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Characterizing User Requirements for Future Land Observing Satellites

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ABSTRACT

This study developed an objective procedure for identification of probable sensor and mission characteristics for an operational satellite land observing system. Requirements were systematically compiled, quantified and scored by type of use, from surveys of federal, state, local and private communities conducted by the National Oceanic and Atmospheric Administration (NOAA). Incremental percent increases in expected value of data were estimated for critical system improvements. Comparisons with costs permitted selection of a probable sensor system, from a set of 11 options, with the following characteristics: 30 meter spatial resolution in 5 bands and 15 meters in 1 band, spectral bands nominally at Thematic Mapper (TM) bands 1 through 6 positions, and 2-day data turnaround for receipt of imagery. Improvements were suggested for both the form of questions and the procedures for analysis of future surveys in order to provide a more quantitatively precise definition of sensor and mission requirements.

CHARACTERIZING USER REQUIREMENTS FOR FUTURE LAND OBSERVING SATELLITES

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INTRODUCTION

Digital images from orbiting land observing systems have been available on an experimental basis since 1972 from NASA's Landsat satellites. The 4-band multispectral scanner (MSS) has been the primary sensor on Landsats 1-3. The 4 contiguous bands from 0.5 through 1.1 μm (micrometers) on the MSS have been expanded to a thermal infrared band and 6 narrower, more advantageously located visible, near and middle infrared bands (0.45-2.2 μm) on the Thematic Mapper (TM) scanner scheduled for flight on the second generation, experimental Landsat-D system in 1982. As a result of Presidential Directive Number 54 in November 1979, the National Oceanic and Atmospheric Administration (NOAA) has been given responsibility for the planning and operating of the civilian operational land remote sensing system (NOAA, 1980). Consequently, NOAA took responsibility for defining the first generation operational system which will probably fly in the 1990's.

During feasibility and definition trade-off stages it is desirable to compare benefits of sensor and mission options to cost. In order to perform a sensitivity analysis of the almost infinite options, it is desirable to quantify the relative "value" of system options on a numerically continuous scale. Establishing a credible quantitative value is particularly difficult because system characteristics must be fixed many years ahead of flight, before the user is thoroughly familiar with the value of preceding systems.

In 1980, scientists and engineers at Goddard Space Flight Center completed a user-based requirements study to identify a "most probable" sensor system for a potential NASA demonstration of the NOAA operational mission. In past studies devoted to the identification of desirable sensor systems, performance characteristics and attendant supporting flight and ground systems were developed from a qualitative concensus of collected subjective opinions based on broad, knowledgeable experience in remote sensing (the "wise man" approach). This study developed means to more quantitatively examine user perceived requirements and compare them to costs in order to identify a system of high net value to users. This paper describes the process, the system identified through its use, and possible improvements for future user requirements surveys.

METHODOLOGY

As the system to be defined emphasized operational rather than experimental use, the operational user community needs were considered in the main to define the system characteristics. NOAA, as the agency responsible for operational land observing systems, aggregated and confirmed the validity of hundreds of user questionnaires from federal, state and local governmental groups as well as from industrial and individual users. Tabulations of these queries were the primary source for a requirements data base. The constantly evolving data base was scanned at the outset of this study to estimate the range of requirements, and from this range, modified by perceptions of engineering and/or budgetary feasibility, 11 sensor options were chosen. Then relative quantitative "values" of the performance capabilities of the options were determined. Three methods were used to estimate value. Two depended upon information in the NOAA Users Data Base. They were (1) annual anticipated scene volume requirements, i.e., total number of 185x185 km images per year the user would order, and (2) user requirements met, i.e., a relative measure of how well a particular sensor option met the user's operational requirements. The third method was an independent check on the first two: Discipline panels identified user requirements, as perceived by scientists, in a manner similar to that used to develop the NOAA data base. This "Methodology" section contains a description of the NOAA data base, the 11 sensor options, and the methods by which the 3 quantitative sets of scores were developed.

1980 NOAA USER DATA BASE

To provide a preliminary assessment of user needs for an operational system, NOAA synthesized information from a variety of sources dating as far back as 1977. Federal agency input was obtained by NASA as part of a 1979 study known as the Integrated Remote Sensing Systems Study (IRS^3), through questionnaires provided to remote sensing specialists in the U.S. Department of Agriculture (USDA), the U.S. Department of the Interior (USDI), the U.S. Army Corps of Engineers, and other federal agencies. These specialists gathered requirements from programs within their agencies. During early 1980, NOAA validated these requirements by requesting each agency to reexamine and verify the information. Since these federal responses usually represented the official agency positions, the responses provided a systematic inventory of the interest and commitment to land remote sensing at that time. Furthermore, because these federal surveys often represented reassessment of earlier more detailed NASA surveys, there was a commonality and utility in them that had never been achieved before in terms of potential for quantitative reduction of the data. State and local requirements were summarized from the Intergovernmental Science Engineering and Technology Advisory Panel (ISETAP) report, State and Local Government Perspectives on a Landsat Information System (ISETAP, 1978). Private sector requirements were drawn primarily from the Geosat Committee Report, Geological Remote Sensing from Space (Geosat, 1976) and foreign requirements were taken in part from Resource Sensing from Space, Prospects for Developing Countries by the National Academy of Sciences (NAS, 1977). This material was supplemented with information from other reports and from personal contacts by Metrics, Inc., which organized this data base for NOAA. For convenience in further analysis, the non-federal inputs were entered on the same type of questionnaire as had been used in the federal survey. This data base preceded material from the NOAA questionnaires distributed in March 1980 at 5 regional user conferences (Metrics, 1980; Spann et al., 1981).

A total of 165 summary user survey sheets made up the data base, representing perhaps thousands of requirements as submitted by the federal, state and local governments, foreign users, and the private sector. An illustrative example of such a summary sheet is shown in Figure 1. The agency or organization submitting the input was identified on the sheet as was the programmatic category selected from the list in Table 1. Thus, for example, if 3 agencies had programmatic responsibilities for monitoring forest conditions, each would have a separate requirements sheet which summarized that agency's needs for spectral and spatial resolution and timeliness. Programmatic priority was assigned by each respondent based on the importance of that program compared to the full range of programs for which that agency was responsible. Not everyone played the "game", e.g., one user assigned high priority to all programs on the basis that all were equally essential to meet programmatic requirements. Coverage requirements were separated by users into domestic and foreign. The user was asked to identify both optimum and minimally acceptable spatial resolutions, spectral bands, and the percent of programmatic requirements met by each. The survey also requested evaluation of the significance of satellite imagery in obtaining the required spectral and spatial information. These responses from users formed the basis for calculations of the value of each sensor option.

ILLUSTRATIVE REQUIREMENTS SURVEY SHEET

AGENCY: U.S. DEPT. OF INTEREST

PROGRAMMATIC CATEGORY: CROP IRRIGATION

PROGRAMMATIC PRIORITY: HIGH, [✓ MEDIUM], LOW

KEY PERFORMANCE PARAMETERS	COVERAGE		SIGNIFICANCE* OF SATELLITE DATA	PARAMETER VALUES		PERCENT OF REQUIREMENTS MET		ANNUAL VOLUME
	DOM.	FOR.		OPTIMUM	MINIMUM ACCEPTABLE	OPTIMUM VALUE	MINIMUM VALUE	
SPATIAL RESOLUTION (METERS)	X		A	30		90		600
					80		70	400
		X	A	30		90		100
					80		70	50
SPECTRAL REGIONS (MICROMETERS)	X	X	A	0.45-0.52 0.52-0.60 0.63-0.69 0.80-1.1 10.5-12.5	0.5-0.6 0.6-0.7 0.7-0.8 0.8-1.1	90	80	
TIMELINESS (DAYS) OBSERVATION TO USER	X	X		7	30	90	70	

*SIGNIFICANCE A (ESSENTIAL TO INCLUDE SATELLITE DATA), B (IMPORTANT), AND C (UNIMPORTANT)

Figure 1

TABLE 1

PROGRAMMATIC CATEGORIES

RENEWABLE RESOURCES

Agriculture

- Inventory
- Yield
- Condition
- Irrigation
- Episodal Event

Soils

- Classification
- Erosion
- Moisture

Forests

- Inventory
- Stand Evaluation
- Condition
- Episodal Event

Range

- Vegetation Inventory
- Condition
- Episodal Event

NON-RENEWABLE RESOURCES

Geology

- Structure
- Landforms
- Lithology
- Thermal Anomalies
- Geobotanical Anomalies
- Topography (Stereo)
- Episodal Event**

PLANNING/ENVIRONMENTAL MANAGEMENT

Regional/Urban

- Cover Classification
- Cover Change
- Environmental Impact

Coastal Zone

- Monitoring

Hydrology

- Drainage Patterns
- Inland Water Inventory
- Snow Pack Parameters
- Ice--Inland & Near Shore
- Water Quality--Inland & Near Shore
- Wetland/Estuaries Inventory
- Episodal Event

Wildlife Habitat

- Inventory
- Evaluation

Oceans*

- Currents (Near Shore)**
- Tides**
- Bathymetric Charts
- Ocean Pollution (Near Shore)

*No Panel Data
**No User Data

There were a number of weaknesses in this NOAA user data base. First, several of the answers were non-numerical and therefore required somewhat arbitrary assignment of numerical replacements in order to be useful in value calculations. Second, some of the surveys were gathered in different formats; for example, the inputs from the federal government and private industry were not equivalent. Third, not all summary sheets were adequately representative, especially with regard to potential non-federal users. Fourth, inputs were gathered over several years in a new high technology field where requirements, knowledge and experience are changing rapidly. Fifth, considerable differences existed in the capability and thoroughness of the users in interpreting and answering the requested information. Sixth, there was no clear statement of whether these were current or future requirements. Finally, some groups provided inconsistent or incomplete information on certain subjects, necessitating assumptions or inferences for the current analysis. Categories most frequently affected were data volume requirements, priority of requirements, and percent of requirements met. Although these difficulties inherently limited the precision of predictions based on this 1980 NOAA user data base, this nevertheless represented the most complete and focused aggregation of perceived user needs to date, and provided a satisfactory basis for development of a procedure for quantitatively scoring the relative values of various sensor options.

SENSOR OPTIONS FOR THIS STUDY

Ideally, the choice of sensor options for consideration should be made from the optimization of performance for spatially and spectrally continuous variables. Unfortunately, the necessary mathematical functional relationships do not exist. Therefore, 11 options were created from a few discrete choices of spectral bands and spatial resolutions which appeared to bound practically achievable user requirements. The sensor options which were chosen are given in Table 2.

Spectral options included bands in the visible (0.4-0.76 μm) and near infrared (0.76-1.0 μm) regions similar to that currently available in the Landsat MSS, two shortwave or middle infrared (SWIR 1.0-2.5 μm bands) and one thermal infrared (TIR, 10-12 μm) band. The data did not reveal any major requirement for bands beyond the 7 proposed for TM (Thematic Mapper scanner planned for Landsat-D launch in 1981). Thus the nominal band locations for the various options were set at TM band locations, but it should be emphatically stated that the precise band locations and widths for an operational system should be the subject of detailed study. Three spectral options were quantitatively examined in this study: 1) 4 bands in the 0.4-1 μm region, 2) 6 bands in the 0.4-2.5 μm region, and 3) 7 bands in the 0.4-12.5 μm region. The 11 options contain 3 major spatial groups--nominally 80-meter, 30-meter and 10-meter systems. These are consistent spatially with the minimum, middle and maximum candidate sensors for a fully operational system initially identified by NOAA (1980) in a preliminary

TABLE 2

SPECTRAL AND SPATIAL CHARACTERISTICS OF MLA SENSOR OPTIONS

SPECTRAL REGION	NOMINAL BAND LOCATION (MICRO METERS)	INSTANTANEOUS FIELD OF VIEW (IFOV, IN METERS) BY OPTION										
		1	2	3	4	5	6	7	8	9	10	11
		80m SYSTEMS			30m SYSTEMS					10m SYSTEMS		
VISIBLE (VIS)	0.45- 0.52	80	80	80	30	30	30	30	30	10	10	10
	0.52- 0.60	80	80	80	30	30	30	30	30	10	10	10
	0.63- 0.69	60	40	40	30	15	30	15	15	10	10	10
NEAR INFRARED (NIR)	0.76- 0.90	80	80	80	30	30	30	30	30	10	10	10
SHORT WAVE INFRARED (SWIR)	1.55- 1.75	—	—	80	—	—	30	30	30	—	20	20
	2.08- 2.35	—	—	80	—	—	30	30	30	—	20	20
THERMAL INFRARED (TIR)	10.4- 12.5	—	—	—	—	—	—	—	120	—	—	60
ASSUMED OPTION IFOV		80	60	60	30	22	30	22	22	10	10	10
		MSS							ADVANCED TM *			

*THEMATIC MAPPER SCANNER SCHEDULED FOR LAUNCH ON LANDSAT IN 1982 analysis of the data base used in this study. The range of spectral and spatial options thus varied from the existing MSS capability to a high resolution multiband option which approached the limits of technical and political feasibility. Recent work which utilized the 40-meter panchromatic band of the Return Beam Vidicon (RBV) on Landsat 3 to "sharpen" the resolution of the 80-meter MSS (e.g., Cox and Roller, 1981) indicated that a single band at two or three times the resolution of the other bands in the system was potentially useful for two reasons: boundary definition was increased for visual interpretation and training site selection, and errors in supervised classification procedures could be reduced by the labeling of mixed pixels (picture elements) which contained more than one type of category. Therefore, options with one band of higher resolution than the other bands in the visible portion of the spectrum were included (options 2, 3, 5, 7 and 8). The mixed spatial resolution of options 10 and 11 (and the thermal band on option 8), however, were due to engineering constraints in the shortwave and the thermal infrared regions.

ANNUAL SCENE VOLUME REQUIREMENTS

One measure of "value" between various sensor options was the demand, in the sense of scene volume, each generated. In the NOAA data base, the users estimated the annual volumes of 185x185 km scenes they would need from their "optimum" and "minimum" acceptable systems to meet identified programmatic objectives. In this study, the annual scene volume requirements related to the 11 sensor options were calculated for each data base input (e.g., Figure 1) using the following 4 steps (all descriptors in quotations refer to data from the data base): (1) for sensor options whose spatial and spectral characteristics were less than "minimum acceptable" the volume was defined as zero, (2) for sensor options whose characteristics were between the user defined "minimum" and "optimum" the "minimum volume" was assigned (e.g., 400/50 scenes/year in Figure 1 for domestic and foreign requirements), (3) for sensor options whose characteristics equaled or exceeded the "optimum requirements" the "optimum volume" (600/100 in the example) was assigned, and (4) the volume number in step (2) or (3) was multiplied by a timeliness factor.

Timeliness factors were defined as the number of days from acquisition to receipt by a user and reflected the decreasing value of data with time. For timeliness better than or equal to "optimum" (7 days in the example) the "Optimum Percent of Requirements Met" (90 percent in the example) was assigned as the timeliness factor. For timeliness poorer than "minimum acceptable" a zero value was assigned. In between, a linear interpolation on a log-log plot between the graphical points ["optimum timeliness" (7 days)--"optimum percent of requirements met" (90 percent)] and ["minimum timeliness" (30 days)--"minimum percent requirements met" (70 percent)] was used to assign a value for the factor. When no timeliness was given, the timeliness factor was set at unity.

The volumes calculated from each user data sheet were added together to yield total estimated scene volumes, by user community and by discipline area, for various choices of sensor options and timeliness. These volume requirements are not to be equated with scene sales, since a given scene might be used to satisfy several measurement objectives by a given user. However, the pattern of volume distribution should be a reasonable guide to relative user-perceived sensor option value and to the importance of data turnaround.

There are a number of uncertainties and assumptions in these annual scene volume requirements. The estimates did not take into account increases in image costs for improved imagery, nor availability of subsets of a standard scene. The volume estimates on the data base sheets were only related to optimum and minimum spatial resolution; volume requirements related to coverage frequency were not indicated, and the effect of timeliness was often not estimated. Since volume estimates were invariably listed only in the "spatial resolution" row of the forms, no distinction in volume was possible between minimum and optimum spectral configurations. The most important assumption was that official federal approval of these requirements by individual agencies had an averaging effect on the uncertainties and probably kept the volume estimates within feasible budgetary limits and the coverage capability of a satellite mission.

USER REQUIREMENTS SCORES

A related measure of the potential utility of the sensor options can be computed from the significance attached by the users to spatial and spectral performance parameters, and the degree to which the parameters for each sensor option met their requirements.

A procedure was developed for obtaining a single user score of requirements met for each of the 11 sensor options, using 5 quality factors derived from the user's questionnaire: "Spatial Value", "Spectral Value", "Spatial Significance", "Spectral Significance", and "Programmatic Priority". A relative number for each of the quality factors was determined as a function of sensor option. The product of these 5 numbers for each sensor option provided a relative measure of how well the users perceived that an option met their requirements. As in the annual scene volume case above, each user data sheet was analyzed separately before aggregating. The next several paragraphs describe the methods for determining a score for the quality factors using data from Figure 1 as an example.

A "Spatial Value", expressed as a fraction, was determined for each option from a linear interpolation on a log-log plot of "percent of requirements met" versus the "parameter values" for spatial resolution. Log-log interpretation was used because of the geometric rather than arithmetic nature of these data. For example, using data from Figure 1, a straight line was drawn on a log-log graph between the optimum "percent of requirements met" of

90 percent at the "optimum" resolution of 30 meters and the corresponding "minimum acceptable" point of 70 percent at 80 meters. For 80 meter systems with a 40 meter sharpening band, the effective IFOV was assumed to be the average, 60 meters; similarly, the 30/15 systems were assumed to have an effective IFOV of 22 meters. Therefore, the effective ground IFOV's for the 11 options were taken to be 80, 60, 60, 30, 22, 30, 22, 22, 10, 10, and 10 meters, respectively. For sensor options above the optimum, the "spatial value" number was assumed constant at the "optimum" (e.g., better than 30 meters = 90 percent of requirements met for Figure 1). For options not meeting the minimum, the number assigned was zero. Inputs for state and local government and for private industry did not include data for "percent of requirements met". In these cases, 100 percent was assumed for optimum and 80 percent for minimum, since this represented a typical pattern of users.

Since spectral parameters were discrete, the "spectral value" could not be estimated in such a continuous fashion. The number assigned to "spectral value" was set at the "optimum" or "minimum" value as given in the questionnaire for each option that met the optimum or minimum spectral requirements. Using Figure 1 as an example, the value was 0.80 for all options except 8 and 11 which received the "optimum" value of 0.90, because of the thermal capability included in these options. In a few cases where "percent of requirements met" was only noted for the spatial parameters, the same values were assumed for the "optimum" and "minimum" spectral values. The VIS/NIR bands of the MSS and TM were considered to be essentially equivalent for the purpose of comparing sensor option characteristics. "Spectral value" was set at zero if the option did not meet the minimum spectral requirements.

Three of the factors used in calculating the user requirement scores from the survey sheets were qualitative. In order to permit a quantitative scoring of user requirements, the "spatial and spectral significance of satellite data" responses were assigned one of three values as follows: A (essential to include satellite data) = 1, B (important) = 0.5, and C (unimportant) = 0.1. Similarly, the qualitative "Programmatic Priority" of high, medium, or low was assigned a numerical value of 1, 0.5, or 0.1, respectively. For the example in Figure 1, "Spatial Significance" = 1, "Spectral Significance" = 1, and "User Priority" = 0.5. The somewhat arbitrary choice of the three relative weighting factors assured minimal impact of low priority items.

As mentioned earlier, a user score of requirements met for each option was obtained by multiplying these five factors together and then producing an integer value by multiplying by 100. For example, option 1 with MSS bands at 80-meter resolution would have a user score from the data in Figure 1 of 28 (Spatial Significance = 1.0, Spatial Value = 0.70, Spectral Significance = 1.0, Spectral Value = 0.80 and Programmatic Priority = 0.5). For option 11, the user score is 40.5 (1.0 x 0.90 x 1.0 x 0.90 x 0.5 x 100). Thus a single score is produced for each option for each survey sheet.

Computations of these user requirements scores were performed for all survey sheets. In cases where foreign and domestic parameters differed, separate calculations were carried out. The 165 individual sets of user requirements scores were aggregated to produce a single score for each option. The aggregation was performed in three averaging steps: from individual user scores to 38 programmatic category (see Table 1) scores, then to 10 user discipline scores (forests, soils, etc.), and finally to a grand weighted average score. Simple arithmetic averaging was not employed in aggregating scores because that process would have assigned equal importance to all users, all programs and all disciplines. The users' own estimates of data volume requirements associated with a given programmatic category provided the means of weighting. User-perceived volume requirements were rounded into three volume weighting factors: 0.1 for volumes up to 100 scenes per year, 0.5 for volumes between 100 and 1000, and 1 for volumes greater than 1000. These limits on annual volume requirements weighting factors were increased by a factor of 10 for the final aggregation of the 10 disciplines.

PANEL REQUIREMENTS SCORES

In order to provide an independent check, and perhaps a more prophetic measure of user requirements, four panels of remote sensing specialists were convened at Goddard Space Flight Center and asked to fill out questionnaires similar to those used in forming the data base. The specialists were shown neither the completed user questionnaires nor the method of scoring, in order to avoid the possibility of the panels being influenced by the data base analysis. It was felt that the user inputs might be biased by the state-of-the-art as they knew it, especially since some of the state and local surveys were taken several years ago. Scientists, on the other hand, might be cognizant of research that users have not seen. Thus panel requirements scores were seen as a powerful check on the user scores. Panelists were also asked some key questions that were not fully covered in the user survey, such as requirements for repeat frequency coverage.

The methodology for arriving at panel scores was identical to that for the users. Questionnaire sheets from the panelists consisted of single inputs for each of 35 programs (see Table 1), rather than multiple inputs from each program as in the users' data base. Panelists did not complete survey sheets in the ocean discipline (currents, tides, bathymetry, and ocean pollution) and added one programmatic category in geology (episodic events).

ANNUAL SCENE VOLUME REQUIREMENTS SCORES

Table 3 shows the annual volume of scenes required by potential users as a function of sensor option and timeliness, summed from all 165 user data sheets. As expected, the scene volume requirements dropped with increasing time between acquisition and receipt. However, as there was little change between 1 and 2 days, the volume figures for the more likely 2-day timeliness (highlighted in Table 3) were used in subsequent discussion. Also, due to the general ordering of options from lowest to

TABLE 3

ANNUAL VOLUME REQUIREMENTS FOR 185 x 185 km SCENES

TIMELINESS* (DAYS)	THOUSANDS OF SCENES BY SENSOR OPTION										
	1	2	3	4	5	6	7	8	9	10	11
1	36	36	43	50	50	65	66	71	60	76	100
2	36	36	43	50	50	64	64	70	60	75	99
4	27	27	34	39	39	52	52	58	50	64	78
8	17	17	23	28	28	38	38	42	35	45	54
16	3	3	3	11	11	14	14	15	16	20	25
32+	2	2	2	10	10	12	12	13	15	18	23

*TIMELINESS IN DAYS BETWEEN SATELLITE ACQUISITION AND RECEIPT BY USER highest spectral and spatial resolution, the scene volumes increased with option number. Some of these increases were discontinuous, presumably due to some programs being enabled for the first time rather than simply enhanced. The maximum scene volume in Table 3 of 100,000 scenes per year for option 11 and 1-day turnaround would be increased by only about 35 percent if all the spatial and spectral requirements identified in the data base could be met--including 2-meter spatial resolution.

More detailed tabulations of volume requirements are given in the Appendix. Appendix 1 gives the annual scene volume requirements by option for each of the 10 disciplines and for 6 values of timeliness from 1 to 32+ days. Appendix 2 gives a breakdown of the 2-day timeliness volume requirements in Table 3 by the 36 programmatic categories. Finally, Appendix 3 shows the same total volume requirements by option for 6 types of user communities.

USER AND PANEL REQUIREMENTS SCORES

Relative user scores of requirements met for each option are given in Table 4 as a function of discipline. The weighting factors, based on scene volumes, used to compute the weighted averages are also shown. Finally, the science panel scores of requirements met are shown in the same manner in Table 5. Appendices 4 and 5 are breakdowns by programmatic category of user scores and panel scores respectively.

Two of the 3 measures of perceived value are shown in Figure 2 where user volume requirements for a 2-day timeliness are compared

TABLE 4

USER SCORES OF REQUIREMENTS MET

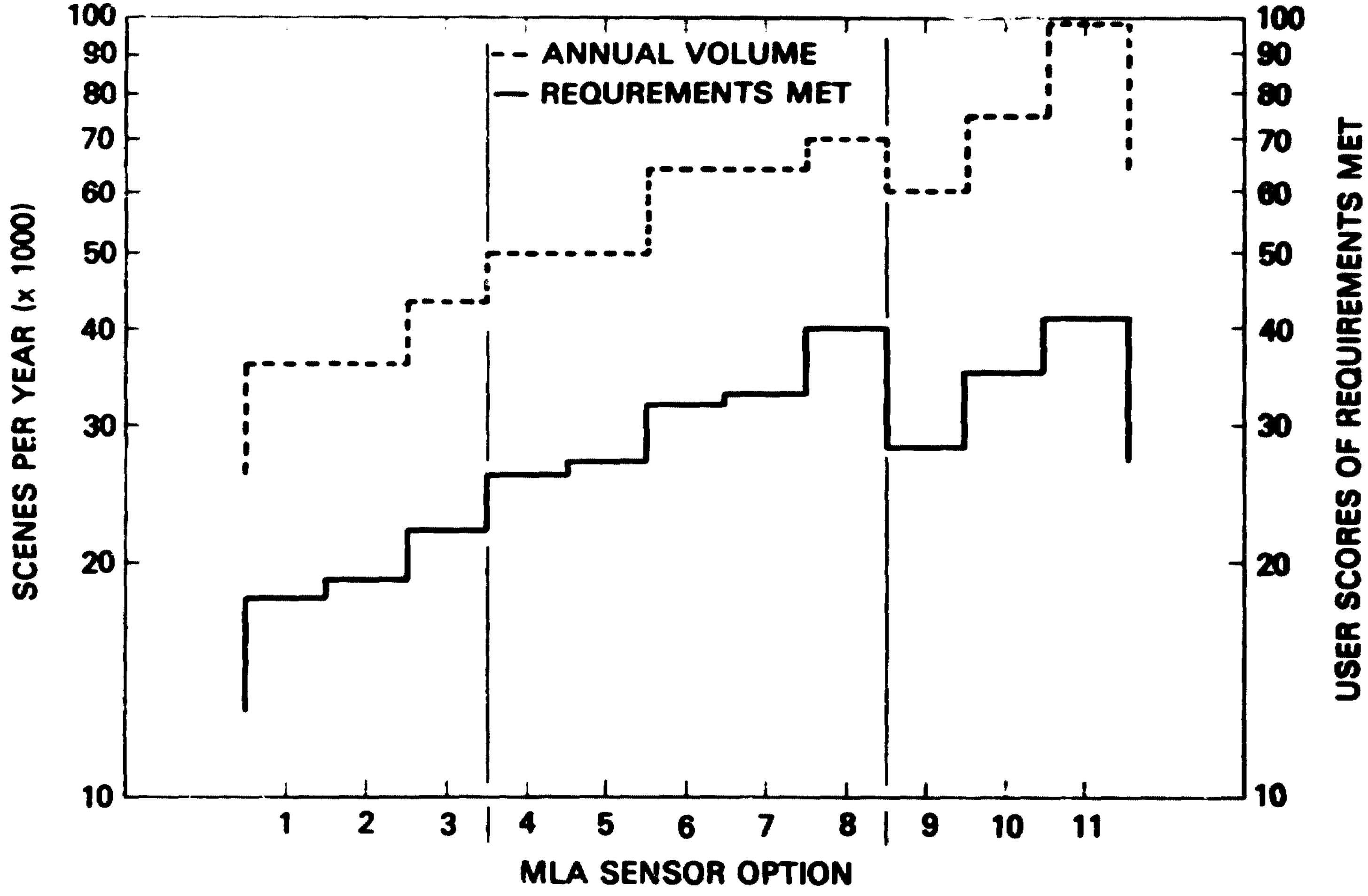
DISCIPLINE	VOLUME WEIGHT	UNWEIGHTED DISCIPLINE SCORES BY SENSOR OPTION (PERCENT)										
		1	2	3	4	5	6	7	8	9	10	11
AGRICULTURE	1	21	22	22	31	32	31	32	41	35	35	45
SOILS	.5 (1 for 10,11)	3	3	21	3	3	24	25	26	4	27	28
FORESTRY	.5	7	9	14	11	11	17	17	22	11	18	23
RANGE	.5	14	15	16	16	16	18	18	26	16	18	27
GEOLOGY	1	0	0	3	15	15	27	28	45	18	33	50
HYDROLOGY/WATER	1	37	37	39	44	45	45	45	49	45	46	49
WILDLIFE	.5	26	29	31	36	36	40	40	41	36	40	41
REGIONAL/URBAN ANALYSIS	.5	20	21	26	34	35	41	43	48	41	51	56
COASTAL ZONE	.1 (.5 for 8,11)	32	33	33	37	37	37	37	44	38	38	44
OCEANS	.1	48	48	48	55	56	55	58	58	56	56	59
WEIGHTED AVERAGE		18	19	22	26	27	32	33	40	28	35	41

TABLE 5

PANEL SCORES OF REQUIREMENTS MET

DISCIPLINE	VOLUME WEIGHT	UNWEIGHTED DISCIPLINE SCORES BY SENSOR OPTION										
		1	2	3	4	5	6	7	8	9	10	11
AGRICULTURE	1	24	33	52	43	43	67	67	79	43	67	79
SOILS	.5 (1 for 10,11)	30	36	57	43	43	67	67	79	43	67	79
FORESTRY	.5	0	0	0	3	3	8	9	13	6	16	22
RANGE	.5	4	6	11	20	20	33	33	51	20	45	51
GEOLOGY	1	16	21	36	30	34	49	53	68	36	61	73
HYDROLOGY/WATER	1	27	33	47	40	45	57	63	75	50	70	85
WILDLIFE	.5	0	0	0	33	36	42	46	58	46	58	75
REGIONAL/URBAN ANALYSIS	.5	1	1	1	5	7	7	11	12	9	14	17
COASTAL ZONE	.1 (.5 for 8,11)	0	0	0	5	5	8	8	19	6	10	22
OCEANS	.1	—	—	—	—	—	—	—	—	—	—	—
WEIGHTED AVERAGE		15	19	30	30	32	45	48	56	34	58	64

COMPARISON OF USER REQUIREMENTS MET* AND ANNUAL SCENE VOLUME REQUIREMENTS**



* WEIGHTED AVERAGE OF USER SCORES OF REQUIREMENTS MET

** ANNUAL VOLUME REQUIREMENTS FOR 185 x 185 Km SCENES BASED ON 2-DAY TIMELINESS

Figure 2

with the user scores. Scenes per year and numerical scores are plotted on a log scale to permit easier comparison of percent differences between options. The similarity between these two measures of "value" from the users' data base is apparent; on an option-by-option basis the relative agreement is approximately ±10 percent. These two user values are not completely independent measures, since a) the same groups did each, b) scaled scene volume was used to aggregate requirements met, and c) requirements met was used as a multiplicative factor in estimating volume requirements by option.

A comparison of user and panel requirement scores is shown in Figure 3 using weighted average values derived from Tables 4 and 5. The first and most important observation is that increases and decreases by option are nearly identical for users and panelists. However, the panelists did rate options 1 and 2 much lower in relative "value" than the users. Overall, the fact that these two independent measures of "requirements met" agree, in a relative sense, tends to give additional credence to both of them.

INCREMENTAL SPATIAL AND SPECTRAL VALUE

Spatially, there are several ways to look at the impact of improvements represented by the 11 options. To a first approximation, there are 5 spatial options. Options 1, 4 and 9 each have 4 VIS/NIR spectral bands at a single resolution, i.e., 80, 30, and 10 meters, respectively. For some options one visible

USER AND PANEL PERCEPTIONS OF REQUIREMENTS MET

INCREMENTAL VALUE OF SPATIAL IMPROVEMENT

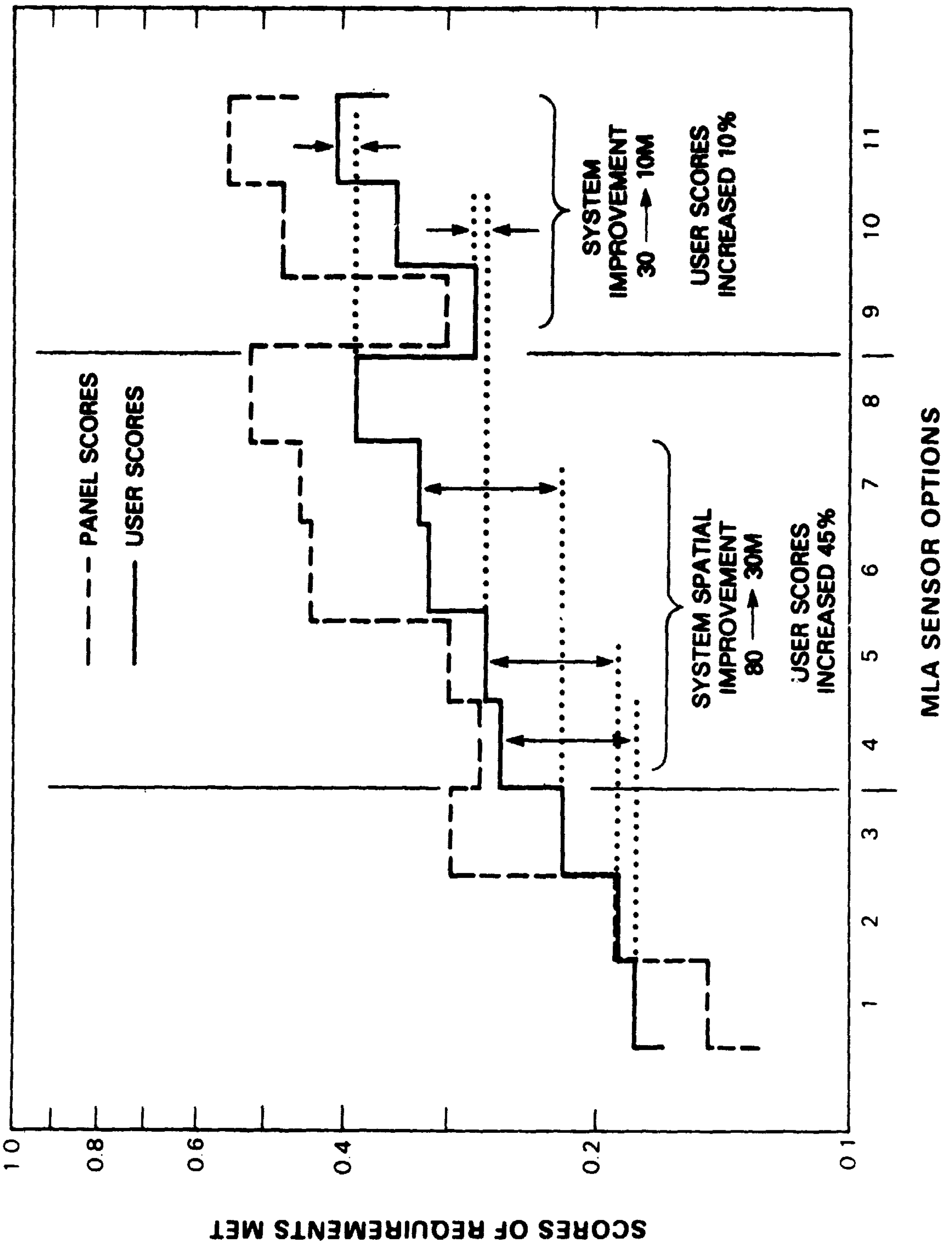


Figure 3

band has been "sharpened" by a factor of two in spatial resolution, to 40 meters (options 2 and 3) and 15 meters. The effective resolution of the system for each option has been assumed to be intermediate between the range of values in the VIS/NIR region, 60 meters for options 2 and 3, and 22 meters for options 5, 7 and 8.

Spectrally, the comparison among options is limited to three combinations: four VIS/NIR bands, six VIS/NIR/SWIR bands, or seven VIS/NIR/SWIR/TIR bands. There are four comparisons which isolate the increased "value" expected from the addition of the two SWIR bands to the four VIS/NIR bands. These are comparisons between options 2 and 3, 4 and 6, 5 and 7, and 9 and 10. Similarly, there are two comparisons for assessing the expected change due to the addition of a thermal band: options 7 and 8, and options 10 and 11.

Spatial comparisons by option of the user requirement scores are highlighted in Figure 3. Three comparisons between 80-meter systems (options 1, 2, and 3) and spectrally similar 30-meter systems (options 4, 5, and 7) all show about a 45 percent increase in user score due to improved spatial capability. Comparisons between 30-meter and spectrally similar 10-meter systems (5 and 8 to 9 and 11) show a lower, approximately 10 percent increase in user scores even though there is a factor of three improvement in spatial resolution.

Using this technique, the percentage incremental improvements in value caused both by spatial and spectral improvements was determined for all three value measures: annual scene volume requirements for 2-day timeliness (from Table 3), user scores of requirements met (from Table 4), and discipline panel scores of requirements met (from Table 5). While there was always an enhancement of performance with an improvement in sensor characteristics, the relative incremental improvement was much greater in some cases than in others. Value enhancements, expressed as percentage improvement, are summarized in Table 6. These are average values based on option-by-option comparisons summarized in Appendix 8. More detailed comparisons among the 10 disciplines are provided in Appendices 6 (users) and 7 (panel scientists). All three "value" categories showed a dramatic increase of at least 40 percent in the value of 30-meter data as compared to imagery taken at 80 meters. The average increase in value by improving spatial resolution from 30 to 10 meters was less than 20 percent. Discipline panelists perceived SWIR to be twice as valuable as users, probably because of the greater experience of scientists with SWIR data. None of the three estimates of the increased value of the addition of TIR exceeded 20 percent, possibly indicating a lack of familiarity with thermal data.

VALUE-TO-COST RATIOS

The final step in the analysis was to calculate a "value" to mission cost ratio, to determine which option was most cost effective. Costs were based on estimated total expenditures by the

TABLE 6

INCREMENTAL VALUE OF SENSOR IMPROVEMENT

SENSOR IMPROVEMENT	INCREASED VALUE (%)		
	VOLUME REQUIRED	USER SCORES	PANEL SCORES
SPATIAL			
80 TO 30 m	40	45	100
30 TO 10 m	20	8	14
SPECTRAL			
ADD SWIR	30	20	50
ADD TIR	10	20	15

government for sensor development, a demonstration mission, and a 10-year lifetime for an operational land observing system, including the ground system development and operation, but excluding any cost for information extraction. The costs to the government, relative to the cost of the most expensive option, are shown on the first row of Table 7. The value-to-cost ratios for each option, normalized to 100 for the highest ratio in each test, are shown for the three measures used in this study, namely those derived from: Table 3, User Volume for 2-day timeliness; Table 4, User Requirements (weighted average); and Table 5, Panel Requirements (weighted average). Value-to-cost ratios are given by discipline in Appendix 9 for both user and panel scores. It can be seen from Table 7 that even though options 9, 10 and 11 have higher values, the value-to-cost ratios peak around options 6, 7 and 8, with option 8 having the highest total score. This is due to mission costs rising more rapidly than "value" as a function of performance. Actually, due to the lag in development of thermal IR solid state detectors compared to visible and SWIR detectors, and the closeness of the value-to-cost ratios for options 7 and 8, option 7 would be the choice if only solid state sensors were used and an early launch date was a criterion.

FREQUENCY OF COVERAGE

As stated earlier, this 1980 NOAA data base did not contain some information which was essential for a first level definition of an operational system. First and foremost was temporal information about the required frequency of observation. This meant questions

TABLE 7

RELATIVE VALUE-TO-COST COMPARISON BY OPTION

	PERCENT OF MAXIMUM VALUE BY OPTION										
	1	2	3	4	5	6	7	8	9	10	11
RELATIVE COST TO GOVERNMENT	34	36	37	41	45	46	48	53	84	93	100
VALUE-TO-COST RATIOS											
VOLUME REQUIREMENTS	75	72	84	86	79	100	96	95	51	58	71
USER SCORES	69	70	79	83	79	92	90	100	44	50	54
PANEL SCORES	41	50	77	68	67	93	94	100	38	59	60

such as swath width, orbital swathing patterns, number of satellites in orbit at any time, and need for across track pointing could not be assessed from the user surveys. Therefore in the study reported here, the four discipline panels were asked to add temporal resolution to the evaluation, in the same manner as spectral and spatial resolutions were handled, i.e., optimum and minimum values were reported with the percent of requirements met for each. The results are summarized in Table 8 for cloud-free conditions. The shortest repeat cycles that received a 50 percent or greater value were highlighted. Imagery acquired less frequently than this might not be useful at all.

Landsat 1-3 statistics indicate about a 10 percent chance of acquiring a nearly cloud-free scene. Agricultural and agronomic requirements for a usable scene every 8 days necessitate more frequent observations to allow for cloud cover. For 5 by 6 km agricultural segments, the probability is more like 50 percent of obtaining cloud-free images 3 days apart. This global requirement might be met by two 16-day repeat nadir-looking satellites able to look off-track as much as two scenes. The 4 to 8 day repeat view for regional and urban planning was the most stringent discipline need. It could not be met with a two-satellite system unless the systematic acquisition of imagery could be occasionally relaxed to provide dedicated coverage over a few targets. Clearly, adding satellites and pointing capabilities will affect system complexities and costs. Neither user surveys nor discipline panels were useful in evaluating these complex acquisition requirements.

TABLE 8

PANEL REPEAT FREQUENCY REQUIREMENTS FOR CLOUD-FREE IMAGERY

DISCIPLINE	VOLUME REQUIREMENTS 2 DAY TIMELINESS (185 x 185 km SCENES/YR)	NORMALIZED VALUE* BY REPEAT FREQUENCY (DAYS)				
		2	4	8	16	32+
AGRICULTURE	16,000	1.00	1.00	**.59**	[illegible]	[illegible]
GEOLOGY	14,000	1.00	.96	.92	.85	**[illegible]**
HYDROLOGY	14,000	1.00	.88	.75	**.57**	[illegible]
SOILS	9,000	1.00	1.00	**.79**	[illegible]	.22
REGIONAL/URBAN	5,000	1.00	**.89**	[illegible]	.22	.22
FORESTRY	2,000	1.00	.63	**.50**	[illegible]	[illegible]
WILDLIFE	1,000	1.00	1.00	1.00	1.00	**1.00**
RANGE	1,000	1.00	.96	.81	**.70**	[illegible]
COASTAL ZONE	500	1.00	1.00	1.00	**1.00**	[illegible]
OCEANS	500	—	—	—	—	—

*VALUE = (VALUE AT GIVEN FREQUENCY) ÷ (VALUE AT 2 DAY FREQUENCY)

BOLD VALUES INDICATE FREQUENCY NECESSARY TO MEET AT LEAST 50% OF REQUIREMENTS

STEREO

Stereo requirements were requested on the forms in the NOAA surveys. Forty-four of the 165 responses identified stereo requirements, but not enough parameters were given to permit a quantitative reduction of their requirements. Base-to-height needs ranged from 0.4 to 1.0 with spatial resolution of at least 20 meters. Future surveys should identify, at a minimum, base-to-height ratio, number and location of spectral bands, expected scene volume, nadir spatial resolution, and if side-to-side, fore-aft, or fore-nadir-aft stereo is required.

SUMMARY

Analysis of user requirements, validated by panels of scientists, allowed selection of an operational satellite remote sensing system from a set of 11 options. Characteristics included 3 visible (VIS) bands, 1 in the near infrared (NIR), 2 in the shortwave infrared (SWIR), and if an early launch date were not critical, 1 band in the thermal infrared (TIR) region (identical to the Thematic Mapper). Desired spatial resolutions were: 120 meters TIR, 30 meters SWIR, and 30 meters for all but one VIS/NIR band; that one "sharpening" band would have 15 meter resolution. Repeat visit requirements necessitate at least a two-satellite system with off-track viewing capability.

While we believe the procedure identified the most suitable of the 11 choices, we have no illusions that the identified system is superior to options that were not considered. The value to cost ratio for a 20-meter VIS/NIR system might be superior to our 15/30 meter mixed resolution options. A 10-meter sharpening band might have sufficiently greater value than a 15-meter band to offset increased cost. Additional or different spectral bands might improve the utility of the data.

Continued research on the spatial, spectral and radiometric capabilities of advanced systems is essential to provide a firm basis for reassessing (or continually assessing) user requirements, and to improve approaches for acquiring (e.g., surveys) and analyzing user needs.

Such surveys must be considered parts of an iterative process, involving familiarizing users (research or operational) with recent technological advances, soliciting requirements in terms most meaningful to their work, interpreting the results in terms of research requirements (or sensor/system/mission requirements), and feeding the results back to the survey population.

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APPENDICES

1. Annual scene volume requirements, by option, discipline, and timeliness.

2. Annual scene volume requirements, by option and programmatic category, for 2-day timeliness.

3. Annual scene volume requirements, by option and user group.

4. User scores of requirements met, by option and programmatic category.

5. Panel scores of requirements met, by option and programmatic category.

6. User incremental spatial and spectral values, by discipline.

7. Panel incremental spatial and spectral values, by discipline.

8. Total incremental spatial and spectral values for scene volume, user and panel scores.

9. Value-to-cost ratios, by option and discipline, for both user and panel scores.

Appendix 1 (first of three)

ANNUAL SCENE VOLUME REQUIREMENTS BY DISCIPLINE

(Thousands of Scenes)

DISCIPLINE	TIMELINESS (DAYS)	MLA SENSOR OPTIONS										
		1	2	3	4	5	6	7	8	9	10	11
Agriculture	1	14.7	14.7	14.7	15.0	16.0	16.6	16.6	16.8	16.0	16.6	27.3
	2	14.6	14.6	14.6	15.9	15.9	16.4	16.4	16.6	15.9	16.4	27.1
	4	14.0	14.0	14.0	15.3	15.3	15.3	15.3	15.3	15.3	15.3	20.1
	8	13.1	13.1	13.1	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.7
	16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
	32+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Coastal Zone	1	0.5	0.5	0.5	0.6	0.6	0.6	0.6	1.2	0.6	0.6	1.2
	2	0.5	0.5	0.5	0.6	0.6	0.6	0.6	1.1	0.6	0.6	1.1
	4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.1	0.1	0.4
	8	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.3
	16	0.0	0.0	0.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	32+	0.0	0.0	0.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Forestry	1	1.0	1.0	1.8	1.2	1.2	2.3	2.3	3.0	1.5	2.3	8.5
	2	0.9	1.0	1.8	1.2	1.2	2.3	2.3	2.8	1.4	2.3	8.5
	4	0.9	1.0	1.7	1.1	1.1	2.1	2.1	2.5	1.3	2.1	7.4
	8	0.9	0.9	1.3	0.9	0.9	1.5	1.5	1.7	0.9	1.5	6.0
	16	0.8	0.8	0.8	0.8	0.8	1.0	1.0	1.1	0.8	1.0	5.0
	32+	0.7	0.7	0.7	0.7	0.7	0.9	0.9	1.0	0.7	0.9	4.5
Geology	1	0.4	0.4	0.7	9.4	9.4	13.8	13.8	16.7	15.8	20.2	23.6
	2	0.4	0.4	0.7	9.4	9.4	13.8	13.8	16.7	15.8	20.2	23.6
	4	0.4	0.4	0.7	9.2	9.2	13.6	13.6	16.1	15.0	19.4	22.4
	8	0.4	0.4	0.7	8.3	8.3	12.6	12.6	14.6	11.7	16.0	18.0
	16	0.3	0.3	0.3	7.4	7.4	9.9	9.9	10.2	8.9	12.4	12.7
	32+	0.3	0.3	0.3	6.8	6.8	9.0	9.0	9.3	8.2	11.4	11.7

Appendix 1 (second of three)

ANNUAL SCENE VOLUME REQUIREMENTS BY DISCIPLINE

(Thousands of Scenes)

		MLA SENSOR OPTIONS										
DISCIPLINE	TIMELINESS (DAYS)	1	2	3	4	5	6	7	8	9	10	11
Hydrology/Water	1	12.5	12.4	12.4	14.1	14.1	14.1	14.1	15.3	14.8	14.8	16.2
	2	12.3	12.3	12.3	13.7	13.7	13.7	13.7	14.8	14.4	14.4	16.0
	4	6.7	6.7	6.7	6.7	6.7	6.7	6.7	8.4	8.8	8.8	9.3
	8	1.1	1.1	1.1	1.5	1.5	1.5	1.5	2.0	2.2	2.2	2.8
	16	0.8	1.0	1.0	1.3	1.3	1.3	1.3	1.7	2.1	2.1	2.5
	32+	0.7	0.9	0.9	1.2	1.2	1.2	1.2	1.5	2.0	2.0	2.3
Oceans	1	0.4	0.4	0.4	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.7
	2	0.4	0.4	0.4	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.7
	4	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	8	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	16	0.0	0.0	0.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	32+	0.0	0.0	0.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Range	1	0.7	0.7	0.7	0.7	0.7	1.2	1.2	1.4	0.7	1.2	1.8
	2	0.7	0.7	0.7	0.7	0.7	1.2	1.2	1.4	0.7	1.2	1.8
	4	0.5	0.5	0.5	0.6	0.6	1.0	1.0	1.3	0.6	1.0	1.3
	8	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.5	0.3	0.3	0.5
	16	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	32+	0.0	0.0	0.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Regional/Urban Analysis	1	3.6	3.6	3.6	5.1	5.1	5.2	5.2	5.9	5.2	6.6	7.3
	3	3.6	3.6	3.6	5.0	5.0	5.0	5.0	5.7	5.0	6.6	7.3
	4	2.2	2.2	2.2	3.7	3.7	3.7	3.7	4.4	3.7	4.4	5.1
	8	0.5	0.5	0.5	1.9	1.9	1.9	1.9	2.6	1.9	1.9	2.6
	16	0.1	0.1	0.1	0.5	0.8	0.8	0.8	0.9	0.8	0.8	0.9
	32+	0.1	0.1	0.1	0.5	0.7	0.7	0.7	0.8	0.7	0.7	0.8

Appendix 1 (third of three)

ANNUAL SCENE VOLUME REQUIREMENTS BY DISCIPLINE

(Thousands of Scenes)

		MLA SENSOR OPTIONS										
DISCIPLINE	TIMELINESS (DAYS)	1	2	3	4	5	6	7	8	9	10	11
Soils	1	1.3	1.3	7.4	1.3	1.3	9.2	9.2	9.2	4.0	11.8	11.8
	2	1.3	1.3	7.4	1.3	1.3	9.2	9.2	9.2	4.0	11.8	11.8
	4	1.2	1.2	6.7	1.2	1.2	8.3	8.3	8.3	3.9	11.0	11.0
	8	0.6	0.6	5.6	0.6	0.6	5.6	5.6	5.6	3.3	8.3	8.3
	16	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	3.1	3.1	3.1
	32+	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	2.9	2.9	2.9
Wildlife	1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	4	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	8	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	16	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	32+	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Appendix 2 (first of three)

ANNUAL SCENE VOLUME REQUIREMENTS BY PROGRAMMATIC CATEGORY

(2 Day Timeliness)

PROGRAMMATIC CATEGORY (PROGRAM)	MLA SENSOR OPTIONS 1	2	3	4	5	6	7	8	9	10	11
Agriculture											
Crop Inventory	200	200	200	1425	1425	1425	1425	1425	1425	1425	1625
Crop Yield	6100	6100	6100	6100	6100	6100	6100	6100	6100	6100	12100
Crop Condition	6260	6260	6260	6260	6260	6740	6740	6740	6260	6740	10255
Crop Irrigation	1480	1480	1480	1580	1580	1580	1580	1805	1580	1580	2205
Agr. Episodal Event	570	570	570	570	570	570	570	570	570	570	920
Total	14610	14610	14610	15935	15935	16415	16415	16640	15935	16415	27105
Soils											
Soil Classification	525	525	525	525	525	1525	1525	1525	1525	2525	2525
Soil Erosion	725	725	725	725	725	1525	1525	1525	2425	3225	3225
Soil Moisture	0	0	6100	0	0	6100	6100	6100	0	6100	6100
Total	1250	1250	7350	1250	1250	9150	9150	9150	3950	11850	11850
Forests											
Forest Inventory	800	800	890	890	890	1140	1140	1270	980	1140	4110
Forest Stand Evaluation	0	0	350	0	0	440	440	530	90	440	1910
Forest Condition	100	100	450	100	100	540	540	730	190	540	1660
Forest Episodal Event	44	112	112	180	180	180	180	303	180	180	789
Total	944	1012	1802	1170	1170	2300	2300	2833	1440	2300	8469
Range											
Range & Natural Vegetation Inventory	470	470	470	525	525	975	975	975	525	975	975
Range Forage Condition	0	0	0	0	0	0	0	260	0	0	260
Range Episodal Event	199	199	199	199	199	199	199	199	199	199	549
Total	669	669	669	724	724	1174	1174	1434	724	1174	1784

Appendix 2 (second of three)

ANNUAL SCENE VOLUME REQUIREMENTS BY PROGRAMMATIC CATEGORY

(2 Day Timeliness)

PROGRAMMATIC CATEGORY (PROGRAM)	MLA SENSOR OPTIONS										
	1	2	3	4	5	6	7	8	9	10	11
Hydrology											
Drainage Patterns	1160	1160	1160	1593	1593	1593	1593	1693	1593	1593	1748
Inland Water Inventory	4095	4095	4095	4555	4555	4555	4555	4855	4555	4555	4855
Snow Pack Parameters	4630	4630	4630	4955	4955	4955	4955	4955	4955	4955	4955
Ice (Inland Near Shore)	99	99	99	229	229	229	229	229	229	229	272
Water Quality	725	725	725	725	725	725	725	1295	725	725	1295
Wetland/Estuaries Inv.	1445	1445	1445	1490	1490	1490	1490	1535	2240	2240	2285
Hydrologic Episodal Ev.	148	148	148	148	148	148	148	248	148	148	598
Total	12302	12302	12302	13695	13695	13695	13695	14810	14445	14445	16008
Wildlife											
Wildlife Habitat Inv.	800	800	800	800	800	800	800	800	800	800	800
Wildlife Habitat Eval.	400	400	400	400	400	400	400	400	400	400	400
Total	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Geology											
Structures	50	50	50	1900	1900	1900	1900	1900	2852	2852	2852
Landforms	0	0	0	1150	1150	2550	2550	2550	1500	2750	275
Lithology	0	0	0	0	0	2600	2600	3700	600	3400	450
Thermal Anomalies	0	0	0	0	0	0	0	1570	0	0	157
Geobotanic Anomalies	210	210	570	210	210	570	570	660	210	570	750
Topography	100	100	100	6160	6160	6160	6160	6160	10660	10660	10660
Episodal Event	0	0	0	0	0	0	0	100	0	0	480
Total	360	360	720	9420	9420	13780	13780	16700	15822	20232	23562

Appendix 2 (third of three)

ANNUAL SCENE VOLUME REQUIREMENTS BY PROGRAMMATIC CATEGORY

(2 Day Timeliness)

PROGRAMMATIC CATEGORY (PROGRAM)	MLA SENSOR OPTIONS										
	1	2	3	4	5	6	7	8	9	10	11
Regional/Urban											
Land Use/Cover Classification	560	560	560	835	835	835	835	1135	835	1035	1335
Land Use/Cover Change	605	605	605	1416	1416	1416	1416	1716	1416	1641	1941
Environmental Impact	2440	2440	2440	2787	2787	2787	2787	2887	2787	3875	3975
Total	3605	3605	3605	5038	5038	5038	5038	5738	5038	6551	7251
Coastal Zone Monitoring	532	532	532	566	566	566	566	1126	566	566	1126
Oceans											
Currents (Near Shore)											
Tides											
Bathymetry	225	225	225	270	270	270	270	270	270	270	270
Ocean Pollution (Near Shore)	136	136	136	330	330	330	330	386	330	330	386
Total	361	361	361	600	600	600	600	656	600	600	656

Appendix 3

ANNUAL SCENE VOLUME REQUIREMENTS BY USER COMMUNITY

Two Day Timeliness

(Thousands of Scenes)

	MLA SENSOR OPTIONS										
USER COMMUNITY	1	2	3	4	5	6	7	8	9	10	11
US Dept. of Agriculture	0	0	0	0	0	0	0	0	4.4	4.4	19.1
US Army Corps of Engineers	0.2	0.2	0.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
US Dept. of Interior	17.4	17.4	18.1	21.2	21.2	24.8	24.8	28.3	24.5	29.0	33.7
Other Federal	15.0	15.0	21.6	17.7	17.7	24.5	24.5	25.5	17.7	24.5	25.5
State & Local	3.0	3.0	3.0	3.0	3.0	3.0	3.0	4.3	3.0	3.0	4.4
Private	0.6	0.6	0.6	6.9	6.9	10.9	10.9	11.4	8.6	12.6	13.4

Appendix 4 (first of three)

USER PROGRAM SCORES (UNWEIGHTED)

PROGRAMMATIC CATEGORY (PROGRAM)	MLA SENSOR OPTIONS											VOLUME WEIGHT
	1	2	3	4	5	6	7	8	9	10	11	
Agriculture												
Crop Inventory	9	11	11	18	19	18	19	42	21	21	45	1.0
Crop Yield	34	35	35	39	39	39	39	41	39	39	44	1.0
Crop Condition	28	29	29	32	32	32	32	36	32	32	38	1.0
Crop Irrigation	14	15	15	39	41	39	41	43	49	39	55	1.0
Agr. Episodal Event	20	21	21	26	28	26	28	31	35	35	42	0.5
Weighted Average	21	22	22	31	32	31	32	41	35	35	45	
Soils												
Soil Classification	5	5	5	6	6	8	8	8	7	8	10	1.0
Soil Erosion	3	3	3	4	4	5	5	5	5	5	5	1.0
Soil Moisture	0	0	56	0	0	60	62	60	0	68	68	1.0
Weighted Average	3	3	21	3	3	34	25	24	4	27	28	
Forests												
Forest Inventory	15	17	18	19	19	21	21	27	19	21	28	1.0
Forest Stand Evaluation	0	0	20	0	0	22	23	27	0	24	29	0.5(1@11)
Forest Condition	5	5	9	6	6	11	11	15	6	12	16	0.5(1@11)
Forest Episodal Event	2	6	6	9	9	9	9	16	10	10	18	0.5
Weighted Average	7	9	14	11	11	17	17	22	11	18	23	
Range												
Range & Natural Vegetation Inv.	36	38	42	42	42	46	46	49	42	46	49	0.5
Range Forage Condition	0	0	0	0	0	0	0	20	0	0	23	0.5
Range Episodal Event	6	6	6	7	7	7	7	8	7	7	9	0.5
Weighted Average	14	15	16	16	16	18	18	26	16	18	27	

Appendix 4 (second of three)

USER PROGRAM SCORES (UNWEIGHTED)

PROGRAMMATIC CATEGORY (PROGRAM)	MLA SENSOR OPTIONS											
	1	2	3	4	5	6	7	8	9	10	11	VOLUME WEIGHT
Hydrology												
Drainage Patterns	46	47	47	53	53	53	53	53	54	54	54	1.0
Inland Water Inventory	55	57	57	66	66	66	66	70	67	67	71	1.0
Snow Pack Parameters	32	32	32	34	34	34	34	35	35	35	36	1.0
Ice (Inland Near Shore)	27	27	27	32	34	32	34	32	35	35	35	0.5
Water Quality	27	28	31	32	32	34	34	40	32	34	40	0.5(1@8,11)
Wetland/Estuaries Inv.	31	34	34	43	43	43	43	60	44	44	57	1.0
Hydrologic Episodal Ev.	28	29	29	32	32	32	32	38	32	32	38	0.5
Weighted Average	37	39	39	44	45	45	45	49	45	46	49	
Wildlife												
Wildlife Habitat Inv.	19	21	21	23	23	25	25	28	23	25	28	0.5
Wildlife Habitat Eval.	32	26	40	48	48	54	54	54	48	54	54	0.5
Weighted Average	26	29	31	36	36	40	40	41	36	40	41	
Geology												
Structures	3	3	3	44	45	44	45	46	52	52	55	1.0
Landforms	0	0	0	17	18	47	49	50	20	57	60	1.0
Lithology	0	0	0	0	0	30	32	49	0	36	55	1.0
Thermal Anomalies	0	0	0	0	0	0	0	48	0	0	48	1.0
Geobotanic Anomalies	2	2	32	3	3	35	35	39	3	36	40	0.5
Topography	1	1	1	26	27	26	27	26	33	33	33	1.0
Episodal Event	0	0	0	0	0	0	0	51	0	0	61	0.5
Weighted Average	4	4	3	15	15	27	28	45	18	33	50	

Appendix 4 (third of three)

USER PROGRAM SCORES (UNWEIGHTED)

PROGRAMMATIC CATEGORY (PROGRAM)	MLA SENSOR OPTIONS											
	1	2	3	4	5	6	7	8	9	10	11	VOLUME WEIGHT
Regional/Urban												
Land Use/Cover Classification	27	29	36	39	40	49	51	57	44	59	67	1.0
Land Use/Cover Change	19	20	26	42	43	49	51	56	48	59	66	1.0
Environmental Impact	13	15	17	21	23	24	26	25	30	34	34	1.0
Weighted Average	20	21	26	34	35	41	43	48	41	51	56	
Coastal Zone Monitoring	32	33	33	37	37	37	37	44	38	38	44	
Oceans												
Currents (Near Shore) Tides Bathymetry	60	61	61	68	68	68	68	68	68	68	69	0.5
Ocean Pollution (Near Shore)	35	35	35	42	43	42	43	47	44	44	49	0.5
Weighted Average	48	48	48	55	56	55	56	58	56	56	59	

Appendix 5 (first of three)

PANEL PROGRAM SCORES (UNWEIGHTED)

PROGRAMMATIC CATEGORY (PROGRAM)	MLA SENSOR OPTIONS 1	2	3	4	5	6	7	8	9	10	11	VOLUME WEIGHT
Agriculture												
Crop Inventory	24	34	53	44	44	68	68	80	44	68	80	1.0
Crop Yield	24	33	52	43	43	67	67	79	43	67	79	1.0
Crop Condition	24	33	52	43	43	67	67	79	43	67	79	1.0
Crop Irrigation	23	33	51	42	43	66	66	77	42	66	77	1.0
Agr. Episodal Event	24	34	53	44	44	68	68	80	44	68	80	0.5
Weighted Average	24	33	52	43	43	67	67	79	43	67	79	
Soils												
Soil Classification	24	34	53	44	44	68	68	80	44	68	80	1.0
Soil Erosion	24	33	52	43	43	67	67	79	43	67	79	1.0
Soil Moisture	42	42	66	42	42	66	66	77	42	66	77	1.0
Weighted Average	30	36	57	43	43	67	67	79	43	67	79	
Forests												
Forest Inventory	0	0	0	3.5	3.5	6.2	7	11.9	5.2	10.3	17.4	1.0
Forest Stand Eval.	0	0	0	1.0	1.0	2.2	2.5	2.8	1.3	3.2	3.6	0.5(1@11)
Forest Condition	0	0	0	1.7	1.7	3.8	4.0	5.8	11.2	26.8	38.0	0.5(1@11)
Forest Episodal Event	0	0	0	4.2	4.2	24.0	24.9	31.1	4.8	28.5	35.6	0.5
Weighted Average	0	0	0	3	3	8	8	13	6	16	22.0	
Range												
Range & Natural Vegetation Inv.	10.0	12.0	19.0	19.0	19.0	33.2	33.2	47.5	19.0	33.2	47.5	0.5
Range Forage Condition	2.0	4.8	38.8	38.0	38.0	57.0	57.0	95.0	38.0	93.1	95.0	0.5
Range Episodal Event	1.6	2.0	3.8	3.8	3.8	8.6	8.6	9.5	3.8	8.6	9.5	0.5
Weighted Average	4.5	6.3	20.3	20.3	20.3	32.9	32.9	50.6	20.3	45.0	50.6	

Appendix 5 (second of three)

PANEL PROGRAM SCORES (UNWEIGHTED)

PROGRAMMATIC CATEGORY (PROGRAM)	MLA SENSOR OPTIONS											
	1	2	3	4	5	6	7	8	9	10	11	VOLUME WEIGHT
Hydrology												
Drainage Patterns	12	23	28	35	46	43	57	71	58	71	89	1.0
Inland Water Inventory	22	26	41	35	40	55	62	78	44	69	87	1.0
Snow Pack Parameters	36	40	62	40	40	62	62	72	40	62	72	1.0
Ice (Inland Near Shore)	32	36	55	40	40	62	62	72	45	69	80	0.5
Water Quality	40	47	58	60	60	75	75	86	67	83	95	0.5(1@8,11)
Wetland/Estuaries Inv.	30	41	53	47	53	61	68	79	59	76	88	1.0
Hydrologic Episodal Ev.	20	23	37	31	35	49	55	69	39	61	77	0.5
Weighted Average	27	33	47	40	45	57	63	75	50	70	85	
Wildlife												
Wildlife Habitat Inv.	0	0	0	30	32	42	45	59	39	54	69	0.5
Wildlife Habitat Eval.	0	0	0	36	40	42	41	59	54	63	81	0.5
Weighted Average	0	0	0	33	36	42	43	59	46	58	75	
Geology												
Structures	17	21	36	34	34	57	57	66	38	64	74	1.0
Landforms	18	26	44	35	35	58	58	66	40	66	74	1.0
Lithology	13	21	35	29	38	49	63	75	42	70	83	1.0
Thermal Anomalies	17	17	34	20	22	30	46	62	20	40	55	1.0
Geobotanic Anomalies	14	18	29	28	37	43	58	67	41	65	76	0.5
Topography	14	19	29	29	38	44	58	66	34	66	75	1.0
Episodal Event	17	25	41	34	38	54	61	73	38	61	73	0.5
Weighted Average	16	21	36	30	34	49	53	68	36	61	73	

Appendix 5 (third of three)

PANEL PROGRAM SCORES (UNWEIGHTED)

PROGRAMMATIC CATEGORY (PROGRAM)	MLA SENSOR OPTIONS											
	1	2	3	4	5	6	7	8	9	10	11	VOLUME WEIGHT
Regional/Urban												
Land Use/Cover Classification	1.6	1.8	2.6	5.4	5.6	8.0	8.0	9.7	6.6	9.8	11.4	1.0
Land Use/Cover Change	0.0	0.0	0.0	3.5	3.6	5.2	5.4	6.3	7.3	11.0	12.8	1.0
Environmental Impact	0.0	0.0	0.0	5.6	12.1	8.4	18.2	21.2	14.4	21.6	25.2	1.0
Weighted Average	0.5	0.6	0.9	4.8	7.1	7.2	10.5	12.4	9.4	14.1	16.5	
Coastal Zone Monitoring	0.0	0.0	0.0	5.0	5.3	7.5	8.0	18.6	6.4	9.6	22.4	

Appendix 6

USER INCREMENTAL SPATIAL AND SPECTRAL VALUES**

SYSTEM IMPROVEMENT	DIFFERENCE OF OPTIONS	INCREASED REQUIREMENTS BY DISCIPLINE (%)									
		AGR	SOIL	FOR	RANGE	GEOL	HYDRO	WILDL	REG.	CZ	OCEANS
SPATIAL											
80 TO 60m	2-1	5	0	30	8	*	0	12	5	3	0
TO 30m	4-1	50	0	60	14	*	20	40	70	15	14
TO 22m	5-1	50	0	60	14	*	20	40	80	15	16
TO 10m	9-1	70	35	60	14	*	20	40	100	20	15
60 TO 30m	4-2	40	0	20	6	*	20	25	60	12	14
TO 22m	5-2	45	0	20	6	*	20	25	70	12	16
TO 10m	9-2	60	35	20	6	*	20	25	100	16	15
30 TO 22m	5-4	3	0	0	0	0	2	0	3	0	2
TO 10m	9-4	12	35	0	0	20	2	0	20	3	2
22 TO 10m	9-5	10	35	0	0	20	0	0	15	3	0
SPECTRAL											
ADD SWIR TO VIS/NIR											
AT 60m EFFECTIVE	3-2	0	600	60	6	*	5	6	25	0	0
AT 30m EFFECTIVE	6-4	0	700	50	12	80	2	12	20	0	0
AT 22m EFFECTIVE	7-5	0	750	50	12	90	0	12	25	0	4
AT 15m EFFECTIVE	10-9	0	600	60	12	80	2	12	25	0	0
ADD TIR TO VIS/NIR/SWIR											
AT 120m	8-7	30	4	20	45	80	8	2	12	20	0
AT 60m	11-10	30	4	30	50	50	6	2	10	15	5

*INDETERMINATE DUE TO DIVISION BY 0

**INCREASED VALUE IN PERCENT ROUNDED TO APPROXIMATELY 1 PART IN 10

(0-5 = ±1, 5-15 = ±2, 15-50 = ±5, 50-100 = ±10, 100-200 = ±25, 200+ = ±50)

Appendix 7

PANEL INCREMENTAL SPATIAL AND SPECTRAL VALUES**

SYSTEM IMPROVEMENT	DIFFERENCE OF OPTIONS	INCREASED REQUIREMENTS MET BY DISCIPLINE (%)									
		AGR	SOIL	FOR	RANGE	GEOL	HYDRO	WILDL	REG.	CZ	OCEANS
SPATIAL											
80 TO 60m	2-1	40	20	*	50	30	20	*	0	*	
TO 30m	4-1	80	45	*	400	90	50	*	400	*	
TO 22m	5-1	80	45	*	400	100	70	*	800	*	
TO 10m	9-1	80	45	*	400	125	90	*	800	*	
60 TO 30m	4-2	30	20	*	250	45	20	*	400	*	
TO 22m	5-2	30	20	*	250	60	35	*	800	*	N
TO 10m	9-2	30	20	*	250	70	50	*	800	*	O
30 TO 22m	5-4	0	0	0	0	14	12	10	40	0	D
TO 10m	9-4	0	0	100	0	20	25	40	80	20	A T
22 TO 10m	9-5	0	0	100	0	6	12	30	30	20	A
SPECTRAL											
ADD SWIR TO VIS/NIR											
AT 60m EFFECTIVE	3-2	60	60	*	80	70	40	*	0	*	
AT 30m EFFECTIVE	6-4	60	60	175	60	60	40	25	40	80	
AT 22m EFFECTIVE	7-5	60	60	200	60	60	40	30	60	80	
AT 15m EFFECTIVE	10-9	60	60	175	125	70	40	25	60	70	
ADD TIR TO VIS/NIR/SWIR											
AT 120m	8-7	20	20	45	50	30	20	25	10	150	
AT 60m	11-10	20	20	40	14	20	20	30	20	125	

*INDETERMINATE DUE TO DIVISION BY 0

**INCREASED VALUE IN PERCENT ROUNDED TO APPROXIMATLEY 1 PART IN 10

(0-5 = ±1, 5-15 = ±2, 15-50 = ±5, 50-100 = ±10, 100-200 = ±25, 200+ = ±50)

Appendix 8

INCREMENTAL SPATIAL AND SPECTRAL VALUES** FOR USER AND PANEL REQUIREMENTS

SYSTEM IMPROVEMENT	DIFFERENCE OF OPTIONS	INCREASED REQUIREMENTS MET		
		USER VOLUME (%)	USER SCORES (%)	PANEL SCORES (%)
SPATIAL				
80 TO 60m	2-1	0	6	25
TO 30m	4-1	40	45	100
TO 22m	5-1	40	50	125
TO 10m	9-1	70	60	125
60 TO 30m	4-2	40	35	60
TO 22m	5-2	40	40	70
TO 10m	9-2	70	45	80
30 TO 22m	5-4	0	4	6
TO 10m	9-4	20	8	14
22 TO 10m	9-5	20	4	6
SPECTRAL				
ADD SWIR TO VIS/NIR				
AT 60m EFFECTIVE	3-2	20	14	60
AT 30m EFFECTIVE	6-4	30	25	50
AT 22m EFFECTIVE	7-5	30	20	50
AT 15m EFFECTIVE	10-8	25	25	70
ADD TIR TO VIS/NIR/SWIR				
AT 120m	8-7	10	20	15
AT 60m	11-10	30	15	10

**INCREASED VALUE IN PERCENT ROUNDED TO APPROXIMATELY 1 PART IN 10

(0-5 = ±1, 5-15 = ±2, 15-50 = ±5, 50-100 = ±10, 100-200 = ±25, 200+ = ±50)

Appendix 9

VALUE-TO-COST RATIO FOR USER SCORES

	MLA SENSOR OPTIONS										
DISCIPLINE	1	2	3	4	5	6	7	8	9	10	11
AGRICULTURE	79	80	77	97	91	87	85	100	54	48	58
SOILS	15	15	100	13	12	92	90	86	8	51	49
FORESTRY	49	61	91	64	58	89	84	100	31	46	55
RANGE	83	86	89	79	72	80	76	100	39	39	55
GEOLOGY	0	0	10	43	39	69	68	100	25	42	59
HYDROLOGY/WATER	100	96	99	99	92	91	86	86	50	46	46
WILDLIFE	87	93	97	100	91	100	95	89	49	49	47
REGIONAL/URBAN ANAL.	64	65	78	91	85	98	98	100	54	60	62
COASTAL ZONE	100	99	96	96	88	87	82	89	48	44	47
OCEANS	100	96	94	95	89	86	86	78	48	43	42

VALUE-TO-COST RATIO FOR PANEL SCORES

	MLA SENSOR OPTIONS										
DISCIPLINE	1	2	3	4	5	6	7	8	9	10	11
AGRICULTURE	47	62	95	70	64	98	92	100	34	48	53
SOILS	56	65	100	67	61	94	89	96	33	46	51
FORESTRY	0	0	0	30	27	71	76	100	29	70	89
RANGE	12	18	31	50	46	75	71	100	25	50	53
GEOLOGY	36	46	76	56	58	83	85	100	33	51	57
HYDROLOGY/WATER	55	65	90	68	70	88	92	100	42	53	60
WILDLIFE	0	0	0	73	72	84	86	100	50	57	68
REGIONAL/URBAN ANAL.	13	12	12	53	68	67	100	100	47	66	75
COASTAL ZONE	0	0	0	34	31	49	46	100	20	30	61
OCEANS						NO DATA					