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FINAL REPORT  
LANDSAT TM IMAGE DATA QUALITY  
ANALYSIS FOR ENERGY-RELATED  
APPLICATIONS



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FINAL REPORT  
LANDSAT TM IMAGE DATA QUALITY  
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August 13, 1985

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ABSTRACT

This project represented a no-cost agreement between National Aeronautic Space Administration Goddard Space Flight Center (NASA GSFC) and the Pacific Northwest Laboratory (PNL). PNL is a Department of Energy (DOE) national laboratory operated by Battelle Memorial Institute at its Pacific Northwest Laboratories in Richland, Washington. The objective of this investigation was to evaluate Landsat's thematic mapper (TM) data quality and utility characteristics from an energy research and technological perspective. Of main interest was the extent to which repetitive TM data might support DOE efforts relating to siting, developing, and monitoring energy-related facilities, and to basic geoscientific research. The investigation utilized existing staff and facility capabilities, and ongoing programmatic activities at PNL and other DOE national laboratories to cooperatively assess the potential usefulness of the improved experimental TM data.

The investigation involved 1) both Landsat 4 and 5 TM data, 2) qualitative and quantitative use consideration, and 3) NASA P (corrected) and A (uncorrected) CCT analysis for a variety of sites of DOE interest. Initial results were presented at the Landsat Investigator's Workshops and at specialized Landsat TM sessions at various conferences (1-3)(a). More recent findings are contained in papers prepared for the final Landsat Image Data Quality Analysis (LIDQA) Symposium(4, 5)(a). All results substantiate the consistent performance of the Landsat TM system, and the added application value associated with the increased spectral and spatial capabilities of the TM. Such data are being incorporated into several DOE programs involving continental scientific drilling, acid rain, wind energy, contaminant transport,

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(a) Copies attached to original only.

geologic studies, and environmental/ecological research. Moreover, remote sensing research is presently in progress using both DOE and NASA funds to develop additional analytical techniques which will enhance the scientific and programmatic exploitation of repetitive, high-resolution, multispectral satellite data.

## INTRODUCTION

This is the final report summarizing the participation of the Pacific Northwest Laboratory (PNL)<sup>(a)</sup> in the National Aeronautics and Space Administration Goddard Space Flight Center (NASA-GSFC) Landsat Image Data Quality Analysis (LIDQA) Program. Under a no-cost agreement (NASA Order No 5-12402C), NASA acquired and provided selected Landsat thematic mapper (TM) data requested by PNL to support basic research efforts in progress for the Department of Energy's (DOE's) Office of Basic Energy Sciences (OBES). The goal of this continuing research is to develop advanced and effective computer techniques for analyzing combinations of remote sensing and geoscience data that can be integrated into research and technology programs of direct interest to the DOE. In turn, PNL's findings, relative to the quality and potential use of the experimental TM data analyzed, would be provided to NASA. Accordingly, this final report describes and documents the results of the two-year (1983-1984) LIDQA investigative effort. The scope of research activities included, principally:

- upgrading computer hardware and software at PNL, as necessary, to support processing and analyzing TM data
- evaluating the quality and the energy-related potential utility of the analyzed TM data
- publishing relevant findings and conclusions.

This final report contains three sections highlighting activities and results associated with each activity category. Details are contained in the referenced publications prepared in support of the cooperative effort.

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(a) Operated for the U.S. Department of Energy by Battelle Memorial Institute.

## IMAGE PROCESSING/COMPUTER SOFTWARE IMPROVEMENT

The addition of a 6250 tape drive to the existing PNL interactive image processing/analyzing system was the only computer hardware upgrade required to effectively process and analyze the Landsat TM-CCT data. However, several new and/or improved analytical programs (e.g., Principal-Component, Intensity-Hue-Saturation, etc.) were added to upgrade the system's image enhancement, spectral characterization and classification, and change-detection functions for general usage with the new seven-band TM data configuration. This included specially developed interactive analytical programs to accommodate both qualitative and quantitative TM analysis efforts<sup>(1)</sup>. A noteworthy problem area from a user perspective was the occasional difficulty encountered in reading some of the NOAA TM CCTs (6250 bpi) which required transporting the tapes to other facility locations having different tape drive units. In addition, not having the option to procure TM data in total scene format did result in extensive user reprocessing of multi-quadrant data to accommodate study areas that straddled or covered more than one quadrant.

### TM DATA QUALITY AND UTILITY ASSESSMENTS

As agreed, NASA provided PNL with a variety of TM scenes in both A tape (uncorrected) and P tape (corrected) formats for both day- and night-time acquisitions for selected DOE study sites of interest. In turn PNL analyzed representative TM data sets to help NASA determine TM system performance and to assess both potential qualitative/subjective and quantitative utilization of TM data for DOE interests.

#### QUALITATIVE RESULTS

##### Multispectral/Multitemporal Studies

Initial LIDQA efforts at PNL involved applying existing and newly developed interactive analytical programs to the digital seven-band TM data to ascertain the image quality and their potential DOE utility of the experimental data. With the exception of the banding that appeared in several of the earlier

Landsat 4 images, the TM data provided by NASA-NOAA were consistently of excellent quality.

The ability to generate enhanced, multiband natural color composites (bands 1, 2, and 3) and tailored thermal color composites (bands 4, 7, and 6 or bands 1, 4, and 6) from the TM data adds greatly to the potential qualitative value of satellite multispectral data. Moreover, the increased spectral and spatial capabilities were found to substantially improve the change-detection value of repetitive (multitemporal) TM data for monitoring changes in natural and cultural features of user interest.

The high-geometric accuracy of pixel locations and the band-to-band registrations of the TM images analyzed proved extremely useful in multitemporal (change-detection) and multisource (data merger) experiments described below. In addition, the geometric control between visible and non-visible (thermal) bands was found to provide one approach for minimizing mixed-pixel efforts encountered in using the lower-resolution (120 m) band 6 data.

#### Thermal Studies

Prior PNL analysis of thematic mapper simulator (TMS) data indicated that thermal plumes in surface waters used for power-plant cooling would be discernable in TM thermal (band 6) data. This use was readily confirmed during initial analysis of day- and night-time TM band 6 data for reactor cooling ponds and streams at DOE's Savannah River Plant in Aiken, South Carolina. Graphics (black and white and color) illustrating this qualitative TM use potential have been included in several PNL presentations and publications (1-3). Thematic mapper data for this site were also used to demonstrate how low-resolution (120 m) TM band 6 data could be effectively merged with high-resolution (2-10 m) aircraft color infrared (IR) and multispectral scanner data to improve the subjective interpretation of TM band 6 data. Moreover, the integration of multitemporal acquisitions illustrated the potential value of the repetitive TM data for monitoring the changes in the spatial distribution of the thermal patterns(1-3).

#### Geotechnical Site Assessments

Major emphasis in the PNL LIDQA investigation was on determining the extent that TM data could be enhanced, registered, and merged with topographic and

geologic data to aid in geoscientific site assessments. Figures 1-3 represent a series of experimental (demonstration) graphics for the Valles Caldera area in New Mexico, which is being evaluated as a candidate deep-drilling site under the ongoing multi-agency (DOE, NSF, USGS) Continental Scientific Drilling Program (CSDP). Similar multisource composites using NASA-supplied TM data as the reference base are being prepared for other CSDP sites as well (viz. Long Valley, California and Salton Sea, California).

More recently software programs have been developed that make it possible for the computer to generate ground-level views of Landsat data in contrast to the conventional vertical view. This capability is illustrated in Figure 4 where combinations of Landsat TM topographic and geologic data for the Valles Caldera site are transposed to produce a field-geologist's view. This capability is expected to significantly improve the geoscientific value of TM based, multi-source products.

#### Geologic Studies

Multitemporal (seasonal) TM data from Landsat 4 and 5 for the Nevada Test Site (NTS) have been extensively processed and analyzed to determine the significance of the improved spectral and spatial capabilities of TM data to geologic remote sensing applications. Figure 5 shows the comparative results of applying various online image analytical techniques to produce TM composites of NTS to enhance different geologic features or rock types.

During this NTS experiment, advanced computer techniques were developed and applied to correct for topographic-induced shading on TM surface reflectance and to perform topographic analysis to define crustal fracture zones as aids to geologic studies. These techniques require the use of only digital terrain and TM data. The analytical techniques have been successfully applied to the Paiute Ridge Quadrangle in Nevada, demonstrating the increased utility of the techniques developed and improved TM data to geologic studies. Figure 6 shows the results of correcting TM band 7 data for topographic shading effects. Figure 7 shows how the TM composite closely matches the available USGS geologic map of the study site (after reflectance reduction and decorrelation stretch have been applied). A detailed description of this TM experiment and associated results is contained in the paper to be presented at the final LIDQA conference<sup>(4)</sup>.



## QUANTITATIVE RESULTS

### Temperature Estimates

The high-thermal sensitivity of TM band 6 [(NE T) = 0.5°K] combined with its high spatial resolution (120 m) provide users with the possibility of determining small temperature differences (relative and absolute) in localized areas required for numerous applications. However, the evaluation of the quantitative potentialities of band 6 data require the validation of the satellite measurements with respect to ground truth or "measured temperature." In addition, such quantitative analysis requires considerations be given to system calibration constants, tape pre-processing factors, mixed-pixel effects and atmospheric influences.

As a follow-on to the qualitative analysis which demonstrated that repetitive, high-resolution TM band 6 data can be used to monitor thermal plumes in surface waters used for reactor cooling, we also made a preliminary assessment of the quantitative potentialities of the band 6 radiometric data. Preliminary findings describing initial but highly successful Landsat 4 results associated with estimating uncorrected surface water temperatures were previously published<sup>(1-3)</sup>. More recent and more detailed research has involved the analysis of day- and night-time TM band 6 data in both corrected (P tape) and uncorrected (A tape) formats as noted in Table 1.

TABLE 1. Landsat 4 and 5 Thematic Mapper (Band 6) Data Analyzed

<u>Study Site</u>	<u>Path/ Row</u>	<u>Date</u>	<u>ID</u>	<u>Comments</u>
1) Par Pond (Aiken, SC)	17/37	8/28/82	40034-15270	P tape only
	116/207 (night)	12/24/82	40161-02481	P tape only
	17/37	5/05/84	50065-15274	A & P tapes
	17/37	12/31/84	50305-15303	A & P tapes
2) Columbia River (Richland, WA)	137/216 (night)	6/15/84	50106-05014	A & P tapes
	44/28	7/04/84	50126-18121	A & P tapes

The results of these analyses are described in the paper entitled "Opportunities and Difficulties Associated with Using Landsat Thematic Mapper Data for Determining Surface Water Temperatures"<sup>(5)</sup> which was presented at the NASA LIDQA Final Symposium and is attached.

In summary, results of quantitative studies are reported for two study sites: 1) a reservoir reactor cooling system (PAR Pond) at the Department of Energy's (DOE) Savannah River Plant in Aiken, South Carolina (Figure 8), and 2) the Columbia River adjacent to the DOE's Hanford site in southeastern Washington state (Figure 9). Differences between Landsat-derived surface water temperatures and ground truth values before and after correcting for atmospheric effects (using LOWTRAN) are described. The results substantiate the consistent performance of the Landsat TM thermal sensor for providing potentially useful estimates of relative and absolute temperatures for large water bodies within and between TM scenes. In addition, technical difficulties encountered that currently limit routine use of such data for environmental monitoring, such as sensor calibration and atmospheric effects are addressed in the paper and are briefly summarized below.

As indicated in the attached paper, it is important for users desiring absolute temperatures and/or high temperature calibration to examine data from the radiometrically corrected A-tape rather than the P-tape, which is both radiometrically and geometrically corrected. Our experience indicates that for elevated temperatures or high digital counts there can be a difference of as much as 12 counts (5%) between the two tapes, which can translate into  $\pm 2^\circ\text{K}$  in the blackbody temperature inversion procedure. Also the mixed-pixel problem becomes very important when investigating temperatures near the boundaries between objects due to the lower resolution of the thermal band (120 m) versus the higher resolution of the visible bands (30 m).

An important question addressed, yet to be answered unequivocally, is the nagging problem of TM sensor radiance calibration. Since the data from the sites included not only Landsat 4 data but also Landsat 5, it was necessary to consider two different calibration curves as published by Lansing and Barker [1983] for pre- and post-outgas periods for TM 4 and the relative sparse calibration information on TM 5 by Marchant and Barker [1983]. The uncorrected

temperatures determined using these calibration data, and assuming no atmospheric effects over the sites, provided the 'best' values most being within about  $\pm 3^{\circ}\text{C}$  of measured ground values.

Because the atmosphere does affect the radiance recorded by the satellite, it must be considered in user applications such as estimating global aerosol effects. However, again confusion arises, when utilizing the LOWTRAN5 code, to describe the transmissivity and path radiance of the modeled atmosphere. In order to compare predicted temperatures after correction, several models were inputted, including meteorological radiosonde data at varying distances from the study sites to obtain "corrected" temperatures. These inputs, however, in general moved the estimated values farther away, indicating that the predicted, corrected temperatures by use of the code was higher than ground truth.

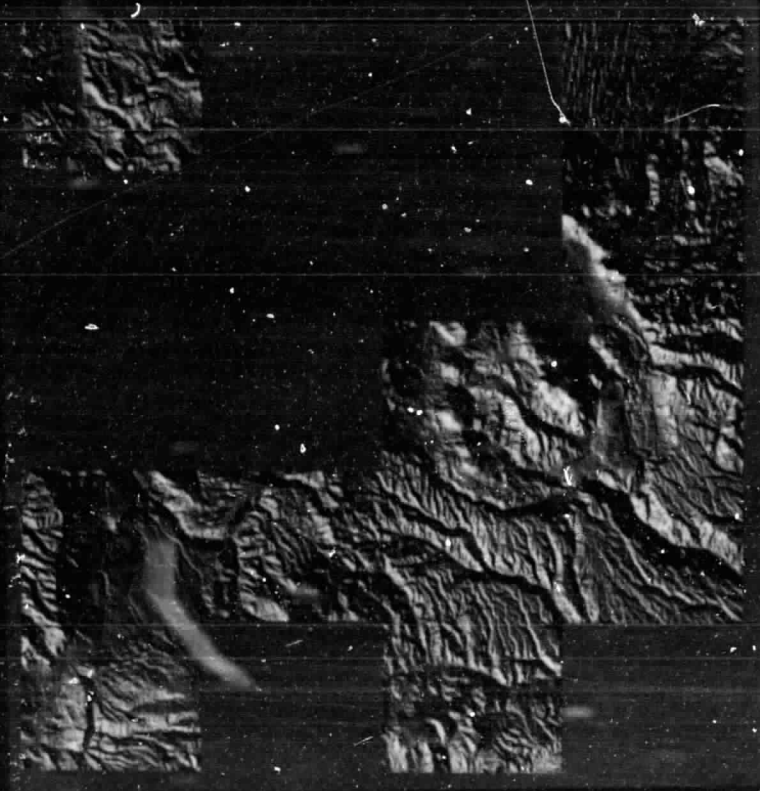
Since the NASA published TM calibration paper [Lansing & Barker, 1983] used a maritime aerosol model of 23 km and 5 km in a calibration correctional study of Landsat 4 data, by using the LOWTRAN5 code, a high and low maritime aerosol model was performed on our data. The values obtained once again moved the satellite-determined temperatures even farther from the ground truth. Again the no-aerosol, atmospheric-corrected values were nearest the values obtained at the surface of the large bodies of water being measured. In conversations with other Landsat investigators the fault seems to lie in the initial calibration equation for the sensor itself in converting from digital counts to radiance rather than the model codes. This is especially true with Landsat 5 data.

In the thermal band 6, the atmospheric effects caused by molecular, ozone, and Rayleigh scattering/absorption are practically zero; this is one of the reasons for choosing the 10.5  $\mu\text{m}$  to 12.5  $\mu\text{m}$  band. Of course, water vapor absorption/emission is still important but is addressed by the LOWTRAN5 code. A question arises as to the validity of the code in the thermal infrared where the concepts used as extensions from the visible may not be valid, especially in specifying a visibility parameter for visual bands and then extrapolating into the thermal infrared. A further study will address this potential problem.

**Develop and Test Digital Techniques for Combining High-Resolution (30 meter) Landsat and DEM Data**  
**Study Site: Valles Caldera, N.M. (CSDP Site)**



**Landsat 5 TM Bands 1, 7 and 4**



**Composite of 7.5 min. Shaded Topography Data**

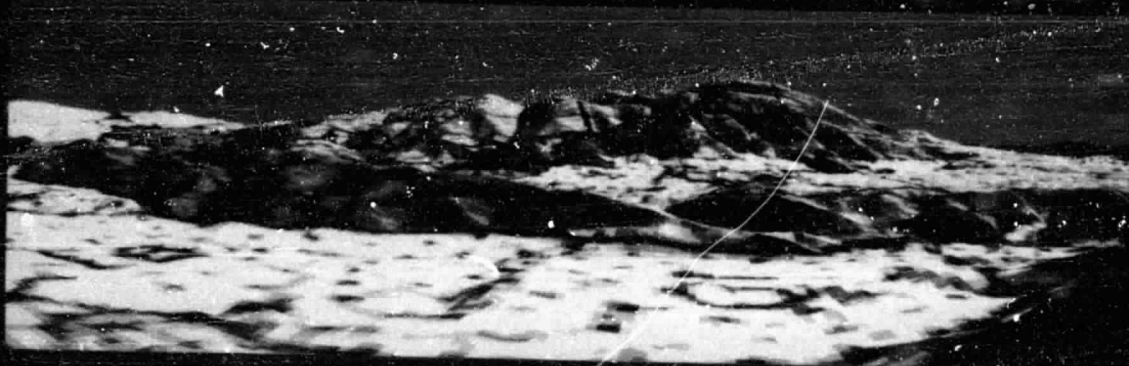
**FIGURE 1.** Oblique View of Enhanced Landsat TM Composite and Shaded, High-Resolution Topographic Data.



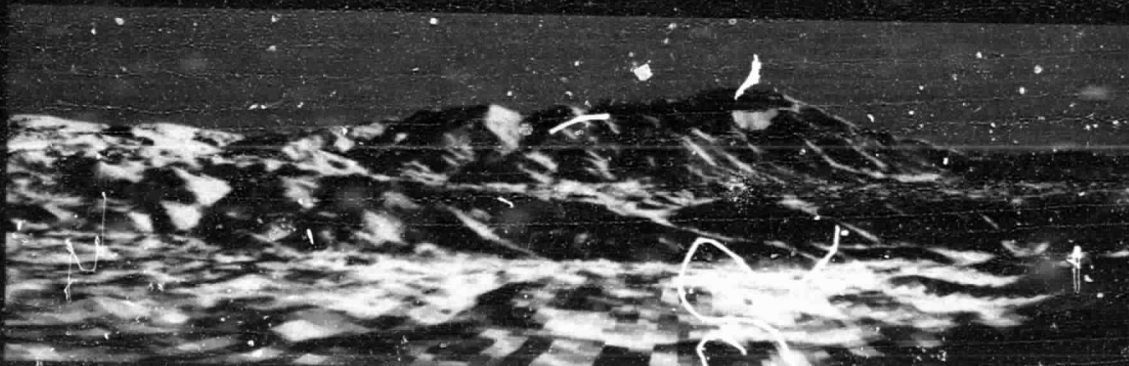
FIGURE 3. Oblique View of Valles Caldera Geologic Map Registered With 30 m Topographic Data.



# A Field Geologist's Perspective (View Looking East From Fenton Hill)



Geology and Topography Combined



Landsat 5 and Topography Combined



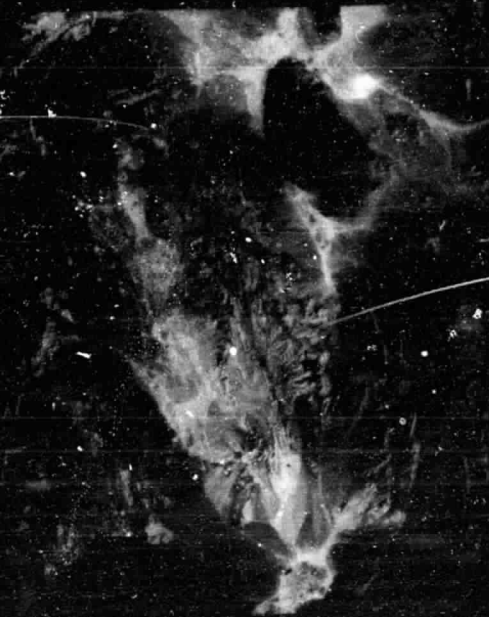
35 mm Color Photograph

FIGURE 4. Comparison of Computer Generated Ground-level Views of Geology and Landsat With a Color Photograph for Valles Caldera, NM site.

# Evaluation of Landsat Thematic Data for Geologic Studies Study Site: Nevada Test Site



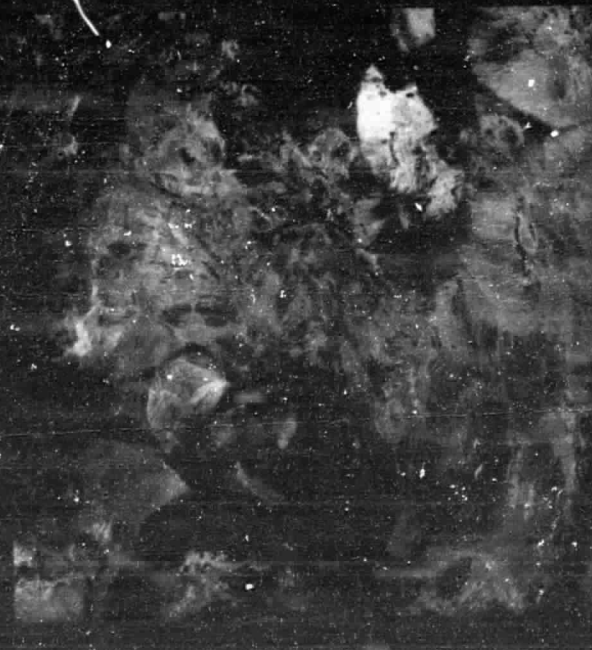
**Visible Bands**



**Decorrelation Stretch**



**Principal Components**

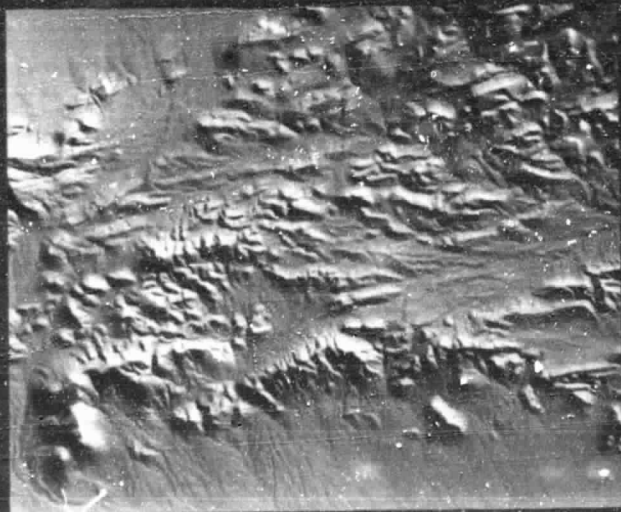


**Band Ratio**

FIGURE 5. Graphic Comparing PNL Technique for Enhancing TM Data For Geologic Studies.



Reduction of Topographic Shading Effects to Improve Lithologic Interpretations  
and Mapping Using Landsat TM Data. Study Site: Nevada Test Site-  
Paiute Ridge Quadrangle



Simulated Surface Reflectance



Registered Landsat TM Band 7



TM Band 7 with Shading  
Removed

FIGURE 6. Illustration of Techniques Developed to Improve Geologic Uses of TM  
Data by Reducing Topographic-Shading Effects.



**Comparison of Research Results with Registered  
Geologic Map Study Site: Nevada Test Site-  
Paiute Ridge Quadrangle**



**Reflectance-Reduction Plus  
Decorrelation Stretch**



**USGS Geologic Map Paiute  
Ridge Quadrangle**

FIGURE 7. Comparison of Corrected TM Composite with USGS Geologic Map.

L/S 5/5/84 (DAY)  
PATH 17 / ROW 37  
ID: 50065-15274

PNL

N

NORTHERN ARM

REACTOR

CANAL POND

SURFACE TEMPERATURE MEASUREMENT \*

SOUTHERN ARM

PAR POND

L/S THERMAL COMPOSITE

BAND1:BLUE BAND4:GREEN BAND6:RED

FIGURE 8. Portion of Landsat 5 TM Band 6 Image Showing Par Pond Study Site (Aiken, SC) and Ground Truth Data Location (Southern Arm).

COLOR PHOTOGRAPH

L/5 JULY/4/84 (DAY)  
PATH 44 / ROW 28  
ID: 50126-18121

PNL

N

COLUMBIA RIVER

\* SURFACE MEASUREMENT  
(NORTHERN)

HANFORD SITE

5.2 km

SURFACE MEASUREMENT (SOUTH) \*

RICHLAND WASH

L/5 TM COLOR COMPOSITE

BAND4:RED BAND3:GREEN BAND1:BLUE

FIGURE 9. Portion of Landsat 5 TM Band 6 Image Showing Columbia River Study Site (South-eastern Washington State) and Northern and Southern Ground Truth Location.



## CONCLUSIONS

- With few exceptions, the experimental TM data acquired for DOE study sites by NASA-GSFC were consistently of high radiometric and geometric quality. The improved spectral and spatial resolutions of the high-quality TM data coupled with existing and improved multispectral data analysis programs at PNL produced qualitative and quantitative research results during the LIDQA investigation that have basic scientific and application potential of significance to DOE.
- Under LIDQA, several favorable qualitative use possibilities were examined, demonstrated, and documented. Major among these were 1) opportunities for monitoring selected energy-related sites and activities based on the change-detection capability inherent in the digital, multi-temporal TM data and 2) improvements in geotechnical and geoscientific studies resulting from multi-source digital data fusion possibilities (e.g., TM, topographic, and geologic data).
- Quantitative studies during LIDQA participation were limited to TM thermal (band 6) use considerations. Results obtained strongly support the use of such satellite radiometric data (even when uncorrected) for estimating surface temperatures and temperature differences of large water bodies.
- Although some progress has been made, much uncertainty remains relating to optimum procedures for handling sensor calibration, preprocessing, emissivity, atmospheric and mixed-pixel factors encountered during our experiments to use band 6 data. These factors represent topics for follow-on research currently in progress at PNL.

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