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Architecture and Technology Program

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Offline Archive Media Trade Study

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Preface

This document contains the Offline Archive Media Trade Study prepared by SAIC for the USGS. The Trade Study presents the background, technical assessment, test results, and recommendations.

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Abstract

This document is a trade study comparing offline digital archive storage technologies. The document compares and assesses several technologies and recommends which could be deployed as the next generation standard for the USGS (United States Geological Survey) at EROS (Earth Resources Observation and Science). Archives must regularly migrate to the next generation of digital archive technology and the technology chosen must remain reliable until the next migration. Note that this is the FY06 revision of a study completed in FY01 (Fiscal Year 2001) and revised in FY03 and FY04.

Revision History

February, 2004

- Added revision history page
- Changed to allow for consideration of helical scan as long as certain performance criteria are met
- Added LTO2 as a current archive technology
- Added SAIT-1 and SuperDLT 600 as considered drives
- Replaced IBM 3590 with IBM 3592
- Removed LTO1 and SDLT 320 from the study
- All drives in the study are considered
- Increased the minimum specs for capacity and transfer rate
- Reworked cost scenarios, and reduced to three
- Removed transfer time scenarios
- Removed maintenance from cost scenarios
- Removed criteria showing multi-vendor availability as an advantage

September, 2006

- Overall refresh of study
- Revised description of drive classes (enterprise, backup)
- Added LTO3, TS1120, T10000, DLT-S4 as current technologies and removed drives they replaced
- Added LTO4, SAIT2 as future technologies
- Made vendor analyses formula more equitable, increasing weight of company age
- Added citation appendix

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1.0 Introduction

1.1 Purpose and Scope

Typically, the purpose of a trade study is to analyze different courses of action, and to provide the necessary information for the sponsor to reach a conclusion. In other cases, a trade study is used to re-validate an ongoing course of action.

This document provides an assessment of the options for the next generation of offline digital archive storage technology to be used for the Digital Archives of the USGS. The selected technology must be capable of safely retaining data until space, cost, and performance considerations drive the next migration. Data should be migrated before reliability degrades.

Nearly all of the USGS working archive holdings now reside on nearline robotic tape storage and are backed by an offline master copy. The nearline copy is referred to as the working copy. There continues to be a need for offline storage for infrequently used working copies, as well as master and offsite copies where the working copy is stored nearline.

Note that LTO3 is the current archive media of choice at EROS. There is no compelling reason for the USGS to change technologies at this time and given the advantages of inter-generation compatibility in an offline archive environment, there will be a continued interest in “staying the course” with LTO technology for the foreseeable future. This predisposition to use LTO technology does not negate the need to periodically revisit offline storage technologies in order to stay abreast of changes. As with all technologies, eventually LTO will no longer meet EROS requirements and this study (in future revisions) will have shown the way to the obvious emerging replacement.

1.2 Background

The USGS Center for Earth Resources Observation and Science (EROS), located in Sioux Falls, SD, currently archives offline datasets using several technologies. In 1992, the TMACS (TM/MSS Archive Conversion System) was deployed to transcribe Landsat archives from HDT (High Density Tape) to DCT (Digital Cassette Tape). Both HDT and DCT utilize large, expensive analog instrumentation drives which require frame synchronization, driving the cost of transcribing Landsat HDTs to DCTs to exceed $1,000,000. Note that DCT and HDT are not purely analog. Although the crucial IRIG (InteRange Instrumentation Group) data is stored in analog format, the image data is stored in digital format. Transcription from HDT and DCT to fully digital media (9940B) is underway, with a projected completion in 2007.

Locating, rehabilitating, and integrating HDT and DCT drives has been costly in terms of labor, parts, and vendor service costs. The ongoing maintenance costs for the HDT and DCT drives are excessive compared to drives such as SDLT and LTO since there is little industry experience and only a single vendor to support each model of drive. The HDT and DCT drives in existence today number in the dozens, with the count decreasing each year as other users transition to digital media. Three transcription systems were implemented in the past eight years, two of them transcribing HDT media to computer compatible DLT 7000. The latest transcription system (LACS) transcribes HDT or DCT data to disk files, which are copied to nearline and offline media.

Table 1-1 summarizes the offline archive tape technologies currently in use:

Tape Drive Technology	Capacity	Transfer rate	Type
HDT	3.4 GB	10.6 MB/sec	Analog
3480	200 MB	2.0 MB/sec	Digital
3490	900 MB	2.7 MB/sec	Digital
DLT 7000	32 GB	4.7 MB/sec	Digital
DCT (Ampex DCRsI)	45 GB	12.0 MB/sec	Analog
SuperDLT 220	98.8 GB	8.1 MB/sec	Digital
HP LTO Ultrium 2	197 GB	23.8 MB/sec	Digital
HP LTO Ultrium 3	378 GB	31.0 MB/sec	Digital

Table 1-1 Past and Current Archive Technologies Used at EROS

In 2003, the USGS migrated more than 50,000 3480 and 3490 tapes to nearline storage, and to 110 LTO2 tapes. This migration was performed over a period of 5.5 months, slowed by the handling of the large number of 3480/3490 tapes. This migration freed up enough library shelving to ensure that the library should never need to be expanded, and may in fact be reduced in size. Several other smaller migrations are continuing, with the intent to reduce the offline archive to as few tapes as possible.

The USGS has utilized SuperDLT 220 extensively for onsite backups. HDT, 3480/3490, and DCT have proven to be robust and high-performance for their time. As technology advances, as datasets grow, as media ages, and as USGS Digital Library space fills, the USGS will migrate data to newer, more physically compact, and higher performing storage technologies.

1.3 Data reliability

Since the foremost goal of an archive is data preservation, the primary criteria for the selection of the drive technology must be reliability. Several elements contribute to data reliability:

- The number of archival copies: The dependence on the master copy, and the level of risk rise when a working copy is not robust. Note that the master and working copies need not be on similar media, though generation and recovery of a working copy is simplified if the storage capacities are similar. USGS archives typically have both working and master copies, and an offsite copy is desirable. Note that a slightly less reliable drive technology can be used if there are a sufficient number of copies of the archive or if one copy utilizes an enterprise or archive drive technology.

- The storage location and environment: This is a constant for all of the technologies assessed since all media would be stored in a secure and climate-controlled environment.

- The composition of the media: Some media compositions last much longer than others, though all of the technologies in this study use similar long-lasting media compositions.

- Tape handling within the drive: This characteristic defines how a tape is handled by the drive, whether contact is made with the recording surface, how many serpentine passes are required to read or write an entire tape, and the complexity of the tape path.

- Error handling: Drives typically minimize data loss through CRC (Cyclic Redundancy Check) or other data recovery methods, and allow data to be read after skipping over an error. Though error detection upon write is required, additional attention to data recovery upon read is a higher priority since media degradation will lead to eventual read errors.

- Primary Market: This criterion describes the target market of a drive, and the characteristics of drives within that market.
    - A drive targeted to the backup market is designed for write many/read rarely and depends more on write error detection since the data is still available and can be easily rewritten. Backup drives are typically built for speed, capacity, and low cost.
    - A drive targeted to the Enterprise market is designed for write many/read many use in a robotic library or auto-stacker and equal emphasis is placed on detecting errors upon read and write. Enterprise drives are typically built for reliability and speed, with capacity a secondary factor. Cost is a not a major consideration.
    - A drive targeted to the archival market would be designed for write once/read many and more emphasis would be placed on detecting and correcting errors upon read – though there are currently no drives designed or marketed primarily for archive. Most vendors would argue that their products are archive devices, but if forced to choose their primary market no vendor would choose the very limited archive market over the lucrative backup market.

Primary Market	Reliability	Usage	Driving Design Factors
Backup	Moderate	Write many, read rarely	Low cost, high capacity, high speed
Enterprise	High	Write many, read many	Up to 100% duty cycle for drives and media used with robotics.
Archive	High	Write once, read many	Long term reliability

Table 1-2 Tape Drive Markets and Characteristics

The reliability of a long-term archive technology relates primarily to the long-term viability of the recorded media. Since it is wise to implement a technology early enough in its life cycle that drives can be kept viable through the lifetime of a given media (or replaced with newer backward-compatible models), a definitive leader in reliability is difficult to determine except in retrospect. This study bases the reliability assessment on past experience with the vendor and their products, on specifications, on the experiences of others, or experience gained from benchmarking.

Experience with 3480, 3490, 9840, 9940A and 9940B has shown Sun/StorageTek products to be very reliable, though the Sun/StorageTek D3 helical scan drive was problematic and was discontinued quickly. On two occasions, 9840 tapes that encountered unrecoverable errors were sent to StorageTek for recovery. One tape was recovered, but the other was unrecoverable due to cartridge contamination. The LP-DAAC has experienced problems with replacement 9940B drives coming from the Philippines plant. Sun is pre-testing the drives and investigating the issue.

1.4 Selection criteria

The criteria used in determining which technologies should be considered were:

1. The technology must be currently available and shipping in order to be considered in the final analysis. It also must be the latest drive in the line. Drives that are announced but not shipping are mentioned but not ranked in the final analysis.
2. The technology must hold at least 300 GB of data.

3. The technology must have a write transfer rate of at least 30 MB/sec.

4. The technology must use a media that can remain readable for at least 10 years in a controlled environment. The lifetime of 10 years was selected since it is the longest that a media technology would conceivably be used before space and transfer rate concerns would dictate a move to a new technology.

5. The technology must not be hampered by a poor reliability or performance history. Helical scan technologies such as 8mm, 4mm, DAT and D3 have proven unreliable in the past.

The currently available drive technologies selected for consideration are:

1. Sun (StorageTek) T10000

2. HP LTO3 (Linear Tape Open)

3. Quantum DLT-S4

4. IBM (International Business Machines) TS1120

5. Sony SAIT-1 (SAIT-2 was to ship in June 2006)

1.5 Dismissed technologies

The following technologies were dismissed from further analysis or consideration for the reasons listed.

1.5.1 CD-ROM, DLT 8000, QIC, Mammoth, and Erasable Optical (EO)

This category includes technologies that are low capacity, low performance, or aged. All of these products have been available for some time, but can immediately be dismissed based on obvious limitations in performance, capacity, or reliability. These products are clearly not a good fit for large digital archives.

1.5.2 Sun (STK) 9840C

The Sun 9840C is a fast access technology used almost exclusively in conjunction with Sun robotic libraries. Although it is an enterprise class drive, it has relatively low capacity, low transfer rate and high cost. The upside of this drive is the fast access, since it is a dual reel design which does not require a lengthy loading sequence and it is positioned at tape midpoint for faster access. While this technology is useful where fast nearline access is required, it offers minimal benefit in the offline archive media arena.

1.5.3 Exabyte VXA320 (and similar 4mm/8mm helical scan technologies)

Exabyte has evolved its early helical scan technology into the VXA320 with a native capacity of 160 GB and a native transfer rate of 24 MB/sec. This technology is based on consumer-grade cartridge and drive technologies. While media costs are low, transfer rates are low and the USGS experience with consumer-grade storage technologies has shown that they cannot withstand the rigors of a long-term archive.

Tape drives such as the 8mm/Exabyte which became popular in the 1990's were based on consumer-grade helical scan technology and were notably slow and unreliable. Long start/stop times dictated that if data was not kept streaming, then the effective transfer rate dropped exponentially. The necessarily complex drive path led to problems with 8mm drives "eating tapes", and a confusing array of firmware versions often yielded unpredictable/quirky behavior and hangs. The STK foray into helical scan was also a failure. The transition

from a market once ruled by 4mm/8mm helical scan drives to one ruled by LTO/DLT was an overnight stampede, and the small current market share of helical scan technologies may indicate that the marketplace still holds a grudge over the pains of earlier helical scan drives. The market may never reconsider whether the earlier problems are overcome, unless new terminology replaces “helical scan”.

1.5.4 DVD, HD-DVD, Blu-Ray

DVD (Digital Video Disc) and related technologies seem promising from the standpoint of longevity of the media although studies have shown that optical media can degrade and become unusable in as little as five years. Low capacity per media, low transfer rates, lack of media protection (no shell), no single standard, and high media costs add up to a product that simply would not work for high volume archival use.

1.5.5 Newer optical technologies

Several high capacity optical disk technologies have been in the development phase for the past few years. Of the 100+ GB technology proposals that have appeared in trade journals and at conferences, to date none are shipping products.

Another high-tech example of future technologies is holographic storage. Products have been announced perpetually, but have yet to ship. The specifications currently indicate a capacity around 300GB per disc, and a transfer rate of 20MB/sec. Like other optical products, the cost model will likely be prohibitive compared to tape, and vendors seem to be developing their own formats on top of a common base product, which will reduce the likelihood of a industry standard format.

2.0 Technical Assessment

2.1 Analysis

This technical assessment includes drives selected for final evaluation (T10000, LTO3, DLT-S4, TS1120, SAIT-1), as well as drives anticipated to be released in the near future (LTO4, SAIT-2). Note that LTO drives are available from multiple vendors (Tandberg, Quantum, IBM, HP), though HP was selected to represent LTO technology as they are the apparent market leader. The following tape technologies will be assessed, though only the bolded drives will be included in the final evaluation:

- **Sun (StorageTek) T10000**
- **HP LTO3**
- HP LTO4
- **Quantum DLT-S4**
- **IBM TS1120**
- **Sony SAIT-1**
- Sony SAIT-2

Specification	T10000	HP LTO3	HP LTO4	DLT-S4	TS1120	SAIT-1	SAIT-2
Native capacity	500GB	400GB	800GB	800GB	500GB	500GB	800GB
Native transfer rate	120MB/sec	80MB/sec	120MB/sec	60MB/sec	104MB/sec	30MB/sec	45MB/sec
Recording technology	Serpentine	Serpentine	Serpentine	Serpentine	Serpentine	Helical scan	Helical scan
Tracks	768	704	1024	1280	896	NA	NA
Channels	32	16	16	16	16	NA	NA
Passes	24	44	64	80	56	1	1
Type	Enterprise	Mid-range	Mid-range	Mid-range	Enterprise	Mid-range	Mid-range
Hardware encryption?	HW option	No	HW option	Software	No	No	No
Adaptive speed?	2 speeds	Continuous	Continuous	No	5 speeds	Unlikely	Unlikely
Price	$25k	$1.8k	$4k est	$3.8k	$32k list	$5k	$14k list
Shelves compatible?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Prev generations read	NA	2	2	2	1	NA	TBD
Prev generations written	NA	1	1	0	1	NA	TBD
Bit Error Rate (BER)	$1x10^{-19}$	$1x10^{-17}$	TBD	$1x10^{-17}$	TBD	$1x10^{-17}$	TBD
Drive manufacturers	1	4	TBD	1	1	1	1

Table 2-1 Technology comparison

(yellow hilited text indicates unverified information)

Sun (StorageTek) T10000:

In 2005, Sun bought STK (StorageTek) and is evolving it into the data storage division within Sun. The T10000 is the first new tape technology release under the Sun moniker, though it was developed by STK. It replaces the 9940B as the flagship high-capacity enterprise drive typically used in conjunction with Sun/STK robotic libraries, such as the new Sun/STK SL8500. EROS has two T10000 drives on order for use in the new SL8500.

Advantages:

- The T10000 is an evolution of the 9940 which the USGS has found to be to be extremely reliable.
- Native capacity is 500GB and native transfer rate is 120MB/sec. It can also stream at 50MB/sec which is important since some disks may not be able to keep up at 120MB/sec.
- The T10000 utilizes 32 channels per pass (vs 8 or 16 on competing drives) which reduces serpentine passes. With 768 tracks, only 24 passes are required to read or write the entire tape.
- The T10000 is targeted to the Enterprise Storage market where data viability, speed, and capacity are more important than cost.
- The T10000 was designed as a robust storage media, with the tape cartridge and drive built to withstand constant and/or frequent use in a robotic environment. The drives are compatible with the USGS StorageTek silos and excel in a robotic environment due to their durability.
- T10000 drives provide drive statistics for servo errors, bytes read/written, I/O retries, and permanent errors.
- T10000 media is available from Fujifilm and Imation.
- Sun indicates that the follow-on drive will utilize the same media, allowing media reuse.
- The T10000 has a 256MB buffer which prevents occasional data starvation from reducing the transfer rate.
- The Bit-error-rate (BER) is very good at $1x10^{-19}$
- A hardware encryption option module will become available in 2006.

Disadvantages:

- While the T10000 is an evolution of the 9940, the media is incompatible – therefore the media cannot be reused or read by the T10000.
- The drives are relatively expensive, 5-13 times the price of the SDLT, SAIT or LTO.
- Based on sales of past STK drives such as the 9840 and 9940, it is anticipated that sales of the T10000 will be primarily for use in Sun/STK robotics. For this reason, it is anticipated that market share will remain very low.
- The T10000 drive is only available from Sun. This keeps the price high, but does eliminate any concern of incompatibility.

Summary:

The T10000 is a high capacity, high transfer rate enterprise class drive for use in robotic libraries. The cost of media and drives far exceeds the cost of most competing products, though media reuse for future generations would effectively reduce media costs. The robust technology would be a prime choice if only one copy of a dataset could be kept. When two or more copies of a dataset exist, and one is already on an enterprise technology, use of an enterprise solution for the second copy is not warranted. Sun has stated that the second generation of the T10000 will have a capacity of 1TB and a transfer rate of 240MB/sec. This drive will use the same media and should ship in 2008.

HP LTO3:

The LTO3 is the latest generation of the LTO tape family. EROS has adopted the LTO product family for offline archive use. LTO1 was not used extensively at EROS, though LTO2 and LTO3 have been. The LTO family is a mid-range technology targeted for the backup industry. This analysis is based on the highest performing drives from HP.

Advantages:

- LTO has enjoyed phenomenal growth from the day of release, and as of 2005 held a 77% market share, with over 1,000,000 drives installed worldwide.
- Native capacity is 400GB and native transfer rate is 80MB/sec. The HP LTO3 drive has the capability to adapt the transfer rate between 27 and 80MB/sec.
- The LTO3 is backward read compatible with LTO1 and LTO2, and backward write compatible with LTO2. All future drives are slated to be able to read two previous generation of tape and write one previous generation of tape.
- LTO was developed by a consortium of HP, IBM, and Quantum (acquired from Seagate Certance) and is licensed to others, including media manufacturers. This wide acceptance has introduced competition which has in turn controlled costs.

Disadvantages:

- LTO is targeted to the backup market where speed, capacity, and cost are more important than long-term viability of the data. Since backup tapes are write-many/read-rarely, errors would likely show up in a write pass where they can be worked around (rewrites) or the media discarded.
- EROS has experienced write errors with the HP LTO3 drives where the drive encounters EOT when it shouldn't. Drives can usually be cleared of this problem by running the HP diagnostics.
- Repeated end-to-end use of a tape would be a concern since one end-to-end read/write would incur 44 passes (704 tracks divided by 16 channels).
- When STK adopted LTO technology for support by their Powderhorn robotic library, the robotic hand pressure was reduced in order to prevent crushing the LTO shell. With the decreased hand pressure, the speed of the robotic arm was reduced to prevent the arm from throwing tapes. This reduced the tape exchange rate of the Powderhorn.
- Each generation of LTO requires new media, ensuring that media costs will be significantly higher until market saturation drives the price down.
- LTO was designed as a moderate usage storage media, with the tape cartridge and drive not built to withstand constant use.
- LTO was co-developed by IBM, HP, and Quantum (acquired from Seagate/Certance). This type of deployment makes it possible for each vendor to interpret the specifications differently, and to design drives which may have incompatibilities, though compatibility tests are performed. EROS observed two LTO1 incompatibility problems between HP and IBM: tapes written to EOT on the IBM cannot be read on the HP, and tapes written on the HP read at less than half speed on the IBM. EROS resolved this issue by only deploying HP drives for production use.

Summary:

LTO has had such wide market acceptance that nearly every competitor has added LTO drives to their product line (Quantum, Sun/STK, Exabyte). LTO3 is the current offline media-of-choice at EROS. At this point the LTO line has performed well enough at EROS and for the IT industry in general that EROS has no interest in switching technologies other than continuing to move to the next generation of LTO as appropriate.

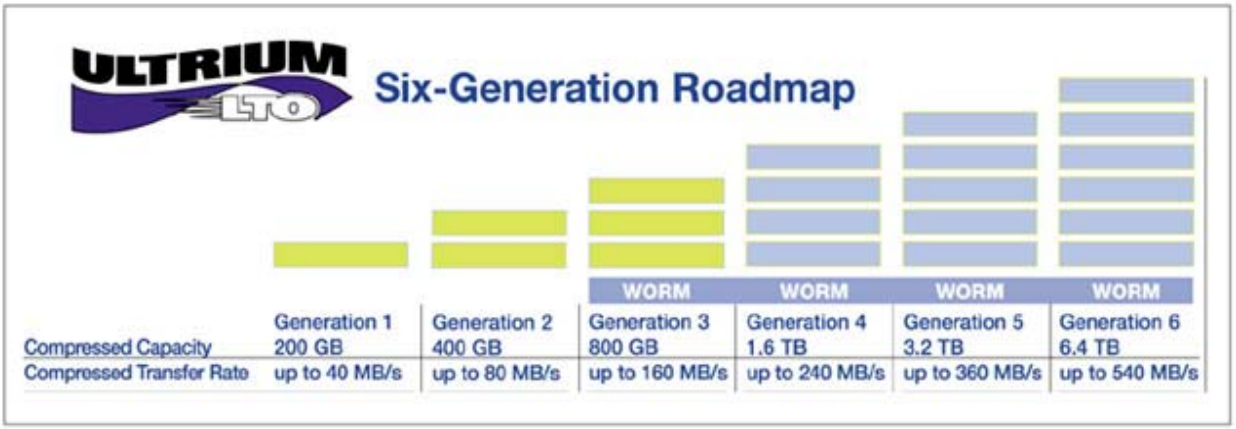

Figure 2-2 LTO Roadmap (with 2:1 compression)

HP LTO4:

The LTO4 is the next generation of the LTO tape family, slated for release in January/February, 2007.

Advantages:

- LTO has enjoyed phenomenal growth from the day of release, and as of 2005 held a 77% market share, with over 1,000,000 drives installed worldwide.
- Native capacity is stated to be 800GB and native transfer rate is 120MB/sec. The HP LTO4 drive will likely have the capability to adapt the transfer rate to match the streaming speed of the source.
- The LTO4 should be backward read compatible with LTO2 and LTO3, and backward write compatible with LTO3.
- LTO was developed by a consortium of HP, IBM, and Quantum (acquired from Seagate Certance) and is licensed to others, including media manufacturers. This wide acceptance has introduced competition which has in turn controlled costs.
- A hardware encryption option will become available in 2007.

Disadvantages:

- LTO is targeted to the backup market where speed, capacity, and cost are more important than long-term viability of the data. Since backup tapes are write-many/read-rarely, errors would likely show up in a write pass where they can be worked around (rewrites) or the media discarded.
- Repeated end-to-end use of a tape would be a concern since one end-to-end read/write is expected to incur 64 passes (1024 tracks divided by 16 channels).
- When STK adopted LTO technology for support by their Powderhorn robotic library, the robotic hand pressure was reduced in order to prevent crushing the LTO shell. With the decreased hand pressure, the speed of the robotic arm was reduced to prevent the arm from throwing tapes. This reduced the tape exchange rate of the Powderhorn.
- Each generation of LTO requires new media, ensuring that media costs will be significantly higher until market saturation drives the price down.
- LTO was designed as a moderate usage storage media, with the tape cartridge and drive not built to withstand constant use.
- LTO was co-developed by IBM, HP, and Quantum (acquired from Seagate/Certance). This type of deployment makes it possible for each vendor to interpret the specifications differently, and to design drives which may have incompatibilities, though compatibility tests are performed. EROS observed two LTO1 incompatibility problems between HP and IBM: tapes written to EOT on the IBM cannot be read on the HP, and tapes written on the HP read at less than half speed on the IBM. EROS resolved this issue by only deploying HP drives for production use.

Summary:

It is anticipated that the official LTO4 announcement is imminent. In an April, 2006 announcement regarding encryption it was stated that LTO4 will ship in 2006. EROS anticipates evolving to LTO4 for new datasets. Given that LTO4 does not yet exist as a product, it cannot be one of the technologies assessed in the final evaluation.

Quantum DLT-S4:

Several years ago, SDLT overcame 4/8mm helical scan as the technology of choice for backups. Over the past three years, LTO has overtaken SDLT although SDLT is not gone yet. Although Quantum recently bought out Certance in order to buy into the LTO marketplace, Quantum continues to evolve SDLT as a strong technical competitor to LTO though the marketplace has already spoken regarding which technology they prefer.

Advantages:

- Native capacity is stated to be 800GB and native transfer rate is 60MB/sec.
- The DLTSage software suite provides a number of data integrity features primarily related to backups.
- The DLT-S4 is backward read compatible with SDLT 320 and SDLT 600.

Disadvantages:

- DLT-S4 uses different media than previous generations, ensuring that media costs will be significantly higher until market saturation drives the price down.
- DLT-S4 is targeted to the backup market where speed, capacity, and cost are more important than long-term viability of the data. Since backup tapes are write-many/read-rarely, errors would likely show up in a write pass where they can be worked around (rewrites) or the media discarded.
- Repeated end-to-end use of a tape would be a concern since one end-to-end read/write would incur 80 passes (1280 tracks divided by 16 channels).
- DLT-S4 was designed as a moderate usage storage media, with the tape cartridge and drive not built to withstand constant use.
- The DLT-S4 is not write compatible with any previous generations.
- The DLTSage software suite includes software data encryption, which is typically CPU intensive when encrypting or decrypting data at high speed. If CPU resources are insufficient, drive streaming may not be possible.

Summary:

The DLT-S4 has a temporary advantage in capacity and transfer rate over the LTO, but since the IT industry has heard that the LTO4 will outperform the DLT-S4 it may be willing to wait a few months for LTO4 rather than buying into DLT-S4. Based on past history and the product roadmap below, the DLT-S5 will be capable of about 1.6TB (uncompressed) at about 120 MB/sec (uncompressed) and be available by the second half of 2008, which will likely be trumped by the LTO5 shortly thereafter. Quantum SDLT is a product similar to LTO with a few advantages and disadvantages, though the market heavily favors LTO. Unless Quantum evolves SDLT to compete in a different market segment not already dominated by LTO, it is difficult to believe that Quantum will continue to develop it.

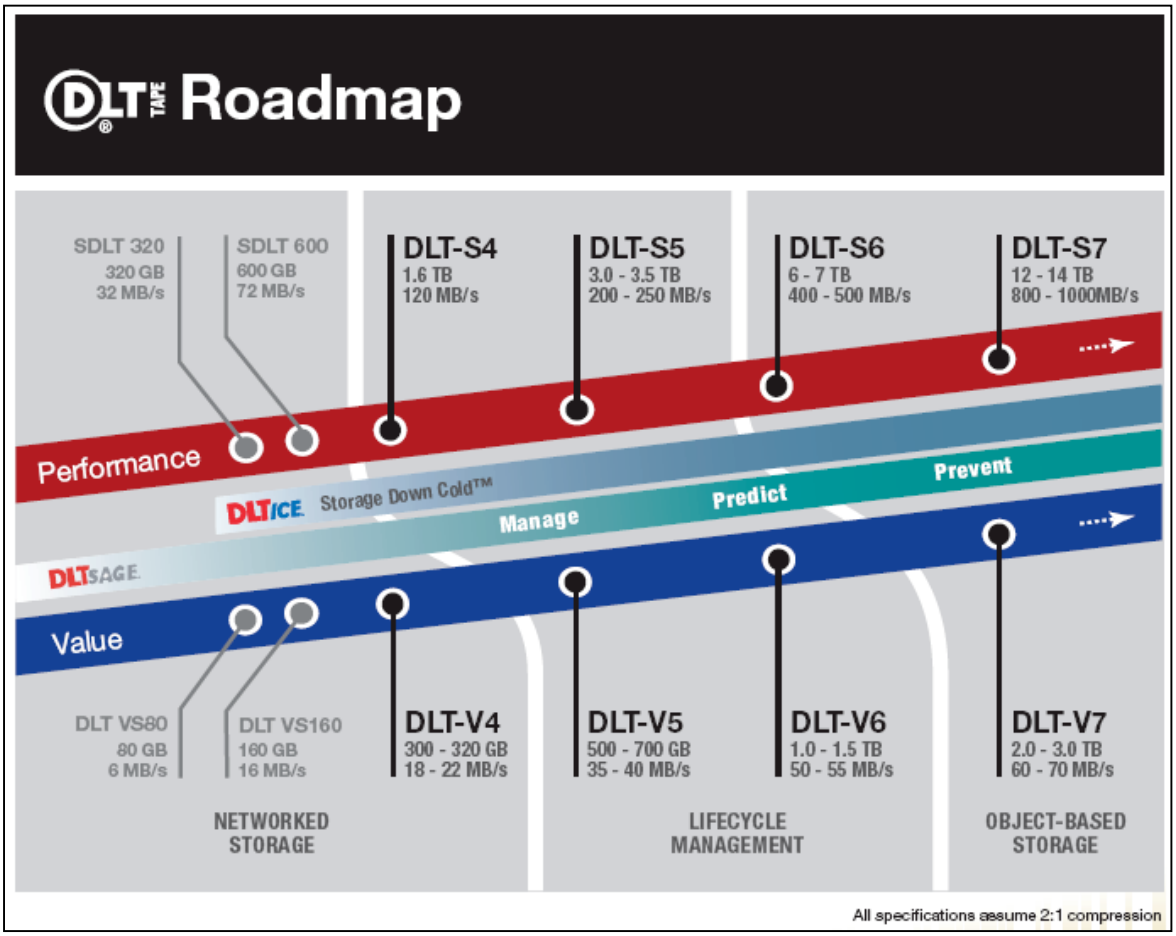

Figure 2-3 DLT Roadmap (with 2:1 compression)

IBM TS1120:

The TS1120 is an enterprise–class tape drive, used primarily in robotic libraries and autoloaders. It is a follow-on drive to the 3592.

Advantages:

- Based on the very reliable 3480, 3490, 3590, and 3592.
- 4Gbit/sec Fiber Channel interface.
- Native capacity is stated to be 500GB and native transfer rate is 104MB/sec.
- The TS1120 was designed as a robust storage media, with the tape cartridge and drive built to withstand constant and/or frequent use in a robotic environment. When used with a custom IBM rack, the drives are compatible with the Sun/STK Powderhorn library and would excel in a robotic environment due to their durability. Compatibility with the Sun/STL SL8500 library has not been announced.
- The TS1120 uses the same media as the 3592.
- A hardware encryption option module will become available in 2006.

Disadvantages:

- The TS1120 is not currently compatible with newer Sun robotic libraries such as the SL8500.

Summary:

The TS1120 does not compare favorably in cost to LTO, and the robustness does not warrant the additional cost when the working copy of a dataset is already on enterprise-class technology in the EROS Silo. IBM recently announced a prototype tape technology which would be capable of storing 8TB per cartridge and is planned to be available by 2011. IBM is expected to ship a 1TB TS1120 drive in 2007.

Sony SAIT-1:

The Sony SAIT is a helical-scan (rather than linear-serpentine) technology. SAIT is loosely based on their AIT technology, which is an 8mm dual-reel cartridge. The SAIT cartridge is similar in size and design to the other cartridges in the study (LTO, SDLT, etc).

Advantages:

- Native capacity is stated to be 500GB.
- Single pass (vs. serpentine) reduces linear tape movement, though wear may actually be higher due to helical scan design.

Disadvantages:

- Helical scan technologies have proven unreliable in the past due to complex drive path, high and constant head contact, poor transfer rates, and extremely poor start/stop/repositioning times. Ancestor 8mm technology was prone to destroying tapes due to mis-queues in controlling the complex tape path. Time will tell whether this heritage has been overcome.
- The stated native transfer rate of 30MB/sec is low compared to the others, but still usable.

Summary:

It is unclear whether major robotic manufacturers will adapt robots to accept SAIT. Their ability to adapt depends on cartridge dimensions, cartridge rigidity, and barcode label size/location. Vendors such as Sun may not be willing to support this drive, though they do sell and support SDLT and LTO technology in their current line of robots.

Though the SAIT-1 has an excellent capacity and decent transfer rate, the market may still be holding a grudge for the pains associated with the ancestor 8mm helical scan technology. Market share against such formidable market predecessors has been only about 5%, partially due to limited marketing. If Sony is making an attempt to directly market SAIT, it is not apparent. They may be depending on partners to market SAIT as integrated with robotic libraries and backup software.

Sony is projecting three more generations of SAIT, with SAIT-4 having a native capacity of 4 TB. No timelines or transfer rate projections are given. Though SAIT-2 was expected in June, 2006 it has not yet shipped.

Sony SAIT-2:

The SAIT-2 is the second generation of SAIT, which was expected to be released in June, 2006.

Advantages:

- Is expected to tie DLT-S4 and LTO4 for highest native capacity at 800GB and will have a respectable native transfer rate of 45MB/sec.
- Single pass (vs. serpentine) reduces linear tape movement, though wear may actually be higher due to helical scan design.

Disadvantages:

- Helical scan technologies have proven unreliable in the past due to complex drive path, high and constant head contact, poor transfer rates, and extremely poor start/stop/repositioning times. Ancestor 8mm technology was prone to destroying tapes due to mis-queues in controlling the complex tape path. Time will tell whether this heritage has been overcome.

Summary:

Though the SAIT-2 ups the ante with an excellent capacity and decent transfer rate, marketing would need to be stepped up in order to make any headway in a marketplace which may still hold a grudge against anything labeled “helical scan”. Though announced several times, SAIT-2 was not released in June as last announced.

3.0 Tables

3.1 Design criteria

The design criteria and target market of a drive are interrelated. Drive technologies such as LTO, SAIT and SDLT are targeted to the backup market, as demonstrated by their marketing. The T10000 and TS1120 are targeted to the Enterprise (data center) market.

A drive targeted to the backup market is designed for write many/read rarely and depends more on write error detection since the data is still available and can be easily rewritten. Backup drives are typically built for speed, capacity, and low cost.

A drive targeted to the Enterprise market is designed for write many/read many use in a robotic library or auto-stacker and equal emphasis is placed on detecting errors upon read and write. Enterprise drives are typically built for reliability and speed, with capacity a secondary factor. Cost is a not a major consideration to enterprise users willing to pay for quality.

A drive targeted to the archival market would be designed for write once/read many and more emphasis would be placed on detecting and correcting errors upon read – though there are currently no drives designed or marketed primarily for archive use.

The formula used to rank Design Criteria was:

((100-passes)/10)+
(error factor/2)+
(construction 3=moderate usage, 5=high usage)+
(head contact 3=yes, 5=minimum)
/ 2.71 (to adjust the highest rank to 10)

Technology	Serpentine tracks/ Passes	Target Market	Tape Composition	Uncorrected Error Rate	Cartridge Construction Rating	Head Contact	Ranking
Sun T10000	768/24	Enterprise	Advanced MP	$1x10^{19}$	High usage	Min contact	10.0
HP LTO3	704/44	Backup	Metal Particle	$1x10^{17}$	Moderate usage	Contact	7.4
HP LTO4	1024/64	Backup	Thin film MP	$1x10^{17}$	Moderate usage	Contact	6.7
DLT-S4	1280/80	Backup	Advanced MP	$1x10^{17}$	Moderate usage	Contact	6.1
IBM TS1120	896/56	Enterprise	Advanced MP	$1x10^{17}$	High usage	Contact	7.7
Sony SAIT-1	80*	Backup	Advanced ME	$1x10^{17}$	Moderate usage	Contact	6.1
Sony SAIT-2	80*	Backup	Advanced ME	$1x10^{17}$	Moderate usage	Contact	6.1

Table 3-1 Design Criteria and Target Market

*Prior experience with helical scan dictates caution. Helical scan cannot be rated for serpentine passes, but the equivalent is the helical passes per inch which are believed to be high (but unknown). For this reason SAIT was assigned the same number of passes as the DLT-S4.

Uncorrected Error Rates for some newer drives may not be available, but are presumed to be at least the same as their predecessors since it would be showcased if improved.

(yellow hilited text indicates unverified information)

3.2 Transfer Rate

Transfer rate is important since it dictates how quickly the migration of an archive data set may be completed, and how fast a production system may generate products from the archive media. Although 30 MB/sec is the minimum, it is desired to attain 50 MB/sec. Since much of the data archived at the USGS is not compressible, all transfer rates are native (uncompressed).

Where measured transfer rates were not available, estimated rates are determined based on the accuracy of specified transfer rates of previous generations. Note that the source of the test results also applies to capacities in table 3-3.

The ranking was determined by adding the actual/estimated read and write rates for each drive, setting the ranking for the fastest drive to 10, then ranking the others against the leader. As an example, a drive having half of the total read/write transfer rate of the leader would be ranked 5.

Tape Drive Technology	Advertised Native Rate	Source Of Test Results	Actual/estimated Native Write Transfer Rate	% Of Adv.	Actual/estimated Native Read Transfer Rate	% Of Adv.	Ranking
Sun T10000	120 MB/sec	CERN	120.00 MB/sec	100%	120.00 MB/sec	100%	10.0
HP LTO3	80 MB/sec	CERN	73.00 MB/sec	91.2%	73.00 MB/sec	91.2%	6.1
HP LTO4	120 MB/sec	Estimated	115.62 MB/sec	92.5%	116.40 MB/sec	97.0%	9.7
DLT-S4	60 MB/sec	Estimated	55.44 MB/sec	92.4%	60.00 MB/sec	100%	4.8
IBM TS1120	100 MB/sec	Vendor	100.00 MB/sec	100%	100.00 MB/sec	100%	8.3
Sony SAIT-1	30 MB/sec	Vendor	31.03 MB/sec	103%	31.00 MB/sec	103%	2.6
Sony SAIT-2	45 MB/sec	Estimated	46.35 MB/sec	103%	46.35 MB/sec	103%	3.9

Table 3-2 Transfer Rates
(yellow hilited text indicates unverified information)

3.3 Capacity

A secondary requirement is to conserve archive rack space and reduce tape handling by increasing per media capacity. The current archive media of choice at the USGS is LTO3 at 386 GB of usable capacity per tape. The new minimum capacity requirement is 300 GB, with 500 GB or more desired. All of the reviewed technologies meet the 300 GB requirement. Since much of the data archived is not compressible, all capacities are native (uncompressed). Where measured capacities were not available, estimated capacities are determined based on the accuracy of specified capacities of previous generations.

The capacities below presume that a Gigabyte = 1,073,741,824 bytes. The CERN tests refer to a KB as having 1,024 bytes but they call a Gigabyte 1,000,000,000 bytes. In the table below, CERN capacities have been converted to the more standard 1,073,741,824 byte Gigabyte.

The ratings were determined by calculating each as the percentage of the highest capacity drive, on a scale of 1 to 10, with the highest capacity as a 10. The source of the capacity ratings are as noted in table 3-2 above.

Tape Drive Technology	Advertised Native Capacity	Measured/Estimated Native Capacity	% Of Advertised Capacity	Ranking
Sun T10000	500 GB	465.70 GB	93.1%	6.1
HP LTO3	400 GB	379.00 GB	94.7%	5.0
HP LTO4	800 GB	788.00 GB estimated	98.5%	10.0
Quantum DLT-S4	800 GB	764.80 GB estimated	95.6% estimated	10.0
IBM TS1120	500 GB	475.00 GB estimated	95.0% estimated	6.2
Sony SAIT-1	500 GB	475.00 GB estimated	95.0% estimated	6.2
Sony SAIT-2	800 GB	760.00 GB estimated	95.0% estimated	9.9

Table 3-3 Storage Capacities

* Note that while the LTO4 is estimated to have the highest usable capacity it is not under consideration since it is not yet shipping. Therefore, the rankings are calculated against DLT-S4 as the leader in capacity.

(yellow hilited text indicates unverified information)

3.4 Cost Analysis

Table 3-4 shows the relative drive and media costs, maintenance costs, and the cost per Terabyte for media. Rankings were established by setting the cheapest (drive, maintenance, media) to 10 then rating each of the others against the lowest cost. Maintenance is based on actual annual costs after the end of warranty. Media costs per terabyte are based on advertised capacity. Costs do not include system interfaces or cables.

Technology	Drive $/each	5 yr Maint	Drive Warranty	Media $/each	Media $/TB	Ranking Drive Cost	Ranking Maint Cost/5yr	Ranking Media Cost/TB
Sun T10000 *	$25,000	$6,820	12 mo	$156	$312	0.7	0.4	3.5
HP LTO3	$1,800	$277	36 mo	$63	$157	10.0	9.8	7.0
HP LTO4 *	$4,000 est	$277	36 mo	$100	$125	4.5	9.8	8.8
Quantum DLT-S4	$3,500	$271	36 mo	$88	$110	5.1	10.0	10.0
IBM TS1120	$32,000	$8,736	12 mo	$120	$240	0.6	0.3	4.6
SONY SAIT-1	$5,000	$310	36 mo	$127	$254	3.6	8.7	4.3
SONY SAIT-2 *	$14,000 est	$310	36 mo	$292	$365	1.3	8.7	3.0

Table 3-4 Drive, Maintenance and Media Costs
***T10000, LTO4 and SAIT-2 costs should drop quickly**
(yellow hilited text indicates unverified information)

3.5 Scenarios

Table 3-5 shows the total drive and media cost for three scenarios. These scenarios presume that each dataset or project stands on their own, but pooling resources for multiple datasets can mitigate cost. Note that prices are expected to drop considerably within six months after product introduction. Rankings were established by setting the cheapest to 10 then rating each of the others against the lowest cost. Costs do not include system interfaces or cables.

Technology	100 TB 2 drives	200 TB 4 drives	400 TB 6 drives	100 TB Ranking
Sun T10000	$81,200	$162,400	$274,800	2.2
HP LTO3	$19,300	$38,600	$73,600	9.3
HP LTO4	$20,500	$41,000	$74,000	8.8
Quantum DLT-S4	$18,000	$36,000	$65,000	10.0
IBM TS1120	$88,000	$176,000	$288,800	2.0
SONY SAIT-1	$35,200	$70,400	$130,800	5.1
SONY SAIT-2	$64,500	$129,000	$230,000	2.8

Table 3-5 Scenario Costs (drives, media)

3.6 Vendor analyses

Table 3-6 is intended to provide an analysis of each company and the stability of each technology. All seem to be established and stable companies, and this rating should in no way be viewed as a market analysis. When selecting an archive technology, it makes sense to look at the company and product histories. For SDLT and T10000, the technologies were based on predecessors (DLT and 9940), therefore the technology age included those predecessors. The longevity rankings were determined by the following formula:

((company age) +
(technology age))
/ 10.6 (to adjust the highest rank to 10)

Company	Technology	Years in business	Technology age in years	Longevity Ranking
Sun/STK	T10000	37 (1969)	6 (2000)	4.0
HP	LTO	67 (1939)	6 (2000)	6.9
Quantum	SDLT (DLT)	26 (1980)	17 (1989)	4.1
IBM	3592 (3590)	95 (1911)	11 (1995)	10.0
Sony	SAIT (AIT)	60 (1946)	10 (1996)	6.6

Table 3-6 Vendor Analyses

3.7 Drive compatibility

Table 3-7 shows the level of inter-generation drive compatibility as well as the future drives planned. The column "% Previous Generations Read" and "% Previous Generations Written" indicate the percentage of previous generations which are read/written by the generation indicated. Drives that are the first of their generation receive a score of 50%, since it would be unfair to penalize them for being the first generation. The column "Future Generations Planned" indicates the number of generations planned in the current drive family, following the drive indicated. The ranking was determined by the following formula:

((% Previous Generations Read + % Previous Generations Written) + (Future Generations Planned x 20))
/ 22 (to adjust the highest rank to 10)

Technology	% Previous Generations Read	% Previous Generations Written	Future Generations Planned	Ranking
Sun T10000	50	50	1	5.5
HP LTO3	100	50	3	9.5
HP LTO4	100	33	2	7.9
Quantum DLT-S4	66	0	3	5.7
IBM TS1120	100	100	1	10.0
Sony SAIT-1	50	50	3	7.3
Sony SAIT-2	100	0	2	6.4

Table 3-7 Drive Compatibility
(yellow hilited text indicates unverified information)

3.8 Ranking summary

The ranking summary provides a quick reference to the rankings.

Drive	Design Criteria	Capacity	Media Cost	Drive Compat.	Transfer Rate	Drive Cost	5yr Maint Cost	Vendor Analyses	Scenario Cost
Sun T10000	10.0	6.1	3.5	5.5	10.0	0.7	0.4	4.0	2.2
HP LTO3	7.4	5.0	7.0	9.5	6.1	10.0	9.8	6.9	9.3
HP LTO4	6.7	10.0	8.8	7.9	9.7	4.5	9.8	6.9	8.8
DLT-S4	6.1	10.0	10.0	5.7	4.8	5.1	10.0	4.1	10.0
IBM TS1120	7.7	6.2	4.6	10.0	8.3	0.6	0.3	10.0	2.0
Sony SAIT-1	6.1	6.2	4.3	7.3	2.6	3.6	8.7	6.6	5.1
Sony SAIT-2	6.1	9.9	3.0	6.4	3.9	1.3	8.7	6.6	2.8

Table 3-8 Ranking Summaries
(Blue indicates the highest ranking in category)

4.0 Conclusions and Recommendations for USGS Offline Archiving Requirements

4.1 Weighted Decision Matrix

The following table provides a weighted analysis of the drives considered. The criteria emphasize the importance of traits contributing to data preservation. The USGS made the final decision regarding which criteria to use and the relative weighting of the criteria. The columns in green are relative ratings for each technology. The columns in yellow are calculated by multiplying the relative weight by the relative rating. The following describe each criterion:

- Design Criteria (Reliability of media): This criterion describes the ability of the media to remain readable over time. Included in this criterion is the number of passes per full-tape read or write, cartridge construction, uncorrected bit error rate (BER) and amount of head contact. (See table 3-1)
- Capacity: This criterion describes the measured or estimated capacity per cartridge, which is typically less than the advertised capacity. (See table 3-3)
- Media cost/TB: This criterion is a rating of the relative cost per Terabyte for media using the advertised capacity. (See table 3-4)
- Compatibility: This criterion describes the likelihood that the drive technology will continue to evolve and the extent to which future drives will have backward read and write capability. This will give an indication of the ability to maintain drives that can read an aging archive. (See table 3-7)
- Transfer rate: This criterion describes the aggregate read and write transfer rate, which is typically less than the advertised transfer rate. (See table 3-2)
- Drive cost: This criterion is the rating of relative cost of each drive at the lowest currently available price. (See table 3-4)
- 5 year maintenance cost: This criterion rates the relative cost of maintenance over the first 5 years, taking into account warranty. (See table 3-4)
- Vendor analyses: This criterion is the rating of the viability of the vendor and technology. (See table 3-6)
- Scenario cost: This criterion is the rating of the cost of scenario #1. This includes media cost and drive cost. The measured or estimated capacity is used rather than advertised capacity. (See table 3-5)

Note that in the decision matrix spreadsheet below, not all criteria have been selected for the final analysis of this trade study. These unused criteria were left in the spreadsheet so that others may insert the criteria weights for their specific application.

Selecton Criteria	Wt	Sun T10000	HP LTO3	Quant DLT-S4	IBM TS1120	Sony SAIT-1	Sun T10000	HP LTO3	Quant DLT-S4	IBM TS1120	Sony SAIT-1
Design criteria		10.0	7.4	6.1	7.7	6.1	0.0	0.0	0.0	0.0	0.0
Capacity	20	6.1	5.0	10.0	6.2	6.2	122.0	100.0	200.0	124.0	124.0
Media cost/TB		3.5	7.0	10.0	4.6	4.3	0.0	0.0	0.0	0.0	0.0
Compatibility	15	5.5	9.5	5.7	10.0	7.3	82.5	142.5	85.5	150.0	109.5
Transfer rate	15	10.0	6.1	4.8	8.3	2.6	150.0	91.5	72.0	124.5	39.0
Drive cost		0.7	10.0	5.1	0.6	3.6	0.0	0.0	0.0	0.0	0.0
5yr maint cost		0.4	9.8	10.0	0.3	8.7	0.0	0.0	0.0	0.0	0.0
Vendor analyses	15	4.0	6.9	4.1	10.0	6.6	60.0	103.5	61.5	150.0	99.0
Scenario cost	35	2.2	9.3	10.0	2.0	5.1	77.0	325.5	350.0	70.0	178.5
Total Weighted Score							**491.5**	**763.0**	**769.0**	**618.5**	**550.0**

Table 4-1 Weighted Decision Matrix

4.2 Conclusions and notes

DLT-S4 (769.0) barely edged out LTO3 (763.0), though LTO4 would have scored 875.5 and would beat DLT-S4 if the estimated LTO4 drive and media costs hold true. There is no compelling reason to adopt a new standard archive device such as the DLT-S4 even if LTO comes out slightly behind at this point in time.

- There was no opportunity to test devices for this study. Performance and capacity figures were based on vendor or customer benchmarks where available, or based on drive specifications combined with past performance (percentage of the claimed specs that were achievable in the past).
- When multiple copies of a dataset are maintained, it becomes acceptable to trade cost and performance for reliability particularly when the working copy is on an enterprise technology such as Sun T10000, 9940, or 9840 as is the case for most archives at EROS.
- As any drive saturates the market, media and drive costs drop.
- With proper handling and multiple copies, any of the technologies evaluated in this report could be deployed for archive use.

4.3 Recommendations

1. It is advised that the USGS continue with LTO as the offline storage media of choice, testing and then moving to LTO4 when available. Data stored on LTO2 and LTO3 need not be migrated to LTO4 unless media degradation is suspected or observed.

2. When LTO4 drives are available from Sun/STK there would be benefit in placing two or more drives into the SL8500 robotic library in order to automate generation of offline copies. Once written, tapes would be ejected and stored elsewhere.

3. In order to reduce risk, the USGS should continue the strategy of storing datasets on multiple technologies. An example of this would be to store a working copy of a dataset on nearline T10000, and offline/offsite copies on LTO4. This strategy partially mitigates the risks of one or the other technology failing or being retired prematurely.

4. The USGS should adopt a policy of periodically testing archive tapes for readability. This testing should not be extensive enough to incur undue wear on the media, but should be frequent enough to provide an opportunity to detect deteriorating media. At a minimum, a 10% annual random sampling should be implemented by all EROS projects.

5. All archived files should be checksummed and the checksum stored in the corresponding Inventory record. When a file is retrieved from either the Silo or from the offline media, integrity can then be verified.

6. It is advised to migrate all data to new media between three and five years after it was written. While most tape technologies can reliably store data for much longer periods, after 5 years the transfer rates and densities that once were leading edge will become problematic, and drives will become difficult to maintain. This is a best practice supported by the National Archives and Records Administration.

7. When writing archive tapes, the tapes should be verified on a second drive. This will help identify any drive incompatibility.

8. Each time this study is revisited, it is possible that the highest scoring technology will change. This does not indicate that the USGS should change offline tape technologies frequently. There is benefit in staying with a given technology for several years, even if it is not the leading technology continuously. This study is a snapshot in time, and results would differ even a few months earlier/later due to new releases. There currently is no compelling reason to abandon LTO technology.

9. Sun and Imation have apparently been in discussions regarding a new technology (Ulysses) which would place a disk drive in a cartridge the size of a 9840/9940/T10000. The “drive” would simply be an interface and power connection to the drive cartridge. This would provide a tremendous decrease in access times over tape. Another advantage is that increased capacity cartridges would be supported without upgrading the “drive”. These drives should be quite cheap and will only require upgrade when the internal disk drive interface changes, though the cartridges will be about $1,250/TB (estimate based on current 2.5” drive costs). This technology should be monitored although it would likely be deployed for nearline applications, rather than for an offline archive.

10. The USGS should plan to update this trade study periodically so that when a logical replacement for LTO ultimately emerges, it will not be a surprise.

Abbreviations and Acronyms

AIT	Advanced Intelligent Tape
BER	Bit Error Rate
CD-ROM	Compact Disc - Read Only Memory
CERN	Conseil European pour la Recherché Nucleaire
CRC	Cyclic Redundancy Check
DCT	Digital Cassette tape
DLT	Digital Linear Tape
DVD	Digital Video Disc
EO	Erasable Optical
EROS	Earth Resources Observation and Science
FYyy	Fiscal Year yy
GB	Gigabytes (1,024 MB, or 1,073,741,824 bytes)
HD-DVD	High Definition Digital Versatile Disc (formerly Digital Video Disc)
HDT	High Density Tape
HP	Hewlett Packard
HW	Hardware
IBM	International Business Machines
IRIG	InteRange Instrumentation Group (timecode format)
LACS	Landsat Archive Conversion System
LP-DAAC	Land Processes Distributed Active Archive Center
LTO	Linear Tape Open
MB	Megabytes (1,048,576 bytes)
MSS	Multi-spectral Scanner
NARA	National Archives and Records Administration
QIC	Quarter-inch Cartridge
SAIC	Science Applications International Corporation
SAIT	Super Advanced Intelligent Tape
SD	South Dakota
SGT	Stinger Ghaffarian Technologies, Inc.
SDLT	Super Digital Linear Tape
STK	StorageTek (now a Sun business unit)
TB	Terabytes (1,024 GB or 1,099,511,627,776 bytes)
TBD	To Be Decided/Determined
WORM	Write Once, Read Many
TM	Thematic Mapper
TMACS	TMMSS Archive Conversion System
USGS	United States Geological Survey

Citations

Note that this section was an afterthought and therefore the body of the study does not refer to specific citations listed here. A majority of my references are listed here, but not all of the citations listed here were specifically used in the study. Where I used magazine articles, I've listed a link to the online copy.

Vendor sites:

http://h18006.www1.hp.com/storage/tapestorage/tapedrives.html (HP)

http://www.sun.com/storagetek/tape_storage/tape_drives/ (Sun/STK)

http://www-03.ibm.com/servers/storage/tape/index.html (IBM)

http://www.quantum.com/Products/TapeDrives/Index.aspx (Quantum)

http://b2b.sony.com/Solutions/subcategory/storage/branded-tape/SAIT (Sony)

http://www.tandberg.com/tandberg.html#tapedrives (Tandberg)

http://www.exabyte.com/ (Exabyte, recently bought by Tandberg)

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http://www.infostor.com/articles/article_display.cfm?Section=ARCHI&C=Labsr&ARTICLE_ID=255609&KEYWORDS=super%20tape%20paradox&p=23

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