NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-803

Volume I

Landsat Follow-On: A Report by the Applications Survey Groups

Executive Summary

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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

December 15, 1976

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Executive Summary

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PREFACE

This survey was conducted by the Space Sciences Division of the Jet Propulsion Laboratory for the Office of Applications of the National Aeronautics and Space Administration.

ACKNOWLEDGEMENTS

The users who contributed to this report are listed in Appendix E with identification of their discipline group. Further information on each contributor is in the contributor's respective discipline part. The chairmen of the groups are from the user community and are as follows:

Mineral and Petroleum Exploration (MP): Dr. Robert Vincent
Inland Water Resources (IW): Dr. Robert Ragan
Land Inventory (LI): Mr. Charles Parrish
Agriculture (A): Dr. Ernest Hardy

The bulk of the material in this study was provided by the members on a voluntary basis. The amount of material and time invested by each member is, in itself, indicative of the concern and need for user participation in a Landsat program. The group chairmen coordinated their groups' activities, contributed as authors, organized their group study and report, and participated in a presentation of the study to NASA.

Several of the members were of invaluable help to the chairmen with these activities. They include: Ernest Lathram and William Trollinger for Mineral and Petroleum Exploration, along with the sub-group chairmen,

Ron Marrs - Mineral Resources Exploration
John Bennett - Energy Resources Exploration
Paul Merifield - Hazards, Engineering Geology
Yngvar Isachsen - Mapping and Interpretation

For Land Inventory, Bruce Rado and Lawrie Jordan (not an ASG member), along with the sub-group chairmen,

G. Robinson Barker - Forestry, Range and Wildlife
Bruce Bullamore - Natural Resource Inventory
Virginia Carter - Wetland Mapping and Inventory
A. Lawrence Grabham - Coastal Zone and Shoreline Mapping
Alden Colvocoresses - Mapping and Cartography
Charles Hoyt - Surface Mining Extent and Reclamation
Roger Zanarini - Urban and Special Environment

For Agriculture, Jack Estes, David Brueck, Richard Phelps, and Don Moore.

The coordinating members from Jet Propulsion Laboratory (JPL) are:

Mr. Fred Billingsley

Mr. Michael Helton

Mrs. Veronica O'Brien

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ABSTRACT

In January 1976, NASA requested the Jet Propulsion Laboratory (JPL) to conduct a study of the attempts at operational usage of the Landsat imagery by non-NASA users. In this study, particular emphasis was to be placed on profitable use of the imagery, as contrasted to those investigations concerned with research and development of a technology. The outcome of the study was to be an evaluation of the proposed Landsat follow-on effort as seen from the point of view of users attempting profitable use.

In support of this, four Applications Survey Groups (ASGs) were formed. These four groups so defined are:

- Mineral and Petroleum Exploration
- Inland Water Resources
- Land Inventory
- Agriculture

Other possible major interest areas such as Oceanography and Weather and Climate already have operating user groups. It was therefore decided not to try to parallel or duplicate that effort.

The task for each of the four AGCs was defined as ".....will provide to JPL for OA/NASA a formal evaluation of Landsat follow-on capabilities from the total community of users of NASA technology in its discipline area. The area of concern will be limited to Landsat follow-on activities." The specific end product was to be an evaluation of the functional capabilities of the Landsat follow-on and ground systems designs in terms of user requirements and desiderata for data measurements, products, and parameters.

The members were drawn from all segments of the user community: federal agencies, state and local governments or agencies (or from associations of such constituencies), industry and universities. They were selected so that in aggregate they would be able to adequately assess the state-of-the-art in their technical areas and represent this in the ASG deliberations.

CHAPTER I

FORMATION OF THE APPLICATIONS SURVEY GROUPS

In January, 1976 NASA requested the Jet Propulsion Laboratory (JPL)* to conduct a study of the attempts at operational usage of the Landsat** imagery by non-NASA users. In this study, particular emphasis was to be placed at profitable use of the imagery, as contrasted to those investigations concerned with research and development of a technology. The outcome of the study was to be an evaluation of the proposed Landsat follow-on effort as seen from the point of view of users attempting profitable use.

Note the term "profitable use" as contrasted with "quasi-operational use" or "operational use". This term is used to differentiate on one hand that group of people for whom the development of technology is their raison d'etre, and from that group for whom technology is a tool in the accomplishment of some other task. We have avoided the terms involving "operational" to avoid the question of "when does a quasi-operational system become operational?". The term "profitable" permits the possibility of getting real use from the data from even a quasi-operational spacecraft/data exrmination system. We anticipate that those who have found the use of such data profitable will continue and expand its use, thus in a defacto way becoming operational, whether or not the formal definition has been made.

In support of this, four Applications Survey Groups (ASGs) were formed. These have been defined to have interest areas parallel to four of the NASA discipline teams, as these teams have proven to have an effective distribution of interest areas and could be used as technical resources. These four groups so defined are:

- Mineral and Petroleum Exploration
- Inland Water Resources
- Land Inventory
- Agriculture

Other possible major interest areas such as Oceanography and Weather and Climate already have operating user groups. It was therefore decided not to try to parallel or duplicate that effort.

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* Pasadena, California. JPL is operated under contract to NASA by the California Institute of Technology.

** Landsat 1, the first earth resources satellite, was launched July 23, 1972 and is still operating. Landsat 2 was launched on January 22, 1975 and is also operating. (These are discussed in more detail later.)

The task for each of the four ASGs was defined as " . . . will provide to JPL for OA/NASA a formal evaluation of Landsat follow-on capabilities from the total community of users of NASA technology in its discipline area. The area of concern will be limited to Landsat follow-on activities." The specific end product was to be an evaluation of the functional capabilities of the Landsat follow-on and ground systems designs in terms of user requirements and desiderata for data measurements, products and parameters (see Appendices B and C).

To keep the discussions within bounds the discipline areas of each group were defined to have sub-applications as listed below. These were felt to include the major interest areas of each group. However, it was left to each group to modify the list (keeping within the general framework) as it saw fit.

Mineral and Petroleum Exploration

- Mineral Resources Exploration
- Energy Resource Exploration
- Hazards/Engineering Geology; Detection, Assessment, and Monitoring
- Mapping and Interpretation; Landform, Rock Type, Structural

Inland Water Resources

- Snow Mapping and Runoff Prediction
- Lake Ice Monitoring
- Glacier Inventory
- Estuary Dynamics and Water Quality
- Subsurface Water Survey
- Water Use Survey
- Watershed Survey, Management and Modeling
- Surface Water Mapping

Land Inventory

- Natural Resources Inventory
- Coastal Zone and Shoreline Mapping and Inventory
- Wetlands Mapping and Inventory
- Surface Mining Extent and Reclamation Monitoring and Inventory
- Wildlife Habitat Location and Inventory
- Urban and Special Environmental Area Land Cover Inventory
- Mapping and Cartography
- Information Management Systems
- Forest and Range
    - Timber Inventory - Large Area
    - Range Readiness and Management
    - Forest and Range Renewable Resources Inventory
    - Wildland Protection and Damage Survey

Agriculture

- Crop Survey and Reporting (Identification, Mensuration, Location, Yield, Production, Signature Extension)
- Crop Stress (Insect Damage, Disease Damage, Crop Vigor, Soil Moisture)
- Crop Management (Damaged Crop Identification, Quantification, and Location: Field Operations Information)

The groups vary in size from 13 members (Agriculture) to 46 (Land Inventory), reflecting the variation in the number of sub-application areas covered. Membership was by invitation from JPL, drawn from tentative lists provided by the Federal Interagency Decision Team, review of various lists of Landsat experimenters, participants in such activities as the Earth Resources Survey Symposium and the National Research Council study on practical applications of space systems, personal knowledge of the organizers, and recommendations from other individuals. The membership was limited to recognized experts in one or more of the fields covered by the ASGs. The members included both those who do and do not possess extensive hardware or space-related training and experience. They were drawn from all segments of the user community: federal agencies, state and local governments or agencies (or from associations of such constituencies), industry and universities. They were selected so that in aggregate they would be able to adequately assess the state-of-the-art in their technical areas and could represent this in the ASG deliberations.

Two figures are shown herewith: (1) a map showing the geographical location of the various members, and (2) a histogram representing the members' evaluation of themselves on a scale from scientist to manager and a member classification distribution.

The survey was initiated at a combined meeting in early March 1976, at which briefings (primarily by NASA personnel) defined the spacecraft mission and some of the concepts of the data dissemination. As much back-up material as was available was distributed to the groups, both at the meeting and subsequently. Under the general direction of JPL, each group organized itself and assigned specific tasks for members to be accomplished prior to the second meeting. At the second meeting of each group the reports which had been generated to date were reviewed and the combined report begun. The first drafts of these reports were received by JPL in mid-June, and after minor editing were submitted to NASA in preliminary form on July 1, and after further polishing, in final form on August 1. This edition is the material of the August 1 report, re-edited to a more compact format. This is the second edition of the August 1 version of the reports which contains the same information but in a slightly different organization.

This edition is published in the form of two volumes, a summary volume plus one covering discussions of the discipline areas. Each of the individual discipline parts begins with a summary of the state-of-the-art of the applications, followed by detailed discussions of the area. The format of the discussions follows general suggestions from JPL. Except for some chapter reorganizations for uniformity of all the discipline parts, these reports are presented in essentially unedited form. Thus the user thoughts and flavors are preserved as much as possible; the editors take any responsibility for damage done to them in the editing process.

It will be found that a number of the areas of discussion are multi-faceted and therefore parallel discussions occur, both within some parts and across parts, e.g., snow and ice melt mapping is of interest to Land Inventory in their considerations of timber, range and wild land, to Inland Water in their considerations of water supply, stream runoff, and the like, to Agriculture as a possible water source for irrigation, and to Mineral and Petroleum as it affects shipping to the Polar regions and provides demarcation of geomorphic land forms. Rather than attempt to edit out the overlap, we felt that a better picture of some of the parallel activities and overlapping considerations would be preserved if the overlap remained.

In summary, the study was designed to provide an opportunity for knowledgeable and experienced users to express their need for data which might be expected to be provided by space systems and to relate the proposed capabilities of Landsat follow-on system to these needs. Although an attempt has been made to provide a background discussion for each of the evaluations, the study does not attempt to develop these in scientific detail, nor does it provide detailed economic analysis, nor justifications for the expressed use.

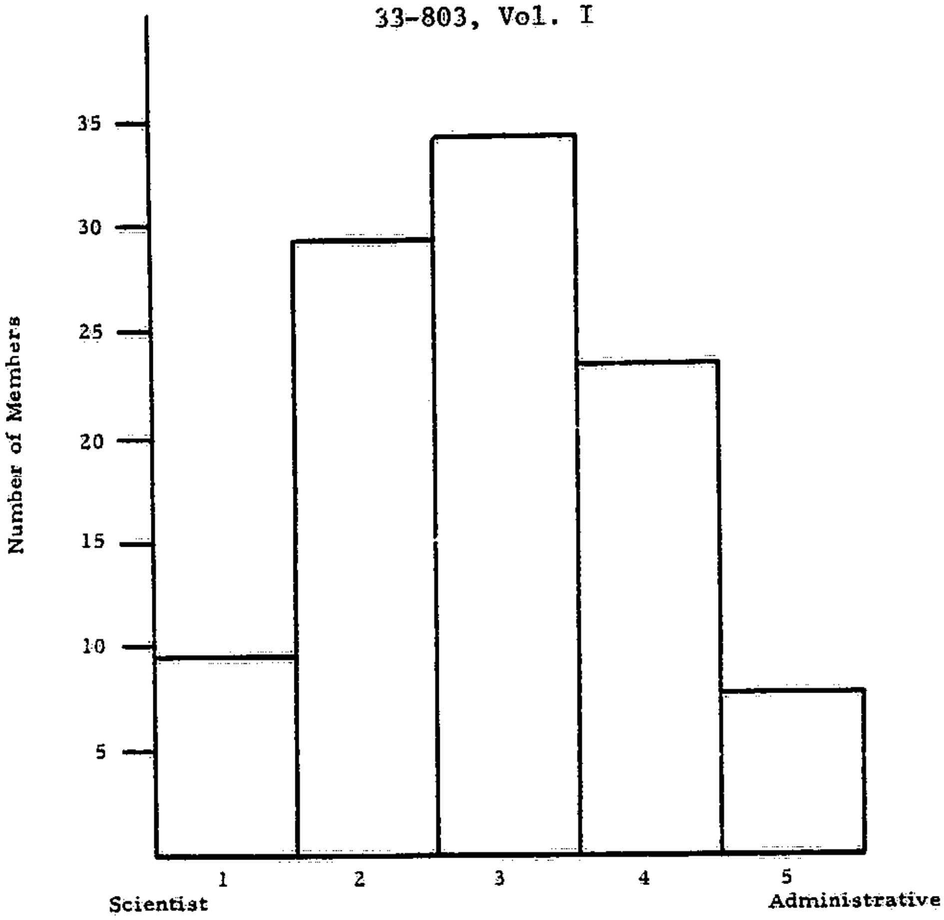
FIGURE I-1

GEOGRAPHICAL LOCATION OF ASG MEMBERS

■ 1 - 3 members

▲ 4 - 6 members

★ 7 and over members



HISTOGRAM OF ASG MEMBERS

MEMBER CLASSIFICATION DISTRIBUTION

ASG	FED. WASH	FED. NON-WASH	STATE & REGIONAL	UNIVERSITY	INDUSTRY	TOTAL
MP	5	5	3	6	8	27
IW	7	7	5	5	1	25
LI	25	2	10	5	4	46
A	3	1	1	3	5	13

TABLE I-1

TABLE I-2

USER ORGANIZATIONS

FEDERAL	STATE/REGIONAL	UNIVERSITY	INDUSTRIAL
USGS/GAP, WRD, LUDA, Topo., Geol. Div., EROS	Dept. of Water Res. (Sacramento, CA) (Denver, CO)	Texas A & M	St. Regis Paper Company
NSF	Area IV Reg. Plan. (Ottuma, IA)	University of Connecticut	Exxon
CERC	Nat. Weather Serv. (Sacramento, CA)	University of California	FMC
EPA EMSL/MOW	Gt. Lake Basin Comm. (Ann Arbor, MI)	University of Virginia	Monsanto Company
NOAA/Ocean Survey, NESS, EDS, OCZM	Water Div. Board (Austin, TX)	University of California at Santa Barbara	Geoscience, Inc.
NPS/MSTL	Dept. of Conserv. (Sacramento, CA) (Nashville, TN)	California Institute of Tech./Jet Propulsion Lab.	Coastal Environments
USAC of Eng./Water Resources, NCD	State Ed. Dept. (Albany, NY)	Bureau of Econ. Geo.	Halbouty Alaska Oil
OCE	Dept. City Planning (Los Angeles, CA)	Colorado State University	Bittinger and Associates
ETL	Geo. Survey (Iowa City, IA)	Cornell University	Ralston Purina
EMA Hydro. Ctr.	Dept. of Nat. Res. (Atlanta, GA)	University of California at Berkeley	California Earth Sciences
Bureau/Mines, Census, Land Mgmt., Indian Affairs, Reclamation	Kern Cty. Water Agency (Bakersfield, CA)	University of Delaware	Cargill Grain
ERL	State Planning Agency (St. Paul, MN)	Stanford University	Anderson Clayton
USDI/Fish and Wildlife Service	Reg. Council of Govts. (Denver, CO)	San Diego State University	Chevron Oil Field
USDA/ARS/Forest Serv.	Res. Information Sys. (Phoenix, AZ)	University of Maryland	Metrics, Inc.
HUD/FIA		Auburn University	Trollinger Geological Assoc.
Dept. of Trans.		University of Georgia	Geospectra Corporation
		University of Wisconsin	Upland Industries
		University of Wyoming	
		Pennsylvania State Univ.	

The next chapter presents the results of the study in a condensed summary form with references to the individual ASG discipline discussions. Chapters III, IV, V, and VI present the key point issues in each of the four disciplines. The wording of these four chapters has been extracted from the four ASG discipline discussions so that the Executive Summary could stand by itself, thus a certain amount of repeat wordage exists between the Executive Summary and the discipline discussions.

CHAPTER II

SURVEY RESULTS SUMMARY

The general consensus of the users surveyed is that Landsat is an extremely desirable information gathering device which could be of limitless value if a fully operational program would proceed, and that Landsat Follow-on is progress to that end, even though it is only one of many tools utilized in accomplishing their tasks. No attempt is made to outline all of the visible tasks which Landsat may serve. Indeed, some 520 applications have been suggested in the June 1974 Technology Applications Center report from the University of New Mexico. The general user consensus is that once an operational program is effective, the uses and applications will continue to expand. This survey's intent is to expose the advance in benefits of the Landsat Follow-on mission. This chapter summarizes the results.

A. APPLICATION AND OPERATION INTERACTION

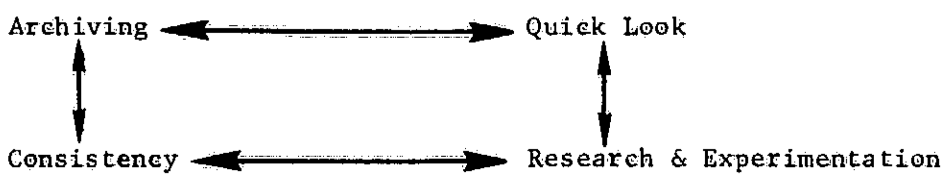
No one particular application can guarantee to reimburse the cost of a satellite program (even though several uses may eventually do so). However, in the aggregate, costs are more justified, especially if the commonality of applications is considered. This commonality is obvious from reviewing the needs of the major applications:

- Environmental Managing (forecasts, studies, urban planning, mapping...)
- Resource Managing (crops, water, energy, minerals, forests...)
- Transient Assessing (floods, fire, earthquakes, crop disease...)

For example, some of the cross utilizations which Landsat Follow-on will affect are:

- more accurate crop managing and production forecasting with better estimates of water use, needs, and availability.
- ice flow patterns for offshore petroleum exploration as well as commercial navigation.
- soil and rock type for crop studies and mineral exploration.

The operational requirements which Landsat Follow-on will advance involve the following interaction loop.



Even though some applications may be operationally opposed, their commonality dictates a Landsat follow-on type system in that research and archiving could both be supported by one satellite.

B. BENEFIT ADVANCES FROM LANDSAT FOLLOW-ON

The following items have been extracted from the four volumes of this survey as benefits which would be realized from the Landsat follow-on over and above the current Landsat and Landsat C missions. The reference in parenthesis is the discipline discussion.

1. Shoreline changes can be detected with critically greater precision (IW; LI)
2. Streets and rows of houses can be detected and can distinguish between multi-family residential areas and single unit areas (IW)
3. Addition of bands will help distinguish between snow/cloud and snow/rock (IW)
4. Band 6 will provide details of estuarine circulation and surface salinity charting (IW).
5. Detection of smaller lakes and ponds allowing more accurate surveys to be made (IW)
6. High resolution thermal infrared band 6 should provide information on rock types and soil moisture patterns (IW)
7. Band .45 - .52 μm will provide better monitoring of lakes and reservoirs (IW)
8. Appreciable increase in number of alteration patterns from 30 m resolution, addition of 1.5 - 1.8 μm and .5 - .52 μm channels will aid in discrimination of alteration patterns associated with hydrocarbon seepage (MP)
9. Ratioing of the additional 1.55 - 1.75 μm band in the TM with existing bands will allow the sensing of carbonaceous materials and other rocks (MP)
10. Landsat 1 and 2 can find geographic faults, but Landsat follow-on will be able to better distinguish active faults from inactive faults due to the increased resolution (MP)
11. Increased resolution will help define hazards such as faults, landslides, subsidence and cave-ins (MP)

12. Increased resolution means that shorter linears can be detected which will provide maps of joint systems, and fine structure of large lineaments may be made. (MP)

13. The 256 quantification levels along with the increased resolution should broaden classification capability and advance pattern recognition techniques. (LI)

14. The improvement of IFOV may enable the positioning of off-shore oil platforms. (LI)

C. COST BENEFITS WITH LANDSAT FOLLOW-ON

The general consensus among users is that it is very difficult, if not impossible, to assign net dollar gains of a Landsat system. For example, new world-wide energy resources and food production forecasting may be invaluable. However, other more specific applications such as urban water planning may cost <u>more</u> man hours to interpret data if the data is not in a quick and simple form. Some of the cost savings which <u>can</u> be foreseen are as follows:

1. For inventory and management of underground aquifers, the net dollar savings from current Landsat is $.6 million and Landsat follow-on is $1.7 million/yr. (IW)
2. $2 million/yr. could be saved in defining sediment sources and developing sites if satellite images are of sufficient quality. (IW)
3. Estuary surveys could be done at a savings of $2-5 million and 5 years time. (IW)
4. Approximately $19 million/yr. could be saved in urban water resources development. (IW)
5. Conservative $1 million/yr./mining company could be saved in expenditures for exploratory mining. (MP)
6. Trafficability and access information from Landsat maps for energy resource exploration can save $1.8 million/yr. (MP)
7. The air photo to Landsat costs are approximately $300 to $.50 per 10,000 sq. miles for monitoring surface mining areas -- the increased resolution from 80 to 30m will allow Landsat imagery to be used instead of air photos. (MP)
8. Net savings in property damage from geologic hazards (earthquakes, landslides, etc.) with foreseeable advances in loss reduction measures could be $1 billion/yr. in California alone (30 yr. average). A conservative 1% of this could be attributed to a Landsat system or $10 million/yr. in California. (MP)

9. Cost benefit studies indicate that satellite spectral information may give an overall economic savings to saline soil management compared to aircraft or photo interpretive information. (A)

10. The total cost of operation of two survey vessels for straits and passages, harbor approaches, harbors, shoals, reefs, etc., was $9.1 million in 1973. Landsat could provide a partial, if not total, relief of this cost. (LI)

11. An Ohio study reports the feasibility of using Landsat data to reduce the costs of mapping and monitoring strip mining and reclamation to less than one-tenth the conventional techniques which cost about $7 per square mile. (LI)

12. The Canadian government in 1973 assessed the benefits of a continuing aircraft-NOAA-Landsat system to aggregate to $11-12 million by 1990 for Canadian Arctic exploration. (MP)

D. ORBITAL COVERAGE TRADEOFFS

The general user consensus is that circular, sun-synchronous orbits provide adequate repeat consistency in the data. Also, a 9-day repeat cycle (requiring two satellites in an approximate 900 KM orbit) would be adequate for most applications. However, if cloudy weather occurs, many applications connected with the weather would be heavily jeopardized. These include:

- snow accumulation
- melt-off measurements
- ice monitoring
- crop changes
- landslides and other hazards

If a lower orbit (~700 KM) is utilized, the design data resolution of 30 meters would be attained. The orbit inclination would change from about 99° to about 98° to maintain sun-synchronism. This would increase polar coverage from about 83°N to about 84°N. Since resource exploration areas are extending to 85°N, a Landsat lower orbit would enhance this exploration. If the higher orbit (~900KM) is utilized, the resolution grows to about 40 meters. This is adverse to most applications since 30 meters is already marginally adequate and some users would prefer 10 meter resolution.

The orbital time of day of Landsat coverage was considered to be 11:00 AM for the follow-on study. The tradeoffs for this time, compared to 9:30 AM are shown below.

11:00 AM Advantages	11:00 AM Disadvantages
1. Improve water depth mapping	1. More cloud cover
2. Discriminate surface materials if night coverage is also made	2. Less enhancement of landforms
3. Detect crop stress (stress increases during the day)	3. Sun glint would eliminate water quality work and estuarine research.
4. Strengthen signal of reflected ground	4. Atmospheric haze will be 3 times signal strength of the .45-52 m band.
5. Better day-night thermal diurnal effects	5. Atmospheric haze will be 3 times signal strength of the .45-52 μm band.

Subsequent to the main study effort, the planned orbit time was changed to 9:30 AM. Most of the comments by the users concerning the 11:00 AM are left in to show their preferences. Further assessment of these orbital parameters are given in the tables at the end of this chapter.

E. LANDSAT UTILIZATION LIMITATIONS

The following items limit the use of Landsat and will be eliminated to various degrees with Landsat follow-on.

1. Psychological inertia
2. Lack of adequate training and information to potential users
3. Limited availability of digital processing by potential users
4. High cost of digital processing
5. Spatial and spectral resolution of the products
6. Time delay of receipt of data after overpass
7. Lack of geometric agreement with map scales and difficulty in determining data element positions.

There are needs which are considered vital by many users and which Landsat follow-on will leave unresolved. Some of these are:

- Stereoscopic mapping could discriminate rock type and add another dimension and more insight to structural mapping for the mineral and oil explorationists and waterway managers.

- A spectral band of 2.0 - 2.4μm on the TM would enable discrimination between iron oxides associated with mineralization from more common iron oxide occurrences. (MP)
- Other bands would help distinguish other materials (i.e., an 8-9μm band for distinction between silicates and non-silicates).
- An easy quick-look option needs to be perfected for the following kinds of applications:
  - forecasting snow-melt runoff
  - lake research
  - resource management (water, crops...)
  - navigation (including ice pattern mapping)
  - hazards (fire, floods...)

F. PARAMETER ASSESSMENT

1. <u>Reactions to Thematic Mapper Proposed Technical Parameters</u>

a. 30 Meter Resolution

- Strongly supported by all groups.
- Will aid increase accuracy of boundary positions of all mapping and cartography utilizations.
- Will allow water and crop inventories to be made since the inventories depend to a significant extent on the aggregate of small areas to be accounted.
- Will allow urban distinctions to be made.
- Not necessary for a few applications, useful to essential for most; some users want even better
- A word of caution: data processing load goes up, possibly driving it out of reach (at least at full resolution) for some users.

b. Additional .5μm (Blue) Band

- Supported by all groups.
- Will allow natural-color presentations -- useful for some mineral discriminations.
- Water penetration aids underwater shallow water feature mapping, suspended sediment monitoring.
- Will aid discrimination of hydrocarbon-altered zones.
- Caution: Haze will cause some difficulty but not expected to be fatal.

c. Additional 1.5µm Band
- Strongly supported by all groups.
- Allows some additional discrimination of altered rock zones, separation of some rock types not now possible.
- Allows detection of some geobotanical stresses which may be indicative of lack of groundwater, presence of mineral stressants, or plant disease.
- Will aid snow melt mapping by better snow/cloud separation.
- Will aid in water boundary determination.

d. Thermal Band at 120µm Resolution
- Strongly supported by all groups.
- Will aid snow melt and arctic ice melting by better ice/snow/cloud separation.
- Day-night comparisons will aid rock/soil discrimination based on diurnal temperature variations.
- Will help isolate thermally-anomalous areas possibly indicative of geothermal interest.
- Will aid in water boundary mapping and possibly salinity.

e. Increased Signal/Noise and More Quantization Levels
- Supported by all groups.
- Will aid in the distinction between crop types and soil and rock types.
- Will enhance pattern recognition techniques.

2. <u>Reaction to Landsat Follow-on Operational Features</u>

a. Availability of Digital Data Corrected to <1 Pixel
- Generally supported by all groups.
- Minimal input internal distortions critical, especially in areas with no ground control.
- Overlay capability critical for all change detection problems (e.g., urban, geologic, agriculture).
- Lack of this capability may eliminate some uses of the data by small users.
- Caution: Some users, particularly cartographic and mapping, want uninterpolated data (as well as the corrected),

with correction parameters.

b. Data available at EDC in 48-72 hours

- Necessary for any applications which involve rapid decision processes, useful for most.
- Necessary for water planning decisions.
- Necessary for crop management decisions.
- Necessary for navigation applications.
- Necessary for hazard and disaster assessments.

The following tables show the user reactions in group form of the Landsat Follow-on parameters and other considerations to each significant application represented by the survey.* These reactions range from Good (3) to Detrimental (-3). The specific meaning of the numbers can be interpreted as follows:

3: essential
2: very valuable
1: valuable
0: inconsequential
-1: degrades data utility or reduces probability of acquiring
-2: makes data very hard to use or generates low probability of acquiring
-3: makes data useless

*NOTE: The Mineral and Petroleum Exploration Group developed these kinds of tables at their second meeting.

The comment column relates to the application needs and requirements which will be improved to some degree by Landsat follow-on. Most of the parameters in these tables are self-explanatory. "Better S/N" refers to better signal to noise ratio which would yield the 256 quantization levels instead of the present 64. This increase in data is achieved by the strong reflectance from the mid-day coverage by the considered 11:00 am orbit as well as reduced noise levels of the sensors. "Digital Tape Corrected - Registration <1 Pixel" indicates the desirability to have the data elements undergo a correction operation to reduce distortions so that data correlation may be made on different repeat cycles. "Need for HDTA" reflects the necessity for a High Density Tape of the uncorrected data with auxiliary data added.

Following these tables is a histogram (Figure II-1) summarizing the tables. This histogram shows the summation of all the Application numbers for each parameter in each discipline. For simplicity, each Application was considered to have equal weight of importance. The total overall discipline is also shown. Note that the three highest ratings are: Continuity with previous Landsats, 30 meter resolution, and Better S/N. Some parameters received no response indicating user indifference or non-consideration. (The columns indicated with an asterisk (*) were added late in the survey, and all users did not have a chance to respond.)

TABLE II-1

PARAMETER ASSESSMENT TABLES

GOOD						DETRIMENTAL
3	2	1	0	-1	-2	-3

APPLICATION:	Improved TM Technical Parameters						Operational Features							
MINERAL & PETROLEUM EX.	Thermal Bands @ 120 M Res.	30 M Res.	Blue Band	1.6μm Band	Better S/N		Digital Tape Corrected - Regis ≤ 1 Pixel	Data Ready @ EDC in 48 Hrs	Continuity with Previous L's	11 AM Comp. w 9:30 AM	Need for HDTA	9 Day Cycle Comp to 18 Days	Image Format	
1. Tectonics & Impact Structure	1	3	0	3	2		3	0	3	-3	0	3		
2. Surface Materials & Alteration	0	3	1	3	3		0	0	3	1	0	3		
3. Deposition & Erosion	1	3	2	3	2		3	0	3	-3	0	3		
4. Vegetation	1	3	1	3	3		3	0	3	2	0	3		
5. Ground Water	1	3	1	3	2		3	0	3	-2	0	3		
6. Coal	0	2	0	2	2		2	2	3	-1	2	1		
7. Shale Oil & Tar Sand	0	3	0	1	3		2	3	3	0	0	3		
8. Petroleum (On-Shore)	1	3	1	1	2		0	1	3	-3	-3	2		
9. Geothermal	3	3	2	3	3		3	3	2	1	0	3		
10. Petroleum (Off-Shore)	3	3	3	0	2		0	3	3	-3	-3	3		
11. Earthquake Damage	1	2	0	0	2		2	1	0	-2	-1	0		
12. Landslides	0	2	0	0	2		2	3	2	-2	-1	2		
13. Subsidence & Cave-ins	0	2	0	0	3		3	0	3	-3	-3	2		

TABLE II-1 (cont'd)

GOOD — DETRIMENTAL: 3, 2, 1, 0, -1, -2, -3

APPLICATION: MINERAL & PETROLEUM EX. (Cont)	Improved TM Technical Parameters: Thermal Bands @ 120 M Res.	30 M Res.	Blue Band	1.6µm Band	Better S/N		Operational Features: Digital Tape Corrected - Regis ≤ 1 Pixel	Data Ready @ EDC in 48 Hrs	Continuity with Previous L's	11 AM Comp. w 9:30 AM	Need for HDTA	9 Day Cycle Comp to 18 Days	Image Format
14. Volcanic Eruptions	0	2	0	3	2		0	3	3	0	-1	3	
15. Foundation & Constr. Mt.	1	2	1	3	2		3	0	0	1	-1	3	
16. Earth Moving	0	2	0	2	3		3	0	0	-3	-3	0	
17. Subsurface Water	0	2	0	0	3		3	0	3	-2	-3	0	
18. Drainage & Erosion	0	2	0	0	3		3	0	3	-3	-3	0	
19. Environmental Impact of Grading	0	2	0	0	3		3	3	3	-1	-3	2	
20. Orthophoto Mapping	0	2	2	0	1		2	0	3	-3	-1	1	
21. Mapping Rock Types	1	2	1	3	3		2	0	0	1	0	1	
22. Geomorphic Mapping	1	2	3	1	2		2	0	0	-3	0	1	
23. Structural Mapping	1	2	0	1	1		2	0	0	-3	0	1	
24. Linears, Lineaments & Cir.	1	2	0	1	1		2	0	0	-1	0	1	
25. Arctic Sea Ice	1	2	0	2	1		0	0	3	0	-1	3	

TABLE II-1 (cont'd)

GOOD 3 2 3 0 -1 -2 -3 DETRIMENTAL

COMMENTS	ANCILLARY CONSIDERATIONS				OTHER PREFERENCES					
ASSUME DIGITAL FORMAT & 185 KM COVERAGE AVAILABLE MINERAL AND PETROLEUM EXPLORATION (Cont'd)		Long Time Data Compatibility	Usefulness of Training Centers			Real Quick Look	Stereo	Registration to Some Map	Add 2.2 µm	Add 8.2-9.4
1. Geologic Structures Associated with Mineralization & Aquifers							3+		2	2
2. Overall Mapping, Hydrothermal Alterations 1.6 for FE, 2.2µm for Hydrous Sepins							2		3	3
3. Deposits of Economic Materials - Alluvial, Playas							3		1	1
4. May Indicate Aquifers, Related to Fracture Zone Mineralization							1		1	1
5. Geomorphic Patterns Showing Fracture System - Vegetation Habit from Textural Character							3		1	1
6.							3		3	0
7.							0		2	2
8.							3		0	0
9.							2		3	3
10.							2		0	0
11. Regional Soil Mapping, Unstable Slopes, Position of Ground Water Table							3		0	0
12. Slides on Unstable Ground, Retreating Cliffs (10 M Res. would be more help).							2		0	2
13. Faults, Joints, Intersect Mine Workings, Tunnel Routes							3		0	2

TABLE II-1 (cont'd)

GOOD 3 2 3 0 -1 -2 -3 DETRIMENTAL

COMMENTS	ANCILLARY CONSIDERATIONS				OTHER PREFERENCES				
ASSUME DIGITAL FORMAT & 185 KM COVERAGE AVAILABLE MINERAL AND PETROLEUM EXPLORATION (CONT'D)	Long Time Data Compatibility	Usefulness of Training Centers			Real Quick Look	Stereo	Registration to Some Map	Add 2.2 um	Add 8.2-9.4
14. Active Volcanoes and Distribution of New Volcanic Products						2		2	2
15. Landform, Color, Associated Vegetation, Bedding and Jointing, Drainage Pattern						1		2	2
16. Excavation, Tunnelling, Reinforcing Costs, Rock Consolidation, Linears, Porosity						3		1	0
17. Location and Evaluation of Aquifers, Distinguish Sand & Gravel from Clays						1		0	2
18. Areas of Construction Related Sedimentation, Filling of Reservoirs, Lakes						1		0	2
19. Disruption of Land Surface, Vegetation Drainage System, Air & Water Pollution						3		0	0
20. Morphologic, Hydrologic & Cultural Features in Contrast						3		0	0
21. True Reflectance in Spectral Bands 1.55-1.75 Band Max. Reflectance - Need 2.2μm						3		3-	3
22. Inc. Resolution Improves Cap. Need Stereo and/or Shadowing.						3		3	0
23. Folds, Faults, Lithologic Differences, Short Linears						3		3	0
24. Alined Morphologic Features, Tonal Contrast Boundaries						3		3	0
25. "Real-Time" Identification of Floes, Bergs, and Movement Direction						0		2	3

TABLE II-1 (cont'd)

GOOD — DETRIMENTAL

3 2 1 0 -1 -2 -3

APPLICATION:	Improved TM Technical Parameters						Operational Features						
INLAND WATER RESOURCES	Thermal Bands @ 120 M Res.	30 M Res.	Blue Band	1.6µm Band	Better S/N		Digital Tape Corrected - Regis < 1 Pixel	Data Ready @ EDC in 48 Hrs	Continuity with Previous L's	11 AM Comp. w 9:30 AM	Need for HDTA	9 Day Cycle Comp to 18 Days	Image Format
1. Area Snowcover	1	2	0	3	2		1	3	3	-1	3	+2	
2. Snow Water Content	1	2	3	0	1		1	3	3	1	1	+2	
3. Thermal Charac.	3	0	3	3	1		1	3	3	3	-2	+1	
4. Reflectance Charac.	1	0	0	3	1		1	3	3	3	-2	+1	
5. Thermal Detection	2	3	3		2		1	2	2				
6. Land Use Classification	0	3	0		2			0	2			1	
7. Turbidity Detection	1	3	2		2			0	2				
8. Wet Land Delineation	0	2	2		2			0	2			0	
9. Flood Plain Mapping	0	2	2		2			0	2			0	
10. Data Collection	0							0	2			+1	
11. Measuring Runoff Coefficients	3	3	0	0	3		0	3	3	-3	0	3	
12. Soil Moisture	2	2	0	0	2		1	2	0	-3	1	+3	
13. Study Lakes, Reservoirs	2	2	2	1	3			1	2	-3	-3	+3	

TABLE II-1 (cont'd)

GOOD — DETRIMENTAL

3 2 1 0 -1 -2 -3

APPLICATION:	Improved TM Technical Parameters						Operational Features						
INLAND WATER RESOURCES	Thermal Bands @ 120 M Res.	30 M Res.	Blue Band	1.6µm Band	Better S/N		Digital Tape Corrected - Regis < 1 Pixel	Data Ready @ EDC in 48 Hrs	Continuity with Previous L's	11 AM Comp. w 9:30 AM	Need for HDTA	9 Day Cycle Comp to 18 Days	Image Format
14 Monitor Inland Lakes	2	2	3	1	3			1	2	-3	-3	+3	
15 Monitor Lake Ice	2	3	1	2	3			-2	2	-3	-3	+3	
16 Delineate Inundated Area	3	3	1	2	3			0	2	-3	-3	+3	
17 Study Estuarine Dynamics	2	2	2	1	3			1	2	-3	-3	+3	
18 Study Sediment	1	2	1	0	3			1	2	-3	-3	+3	
19 Urban Hydrology	1	3	2	3	2			-1	3	0	1	0	
20 Sub-surface Water Supply	1	3	0	1	0			-1	2	-3	-1	2	
21 Water Resource Management	3	3	1	0	1			0	3	-2	-1	+2	

TABLE II-1 (cont'd)

GOOD 3 2 3 0 -1 -2 -3 DETRIMENTAL

	COMMENTS	ANCILLARY CONSIDERATIONS				OTHER PREFERENCES					
	ASSUME DIGITAL FORMAT & 185 KM COVERAGE AVAILABLE INLAND WATER RESOURCES (CONT'D)		Long Time Data Compatibility	Usefulness of Training Centers			Real Quick Look	Stereo	Registration to Some Map	Add 2.2 µm	Add 8.2-9.4
1	1.55-1.75µm will help distinguish snow & clouds, and snow & white rock										
2											
3	10. +-12.5µm I										
4											
5	10.0 +- 12.5 µm I										
6	Discrimination between Natural and Man made Features										
7											
8	Soil Surface Temperature-Vegetation Topography										
9	Good Spatial and Spectral Discrimination										
10											
11	Watershed Area, Landcover, Stream, Network, Tonal Variation-Vegetation							0		0	0
12	Soil Surface Temperature-Vegetation Topography							0		0	2
13	Size, Shape, Volume, Chem., Physical and Biological Constituents							0		1	1

TABLE II-1 (cont'd)

GOOD 3 2 3 0 -1 -2 -3 DETRIMENTAL

COMMENTS	ANCILLARY CONSIDERATIONS				OTHER PREFERENCES					
ASSUME DIGITAL FORMAT & 185 KM COVERAGE AVAILABLE INLAND WATER RESOURCES (CONT'D)		Long Time Data Compatibility	Usefulness of Training Centers			Real Quick Look	Stereo	Registration to Some Map	Add 2.2 µm	Add 8.2-9.4
14. Size, Shape, Volume, Chem., Physical and Biological Constituents							0		1	1
15. Distribution, Thickness, Temperature, Patterns, Leads, Fractures, Other Classes							0		1	1
16. Good Spatial & Spectral Discrimination							0		2	1
17. Identify Current Patterns, Pollutants Sediment, Shorelines Flooding							0		0	1
18. Identify Source, Movement, Deposition, Particle Size, Concentration							0		0	0
19. Discrimination Between Natural & Man made Features							0		1	1
20. Topographic Relief, Geologic Structures							3		0	2
21.							2		0	0

TABLE II-1 (cont'd)

GOOD — DETRIMENTAL

3 2 1 0 -1 -2 -3

APPLICATION:	Improved TM Technical Parameters						Operational Features						
LAND INVENTORY	Thermal Bands @ 120 M Res.	30 M Res.	Blue Band	1.6μm Band	Better S/N		Digital Tape Corrected Regis ≤ 1 Pixel	Data Ready @ EDC in 48 Hrs	Continuity with Previous L's	11 AM Comp. w 9:30 AM	Need for HDTA	9 Day Cycle Comp to 18 Days	Image Format
1. Forest	2	3	0	2	2		3	2	3	2		2	
2. Range	2	3	0	1	2		3	2	3	-1		2	
3. Wildlife	2	3	1	2	2		3	1	3	2		2	
4. Natural Resource Inventory	3	3	3	2	0		3	3	3	-3	-2	2	
5. Wetland Mapping & Inven.	1	3	3	1	2		2	3	3	-2		0	
6. Coastal Zone & Shoreline Mapping & Inventory	2	2	3	1	2		3	2	3	-3	-3	1	
7. Mapping & Cartography	1	3	2	1	3			3	3	-3	-3	3	
8. Surface Mining & Reclamation	1	3	1	0	2		3	2	3	2	0	3	
9. Urban & Special Environment	2	3	0	0	3		2	3	3	2	1	3	
10. Information & Management Systems.	-1	-2	-1	0	1		3	2	2	0	2		

TABLE II-1 (cont'd)

GOOD 3 2 3 0 -1 -2 -3 DETRIMENTAL

COMMENTS	ANCILLARY CONSIDERATIONS				OTHER PREFERENCES					
ASSUME DIGITAL FORMAT & 185 KM COVERAGE AVAILABLE LAND INVENTORY (CONT'D)		Long Time Data Compatibility	Usefulness of Training Centers			Real Quick Look	Stereo	Registration to Some Map	Add 2.2 um	Add 8.2-9.4
1. Spectral Separation of Species Groups Need at Least 30 M Res.						2			1	1
2. Inc. Cap. to Isolate Vegetation, Change Detection, and Monitoring, Need Detail System						1			1	1
3. Water & Vegetation Monitoring						1			1	1
4. Assessment of Natural Resource Interrelationships						1			2	0
5. Could Relate to Dredge & Fill Operations						1			-	-
6. Landslides, Positioning of Oil & Mining Platforms, Water & Vegetation Boundaries						3			0	0
7. Location of Shoals, Islands, Coastal Zones, Navigation, Chart Revisions						3			1	2
8. Type of Mining, Access Roads, Water Impound. Surface Spoil, Erosion, Landslides						2			0	0
9. Urban Change Detection and Boundary Delineation										
10. Data Availability, Continuity, User Training Needed						-2				

TABLE II-1 (cont'd)

GOOD: 3, 2, 1 — 0 — DETRIMENTAL: -1, -2, -3

APPLICATION:	Improved TM Technical Parameters						Operational Features						
AGRICULTURE	Thermal Bands @ 120 M Res.	30 M. Res.	Blue Band	1.6μm Band	Better S/N		Digital Tape Corrected-Regis < 1 Pixel	Data Ready @ EDC in 48 Hours	Continuity with Previous L's	11 [illegible] Comp. w 9:30 AM	Need for HDTA	9 Day Cycle Comp to 18 Day	Image Format
1. Production Estimates	2	3		3	3		1	3	3	3		3	1
2. Soil Erosion	1	2		1	2		1	1	3	3			1
3. Brushland, Timberland, Grassland Interfaces	1	3		3	3		1	0	1	3			1
4. Bare Soil & Rock vs. Vegetation Areas	3	3		1	1		1	0	1	3			1
5. Macro-Linear Identifiers, Timberline	2	2		2	1		1	0	1	3			1
6. Range & Brushland Interface	2	2		2	1		1	0	1	3			1
7. Farmsteads	1	1		0	1		1	0	1	3			1
8. Crop Species in Fields 1 Acre or More	2	3		3	3		1	2	2	3		2	1
9. Encroachment	1	2		0	1		1	0	3	3			1
10. Monitoring World Agricultural Land Use	2	1		3	3		1	1	3	3			1
11. Survey of Irrigation Potential	3	2		2	3		1	2	2	3		1	1
12. Irrigation Scheduling	2	2	2	3	3		1	3	2	3		3	1
13. Water Budget	2	1	3	2	2		1	3	2	3		2	1

TABLE II-1 (cont'd)

GOOD 3 2 1 0 -1 -2 -3 DETRIMENTAL

APPLICATION:	Improved TM Technical Parameters						Operational Features						
AGRICULTURE	Thermal Bands @ 120 M Res.	30 M Res.	Blue Band	1.6µm Band	Better S/N		Digital Tape Corrected Regis ≤ 1 Pixel	Data Ready @ EDC in 48 Hrs	Continuity with Previous L's	11 AM Comp. w 9:30 AM	Need for HDTA	9 Day Cycle Comp to 18 Days	Image Format
14. Water Deficit Areas	2	1	3	0	2		1	3	3	3		3	1
15. Depth to Water Table	2	1		1	1		1	2	2	3		1	1
16. Water Availability	2	0	2		0		1	1	2	3		3	1
17. Soil Classification	1	2		1	2		1	0	2	3			1
18. Range Land	1	2		2	2		1		2	3		1	1
19. Crop Production	2	3		3	3		1	3	3	3		3	1
20. Irrigation Potential	3			1	2		1		2	3		2	1
21. Soil Salinity & Drainage	1	3		2	2		1	1	2	3		2	1
22. World-wide Crop Production Forecasting for Maj. Crops	2	3		3	2		1	3	3	3		3	1
23. Crop Stage	2	3		3	3		1	3	3	3		3	1
24. Crop Stage	2	3		3	3		1	3	3	3		3	1
Agriculture overall	2	3	2	3	3		2	2	3	3		(3)	(2)

TABLE II-1 (cont'd)

GOOD — DETRIMENTAL

3 2 3 0 -1 -2 -3

COMMENTS	ANCILLARY CONSIDERATIONS					OTHER PREFERENCES				
ASSUME DIGITAL FORMAT & 185 KM COVERAGE AVAILABLE — AGRICULTURE		Long Time Data Compatibility	Usefulness of Training Centers			Real Quick Look	Stereo	Registration to Some Map	ADD 2.2µm	ADD 8.2-9.4
1. Yield Models Based on Reflectance & Emittance Indicators - Verification Needed		3	3			3	0	2	2	0
2. Erosion Potential Associated with Changes in Vegetal Cover Identified		2	3			3	0	2	2	0
3. Grassland Distinct Spectral Response - Delineation of Grassland/Timber/ Brush		2	3			3	0	2	2	0
4. Heat Sensing for Definition Between Bare Soil-Rock-Vegetative Cover		2	3			3	0	2	2	0
5. Good to Excellent Definition		3	3			3	0	2	2	0
6. Difference Between Woody-Stemmed Plant, Succulent Grass, Herbaceous Growth		2	3			3	0	2	2	0
7. Identification of Buildings, Roads, Storage Areas - Need More Res.		1	3			3	0	2	2	0
8. Planting Pattern, Size, Shape, Color, and Crop Configuration for Seasons		2	3			3	0	2	2	0
9. Land Use Patterns, Soil-Vegetation		2	3			3	0	2	2	0
10. Assessment of: Soil Types, Water Availability, Topography, Lithologic Material, Native Vegetation, Drainage		1	3			3	0	2	2	0
11. Salinity, Texture, Water Availability, Drainage Type - Need Field Inspection		2	3			3	0	2	2	0
12. Areas of Soil Moisture, Fallow & Crop Reflectance		2	3			3	0	2	2	0
13. Water Supply: Ground, Surface, Precipitation, New Irrigated Area Potential		2	3			3	0	2	2	0

TABLE II-1 (cont'd)

GOOD 3 2 3 0 -1 -2 -3 DETRIMENTAL

COMMENTS	ANCILLARY CONSIDERATIONS					OTHER PREFERENCES				
ASSUME DIGITAL FORMAT & 185 KM COVERAGE AVAILABLE **AGRICULTURE**		Long Time Data Compatibility	Usefulness of Training Centers			Real Quick Look	Stereo	Registration to Some Map	Add 2.2 um	Add 8.2-9.4
14. Good Definition with Min. Ground Data		3	3			3	0	2	2	0
15. Locate & Predict Depths of Shallow Water Tables		1	3			3	0	2	2	0
16. Geologic Features, Well Depth, Recharge		2	3			3	0	2	2	0
17. Soil Permeability Incl. Subsoil, Topography, Res. Limited		1	3			3	0	2	2	0
18. Quality, Variety, Grass Quantity, Soil Type, Fertility, Erosion		3	3			3	0	2	2	0
19. Type, Yield, Soil Fertility, Crop Intensity		3	3			3	0	2	2	0
20. Vegetation & Area - Sequential Coverage		3	3			3	0	2	2	0
21. Large Area - Color of Soil, Permeability, Topography, Ponding		1	3			3	0	2	2	0
22. Crop Type, Crop Aerial Extent, Crop Vigor, Yield Potential		3	3			3	0	2	2	0
23. Maturity		1	3			3	0	2	2	0
24. Identify & Locate Stress (Insects, Disease, Moisture, Climate, Etc.) Needs - Repeat Cycle & Res.		3	3			3	0	2	2	0
Agriculture overall			3			3	0	2	2	0

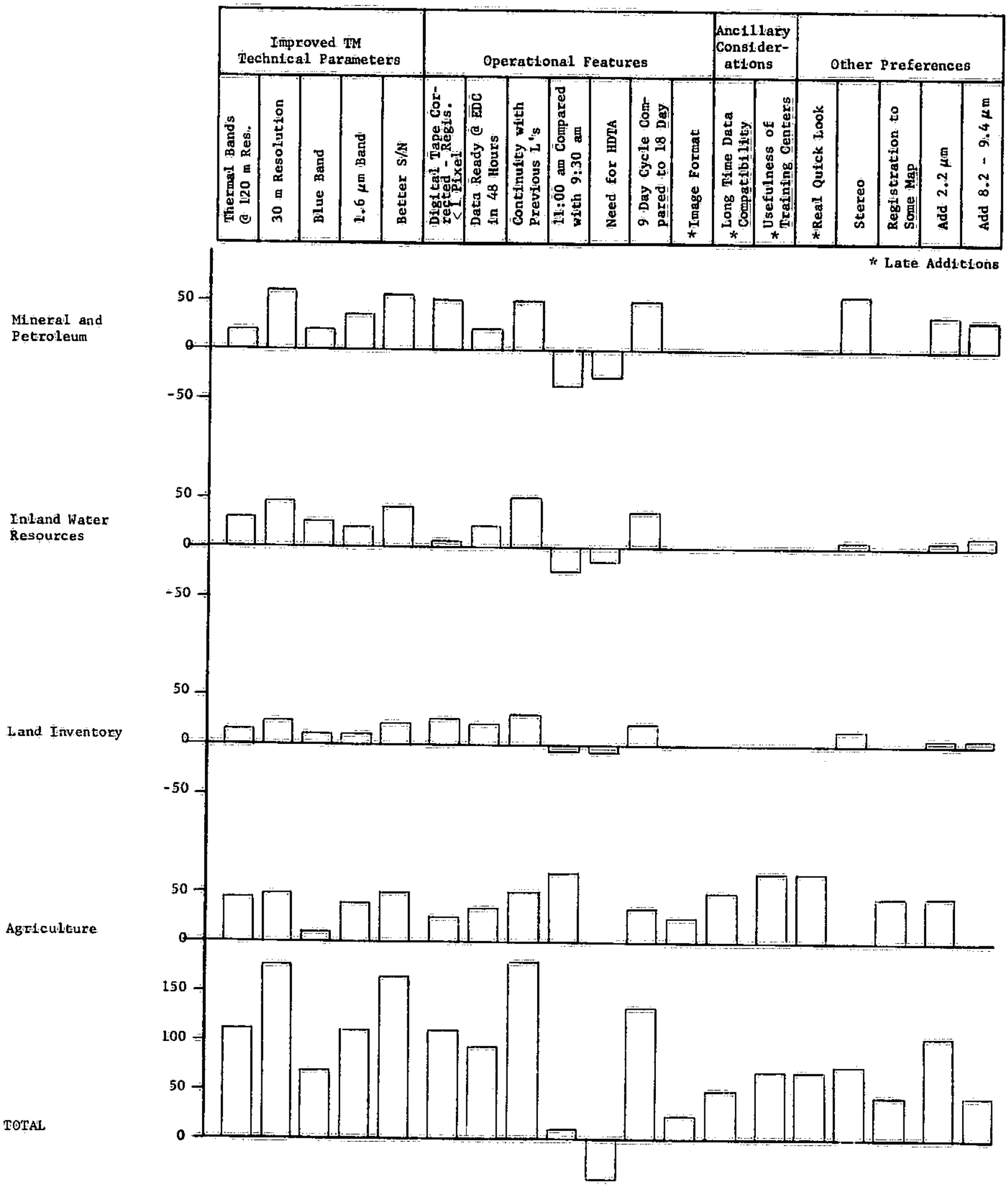


FIGURE II-1. PARAMETER ASSESSMENT HISTOGRAM

G. LANDSAT DATA DELIVERY SYSTEMS

1. Background

From the earliest beginnings of the Landsat (formerly ERTS) program, efficient distribution of data to all users has been a firm program objective. The cooperative program with the EROS Data Center (EDC) was established for just this purpose. In the early stages of the program, however, much frustration was caused by start-up and other problems. These unavoidable problems are apparently still causing many potential users to hesitate before making a significant commitment to operational use of the data.

The complete process of receiving a data request, producing the product, and delivering the requested data to a customer typically takes from two to three weeks for film products. For digital data, the process is considerably longer and generally requires from one to two months. These delays are unacceptable to a major fraction of users and potential users. The TERSSE study found that approximately 37% of federal requirements for Landsat data could only be met with data delivery times of one week or less. Sixty-one percent of the federal requirements called for data delivery in one month or less. Data delivery needs of the non-federal public agencies and the private sector concentrated in the one week or under category.

Based on the above it can be seen that many potential users are presently effectively denied access to the Landsat system since the data delivery schedules do not meet their operational requirements. This serious problem has not gone unnoticed, and substantial improvements in data delivery are planned for inauguration at about the time Landsat-C is launched.

2. Improved Data Delivery System

A vastly improved data delivery system is proposed for initiation in about two years. The new system will consist of satellite communications data links to expedite delivery of the data to users as well as additional processing to provide better digital and photographic products.

Planned improvements in Landsat data delivery include:

1) Collection of the data from the Landsat satellite itself via the tracking and Data Relay Satellite System (TDRSS),

2) Relay of the Landsat data to the TDRSS ground receiving station,

3) Retransmission of Landsat data to GSFC via a domestic communications satellite (Domsat),

4) Initial processing of Landsat data at GSFC to provide annotation data, system corrections, approximate geographical reference data, etc.,

5) Transmission of "cleaned-up" raw Landsat data to EDC via Domsat,

6) Rapid screening of Landsat data at EDC to determine those scenes which should receive additional processing, and preparation of archival copies of high density digital tapes (HDDT),

7) Preparation for users, on demand, of CCT's which have been geometrically corrected and/or contain special processing features such as a specific map projection.

The above procedures are estimated to cut data delivery time (from acquisition to delivery to users) to 2-4 days. Obviously this is a tremendous improvement over the current data delivery schedule. However, it still fails to satisfy the users who want data within one or two days of its acquisition. Also, depending on the exact nature of the customization provided by EDC, it may or may not serve the user's needs.

For example, a problem which is discussed in more detail under the management and information systems topic concerns geometric corrections to the data. To include Landsat data in a natural resources information system, for instance, along with other data inputs, the Landsat data must be corrected for geometric distortions and accurately located with respect to the coordinate system used in the information system. Furthermore, it is very useful that the data be rotated to provide E-W line orientation.

Inland water resources is an area where timeliness is particularly critical for many applications. In fact, the timeliness of the data will determine, in large measure, whether the Landsat data are useful at all in some applications. Historical data and slow delivery times have served the research projects needed to verify the usefulness of Landsat. If the use of Landsat is to become operational in snow and ice surveys, flood mapping, and surface water quality studies, the data delivery system must be further improved over that now proposed.

The next section will present proposed improvements in the data delivery system. The effect of these changes on the operational use of Landsat data in inland water resources programs will also be discussed in more detail.

3. <u>Alternative Data Delivery System for Landsat follow-on</u>

The data delivery system suggested here closely parallels that described in the previous sections. However, there are important differences which make the data delivery system more responsive to user needs. The proposed alternative system is the same as that described previously through receipt of the Landsat data at an Image Data Processing Station (IDPS).* However, significant differences appear in the types of processing provided and in the functional roles played by IDPS and EDC.

The following changes in the data delivery are proposed for consideration:

1) Processing of data at IDPS to provide all necessary internal geometric corrections,

2) Reformatting (rotation) of data to provide E-W pixel lines,

3) Precise recasting of data to a preselected map projection using ground control points if necessary,

4) Transmission of the above data to EDC via Domsat one band at a time instead of with bands interleaved,

5) Transmission of raw Landsat data to EDC via Domsat or by mail with only annotations and registration data added.

There are substantial advantages to the above procedure to justify the revisions. First, steps 1-3 above are very expensive preprocessing

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* The IDPS may be located at the White Sands TDRSS Receiving Facility, at Goddard Space Flight Center (GSFC), or elsewhere. The location is not critical to the argument providing that the processing is accomplished prior to the Domsat link step.

tasks that many users must perform if they are to accurately register Landsat data to other data in a natural resources information system, for example. Performing these functions at IDPS to a standard map projection and to a known accuracy will help to standardize the nature of information systems -- at least with respect to the land cover component -- and thus encourage data interchange.

Providing a standardized, corrected format for Landsat data is properly a part of data delivery to users. While it is true that many users have been providing their own geometric corrections, the present effort is extremely fragmented. Furthermore it is probable that the same corrections have been applied to a scene by multiple users -- unaware that corrected data already exist. This is a wasteful utilization of resources which could more properly be applied elsewhere. With the increase in the number and scope of users, the need for standardization at the earliest possible point in the data delivery system becomes more evident.

By its very nature, however, a standardized data format will not satisfy all users. Customization of data products would take place at EDC using the raw Landsat data with only the annotations added. Providing these custom products from EDC would tend to increase the efficiency of data distribution to all users since delivery of standard products by EDC would require little more than copying the data tapes. Customizing the data products, however, would likely require additional time and effort which might severely delay delivery of these products if they had to compete with the standard processing for analysis time. However, it is expected that customization would be required for only a small fraction of the total data.

For those users who cannot wait an additional 2-3 days to get data from EDC, transmission of data band-by-band will enable direct reception from the Domsat at minimum costs -- provided these users are willing to make the additional investment in receiving equipment.

The primary benefit here is likely to result from transmission of the data to EDC in a mode that makes direct reception from the Domsat an attractive possibility. Since data timeliness is critical in many of these applications, direct reception of the data from Domsat may mean the difference between acceptance and rejection of the Landsat data.

There are several specific areas in the water resources activity, for example, where the timely receipt of data is critical; as discussed in detail in other sections of this report:

* Snow and ice surveys
* Surface water surveys
* Surface water quality surveys

Based on the above considerations, it appears that the proposed data delivery system will better serve those users concerned with transient or short lived phenomena. Certainly any improvement in data delivery will aid the detection and mapping of non-point pollution sources, for example. Other applications, such as those discussed above, may only be served by a rapid and efficient data distribution system similar to the proposed alternative.

The current series of Landsat satellites has conclusively demonstrated the superiority of digital data products for most purposes. The use of digital data is likely to continue to predominate as should the trend toward inclusion of Landsat data in natural resources information systems. Therefore, it is worthwhile to give additional serious consideration to <u>user-oriented</u> data delivery systems.

Currently, a satisfactory delivery system exists to meet the needs of only a small number of the major users of satellite information. We have not obtained a system that is readily available to the vast audience of users that can provide frequent, accurate, standardized information to the user at his own location, in a format he can use at a time he can use it.

A streamlined, rapid turn-around contact service for data from EDC has yet to be developed. It should reach the local level frequently, provide geographically referenced output, be available at low cost, with suitable resolution, in a format that needs no further interpretation.

One can envision a system operated on a nationwide basis, through local contacts that would retrieve on demand the most recent available information for that locality concerning that particular area about any activity, or resource condition, as requested by the user.

The present systems of data analysis are not yet capable of preparation of data to these standards. Work must continue toward this end if the goals of maximizing the benefits to be derived from remote sensing are to be met. Although this may not be part of the NASA activity, it needs to be considered in the total context of putting the data into the users' hands in a timely fashion.

CHAPTER III

KEY POINT SUMMARY FOR MINERAL AND PETROLEUM EXPLORATION

This chapter contains highlights of the Mineral and Petroleum Exploration (Part 2) from the discipline discussion volume. These highlights have been extracted from the more detailed treatments of each application. The reader should consult the more detailed treatments for background material, supportive information, and further development of arguments and positions taken.

A. BRIEF PROBLEM OUTLINE

1. Mineral Exploration

There is increasing demand for raw materials for industry. This problem is made critical by the non-renewability of these materials. Proper management, therefore, requires complete and updated inventories. Remote sensing can possibly identify favorable areas and rule out less favorable areas, thus, contributing to inventory information and making exploration more cost effective.

2. Energy Resources Exploration

Energy demand is obvious. Remote sensing can define alteration patterns and thermal characteristics which may directly or indirectly indicate petroleum, gas, and geothermal areas. Although most coal areas are known, remote sensing can play a significant role in inventory, reclamation, and other management needs. Remote sensing can also contribute to the knowledge of ice flow patterns and off-shore changes (i.e., sand bar movements) for tanker navigation and oil platform positioning.

3. Environmental Geology

Because of the increasing awareness of environmental concerns, there is an increasing desire for information which remote sensing can facilitate. These concerns involve water drainage systems, surficial material consolidation, sediment changes, retreating cliffs, landslides, and active faults and volcanoes.

4. Mapping and Interpretation

The above problem statements indicate the need for a global remote sensing capability which can give the true position of earth features with appropriate tonal contrast boundaries. The future for remote sensing to extend the capabilities may include additional spectral bands and stereo projections.

B. KEY POINT SUMMARIES

1. Mineral Exploration

Remote sensing shows promise in identifying areas favorable for the location of mineral deposits, and in ruling out areas of little promise, thus enabling a more selective use of costly ground exploration. Specifically, the synoptic view from remote sensors in space permits delineation of distinctive geologic features of many kinds known to be associated with various types of mineral deposits. Before the information can be used effectively for exploration, the relationship with a "target" -- an ore deposit, oil field, concentration of construction materials, or other extractable resources -- must be established. All degrees of relationships can exist.

The need for these data is made even more critical by the fact that our mineral resources are non-renewable and a complete and immediate inventory of such resources is critical to their proper management.

a. Surface Materials Composition

The most promising techniques for acquiring information about the chemical and mineralogical composition of surface materials from satellite-borne instruments are based on measurements of the following physical parameters:

1. visible and near-infrared spectral reflectance
2. thermal inertia
3. thermal-infrared spectral emittance

It is now clear that processing the MSS spectral radiance data permits subtle distinctions among rock and soil units that cannot be achieved through analysis of unenhanced images or color photographs.

- In stretched-ratio image concentrations of iron-oxide minerals can be distinguished from other mineral assemblages. This is important, not only because of the association of limonite with some hydrothermal alteration zones, but also because it illustrates the potential for using spectral data for estimating surface composition. With the exception of limonite, the MSS data can be used with careful processing and analysis to discriminate some materials, but it does not permit identification.

- Addition of spectral bands near 1.6 μm and 11 μm and imaging at both 11:00 am and 11:00 pm with the Thematic Mapper would markedly improve the capability to discriminate surface materials. Reflectance contrast between broad categories of rocks is highest in the 1.6 μm region. Another advantage of the planned 1.6 μm band is that vigorous vegetation is darker in this region than most rocks, expecially hydrothermally altered rocks. This characteristic should allow discrimination of altered rocks in areas of denser vegetation cover than is possible with present MSS data.

- Thermal inertia measurements permit discrimination of surface and near-surface materials that cannot be achieved, using any other remote sensing techniques. Moreover, the compositional information obtained is highly complementary, rather than redundant, to techniques that depend on spectral reflectance differences.

- Comparison of the average reflectance spectra for rocks with the proposed Thematic Mapper spectral bands shows that only the iron absorption bands and the 1.6 μm window are included in the sensitivity range of the Thematic Mapper. No radiation will be measured in the 2.2 μm region. Therefore, critical information pertaining to hydrous rocks will not be available.

- The rationale for thermal-emissivity ratioing rests on the fact that some rocks depart significantly from black-body behavior in the 8 to 14 μm region, resulting in an absorption (or reststrahlen) band. This phenomenon is most prominent in silicates, and its wavelength position can be related to the composition of the rocks. Multi-thermal channels permit a separation of compositional and temperature differences among geologic targets. Two crucial questions can be answered by monitoring multiple spectral bands in this region: (1) is the material a silicate or non-silicate, and (2) if it is a silicate, what is its general composition?

- The thermal-infrared band with 120-meter resolution offers the best thermal data yet available. Specific applications for uranium exploration will probably center on definition of lithologic variations in potential host strata, especially where standard geologic mapping is difficult.

b. Igneous Intrusives and Impact Structures

Many of the important mineral deposits of the world are associated with intrusive igneous bodies. Of great importance are porphyry copper deposits within igneous bodies of intermediate to felsic composition. In the enclosing rocks commonly found peripheral to these intrusives are deposits of base and precious metals. Where igneous bodies intrude carbonate rocks, deposits of tungsten, silver, and base metals may form within the surrounding zone of metamorphism.

- Discrimination of rock types or alteration associated with mineralization can be made on the basis of spectral information properly combined and enhanced. Study of satellite images thus provides a basis for identifying promising exploration areas in which necessary field data can then be acquired to confirm or deny mineral potential.

- The principal contribution of the planned Landsat follow-on to the delineation of igneous intrusives will lie in the increased resolution of the Thematic Mapper.

- In desert areas, thermal data probably will serve to distinguish many intrusive bodies from surrounding rocks, and will help to discriminate among different types of intrusive rocks.

- The added 1.55-1.75 μm band may aid in defining intrusives of different iron-mineral content than surrounding rock.

The brecciated and fractured rocks below and around impact structures provide conduits and traps for ore-forming fluids. Much of the world's nickel and cobalt is produced from a probable impact structure at Sudbury, Canada, and gold is being mined in the Ishim ring structure, another probable impact structure in north-central Kazakhstau. The Carolina bays in the Carolinas and Georgia, long-suspected impact structures, produce much of the peat in that part of the U.S.

- Over 800 of these have been located on Landsat images. Space photography is an excellent tool for finding such circular structures.

c. Tectonics

Geologic structures that influence the location of mineral deposits include faults, shear zones, joints, and other fractures. Many of these structural features can be mapped effectively from space.

Using new concepts of "continental drift" or "plate tectonics", many geologists postulate a relationship between major crustal breaks, igneous activity, and ore deposits. Structural geologic information extracted from data provided by space-borne remote sensors is being used to attempt to unify the "classical" concepts and the newer plate tectonics hypotheses.

- The synoptic view is invaluable for regional geologic studies because it provides a view of a much larger area and permits correlation of structural features over much greater distances than by using aerial photographs.

d. Erosional and Depositional Features

Depositional features of economic potential are features where economic deposits of precious metals and/or nonmetallic minerals may be concentrated by primary deposition or secondary enrichment.

Erosional features are important in mineral exploration because they provide evidence as to surface condition, recent morphologic history, and mechanisms of possible redistribution of material.

- Both erosional and depositional features are identified from aircraft or satellite images, mostly on the basis of surface pattern and topography.

- Three image characteristics are of prime importance in identification and mapping of these features: (1) a reliable presentation of normal tonal values and/or colors, (2) stereoscopic presentation of the scene, and (3) a regional perspective.

- Digital analysis can be useful in enhancing surface textural features.

e. Vegetation

Although vegetation masks soils and rock outcrops, it can be used as an important indicator of the underlying geologic terrain.

Many ore deposits are concentrated along fractures in the Earth's crust. Where such fractures are water rich, they are often marked by healthier and more abundant vegetation.

Variations in vegetative cover also indicate differences in soils which reflect differences in the underlying rock units (such as in the Powder River Basin, Wyoming) and accreting shorelines (i.e., those along the east coast of the United States where valuable titanium deposits were found). Local, anomalous vegetation patterns may also serve as indicators of anomalous concentrations of heavy metals in groundwater (metal poisoning) or nutrient-deficient parent rocks (such as serpentines and other ultrabasics).

- The proposed system will offer some improvement over the present Landsat by the addition of the 1.6 μm band and improved resolution for use in vegetative mapping.

f. Economic Considerations

The use of Landsat data to their fullest potential for minerals exploration should produce the following economic advantages:

(1) Savings during the reconnaissance exploration stage. The savings will be proportional to the decrease in amount of exploration effort (and cost) for this first stage of exploration.

(2) Savings during the exploration of individual prospects. This function would be to help eliminate unfavorable areas and permit concentration of the more expensive exploration procedures on the most favorable areas.

- Actual monetary savings are difficult to assess and virtually impossible to document. An expected increase in efficiency of 20 per cent through the use of Landsat imagery in ruling out unfavorable areas and selecting the most promising areas is not unreasonable.

- Another important consideration for mineral exploration and development is more efficient planning that might result from accelerated discovery of ore bodies. For example, in Georgia, recent discovery of a carbonaceous clay (an excellent light-weight aggregate) deposit was made near a rail line that was abandoned and dismantled only two years ago. These deposits, currently uneconomic, would have been economic had they been discovered in time to save the line. Re-establishment of the rail line now would involve unacceptable costs.

- Additional savings can be expected by the use of Landsat follow-on data during the development and operational stages of mineral extraction. These savings will come from more efficient operations resulting from better site selection for processing facilit. es, waste disposal areas, and other development associated with a major mine.

2. Energy Resources Exploration

a. Petroleum (On Shore)

1. Structural Studies

Petroleum exploration and production typically follows six states of activity for companies that have begun using satellite data:

1) Regional geologic reconnaissance of large areas are used to recognize sedimentary basins and major structural features within the basin.

- Landsat images compiled into mosaics have proven valuable to many companies for this exploration phase.

2) Surface geologic mapping and sampling of outcrops.

- Enlarging Landsat images can aid in locating areas suitable for these studies.

3) Aerial magnetic surveys and ground-based gravity surveys are the initial geophysical reconnaissance.

- Trends of lineament and structures for Landsat interpretation of regional reconnaissance can aid in locating and orienting these surveys to obtain optimum crossing of the structural pattern.

- Base maps derived from Landsat can be valuable aids to the aircraft navigators and field party chiefs.

4) Seismic surveys are made over promising anomalies located in the previous 3 stages.

- Trafficability and access information from the Landsat maps can save several days of crew time each month at a typical cost of $5,000 per day in isolated foreign areas.

5) Drilling of prospects that have been targeted by activities 1 through 4.

6) If the 1 to 20 odds against success have been overcome and an oil field discovered, the final stage is to produce and transport the oil to market.

- Preliminary pipeline route studies can be made from Landsat images and environmental impacts assessed.

2. Direct detection of Hydrocarbons

Although many of the detailed geochemical processes and interactions are poorly understood, some general pathways of petroleum microseepage are known. The surface manifestation of these processes can be used empirically in the search for new oil and gas deposits and, given the proper conditions, they are amenable to remote detection.

- Feasibility studies have suggested the practicality of using Landsat data in certain areas to reconnoiter for different kinds of surface alterations. Landsat follow-on should appreciably increase the number of such alteration patterns that can be detected, owing principally to its 30-meter resolution.
- Addition of the 1.5-1.8 μm and 0.50-0.52 μm channels will aid in the discrimination of alteration products associated with hydrocarbon seepage.

b. <u>Petroleum (Off Shore)</u>

There are several offshore exploration problems that Landsat data can be helpful with, though most of these uses are just beginning to occur. The most rudimentary is ice flow and iceberg mapping, which is particularly important to the increasing petroleum exploration and tanker transportation in Arctic waters.

- Landsat 1 and 2 repetitive coverage would be useful for this purpose if newly collected images were available on a timely basis.
- The thermal IR capability of Landsat C and follow-on should help somewhat in discriminating ice from snow and clouds.

Since seismic exploration in shallow shelf seas is commonly hampered by uncharted underwater obstructions, such as coral reefs and sand bars, Landsat imagery and computer-enhanced images can be of important use for bathymetric mapping.

- The addition of the 0.50-0.52 μm band on Landsat follow-on is expected to increase water penetration by approximately 30%. Sea-bottom structural features (lineaments, salt domes, etc.) interpreted from Landsat data can lead seismic teams to likely regions of favorable structure for shallow petroleum deposits.

- The new blue band of Landsat follow-on will be quite helpful, though the later time of day may be harmful in that more sunglint from normal sea state wave action may be expected.

c. Coal

In general, domestic exploration for coal has not operationally utilized Landsat imagery because U.S. coal deposits are known. Thus, industry's interest in remote sensing for coal deposits involves resource assessments, reserve determination, mine planning, geologic hazards evaluations, land inventorying, and reclamation and environmental surveys.

- The principal improvement in the present Landsat (1, 2, and C) imagery which would encourage active utilization of Landsat remote sensing by the coal industry would be to significantly increase the resolution from which their operational maps are being derived. The planned 30-meter resolution of Landsat follow-on will undoubtedly encourage the coal industry's utilization of Landsat follow-on imagery in domestic coal operations.

- Anderson cites a cost comparison between air photo and Landsat monitoring of surface mining areas per 10,000 square miles of $265 - 360 versus $0.30 - 0.60, a cost factor of 880/1 to 600/1 in favor of Landsat imagery.

- A major improvement will be the addition of the 1.55 - 1.75 μm band. This band can be ratioed with the shorter wavelength to better sense carbonaceous material, specifically coal, because of its high absorption compared to most other rocks and vegetation.

d. Shale Oil and Tar Sand

The extensive deposits of oil shale and tar sands in Western U.S. and Canada could provide a potential future source of petroleum. Unfortunately, the current technology of extracting this valuable hydrocarbon source does not make it economically attractive at this time.

When this hydrocarbon source becomes operationally and economically feasible, Landsat data will be invaluable in monitoring the environmental impact of the mining process and Landsat follow-on, with its improved spatial resolution, will greatly increase our ability within this application area.

e. Geothermal Exploration

Geobotanical anomalies (e.g. vegetation-stressed areas) are often associated with surface temperatures, some of which are 2° C or more warmer over geothermal resource areas than over the surrounding terrain. Aerial surveys of geothermal anomalies have outlined the extent of thermally active geothermal resource areas about as well as shallow ground surveys and required only 6% of the time and cost.

- Landsat follow-on will have the potential of detecting these areas because of the inclusion of the 1.5 - 1.6 μm band.

Indirect evidence of geothermal resource areas manifested by volcanism, tectonism, or high heat flow is provided through the flow of hydrothermal fluids and surface alterations.

- The visible and near infrared bands, when ratioed, have been used to identify some hydrothermally altered areas.

- Landsat imagery is useful for locating fracture systems that allow hydrothermal fluids to circulate.

Thermal inertia maps outline contrasting features associated with the different physical characteristics of near-surface geologic materials (e.g moisture content, density, specific heat, thermal conductivity). This provides a photogeologic aid for locating faults and hydrothermally altered materials found in association with geothermal resources.

- Day-night temperature differences determined from 10.4 to 12.5 μm infrared radiation, measured twice daily on Landsat C and follow-on satellites, could be useful for thermal inertia studies. Some areas with surface isotherms above the surrounding areas may contain exploitable concentrations of hydrothermal fluids at temperatures near 200 $^\circ$C and depths from 1/2 to 3 km. These hydrothermal fluids discharge along faults, fractures and channelways. This raises the local isotherms, increases the vertical temperature gradients and transfers heat partly by conduction, but mostly by convection to the surface.

- Landsat nighttime thermal imagery is expected to outline the aerial extent and thermal energy patterns over geothermal areas with surface isotherms 1 or 2 $^\circ$C and 3 to 10 $^\circ$C or more above surface ambient.

3. Environmental Geology

This section addresses the application of Landsat follow-on to the selection and evaluation of sites for engineered structures in terms of geologic hazards, earth materials for engineering usage and environmental impact (exclusive of mineral and mineral fuel extraction). Remote sensing data are typically used in site investigations for dams, power plants, flood control structures, towns, airfields, bridges, tunnel locations and high-rise buildings. These data are also applied to corridor surveys for highways, railways, canals, pipelines and powerlines, as well as in exploration for stone and aggregate and fill material.

- The synoptic view of the project region available from Landsat follow-on will depict conditions existing at a given time and provide data relating to the relationships between climate, geology and cultural factors that are of particular value in evaluating the impact of a new engineering facility on the environment.

- Evaluation of sequential coverage of the Landsat follow-on will provide a method for noting changes in the landscape and its environment.

- The system's greater resolution capabilities will be an improvement over the present MSS system in Landsat 1 and 2 for numerous applications, such as linear delineation, landform analysis, rock and soil identification, and recognition of potential hazards such as landslides and sinkholes.

- The greater spectral range of the TM will permit better discrimination of soil and rock types and vegetation cover.

- The 9-day coverage frequency of Landsat follow-on, coupled with the resolution of the TM, will allow it to be utilized to monitor such post-construction changes as landslide activity, erosion, and reservoir leakage occurring over large areas.

a. Earthquake Damage

Both active and inactive faults present potential hazards for engineered structures. During earthquakes, structures astride the fault trace are subject to rupture, and structures within the area of significant ground-shaking are affected by ground acceleration and secondary ground failures associated with the ground-shaking (liquefaction, landslides, lateral spreading, soil collapse). Inactive faults present a hazard to certain structures, such as dams, because fault breccia zones are generally highly permeable to fluids moving parallel to the fault.

- Because of its improved resolution, Landsat follow-on will permit the identification of many faults capable of generating damaging earthquakes, especially useful in areas where limited aerial photo coverage is available.

In contrast to the great potential for locating possible active fault zones by remote sensing techniques in the arid United States, location in the eastern United States is one or two levels more difficult. Location is hindered by the thick soil and vegetation cover, and by the generally lower level of seismicity. Ground investigations have revealed several small post-Cretaceous faults, some of which may be as young as Holocene. These do not appear prominently on Landsat 1 and 2. The higher resolution of the Landsat follow-on might permit better identification of possible fault zones through the recognition of aligned vegetation and land use patterns, and anomalous land use patterns resulting in identifiable lineaments.

Cross-strike lineaments may be identified with seismicity in some parts of the eastern United States. The preparation of regional fracture-lineament maps to accompany the growing number of regional seismic networks throughout the United States is an important step in consideration of nuclear power plant siting. Landsat 1 and 2 images are currently being analyzed with respect to cross strike linears throughout the eastern seaboard, and possible correlations with seismicity noted.

- Landsat follow-on images will improve analysis of cross-strike linears because of the better resolution; however, the higher sun angles will be detrimental.

b. <u>Landslides</u>

Monitoring landslides is one of the more significant potential applications of earth-orbiting satellites in the earth sciences because earth movements are one geologic process which proceeds on a relatively short time base. Little use has been made of Landsat 1 and 2 in the direct identification of landslides because the 80m resolution is insufficient.

- Improvement to 30m resolution with Landsat follow-on should permit larger landslides to be identified; however, the vast majority of landslides are much smaller and will still be below the resolution limit.

- The planned higher sun angle and lack of stereo are detrimental to landslide identification.

c. <u>Subsidence and Cave-ins</u>

The hazard of cave-ins and sinks in limestone terrain has been identified by observing alignments of the larger sinkholes on Landsat 1 and 2 images. Knowledge of the areas where limestone sinks were most likely to be encountered permits significant savings in highway construction.

- Landsat follow-on, by permitting smaller sinks to be identified, will sharpen the ability to predict sinkhole hazards.

d. <u>Volcanic Eruptions</u>

The hazard from volcanic eruptions is one that is typically monitored at a variety of scales from ground observations to satellite reconnaissance. The greatest value from satellite observations is in remote areas.

- Landsat monitoring of Iceland has revealed the potential to quickly map new flows and tephra falls.

e. Foundation and Construction Materials

The physical properties characterizing a foundation material are dictated by the composition, degree of consolidation,and structure (e.g., the presence or absence of planes of weakness). The occurrence of construction materials (quarry rock, sand and gravel, and clay binders) is closely related to associated landforms. Landform analysis, therefore, is the commonly used approach to the search for construction materials. Examples are alluvial deposits (sand and gravel), sand dunes (sand), and residual deposits (lag gravels and cinder cones).

Although large-scale color photography has been noted to be best for the location of construction materials, the close relationship of material type to associated landforms provides the opportunity for the use of Landsat follow-on for this purpose.

f. Cost Benefits

Available data do not make possible a definitive evaluation of the cost benefits that can be realized from utilization of Landsat follow-on data. Toward this goal, however, a recent study exemplified the losses associated with geologic hazards in California. Losses in property damage, life,and mineral resources from geologic hazards in California are estimated to be $55 billion for the period 1970-2000. An estimated $38 billion of this could be saved by application of current state-of-the-art reduction measures at a cost of $6 billion. Foreseeable advances in the state-of-the-art loss reduction measures could result in near-zero loss of life and a 90 percent reduction in property damage.

- Landsat follow-on data can reasonably be expected to play a significant role (conservative -- 1%) in this reduction because of its ready availability, frequency of coverage, and low cost to the user.

4. Mapping and Interpretation

Geologic mapping and interpretation include all mapping of the geometry and composition of the earth's surface materials, i.e. lithologic and structural mapping (the two basic facets of the standard geologic map), as well as special purpose mapping, such as geomorphic (landform) maps, surficial deposits maps, etc. Also included in this context is planimetric base mapping, since the geologic information must be plotted on an adequate base, and since Landsat imagery itself has proven to be a near-perfect Orthophoto base map medium for this purpose.

The importance of geologic mapping and interpretation for mineral and petroleum exploration (and hazards/engineering or environmental geology) cannot be overstated. The geologic map provides the data base from which the fundamental interpretations are made to reconstruct the chronology of geologic events affecting a region. Then, and only then, can a comprehensive and efficient exploration program (or hazards assessment) be effectively carried out.

- Generally speaking, the overall quality of the geologic maps that can be produced using Landsat follow-on imagery will be significantly improved, principally as a result of the three-fold increase in spatial resolution of the Thematic Mapper.

- The reduction in shadows will reduce the ability to interpret surface morphologic features. Distortions, both radiometric and geometric, caused by the wider angle of instantaneous "view" of the sensors will adversely affect many applications to an unknown degree.

a. Orthophoto Map Preparation

A very useful product of Landsat 1 is the orthophoto map, a number of which are already available as federal and state publications. These are printed halftone reproductions of Landsat mosaics of individual states or smaller regions. They may be monochromatic, made from a single spectral band, or polychromatic (false color) combinations of two or three bands. They are "photographic" renditions of landscape reality rather than man-made maps, and as such are extremely useful in regional structural analysis. Cultural information is easily overprinted on these maps.

b. Mapping Rock Types

Addition of the MSS band 1.55 - 1.75 μm in the "Thematic Mapper".

In the region of 1.6 μm there is a greater range of intrinsic reflectance for surface materials than at any other wavelengths in the 0.4 - 2.5 μm range. With the exception of playa materials, reflectance values of surface materials in the 1.6 μm band range from 10 to 75% versus 8 to 40% in the present Landsat spectral bands.

- The 1.6 μm band will provide a unique capability for measuring vegetation stress by reflecting the underlying soil composition in addition to other factors.

- Analysis applied to 10 classes of materials including basalts, limestones, altered materials and others showed the 1.6 μm band to be the most important band for separation of these classes.

- The increased signal-to-noise ratio, providing 256 gray levels instead of 64 will allow subtle tonal features associated with facies changes of all kinds to be displayed.

- Addition of the 10-12 μm thermal infrared band

Thermal inertia is generally correlated with density, but moisture content is also an important factor. Under reasonably dry conditions, distinctions such as limestone and granite vs. dolomite or quartzite, shale and marl vs. limestone and granite, and basalt and amphibolite vs. ultramafic rocks, should be achievable because of mineralogically related density differences. Also, some surface materials are distinguishable because of their different moisture retention property.

Studies employing the thermal inertia approach have not been specifically directed towards altered rocks, but consideration of mineralogical and porosity changes during alteration indicate that some altered rocks might be distinctive. In general, thermal inertia might be expected to increase with increasing alteration intensity due to decreasing porosity and increasing quartz content.

- This will be most useful for geologic applications, if night-time data can be obtained. Although the 11:00 am and 11:00 pm acquisition times are not optimum, and 9:30 AM time is even worse, thermal inertia maps can be created which will provide information complementary to that obtained from the reflective region.

c. Mapping of Geomorphic Features

- The nearly three-fold increase in resolution (from 80 m to 30 m) in the Thematic Mapper will significantly improve the capability to map glacial, fluvial, desert, and permafrost features, which are marginally observable or below the limits of detection on earlier Landsat imagery.

Coastal mapping will increase our knowledge of dynamic coastal processes in both a fundamental way and in the solving of practical problems of coasts and harbour engineering. Such applications include mapping seasonal changes along beaches, mapping erosional and depositional changes along coasts, measuring rates of constructional and destructional processes, mapping the changing geometry of land both above and below water level, mapping subaqueous bedrock structures, shifting shoals, monitoring the effects of coastal engineering, providing guidance for dredging operations, monitoring (and ultimately predicting?) coastal landslides based on the mapping of soil moisture and the arcuate development at heads of slides.

- The water penetrating capability of the .45 - .52 μm band will also permit the mapping of suspended materials and the calculating of settling rates after storms. Reservoir filling patterns and rates of reservoir filling might become mappable and hence measurable.

- An inescapable shortcoming of this waveband is that atmospheric haze will be about three times the signal strength, but digital enhancement of the data will hopefully diminish this disadvantage to a significant degree.

d. Structural Mapping

Structural mapping includes the delineation and analysis of all visible folds (anticlines, synclines, monoclines, structural terraces, etc.) and fractures (faults of all types, joints, etc.) revealed on the imagery. Most of the structural information derived from Landsat to date has been in the form of "linears" as well as curvilinear and arcuate features. These phenomena have been strikingly discernible on the Landsat imagery to date due to the shadowing effect of the low sun angle (9:30 am time of equatorial crossing). The change of time to 11:00 am will result in a higher sun angle, fewer shadows and hence, diminished visibility of linears.

- Unfortunately, effective and comprehensive structural mapping is not possible to achieve in the "monocular" mode of the present Landsat imagery. Stereo vision is needed to determine the inclination of dipping strata, the presence of fold structures and the direction and magnitude of offset (if any) along the faults (or linears).

e. Linear and Long Lineament Mapping

Earlier Landsats have demonstrated the value of MSS imagery for the detection and delineation of tens of thousands of kilometers of hitherto unknown linear, curvilinear, and circular features. Many of these are now being investigated on the ground, by both conventional and geophysical methods. The goals of these ground investigations range from basic mapping and research into fracture pattern geometry and brittle deformation, to the search for indicators of petroleum and mineral deposits.

The preparation of regional fracture-lineament maps is vital to the growing need to ascertain which fractures are related to current earthquake activity. The proliferation of regional seismic networks (e.g., California, Missouri, the Northeastern States) is already providing a data bank of fault plane solutions. Companion brittle structure maps are now needed. Applications to nuclear power plant siting are obvious and compelling in view of the National goal of energy independence by the late 1980's.

- The nearly threefold increase in resolution (from 80 m to 30 m) will provide at least two additional new contributions to the mapping of linear features: 1) the detectability of shorter linears which, in the extensive plateau areas of the globe can be expected to provide maps of joint systems; 2) a look at the "fine structure" of large-scale lineaments which are already mapped, but which have very complex surface expressions and origins.

Attempts to predict new mineral-rich areas have been made by relating the distribution of known mineralization to three tectonic concepts: 1) classical geosynclinal theory, 2) plate tectonics, and 3) crustal block tectonics. All three relate mineralization to linear elements in some way.

- The synoptic view of Landsat has permitted the recognition of a pervasive system or systems of long lineaments, many of which correlate with the crustal zones already postulated, and many of which represent new alinements. Research on these lineaments, and their relation to tectonic linear features, to crustal block boundaries, and to mineralized areas, has presented persuasive evidence that Landsat long lineaments do reflect crustal features that have controlled mineralization.

- Once world-wide, multi-season coverage is obtained, repeated views are not necessary. The value of repeated views to take advantage of surface changes (denudation, fault offset, etc.) will be felt in structural mapping and short linear study, directed to location of areas meriting detailed study, sampling, geophysics, and drilling.

f. <u>Circular Features</u>

Recognition of unsuspected circular features is perhaps the most unique immediate return from Landsat. The value of this phenomenon is readily apparent. Some represent buried volcanic centers, alined along earth fractures characterized by progressively offset eruption, and help in the prediction of progression of volcanic activity. Most outline calderas, ring dike systems, impact craters, or subjacent plutonic bodies, features known to have mineral deposits along their periphery, or contained within them, or which provide indicators of high temperature activity nearer the surface than elsewhere, and hence possible source areas of geothermal power. Others suggest basins, or domal structures in the sediments of those basins, guides to oil and gas, or saline deposits.

- The qualifications with respect to the value of Landsat follow-on described for long lineaments apply to circular features as well.

- The addition of capability for first approximation thermal inertia maps will be of additional assistance for exploration for geothermal power, although the data will probably be insufficiently detailed for more than corroboration of the potential of areas.

g. <u>Arctic Sea Ice Mapping</u>

Sea ice monitoring and forecasting impact transportation of exploration and development materials to the site and products from the site, providing knowledge of present conditions for navigation and predicting future conditions for route selection. This involves location and extent of navigable leads, bergs, floes, pressure ridges, and areas of weak and new or strong and old ice. Marine seismic exploration is similarly affected. Increasing use of on-ice winter seismic methods requires similar knowledge of leads, melt areas, pressure ridges, ice islands, and surface roughness. Installation of off-shore platforms and loading facilities is impacted, as well as construction of between-island pipelines and overland pipelines at land-water interfaces.

- Ice watch and forecasting, begun by surface methods, and later aerial surveillance, has been significantly advanced by the meteorology satellites. Minimum resolution on these, however, is about 1 km (NOAA 3-4). Landsat resolution of 80 m, and MSS discrimination of near-IR, has provided additional benefit.

- The Canadian government in 1973 assessed the benefits of a remote sensing system including sustained Landsat data (based on Landsat 1). They estimate an aggregate of $11-$12 million in benefits by 1990 for all phases of Arctic exploration (Canada only), assuming an aircraft-NOAA-Landsat continuing system.

- The greater resolution, increased spectral bands, and increased repetition of viewing will enhance the capability to identify and locate accurately floes, bergs, leads, new and old ice, pressure ridges, and melt water areas on ice, improving both exploration and development activities in the Arctic.

- The sun angle of the proposed 11:00 am flight will be of little benefit or detriment, as the sun angle is universally low in the Arctic.

- The increase in atmospheric attenuation and disturbance generally experienced in the middle of the day may be deleterious.

- As positioning is of great importance in the ice, the increase in viewing angle producing geometric distortion of any significant amount is detrimental. On-ice relief is minimal, but position is obtained locally commonly with respect to high relief land areas.

- For effective use, geometric distortions should be routinely and rapidly removed before imagery is supplied to the user.

- As potential resource areas extend north to about 85°, exploration will be enhanced by a more polar orbit due to the inclination change required to maintain sun-synchronism for a lower orbit.

C. CONTINUING ISSUES

1. The Case for Stereo

Landsats 1 and 2 have not yet had the striking impact needed to meet the growing world-wide demand for energy and minerals resources. Although Landsat C and follow-on, as designed, will have important improvements to their forerunners, they will not square up to the needs of the exploration geologists, particularly the oil explorationist. In the view of many geologists, the greatest need is the capability for stereo viewing.

Regional geologic mapping includes at least two basic facets, i.e., (a) lithologic mapping (discrimination of rock type composition) and (b) structural mapping (folds, faults, etc.). This basic geologic map becomes the data base interpretation and determination of the chronology of geologic events, from which effective petroleum (and mineral) exploration begins.

Discrimination of Rock Type is the first phase of the basic geologic mapping process. The experienced photogeologist is able to routinely discriminate between the basic rock types to a remarkable degree of accuracy when the imagery is viewed in the stereoscopic perspective, because the lithologic character of the bedrock produces unique land form and textures that can be readily recognized using stereo vision. The "form" and "texture" of the terrain, and the associated drainage patterns provide remarkable clues to underlying lithologies, even in heavily vegetated areas and in areas with a thin veneer of surficial deposits.

Structural Mapping includes the delineation and interpretation (evaluation) of all visible folds (anticlines, synclines, monoclines, structural terraces, etc.) and fractures (faults of all types, joints, etc.) revealed on the imagery. It is important to perceive and delineate the small and large structural features alike, since the smaller features are products of movements of the larger elements.

Effective and comprehensive structural mapping cannot be achieved in a "monocular" mode. Stereo vision is needed to determine the inclination of dipping strata and the direction and magnitude of offset (if any) along the faults (or linears). Most of the structural information derived from

Landsat to date has been only two dimensional while in fact they represent profound three-dimensional elements to the geologic puzzle. Their correct interpretation holds the key to unlocking the chronology of geologic events responsible for the implacement of petroleum and mineral deposits in the subject area.

2. Addition of a Band Near 2.2 μm

The 2.2 μm region is particularly important for providing information pertaining to hydrous rocks. The lack of a 2 - 2.4 μm band on the Thematic Mapper will have the consequence that (1) limonitic (or hematitic), but anhydrous unaltered rocks, such as ferruginous sandstone and tuff, will not be distinguishable from limonitic altered rocks, and (2) unaltered anhydrous rocks that are highly reflective in the 1.6 region will appear similar to iron-poor hydrous altered rocks. Thus, a problem of major importance, the ability to separate iron oxide associated with mineralization from more common iron oxide occurrences, will remain unsolved.

Additional support for the importance of the 2.2 μm band comes from analysis of S-192 spectral radiance data by Marrs and his associates concerning sedimentary rocks in Wyoming. Of the visible and near-infrared spectral bands, contrast among the units was found to be highest in the 2.2 μm band, although contrast was also high in the 1.6 μm region. This observation is consistent with the presence of hydrous (shale), anhydrous (sandstone) and carbonate (limestone and dolomite) rocks in the sedimentary sequence.

3. Thermal Bands

There is a need for dual thermal bands of 8.2 - 9.4 μm and 10 - 12 μm. The ratioing of these bands will allow the determination of the non-black-body emissivity necessary to thermal measurements, particularly in silicates, thus permitting a separation of compositional differences concerned with silicate materials. A dual thermal band would also have built-in redundancy.

D. SUMMARY AND CONCLUSIONS

Table III-1 gives a summary of the subgroup evaluations. The last column of the table gives a grand average of all four sub-applications. The evaluation numbers range from -3 (Detrimental) to +3 (Good), with zero being Neutral. These numbers are relative to the best attributes of Landsat 1, 2, C, and follow-on for geological remote sensing.

Of the three lowest rated line items, two were ground station functions. Low contrast images were considered worst by users, although high contrast stretched single channel images are available commercially by several data processing firms. To correct this ground function would place the government in direct competition with existing firms on existing products. Slow data delivery, on the other hand, is a low-graded ground function which, if corrected, would help everyone. The lack of stereo coverage is the most down-graded satellite function listed in the table, and stereo will not be included even on Landsat follow-on.

The mid-day coverage of Landsat follow-on was rated approximately neutral for geological remote sensing, because improvement in signal-to-noise (only partially due to mid-day coverage) was better received (average rating of +2.2) than the high sun angle (rated -0.5) was degraded. Quite clearly, the most meaningful improvement in Landsat follow-on over previous Landsats is the improved 30 meter spatial resolution (rated +2.5). Program continuity (no time gaps in data collection by Landsat 1-type scanners) was surprisingly high-rated (+2.1) by the panelists. It should also be noted that the addition of a 10.4 - 12.5 μm thermal channel on Landsat C was received rather cooly (rating of only +0.8), but that the addition of day-night coverage by the same channel received a high rating (+2.0). NASA should strongly consider adding day-night thermal coverage to Landsat C. The new reflective IR band near 1.6 μm was rated highly (+1.7) on the average, but especially high (+3.0) by the minerals exploration subgroup.

As important an improvement as Landsat follow-on promises to be for geology, the members of this Applications Survey Group felt it necessary that NASA be made aware of the shortcomings of all the planned Landsats for geological remote sensing. The second page of Table III-1 lists some of the properties that are needed from satellite systems that are not available on any Landsat. The two highest-rated line items are better than 30 meter resolution and day-night thermal IR coverage at optimum times for making thermal inertia measurements (when the day-night temperature differences are maximum, which are predawn and early afternoon for most cases).

Next most important was stereo coverage, which might better be accomplished by an inexpensive satellite designed principally for stereo (low sun-angle, changeable orbits, one or two channels with excellent spatial resolution, etc.). Of the new spectral regions that hold important new information for geological problems, radar was ranked highest, followed by a 2.0-2.5 μm channel (in conjunction with a 1.55-1.75 μm channel), and an 8.2-9.4 μm channel (in conjunction with a 10-12 μm channel). The radar channel would permit better structural analysis of tropical terrain and might even be an acceptable substitute for stereo if low depression angles and overlapping coverage were obtained at high spatial resolution. However, it probably would have to be borne by a satellite especially tailored for radar. The 2.0-2.5 μm and 8.2-9.4 μm infrared channels, in conjunction with the 1.55-1.75 μm and 10-12 μm channels already provided by Landsat follow-on, would provide significant new mineral, rock, and soil compositional information that simply cannot be obtained by Landsat follow-on in any other manner. Note that all three of these highly-rated channels are outside the wavelength regions that the eye or photographic film can detect. Hence, these data have a higher than average probability of performing totally new tasks.

In summary, Landsat follow-on will be a marked improvement over previous Landsats in terms of solving geological problems with remote sensing, though it is indeed unfortunate that we will have to wait so long for this improvement. Landsat follow-on will not, however, meet many of the needs of geological remote sensing. As non-renewable resources grow more important every year on a world-wide scale, the need for one or more satellites dedicated to geological remote sensing becomes increasingly compelling. If the history of science teaches us anything, it shows us that new information breeds far more applications than those for which the information was sought. Because little experimentation has been conducted applying the above desired satellite characteristics to other scientific disciplines, especially those involving vegetation, it would appear likely on a historical basis that satellites designed principally for geology would significantly improve remote sensing in several other disciplines, including those for which the Landsat series were "optimally" designed.

Finally, NASA must bear in mind that one of the agency's major tasks outside of Earth resources would be greatly aided by the development of one or more satellites designed principally for geology, namely, extraterrestrial exploration. Unlike satellites designed principally for vegetation, geological satellites can yield significant information about Mars, Mercury, several planetary moons, and the asteroids. Thus, satellites designed primarily for geological remote sensing would appear to be cost effective in overlapping both Earth resources and extraterrestrial exploration missions.

TABLE III-1
SUMMARY OF GROUP EVALUATIONS

Good (Neutral) Detrimental
3 2 1 0 -1 -2 -3

	Mineral Exploration	Energy Resources Exploration	Environmental Geology	Mapping and Interpretation	Grand Average
LANDSAT 1 and 2					
80 m Spatial Resolution	0.6	1.6	0.7	1.0	1.0
Signal/Noise - Moderate	1.4	0.2	-2.6	0.7	-0.1
Spectral Range 0.5 - 1.1 μm	1.0	0.2	-2.2	1.0	1.1
Repeat Coverage	3.0	1.4	1.1	1.3	1.7
182 x 182 km mi. Format	3.0	1.6	0.7	3.0	2.1
Mid-morning 9:30 a.m.	[illegible]	2.0	1.4	2.5	2.0
Digital Tapes - Raw data	2.6	2.0	2.0	1.2	1.9
* Data Delivery as presently experienced	0.0	-1.6	-1.0	-1.8	-1.1
* Image Quality as presently available	-2.4	-2.2	-2.4	-2.2	-2.3
Incidental Stereo	-2.4	-0.8	-1.7	-2.0	-1.7
Geometry - Excellent	2.8	2.6	1.8	1.2	2.1
LANDSAT C					
Add: 10.4 to 12.5 μm	0.8	1.4	0.2	0.8	0.8
* Digital Tapes, Corrected	2.4	1.4	2.4	1.7	2.0
* Data Delivery, Rapid (48 hr.)	0.0	2.4	1.1	2.0	1.4
RBV Panchromatic	2.4	1.0	2.4	1.2	1.8
LANDSAT FOLLOW-ON					
30 m Resolution (except thermal)	3.0	2.8	2.0	2.0	2.5
Add: Blue Band (water penetration)	1.0	1.2	0.1	1.0	0.9
Add: Near IR (1.6 μm - mineral)	3.0	1.4	0.9	1.3	1.7
Program Continuity	3.0	2.6	1.9	1.0	2.1
Near-Noon - 11:00 a.m.	-0.2	0.0	-1.7	-0.2	[illegible]
Signal/Noise - Improved	2.4	2.4	2.6	1.5	2.2
Geometry - Degraded at lower altitude	0.0	-0.8	-2.1	-0.3	-0.8
10.4 - 12.5 μm Day-Night coverage	3.0	--	2.1	1.0	2.0
Resolution - better than 30 m	1.4	2.2	2.8	3.0	2.4
Additional Spectral Bands					
Passive Microwave	1.2	1.0	0.2	0.5	0.7
Radar	2.0	1.2	2.3	2.2	1.9
Laser Topog. Profile	1.0	0.6	0.8	0.5	0.7
Fraunhoffer Line Discrim.	1.4	1.2	0.0	0.2	0.7
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	1.6	1.6	0.6	2.3	1.5
8.2 - 9.4 μm (with 10 - 12 μm)	1.6	1.0	1.3	1.0	1.2
Different Variable Time of Day					
Very low sun angle	0.2	2.0	2.1	0.3	1.2
Night (for thermal IR)	1.8	2.2	1.9	1.0	1.7
Non-Sun synchronous	2.0	0.0	2.2	1.5	1.4
Day + Night IR (Max T)	3.0	--	2.7	1.5	2.4
Stereo Coverage - complete w/vert. exag.	2.4	2.0	2.1	2.5	2.3
* Additional Pre-processing of digital data					

* = Ground Station Function

CHAPTER IV

KEY POINT SUMMARY FOR INLAND WATER RESOURCES

A. KEY POINT SUMMARIES

The purpose of this section is to summarize the key points raised in the detailed discussions of the Inland Water Resources (Part 3) from the discipline discussion volume. As in that discussion, issues in specific problem areas are treated successively.

1. Snowcover and Runoff Forecasting

a. Application of Current Landsat Program

. Preliminary investigations indicate that snowcovered areas have potential for use in an independent procedure for updating or correcting water supply forecasts as the snowmelt season progresses, as well as in some aspects of modeling snowmelt runoff. Snowcovered area from satellite imagery, however, constitutes only one source of input data for water supply forecasts and updating.

. At present it is difficult to put a dollar value on using snowcover in runoff forecasting. However, the potential benefits in terms of more efficient use of water are of such magnitude that even a 1 or 2 percent improvement in the forecast schemes as a result of using satellite data should offset the costs involved in adding the satellite information to the forecast schemes.

. An add-on benefit to the use of satellite imagery is in the area of being able to ascertain if farmers and ranchers are indeed cutting back during low water years and adding on during big years.

b. Anticipated Impact of Landsat Follow-on

. Rapid throughput of the satellite data to the USER is essential for operational snowcover mapping and snow runoff forecasting. The satellite data must be available to the forecasting agency within 48-72 hours after satellite passage. It's impossible right now to establish the value of having satellite data arrive quickly, but its value in forecasting becomes zero if delayed very long.

. Nine-day coverage frequency may be adequate for routine snowcover observations in many areas of the western United States during the period of snow accumulation, but it is not adequate anywhere during the period of snow melt-off. If two or more cloudy days occur in a row at each nine-day pass during melt-off, then the satellite imagery has lost its value.

. Landsat imagery probably has more than adequate resolution for snow mapping, more accuracy in fact than an interpreter is capable of. So long as the imagery is operator-interpreted it remains interpretation dependent, and its accuracy is dependent upon the interpreter. But the high resolution of Landsat doesn't "hurt" the snow mapping effort.

. The addition of Band 5 (1.55-1.75 micrometer wavelength) on the proposed thematic mapper should be valuable in helping to distinguish between snow and clouds, or between snow and exposed white rock.

. Thermal imagery, to be provided by Band 6 (10.4-12.5 micrometer wavelength), should provide a potential for determining portions of the snowpack that are melting.

. Changing the equatorial crossing time to 11:00 am will have varying effects on snowcover determination.

. The build-up of excessive cloud cover over mountain areas is apt to be greater in mid-day than in the morning during the snowmelt season when snowcover observations are the greatest value.

. The lesser shadow effect of a mid-day vs. early morning crossing is not a significant factor, but could improve the determination of snow under trees.

. The mid-day crossing will mean a more pronounced difference in rock temperature vs. snow temperature, which may provide more contrast in Bands 5 and 6 of the thematic mapper.

. Also, snowmelt will be more advanced at mid-day and perhaps easier to detect.

. The lower orbit and higher power of the Landsat follow-on would not have a significant effect on determining snowcover, other than each RBV frame would cover less area (182.4 X 98.2 km vs. 185 X 185 km of Landsat 1 and 2), and the grain of enlargements may be better.

c. <u>Continuing Issues</u>

. A quick-look option in the throughput system would be a great advantage in forecasting runoff.

. Besides snowcover, though, it would be desirable if auxiliary instrumentation aboard the satellite could record "something" (such as albedo, or attenuation of electromagnetic energy) which relates to water content of the snowpack.

2. Hydrologic Impact of Coniferous Forest Cover Changes

. The proposed Landsat follow-on parameters are apparently designed to obtain the maximum information possible on forest vegetation and snow. Accordingly, they would find direct application in describing many key features of the hydrologic processes. There is currently a need for information of the type which will be available from Landsat follow-on in water resource problems associated with forest management. At least one federal agency is utilizing remote sensing procedures in assessing the multi-resource impacts of forest cover changes. There are large sums of money being spent on these activities. Moreover, these activities will continue to have an ever expanding role in day-to-day operations.

3. Soil Moisture

Remote sensing of soil moisture has and will continue to have a high relative benefit.

. At the present time there does not appear to be a satellite system capable of collecting all the soil-moisture data desired. However, the Landsat C and follow-on programs with the thermal band will give tremendous advantages. Even with this the major limitation in any operational system appears to be the lack of ability to "see through" the vegetation. The vegetation problems should receive research attention to help meet operation requirements.

. Attention should be given to the various estimation techniques so that these can complement the satellite obtainable information. Similarly, some reliance should be placed on satellites other than the Landsat series--if they have instrumentation that would complement the soil-moisture program, then it should be used insofar as possible.

. All possible sources of information should be utilized to help solve a problem such as remote sensing of soil moisture rather than attempting to combine all requisite elements into one package.

4. Groundwater

a. Application of Current Landsat Program

. Landsat data presently is being used to detect lithologies and structures favorable for groundwater occurrence, to delineate at least parts of the limits of aquifers, and to obtain information on the operation of aquifers.

. About eight Federal Bureaus, 20 State geological-survey or water resource agencies, 30 universities, and several consulting-engineering firms are using Landsat data for the study of problems involving or impacting groundwater problems and resources. The use of Landsat data for groundwater studies is increasing, but this use presently involves a relatively low level of effort.

. Total present use of Landsat data for subsurface water problems is estimated at 10 man years per year. In order to properly utilize the information content of Landsat data in groundwater studies that are underway at the present time, this effort would have to increase to about 30 man years per year.

. The main reasons for a reluctance to fully utilize Landsat data are (1) psychological, (2) lack of adequate training, (3) limited availability of digital processing, and perhaps (4) high costs of digital processing.

. In the Western United States, most groundwater recharge comes from melting of the mountain snowpacks in the spring months. The blooming desert at this time of year reflects the relatively high soil moisture conditions, which accompany the recharge process. The rapidly growing and relatively dense stands of vegetation produce subtle but distinctive hues on color composite Landsat images.

b. <u>Anticipated Impact of Landsat follow-on</u>

. More detailed interpretations of tones, textures, and patterns of vegetation and soils. Detection of numerous smaller patterns. Development of more information on the significance of the patterns for groundwater occurrence, recharge, discharge, and water use.

. If sun illumination angles are equal, detection of more topographic detail, detection of smaller and more numerous geologic structures, and detection of many more hydrologically significant landforms.

. Detection of more detail in snowmelt and soil moisture patterns. Detection of more hydrologically significant features in these patterns.

. Detection of smaller lakes and ponds and more patterns formed by shapes and alinements. More accurate measurements of water area and a better understanding of aquifer recharge.

. Delineation of water in small streams in headwater areas and location of more areas of aquifer discharge.

. Detection of more and smaller lineaments. More potential locations for large well yields in consolidated rock terrains. A better understanding of the patterns formed by dominant lineaments, trends, and by intersecting lineaments.

. A better definition of drainage patterns, of the geologic structures indicated by these patterns, and of the hydrologic significance of the patterns.

. More accurate measurements of drainage density and thus of surface permeabilities in unmapped areas.

. Easier detection and classification of drainage textures in arid regions.

. More accurate measurements of stream-channel width and thus better locations of reaches of streams where aquifer discharge occurs.

. A more accurate determination of the types of outcropping rocks and a more accurate interpretation of the water-bearing characteristics of the rocks.

. A more accurate determination of crop type and thus better estimates of water use and water needs.

. Detail by which hydrologically significant surface features can be distinguished more easily from those that are not significant.

. A better definition of aquifer limits and a better understanding of aquifer operations.

. A greater variety of formats for manual interpretation.

. Improving the capabilities and results of digital processing.

. An additional impetus to the trend for digital processing.

. The high resolution thermal infrared band 6 on the thematic mapper should provide information on rock types and soil moisture patterns.

. The higher sun-elevation angles of Landsat follow-on will produce less enhancement of landforms, the interpretations of which have a relatively high degree of confidence for groundwater information.

. An increase in coverage frequency will increase the chances of obtaining good quality, cloud-free Landsat images at times that are important for groundwater interpretations. Also, it will shorten the time needed to obtain a sequence of Landsat scenes showing emerging and developing patterns of vegetation and soil moisture.

. About 175 man years per year at a cost of $7 million are spent on the inventory and management of underground aquifers.

. The costs of using data from Landsats 1 and 2 are estimated at 10 man years per year and 0.4 million dollars; the benefits resulting from this use are estimated at $1 million. Thus the present level of effort results in a net cost savings of $.6 million per year.

. Costs of using Landsat data (including data from Landsat follow-on)are expected to increase to $0.8 million (at 1976 costs) by 1985. Benefits should increase to about $2.5 million. Cost/benefit ratios will be higher than this for about two years after launch of Landsat follow-on, however, as scientists learn to use these new data efficiently.

. Remote sensing generally will not provide the information on subsurface water supply that is needed for watershed modeling and systems management; the only exception is the detection and delineation of some aquifer limits, which also form model limits.

5. Lake and Reservoir Mapping

a. Application of Current Landsat Program

. Studies in the Northern Great Plains on assessing the volume of stored water in prairie pothole lakes have found that lake areas could be used to account for up to 89% of the variation in lake water volume in the shallow prairie lakes. Therefore, an assessment of stored water volume with time is feasible using remote observations of area. As the trophic status of these prairie lakes is primarily dependent on the depths, the ability to assess the potential of eutrophication is at hand.

. A study of the prairie pothole lakes in South Dakota using visual interpretation which employs the additional advantage of interpreting photographic textural and pattern properties found that recognition of non-vegetated lakes 1.5 hectares (3.7 acres) and larger could be accomplished at 100% accuracy.

. Even with the partial pixel approach applied in a stagnant ice region of North Dakota, only 14 to 18.5 percent of the total ponds and lakes were recorded because of the large numbers of small ponds which were not detected.

. Various water resources agencies have the need for total-area inventories, but in the Great Plains Region the existing Landsat capabilities are not suitable for the inventory purposes.

b. Anticipated Impact of Landsat follow-on

. The proposed spectral bands with shorter wavelength intervals should be more specific for discrimination of substances suspended in water. Presently, suspended particulate matter can be detected. However, there is little prediction capability as to its composition. The 0.45-0.52μm spectral region because of its penetration potential will provide an advantage for monitoring lakes and reservoirs.

. Sensitivity to depth variations should also be improved due to the higher incoming radiance associated with the higher sun angles at the time of data acquisition. Bathymetric mapping has been effectively demonstrated in clear waters using the existing sensor capability and this improved capability will be of importance.

. The instantaneous field of view (IFOV) of the Landsat follow-on at ≃30m will perhaps be of the greatest advantage for use in lake and reservoir operations. The existing system provides reliable information for recognition and quantitative measurements for large lakes but is limited for small lakes. The IFOV of the present Landsat system in terms of ground coverage is approximately 0.45 hectares (1.1 acres). The minimum possible dimensions which should always be detectable are twice the directional ground coverage or would correspond to the area covered by four pixels (≃1.8 hectares or 4.4 acres). The Landsat follow-on IFOV in terms of ground coverage is ≃0.09 hectares (0.22 acres). The minimum detectable area would be 0.36 hectares (0.88 acres).

. Increased resolution is required before operational surveys can be reliably conducted. The small lakes because of their numbers and physical characteristics in many regions are of importance. The Landsat follow-on will provide this required spatial resolution.

. Lake bathymetric mapping in any but clear waters, even in the better spectral window, will probably not supply these maps except for near-shore areas. However, for the location of sedimentation patterns, these near-shore regions are of greatest importance. In addition, the improved spatial resolution will allow the updating of shoreline contours as the guage of the reservoir fluctuates.

. As with any developing tool, a considerable time lag exists between the development of the technology and its actual use and implementation. These time lags especially occur with local users in contrast to the large, well-structured users. The Army Corps of Engineers use of Landsat data for the national dam inspection program is perhaps the best illustration of a large-effort, coordinated use of the technology. The local water development board or water resources agency will, in general, considerably lag behind in time for the operational use. These small agencies may use traditional aerial photography at great expense for resources assessments which could be easily and less expensively conducted using space-acquired data. Many reasons for this may exist. The education in uses and effective procedures may be the most crucial deficiency. The complications involved in maintaining the technological pace of the space program and its investigation products are too demanding for small organizations. This definition of small organizations may even traverse into state governmental agencies. The illustrative uses to the public generally also involve very complex data analyses systems which are not generally available and which may, for certain applications, be cost prohibitive for the smaller agency.

When these users have available the normal interpretative products provided with the existing Landsat program, they are at scales and resolutions uncommon to the interpreter. The patterns easily recognized on the traditional aerial photography of high resolution may now be textural variations or tonal variations or may be non-existent on the satellite imagery. The synoptic view, multispectral data, repetitive coverage, and other desirable characteristics may be overlooked. Therefore, an increase in resolution of the satellite system as proposed in Landsat follow-on will definitely increase the user acceptance in their normal operational programs.

6. Water Quality

a. Application of Current Landsat Program

. Many investigators have demonstrated that it is possible to estimate Secchi disc transparency using the Landsat MSS data.

. Landsat can be utilized to measure water quality by measuring the concentration of suspended solids in water. It has been shown that Landsat MSS data can be used to estimate suspended sediments in Kansas reservoirs with a 67% confidence interval of accuracy of 12 parts per million (ppm) over the range of 0-80 ppm and 35 ppm over the range 0-900 ppm.

. It is apparent from the findings of many Landsat investigators that the detection of large turbidity plumes and turbidity related patterns in lakes is easily accomplished using MSS imagery.

. The detection of algal blooms is a straightforward procedure with Landsat MSS data.

In lakes where inorganic sediments have not masked the presence of chlorophyll, it has been possible to show a good correlation between MSS data and chlorophyll a.

. The feasibility of classifying lakes according to trophic state has been demonstrated by several investigators.

. The Landsat MSS bands are optimized for land studies. The energy return from water is very low and although the four bands contain information which is related to water phenomena, it is in a very small range of digital number levels.

. The time between satellite flyover and receipt of the MSS data by the user is another problem area. In many cases, data processors have to wait for many weeks and even several months for the CCTs. The long turn-around time hinders lake researchers and discourages resource managers.

b. Anticipated Impact of Landsat follow-on

. The improved spatial resolution of the TM will permit the more accurate mapping of turbidity plumes, demarcation of shorelines, plotting of currents, and delineation of large beds of aquatic macrophytes. It is anticipated the smaller pixel size will result in the inclusion of small lakes into survey programs.

. The band selection is an improvement and should permit better estimates of parameters such as chlorophyll a. The addition of the blue band may add a new dimension to the remote sensing of water. Work by Piech, et al., (1975) has shown the value the blue in water-related studies. However, it is likely atmospheric effects will be severe and that corrective measures will have to be taken. The thermal band (10,400 - 12,500 nanometers) will be of value in the determination of lake surface temperatures; however, it will be less effective in monitoring lake thermal plumes because of its 120 meter resolution.

. The increase of quantization levels from 127 to 256 may be of value if this means that the dynamic range of the sensor has actually been increased.

. Benefits will be more readily derived from the Landsat follow-on than from Landsat 1 and 2 if NASA reduces significantly the time delay between data acquisition by the satellite and receipt by the users.

. The insertion of two satellites so as to provide repetitive coverage on a 9-day basis is an improvement over the 18-day single satellite concept. However, as is evident from the experiences derived from the tandem Landsat 1, Landsat 2 coverage, temporal coverage of the lacustrine resources will still be fragmentary.

. Still another problem is that of sun glint. If the projected equatorial cross-over time of 11:00 am is used, sun glint is likely to make the satellite of little value in water quality related work. Water quality depends highly upon volume reflectance which in this case will be masked by the specular reflection (sun glint).

7. Lake Ice

a. Application of Current Landsat Program

. Landsat 1 MSS bands 5 and 7 have been used to identify melting snow. Similarly, Landsat 1 MSS images over Lake Erie were examined for melting ice. The ice field in band 5 exhibits a highly reflecting but "lacy" appearance resulting from many thaw holes, a characteristic of "rotten" ice, i.e., deteriorating under warm temperatures.

The following ice features have been tentatively identified from Landsat 1 MSS images of Lake Erie and Lake Ontario (Note that ground truth is not available for verification): Shuga, light and dark nilas, fast ice, icefoot, ice breccia, brash ice fracturing, ridging, rafting, sastrugi, thaw holes, rotten ice, ice floes, dried ice puddles, hummocked ice and leads.

. The best technique now available for ice study is a combination of Landsat data, the current NOAA operational environmental satellite, and aerial reconnaissance using SLAR and short pulse radar.

. For monitoring ice conditions, Landsat 1's 18-day revisit cycle again presents problems as ice formation, movement, and breakup may all take place within a very short time, thus possibly go totally unrecorded by the Landsat 1 sensors.

b. <u>Anticipated Impact of Landsat follow-on</u>

. The 9-day revisit cycle will be a great improvement over the previous cycle.

. Landsat follow-on, with its much improved spatial resolution and the increased spectral response of the thematic mapper will generally improve monitoring distribution of ice on the Great Lakes and in the identification of the condition of the ice.

. The more rapid turn-around time associated with the Landsat follow-on output will facilitate the use of the data by shippers and improve the predictions of ice build up and movement.

. The Landsat follow-on data, with increased spectral response and improved spatial resolution, will be used for Lake Ice monitoring for input into the Navigation Season Extension Program.

. Landsat follow-on will not eliminate the need for conventional monitoring techniques, but it will, when available, provide a regional assessment of ice conditions, at a much lower cost than conventional methods. A comprehensive lake ice monitoring program must utilize several means of monitoring data collection and analyses including airborne SLAR, short pulse radar, NOAA environmental satellite, VHRR data, and Landsat data.

. No single tool would be of more value to ice forecasters than a quick-look Landsat image of the Great Lakes, especially if it could be available much more frequently than every 18 days.

8. Sediment

a. Application of Current Landsat Program

. The multispectral scanner (MSS) imagery provided by Landsat 1 which has a ground resolution of about 70 meters is highly useful.

. Qualitative descriptions of surface currents near river mouths can be derived from Landsat bands 1 and 2 from the shapes, successively observed at various tidal stages, of river plumes where fresh water enters an inlet.

. Dredging and harbor maintenance are continually required in all major harbors. As many as 5,000 man years may be involved at a total annual cost of as much as $0.2 billion per year. It is conceivable that savings of $2 million per year could be achieved by improvements in selecting dumping sites and in defining sediment sources from satellite imagery of sufficient quality.

b. Anticipated Impact of Landsat follow-on

. Regional analysis of tidal flats is quickly and conveniently accomplished by comparing bands 4 and 7. Detailed analysis is limited by the 70 meter resolution. Improved resolution will greatly increase the usefulness of the Landsat MSS imagery for this purpose; at least one meter resolution is needed.

. The spectral bands available are sufficient for needs at present insofar as sediment detection is concerned. Refinement will depend upon detailed comparisons and research during the next five to ten years to recognize the relationship between sediment types and their spectral signatures.

. The Landsat C MSS imaging device is identical to that on the two preceding vehicles except for a fifth spectral channel covering the thermal IR (10.4-12.6 microns). Resolution of this band, however, is expected to be about 200 meters, about three times poorer than that of the other four channels. Nevertheless, this band is expected to be very useful. It should aid in defining and characterizing water masses, confirming and extending the interpretations that have been described as possible from bands 1 and 2.

. Taken in the aggregate, the improvement over Landsat 1 and 2 offered by Landsat C and Landsat follow-on for this application is insignificant except for the addition of the thermal IR channel. The increment of improvement represented by this addition is unknown and, I believe, cannot be very well estimated at this time. It is unlikely to significantly affect any of the activities associated with removal and control of sediment and sedimentation, respectively. However, the potential for improving the management of fisheries may be great.

c. Continuing Issues

. Improve the provision for technology transfer within user agencies and organizations, and to the institutions from NASA.

. Additional research and development is required to facilitate the use of the required imagery in digital form, bypassing as much as possible the necessity for hard copy prints as the format of choice.

. Research is needed to develop and optimize the imaging processing and enhancement techniques required for this application. This includes the development of algorithms and numerical models that can accept the data on sediment.

9. Estuarine Dynamics

a. Anticipated Impact of Landsat follow-on

. Modeling of all the nation's estuaries has never been done, and Landsat follow-on alone will not be able to meet the task. It will, however, permit synoptic coverage of the estuaries so that natural tracers such as sediment, turbidity, foam and debris lines, and--at last--120 m thermal mapping, will provide details of estuarine circulation, and surface salinity charting (where thermal/salinity relations permit).

. It may be possible to characterize the estuaries by salinity structure using Landsat follow-on data, e.g.,

(a) the highly stratified estuaries, salt-wedge type,

(b) the highly stratified estuaries, fjord type,

(c) the partially mixed estuary,

(d) the vertically homogeneous estuary

. With the presently proposed orbital crossing time (11:00 am) sun glint will negate the blue band's increased penetrating ability (on the TM) as the glint will "overpower" the sensor. Only surface phenomena will be observable most of the time. This problem will be disastrous to the water resources community. Unless it is changed, this one problem will obviate the TM for most estuarine research (other than surface effects).

. The improvement over prior satellite sensors will lie chiefly with the improved resolution (120 m) in the thermal channel. Though this resolution is important in the quest for basic data on estuarine dynamics, the thermal data represent only a partial, interim "step" toward the goal of accurate numerical modeling of U. S. estuaries.

. Use of the TM thermal and visible channels will save money, chiefly by permitting the installation of in-situ instruments in the optimum location. This is especially true of current meters and temperature/salinity measurements. Ground truth will be required and will supplement the satellite data.

. The generalized circulation dynamics of all moderately sized estuaries can probably be charted by MSS and TM data. It is in the national interest to do so. If successful, it would represent a savings of at least 5 years and $2-5 million over the cost of a preliminary ground survey of these estuaries.

. Additional research and facilities would be helpful in the area of estuarine research to augment the Landsat follow-on data. State coastal zone institutes would be able to handle the effort with modest expansion. The primary Federal research effort would include interests of NASA, Interior, NOAA, Navy and Coast Guard interest, at least.

10. Inundated Areas and Shorelines

a. Application of Current Landsat Program

. During recent years, satellite data have been used to delineate inundated areas.

. The main problems concern low resolution, timing of the flood event with a satellite overpass, and overhead clouds.

. The present delineation of flooded areas, based upon Landsat 1 and 2 data, probably would provide products of somewhat similar purpose to that of the "flood-prone maps." The delineations using Landsat data generally have been at 1:250,000 scale, although other (smaller and larger) scales have been used.

b. Anticipated Impact of Landsat follow-on

. The spectral data of the thematic mapper planned for the Landsat follow-on mission should be a big improvement over the Landsat 1, 2 and C systems with respect to spectral selection and spectral and spatial resolution. The 1.55 to 1.75μm and 10.40 to 12.50μm bands should provide additional information useful to identify the boundary of water-land interfaces.

. The 30 meter ground resolution of the Landsat thematic mapper (120 m for the thermal band) should provide the basis for a map produced at an accuracy comparable to flood-prone maps.

. The problems of cloud cover and vegetative overstory may interfere with the delineation of certain floods and stream reaches, respectively. Thus, the application of Landsat to provide a basis for delineating flood-prone areas appears feasible but the random nature of floods as to timing and location may mean that it will take many years to complete a national program.

. The delineation of flooding areas from Landsat follow-on data probably will be a hit-or-miss process, except for conditions of broad area floods such as those resulting from hurricanes.

c. Continuing Issues

. It may be advisable to reconsider the proposal of the 11:00 am equator crossing time to assure that the data will not be affected by solar specular reflection during midsummer.

. An effort should be made to quickly process the data for field use to aid in disaster relief and permit easy field verification of the delineated areas of inundation. High water marks deteriorate quickly with time.

. Although Landsat data are available at relatively low cost, there are problems (time, money, and equipment) of reducing the data into quantitatively meaningful products. For example, the reformatting of digital tapes to obtain accurate geometric positioning for temporal comparison of picture elements is time consuming and costly. Also, the equipment needed to process those digitized data are not readily available to most investigators and are expensive to use. The development of remote sensing technology into operational programs probably is constrained because users may have difficulty processing the data.

11. River Forecasts

Because of the "real-time" mode required for the operation of a river forecast center, the survey type of data available by remote sensing is of a significantly lesser accuracy than that which is economically necessary in consideration of potential damages from flood circumstances or the use of water as a valuable resource.

12. Data Communications System

- In cooperation with NASA, the New England Division of the USACE has constructed a ground receiving station at Waltham for direct data acquisition from the satellite. This will remove all ground transmission problems that can occur with teletype relay between NASA and Waltham (teletype relay suffers a 45 minute time lag between the initial data measurement and data reception at control center). The system is under operational condition.

- The Jacksonville District, in cooperation with the USGS, has been receiving Landsat relay hydrologic data for almost 3 years from 9 different locations in central and southern Florida.

- The launching of NOAA's Geostationary Operational Environmental Satellite (GOES) makes both periodic and real-time data transmission closer to reality. At present, the Lower Mississippi Valley and North Pacific Division are planning to undertake experiments in relaying hydrologic data using the GOES system.

- The investigations indicate that costs for data relay by satellite can be less than those for ground-based systems. For example, the New England Division's ground-based Automatic Hydrologic Radio Reporting Network had an initial cost per station in 1969-70 of $20,000. This includes all equipment for the total system (i.e., transmitters, antennas, 4 relays, 12 repeaters and the central control facility with an IBM 1130 computer for data readout and processing). The division estimates the initial cost of an operational orbiting satellite data collection system to be between $5,000 and $10,000 per data collection platform location. This figure is based on 2 satellites, 10 ground receiving stations and 2,000 platforms nationwide. The cost per platform would be lower if more were installed. Cost estimates are not yet available for a GOES system.

- A questionnaire sent to all Corps offices in July 1973 found that, over the next 5 years, nearly 4,500 data collection locations will be needed Corps-wide for the relay of hydrologic information for water management activities.

13. Streamflow Modeling

a. Application of Current Landsat Program

. An experiment with Landsat data (Blanchard, 1975) has shown that the coefficient for the simple empirical watershed runoff model used by the soil conservation service can be estimated by using reflectance of visible and near-infrared light from the watershed surface.

. The classification of surface reflectance using Landsat data has been used to identify and map the impervious areas within a watershed.

. Another approach to hydrologic modeling involves prediction schemes based on the physical dimensions of watershed characteristics. Such measurements as stream length, stream channel classification, and length-to-width ratio of the drainage area can more readily be acquired from multispectral scanner data when large areas are involved. In most instances, these measurements can be made.

b. Anticipated Impact of Landsat follow-on

. Development of new applications of remote sensing in water resources models should increase rapidly with the increasing availability of data and training of personnel.

. Constant development and testing will allow the full benefits from the addition of spectral bands, the assurance of available temporal data and concurrent improvement in mathematical modeling.

. The current resolution of Landsat is adequate for use in watershed planning where empirical equations are used. The improved resolution and band wavelength of the thematic mapper is likely to increase the value of classification schemes and will therefore open opportunities to measure variables for the more complex studies.

14. Urban Hydrology

a. Application of Current Landsat Program

. It is estimated that $27,580,000.00 is expended annually on inventory and parameter estimate studies associated with urban water resources development. It is estimated that this figure could be reduced to approximately $8,000,000.00 by shifting from conventional to Landsat technology.

. Studies conducted with the SCS Model using land delineations obtained from aircraft, compare very well with those obtained from Landsat using an abbreviated land use table.

. Landsat is now being used in a number of 208 studies which are developed for determining non-point sources of pollution in urbanized areas.

. A major limitation in the use of Landsat data is the lack of geometric agreement with map scales and a difficulty in determining the position of a Landsat element on the ground.

b. Anticipated Impact of Landsat follow-on

. The 30 meter resolution will allow some utilization of air photo interpretation techniques of the hardcopy products for some of the urban hydrologic tasks.

. The geometric corrections that will be included in the product will be extremely important in urban hydrologic problems. The current problems associated with skew and distortion make it extremely difficult to interface Landsat data with other information required in hydrologic studies. By overlaying the Landsat products onto topographic maps, it will be much easier to develop parameter estimates for models and to develop inventory studies.

. The inclusion of a thermal band, even though the resolution is in the vicinity of 120 meters, will do a great deal in reducing the confusion between classes. For example, the thermal band should easily discriminate between a shopping center and a large area of bare soil. The same is true with the shadow effect in urban complexes creating a confusion with water in the current Landsat package. It is believed that the thermal capability will be a very important factor in discriminating between natural features and those developed by man.

c. Continuing Issues

. Presently, many potential users find that machine processing capabilities are presently available at only a few locations. Systems that can be operated by consultants or agencies from the remote terminals that they presently use to access a general purpose computer net would aid in the utility of Landsat data.

. More work needs to be done on developing the mechanics for efficient interfacing with auxiliary data needed for water resource studies. The correction of the geometrics will go far in alleviating this problem. Still, the large quantity of data involved and the need for multi-layered random access storage encompasses problems that the routine programmer with a small organization cannot handle. It would probably be a good idea for NASA to develop and distribute the software to accomplish this interfacing function.

. Most of the models used to estimate the quantity or quality of water were developed long before the launching of Landsat. The parameters were designed to be derived from readily available data. Generally this readily available data centers on topographic maps. Much of the data required as input to these existing models cannot be defined even with Landsat follow-on. Since there is nothing sacred about the parameters of these existing models, there is no reason that alternate parameters cannot be developed that could be identified with Landsat. It is important that extensive research be undertaken to develop such models.

. The numerous municipal and 3069 county governments who administer most of the $12 billion dollar annual expenditure on urban water resources constitute a large potential user of Landsat data. Still, most of these governmental organizations probably spend less than $3,000.00 per year for their inventory and parameter estimating responsibilities that could be accomplished on Landsat. Thus, it is not very attractive for them to train personnel, visit browse centers, screen Landsat scenes, and purchase tapes as part of an alternate effort to accomplish their responsibilities. Thus, the establishment of regional, or perhaps state, centers that would routinely classify the land cover within their jurisdictions should be considered. In this way, the smaller governmental organizations could simply request information within a watershed boundary, census tract, or other geographic area. The potential annual saving by shifting from traditional to Landsat cover and parameter estimating approaches cannot be achieved unless there is some attractive mechanism by which the local governments can participate.

B. CONTINUING ISSUES

There have been important advancements in remote sensing technology during the past 10 years. Although Landsat data are available at relatively low cost, there are problems (time, money, and equipment) of reducing the data quantitatively leading to the production of meaningful products. For example, the reformatting of digital tapes to obtain accurate geometric positioning for temporal comparison of picture elements is time consuming and costly. Also the equipment needed to process those digitized data is not readily available to most investigators and is expensive to use. The development of remote sensing technology into operational programs probably is constrained because users may have difficulty processing the data.

As with any developing tool, a considerable time lag exists between the development of the technology and its actual use and implementation. These time lags especially occur with local users in contrast to the large, well-structured users. The Army Corps of Engineers use of Landsat data for the national dam inspection program is, perhaps, the best illustration of a large-effort, coordinated use of the technology. The local water development board or water resources agency will, in general, considerably lag behind in time for the operational use. These agencies may use traditional aerial photography at great expense for resource assessments which could be easily and less expensively conducted using space-acquired data. Many reasons for this may exist. The education in uses and effective procedures may be the most crucial deficiency. The illustrative uses to the public generally also involve very complex data analyses systems which are not generally available and which may, for certain applications, be cost prohibitive for the smaller agency. The complications involved in maintaining the technological pace of the space program and its investigation products are too demanding for small organizations. This definition of small organizations may even extend into state governmental agencies.

Most of these governmental organizations probably spend less than $3,000 per year for their inventory and parameter estimating responsibilities that could be accomplished with Landsat data. Thus, it is not very attractive for them to train personnel, visit browse centers, screen Landsat scenes, and purchase tapes as part of an alternate effort to accomplish their responsibilities. Thus, one alternative might be regional or state centers that would routinely or on request classify the land cover within their jurisdictions. In this way, the smaller governmental organizations could simply request information within a watershed boundary, census tract, or other geographic area. Such centers could also be responsible for short courses and other training missions in the uses of Landsat technology.

1. Snowcover and Runoff Forecasting

. A quick-look option in the throughput system would be a great advantage in forecasting runoff.

. Besides snowcover, it would be desirable if auxiliary instrumentation aboard the satellite could record "something" (such as albedo, or attenuation of electromagnetic energy) which relates to water content of the snowpack.

2. Forest Cover

. More work on models will be justified with the new data.

3. Soil Moisture

. At the present time there does not appear to be a satellite system capable of collecting all the soil-moisture data desired. However, the Landsat C and follow-on programs with the thermal band will give tremendous advantages. Even with this the major limitation in any operational system appears to be the lack of ability to "see through" the vegetation. The vegetation problems should receive research attention to help meet operational requirements.

. Attention should be given to the various estimation techniques so that these can complement the satellite obtainable information. Similarly, some reliance should be placed on satellites other than the Landsat series -- if they have instrumentation that would complement the soil-moisture program -- then it should be used insofar as possible.

. All possible sources of information should be utilized to help solve a problem such as remote sensing of soil moisture rather than attempting to combine all requisite elements into one package.

4. Groundwater

. Remote sensing generally will not provide the information on subsurface water supply that is needed for watershed modeling and systems management; the only exception is the detection and delineation of some aquifer limits, which also form model limits.

. The main reasons for a reluctance to fully utilize Landsat data are (1) psychological, (2) lack of adequate training, (3) limited availability of digital processing, and perhaps (4) high costs of digital processing.

5. Lake and Reservoir Surveys

- As with any developing tool, a considerable time lag exists between the development of the technology and its actual use and implementation. These time lags especially occur with local users in contrast to the large, well-structured users. The Army Corps of Engineers use of Landsat data for the national dam inspection program is, perhaps, the best illustration of a large effort, coordinated use of the technology. The local water development board or water resources agency will, in general, considerably lag behind in time for the operational use. These small agencies may use traditional aerial photography at great expense for resource assessments which could easily and less expensively be conducted using space-acquired data. Many reasons for this may exist. The education in uses and effective procedures may be the most crucial deficiency.

6. Water Quality

- The Landsat MSS bands are optimized for land studies. The energy return from water is very low and although the four bands contain information which is related to water phenomena, it is in a very small range of digital number levels.

7. Lake Ice

- No single tool would be of more value to ice forecasters than a quick-look ERTS image of the Great Lakes, especially if it could be available much more frequently than every 18 days.

- Landsat follow-on will not eliminate this need for conventional monitoring techniques, but it will, when available, provide a regional assessment of ice conditions, at a much lower cost than conventional methods. A comprehensive lake ice monitoring program must utilize several means of monitoring,data collection and analysis including airborne SLAR, short pulse radar, NOAA environmental satellite, VHRR data, and Landsat data.

8. Sediment

- A continuing issue that must be addressed is to improve the provisions for technology transfer within user agencies and organizations. Of course, this is primarily a responsibility of these institutions, but NASA should recognize their need to achieve a greater awareness and participation among the various units within their organization.

9. Estuarine Dynamics

. Modeling of all the nation's estuaries has never been done, and Landsat follow-on will not be able to meet the task. It will, however, permit synoptic coverage of the estuaries so that natural tracers such as sediment, turbidity, foam and debris lines, and -- at last -- 120 m thermal mapping, will provide details of estuarine circulation, and surface salinity charting (where thermal/salinity relations permit).

10. Inundated Areas and Shorelines

. Although Landsat data are available at relatively low cost, there are problems (time, money, and equipment) of reducing the data quantitatively leading to the production of meaningful products. For example, the reformatting of digital tapes to obtain accurate geometric positioning for temporal comparison of picture elements is time consuming and costly. Also, the equipment needed to process those digitized data are not readily available to most investigators and are expensive to use. The development of remote sensing technology into operational programs probably is constrained because users may have difficulty processing the data.

. It may be advisable to reconsider the change to the 11:00 am equator crossing time to assure that the data will not be affected by solar specular reflection during midsummer.

. An effort should be made to quickly process the data for field use to aid in disaster relief and permit easy field verification of the delineated areas of inundation. High water marks deteriorate quickly with time.

11. Streamflow Modeling

. Development of new applications of remote sensing in water resource models should increase rapidly with the increasing availability of data and training of personnel.

. Constant development and testing will be necessary to gain the full benefits from the addition of spectral bands, the assurance of available temporal data, and concurrent improvement in mathematical modeling.

. Testing new models and incorporation of data from the thematic mapper can readily be done on a university level while demonstration of promising applications should be planned under an ASVT program.

• Most of the models used to estimate the quantity or quality of water were developed long before the launching of Landsat. The parameters were designed to be easily derived from readily available data. Generally this readily available data centers on topographic maps. Much of the data required as input to these existing models simply cannot be defined even with Landsat follow-on. There is nothing sacred about the parameters of these existing models, they were simply derived to use information that was available at the time of model development. There is no reason that alternate parameters cannot be developed that could be identified with Landsat. It is important that extensive research be undertaken to develop such models.

12. Urban Hydrology

• Presently, many potential users consider that machine processing capabilities are available at only a few locations. Systems that can be operated by consultants or agencies from the remote terminals that they presently use to access a general purpose computer net would aid in the utility of Landsat data.

• More work needs to be done on developing the mechanics for efficient interfacing with auxiliary needed for water resource studies. The correction of the geometrics will go far in alleviating this problem. Still, the large quantity of data involved and the need for multi-layered random access storage encompasses problems that the routine programmer with a small organization cannot handle. It would probably be a good idea for NASA to develop and distribute the software to accomplish this interfacing function.

• The numerous municipal and 3069 county governments who administer most of the $12 billion annual expenditure on urban water resources constitute a large potential user of Landsat data. Still, most of these governmental organizations probably spend less than $3,000.00 per year for their inventory and parameter estimating responsibilities that could be accomplished on Landsat. Thus, it is not very attractive for them to train personnel, visit browse centers, screen Landsat scenes, and purchase tapes as part of an alternate effort to accomplish their responsibilities. Thus, the establishment of regional, or perhaps state, centers that would routinely classify the land cover within their jurisdictions should be established. In this way, the smaller governmental organizations could simply request information within a watershed boundary, census tract, or other geographic area. The potential annual saving by shifting from traditional to Landsat cover and parameter estimating approaches cannot be achieved unless there is some attractive mechanism by which the local governments can participate.

C. CONCLUSIONS AND RECOMMENDATIONS

- The current Landsat program has shown that satellite remote sensing is important and will become an increasingly important tool in inland water resources.
- Although some dollar benefits have been developed in certain cases, the assessment of economic benefits of satellite technology is difficult at present because of the short time that satellite data has been available compared to the development time characteristic of most applications.
- It must be emphasized that no single data source has the flexibility necessary to meet all the data requirements associated with an inland water resources task. Thus, the utility of the Landsat follow-on program is somewhat affected by its ability to interface with information from other sources.
- Research is needed to develop and optimize the imaging processing and enhancement techniques required for this application. This includes the development of algorithms and numerical models that can accept the data and where appropriate, analyze it in conjunction with other correlative data.
- The increased resolution offered by Landsat follow-on will significantly improve the efficiency of many current tasks and will be very valuable in expanding the list of tasks and organizations that can use Landsat technology.
- Cost and availability of digital processing equipment currently eliminate a number of tasks and organizations. The ability to make more use of the techniques of aerial-photo interpretation will expand utilization.
- Additional research and development is required to facilitate the use of the required imagery in digital form, bypassing as much as possible the necessity for hard copy prints except when deliberately selected for one reason or another, as the format of choice.

- Improve the provisions for technology transfer within and between user agencies and organizations. Of course, this is primarily a responsibility of these institutions, but NASA should recognize their need to achieve a greater awareness of space technology and to achieve interchange and participation among the various units within the organizations.

- The inclusion of the thermal band will significantly improve the discrimination capabilities of the system even though the 120 meter resolution is large.

- Although the 9 day "fly-over" is an improvement, this relative infrequency will still limit the utility of Landsat in many inland water resource problems.

- The band selection of Landsat follow-on will improve the utility of the system. In the past, too much of the data could only be used to verify something that had happened months earlier.

- The geometric corrections in the data products should make ground truth more "locatable." The lack of geometric corrections seriously limited the application of Landsat 1 and 2 in many areas.

- The decision concerning the 11:00 am crossing time should be reevaluated. The high sun angle will benefit a few tasks, but the lack of shadow, increased probability of cloud cover, and the high risk of "sun glint" on water surfaces may completely eliminate Landsat as a tool in other tasks.

- There is a real need for a "quick-look" option in the data output program.

TABLE IV-1
LANDSAT PARAMETER ASSESSMENT

Good (Neutral) Detrimental

3 2 1 0 -1 -2 -3

	Area Snowcover	Snow Water Content	Measuring Runoff Coefficients	Snow Measure	Thermal Identification	Thermal Characteristics	Thermal Detection	Reflectance Characteristics	Soil Moisture	Moisture Identification	Wetland Delineation
LANDSAT 1 and 2											
80 m Spatial Resolution	3	1		1	1	0		0		0	1
Signal/Noise - Moderate	2	-1	2	2	2	-1		-1	1	3	1
Spectral Range 0.5 - 1.1 μm	1	-1	2	1	-2	-1		-1	1	-1	1
Repeat Coverage	-2	-2	3	-1	-1	-1		-1	-3	-1	0
182 x 182 km mi. Format	2	2	3	1	1	-1		-1	2	1	2
Mid-morning 9:30 a.m.	3	1	1	2	2	-2		-2	2	2	0
Digital Tapes - Raw data	0	0	2	1	1	0		0	1	1	0
* Data Delivery as presently experienced	-3	-3	-1	-1	-1	-3		-3	-3	-1	0
* Image Quality as presently available	-1	-1	-1	-1	-1	-1		-1	-1	-1	1
Incidental Stereo	0	0	0	0	0	0		0	0	0	
Geometry - Excellent	0	0	2	1	1	0		0	2	1	0
LANDSAT C											
Add: 10.4 to 12.5 μm	1	1	3	1	3	3	2	1	2	2	0
* Digital Tapes, Corrected	1	1	0	1	1	1	1	1	1	1	
* Data Delivery, Rapid (48 hr.)	3	3	3	-1	-1	3	2	3	2	-1	0
RBV Panchromatic			1	0	0				1	0	
LANDSAT FOLLOW-ON											
30 m Resolution (except thermal)	2	2	3	0	0	0	3	0	2	0	2
Add: Blue Band (water penetration)	0	3	0	0	0	3	3	0	0	0	2
Add: Near IR (1.6 μm - mineral)	3	0	0	0	0	3		3	0	0	
Program Continuity	3	3	3	1	1	3	2	3	0	1	2
Near-Noon - 11:00 a.m.	2	3	-2	-1	-1	3		3	-2	-1	
Signal/Noise - Improved	2	1	3	0	0	1	2	1	2	0	2
Geometry - Degraded at lower altitude	0	0	0	0	0	0		0	1	0	
10.4 - 12.5 μm Day-Night coverage											
Resolution - better than 30 m	2	2	1	0	0	0		0	-1	0	
Additional Spectral Bands											
Passive Microwave	0	3	0			0		3	2		
Radar			3	-1	-1				2	-1	
Laser Topog. Profile	1		0	0	0				0	0	
Fraunhoffer Line Discrim.			0	0	0				0	0	
2.0 - 2.5 μm (with 1.1 - 1.6 μm)			0	1	1				0	1	
8.2 - 9.4 μm (with 10 - 12 μm)			0	3	3				2	3	
Different Variable Time of Day											
Very low sun angle	-1		-3	-2	-2			2	-1	-2	
Night (for thermal IR)	2		0	-1	-2	3			2	0	
Non-Sun synchronous			-3	-2	-2			3	-2	-2	
Day + Night IR (Max T)	1		-2			3			2		
Stereo Coverage - complete w/vert. exag.			0	1	1				0	1	
* Additional Pre-processing of digital data											

* = Ground Station Function

TABLE IV-1
LANDSAT PARAMETER ASSESSMENT (CONT'D)

Good (Neutral) Detrimental

3 2 1 0 -1 -2 -3

	Subsurface Water Supply	Study-Lakes and Reservoirs	Monitor Inland Lakes	Land Use	Land Use Classification	Turbidity Detection	Water Resource Management	Monitor Lake Ice	Study Sediment	Study Estuarine Dynamics	Delineate Inundated Areas
LANDSAT 1 and 2											
80 m Spatial Resolution	3	1	1	1	1		-2	1	1	1	1
Signal/Noise - Moderate	0	1	1	1	1		0	1	1	1	1
Spectral Range 0.5 - 1.1 μm	2	1	1	1	1		1	1	1	1	1
Repeat Coverage	2	-3	-3	1	1		-2	-3	-3	-3	-1
182 x 182 km mi. Format	2	1	1	1	2		1	1	1	1	1
Mid-morning 9:30 a.m.	3	3	3	2	0		3	0	3	2	0
Digital Tapes - Raw data	-1			0	0		0				
* Data Delivery as presently experienced	-2	1	1	0	0		-3	-2	1	1	0
* Image Quality as presently available	-2	-2	-2	-1	1		0	-2	-2	-2	-2
Incidental Stereo	-1	0	0	0			0	0	0	0	0
Geometry - Excellent	0	1	1	1	0		3	1	1	2	2
LANDSAT C											
Add: 10.4 to 12.5 μm	1	2	2	1	0	1	3	2	1	2	3
* Digital Tapes, Corrected	1	1	1	1			2	1	1	1	1
* Data Delivery, Rapid (48 hr.)	2	2	1	-1	0	0	3	3	1	1	3
RBV Panchromatic	0	1	1	0			1	1	1	1	1
LANDSAT FOLLOW-ON											
30 m Resolution (except thermal)	3	2	2	0	3	3	3	3	2	2	3
Add: Blue Band (water penetration)	0	2	3	0	0	2	1	1	1	2	1
Add: Near IR (1.6 μm - mineral)	1	1	1	0			0	2	0	1	2
Program Continuity	2	2	2	1	2	2	3	2	2	2	2
Near-Noon - 11:00 a.m.	-2	-3	-3	-2			-2	-3	-3	-3	-1
Signal/Noise - Improved	0	3	3	0	2	2	1	3	3	3	3
Geometry - Degraded at lower altitude	-1	-3	-3	0			-1	-3	-3	-3	-3
10.4 - 12.5 μm Day-Night coverage											
Resolution - better than 30 m	2	1	2	1			3	2	1	1	3
Additional Spectral Bands	0	1	1					1	1	1	1
Passive Microwave	-1	1	1				3	2	1	1	1
Radar	3	1	1	-1			1	3	0	1	2
Laser Topog. Profile	0	1	1	0				1	0	1	2
Fraunhoffer Line Discrim.	1	3	3	0			0			1	0
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	0	1	1	1			0	1	0	0	2
8.2 - 9.4 μm (with 10 - 12 μm)	2	1	1	2			0	1	0	1	1
Different Variable Time of Day		-3	-3					-3	-3	-3	-1
Very low sun angle	2	-2	-2	-2				-2	-2	-2	-2
Night (for thermal IR)	3	3	3	0			1	3	0	3	3
Non-Sun synchronous	0	-3	-3	-1				-3	-3	-3	-1
Day + Night IR (Max T)	3	2	2					3	0	2	2
Stereo Coverage - complete w/vert. exag.	3	0	0	1			2	0	0	0	0
* Additional Pre-processing of digital data											

* = Ground Station Function

TABLE IV-1
LANDSAT PARAMETER ASSESSMENT (CONT'D)

Good (Neutral) Detrimental

3 2 1 0 -1 -2 -3

	Flood Plain Mapping	Urban Hydrology	Data Collection								
LANDSAT 1 and 2											
80 m Spatial Resolution	1	1									
Signal/Noise - Moderate	1	0									
Spectral Range 0.5 - 1.1 μm	1	2									
Repeat Coverage	0	0	-1								
182 x 182 km mi. Format	1	1	-2								
Mid-morning 9:30 a.m.	0	1									
Digital Tapes - Raw data	0	-1	-1								
* Data Delivery as presently experienced	0	-2	-1								
* Image Quality as presently available	1	-3									
Incidental Stereo		0									
Geometry - Excellent	0	-1									
LANDSAT C											
Add: 10.4 to 12.5 μm	0	1	0								
* Digital Tapes, Corrected		3									
* Data Delivery, Rapid (48 hr.)	0	3	0								
RBV Panchromatic		2									
LANDSAT FOLLOW-ON											
30 m Resolution (except thermal)	2	3									
Add: Blue Band (water penetration)	2	2									
Add: Near IR (1.6 μm - mineral)		3									
Program Continuity	2	3	2								
Near-Noon - 11:00 a.m.		0									
Signal/Noise - Improved	2	2									
Geometry - Degraded at lower altitude		1									
10.4 - 12.5 μm Day-Night coverage											
Resolution - better than 30 m		3									
Additional Spectral Bands											
Passive Microwave		3									
Radar		2									
Laser Topog. Profile		3									
Fraunhoffer Line Discrim.		0									
2.0 - 2.5 μm (with 1.1 - 1.6 μm)		1									
8.2 - 9.4 μm (with 10 - 12 μm)		1									
Different Variable Time of Day											
Very low sun angle		0									
Night (for thermal IR)		3									
Non-Sun synchronous		[illegible]									
Day + Night IR (Max T)		3									
Stereo Coverage - complete w/vert. exag.		0									
* Additional Pre-processing of digital data											

* = Ground Station Function

TABLE IV-2

Requirements Assessment Table

3 = Essential 2 = Very Valuable 1 = Desirable 0 = Inconsequential	Digital Format	Image Format	Regional Image Coverage = 50 mi/side	Stereo	High Resolution	Visible/Near IR	Thermal Bands	Rapid Cycle	Seasonal Coverage	Rectilinear Presentation	
Snow Water Content	3	3	1	0	1	3	3	3	0	1	
Snow Covered Area	3	3	1	0	1	3	3	3	0	1	
Thermal/Reflectance Characteristics	3	2	2	1	0	3	3	3	0	1	
Inland Waters	2	2	1	1	2	2	2	2	2	0	
Subsurface Water Supply	3	3	2	2	2	3	2	2	3	1	
Water Resource Management	3	0	1	0	2	3	3	3	3	1	
Inland Lakes-Water Quality	3	3	2	0	3	3	2	3	3	2	
Lake Ice Monitoring	1	2		0	3	2	2	3			
Sediment Requirement Assessment	3	3	3	1	3	3	3	3	3	3	
Estuarine Dynamics	3	3		1	3	3	3	1	3		
Inundated Areas and Shorelines	3	3	2	0	3	3	2	2	0	2	
Basin Physiography and Land Cover	3	3	2	2	3	3	3	1	3	2	
Runoff Modeling	3	3	2	1	2	3	3	1	3	2	

TABLE IV-2 (Cont'd)

Requirements Assessment Table

3 = Essential 2 = Very Valuable 1 = Desirable 0 = Inconsequential	Digital Format	Image Format	Regional Image Coverage = 50 mi/side	Stereo	High Resolution	Visible/Near IR	Thermal Bands	Rapid Cycle	Seasonal Coverage	Rectilinear Presentation	
Urban Hydrology	3	3	2	2	3	3	3	0	3	3	
Inland Waters (General)	3	3	1	0	3	3	2	3	3	2	

CHAPTER V

KEY POINT SUMMARY FOR LAND INVENTORY

A. SYNOPSIS

The purpose of this chapter is to provide a more extensive summary of issues relating to the use of Landsat satellite data for the land invention-related applications mentioned earlier. Each application will be discussed in the following manner:

1. Use of the Current Landsat Program
2. Anticipated Impact of Proposed Landsat follow-on
3. Continuing Issues

Information in this chapter was abstracted from the detailed reports found in Part 4 of the discipline discussion volume.

B. NATURAL RESOURCE INVENTORY

1. Use of the Current Landsat Program

Systematic methods for collecting, recording, and interpreting data related to natural resource conditions are increasingly needed for planning, developments, or management decisions.

The Landsat program can fill a very important role as common denominator around which other data systems can be developed. Presently, Landsat systems can be used with a high degree of confidence in performing simple functions related to the description, mapping, and analysis of data relating to general land cover types. Programs and laws which call for expanded natural resource inventories and/or regional land-use inventory systems are:

- Public law 92-500, sections 208, 303e and 404, for water quality planning.
- HUD 701 program, for comprehensive areawide Land-Use Plans
- Soil Conservation Service, under laws 74-46 and 89-566 for agricultural and land use-related decisions, and inventories of water impoundments recreational developments, etc.

- National Environmental Policy Act of 1969 (91-190) for environmental impact studies.

- in metropolitan areas for planning grants.

- programs for coastal zone planning, facilities siting, etc.

Some advantages of Landsat data that could revolutionize development of natural resource inventories and regional land-use data systems are:

* Landsat creates a uniform data base covering all surfaces of the earth.

* Landsat allows monitoring and updating on a 9-day basis, weather permitting.

* Landsat has a synoptic view not duplicated by any other imaging system.

* Landsat data is computer-compatible, allowing interpretations to be repeatable, inexpensive, unbiased, quantifiable, easily acquired for relatively low investment.

* Landsat imagery can be utilized by conventional photo interpretation techniques.

Among other uses, Landsat data:

* are being investigated by the State of Georgia as data inventory for the 208 section of PL 92-500.

* have been used to update land use maps of the Washington, D. C. area at a cost significantly lower than by conventional techniques.

* have been used in the Multiple Input Land-Use System (MILUS) to prepare a base for land use inventories successfully.

* have been used to provide basic maps and data documenting generalized land cover (croplands, open space, urban areas, water, etc.). When used in interpretion of land cover areas to determine actual land uses, Landsat information must be related to ground truth information such as aerial photography, existing maps, and reports reflecting actual ground checks. For monitoring purposes existing Landsat systems have broad applications which can be made operational with the present State-of-the-art.

2. Anticipated Impact of Proposed Landsat Follow-on

Of the several proposed technical changes in the satellite specifications for the follow-on, the following comments are offered:

* The proposed time of equatorial crossing (11:00 a.m.) may well cause a decrease of shadows to the point that it will make interpretations of topographical features difficult, as well as resulting in cloud cover problems and high reflecting areas in deserts and water bodies.

* Proposed lower satellite altitude and increased scan angle may degrade uniformity of data and require expensive corrections; may not be compatible with current Landsat. May also decrease the amount of area in which training samples for digital processing will be accurate. This may well increase processing costs.

* 30 meter resolution plus blue and thermal bands should expand the reliability of direct interpretation, number of applications, and confidence levels.

* 9-day coverage, weather permitting, should give greater likelihood of obtaining data to allow monitoring and updating of inventories.

3. Continuing Issues

In consideration of the existing and proposed Landsat specifications and criteria, the following are continuing issues which need to be addressed if maximum benefits are to be obtained for Natural Resource Inventory Applications.

* Of all the factors influencing the use of Landsat, those relating to decisions by NASA officials and Congress to make Landsat a long-term OPERATIONAL program are most important. As long as the program is experimental, State and private agencies will hesitate to invest.

* The data must be geometrically rectified and registered to some map base before it is delivered to the user.

* Present delivery time of Landsat (1 and 2) is not reliable and must be made more consistent.

* Present 80 meter resolution does not allow reliable interpretations of certain localized features for land-use planning purposes. Changes in features such as shorelines, linear patterns of vegetation species and small developments in urban areas are not readily discernible.

* Very little coordination has taken place among agencies for data collection and planning. Natural resource and land-use inventories must be integrated so that methods of collecting, interpreting and presenting data may be standardized.

* Landsat should not be viewed as the total answer for all data collection and inventory needs - some information requirements are currently beyong the capacity of existing Landsat systems.

C. FORESTRY, RANGE, AND WILDLIFE

1. Use of the Current Landsat Program

Although very few, if any, projects have been developed in an operational atmosphere, results strongly suggest a significant contribution by Landsat to overall forest, range, and wildlife resource management systems. The application of Landsat data in these activities has primarily involved stratification (vegetation separation), or measuring strata variation through the use of multi-temporal overlays (seasonal changes). From this, a method for detecting and monitoring change has been established. Stratification has been demonstrated for the following:

* areas of cultural activity, including delineation of:
  - clearcutting
  - conversion to other uses
  - regeneration
  - site preparation and improvement
* broad vegetative and density categories:
  - 75% to 95% performance levels for discrimination of forest and range from other land categories; i.e. urban, agriculture, barren land, water, etc.
  - overall performance of 76.5% when above 5 classes were increased to 8 classes.
  - 85-87% and 85-96% performances in classifying conifers and hardwoods.
  - density measurement capability which relates to timber production has shown overall forest land correlations of 93%.
  - satellite will be useful to more accurately and efficiently perform volume inventories which will have economic benefit to the forest industry.
* evaluation of forest stress and damage, caused by insects, disease, fire, wind, etc. has been done. Using repeat coverage, density stratifications involving the vigor or health of forest stands have been suggested.

Use as a change detection monitor suggests an early warning technique for disease and insect infestation, otherwise undetected by eye or camera (visible range).

* classification capabilities could improve materially through the use of multi-temporal data.

* evidence indicates the possibility for discriminating areas of soil deficiency.

* further evidence indicates possibility of determining underlying geologic and soil characteristics as inferred from vegetation.

* value indicated as the first stage of a multi-stage sampling procedure (augmented by more precise photographic data sources). Landsat used to stratify a multi-stage forest inventory showed a significant reduction in sample variance as compared with conventional technique.

The ability to geometrically rectify and register existing and sequential images and the ability to utilize multi-stage sampling designs with satellite data representing the generalized first stage are the two most critical capabilities in rendering satellite data operational. Turn around time for general inventory is not critical; but for the annual forest inventory and monitoring, current turn around time is unacceptable for an operational program. This is especially true for range management where an index of measurement and conditions need to be correlated with the data immediately after the satellite flight.

2. Anticipated Impact of Proposed Landsat Follow-On

Of the several proposed technical changes in satellite specifications for the follow-on, the following comments are offered:

* The thematic mapper as a second-generation MSS holds promise for future data use from satellite sources:

  30 meter resolution will be significant by allowing more precise boundary and acreage determinations, higher accuracy of classifications (especially level III and higher) and may allow one or more stages of multi-stage systems to be deleted, resulting in a substantial benefit/cost improvement and more efficiency.

256 quantification levels, along with increased resolution, should enhance classification capability, allowing higher statistical classification results and broadening the range of features classifiable through pattern recognition techniques.

* Applications dealing with forestry disasters, rangeland, and wildlife will require data retrieval within days of the satellite flight.

* High density tapes/direct data access provide great possibilities for large volume users.

* Prompt (4 week) acquisition of formatted and geometrically corrected data is essential for most forest applications.

* Maintenance of a multi-spectral scanner (MSS) as proposed will be valuable in maintaining continuity with existing data.

* Proposed equatorial crossing of 11:00 a.m. should be beneficial by allowing improved correlations with underflight data since both sources will not contain tree shadows.

* Two satellites with 9-day, as opposed to 18-day coverage, should provide adequate cloud-free scenes to be useful for monitoring, despite increased cloud coverage and convectional build-up as a result of 11:00 equatorial crossing.

* There is concern over 705 kilometer altitude if it results in non-compatible information with existing satellite data. This should not be a problem for forestry provided skew, vignetting and radiometric distortion are controlled and corrected image data provided.

3. Continuing Issues

In consideration of the existing and proposed Landsat specifications and criteria, the following are continuing issues which need to be addressed if maximum benefits are to be obtained for Forestry, Range and Wildlife applications:

* Data as provided by Landsat satellites should be made OPERATIONAL to give reliable expectations of obtaining information necessary to efficiently manage forest and range resources.

* Satellite data collection systems now and in the foreseeable future are NOT STAND ALONE systems but will rely on some lower level ancillary data to reach the level of user precision required.

* Although many applications have been demonstrated, few if any implementable and operational systems have been documented to date.

The key to a successful operational system required that:

* the data be GEOMETRICALLY RECTIFIED AND REGISTERED before being given to the user

* the user develop an INDEPENDENT PROCESSING CAPABILITY

* the satellite data be made available on a FASTER TURN AROUND BASIS if data is to be used in an operational environment.

D. WETLAND MAPPING AND INVENTORY

1. Use of the Current Landsat Program

To date there are no documented operational programs using Landsat for wetland mapping, the use of Landsat generally being still in the experimental phase for this application. Coastal marshes have received the most attention to date. Although little work has been done with Landsat on inland wetlands, several experiments indicate a potential for inland wetland inventory if spectral parameters are worked out and boundary dynamics problems are solved.

Landsat data have been used experimentally for studies involving gross species composition related to salinity in coastal wetlands, identification of relatively pure species and their relationship to primary productivity, identification of man-made structures and spoil disposal sites. Depending on eventual resolution and positional accuracy, Landsat data could be used as a systematic approach to enforcement of wetland legislation.

2. Anticipated Impact of Proposed Landsat Follow-on

Of the several proposed technical changes in the satellite specifications for the follow-on, the following comments are offered:

* 30 meter resolution and increased number of spectral bands will improve capability to map and inventory wetlands according to present legislative requirements, but will not suffice for conducting regulatory functions or serve as the basis for litigation.

* improvement should be seen in separation of different wetland types through further research on additional bands, seasonal combinations, etc.

* Decrease in orbit altitude will cause multi-temporal comparison problems with previous data and may make processing more difficult and expensive.

* Although species discrimination may improve with 11:00 a.m. equatorial crossing, water penetration may be hampered by glint and cloud cover may be a problem.

3. Continuing Issues

In consideration of the existing and proposed Landsat specifications and criteria, the following are continuing issues which need to be addressed if maximum benefits are to be obtained for Wetland Mapping and Inventory Applications:

* Efficient methods must be devised to extract information on an operational basis to meet present legislative requirements. These wetland inventories for counties or individual project areas could be accomplished with extensions of present methods and improved satellite parameters.

* Improvement in data systems, data interpretation and data processing is extremely desirable, especially given the anticipated increase in quantity of data.

* Until research on methodology is complete, aircraft data will still be needed to check accuracy, evaluate analysis results, and provide high resolution products for ongoing operational programs.

* Questions still remain concerning format and availability. A quantum jump in the number of browse facilities and distribution centers will be needed.

E. COASTAL ZONE AND SHORELINE MAPPING AND INVENTORY

1. Use of the Current Landsat Program

Landsat imagery has been useful in mapping and surveying coastal features by state, federal, and private interests involved in coastal management activities which have been accelerated since the US Coastal Zone Management Act of 1972. Among the applications of existing Landsat data are the following:

* Mapping of significant shoal features in the Caribbean has proved the capability to map shoal features and depths with Landsat MSS data.
* Surface circulation and currents have been mapped through tracing of sediment and dye movement.
* Large scale regional features such as shoreline changes have been mapped.
* Hydrographic charting of reefs, islands and shoals by MSS data may prove to be the only cost effective solution for producing accurate and inexpensive charts for marine navigation.

Existing Landsat is restricted in accurately measuring the dimensions of certain shoreline features and changes over time because of limited spatial resolution. Since vast areas of ocean have not been surveyed or charted, the Landsat data could be used to presurvey these areas, verifying navigational hazards, limited depths, etc. close to national map accuracy standards. Changes in coastal land cover can be monitored with existing Landsat, as well as areas of high bioproductivity using color indicators of chlorophyll content, thermal boundaries, and circulation patterns.

Techniques have been developed for providing baseline data for coastal landforms and land use inventories. Models for computing shoreline dimensions and displaying changes due to storms, erosion, and man-made causes have been developed from Landsat data. Previously uncharted or undetected hazard areas may be located with Landsat. Depths of shoals to 22 meters have been determined by Landsat and verified by ships on site.

2. Anticipated Impact of Proposed Landsat Follow-on

Of the several proposed technical changes in the satellite specifications for the follow-on, the following comments are made:

* Proposed 11:00 a.m. equatorial crossing is a very serious liability for this application. Many problems will be encountered, such as exclusion of up to 75% of water penetration data, because of glint and

reflection problems. If water targets are of any importance, the sun-angle's negative effects on the blue band must be considered.

* Increased resolution (30 m) will allow greater capability to measure shoreline dimensions and changes following storms and over large areas in an economical fashion. The follow-on will be limited in its ability to accurately measure the dimensions of coastal structures (breakwaters, jetties, beaches, groins) which are often 7-9 meters or major beach erosion approaching 15 meters or less.

* Thematic mapper has high probability for enhancing coastal oceanic applications which will show concentrations of pollution, chlorophyll and sediments.

* Increased bands and resolution will increase reliability of data.

* 9-day coverage will allow adequate circulation and dispersion studies provided that rapid data delivery is available.

3. Continuing Issues

In consideration of the existing and proposed Landsat specifications and criteria, the following are continuing issues which need to be addressed if maximum benefits are to be obtained for Coastal Zone Applications:

* data should be made operational and available in easily used formats, inexpensively with minimum response time.

* there is a need for precise reconstruction of the data geometrically without resampling the pixels. This is especially true when pushing the data to its limits of resolution to locate platforms, wrecks, reefs, etc.

* thematic mapper should be flown with existing geometry (sun-angle, crossing, orbit, etc.) for continuity with existing data so as to allow continuity between the MSS and TM.

* data formats should be inter-nationalized so that data collected by foreign ground stations can be processed without reformatting.

F. MAPPING AND CARTOGRAPHY

1. Use of the Current Landsat Program

In general, the current satellite's use for mapping and cartographic applications is summarized below:

* current satellite is well suited to small-scale planimetric mapping and revision, depicting landforms, vegetative patterns, hydrological features and other gross patterns.
* positional accuracy approaches 1:250,000 scale National Map Accuracy Standards for cartographic products.
* useful for recording land feature and land-water interfaces.
* repetitive coverage by electronic means is a basis for automating the production of small-scale cartographic products.
* appropriate for hydrographic charting and surveying for planning and hydro surveys.

Further, a visually impressive and practical use of Landsat imagery are the mosaics of the states of New Jersey, Florida, Arizona, and Georgia as well as the entire United States. A nominal scene format has also been developed which forms the basis for the image format map series. This system has no overlap, is adaptable to worldwide use and is computer compatible.

2. Anticipated Impact of Proposed Landsat Follow-on

Of the several proposed technical changes in the satellite specifications for the follow-on, the following comments are made:

* map accuracies can be improved with proposed resolution of 30 m.
* 11:00 a.m. equational crossing will result in excessive sun glint and will be detrimental to charting tasks.
* addition of thermal and water penetration bands may enhance thematic and shallow sea mapping tasks.

* if altitude is lowered to 705 km it may prove non-compatible with existing satellite data.

* revision of cultural features such as roads, railways, towns, etc. is not possible with existing or proposed satellite.

* desirability of increasing gray scale to 256 levels is questioned. A more desirable range would be 128 levels.

* required data such as topographic (elevation) or cultural detail will not be provided. Topographic (elevation) data is typically derived from stereo coverage; current and proposed Landsat do not have stereo, a major departure from traditional mapping procedures.

3. Continuing Issues

In consideration of the existing and proposed Landsat specifications and criteria the following are continuing issues which need to be addressed if maximum benefits are to be obtained for Mapping and Cartographic applications:

* an operational Landsat must be supplemented by other spacecraft and/or aircraft programs.

* many needed experiments of cartographic value cannot be carried out on an operational Landsat since an operational system would constrain procedure variations.

* basic mission parameters of Landsat follow-on are unacceptable for mapping and cartographic applications.

Cartographers, and those whose work depends on cartographic processes, are requesting an operational system based on the following considerations:

1. An economically viable system;
2. Continuity with respect to Landsat -1, -2, & -C;
3. Spatial and spectral resolution that is meaningful to them;
4. A data flow that is manageable;
5. Completely open access and availability;
6. Near-real-time reception of data on a global basis;
7. Suitability for automation;
8. Expeditious dissemination in digital (tape) and optimum analog (image) form at a reasonable price.

Specific suggestions for technical revisions are found in the appropriate section in the Land Inventory discipline discussion volume.

G. SURFACE MINING EXTENT AND RECLAMATION MONITORING AND INVENTORY

1. Use of the Current Landsat Program

Although there are at present no operational uses of Landsat by state or federal agencies in monitoring surface mining activities, studies indicate that a combination of Landsat and other remote sensing could be a useful tool for this application. In dealing with small areas (several acres or less), the limiting factor is resolution of the sensors. Some research efforts to date include:

* South Carolina project using Landsat as monitoring tool for surface mining had 99% correlation in a number of cases with planimetered areas from aerial photos.
* 93% accuracy in showing areas of strip mine affected acreages in Maryland, including monitoring progress of back-filled areas.
* successful mapping in Ohio of (1) stripped earth, (2) partially reclaimed earth, (3) vegetation, (4) shallow water, and (5) deep water; also in Tennessee for about 50¢/sq. mile, (one-tenth cost of conventional technique) 1:250,000 scale, with accuracies better than 90% in most categories.
* coal mining study in Pennsylvania showed Landsat data may be quite useful for annual updates, although of limited value for monitoring.
* Northern Great Plains study on evaluating Landsat data for strip mining/reclamation was successful on 14 of 30 mines considered.

Landsat has been successfully used to update geologic maps in Tennessee and modify coal reserve estimates. Landsat also has been used in the Western Coal Mining district to determine the map extent and progression of mining activities, and to monitor mined land reclamation. Coal mining in the Cumberland mountains and phosphate mining in Florida have also been studied using Landsat.

Potential usefulness has been indicated in demonstration and research projects and the general conclusion is that Landsat could be a useful tool in providing monitoring and surface classification information to state and federal regulatory agencies.

2. Anticipated Impact of Proposed Landsat Follow-On.

Of the several proposed technical changes in the satellite specifications for the follow-on, the following comment is offered:

* the need of concentrating on the task of literally leading potential users by the hand until convinced of satellite imagery's usefulness overshadows any considerations of concern over Landsat follow-on improved characteristics.

3. Continuing Issues

In consideration of the existing and proposed Landsat specifications and criteria the following are continuing issues which need to be addressed if maximum benefits are to be obtained for Surface Mining Applications:

* more emphasis needs to be placed on the technology transfer aspect of remote sensing for operational uses.

* potential users need to be exposed more to existing systems prior to considering more sophisticated systems.

* question exists to what extent satellite data would replace or supplement current monitoring procedures and what cost savings would be.

H. URBAN AND SPECIAL ENVIRONMENTS

1. Use of the Current Landsat Program

Landsat and Landsat follow-on can have major impacts on the supply of data for urban and metropolitan regions, although such data must be accompanied by more detailed data such as aerial photography, census data, etc. Some uses of Landsat data to date are:

* 90% confidence levels in urban change detection.
* 75% accuracy in delineating Washington, D.C. urban boundary.
* procedures developed to document land use change by census tract.
* General urban categories have been classified to accuracies over 80%.
* census urban atlas file interfaced with Landsat imagery.
* Landsat data classified into 15 classes and aggregated by traffic zones.

2. Anticipated Impact of Proposed Landsat Follow-on

Of the several proposed technical changes in the satellite specifications for the follow-on, the following comments are offered:

* follow-on spectral specifications are endorsed, especially thermal sensors and 256 gray levels.
* certain urban applications such as the analysis of census tracts will need the proposed increase to 30 M resolution
* proposed thermal sensors and increased grey levels have potential for discriminating complex urban patterns.
* aircraft data will be required to satisfy data needs at parcel level.

3. Continuing Issues

In consideration of the existing and proposed Landsat specifications and criteria, the following are continuing issues which need to be addressed if maximum benefits are to be obtained for Urban and Special Environments applications.

* fast data delivery and an operational satellite are essential.
* geometric rectification and registration is necessary if data is to be useful.
* the cost of data processing is too high for local governments or entrepreneurs to assume. Users need access to a center where they can have their products processed without inheriting equipment costs.
* coordination among data users and producers is required. There is a gross lack of coordination and direction at the federal level.
* a total geographically based information system needs to be developed as part of Landsat follow-on activities.

I. PARAMETER ASSESSMENT TABLES

The following tables show the user reactions in group form of the Landsat follow-on parameters and other considerations to each significant application represented by the Land Inventory group. These reactions range from Good (3) to Detrimental (-3). The specific meaning of the numbers can be interpreted as follows:

3: essential
2: very valuable
1: valuable
0: inconsequential
-1: degrades data utility or reduces probability of acquiring
-2: makes data very hard to use or generates low probability of acquiring
-3: makes data useless

TABLE V-1
PARAMETER ASSESSMENT TABLE

Good (Neutral) Detrimental

3 2 1 0 -1 -2 -3

	Forestry	Range	Wildlife	Natural Resource Inventory	Wetland Mapping and Inventory	Shoreline Dimension and Changes	Hydrographic Charting	Land Use Land Cover	Water Characteristics	Coastal Circulation	Shallow Seas Mapping
LANDSAT 1 and 2											
80 m Spatial Resolution	2	2	2	1	0	1	1	1	1	1	1
Signal/Noise - Moderate	2	2	2	2	0	1	0	1	0		0
Spectral Range 0.5 - 1.1 μm	2	2	2	1	0	1	-1	1	-1	-1	-1
Repeat Coverage	3	3	3	2	0	1	1	1	1	1	1
182 x 182 km mi. Format	3	3	3	2	0	1	3	2	2	2	3
Mid-morning 9:30 a.m.	1	1	1	3	1	3	3	3	3	3	3
Digital Tapes - Raw data	1	1	1	3	2	2	3	2	2	1	3
* Data Delivery as presently experienced	0	-2	-1	-1	-2	-1	-2	-2	-2	-1	-2
* Image Quality as presently available	0	0	0	2	-3	-2	-3	-2	-2	-2	-3
Incidental Stereo	0	0	0	-3	0	0	0	0	0	0	0
Geometry - Excellent	3	3	3	3	2	2	1	2	1	1	1
LANDSAT C											
Add: 10.4 to 12.5 μm	2	2	2	3	1	2	1	2	2	1	1
* Digital Tapes, Corrected	3	3	3	3	2	2	3	2	3	2	
* Data Delivery. Rapid (48 hr.)	2	2	1	3	3	2	3	2	2	2	3
RBV Panchromatic	0	0	0	-1	0	2	1	2	1	1	1
LANDSAT FOLLOW-ON											
30 m Resolution (except thermal)	3	3	3	3	3	2	2	2	2	2	3
Add: Blue Band (water penetration)	0	0	1	3	3	3	3	3	3	3	3
Add: Near IR (1.6 μm - mineral)	2	1	2	2	1	0	1	1	0	0	1
Program Continuity	3	3	3	3	3	-2	-3	-3	-2	-3	-3
Near-Noon - 11:00 a.m.	2	-1	2	-2	-2	-3	-3	-3	-3	-3	-3
Signal/Noise - Improved	2	2	2	0	2	1	3	2	3	2	3
Geometry - Degraded at lower altitude				-2		0	-3	-3	-3	0	-3
10.4 - 12.5 μm Day-Night coverage											
Resolution - better than 30 m	-1	0	0	0	0	3	3	3	1	3	3
Additional Spectral Bands					3						
Passive Microwave	0	0	0	1	0	0	1	0	1	1	1
Radar	1	1	1	2	1	0	3	0	1	2	3
Laser Topog. Profile	0	0	0	1	3	0	1	0	1	2	1
Fraunhoffer Line Discrim.	0	0	0	3	1						
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	1	1	1	2		0	0	0	0	0	1
8.2 - 9.4 μm (with 10 - 12 μm)	1	1	1	0		0	0	0	0	0	2
Different Variable Time of Day											
Very low sun angle	-2	-2	-2	1	-3	-3	-3	-3	-3	-3	0
Night (for thermal IR)	0	0	0	3	0	1	1	1	1	1	1
Non-Sun synchronous				-3	-1	-2	-2	-3	-3	-3	1
Day + Night IR (Max T)				3	0	0	0	0	0	0	0
Stereo Coverage - complete w/vert. exag.	2	1	1	1	1	3	3	3	3	3	3
* Additional Pre-processing of digital data											2

* = Ground Station Function

TABLE V-1
PARAMETER ASSESSMENT TABLE (CONT'D)

Good (Neutral) Detrimental
3 2 1 0 -1 -2 -3

	Aeronautical Charting	Small Scale Image Mapping	Map Revision of Told Features	Map Revision of Cultural Features	Thematic Mapping	Metropolitan	Tract	Parcel/Block	Disturbed Areas	Water Impoundments	Spoil Piles (Refuse)
LANDSAT 1 and 2											
80 m Spatial Resolution	3	2	2	-3	0	3	1	-3	-3	-3	-3
Signal/Noise - Moderate	0	0	0	0	0	2	2	-1	2	2	2
Spectral Range 0.5 - 1.1 μm	3	2	2	0	2	2	2	2	2	2	2
Repeat Coverage	3	3	3	3	2	3	3	3	3	3	3
182 x 182 km mi. Format	3	3	3	0	0	3	1	-2	3	3	3
Mid-morning 9:30 a.m.	3	3	3	3	3	1	1	-1	-1	-1	-1
Digital Tapes - Raw data	3	3	3	3	3	-2	-2	-2	-2	-2	-2
* Data Delivery as presently experienced	2	0	0	0	-1	-3	-3	-3	-1	-1	-1
* Image Quality as presently available	-3	-3	-3	-3	-3	-1	-2	-2	-3	-3	-3
Incidental Stereo	0	0	0	0	0	0	0	0	0	0	0
Geometry - Excellent	2	2	2	1	2	2	1	-1	3	3	3
LANDSAT C											
Add: 10.4 to 12.5 μm	0	1	1	1	1	1	2	2	1	1	1
* Digital Tapes, Corrected						2	2	2	3	3	3
* Data Delivery, Rapid (48 hr.)	3	3	3	3	3	3	3	3	0	0	0
RBV Panchromatic	3	3	3	3	3	2	1	-1			
LANDSAT FOLLOW-ON											
30 m Resolution (except thermal)	3	3	3	3	1	2	3	3	3	3	3
Add: Blue Band (water penetration)	1	1	1	0	1	0	0	0	1	1	1
Add: Near IR (1.6 μm - mineral)	1	1	1	1	1	0	0	0	0	0	0
Program Continuity	-3	-3	-3	-3	-3	3	3	0	3	3	3
Near-Noon - 11:00 a.m.	3	-3	-3	-3	-3	2	2	2	2	2	2
Signal/Noise - Improved	-3	3	3	3	3	3	3	3	2	2	2
Geometry - Degraded at lower altitude		-3	-3	-3	-3	2	1	-1	0	0	0
10.4 - 12.5 μm Day-Night coverage											
Resolution - better than 30 m	1	0	1	3	1				3	3	3
Additional Spectral Bands											
Passive Microwave	1	1	1	0	1				3	3	3
Radar	2	2	2	1	1				3	3	3
Laser Topog. Profile	2	0	0	0	1				3	3	3
Fraunhoffer Line Discrim.									2	2	2
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	1	1	1	1	3				0	0	0
8.2 - 9.4 μm (with 10 - 12 μm)	0	1	1	2	3				0	0	0
Different Variable Time of Day											
Very low sun angle	1	1	1	1	1				-2	-2	-2
Night (for thermal IR)				1	3				0	0	0
Non-Sun synchronous	1	1	1	1	1				0	0	0
Day + Night IR (Max T)	0	0	0	0	3				0	0	0
Stereo Coverage - complete w/vert. exag.	3	3	3	3	3				2	2	2
* Additional Pre-processing of digital data	2	2	2	2	3						

* = Ground Station Function

TABLE V-1

PARAMETER ASSESSMENT TABLE (CONT'D)

Good (Neutral) Detrimental
3 2 1 0 -1 -2 -3

	Type and Status of Mining	Access and Haul Roads	Percent Vegetative Cover	Surface Roughness	Vegetation Types	Surface Spoil Types	Erosion/ Sedimentation	Acid Mine Drainage	Mine Subsidence	Landslides	
LANDSAT 1 and 2											
80 m Spatial Resolution	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	
Signal/Noise - Moderate	2	2	2	2	2	2	2	2	2	2	
Spectral Range 0.5 - 1.1 μm	2	2	2	2	2	2	2	2	2	2	
Repeat Coverage	3	3	1	1	1	1	3	3	3	3	
182 x 182 km mi. Format	3	3	3	3	3	3	3	3	3	3	
Mid-morning 9:30 a.m.	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	
Digital Tapes - Raw data	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	
* Data Delivery as presently experienced	-1	-1	-2	-2	-2	-2	-3	-1	-1	-1	
* Image Quality as presently available	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	
Incidental Stereo	0	0	0	0	0	0	0	0	-3	0	
Geometry - Excellent	3	3	3	3	3	3	3	3	3	3	
LANDSAT C											
Add: 10.4 to 12.5 μm	1	1	1	1	1	1	1	2	1	1	
* Digital Tapes, Corrected	3	3	3	3	3	3	3	3	3	3	
* Data Delivery, Rapid (48 hr.)	0	0	1	1	1	1	3	0	0	0	
RBV Panchromatic											
LANDSAT FOLLOW-ON											
30 m Resolution (except thermal)	3	3	3	3	3	3	3	3	3	3	
Add: Blue Band (water penetration)	1	1	0	0	0	0	1	1	1	1	
Add: Near IR (1.6 μm - mineral)	0	0	0	0	0	0	0	0	0	0	
Program Continuity	3	3	3	3	3	3	3	3	3	3	
Near-Noon - 11:00 a.m.	2	2	3	3	3	3	2	2	2	2	
Signal/Noise - Improved	2	2	2	2	2	2	2	2	2	2	
Geometry - Degraded at lower altitude	0	0	0	0	0	0	0	0	0	0	
10.4 - 12.5 μm Day-Night coverage											
Resolution - better than 30 m	3	3	3	3	3	3	3	3	3	3	
Additional Spectral Bands											
Passive Microwave	3	3	3	3	3	3	3	3	3	3	
Radar	3	3	3	3	3	3	0	0	3	3	
Laser Topog. Profile	3	3	2	2	2	2	3	3	3	3	
Fraunhoffer Line Discrim.	2	2	0	0	0	0	0	0	0	0	
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	0	0	0	0	0	0	0	0	0	0	
8.2 - 9.4 μm (with 10 - 12 μm)	0	0	0	0	0	0	0	0	0	0	
Different Variable Time of Day											
Very low sun angle	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	
Night (for thermal IR)	0	0	0	0	0	0	0	0	0	0	
Non-Sun synchronous	0	0	0	0	0	0	0	0	0	0	
Day + Night IR (Max T)	0	0									
Stereo Coverage - complete w/vert. exag.	2	2	0	3	0	0	0	0	3	0	
* Additional Pre-processing of digital data			0	3	0	0	0	0	3	0	

* = Ground Station Function

TABLE V-2

Requirements Assessment Table

3 = Essential
2 = Very Valuable
1 = Desirable
0 = Inconsequential

	Digital Format	Image Format	Regional Image Coverage = 50 mi/side	Stereo	High Resolution	Visible/Near IR	Thermal Bands	Rapid Cycle	Seasonal Coverage	Rectilinear Presentation	
Natural Resources Inventory	3	3	3	2	2	3	3	3	3	1	
Wetland Inventory and Mapping	3	1	0	1	2	3	1	2	3		
Coastal Zone and Shoreline Mapping and Inventory	2	3	2	1	2	3	2	1	2	2	
Urban Land Inventory	3	2	1	0	3	3	2	0	2	0	

CHAPTER VI

KEY POINT SUMMARY FOR AGRICULTURE

A. KEY POINT SUMMARIES

Applications presented here are considered feasible and productive when reviewed in the light of technical competency reported for the Landsat follow-on satellite system. The following material are excerpts from the findings of the Panel with respect to the individual applications groupings considered:

1. <u>Crop Stress</u>

* If Landsat follow-on sensor resolution is approximately 30m, limited areas of crop stress will be detected.
* Accurate detection and identification of stress in crops by image analyst will still require considerable collateral data.
* With respect to the capabilities of the follow-on system to detect specific types of stress:
  - Moisture stress; if sufficient collateral data is available follow-on should be capable of providing a crude estimate of moisture stress.
  - Salinity; salinity maps and knowledge of irrigation practices should permit limited detection of crop stress due to salinity.
  - Nutrient Deficiency; operational application could potentially be achieved here for larger fields with relatively homogeneous materials in areas where good collateral data exist.
  - Disease; follow-on may have sufficient resolution to detect relatively large areas of disease.
  - Insect damage; follow-on is expected to have limited value here.
  - Other cases; infrequent stress types such as those caused by fire, floods or frost should be detectable on follow-on imagery.

* If Landsat follow-on is to be a practical tool for detecting crop stress it must:

  - Provide imagery to users within two weeks or <u>much less</u> of date of imaging.

  - Have at least 30 m resolution

  - Be used in conjunction with much supplemental information needed to properly interpret crop stress.

  - Provide data (imagery, etc.) at a reasonable price.

  - Be employed by interpreters familiar with the management intricacies of modern agriculture.

2. <u>Climatic Information</u>

* Landsat and follow-on data are and will be useful and effective as ancillary input to ground truth in assessment of climatological parameters. It is available once every 18 days for coverage of the same area and will be reduced to 9 days with the Landsat follow-on satellite. This is in comparison to daily reports from NOAA satellites. The qualitative nature of the data, however, precludes its consideration in development of statistical crop/climate models. Until such time as Landsat can provide quantitative climatological input, to the precision needed, in a timely and cost effective manner, its expected use to NOAA's center for climatic and Environmental Assessment(CCEA) will be limited to a contributory, subservient role.

* Research must address quantitative processing of the thematic mapper information. Considerable computer resources are necessary to achieve this. The spatial resolution is sufficient for detailed moisture information on the cloud free areas, but to provide continuous moisture information, some backup means should be considered in the event of persistent cloudiness.

3. Crops - Groundwater and Stress

* In this area considerable research has documented the capabilities of current Landsat series data and leads us to believe that the follow-on system will improve and expand our capabilities in this area.

4. Agricultural Land and Water Resources

* Applications of remote sensing imagery in this area have been initiated by numerous universities with the feasibility phase of these studies being substantially funded by NASA. Cooperation with potential user agencies has maximized the return of this effort by providing consultant review of the research programs and important ground truth data. These investigations are bearing considerable fruit and it is anticipated that an extension of these initial investigations will be made to utilize Landsat follow-on data for world-wide identification, monitoring and prediction of agricultural land and water resources. Table VI-1 is presented here to illustrate the "state-of-the-art" of Landsat remote sensing techniques applied specifically to agricultural water resources investigations.

5. Global and Unique Applications

* A considerable variety of these applications were examined and the consensus of our analysis appears in Table VI-2. Costs and benefits have been established for only a few uses for satellite data, primarily because many applications have not been fully developed, or experience gained to the point where cost-benefits can be established. However, examples of the value of the NASA-RSI effort are presented in studies such as those in Pennington County, South Dakota, Texas, and in Kern County.

TABLE VI-1
NASA - APPLICATIONS SURVEY GROUP
AGRICULTURE
LANDSAT IDENTIFICATION CLASSIFICATION

	STATE OF THE ART (With 80 meter resolution)			TEMPORAL REQUIREMENTS	
	Operational	Development	Research	Frequency Coverage	Data Delivery
WATER STORAGE					
Surface Reservoirs					
Artificial	X			@ 9 days	@ 1 week
Natural	X			@ 9 days	@ 1 week
Water Quality		X------------	------------X	@ 9 days	@ 1 week
Subsurface Reservoirs					
Recharge Facilities	X			@ 18 days	@ 2 weeks
Well Fields			X	@ 18 days	@ 2 weeks
Transmission Facilities			X	@ 18 days	@ 2 weeks
Wells			X	@ 18 days	@ 2 weeks
DISTRIBUTION SYSTEMS					
(Canals)					
Lined	X------------	------------X		@ 18 days	@ 2 weeks
Unlined	X------------	------------X		@ 18 days	@ 2 weeks
(Pipelines)					
Surface	X------------	------------X		@ 18 days	@ 2 weeks
Subsurface			X	@ 18 days	@ 2 weeks
Natural Channels	X------------	------------X		@ 18 days	@ 2 weeks
WATER APPLICATION					
Field Flooding		X------------	------------X	@ 9 days	@ 2 weeks
Ditch Deliveries			X	@ 9 days	@ 2 weeks
Closed Systems (Pipes)	X------------	------------X		@ 18 days	@ 1 month
Irr. Need Recognition			X	@ 9 days	@ 1 week
Irr./Non-Irr.	X			@ 18 days	@ 2 weeks
Crop Identification	X------------	------------X		@ 9 days	@ 1 week
Areal Limitations					
Perched Water			X	Daily	Daily
Saline Soils			X	@ 18 days	@ 2 weeks
Moisture Deficient Soils			X	Daily	Daily
Hard Rock	X------------	------------X		@ 18 days	@ 1 month
Steep Slopes	X------------	------------X		@ 18 days	@ 1 month
WASTEWATER DISPOSAL					
Evaporation Ponds	X------------	------------X		@ 18 days	@ 2 weeks
Surface Conveyance Systems	X------------	------------X		@ 18 days	@ 2 weeks

TABLE VI-2

AGRICULTURAL APPLICATIONS

Application	State of the Art: Operational	State of the Art: Development	State of the Art: Research	Users*
High Water Tables		X	X	CA, CSD, DD, F, FA, ID, SCS, USBR, BIA
Salinity		X	X	CA, CSD, DD, F, FA, ID, SCS, USBR, BIA
Irrigation Management		X	X	CA, CSD, F, FA, ID, SCS, USBR
Soil Moisture		X	X	CA, CSD, F, FA, ID, BIA
Water Budget		X	X	BIA, CSD, FA, ID, SA, SCS, USBR
Ground Water Development		X	X	CSD, F, ID, SCS, SG, USGS, BIA
Soil Survey--Reconnaissance	X			CA, CSD, F, FA, SA, SCS, USBR, BIA
Seed Germination Requirements		X	X	CA, F, ID, SA
Crop Surveys--Acreage	X	X		CA, F, FA, SA, SRS, BIA
Crop Surveys Yield		X	X	CA, F, FA, SA, SRS, BIA
Range Surveys--Biomass	X	X		CA, F, FA, SA, BIA
Disease and Insects	X	X		CA, F, FA, SA, SRS, USBR, BIA
Land Erosion Potential	X	X		CA, CSD, F, FA, SA, SCS, USBR, BIA
Weed Infestations		X	X	CA, F, SA, BIA
Fertility Needs		X	X	CA, F, FA, SA, SCS, SRS, USBR, BIA

*BIA-U.S. Bureau of Indian Affairs
CA-County Agents
CSD-Conservancy Subdistricts
DD-Drainage Districts
F-Farmers
FA-Other Federal Agencies
ID-Irrigation Districts
SA-State Departments of Agriculture
SCS-Soil Conservation Service
SG-State Geologists
SRS-Statistical Reporting Service
USBR-U.S. Bureau of Reclamation
USGS-U.S. Geological Survey

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6. Worldwide Crop Production Estimation

* We are well on our way to achieving a level of scientific and technical know-how sufficient to accomplish the task of estimating the world-wide production of major food crops. The Landsat follow-on system will significantly improve our potential for achieving this goal. Considerable research, however, is still required to operationalize the proper mixes of models which include a variety of types of remotely sensed data coupled with collateral material (including field sampling) to provide the locational spectral, spatial, temporal and resolution components necessary to accomplish this task.

* It must be appreciated that these tasks go beyond the use of Landsat or Landsat follow-on data as the sole remote sensor input. Indeed, to accomplish our goal of global production estimation for major crops we must be prepared to examine models which employ complex mixes of data from a variety of satellite and airborne sensor packages with collateral material from many sources.

* The LACIE program addresses many of the problems involved in providing a world-wide crop production estimate. In this respect LACIE is currently heavily involved in the complex modeling of a variety of important parameters. Results to date appear encouraging, and the Agricultural Applications Survey Group considers it significant that a considerable committment has been made to the LACIE program by a number of agencies.

* It is our opinion that there are strong indications that the state of the art will get us there from where we are in this area.

7. Land Resources Inventory

* Based on member experience and a survey of recent literature, the Agricultural Applications Survey Group feels that the ability to use this technology for land resource inventory has

already been proven practical.

* A key to the amount of use made of this technology and the speed at which it is accepted will be the cost associated with the manual interpretation procedures or software and the computer processing associated with the above land use data.

8. Adjunct Considerations

* Under this heading the strong and definite need for classification systems designed for satellite sensor systems is laid out. Only by associating the characteristics of the remote sensor with the classification system used for presenting the information can we maximize the information retrieval from the satellite imagery and insure its fullest possible use.

* The need for user education is stressed.

* The need to achieve a system capable of rapidly disseminating follow-on data to the widest possible audience is considered extremely important.

  The Agricultural Applications Survey Group recommends that NASA investigate the potential for using the current USDA system of local and county agents for this task.

9. Selected Applications

* In this section, the Agricultural Applications Survey Group considered briefly a number of applications as to their overall feasibility of providing meaningful data from the follow-on system. These applications involved:

  - Production Estimation - Feasible in simple landscapes; difficult in more complex agricultural landscapes.
  - Soil Erosion - Actual erosion difficult to assess, however, areas of potential erosion are easy to identify.
  - Brushland, Timberland and Grassland Interfaces - Good

potential for delineation depending on sensor.

- Bare Soil and Rock vs. Vegetated Areas - Good to excellent potential for delineation with Landsat follow-on system.
- Macro-linear Identifiers, (Timberland, Waterline, Snowline, Desertline) - Good to excellent.
- Rangeland and Brushland Interface - Generally good.
- Farmsteads - Poor to fair.
- Crop Species in Fields One Acre or More in Size (Tree Crops not Included) - Good.
- Encroachment -- Desert - good; Urban - good; Marginal Production Areas - good.
- Monitoring World Agricultural Land Use - Will definitely improve our capability to discriminate major land use categories.
- Survey of Irrigation Potential - Need ground truth at reconnaissance level and at detailed level to 100 meters.

- Irrigation Scheduling - Fair.
- Water Budget - Requires considerable research.
- Water Deficit Areas (Drought) - Good with minimum of ground data.
- Depth to Water Table - Feasible in areas of very shallow water depths where crop has considerable damage.
- Water Availability - Surface - good; depth - poor; quality - good; geology - good; recharge - fair.
- Soil Classification - Color - good; relief, shadows - poor; vegetation dependent on resolution, growth stage and continuity.
- Rangeland - Good to fair.
- Crop Production - Variable
- Irrigation Potential (Water supply assumed) - Variable to good.
- Soil Salinity and Drainage - Good.
- Worldwide Crop Production Forecasting for Major World Food Crops - Requires complex modeling of a variety of environmental parameters. Data needed to accomplish this modeling includes but is not limited to meteorological satellite data, aircraft data, field sampling data, and other collateral information.
- Crop Stage - Poor to fair.

- Crop Stress - Recognition and estimation of areal extents is feasible. Stress type not feasible at this time.

B. CONCLUSIONS

The value of the U. S. agricultural production justifies continued efforts to improve our information acquisition systems, from both conventional and remote sources. Gross farm income has shown consistent increases to 101.5 billions of dollars in 1976. Our exports (mainly in the area of edible grains) have increased from about $12 billion in 1973 to over $20 billion in 1974, and have remained at or above this level since then. Remote sensing products from the Landsat follow-on satellite program will provide valuable information for managing vegetative crop production. The 1975 value of agricultural products that depend on vegetative production was in excess of $74 billions (this includes livestock production). An improvement of even 1 percent in this figure, through either increased production or by reduced costs of production would be worthwhile.

Based on an analysis of the material prepared by group members and as a result of our extensive deliberations the agricultural applications survey panel also concluded that:

* Demands for information for the great majority of users at the production decision making level in agriculture are frequent, and information must be timely, Degradation of agricultural information is extremely rapid for a great many users in the field of agriculture.

* Production applications, are extremely important and can be rewarding. They are best served by instrumentation capable of detecting stress in plant materials. Effective stress detection calls for the selection of spectral bands that will respond to the physical condition of the plant, but equally as important, it calls for a high sun cross-over time that will record the stress condition and the use of highly skilled image interpreters.

* A 9-day, global coverage capability with less than 48 hour data processing and dissemination "turn around time" appears

to be the minimum feasible program that would allow benefits to be derived from the management sector of crop production in agriculture. It is recognized that such a system would be capable of less frequent data acquisition of specific areas if a 9-day cycle was deemed unnecessary (e.g. during periods of plant dormancy or snowcover).

In retrospect, we have made significant progress in the last decade towards an understanding of the application of spectral information such as that aboard the Landsat follow-on system. There is no question that further research and development will produce expansion of improvements in the application of the information produced by future satellite systems. In extensive discussions by the Group, a number of parameters were evaluated for inclusion in, or characteristic of future satellite sensor systems. The following numerical evaluation represents a consensus of Group opinion, with a -3 representing a highly undesirable attribute:

Resolution - better than 30 m	3
Additional Spectral Bands	3
Passive Microwave	1
Radar	3
Laser Topog. Profile	1
Fraunhoffer Line Discrim.	2
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	1
8.2 - 9.4 μm (with 10 - 12 μm)	1
Different Variable Time of Day	
Very low sun angle	-
Night (for thermal IR)	1
Non-Sun synchronous	
Day + Night IR (Max T)	1
Stereo Coverage - complete w/vert. exag.	0
* Additional Pre-processing of digital data	

In addition to these capabilities and attributes the Group feels strongly that:

* A specialized thematic mapping system is highly desirable;

* Development of a high resolution pointable instrument

would be desirable, especially for sample design and disaster or unique phenomena applications;

* A dedicated Ag-Sat should be considered;

* Work must be promoted on development of low-cost and rapid data processing and disseminating techniques;

* Geometrically referenced imagery should be acquired for a variety of temporal situations, to provide the opportunity to interrelate a variety of data from different hours of pass-over, and points in time within a phenological sequence;

* If Landsat follow-on is to be a practical tool for detecting crop stress it must:

  - Provide imagery to users within two weeks but preferably within two days or less of data of imaging;

  - Have at least 30 m resolution

  - Be capable of being used in conjunction with the variety of collateral information needed to properly interpret crop stress;

  - Provide data (imagery, etc.) at a reasonable price;

  - Be employed by interpreters familiar with intricacies of modern agriculture.

* Landsat data are useful and effective as ancillary input to ground truth in assessment of climatological parameters. The present qualitative nature of the data, however, seriously hampers its potential for consideration in development of statistical crop/climate models. Until such time as Landsat series sensor systems can provide quantitative climatological input, to the precision needed, in a timely and cost effective manner, its use to NOAA's Center for Climatic and Environmental Assessment will be limited to a contributory, subservient role.

Much research work has been carried out, enough to convince many involved in this area that it is now time to make the transition from a research effort to an operational program.

Although there are many steps that can be taken to favorably influence the use of satellite information, there are many steps needed to meet the requirements and satisfy the basic premises discussed. It appears that at the present, a satisfactory delivery system exists to meet the needs of only a small number of the major users of satellite information. A system must be developed to reach the vast audience of users with frequent, accurate, standardized information, in a format and a time-frame sufficient to insure maximum data use. We feel that there is a potential to use the USDA system of county and local offices for SCS, ASCS, Cooperative Extension, FHA, etc. With its great experience and excellent record in maintaining rapport with, and providing servi es to individual farmers, landowners, and local officials, the USDA system appears to possess the only currently operational delivery system capable of meeting the urgent needs of the satellite program to reach the major portion of the agricultural audience it hopes to meet.

In conclusion, the Agricultural Applications Survey Group feels there are strong indications the state-of-the-art for interpreting remotely sensed data <u>will</u> get us to an operational use of these data in agriculture from where we are. <u>The Landsat follow-on mission will significantly increase our potential of getting there</u>. To achieve this goal, however, not only must sensor systems and the models which go with them continue to be improved; but increased communication and interaction must occur between remote sensing researchers and users. Appropriate educational programs must be established to implement the transfer of technology to the user community. Rational, operational, institutional arrangements which provide timely acquisition, processing, analysis, interpretation and dissemination of data to potential users anywhere in the world must also be established. All that has been said herein presupposes that adequate funding is provided for research to advance the state-of-the-art in those areas essential to the development of a global agricultural information system. This system would provide accurate, timely information to a variety of users. At the earliest possible time, operational use of such a system should be demonstrated. Operational implementation should quickly follow. Only then can truly credible and quantifiable benefits be determined.

C. RECOMMENDATIONS

After lengthy discussions, the Applications Survey Group for Agriculture reached a consensus of opinion but not unanimous agreement on the following recommendations. Owing to the nature of the task given this group our recommendations are broken down into those directed toward operational considerations; those recommendations where research should be direct to maximize the utility of Landsat follow-on data in the agriculture user community; and those directed towards management for potential implementation to insure optimum use of follow-on data on a global basis in the agricultural decision making process. With respect to operational considerations we recommend:

* The Landsat follow-on satellite be developed and put into operation at the earliest possible date.

* No greater than a 9-day cycle be considered (more frequent coverage is desirable).

* Data products have higher resolution than the 80 meters currently available on Landsat 1 and 2. In addition, inclusion of a higher resolution (10M) pointable imaging device in the Landsat follow-on sensor suite is highly desirable.

* The high sun cross-over time be approved. This parameter is extremely important to agricultural users interest in stress detection.

* Improved spectral sensitivity is highly desirable as is the ability to precisely register images from different dates to a geographic coordinate system.

* Users should have the option to collect thermal channel imagery of a given area both day or night.

* Users must be able to have data within 48 hours of acquisition if data is to approach optimum utility. In addition, the data should include a higher order of graphic, geographically referenced display and statistically output data than is currently available on Landsat 1 and 2 data.

The Agriculture Applications Survey Group feels strongly that research should continue towards the following goals:

* Implementation of a rapid, efficient, effective data dissemination system. Attention must be given to the development of processes and systems that allow for dissemination of data to the largest logical audience of users in formats of their choosing.
* Development of low cost, rapid data processing techniques including a review of computer efficiency in light of the predicted 1980 state of the art.
* Integrating meteorological satellite, Landsat series, and data from high resolution imaging systems along with collateral material into both crop production and resource management models.
* Definition of classification theories and concepts compatible with remote sensing products.
* Solving the problems associated with the spatial/locational dimensions of estimating a variety of crops worldwide.
* Determining the effects of emission and reflection properties of a wide variety of physical and biological parameters which influence the accuracy of crop type identifications.
* Development of a coordinate referenced, rectified data base.
* Acquiring adequate multi-temporal data in a variety of environments.
* Reducing the paucity of remote sensing data on crop stress

conditions in large field commercial settings.

Finally, to increase the level and improve the overall effective use of remote sensing data in agriculture the following management recommendations are made:

* Formalize the Agricultural Applications Survey Group as a standing committee dedicated to maximizing user input to the NASA decision making process as applied to agricultural applications of remote sensing. The Committee should have co-representation from USDA, USDI, NOAA, and advisory units or personnel from NASA. In addition to the members who worked on this report, there should be representation from the banking community, transportation and marketing groups, from plant physiology, plant genetics, as well as public policy interests. The committee should not exceed 20 members, and arrangements made for rotation of membership if deemed appropriate.

* Better coordination between groups within the remote sensing community should be promoted, especially between government, university, and industry. Formalizing an Agricultural Applications Survey Group such as that recommended above could go a long way towards achieving this goal.

* Efforts should be made to recognize the present shortcomings of the relations with the potential audience of users.

* At the user level it appears that--

  - Too much emphasis on expensive equipment.

  - Too little emphasis on applied remote sensing techniques. This means that more attention should be directed towards the user audience that will have to depend for some time on some form of manual interpretation, or at best, a combination of manual and mechanized methods.

- There is a shortage of skilled interpreters. We need to recognize the need to have the imagery interpreted by interpreters who are familiar with the intricacies of modern agriculture.

- Too few people know about the existence of the data. The large audience of users should be recognized. Maximum benefits can only be realized when we reach decision makers with information. That person is typically the owner of the resource. Therefore, educational programs, of both a general and a specific nature, should be undertaken to familiarize users with the capabilities of satellite acquired information. This need not be only for adult audiences. Various service organizations, high school, science groups, 4-H, Scouts, etc. should also be approached. Here we should consider the development of cooperative assignments with existing agency systems already prepared to disseminate information to large or small audiences at the local level.

- Overselling has had a damaging influence. We should recognize the difficulty of the problem we are dealing with and the continued need for supplemental data. Satellite data will simply not provide all the answers.

* Global applications should receive increased immediate consideration, especially in view of population increases, decreasing land resources, and increased demand for food. As part of this we must recognize the significance of

satellite information to developing countries. It may be the only source of national data.

* Finally, NASA management should initiate preliminary planning for the development of an Ag-Satellite to be programmed for the mid 1980's.

APPENDIX A

LETTER OF INVITATION

JET PROPULSION LABORATORY *California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103*

Dear____________________

The National Aeronautics and Space Administration (NASA), in support of its Landsat follow-on and future mission objectives, desires an evaluation of the capabilities of the proposed Landsat follow-on system by the user community. To this end, Applications Survey Groups (ASGs) are being established by JPL to provide to OA/NASA a formal capabilities assessment by the entire community of users of Landsat-type data. The initial four ASGs to be formed are: (1) Agriculture, (2) Inland Water Resources, (3) Land Inventory, and (4) Mineral and Petroleum Exploration.

You have been recommended by the Federal Interagency Decision Team for membership in the ASG for Land Inventory. A charter for this ASG is enclosed (Enclosure 1). Your demonstrated expertise in the use of satellite remote sensing in this field assures us that you can make a significant contribution to the development of this evaluation for the earth resources program.

As you can see from the charter, the members of the ASGs are in a unique position to express to NASA the value to their institutions (and, as experts, the value to their discipline) of the proposed satellite remote sensing system. This input will allow NASA to make better decisions on the proposed system to plan future missions to meet the needs of the user community.

The task of the ASGs is to provide knowledgeable input into the Landsat follow-on decisions. Enclosure 2 outlines this task. It is anticipated that permanent survey groups will be established in the future as similar requirements arise when new sensors and/or platforms are considered.

Most of the effort of the groups will occur in two two-day meetings to be held in Washington, D. C., one each in March and April. The first meeting will be held 1-2 March 1976 at the Sheraton Inn in Reston, Virginia, starting at 8:30 am.

Telephone 354-4321 *Telex 675421* *Twx 910-588-3294*

JET PROPULSION LABORATORY *California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103*

-2-

We look forward to your participation in the ASG. Please indicate as soon as possible to our Administrative Assistant, Mrs. Veronica O'Brien, (Mail address: Jet Propulsion Laboratory, Mail Stop 183-501, 4800 Oak Grove Drive, Pasadena, California 91103) your desire to serve. Mrs. O'Brien can discuss with you the anticipated financial arrangements. Her telephone is: commercial (213) 354-5672 or FTS 792-5672. Enclosure 3 contains additional travel information.

I will be located at NASA Headquarters during this activity and can be reached at:

Mail: Code EK
National Aeronautics and
Space Administration
Washington, D. C. 20546

Phone: (202) 755-8608

Sincerely,

Fred C. Billingsley
Task Manager
Earth Observation Programs
Jet Propulsion Laboratory

Enclosures
(1) Charter
(2) Task for Landsat follow-on
(3) Travel Information

APPENDIX B

TASK ASSIGNMENT FOR ALL APPLICATIONS SURVEY GROUPS (ASGs)

Survey of User Requirements for Landsat Follow-on

1. An objective of the User Affairs Division of the Office of Applications, in its Landsat follow-on activities, is to acquire a detailed study and report, supplemented by preliminary reports, providing an evaluation of the capabilities of the proposed Landsat follow-on system by a comprehensive community of users.

   The initial outputs from each of the ASGs will provide knowledgeable user input to NASA for use in Landsat follow-on decisions. This information will be summarized by JPL in the form of an Evaluation Document to be prepared by 1 July 1976, which encompasses the final Landsat follow-on reports prepared by each of the four Applications Survey Groups.

   The following schedule is established to meet the above output:

   Initial ASG memberships will be complete by 2 February 1976, and Chairmen protem selected.

2. Week of 9 February 1976 - Telephone conferences will be held with the ASG chairmen protem and the Discipline Panel chairmen to discuss and clarify the procedures and meeting agendas.

3. Week of 1 March 1976 - First formal meetings of the ASG. Each ASG will meet for two days, using the following agenda topics:

   a. Briefing by NASA/OA on the purpose, makeup, etc. of the ASG effort, and its relation to other groups, the NASA discipline panels, and other activities. Includes a description of the task being assigned to the ASG, its urgency, and schedule.

   b. Description by the Project Scientist of the various parameters applicable to Landsats 1, 2, and C, and Landsat follow-on. This is to include products available, product schedule, etc. Handout material should be available if possible.

c. Discipline overview describing the overall Earth Resources Program, to acquaint the users with the wide spread of activities. Overview of what future interfaces and assistance users might expect from NASA, EDC, related activities, etc.

d. Briefing by member of NASA Discipline Panel corresponding to each ASG covering the state of the art in the discipline (both (a) technically and (b) who is currently active, (c) present and planned ASVTs, and (d) other potential applications).

Each of the four JSC Panels is made up of NASA individuals well versed in NASA technology, hardware/sensors, and Thematic Mapper applications in each of the four application areas represented by the ASGs.

The JSC briefing teams will bring to the ASGs during the meetings of 1-2 March 1976 a status review of the current and future NASA sensor capabilities and applications in each of the four ASG areas of interest. Much of the final support for Landsat follow-on to be derived from the ASGs may depend on the perception by the ASG membership of the briefing given them by the JSC teams at this meeting.

e. Description by JPL of the detailed expected activities of the ASG and modus operandi. This will assure uniformity of actions, reports, etc., of the various ASGs and thus simplify the eventual collation of the activities.

f. The ASG selects its permanent chairman.

g. The ASG settles on specific questions to attack, and starts in.

h. The chairman carries on, assigns action items, due dates, and whatever else necessary.

4. Period 3 March - 16 April 1976 - Individual ASG members will carry out assigned action items and prepare required documentation and reports.

Task Assignment - page 3

5. Week of 19 April 1976 - Second formal meeting of the ASGs. Each ASG will again meet separately. The principal action at the meetings will be to prepare a draft final report for each group. As such, these will be working sessions devoted to discussions, writing, and identification of problem items. These reports are due to be completed 1 May 1976. These draft reports will be reviewed by members of the IDT and the Discipline Panels and are to be returned with comments by 1 June 1976.

6. Period 1 June - 15 June 1976 - Group chairmen will revise and complete the reports for each of the ASGs, using assistance from group members as desired.

7. 15 June 1976 - Group chairmen will brief the IDT on results of their activity at the June IDT meeting.

8. Period 15 June - 30 June 1976 - JPL will prepare with the assistance of the ASG chairmen a final Evaluation Document incorporating the ASG reports and an executive summary.

APPENDIX C

APPLICATIONS SURVEY GROUP CHARTER

Establishment

The Jet Propulsion Laboratory (JPL) is establishing a series of Applications Survey Groups (ASGs) as entities covering the whole spectrum of earth sciences and applications within NASA.

Objectives and Scope

The ASGs will provide to JPL for OA/NASA a formal evaluation of Landsat follow-on capabilities from the total community of users of NASA technology in its discipline area. The area of concern will be limited to Landsat follow-on activities. The discipline area will cover the following sub-applications, and others that may be defined by OA/NASA in the future or identified by each group.

ASG for Mineral and Petroleum Exploration (ASG/MP)

- Mineral Resources Exploration
- Energy Resource Exploration
- Hazards/Engineering Geology; Detection, Assessment, and Monitoring
- Mapping and Interpretation; Landform, Rock Type, Structural

ASG for Inland Water Resources (ASG/IW)

- Snow Mapping and Runoff Prediction
- Lake Ice Monitoring
- Glacier Inventory
- Estuary Dynamics and Water Quality
- Subsurface Water Survey
- Water Use Survey
- Watershed Survey, Management and Modeling
- Surface Water Mapping

ASG for Land Inventory (ASG/LI)

- Natural Resources Inventory
- Coastal Zone and Shoreline Mapping and Inventory
- Wetlands Mapping and Inventory
- Surface Mining Extent and Reclamation Monitoring and Inventory

- Wildlife Habitat Location and Inventory
- Urban and Special Environmental Area Land Cover Inventory
- Mapping and Cartography
- Information Management Systems
- Forest and Range
  - Timber Inventory - Large Area
  - Range Readiness and Management
  - Forest and Range Renewable Resources Inventory
  - Wildland Protection and Damage Survey

ASG for Agriculture (ASG/A)

- Crop Survey and Reporting (Identification, Mensuration, Location, Yield, Production, Signature Extension)
- Crop Stress (Insect Damage, Disease Damage, Crop Vigor, Soil Moisture
- Crop Management (Damaged Crop Identification, Quantification, and Location; Field Operations Information)

Specific objectives are to:

(a) Evaluate the functional capabilities of the Landsat follow-on and ground systems designs in terms of user requirements and desiderata for data measurements, products, and parameters.

(b) Disseminate to the various users information on the functional capabilities and plans concerning the various NASA activities as these are released to the ASG.

NASA Interface

The coordinator for the ASG activities and its interface to NASA will be through the JPL Lead Engineer to a representative of the Division of User Affairs.

Membership

A membership of about 20 is anticipated for each ASG. The members will be selected by the coordinator from lists of candidates proposed by (at least) Department of Agriculture, Department of Interior, Department of Commerce, and the Corps of Engineers.

Membership in the ASGs is limited to recognized experts in one or more of the fields covered by the ASGs; members may or may not possess extensive hardware- or space-related training and experience. Specifically, such experts are to be drawn as representative users from other Federal agencies, state and local governments (or from associations of such constituencies), industry, and universities. It is expected that, in aggregate, the members will be able to adequately assess the state-of-the-art in their technical areas and represent this in the ASG deliberations.

Interfaces

The ASG will receive information from and submit information to at least the following:

(a) The other ASGs

(b) Federal Interagency Decision Team (FIDT)

(c) NASA Discipline Panels

In addition to serving as personal experts, the individual ASG members will serve as liaison to their respective organizations when technical information needs to be interchanged.

Method of Operation

The ASG group members will elect the chairman for the group at the first meeting. The principal business will be carried out during two meetings, and reported in complete minutes of these meetings.

In addition, the ASG chairman may call such additional working sessions as he deems necessary. Summary minutes of these sessions are to be distributed as appropriate.

Tasks, milestones, and other requirements for action for the ASGs will be defined by the coordinator as appropriate.

APPENDIX D

ACRONYMS

A	Agriculture
ASCS	Agriculture Stabilization and Conservation Service
ASG	Applications Survey Group
CCEA	Center for Climatic and Environmental Assessment (NOAA)
CCT	Computer Compatible Tape
Domsat	Domestic Communications Satellite
EDC	EROS Data Center
EPA	Environmental Protection Agency
EROS	Earth Resources Observation Satellite
ERTS	Earth Resources Technology Satellite
FHA	Federal Housing Administration
FIDT	Federal Interagency Decision Team
FOV	Field of View
FWS	Fish and Wildlife Service
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center
HDDT	High Density Digital Tape
HDPT	High Density Product Tape
HDTA	High Density Tape with Annotations Added
HUD	Housing and Urban Development
IDPS	Image Data Processing Station
IFOV	Instantaneous Field of View
IR	Infrared
IW	Inland Water Resources
JPL	Jet Propulsion Laboratory
L-1	Landsat 1
L-2	Landsat 2
L-C	Landsat C
L-Fo	Landsat follow-on
LACIE	Large Area Crop Inventory Experiment
LI	Land Inventory

MILUS	Multiple Input Land Use System
MP	Mineral and Petroleum Exploration
MSS	Multi-Spectral Scanner
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NESS	National Environmental Satellite System
NOAA	National Oceanic and Atmospheric Administration
OA	Office of Applications (NASA)
ppm	parts per million
RBV	Return Beam Vidicon
SCS	Soil Conservation Service
SLAR	Side Looking Airborne Radar
S/N	Signal-to-Noise Ratio
TDRSS	Tracking and Data Relay Satellite System
TERSSE	Total Earth Resources System for the Shuttle Era
TM	Thematic Mapper
USACE USACofE	U. S. Army Corps of Engineers
USDA	U. S. Department of Agriculture
USDI	U. S. Department of Interior
USGS	U. S. Geological Survey
VHRR	Very High Resolution Radiometer

APPENDIX E
APPLICATIONS SURVEY GROUPS
MASTER ADDRESS LIST

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IW = Inland Water Resources
LI = Land Inventory
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