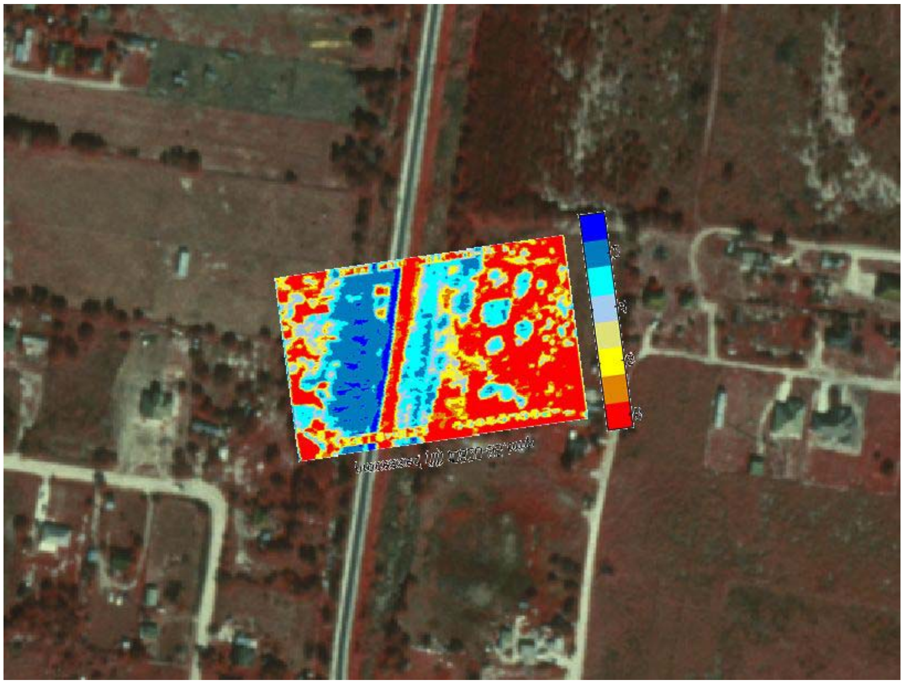


Figure 4b. Site 3 – Inverted thermal image, overlaid onto the DOQQ.

Figure 4c. Site 3 – showing cracks and thick vegetation on one side of the canal.

<u>Site 4 – a lined (concrete) canal segment</u>

Figure 5a shows a canal segment beside a baseball field. While there is no indication of vegetation or wet areas along this segment, there is something other than a dirt road (line-marked on the image). This image was inverted and overlaid on the DOQQ image (Fig. 5b). The rating results are as follows:

- Wetness: 0
- Vegetation:
    - Grass – 0
    - Trees – 0
    - Crops – 0
- Seepage: 1
- Cracks: 1
- Holes: 0

Total: 2

The photograph (Fig. 5c) shows some dead vegetations spread over the sides of the canal, but otherwise the conditions of the canal is good. This canal segment does not have a detectable leak.

Conclusion: this canal segment is unlikely to have a leak.

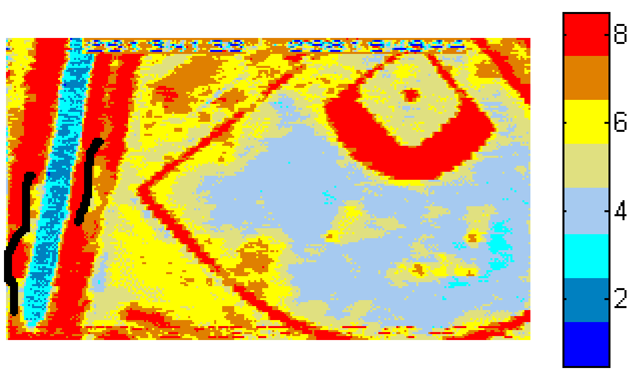


Figure 5a. Site 4 - Original processed image.

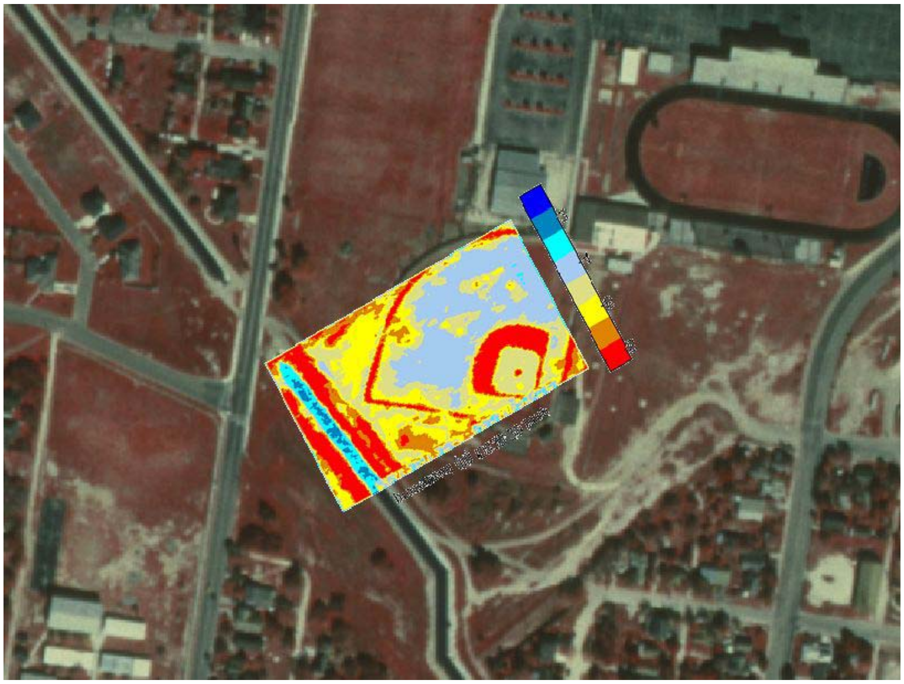


Figure 5b. Site 4 - inverted and overlaid onto DOQQ.

Figure 5c. Site 4 – Photograph showing the dead grass along the canal and that the canal segment is in good condition

Acknowledgements

DMS TEAM

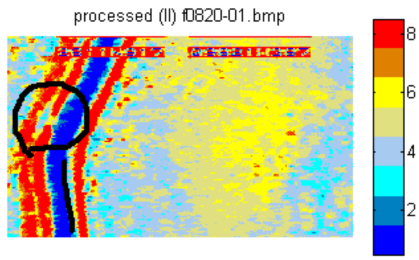
Support provided by the DMS (District Management System) team of:

Martin Barroso, Extension Agricultural Technician
Noemi Perez, Extension Agricultural Technician
Gabriel Ortega, Extension Assistant
Bryan Treese, Extension Assistant (former)
Daniel Wishard, Student Worker
Brock Faulkner, Student Worker

Appendix I

Images identified as possibly indicating seepage or wet areas along the canal segment investigated

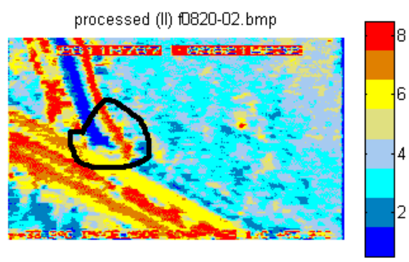
Site 1 - Image 01 at (2611N917, 09821W387)



Investigate:

- Leakage or thick vegetation at the circled spot
- Seepage, vegetation, or shadow at the lined area

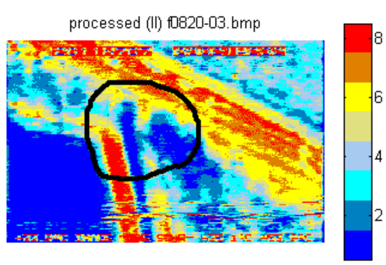
Site 2 - Image 02 at (2611N767, 09821W232)



Investigate:

Leakage at the circled spot

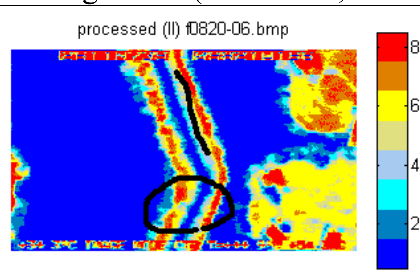
Site 3 - Image 03 at (2611N767, 09821W232)



Investigate:

Leakage at the circled spot

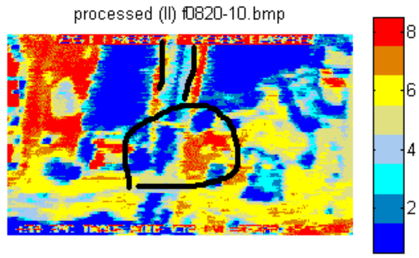
Site 4 - Image 06 at (2622N739, 09821W186)



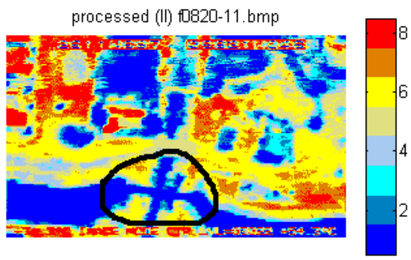
Investigate:

- Leakage or thick vegetation at the circled spot
- Seepage, vegetation, or shadow at the lined area

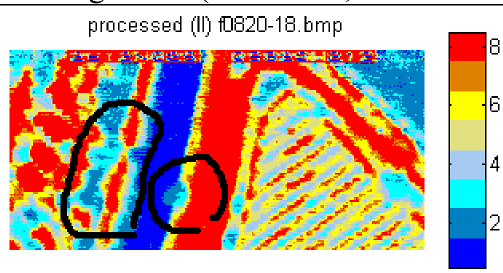
Site 5 - Image 10 at (2611N687, 09821W046)

	Investigate: • Leakage or thick vegetation at the circled spot • Seepage, vegetation, or shadow at the lined areas

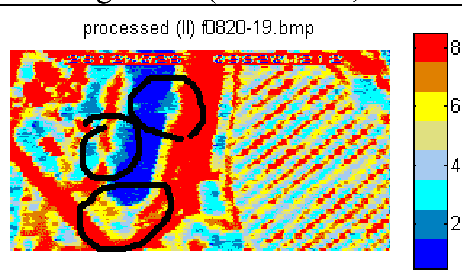
Site 6 - Image 11 at (2611N687, 09821W046)

	Investigate: Junction leakage at the circled spot

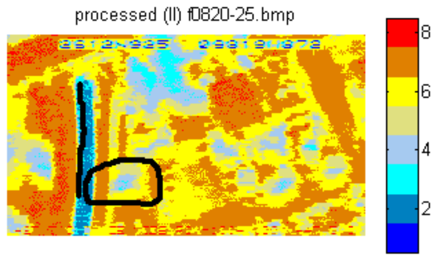
Site 7 - Image 18 at (2612N026, 09820W212)

	Investigate: Leakage or vegetation at the circled spots

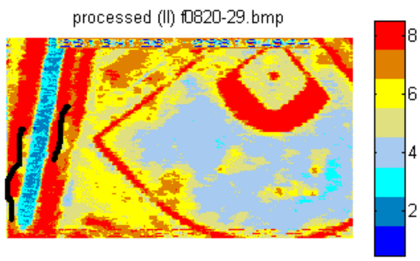
Site 8 - Image 19 at (2612N026, 09820W212)

	Investigate: Leakage or vegetation at the circled spots

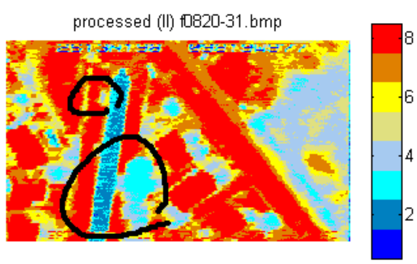
Site 9 - Image 25 at (2612N925, 09819W872)

	Investigate: • Leakage or thick vegetation at the circled spot • Seepage, vegetation, or shadow at the lined area

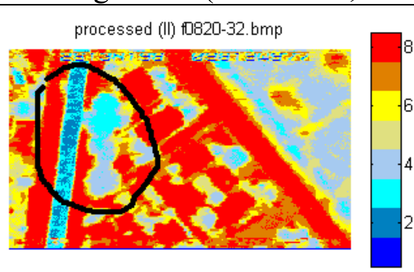
Site 10 - Image 29 at (2613N136, 09819W944)

	Investigate: Seepage, vegetation, or shadow at the lined areas

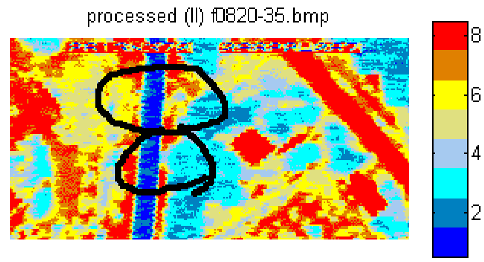
Site 11- Image 31 at (2613N198, 09819W977)

	Investigate: Leakage or thick vegetation at the circled spots

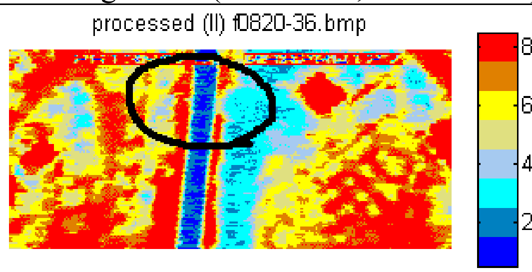
Site 12 - Image 32 at (2613N198, 09819W977)

	Investigate: Leakage or thick vegetation at the circled spot

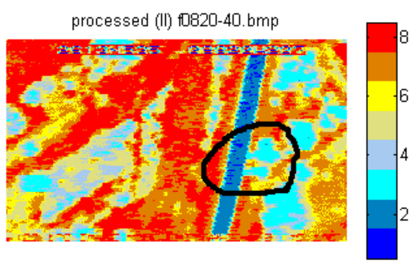
Site 13 - Image 35 at (2613N378, 09820W087)

	Investigate: Leakage or thick vegetation at the circled spots

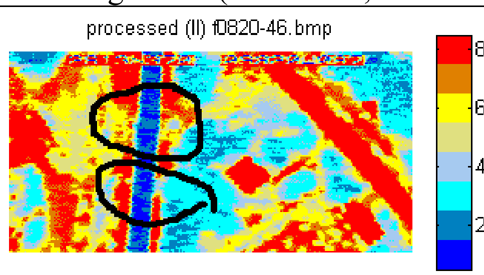
Site 14 - Image 36 at (2613N424, 09820W127)

	Investigate: Leakage or thick vegetation at the circled spot

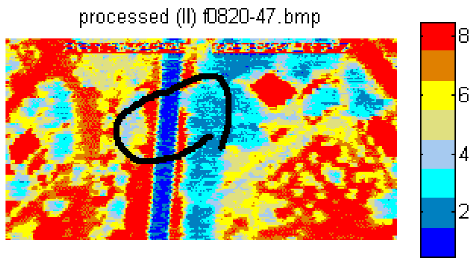
Site 15 - Image 40 at (2613N535, 09820W207)

	Investigate: Leakage or thick vegetation at the circled spot

Site 16 - Image 46 at (2613N370, 09820W087)

	Investigate: Leakage or thick vegetation at the circled spots

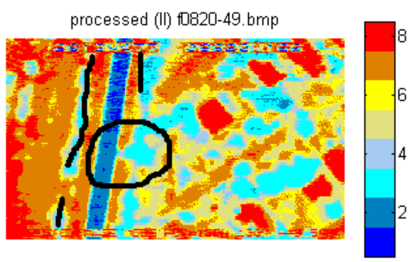
Site 17 - Image 47 at (2613N424, 09820W127)



Investigate:

Leakage or thick vegetation at the circled spot

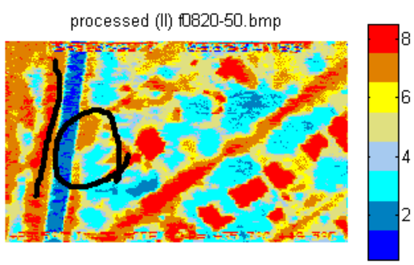
Site 18 - Image 49 at (2613N477, 09820W166)



Investigate:

- Leakage or thick vegetation at the circled spot
- Seepage, vegetation, or shadow at the lined areas

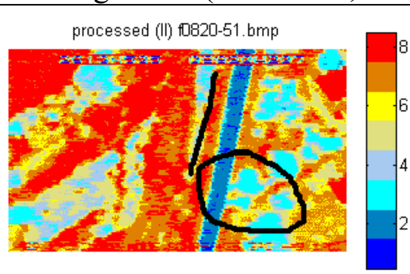
Site 19 - Image 50 at (2613N477, 09820W166)



Investigate:

- Leakage or thick vegetation at the circled spot
- Seepage, vegetation, or shadow at the lined area

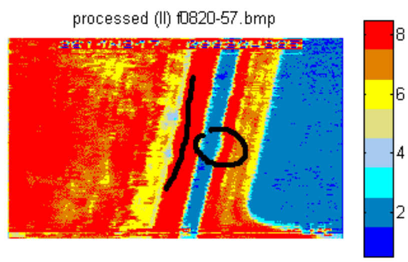
Site 20 - Image 51 at (2613N535, 09820W207)



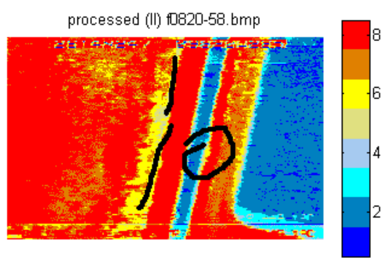
Investigate:

- Leakage or thick vegetation at the circled spot
- Seepage, vegetation, or shadow at the lined area

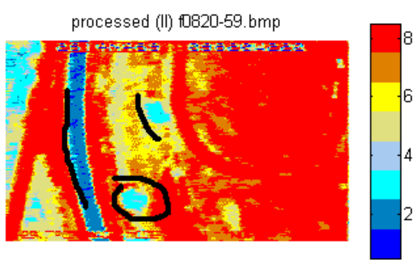
Site 21 - Image 57 at (2614N247, 09820W285)

	Investigate: • Leakage or thick vegetation at the circled spot • Seepage, vegetation, or shadow at the lined area

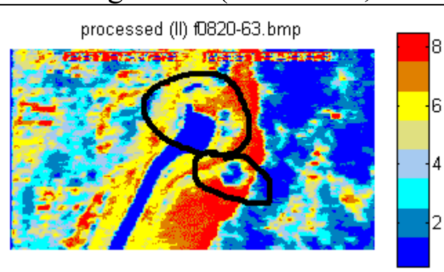
Site 22 - Image 58 at (2614N247, 09820W285)

	Investigate: • Leakage or thick vegetation at the circled spot • Seepage, vegetation, or shadow at the lined areas

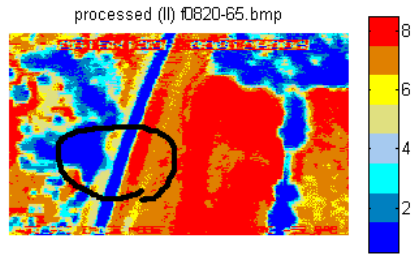
Site 23 - Image 59 at (2614N469, 09820W220)

	Investigate: • Leakage or thick vegetation at the circled spot • Seepage, vegetation, or shadow at the lined areas

Site 24 - Image 63 at (2615N029, 09819W983)

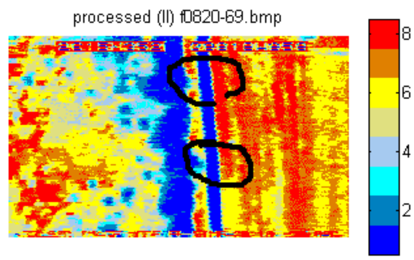
	Investigate: Leakage or thick vegetation at the circled spots

Site 25 - Image 65 at (2615N133, 09819W984)



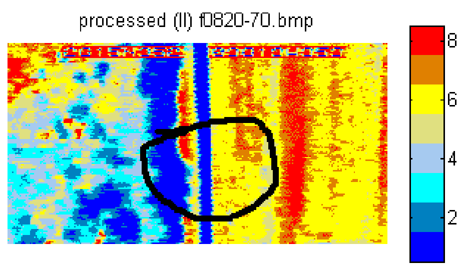
Investigate:
Leakage or thick vegetation at the circled spot

Site 26 - Image 69 at (2615N352, 09819W959)



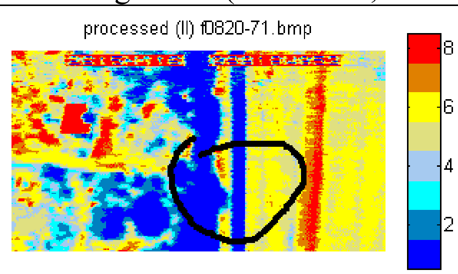
Investigate:
Leakage or thick vegetation at the circled spots

Site 27 - Image 70 at (2615N352, 09819W959)



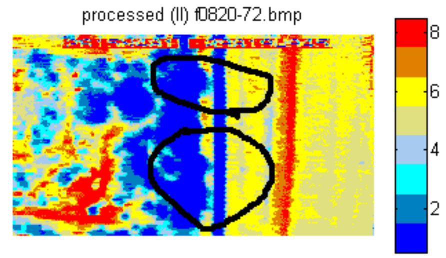
Investigate:
Leakage or thick vegetation at the circled spot

Site 28 - Image 71 at (2615N416, 09819W953)

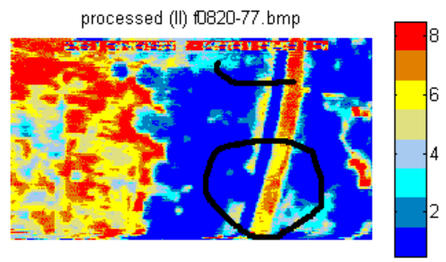


Investigate:
Leakage or thick vegetation at the circled spot

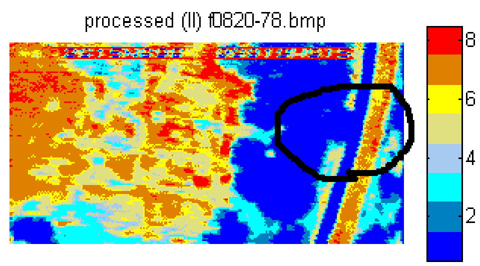
Site 29 - Image 72 at (2615N481, 09819W945)

	Investigate: Leakage or thick vegetation at the circled spots

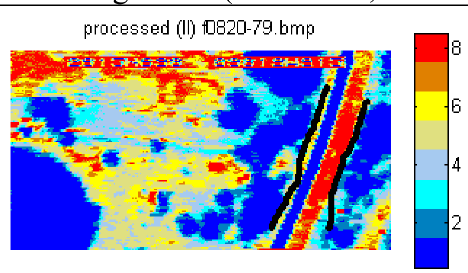
Site 30 - Image 77 at (2615N698, 09819W915)

	Investigate: Leakage or thick vegetation at the circled spots

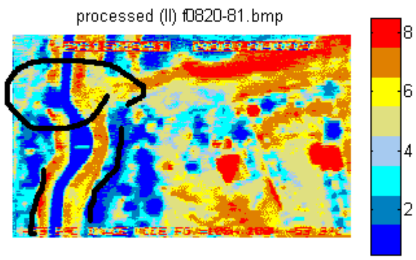
Site 31 - Image 78 at (2615N698, 09819W915)

	Investigate: Leakage or thick vegetation at the circled spot

Site 32 - Image 79 at (2615N698, 09819W915)

	Investigate: Seepage, vegetation, or shadow at the lined areas

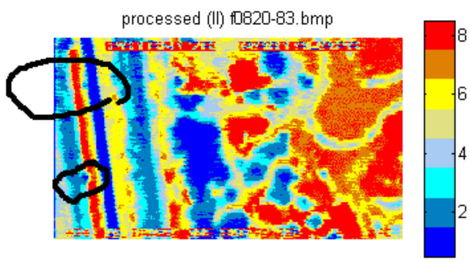
Site 33 - Image 81 at (2615N941, 09819W893)



Investigate:

- Leakage or thick vegetation at the circled spot
- Seepage, vegetation, or shadow at the lined areas

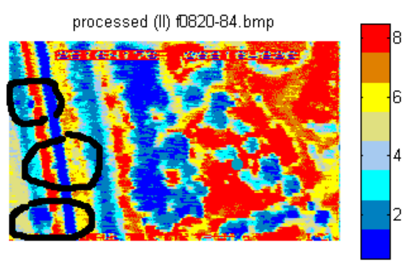
Site 34 - Image 83 at (2616N176, 09819W926)



Investigate:

Leakage or thick vegetation at the circled spots

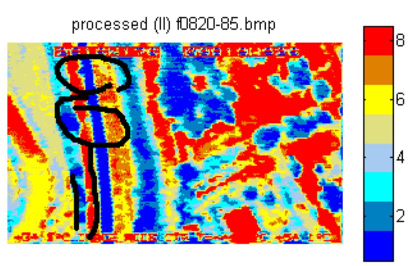
Site 35 - Image 84 at (2616N176, 09819W926)



Investigate:

Leakage or thick vegetation at the circled spots

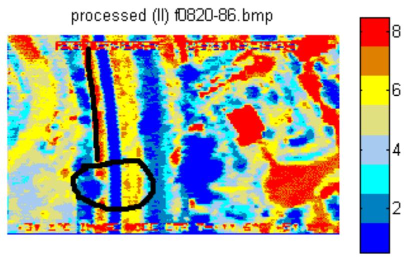
Site 36 - Image 85 at (2616N176, 09819W926)



Investigate:

- Leakage or thick vegetation at the circled spots
- Seepage, vegetation, or shadow at the lined areas

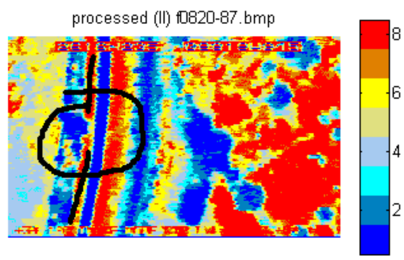
Site 37 - Image 86 at (2616N235, 09819W945)



Investigate:

- Leakage or thick vegetation at the circled spot
- Seepage, vegetation, or shadow at the lined area

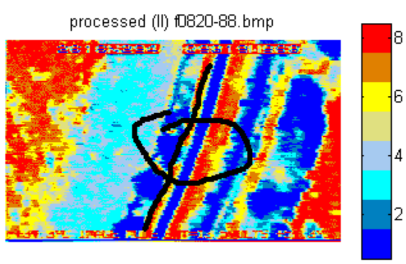
Site 38 - Image 87 at (2616N235, 09819W945)



Investigate:

- Leakage or thick vegetation at the circled spot
- Seepage, vegetation, or shadow at the lined areas

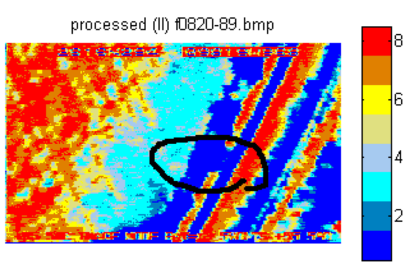
Site 39 - Image 88 at (2616N294, 09819W968)



Investigate:

- Leakage or thick vegetation at the circled spot
- Seepage, vegetation, or shadow at the lined areas

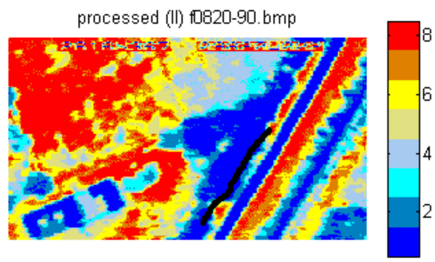
Site 40 - Image 89 at (2616N294, 09819W968)



Investigate:

Leakage or thick vegetation at the circled spot

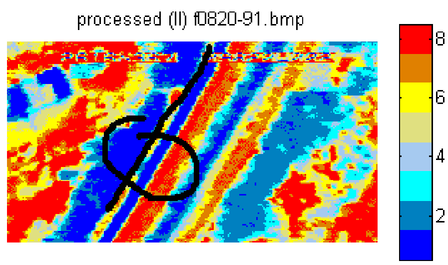
Site 41 - Image 90 at (2616N367, 09820W002)



Investigate:

Seepage, vegetation, or shadow at the lined area

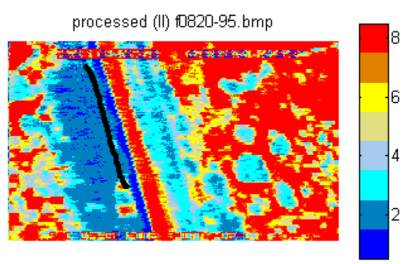
Site 42 - Image 91 at (2616N367, 09820W002)



Investigate:

- Leakage or thick vegetation at the circled spot
- Seepage, vegetation, or shadow at the lined area

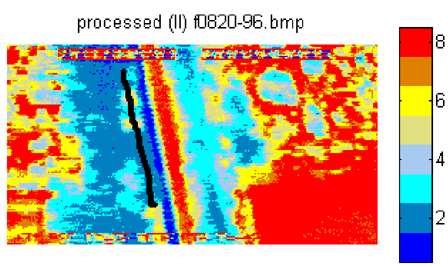
Site 43 - Image 95 at (2616N639, 09820W095)



Investigate:

Seepage, vegetation, or shadow at the lined area

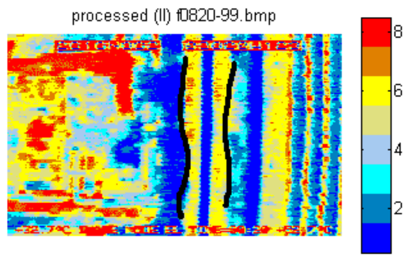
Site 44 - Image 96 at (2616N639, 09820W095)



Investigate:

Seepage, vegetation, or shadow at the lined area

Site 45 - Image 99 at (2616N862, 09820W123)

	Investigate: Seepage, vegetation, or shadow at the lined areas

Appendix II - Literature Review

Nells (1982) reported on a thermal infrared over flight made in 1979 of the North Unit Irrigation District of central Oregon. Equipment included a HRB Singer AN/AAS 14 optical-electronic scanning system mounted on a Mohawk OV-1 aircraft. The wavelengths used in the sensor system ranged from 8 to 18 μm. The thermal infrared imagery was taken of the main canal and portions of the lateral canal system. The main assumption used was soil moisture levels along the canal would be higher in areas of leaks and that soil moisture and conductivity influence the thermal characteristics of the soil which is visible in thermal images. According to Myer (1975), oscillations of temperature in a moist soil are less than in a dry soil area, since sites high in moisture cool slower after sunset and warm slower during the daytime. So, the net result was that moist sites (canal leakage areas) emitted more radiation during the evening hours and less radiation during periods of peak incoming solar radiation than low moisture sites.

Using a film viewing light table, micro-stereoscope, and density slicer system, Nells located thirty nine (39) possible leakages sites. Out of the 39 sites, twelve (12) were verified through field analysis as actual leakage sites, i.e. a 31% detection accuracy. In addition, during the field checking process, no other leakage sites were discovered beyond the 12 that were labeled on the imagery. Nell concluded that, although the detection accuracy was low, the amount of time saved by checking this limited number of sites rather than the entire canal system for leakage was tremendous.

Nell concluded that a remote sensing program of this type can be economical if organized at the appropriate operational scale. Thermal infrared over flights by irrigators on an individual basis would be too costly. If organized, however, at the irrigation district level, thermal infrared over flights could be cost effective. Misinterpretations were commonly cased by dense natural vegetation, farm canals or drainage ditches adjacent to the main canal, small holding ponds, and low depression areas of natural drainage. He suggested using color photography to supplement thermal imagery would significantly reduce misinterpretations.

Pickerial and Malthus (1998) used airborne multispectral remote sensing to determine leakage from rural aqueducts. Daedalus AADS 1268 Airborne Thematic Mapper (ATM) multispectral scanner remotely sensed data were obtained over the Vyrnwy Aqueduct, North West England. True color aerial photographic data were also obtained to aid image interpretation. Two known leaks were under study in a wheat field and in a recently harvested cereal crop. Analysis of the spectral profiles of Leaks 1 and 2 suggested that different indices and single bands are required in order to identify each leak. The spectral profile of Leak 1 suggested that a near-infrared to red ratio or derivative thereof may best highlight differences between the leak center and the surrounding plant canopy, while middle infrared wavebands appear less useful. Thus the Normalized Difference Vegetation Index (NDVI) successfully highlighted Leak 1 as distinct from its surrounding. Conversely, a near infrared to red ratio was less useful in accentuating Leak 2 from its surroundings.

In practice the middle infrared band successfully distinguished the leak. Thermal data taken from Band 11 of the ATM imagery were also examined for their ability to distinguish the leaks from their surroundings. The results were not encouraging. There was little in the way of significant temperature differences between the leaks and their surroundings. The information from this report is useful for canal leak detection.

An airplane-mount thermal scanner was used to measure irradiance in the 8- to 14-μm wavelength interval over an experimental site in the Lower Rio Grande Valley (LRGV) of Texas to obtain surface temperature and to delineate water-stressed and well-watered fields in large irrigated areas (Bartholic et al., 1972). In the experiment Remote Sensing, Inc. flew their Texas Instruments RS-14 scanner at 600 m over the experimental site. This scanner has a scanning rate of a 1 milliradian FOV (field of view) of 200 scans per sec. The resolution element was about 0.6 m square. The ground width of each scan was approximately 900 m. The scanner data were recorded on analog magnetic tape and on 70-mm film, making it possible to digitize the analog record for computer analysis. A relation between film density by a microdensitometer, gray scale step voltage, and blackbody temperature was established. Based on this relationship, different temperatures were obtained for various test plots. Through comparison with ground truth data, it was concluded that thermal imagery offers potential as a useful aid for delineating water-stressed and nonstressed fields, evaluating uniformity of irrigation, and evaluating surface soil water conditions. Bartholic's report may be worth for us to study further because the approaches and test areas are similar to our project for water saving in the LRGV.

Ray D. Jackson surveyed airplane and satellite remote sensing for farm management in 1984. This survey pointed out that early flights with multispectral scanners over agricultural targets clearly showed that emitted thermal infrared radiation was an indicator of the water content of soil and several visible and near-infrared bands could readily distinguish vegetation. Some people used radiometers that measured emitted radiation in the 8-14 □m waveband to infer the temperatures of the plants and soils, while others used radiometers that measure in the visible and the near-infrared wavelengths.

Shih and Jordan (1993) discussed the use of Landsat thermal infrared data and GIS (geographic information system) in soil moisture assessment. In this report Landsat satellite Thematic Mapper ™ (TM) data were explored as an alternative for monitoring regional soil moisture conditions. In a demonstration of Landsat-TM based soil moisture estimation for Lee County in southeastern Florida, the thermal-IR data from TM band 6 (10.42-11.66 □m) were overlain onto four land-use categories using a GIS system and the thermal infrared data were used to access four qualitative soil moisture conditions within each land-use category. The range (173-211) of thermal infrared digital numbers for the TM image was divided into four ground temperature difference groups for analysis. The processed TM thermal infrared image was overlain onto the TM land-use image. This combination provided the capability of assessing the area extent of radiant-temperature differences (corresponding to soil moisture conditions) within each land-use category. This report is interesting in thermal image processing and labeling for soil moisture assessment.

The above reviewed reports summarize methods and applications of thermal imagery for canal leak detection. Other studies include Nellis, 1985; Moran, 1994; Clarke, 1997; and Bastiaanssen et al., 2000.

REFERENCES

Bartholic, J. F., L. N. Namken, and C. L. Wiegand. 1972. Aerial thermal scanner to determine temperature of soils and of crop canopies differing in water stress. *Agronomy Journal.* 64 (September-October): 603-608.

Bastiaanssen, G. M., D. J. Molden, and I. W. Makin. 2000. Remote sensing for irrigated agricultural: examples from research and possible applications. *Agricultural Water Management.* 46(2000): 137-155.

Clarke, T. R. 1997. An empirical approach for detecting crop water stress using multispectral airborne sensors. *HortTechnology.* 7(1): 9-16.

Jackson, R. D. 1984. Remote sensing of vegetation characteristics for farm management. *SPIE* 75: 81-96.

Moran, M. S. 1994. Irrigation management n Arizona using satellite and airplanes. *Irrig. Sci.* 15: 35-44.

Myer, V. I. 1975. Crops and soils. In *Manual of Remote Sensing*, American Society of Photogrammetry, Falls Church, Virginia, pp. 1715-1813.

Nells, M. D. 1982. Application of thermal infrared imagery to canal leakage detection. *Remote Sensing of Environment.* 12: 229-234.

Nells, M. D. 1985. Interpretation of thermal infrared imagery for irrigation water resource management. *Journal of Geography.* January-February: 11-14.

Pickerill, J. M. and T. J. Malthus. 1998. Leaks detection from rural aqueducts using airborne remote sensing techniques. *Int. J. Remote Sensing.* 19(12): 2427-2433.

Shih, S. F. and J. D. Jordan. 1993. Use of Landsat thermal-IR data and GIS in soil moisture assessment. *Journal of Irrigation and Drainage Engineering.* 119(5): 868-879.