

Ramifications of the Landsat 7 Failure: Short-Term Funding Strategies

**A report to the
House Appropriations Committee,
Subcommittee on Interior and Related
Agencies**

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BACKGROUND

The Land Remote Sensing Policy Act of 1992 (P.L. 102-555) directs the Secretary of the Interior to “provide for long-term storage, maintenance, and upgrading of a basic, global land remote sensing data set” and to “assure ... timely access for parties requesting data.” Such data are to be “made available to all users without preference, bias or any other special arrangement [except national security] regarding delivery, format, pricing, or technical considerations which would favor one customer or class of customers over another.” The Act established a program management team to oversee the Landsat 4 and Landsat 5 operations, develop and operate the Landsat 7 mission, establish cooperation with the international community, and assess options for a successor system. The purpose of the program is to provide remotely sensed data for use in applications and scientific investigations conducted by a global community of government, academic, and commercial users.

Presidential Decision Directive National Science and Technology Council-3 (signed May, 1994 and revised October 16, 2000) states “The Department of the Interior (DOI)/U.S. Geological Survey (USGS) will assume responsibility for management and operations of the Landsat 7 ground system elements at the USGS Earth Resource Observation System Data Center and the Landsat 7 Program Management Office and its oversight functions” and will “continue to maintain a national archive of existing and future Landsat-type remote sensing data within the United States and make such data available to the U.S. Government and other users.”

The DOI and the USGS have been involved in the Landsat program since 1966, under then Secretary of the Interior Stewart Udall. During the Earth Observation Summit held in Washington, D.C., on July 31, 2003, Secretary of the Interior Gale A. Norton stated that, “For more than 30 years, the Landsat system, now managed by our Geological Survey, has been the only source for an extended record of moderate-resolution space-based observations of the landmass of our planet.”

Landsat 7 provides unique data for a variety of scientific and commercial activities. Within the DOI, Landsat 7 is an operational tool for such things as detecting and monitoring invasive plant species in remote regions (USGS Biological Resource Programs and DOI Bureau of Land Management), assessing water volume in snow pack and large Western aquifers (USGS Water Resources Programs and DOI Bureau of Reclamation), assessing the stewardship of Federal grazing lands (Bureau of Land Management), and monitoring land use/land change in remote regions (DOI Bureau of Indian Affairs). However, the major U.S. users of Landsat 7 data are the U.S. Department of Agriculture (USDA), for global crop monitoring, and the National Geospatial-Intelligence Agency (NGA), for global mapping (see Appendix A). Other major users are international government agencies concerned with natural resources, agricultural production, and land use/land change, and researchers at universities conducting a wide range of Earth science investigations.

USGS responsibilities in the Landsat Program are to: (1) operate the satellites; (2) capture, process, calibrate/validate, and archive¹ the data; and (3) provide access to, derive, and distribute products – at the cost of fulfilling a user request (COFUR). The USGS budget for the Landsat Program is about \$21.2 million per year. Approximately \$10.2 million is from appropriated funds, and \$11 million is derived from data product sales and cost-share fees from international cooperators.

¹Landsat 7 data are currently archived within the stand-alone Landsat 7 ground data processing system. When the mission ends, these data will be transferred to the USGS National Satellite Land Remote Sensing Data Archive (NSLRSDA) that holds data from several other satellite missions, including declassified data as well as data from previous Landsat missions. NSLRSDA funding does not contribute to operation of the Landsat Program.

The appropriated funds are used to support program administration and satellite flight operations (#1 above). The sales/IC revenue covers the remaining operational expenses (#2 and #3 above) that include: capturing data intended for the U.S. archive; processing, archiving, and providing on-line access to the captured data; data product derivation and distribution, including customer service, billing, and accounting; data calibration and validation; and coordination and management of the international network of 17 ground stations. For FY 2004 and beyond, the \$10.2 million of appropriated funds for satellite mission operations is expected to continue; however, revenues from product sales and international cooperator fees are expected to be significantly reduced.

SCAN LINE CORRECTOR (SLC) PROBLEM

The scan line corrector, which compensates for the forward motion of the satellite, failed on May 31, 2003. Efforts to recover the SLC were unsuccessful; the problem appears to be permanent. Landsat 7 can still acquire useful image data with the SLC turned off, particularly within the central portion of any given scene. Landsat 7 will, therefore, continue to acquire image data with the SLC off.

LANDSAT DATA ARE STILL BEING USED

When determining which data to employ (Table 1), users consider spatial resolution, dynamic range, quality (radiometric and geometric), spatial coverage (swath width), temporal coverage (revisit rate), availability, and price. While the scan line corrector (SLC) failure results in ~25% missing data within each scene, remaining data is unchanged regarding the above-mentioned factors. Applications that target small areas (e.g. coral reefs) may be seriously affected by the missing data. Applications that view broad areas (e.g. crop forecasting) are less effected. Landsat data collected after the SLC malfunction are still being used for military and intelligence, crop monitoring and forecasting, burn severity mapping, long-term monitoring of ecosystems, updating fire fuels assessment, and updating fire atlases. Data currently being collected meets or exceeds design specifications.

Comparison of the Applicability of High Resolution, Moderate Resolution, and Low Resolution Satellite Data			
Application	Low Res. (MODIS)	Moderate Res. (Landsat)	High Res. (Commercial)
Hurricane Damage Assessment	N/A	Best	Marginal
Flood Area Measurement	Marginal	Best	Marginal
Property/Crop Insurance Claims	N/A	Marginal	Best
Military Site Monitoring	N/A	Marginal	Best
Broad Area Change Detection	Marginal	Best	N/A
Urban Mapping	N/A	Marginal	Best
Regional Mapping	Marginal	Best	Marginal
National Mapping	Marginal	Best	N/A
Crop Vigor (Field)	N/A	Marginal	Best
Crop Vigor (Region)	Marginal	Best	Marginal
Crop Vigor (National)	Marginal	Best	N/A
Wildfire Detection	Best	Marginal	N/A
Wildfire Monitoring/Measurement	Marginal	Best	Marginal

Comparison of the Applicability of High Resolution, Moderate Resolution, and Low Resolution Satellite Data			
Application	Low Res. (MODIS)	Moderate Res. (Landsat)	High Res. (Commercial)
Coastal Oil Slick Detection	Marginal	Best	Marginal
Wildlife Habitat Assessment	Marginal	Best	Marginal
Wetlands Monitoring (Region)	Marginal	Best	Marginal
Urban Land Cover	N/A	Marginal	Best
National Land Cover	Marginal	Best	Marginal
Global Land Cover	Marginal	Best	N/A

Table 1. Comparison of the applicability of high resolution, moderate resolution, and low resolution satellite data to various types of activities. Moderate resolution (Landsat) is the most applicable satellite data set for many activities. Applicability is rated as "Best", "Marginal", or "N/A" (not applicable) based on the characteristics (resolution, quality, price, etc.) listed in the above text. The ratings in this table are not "pre" nor "post" anomaly, but rather an "in general" rating.

SALES/INTERNATIONAL COOPERATOR REVENUE HAS DECLINED

Some traditional users of Landsat data have been impacted by the failure of the scan line corrector, which has led to a decline in sales revenue and fees from IC. About 75 percent of the picture elements, or pixels, in each new Landsat 7 scene are intact with the scan line corrector remaining off. Scientists conducting a preliminary study have concluded that incomplete Landsat 7 scenes are still highly useful for many applications (see Appendix B). Users within the USDA (see Appendix B), the Department of Defense, and other Federal agencies have continued purchases of Landsat 7 data at approximately 62 percent of the pre-malfunction level. Factors contributing to the decreases in sales of Landsat 7 data, with the scan line corrector off, include misinformation on the availability and quality of the data, reduced requirements for Landsat data in general, and uncertainty over the future of the Landsat program. The USGS has posted information on websites, sent information and sample products to users, and presented papers and exhibits at conferences, such as the AAG and ASPRS, that described the data, its uses, and the new products under development. Specific demand for Landsat data is dependent upon many factors, including external events, such as droughts, floods, and military activities. These events create interest by specific components of the user communities at different times during a year. The goal of the Landsat Program is to collect and populate an archive with seasonal global data of the Earth's landmasses irrespective of short-lived activities or events. This has resulted in a robust archive that can satisfy these demands when they occur. Table 2 below shows revenue from the sale of Landsat 7 data since FY 2002, while Table 3 shows the Landsat 7 data sales for FY 2003 and FY 2004 by the largest consumers of Landsat data.

Landsat 7 Revenue, FY 2002 - Present			
	<u>Total Revenue</u>	<u>Pre-Anomaly Revenue</u>	<u>Post-Anomaly Revenue</u>
FY 2002	\$8,215,087		
FY 2003	\$6,402,210		
FY 2004 (estimate) *	\$4,750,000	\$4,370,000	\$380,000
FY 2004 (4/2/04) **	\$3,498,530	\$3,292,340	\$206,190

* Anomaly started in May 2003
 * FY 2004 estimate assumes a total of 7,800 scenes sold. Post-anomaly data would account for 600 of the 7,800.
 ** As of April 2, 2004, the USGS has sold 6,421 pre-anomaly and 375 post-anomaly scenes.

Table 2. Comparison of Landsat data sales revenue for last three fiscal years.

Landsat 7 Sales, Largest Customers, FY 2003 and FY 2004

Landsat 7 Data Sales		FY 2003	FY 2004
<u>Organization</u>	<u>Country</u>	<u>Net Sales</u>	<u>Net Sales</u>
RESTEC	Japan	\$941,155	\$452,160
EARTH SATELLITE CORP	United States	\$250,500	\$300,480
DEPARTMENT OF DEFENSE	United States	\$605,130	\$263,040
RADARSAT INTERNATIONAL	Canada	\$357,930	\$259,400
EURIMAGE	Italy	\$340,440	\$184,100
MICHIGAN STATE UNIVERSITY	United States	\$187,560	\$202,560
ISTAR	France	\$72,000	\$96,960
IMAGELINKS	United States	\$172,670	\$108,780
NASA	United States	\$149,138	\$20,665
NIGEL PRESS ASSOCIATES LIMITED	Great Britain	\$53,420	\$77,760
TEXAS WATER DEVELOPMENT BOARD	United States	\$35,200	\$58,880
PHOTOSAT INFORMATION LTD.	Canada	\$3,800	\$26,895
COMPUTAMAPS	South Africa	\$18,720	\$24,605
CHINA REMOTE SENSING	China	\$40,660	\$32,920
SPOT IMAGE CORPORATION	United States	\$63,360	\$25,440
UNIVERSITY OF FLORIDA	United States	\$11,550	\$23,720
UNIVERSITY OF MARYLAND	United States	\$48,925	\$31,640
R&D CENTER SCANEX	Russia	\$54,960	\$24,000
COUNCIL FOR GEOSCIENCE	South Africa	\$1,200	\$23,880
MOTOROLA	United States	\$56,640	\$25,920
CSIR/ICOMTEK	South Africa	\$23,340	\$21,720
PRECISION PARTNERS INC	United States	\$27,250	\$24,650
PACIFIC GEOMATICS LTD	Canada	\$25,880	\$18,705
DOI/USGS	United States	\$281,010	\$31,645
MARCONI CORP. PLC	United States	\$28,800	\$17,280
TALDOR-NAVOT IPRS	Israel	\$7,200	\$17,400
Subtotal		\$3,858,438	\$2,395,205
Other purchasers		\$2,543,772	\$1,103,325
Grand Total for Fiscal Year		\$6,402,210	\$3,498,530

Table 3. Landsat 7 data sales for the largest customers in FY 2003 and FY 2004. A number of these customers purchase data on behalf of a Federal government agency. For example, the USDA purchased an additional \$768,065 of Landsat 7 data through three private companies (Radarsat, Eurimage and Earthsat) in FY2003.

MANAGEMENT CONSIDERATIONS AND FUNDING OPTIONS

Although there are several other Earth observation systems in orbit, Landsat 7 provides a unique set of capabilities. The combination of moderate resolution (30/15-meter), broad-area coverage (31,476 km²/scene), spectral range (9 channels from visible to thermal infrared), and global availability (over 90,000 scenes per year of the Earth's landmasses) is not duplicated by any other existing satellite systems. The standard geographic coverage of some of the instruments that have been considered as possible substitutes for Landsat 7 is shown in Figure 1 below. Table 4 provides a comparison of alternative satellites and their resolutions, costs, etc.

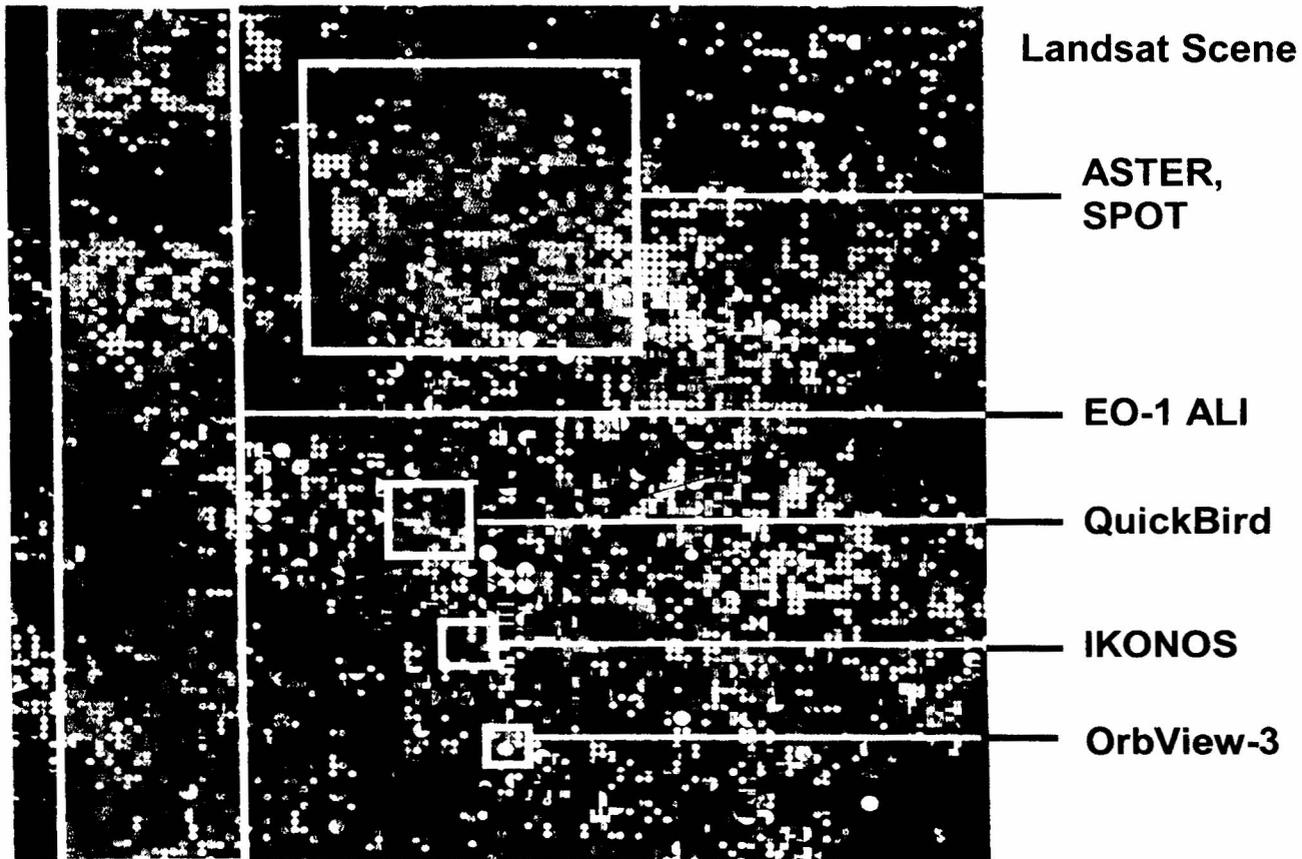


Figure 1. Compares the scene area coverage from other satellite systems to a standard Landsat image.

Comparison of Satellites

Satellite/Instrument

Parameter	Landsat 7 ETM+	SPOT 2, 4 HRVs, HRVIRs	SPOT 5 HRGs	Terra ASTER	Terra MODIS	EO-1 ALI
Spectral Range (um)	.45 - 12.5	.5 - 1.75	.48 - 1.75	.52 - 11.65	.62 - 14.38	.43 - 2.35
Number of Bands	9	4, 5	5	14	36	10
Spatial Resolution (pan/mss in m)	15/30	10/20	2.5/5/10/20	15/30/90	250/500/100 0	10/30
Swath Width (km)	185	60	60	60	2330	37
Revisit Time (days)	16	1 to 4	1 to 4	16	1 to 2	16
Number of Scenes to Equal Landsat Scene	-	9	9	9	<1	-
Cost for "ETM+" Scene	\$600	\$19,350	\$36,450	\$540	free	*

Parameter	Satellite/Instrument (cont.)					
	Space Imaging IKONOS	DigitalGlobe QuickBird	OrbImage OrbView-3	IRS	LDCM	Landsat 5 TM
Spectral Range (um)	.45 - .9	.45 - .9	.45 - .9	.5 - 1.7	.43 - 1.87	.45 - 12.5
Number of Bands	5	5	5	5	9	7
Spatial Resolution (pan/mss in m)	1/4	.61/2.88	1/4	5/20	15/30	30
Swath Width (km)	11	14	8	70/140	185	185
Revisit Time (days)	3	1 to 3.5	< 3	5	16	16
Number of Scenes to Equal Landsat Scene	283	175	535	2	1	-
Cost for "ETM+" Scene	\$566,568**	\$708,210***	****	\$4,092*****	\$50	\$425

* Current mission does not acquire entire Landsat 7 ETM+ scene

** \$18 km²

*** \$22.50 km²

**** No price information available at this time

***** \$0.13 km²

Landsat ETM+ scene is 31,476 km²

Table 4. Satellite comparison.

The costs that would be incurred to utilize other satellite systems to substitute for Landsat 7 would be high. Each system has a different swath width, a different revisit rate and time, and a significantly different resolution, as demonstrated in the above figure. To cover the area of a scene taken from Landsat 7, it would require 9 scenes from either the ASTER or SPOT systems, with costs ranging from \$540 to \$36,450 for the equivalent quantity of Landsat data. For higher resolution satellites such as IKONOS, the costs are even higher, needing 283 scenes at about \$567 per scene to provide the same geographic coverage as a Landsat 7 scene. It would also take many revisits from any of these systems to acquire the equivalent of a single Landsat 7 scene. These revisit times could take from several weeks to months and would be hampered by cloud cover conditions.

FY 2004

The Department of Interior considered several options to manage satellite operations after the SLC failure, including: halting satellite operations; halting archiving and distribution activities and only downlinking data to International Cooperators; limited operations that would continue archiving but not distribute Landsat data; and continuing full Landsat operations. After much discussion and the weighing of costs and benefits, the Department decided to continue satellite operations and product sales from both Landsats 5 and 7 and expects the strategy for a follow-on program to Landsat 7 to be announced in the June/July 2004 timeframe. At that time, the Department expects to ascertain the long-term requirements and funding needs of the Department's land remote sensing program.

To fulfill the Department's Landsat Program mandate, the USGS must ensure continued operation of the two satellites, must archive and maintain all data acquired by those satellites, and must ensure that all customers have access to products available from the data. To address these obligations the USGS is proposing the following for FY 2004:

- **Resume sales and reprogram to cover the balance.** The USGS has been tracking sales of Landsat 7 data with the scan line corrector (SLC) turned off (SLC-off) vs. pre-malfunction

SLC-on data obtained before May 31, 2003. From October 1, 2003, to April 2, 2004, less than 6% of Landsat 7 data sales were for SLC-off data. Based on sales to date, the estimate for Landsat 7 data sales for FY 2004 is \$4.75 million, as compared to the annual average of approximately \$8.0 million. The Landsat 7 funding gap for FY 2004 is projected to be \$5.1 million, due to the SLC-off sales shortfall and reduced revenue from international cooperators. The USGS has proposed to reprogram funds in FY 2004 to cover this projected shortfall, including \$3.4 million of Geography discipline funds intended for National Academy of Sciences studies, leveraging Department of Defense environmental clean-up funds, mapping contracts, remote sensing research, and operating expenses. Central Region facilities operations and maintenance funds will be reduced and two FY 2004 deferred-maintenance projects will be postponed until a later date for an additional \$530,000. The Department of the Interior's Wildland Fire Management account will purchase approximately \$1.0 million of Landsat 7 data to ensure Landsat data availability for fire management, suppression, and remediation measures by the land and resource management bureaus. The combination of projected data sales (\$4.75 million), projected international cooperator fees (\$1 million), reprogrammed funding (\$4.6 million), and Wildland Fire Management purchases (\$1.0 million) adds up to \$11 million – the amount of total reimbursable revenue that would normally cover data archive and product generation expenses.

New Landsat 7 products

As a result of the scan line corrector malfunction, the USGS has been taking actions to increase the utility of the Landsat 7 data that includes “fixing” the data gaps from the malfunctioning scan line corrector. The USGS held a workshop with Landsat users from the Federal government and academia in October 2003 (Appendix C) to identify new products for data acquired since the malfunction. Two new products, Anniversary composites and Multi-scene composites, were identified at the October, 2003 workshop and scheduled for implementation. The initial product, the Anniversary composite, will be generated by replacing all the missing data in the data gaps of a scan line corrector off data set with information derived from a Landsat image that was acquired prior to the scan line corrector malfunction. This technique will result in a composite data product without data gaps, which can be used to meet additional user requirements. In May 2004, the USGS announced a price reduction for the Landsat 7 scenes that contain data gaps after the scan line corrector failure on May 31, 2003. This decision was made in an effort to stimulate sales for post anomaly data. Our customers, per their feedback and data sales figures, are not willing to pay \$600 per scene for the anomalous Landsat 7 data, and the lower price makes these products more marketable. The USGS will sell Landsat 7 scenes that contain gaps in the data at \$250 per scene rather than \$600. In addition, customers would have the option to purchase the Landsat scene with the gaps filled using the data from a previously acquired scene. This product will be priced at \$275 per scene. The revenue from the sale of these composite products is estimated to be \$53,000 in FY 2004. This is primarily due to the release of these products so late in the fiscal year. The lower prices will not exacerbate the shortfall for FY 2004 since 94% of the revenue is being generated from the sale of Landsat 7 data acquired prior to the anomaly. The prices for the pre-anomaly data have not been lowered, i.e., they remain at \$600 per scene. Only the prices for the affected data have been lowered. The USGS has been monitoring Landsat 7 data sales since the beginning of the fiscal year and will continue to monitor the sale of Landsat products over the next few months and use this information to project FY 2005 data sales revenue. In FY 2005, the new products are expected to generate approximately \$290,000. The USGS is continuing to research other methods of providing better Landsat 7 products using the scan line corrector off data. The Multi-scene product uses data from multiple Post-anomaly scenes to “fill in” the gaps of a post-anomaly scene. The USGS expects that this product will be available in the second quarter of FY 2005 and projects that this product will bring in \$95,550 in revenue.

Landsat 5

Increased demand on Landsat 5 since the Landsat 7 instrument malfunction has triggered problems with Landsat 5's ability to transmit data to the ground. Engineers are concerned that increased demands on Landsat 5 could render it incapable of capturing the data it currently provides. Therefore, this report does not contain any option that would include additional tasking of Landsat 5.

FY 2005 and Beyond

Addressing the options for the Landsat 7 mission for FY 2005 and beyond is highly dependent upon decisions regarding a follow-on mission after Landsat 7, referred to as the Landsat Data Continuity Mission (LDCM). Discussions in regard to LDCM are ongoing between the USGS, the Department, NASA, the National Security Council, OSTP, NOAA, DOD, and OMB. The Department and the USGS expect these discussions to yield a final recommendation in the June/July 2004 time frame.

Under the assumption that a follow-on mission will be approved, and that this approval will include a decision to avoid or minimize a gap in the Nation's moderate-resolution earth observation data between now and the launch of the next satellite, the USGS is considering the following short-term management options for dealing with the Landsat 7 satellite are as follows:

- A. **De-orbit and decommission Landsat 5 and Landsat 7:** Almost the entire infrastructure that supports Landsat 5 is shared with and paid for by Landsat 7. There would be essentially no savings realized by decommissioning only Landsat 7 or Landsat 5. A reduced flight-operations staff would gradually de-orbit both satellites over ten to twelve months. Approximately 127 government and contract staff would be laid off. Moderate-resolution data needed for specific purposes would have to be purchased from operators of other currently available satellites. Although the USGS could try to work with the Federal purchasers of these data to obtain the data for archive in the Nation's national database, these special-purpose purchases would not provide the seasonal national or global data coverage that is currently provided through the Landsat Program. Decommissioning of the satellites would take \$10.2 million of appropriated funds, of which \$8.0 million is specified for satellite operations. In FY 2006, after both satellites are decommissioned, the \$8.0 million specified for satellite operations might be available for other purposes such as LDCM support.
- B. **Continue flight operations and data collection only:** These functions, which would require a total of \$16.6 million would retain the keystone of the program and allow for future data processing and distribution should funds become available. No income from data sales or International Cooperator fees would be generated, because no products or services would be provided to generate these revenues. While flight operations and raw-data capture and archiving would continue, data access, production, and distribution would be suspended indefinitely, along with most of the data calibration and validation. The USGS would not be in compliance with its data distribution mandate. All Landsat data distribution would be terminated, and major Federal users such as the Department of Agriculture and DOD would have significant program impacts. All staff directly and indirectly associated with data processing and distribution would be laid off. Jobs lost would total approximately 35, primarily contract staff. With these production people laid off, all sales of current Landsat 7 and historical Landsat 1-5 data would be suspended, and sales revenue would fall to zero. Assuming the use of the existing \$10.2 million in the base, this option would require at least \$6.5 million in additional funds.

- C. Continue flight operations, data collection, and limited production:** With these functions, the USGS would retain the most fundamental responsibility of the program. These functions would require a total funding of \$19.4 million. Under this scenario, in addition to normal collection of 250 global scenes per day, a bare-bones data production and distribution capability would be maintained for responding to national hazards and emergencies (forest fires, floods, etc.), in addition to requests for homeland security support. U.S. Government agencies and other U.S. users would have to obtain other moderate-resolution products from other sources. This would result in data processing, distribution and related staff being reduced. Approximately 20 contract jobs would be lost. As with option B, the USGS would not be in compliance with its data distribution mandate. However, international receiving stations would be able to generate products, since the USGS would resume full data calibration and validation services under this option. Some reimbursable income from International Cooperator fees (up to \$1.5 million) and data sales (\$0.5 million) would be realized under this option. Assuming the use of the existing \$10.2 million in the base, up to \$1.5 million in IC fees and 0.5 million in data sales, this option would require at least \$7.2 million in additional funds.
- D. Continue full mission operations:** These functions, which would require \$6.2 million in addition to the USGS base of \$10.2 million for Landsat operations and an estimated \$4.8 million of revenue generated from data sales and international cooperator fees, would bring the program back to full compliance with P.L. 102-555, thus allowing the Landsat data user community unrestricted access to current Landsat 7 and Landsat 5 data, in addition to historical data. This approach would result in no job losses.

Funding Options

The USGS has been discussing several alternatives for funding the Landsat 7 program shortfall – licensing fees, subscription services, and user underwriting fees. Under the licensing fee option, the USGS would charge customers a fee, allowing them unlimited access to Landsat data. This would have the benefit of raising revenues in the beginning of the year, which would allow for more accurate planning, as the USGS would have a better idea of yearly revenue. Second, based on yearly analysis, the fee schedule would be set in a manner that would ensure that revenue targets would be met. Third, with unlimited access to data, the customer base might be broadened, thus bringing in more revenue or allowing lowering of the fee schedule if archive and distribution costs are fully covered. There are potential drawbacks to this option, however. First, customers might be reluctant to commit their funds when their requirements may change over a fiscal year. Second, customers could either under or over utilize the data based on what they paid. If they underutilize the data, the customer may feel that they did not receive what they paid for and could be reluctant to pay a licensing fee in the future. If they over utilize the data, it could overwhelm the USGS, leading to backlogs in data requests and lost customers for the future. Finally, smaller customers may not want to, or can't afford to, pay for a service they rarely use, perhaps leading them to go elsewhere or pricing them out of the market completely. Fourth, some government agencies would have to "pool" their funds from many bureaus or agencies within a Department to be able to make up the needed fees. And finally, according to P.L. 102-555, the USGS must provide non-discriminatory access to the data.

Subscription services would allow customers to purchase a set amount of Landsat data for the year at a set price. For example, the Department of Agriculture could subscribe to have 100 data sets per month delivered, but instead of paying the normal cost per scene, the rate would

be lower. This would have the benefit of raising revenues early in the fiscal year, or at the least, allowing customers to put in their fiscal year request early in the year, allowing for more accurate planning for the expected revenue. This option also provides the USGS a better view of demand, providing for more accurate workload estimates. With this option, customers would still be able to purchase data on an individual, as-needed basis, preserving the seller-customer relationship and keeping smaller purchasers engaged. Finally, through analysis of yearly subscriptions and individual sales, the fee and price schedule could be set in a manner that would ensure that revenue targets could be met for each year. This option also has a few potential drawbacks. First, customers may not know what their yearly needs will be so early in the year and therefore opt not to commit the funds for subscription. Second, the USGS may not be able to "subscribe" enough customers to make up the fixed costs. If subscription rates were low, coupled with low sales revenue, the USGS would be in the position of not being able to generate the resources needed to fund fixed costs.

Another option being considered is for major users to help underwrite the Landsat program. Under this option, the USGS would enter cooperative agreements with major Federal agency users to underwrite the Landsat program, i.e., share the cost. This has the benefit of having the costs covered from the beginning of the year. The cost to each agency would be prorated based on their past purchases. This also allows the USGS the flexibility to change the share from year to year, based on the amount of data each customer purchases in the current year. Another benefit is that, for planning purposes, the USGS would have a better idea of the revenue to expect for the year, leading to better workload planning. Finally, it preserves the seller-customer relationship for commercial users, as they would still be able to purchase the data as in the past. This option has one major drawback. USGS discussions with other bureaus regarding this option have proven fruitless; therefore, adoption of this option would require Department-level negotiations with Department-level executives of the major user agencies, including OMB endorsement, to ensure that this option receives the necessary support.

If no other option is viable, the USGS will direct savings it expects to generate from its recent workforce restructure within the Geography discipline to the Landsat 7 shortfall. The USGS received approval to offer buy-out and early-out opportunities in FY 2004 to selected personnel within its Geography workforce to restructure the workforce to meet the objectives of *The National Map*. The original intent of this buyout was to use the savings to increase partnerships with state and local governments and other entities to further the implementation and completion of the National Map. A limited amount of the funds were also to be used to increase contractual services with the private sector for data gathering for the national database.

The USGS expects a decision regarding the long-term strategy for Landsat 7 to be made during the summer of 2004. The Department will work with other involved Federal agencies to develop a funding strategy before the beginning of the next fiscal year.

APPENDIX A

<i>Applications of Landsat Data by Federal Agency</i>	
Application	Agency
Hurricane Damage Assessment	FEMA
Flood Area Measurement	NOAA
Military Applications	DOD/Intel Community
Change Detection	BLM, NASA, OSM
Environmental Monitoring	EPA, DOS
National/Regional Mapping	USGS
Crop Vigor	USDA
Crop Yield	USDA
Fire Fuels Mapping	BIA, BLM, NPS, USDA, USGS
Wildfire Monitoring/Measurement	USDA/DOI
Coastal Oil Slick Detection	NOAA
Wildlife Habitat Assessment	BLM, FWS, USGS
Resource Assessment	BLM
Monitoring Irrigation	BOR
Wetlands Monitoring	BLM
Land Cover	BIA, BLM, NPS, FWS, USGS

Table A-1. Applications of Landsat data by Federal agencies. Because agencies purchase data in response to changing and often unforeseen needs, it is impossible to accurately predict future demand.

Landsat 7 Data Purchases by Federal Agencies, FY 2003 - 2004

<u>Organization</u>	<u>FY 2003 Data Purchases</u>	<u>FY 2004 Data Purchases</u>
DoD	\$605,130	\$263,040
EPA	\$28,200	\$20,100
NASA	\$149,138	\$20,665
NOAA	\$3,040	\$3,600
USDA	\$81,175	\$23,720
DOI/BIA	\$13,300	\$1,200
DOI/BLM	\$2,520	\$800
DOI/BOR	\$3,200	\$0
DOI/FWS	\$20,910	\$10,925
DOI/NPS	\$32,260	\$34,110
DOI/OSM	\$600	\$0
DOI/USGS	\$281,010	\$31,645
Department of State	<u>\$6,050</u>	<u>\$0</u>
Total	\$1,226,533	\$409,805

Table A-2. Landsat 7 data sales by Federal agencies in FY 2003 and FY 2004 through April 2, 2004. These data sales figures represent the Federal sales subset of the sales data presented in table 3 on pages 4 and 5.

APPENDIX B

Excerpts from: Preliminary Assessment of the Value of Degraded Landsat 7 ETM+ Data Following Scan Line Corrector Malfunction

This report was compiled and summarized by NASA, USDA and USGS scientists and engineers based primarily on independent feedback from scientists who were former members of the Landsat 7 Science Team. These scientists represent Federal government agencies and many universities and institutions across the country.

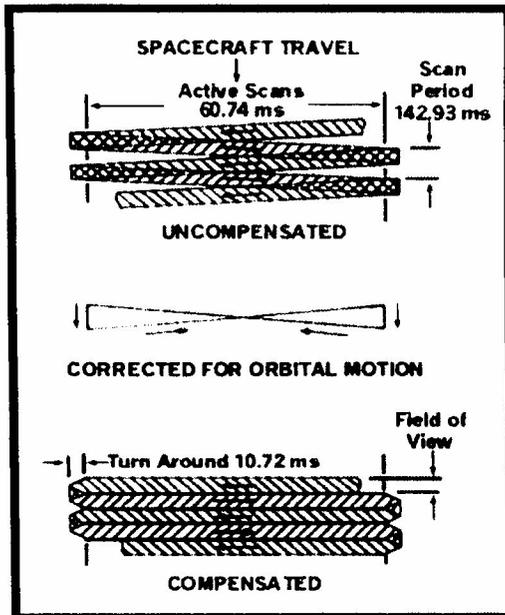


Figure 1: Illustrations of SLC functionality

On May 31, 2003, the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) sensor experienced a failure causing the SLC mechanism within the ETM+ to stop functioning normally. The non functioning Scan Line Corrector causes individual scan lines to alternately overlap and then leave large gaps at the edges of a normal Landsat image (See Figures 1 and 2).

While it is not possible to acquire 100 percent of the data in a normal scene with a non-functioning SLC, approximately 75 percent of the real estate in a normal scene is still captured. All indications are that these data still maintain the excellent radiometric and geometric fidelity that Landsat 7 has become known for. It is also possible, using basic interpolation algorithms, to "fill in" some of the missing pixels toward the center portion of a scene, such that the centermost ~ 60 km, or one-third of a normal 183-km wide scene, is complete. (See Figure 2)



Figure 2. **Top image:** Pre-SLC failure scene, middle of image.
Middle image: Scene after SLC failure.
Bottom image: Scene after SLC failure, with interpolations.

A diverse group of scientists with extensive experience using Landsat 7 data agreed to conduct a "quick turnaround" evaluation of the scientific usability and validity of degraded Landsat 7 products containing the SLC failure. Several former members of the Landsat 7 Science Team participated in this exercise, as did scientists and engineers from the USGS, NASA, and USDA. The goal was to get independent feedback from a variety of users with respect to their assessment of the usability of the degraded data; these people were not funded to conduct these assessments. The disciplines represented by these scientists include Geography, Agriculture, Forestry, Rangeland Ecosystems, Glaciology and Ice Cap Monitoring, Ecological Remote Sensing, Phenological Characterization, Tropical Forest Monitoring, Coastal/Oceanographic Remote Sensing and Coral Reef Monitoring, Water Quality Monitoring, Remote Sensing Methodology and Techniques Development, and Global Change Monitoring.

After considering all of the feedback, it is a fair to say that the majority of the scientists concluded that the degraded data were still quite useful for their particular application(s).

[NOTE: This statement is further corroborated by the recent "open letter to the Secretary of the Interior" by James A. Plasker, Executive Director of the American Society of Photogrammetry and Remote Sensing, as printed in the August 18, 2003, issue of Space News.] Some representative quotes from the scientists follow; complete copies of this feedback can be made available upon request.

- Our "foreign crop analysts were emphatic that the imagery was still of use and very much needed." "In summary, U.S. Department of Agricultural/Foreign Agricultural Service strongly requests that the LTAP (i.e., the global data acquisition strategy) be restored on Landsat 7 as soon as possible." **[Dr. Brad Doorn, USDA/Foreign Agricultural Service]**
- "The utility of ETM+ with its SLC problem is still extremely high for measurement of deforestation and its associated land cover changes. In tests comparing operational data with data containing SLC artifacts, we recover 90 percent of the deforestation." **[Dr. David Skole, Michigan State U.]**
- "For regional/whole earth applications. I would say that the imagery is the same as it has always been, namely outstanding." For intensive studies such as mapping at the local area level "the scan mirror problem is essentially fatal." **[Dr. John Price, Landsat 7 Investigator, USDA retiree]**
- "I can say with extreme confidence that the radiometric quality of the data with the SLC problem is at the same level as prior to the malfunction. ... ETM+ will still be extremely useful in the cross-calibration of sensors; it is the best radiometric sensor in orbit at this time, bar none." Clearly, "... it's worth keeping ETM+ running in the unfortunate case that the SLC cannot be brought back on line." **[Dr. Kurt Thome, U. of Arizona]**
- "Individual live coral reef structures in a coral reef environment are generally on the order of two to three pixels in size. Because of this, an inoperable SLC renders it impossible to conduct high-resolution, local-scale research." **[Response from a team of coral reef experts at the Institute for Marine Remote Sensing, College of Marine Science at the University of South Florida]**
- "Landsat data is still the only high quality high-resolution data available and as such is essential to Environmental Science and Engineering and its many endeavors." "For large area mapping applications it is going to be necessary to start compositing data -- which is

something new for the high-resolution community, but not for the remote sensing community in general. I think with some careful work and thought you could produce some nice composites that it will be hard to tell from the real thing.” “One of the main uses of Landsat data is for land cover and land use change... (as) it takes high-resolution data to track human changes in landscapes. Landsat data has been and will continue to be the workhorse in this domain. From that perspective, having a sensor with problems like Landsat 7 is much better than no sensor at all.” **[Dr. Curtis Woodcock, Boston University]**

Thus, the utility of the degraded data appeared to improve as (a) the scale of their particular information extraction exercise became coarser (i.e., good to very good for regional and/or regional to continental assessments, as opposed to a detailed local assessment), and as (b) multiple data sets for a given area were composited or mosaicked to “fill in the gaps” resulting from an inoperable SLC. When the desired end product was a complete wall-to-wall, map-like assessment on a local level using a single degraded scene product, the data were not found to be useful; again, utility of the degraded data for detailed local assessments improved when some type of composite data set could be created using repetitive coverage over time to piece together complete coverage.

APPENDIX C

Excerpts from: Landsat 7 SLC-Off New Products Workshop (October 28-29, 2003)

EXECUTIVE SUMMARY

Failure of the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) scan line corrector (SLC) in May 2003 has reduced the mission's capability to meet the various demands of the Landsat-based science and applications communities. Specifically, the SLC failure results in approximately 25% of each Landsat scene not being imaged. This is manifest in the imagery products as a set of wedges of null data, which are the intermittent data gaps that result from the absence of the SLC mirror. The U.S. Geological Survey (USGS), the agency responsible for the Landsat 7 mission operations and data access, is evaluating the impact of this system degradation on Landsat data users and seeking ways to mitigate, as much as possible, the impact of this event and to optimize use of the remaining system capacity.

As a starting point, representatives from the former NASA Landsat 7 Science Team (Goward, Schott, Woodcock, Skole, Vogelmann) and selected other users (Doorn of USDA, Justice of UMD, Cohen of USDA FS) were asked to participate in a 1.5 day workshop to review possible steps that might be taken to best utilize the remaining capacity of the Landsat 7 mission. Initially the primary goals of the meeting were:

- 1) Compile a large list of "what if" products and concepts that would enhance the SLC-off data
- 2) Identify one new product idea that could be designed and implemented in the near term with available resources.

In response to the discussions during the meeting, the USGS changed Goal #2 to read:

- 2) (revised) Identify one new product for users who require radiometric/geometric fidelity and one new product for users wanting a good visual product, both of which could be designed and implemented in the near term with available resources.

The specific opinions that emerged from the discussions at this meeting included:

- There is no acceptable alternative to Landsat 7 data for purposes of global change detection; all other possible substitutes are target-oriented (not global mission surveys) or too low a resolution. Examples considered included:
 - ASTER
 - EO-1 ALI
 - SAC-C
 - IRS
 - SPOT
- Compositing real data with the SLC-off ETM+ imagery is the only valid approach to fill the gaps. There were no gap-filling interpolation methods identified that would provide an effective or acceptable correction.
 - Landsat 7-Landsat 7 compositing is the preferred approach (see Figure C-1);
 - Landsat 7-Landsat 5 is acceptable.
 - All other sensors except perhaps MODIS have too many differences or issues related to availability to be acceptable.
 - MODIS compositing is deemed as experimental at this point in time – not operational.
- Any significant alterations to the way the Landsat 7 satellite is flown would alter the data too much and are not acceptable.

Fundamentally, from a science perspective, the observation capacity of Landsat 7 has been halved. That is, it will take at least twice as many scene acquisitions with the SLC-off to provide the same geographic coverage. A previous assessment of the Landsat 7 long-term acquisition plan (LTAP) indicated that it has been predominately achieving a quarterly (seasonal) refresh of most regions of the earth. Landsat 7 is now anticipated to only achieve bi-yearly coverage. This suggests that acquisitions should focus on mid-growing season observations for most locations (with the exception of when this coincides with the primary cloudy season).



Figure C-1. Example of new "gap-filled" Landsat 7 product. The top scene was acquired June 8, 2003. In the bottom image the scan gaps were filled with data from a Landsat 7 scenes acquired on May 7, 2003.