QSLife Technology

From SSD Endurance to SSD Life Cycle

White Paper

July 2022

Announcement

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PREFACE

Executive Summary

The SSD (Solid-State Drive) has been the most popular storage device since these years. It consists mainly of a control chip and flash memory. Compared with traditional hard drives, SSDs offer the advantages of higher performance, lower power consumption and higher impact resistance. Despite this, the lifespan and reliability of SSDs is still lower than traditional hard drives. That's why we need a specific tool to monitor SSDs for users.

Audience

This document is applicable for QSAN customers and partners who are interested in learning about QSLife for solving the problem of monitoring the life endurance of SSDs. It assumes the reader is familiar with QSAN products and has General IT experience, including knowledge as a system or network administrator. If there is any question, please refer to the user manuals of products, or contact QSAN support for further assistance.

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Information, Tip, and Caution

This document uses the following symbols to draw attention to important safety and operational information.

INFORMATION

INFORMATION provides useful knowledge, definition, or terminology for reference.

TIP

TIP provides helpful suggestions for performing tasks more effectively.

CAUTION

CAUTION indicates that failure to take a specified action could result in damage to the system.

1. SSD ENDURANCE

Today, the demand for data-intensive (such as big data, 5G applications, edge computing, real-time analytics, and virtualized environments) is expanding. Therefore, SSD (Solid-State Drive) storage technology is becoming more and more mainstream because it provides ideal performance, energy efficiency, and high density for these applications. Compared with HDD (Hard Disk Drive), SSD provides significant performance advantages and is suitable for applications that require low latency and high random IOPS performance.

Since SSD still uses the traditional interfaces of traditional SAS (Serial Attached SCSI) and SATA (Serial ATA), most of the terms are used as traditional disk drives. But SSD has some unique features that require us to reconsider some of usual assumptions when using them in modern storage. This section outlines the important aspects of using SSDs, namely SSD endurance.

1.1. An Introduction to Endurance

The difference between SSD and HDD is that SSD does not store data as a magnetic field on a spinning disk (traditional HDD), but instead stores data in a NAND storage unit. Compared with HDD, this essential difference profoundly affects the durability and data retention characteristics of SSD.

1.1.1. NAND Features

The NAND flash memory array is composed of pages and blocks. A page is the smallest unit of NAND memory that you can write to. Pages are organized into NAND blocks. A page size is usually measured in kilobytes and NAND block is usually in megabytes. Please note that NAND block is different from the logic block of HDD, such as 512 bytes or 4KB that we often hear.

Regarding NAND features, there are two important things to understand.

1. NAND memory can only be erased at the block level, not at the page level. This means that the SSD controller must relocate and remap any valid data in the block before the controller can erase and write new data.
2. Every time the drive is written or erased, the oxide layer of the NAND cell deteriorates. This is why NAND blocks have a limited number of write cycles before cell failure. But they can

still be read successfully without being affected by the number of writes. It is the fundamental reason for the limited endurance of SSDs.

1.1.2. NAND Types

Although NAND memory began to store one bit per cell, the growing demand for cheaper and larger capacity has prompted engineers to develop new methods to store more bits into a cell. Today, the vast majority of NAND is multi-level cell. The following describes the generation of NAND memory cell.

- **SLC** (Single-Level Cell): SLC supports 50,000 to 100,000 write cycles. This type of flash memory was very popular in the enterprise market due to its life, accuracy and comprehensive performance. However, due to the high storage cost and relatively small storage capacity, it is not very popular now.
- **MLC** (Multi-Level Cell (2-bit data)): The multi-level cell is commonly known as MLC, and its name comes from the fact that it has become 2 bits per cell on the basis of SLC's 1 bit per cell. MLC typically requires up to 3,000 write cycles. eMLC (Enterprise MLC) supports up to 10,000 write cycles. A major advantage of this is that it greatly reduces the cost of large capacity storage of flash memory, because flash memory is the core of SSD, and its production cost is usually reflected in the price of SSD and eventually passed on to consumers.
- **TLC** (Triple-Level Cell (3-bit data)): TLC flash memory is the cheapest specification in flash memory production, and its storage has reached 3 bits per cell. TLS is as low as 300 to 1,000 write cycles, and can reach 1,500 to 3,000 write cycles with 3D NAND. Although the high storage density realizes a cheaper and large capacity format, its read and write life cycle is greatly reduced. And the read and write speed is relatively poor compared to MLC.
- **QLC** (Quad-Level Cell (4-bit data)): Each NAND of QLC can store 4 bit data. Compared with TLC, the storage density of QLC is increased by 33%. QLC can not only withstand 1,000 programming or erase and write cycles, but also has increased capacity and lower cost.

Table 1-1 Summary of NAND Types

NAND TYPE	SLC	MLC	TLC	QLC
Number of Bits per Cell	1	2	3	4
Write Cycles	50,000 ~ 100,000	3,000 ~ 10,000	300 ~ 3,000	1,000
Write Speed	Very Fast	Fast	Slow	Slow
Endurance	Best	Fair	Poor	Poor
Price	Very Expansive	Expansive	Fair	Cheap
Applications	Enterprise / Industry	Consumer / Game Player	Light Consumer	Backup

1.2. Techniques to Increase Endurance

With the advancement of technology, engineers have developed some technologies to improve the endurance of SSDs.

1.2.1. Wear-leveling

The working principle of wear leveling is to continuously remap the SSD logical blocks to different physical pages in the NAND array. This helps to achieve the goal of evenly distributing NAND block erasing and writing on the NAND array, preventing premature wear of NAND blocks and maximizing SSD endurance. Wear leveling is a necessary function, although it runs on background tasks and affects SSD performance.

1.2.2. Over-provisioning

Over-provisioning NAND capacity on the SSD will also increase the endurance of the SSD. By providing the SSD controller with more NAND blocks that are invisible to user, to distribute erases and writes over time, and to provide a larger spare area so that the controller can operate more efficiently. More spare areas can increase endurance, but also increase costs.

1.2.3. Minimizing Write Amplification

Write amplification is an undesirable phenomenon associated with flash memory, where the actual amount of information physically written to the storage medium is a multiple of the logical amount to be written.

Because the flash memory must be erased before being rewritten, the process of performing these operations will result in multiple moves (or rewrites) of data. Therefore, rewriting some data requires reading, updating the used part of the flash memory and writing it to a new location. If the new location has been used at a certain point in time before, the new location must be erased first.

Due to the way flash memory works, it is necessary to erase and rewrite parts of the flash memory that are much larger than the actual amount of new data required. This multiplier effect increases the number of writes required during the life of the SSD, thereby reducing its reliable operation time. The increased write will also reduce the random write performance to the SSD.

Therefore, minimizing write amplification is a problem for SSD manufacturers. Adding an internal cache to the write buffer helps reduce writes. SSD manufacturers will increase the cache by a certain percentage according to the SSD capacity. Of course, this will also increase the cost.

1.2.4. TRIM for Reclaiming Space

TRIM is a SATA command that allows the operating system to tell the SSD which blocks that have previously stored data are no longer needed. If a user deletes a file, it usually marks the file as deleted without actually erasing the actual content on the drive. Because of this, the SSD does not know that it can erase the block previously occupied by the file, so it will still retain them during garbage collection.

TRIM command solves this problem. When a file is permanently deleted or the drive is formatted, the operating system sends the TRIM command according to the block that no longer contains valid data. This tells the SSD which blocks in use can be erased and reused. Therefore, the number of blocks that need to be moved during the garbage collection process is reduced. The result is that SSD will have more free space, while obtaining low write amplification and higher performance.

Although TRIM is a SATA command, the equivalent command is called UNMAP in SCSI and Deallocate in NVMe. They all refer to the same function.

1.3. Measuring SSD Endurance

SSD endurance is usually measured in two ways. Usually when researching SSDs, we try to look for the stat TBW or DWPD (Drive Writes Per Day) or TBW (Terabytes Written) to find the endurance of an SSD. Both of these two are based on the manufacturer's warranty period for the SSDs, it is also known as "lifetime" or "remaining life".

1.3.1. DWPD (Drive Writes Per Day)

DWPD measures how much of the disk can be written to everyday and still be expected to function within the warranty period. For example, if the DWPD on a 500 GB SSD drive is 1, and the warranty period is 5 years, then the user can rewrite the entire 500 GB every day for 5 years before the failure is predicted. If its DWPD is 3 on a 500 GB drive and provides a 5-year warranty, then triple the number of cumulative writes in 5 years.

1.3.2. TBW (Terabytes Written)

TBW measures how many terabytes can be written to the disk before it will begin to malfunction. The equation is on the following.

TBW = DWPD * Warranty (years) * 365 * Capacity (TB)

For example, suppose the capacity of the SSD is 500 GB, the warranty is 5 years, and its DWPD is 3.

TBW = 3 * 5 years * 365 * 500 GB / 1,024 (GB/TB) = 2,673.34 TB

That means you may need to replace the SSD before writing 2,673.34 TB.

1.4. SSD Endurance Levels on the Market

In order to provide a series of SSD solutions, most SSD manufacturers produce three different types of SSDs for specific applications. There are read-intensive, mixed use, and write-intensive. They use DWPD to help classify the different endurance characteristics of each device. The following table lists the general SSD endurance levels on the market.

Table 1-2 General SSD Endurance levels in the Market

	READ-INTENSIVE	MIXED USE	WRITE-INTENSIVE
Workload	High read / Low write	Equal read / write	Unrestricted read / write
DWPD	<= 1	> 1 and < 10	>= 10
Application Examples	Boot device Knowledge base	File service Web service	Mission critical ERP, Database

Generally speaking, a larger DWPD is more secure to store data, but it all depends on the cost. SLC has the best write cycle, but it is more expensive than MLC, TLC and QLC. Over-provisioning has better DWPD, but it requires more NAND flash memory to achieve. Users must choose the right SSD according to the application to optimize TCO (Total Cost of Ownership).

1.5. Endurance vs. MTBF with SSDs

There is a difference between endurance and reliability. Reliability relates to the frequency of failures of drives. MTBF (Mean Time Between Failure) is the total number of service hours. It is a commonly used measurement method for HDD. MTBF is calculated based on statistical evaluation of parts or small sample sizes. Because no supplier is willing to wait for years of uninterrupted testing to obtain results, it is not an accurate measurement.

Fortunately, with modern drive technology, the MTBF is usually millions of hours. Generally speaking, SSDs that have not reached their endurance limits are as reliable as traditional disk drives because they lack moving parts (such as HDDs) that cause mechanical failures. This may be interesting information, but not as useful as DWPD and TBW calculations. However, once they reach their endurance limit, you need to replace them to avoid increased error rates and possible drive failures.

2. QSLife Concept and Operation

Due to the endurance limitations, unlike HDDs, SSDs have a limited lifespan in the system. Once the SSD reaches that end of life, you should replace it to avoid potential data loss due to continued operation. To achieve this process, QSAN provides a disk monitoring feature that can track and report on disks, especially SSDs, called QSLife.

QSLife (Intelligent Disk Drive Analyzer) is based on a specific algorithm to decrypt the attributes within HDDs and SSDs to display detailed information. SSD has become the basic usage of storage system as a mature and reliable data protection device. However, with the rapid growth in data storage capacity demand and the emergence of higher performance applications in recent years, SSDs have gradually exposed their flaws.

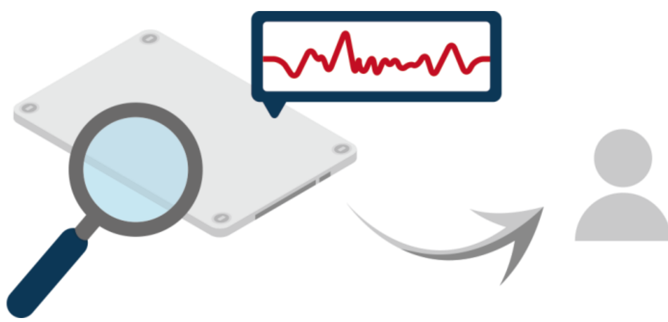

Figure 2-1 QSLife

In the previous chapter, we introduce the SSD endurance. SSDs today are almost universally comprised of NAND flash, which wears out with use. Each flash memory cell can only be written specific times before it becomes unreliable. As the number of I/O increases, the number of SSDs writes also increases significantly. This is one of the toughest issues in enterprise storage management today. In the past few days when SSDs were only written from 10 GB to 100 GB, the lifespan of SSDs was not a problem without special attention. However, as daily writes grow to hundreds of gigabytes or even terabytes, SSD's remaining life management will be one of the major issues in storage management.

2.1. QSLife Concept

QSLife monitors disks of your storage system all the day. By analyzing and reorganizing the information provided by HDDs and SSDs, QSAN provides accurate SSD remaining life for each disk in a clear and understandable manner. With the QSLife feature, users can easily understand the disks which need to be replaced in time, or customize the threshold for replacing disks.

2.1.1. Why Decrypting SSD

In the previous chapter, we learned to measure SSD Endurance. As you can see, if you know the capacity and the warranty of the SSD, you can roughly go from DWPD to TBW with some simple multiplication or division, and vice versa. The two measurements are rough but similar.

However, enterprises can't just pay for the endurance of SSDs every day, and the usage of enterprise storage is obviously amazing. To solve this problem, we designed some methods to measure and monitor the remaining life of the most popular SSDs on the market.

2.1.2. Design Concept of QSLife

There are many parameters hidden in the SSD record. Such as Relocated Sectors Count, Current Pending Sectors Count, Uncorrectable Sector Count, …etc. We summarized these parameters and provided a simple indicator to indicate the health of disks. What you need to know is that you must replace the disk before its end of life. Our design concept is to make it simple and easy to understand for users as much as possible, and leave the complexity to us.

For example, usually we know that ● green light represents normal, ● amber light represents attention, and ● red light represents error. A percentage counting from 100% to 0% indicates that the life span is decreasing. Let's take a look at the operation of QSLife and experience the easy-to-understand user interface.

2.2. QSLife Operation

This section will describe the operations of checking disk status and the threshold settings of SSDs. Click the QSLIfe icon to popup a window.

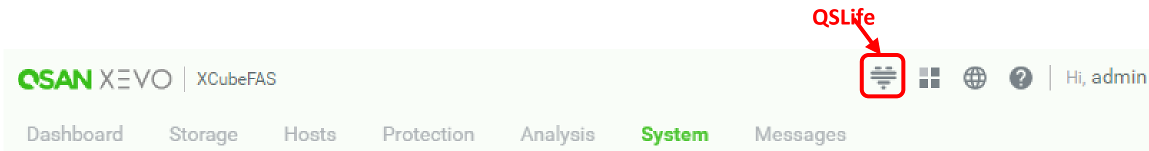

Figure 2-2 QSLife Icon

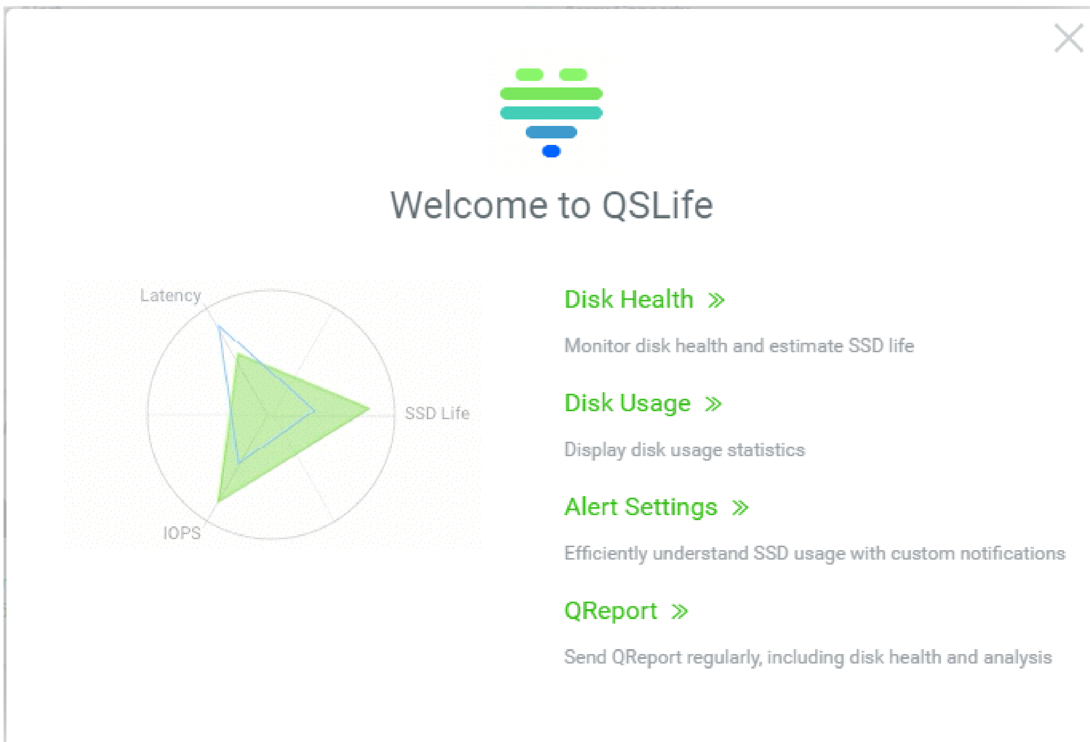

Figure 2-3 QSLife Popup Window

2.2.1. Check the Health and Life Remaining of SSDs

Select the **Disk Health** function menu in the QSLife popup window. It will go to the **Disk Health** function tab which is used to monitor and optimize disk performance and longevity. Here is an example of checking the health and life remaining of SSDs.

1. Select a unit at the **Array** function submenu. It will scan and display all disks of this unit.

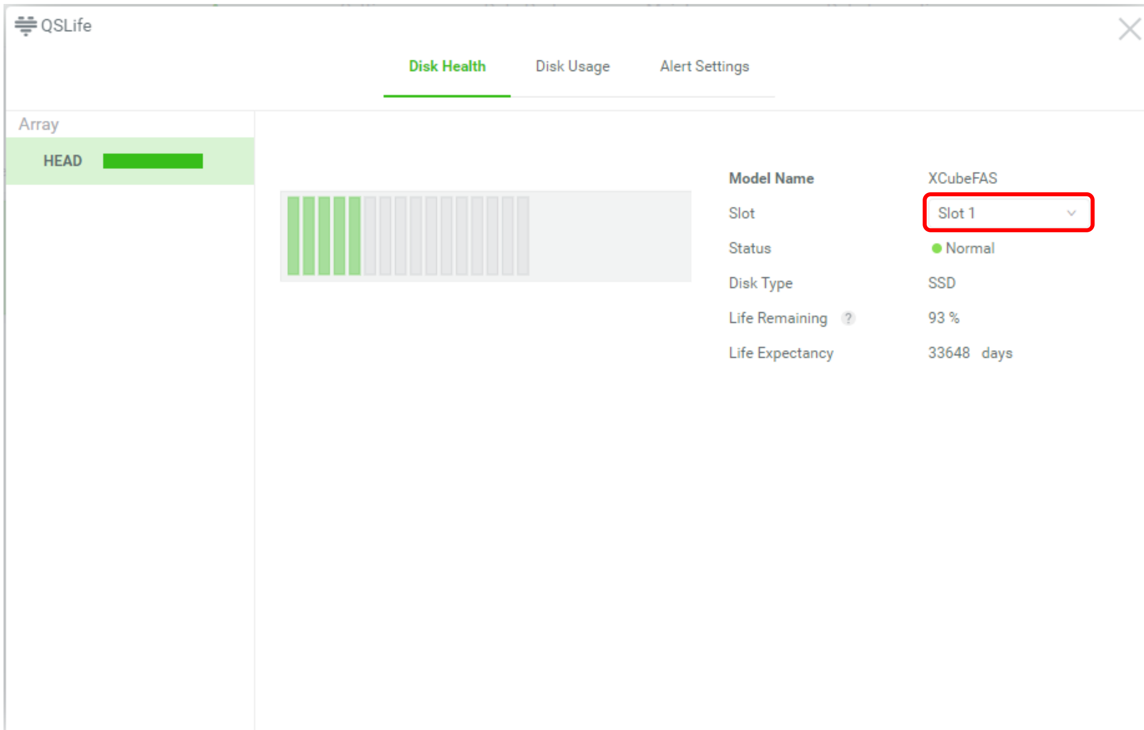

Figure 2-4 Disk Health

2. Select an SSD which you want to watch in **Slot**, the system will display the health status, life remaining, and life expectancy of the SSD. It is highly recommended to replace the SSD if the life remaining is under 10%.

INFORMATION

Life remaining and expectancy are estimated based on workload to date. Only SSDs will show life remaining and expectancy.

2.2.2. Check Disk Usage

Select the **Disk Usage** function tab in the QSLife to be used to monitor the disk usage status and history.

1. Select a unit at the **Array** function submenu. It will scan and display all disks of this unit.

2. Select a disk which you want to watch in **Slot,** the system will display the disk usage information. It includes up to 1 year of usage history to analyze the actual usage of your business.

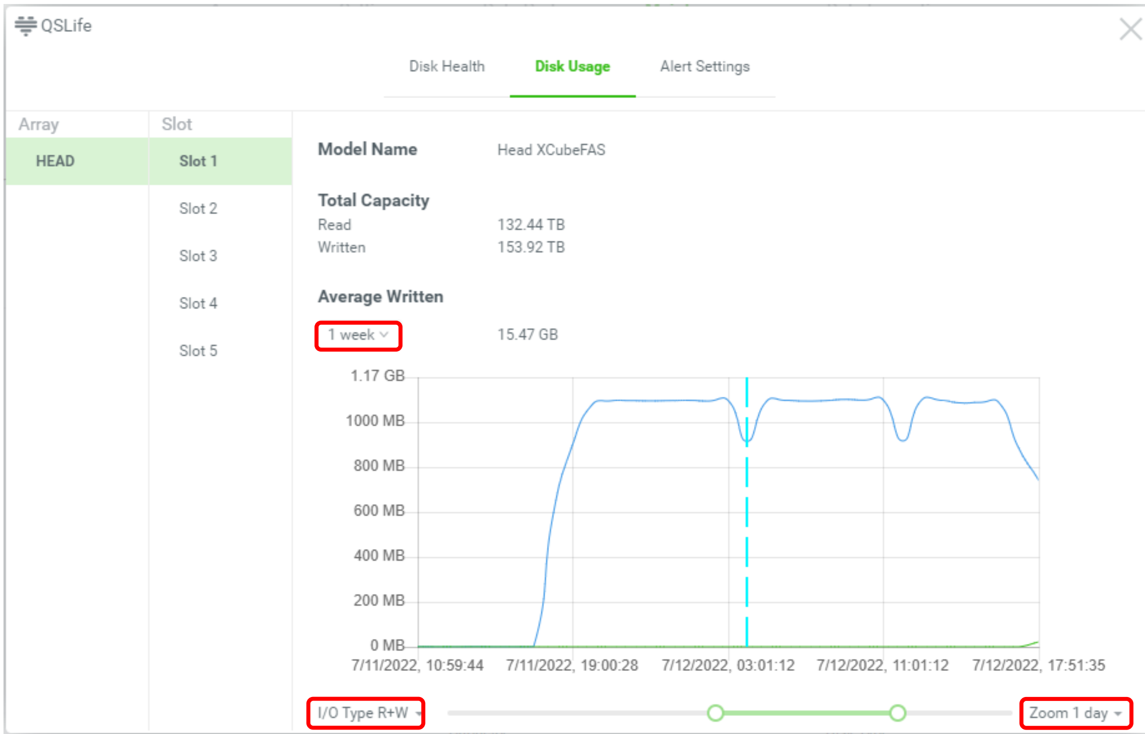

Figure 2-5 Disk Usage

3. It also displays the total capacity of read and written bytes on a disk from the beginning.

Options on Disk Usage

- **Average Written**: The period of average written can be changed to display the current average written bytes. The options are average 1 week, 1 month, and 1 year.
- **I/O Type**: The I/O type of the disk usage can be changed in the diagram for different viewpoint. The options are Read, Write, and R+W (Read + Write).
- **Zoom**: The period of the disk usage can be changed in the diagram to watch the usage in the different period. The options are 1 day, 1 week, 1 month, and 1 year.

2.2.3. Alert Settings

Select the **Alert Settings** function tab in the QSLife to be used to learn SSD usage effectively with custom notifications. User can customize the SSD endurance threshold settings at this page. Here is an example of setting the SSD alert.

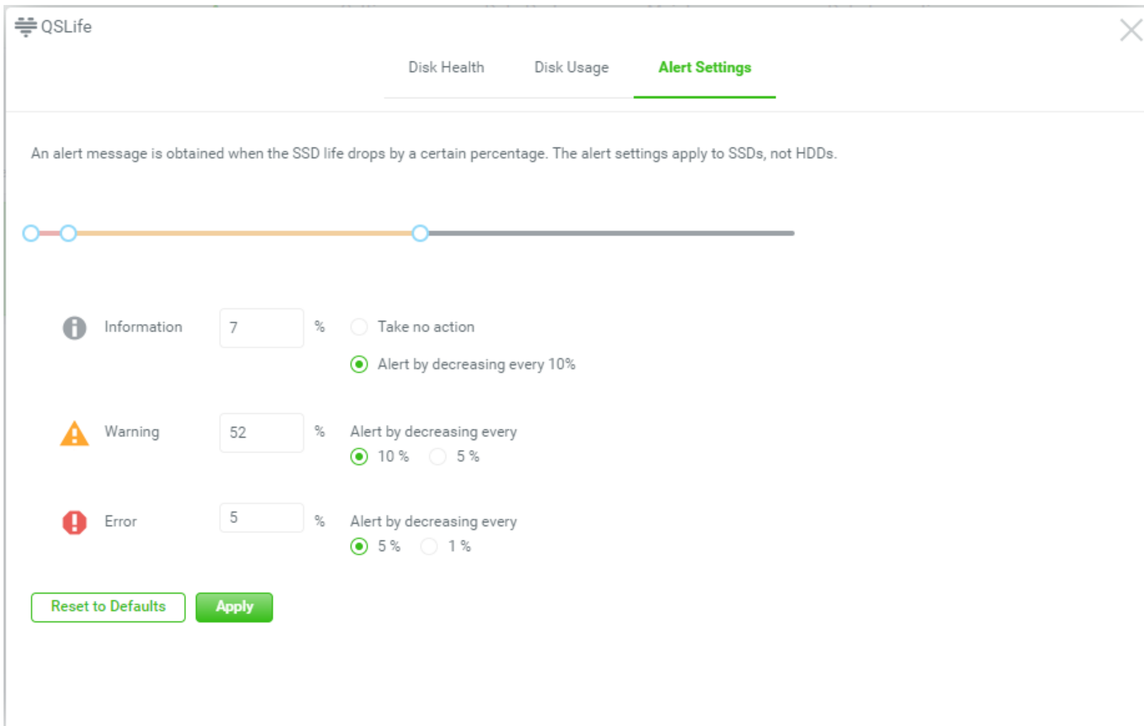

Figure 2-6 Alert Settings

1. There are three levels of the alert can be set. The options include Information, Warning, and Error. Drag the dot on the slide bar or enter the percentages of the SSD endurance thresholds. The actions can also be changed in every alert level.
2. Then press the **Apply** button to confirm your configurations.

INFORMATION

An alert message is obtained when the SSD life drops by a certain percentage. The alert settings apply to SSDs, not HDDs.

TIP

Click the **Reset to Defaults** button to reset to default values. For general SSDs, the **Information** level can be set to 50%, and the option setting alarm is reduced by 10%. When the remaining life of each SSD reaches 50%, 40%, and 30% at the **Information** level, you will receive a notification. At the **Warning** level, the alarm is reduced every 5%, from 30% to 10%. Finally, you will be notified by reducing 1% each time at the **Error** level. The purpose is to let you know that the SSD should be replaced during the remaining life countdown.

3. QSLIFE BENEFITS AND SSD LIFE CYCLE

In the previous chapter, we introduce the SSD endurance. In order to use SSDs in your storage, we care about the life cycle of SSDs. QSLife was invented to monitor and analysis disks, especially the life cycle of SSDs. At this point, we will point out some key features to introduce the benefits of QSLife.

3.1. QSLife Benefits

QSLife design concept is to make it simple and easy to understand for users as much as possible, and leave the complexity to us. Below, we will describe the benefits of the three functions separately.

3.1.1. Disk Status and SSD Life Remaining

Disk Status and SSD Life Remaining are simple factors for users to understand the status of the SSD.

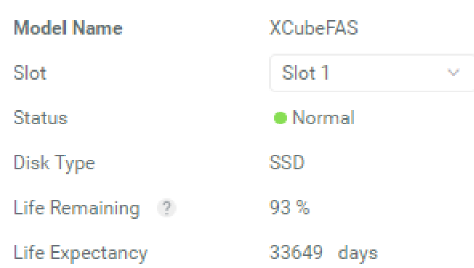

Figure 3-1 Disk Status and SSD Life Remaining

- **Status**: Shows disk status by analyzing some disk variables. We simplify into three states based on the SSD parameters. There are ● Normal (Green light), ● Abnormal (Amber light), and ● Warning (Red light) for users to easily and clearly know the disk status. Users must pay attention to whether the disk turns Abnormal.
- **Life Remaining**: Shows the percentage of SSD remaining life cycle. It is a percentage, counting from 100% to 0%. It is obvious to understand the lifespan of SSD. 100% stands for

a new drive. Users must pay attention to whether the SSD is under the Warning levels which is defined in the Alert Settings.

- **Life Expectancy**: Shows an accurate SSD life expectancy starting from now. Life expectancy is fairly intuitive and is calculated in days. The same, Users must pay attention to whether the SSD counts down to 0.

3.1.2. Disk Usage

Disk Usage is designed to monitor 1 year's disk usage status and history. With this information, users can observe and analyze disk usage, and even debug abnormal read or write I/O occurrences.

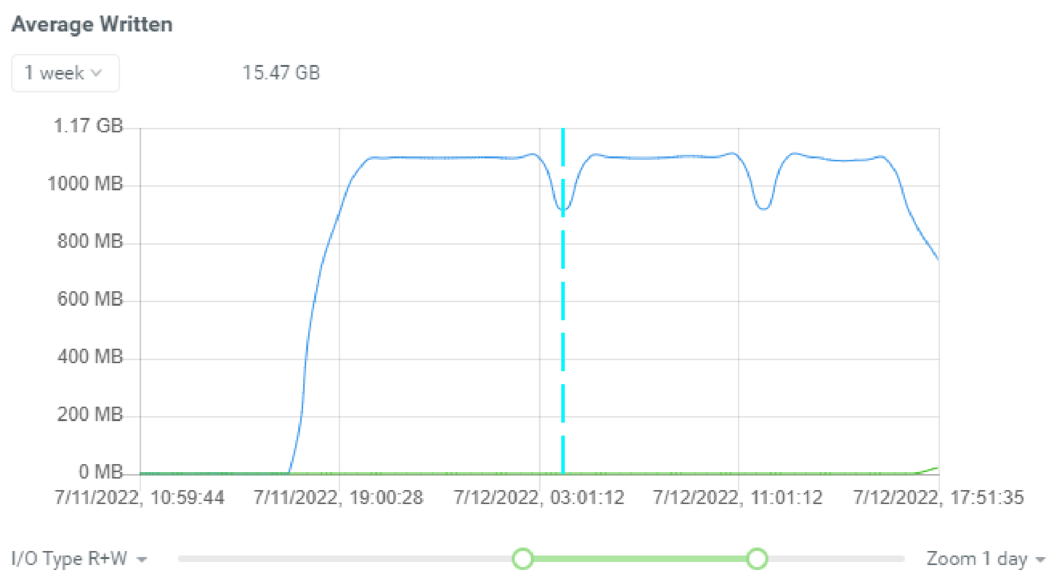

Figure 3-2 Disk Usage

The Secret of SSD Performance

In addition to fulfilling I/O requests, NAND block management in SSD controller maintains a pool of free blocks, as well as data remapping tasks related to wear leveling. Due to the pros and cons of the algorithms in the SSD controller, the management tasks may vary greatly. Of course, changes in the management tasks will affect the performance of the SSD.

When running a benchmark test on an SSD, the SSD behaves as follows.

- When the written data starts to fill up the new SSD storage capacity, performance may drop by half or more. As SSDs are full of data, the NAND management task rises, increasing overhead and affecting performance.
- Once there are no more available or empty pages on the SSD to store data, the management tasks start to run more frequently, and performance will degrade. The worst-case is usually when a random write workload with small transfers is used to write to the SSD, which will cause significant write amplification.

Take Actions on Slow SSDs

By looking at the usage of each SSD, you can easily identify the slower SSD. Trying the TRIM command described earlier may help. At the same time, by watching SSD usage, users can easily estimate the actual TBW required for a more accurate procurement strategy.

3.1.3. Customize Alert Settings

This is a special part of monitoring SSD. We design three stages for alert when the SSD lifespan drops by a certain percentage. We provide default values for information (50%), warning (30%), and error (10%).

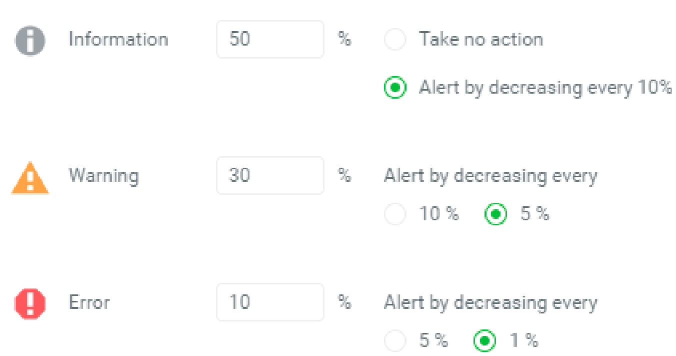

Figure 3-3 Alert Settings

But as you know, SSD capacity is the key. There is a big difference between 1% of 100 GB and 10 TB capacity. Maybe the remaining 1% of 100 GB has a lifespan of only 10 days, but 10 TB is as long as 6 months or more. Therefore, we provide custom alarm settings for practical use. The default values can be used under 500 GB capacity, and can be customized when using large capacity SSD.

3.2. QSLife's Application in SSD Life Cycle

This paper, called [A Large-Scale Study of Flash Memory Failures in the Field], was written by Carnegie Mellon University and the Facebook team. The research object is the Facebook data center, which has used SSD for more than four years.

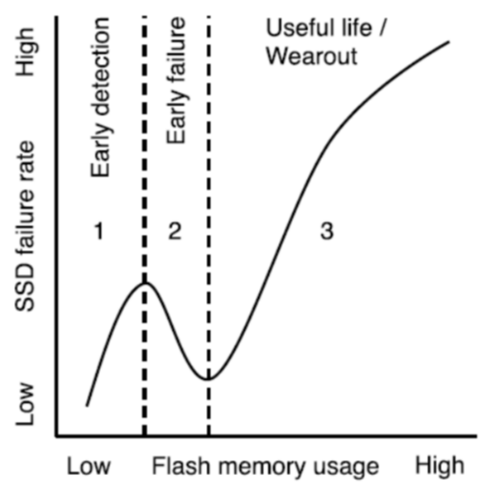

Figure 3-4 SSD Lifecycle Failure Pattern

(Source from A Large-Scale Study of Flash Memory Failures in the Field)

The research team divided the different stages into early detection, early failure, useful life, and wearout based on the relationship between the failure rate and the use time. Researchers have found that SSDs have different failure rates at each different stage, and not all of them grow linearly. The failure rate will be higher in the initial stage of use, and then the overall operation will gradually stabilize, and the failure rate will increase again after a certain amount of use is exceeded.

Below we will use QSLife to help you at each stage of the SSD life cycle.

- **Early Detection** / **Early Failure**: The failure rate decreases rapidly from high, and the cause of failure is lack of design or manufacturing process. For such SSDs, they may not be detected by QSAN storage or may fail the compatibility test. Even if users use these types of SSDs, they may have some signs that can be discovered by monitoring SSD Usage in QSLife. You may find that they have unusual performance curves or high latency.
- **Useful Life**: The failure rate is low and stable, and the failure causes appear randomly. At this stage, the SSDs are relatively healthy. Users only need to observe the changes of Average Written and Total Written. If the numbers increase too much in a short period of time, you may need to adjust the host application.

- **Wear Out**: The failure rate will increase rapidly, and the failure cause is due to aging. At this stage of SSDs, you will be notified according to the Alert Settings in QSLife. Then prepare to replace new SSDs.

The worst case can also be protected by RAID level. You can prepare spare disks just in case. In addition, users only need to pay attention to the event logs at any time and don't need to worry too much.

4. CONCLUSION

As SSDs become more popular in the storage industry, data protection issues become very important. The more data you put into an SSD, the less endurance of the SSD you get. Having a general solution for monitoring the endurance of SSDs is an immediate matter that every IT manager should be concerned about. QSLife can improve disk management and prevent human negligence. QSLife can help users develop appropriate purchasing strategies. QSLife technology analyzes the details of most popular disks for each user, making it easier to manage storage than ever before.

5. APPENDIX

5.1. Apply To

- XEVO firmware 2.0.0 and later

5.2. Reference

- XEVO Software Manual
- A Large-Scale Study of Flash Memory Failures in the Field