PowerVault™ MD1200/MD1220 Solution Optimization Guide

A Dell Technical White Paper

Dell PowerVault™ Storage Systems

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March 2011

ABSTRACT

One of the most important factors to consider when implementing a storage solution is the type of application that will be utilizing the storage solution. To gain the maximum benefit from your investment in Dell's PowerVault™ MD1200/1220 storage enclosures, it is important to optimize this solution for the application it will be serving. Selecting the right components and design for the PowerVault™ MD1200/1220 will not only impact the performance and effectiveness of your application but it will also improve the efficacy of the entire IT infrastructure that relies on that storage. The goal of this whitepaper is to provide recommendations on components that can help guide the implementation of the PowerVault MD1200/1220 DAS solutions based on application type.

Contents

Introduction

There are several factors to consider when selecting an enterprise storage solution. These include reliability, availability and manageability. However, an additionally important factor is the Application utilizing the storage system and its performance requirements such as I/O load and data usage patterns. It is important to ensure these can be met by the selected storage system.

The performance of a storage system is determined by components such as disk type (e.g. HDD vs. SSD), RAID configuration, and adapter parameter settings. When implementing a storage system, therefore, it is important to quantify the impact different component choices have on the performance of the storage system, and select those that match the performance requirements of the application.

To help customers determine the optimal configuration of their PowerVault™ MD1200/1220 for each application type, Dell Labs has tested various configurations of the solution by simulating I/O loads from many widely used applications. To facilitate the tests, IOmeter, an industry-standard I/O benchmark, was used to generate I/O loads on various PowerVault™ MD1200 and MD1220 configurations using different type of hard disk drives (HDDs) and solid state drives (SSDs). These PowerVault configurations were directly connected to servers via a Dell PERC H800 adapter. Tests were also conducted for various read and write cache settings of PERC H800. Results from these tests clearly show that different combination of PowerVault enclosure, drive type, RAID level, and PERC H800 cache configuration provide different levels of I/O performance for each application type depending upon its I/O load characteristics.

Table 1 provides a description of the various hardware configurations tested in this study.

			Traditional HDDs				**Solid State Storage**		
PowerEdge Server	PowerVault Enclosure	PERC Adapter	7.2k NL-SAS	15k SAS	PERC H800 Cache Settings		SSD	PERC H800 Cache Settings	
					Read	Write		Read	Write
R610	MD1220	H800	(24) 500GB	(24) 146GB	Adaptive Read Ahead	Write Back	(8) 149GB	No Read Ahead	Write Through
	MD1200		(12) 2TB	(12) 600GB					

Table 1. Hardware Configurations

Storage Solution Recommendations

This section provides recommendations of storage solutions based on extensive IOmeter testing at Dell Labs of the hardware configurations shown in Table 1 under different application simulated loads. Performance data was collected from various simulation runs of RAID 5, RAID 6, and RAID 10 on the PERC H800 adapter directly attached to either an MD1200 or MD1220 expansion enclosure with 3 disk drive types 7.2K RPM NL-SAS, 15K RPM SAS, and 149GB Pliant SSD.

To maximize performance with traditional hard drives, each RAID implementation used all drives that could fit in each PowerVault enclosure resulting in 12 HDDs per volume (virtual drive) in MD1200 and 24 HDDS per volume (virtual drive) in MD1220. In contrast, only 8 SSDs per volume (virtual drive) were required in both enclosures to achieve maximum performance. All performance metrics were collected

from virtual drives left uninitialized/not formatted as NTFS file systems In order to record maximum performance.

IOmeter was used to simulate I/O load of the most widely used application types on volumes (virtual drives) configured at different RAID levels. Application types that shared similar I/O characteristics were grouped into the five categories listed in Table 2 below. The I/O load profile and the metric by which each is measured is also listed.

Examples of Application Type	Application Category Based on I/O Load Profile	Recommended I/O metric
Web Server	Small Random Reads	I/Os per second
Database Server, Email Server	Random Reads and Writes	I/Os per second
Web Logs and Database Logs	Sequential Writes	MBs per second
Video On Demand	Large Random Reads	MBs per second
Streaming Media	Sequential Reads	MBs per second

Table 2. Application Categories based on I/O load profile and their I/O metric

The simulation runs collected were used to compare the performance of various storage solutions (enclosure, drive type, & RAID level) for each of application categories listed above. Pertinent storage solution information, for example RAID level, enclosure type, drive type, and PERC adapter settings were noted for the storage solution that maximized the recommended I/O metric. The following sections describe our findings and recommendations for each application category listed in Table 2.

Category Type: Small Random Reads

Applications in this category, for example Web Hosting where multiple web pages are requested by multiple users simultaneously, have large number of random Read operations in their I/O load profile. Such applications usually require small-size read operations from their storage solution and the I/O metric to be maximized is IOPS (I/Os per second). Web hosting applications can serve intranet sites with minimal internal company traffic or global internet portals that receive page requests from hundreds of thousands of users daily. For large global web sites, usually several web servers respond to client requests resulting in redundancy of PERC H800 adapters and data-paths. Similarly, different RAID levels provide this level of redundancy. Moreover, small to mid-size web hosting applications may not require significant disk capacity scalability since typical website content is usually small (less than a few TB) and relatively static with only minor content modifications. Table 3 below provides the I/O profile for typical of small random reads.

Application	I/O Profile		
	Read/Write	Random/Sequential	Size
Web File Server	95/5%	75/25%	4k,8k,16k

Table 3. Typical Small Random Reads I/O Profile

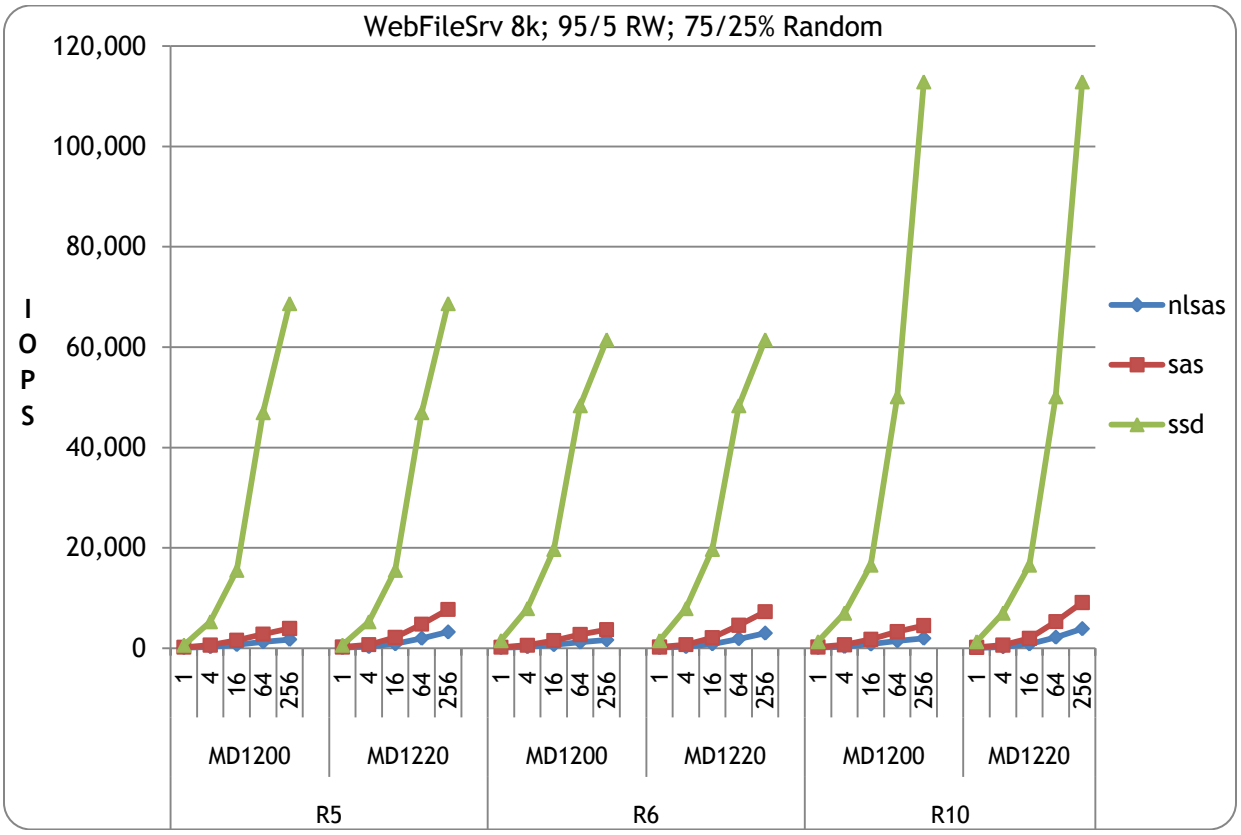

Figure 1. RAID performance comparison of Small Random Reads of 12/24-drive NL-SAS/SAS and 8-drive SSD arrays

RAID TYPE	Enclosure	Queue Depth	NL-SAS	SAS	SSD
RAID 5	MD1200	256	1727.3	3942.4	68691.6
	MD1220	256	3207.7	7719.6	68691.6
RAID 6	MD1200	256	1621.0	3701.0	61486.7
	MD1220	256	2979.1	7278.9	61486.7
RAID 10	MD1200	256	1955.0	4512.3	112889.5
	MD1220	256	3859.7	9116.7	112889.5

Table 4. Results: Max IOPS - Web Server 8K Block Size

SMALL RANDOM READS: RECOMMENDED STORAGE CONFIGURATION		
Component	**Recommendation**	**Rationale**
Enclosure	MD1220 maximum spindles best performance	• To achieve maximum performance, it is beneficial to have more drives because the data can be spread across them and the data access times are reduced • The Powervault™ MD1220 supports up to 24 drives compared to the MD1200 which supports up to 12. Performance between both enclosures can be seen in Figure 1.
Drive Type	SSDs maximum performance	• The advantage of SSDs is that they achieve tremendous performance with fewer drives on random workloads. This can be seen in our testing where 8 SSDs as opposed to 24 HDDs achieved maximum performance.
RAID Level	10	• RAID 10 offers the maximum performance for small random reads. However, the end user can choose the appropriate RAID level depending on the number of drives and redundancy level requirements of data stored on the drives. Refer to Appendix C (RAID Guide) for more details.

Category Type: Random Reads and Writes

Applications in this category include Email Servers and Databases. The storage requirements for e-mail servers can vary depending on the size, the amount, and the type of users. While small departmental e-mail servers may work well with a small amount of storage and limited features; large corporate e-mail servers normally require greater storage capacity, very high availability, performance, and scalability. I/O profiles will vary depending on the number of users and type of mail and attachments sent.

Database servers can range from simple workgroup databases like Microsoft® Access™ with a few hundred users to critical Enterprise databases like Oracle or SQL Server with thousands of users. As a general rule, a greater the need for criticality of the database, the greater the need for data protection. Additionally, the performance requirements increase relative to the number of users accessing the database. Online Transaction Processing (OLTP) oriented servers are used in a number of industries for the entry and retrieval of transactions. These servers are generally critical and require a combination of IOPS and data redundancy.

Table 5 lists the typical database and Exchange email server I/O profile.

Application	I/O Profile		
	Read/Write	Random/ Sequential	Size
DB OLTP	70/30	100% Random	8k
Exchange Email	67/33	100% Random	4k

Table 5. Typical Database OLTP and Exchange Mail I/O Profile

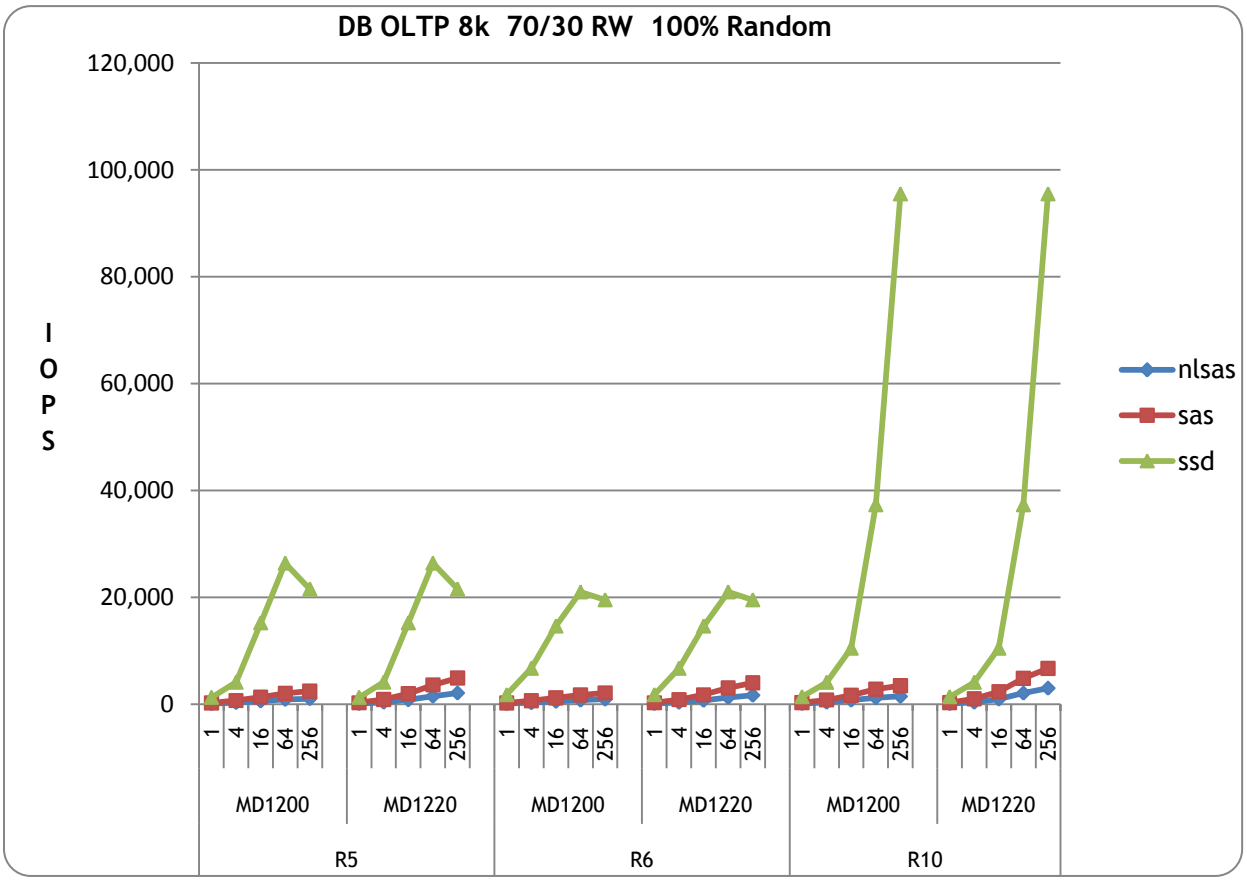

Figure 2. RAID performance comparison of Random Reads & Writes of 12/24-drive NL-SAS/SAS and 8-drive SSD arrays

RAID TYPE	ENCLOSURE	QUEUE DEPTH	NL-SAS	SAS	SSD
RAID 5	MD1200	256	1031.7	2460.6	21549.6
	MD1220	256	2090.0	4907.2	21549.6
RAID 6	MD1200	256	927.8	1994.7	19524.3
	MD1220	256	1665.6	3983.6	19524.3
RAID 10	MD1200	256	1453.9	3446.9	95514.6
	MD1220	256	2991.0	6704.0	95514.6

Table 6. Results: MAX IOPS - Database Server

RANDOM READS AND WRITES: RECOMMENDED STORAGE CONFIGURATION		
Component	**Recommendation**	**Rationale**
Enclosure	MD1220	• For Database servers with typical capacities where performance and power efficiency are more a priority, the Powervault™ MD1220 is our recommended enclosure • For E-Mail servers where large mailbox capacity is a priority, Powervault™ MD1200 is a good fit as it can provide up to 24TB of storage
Drive Type	SSDs maximum performance	• Applications that are primarily based on Random access, SSDs offer significant performance improvements over traditional hard drives however are limited by capacity • Exchange Mail and Database server applications are predominantly random read operations with small packet sizes. These characteristics are a perfect fit for SSDs
RAID Level	RAID 10	• RAID 10 is the recommended RAID level. RAID 10 has similar read performance as RAID 5 but has better write performance and Enterprise-level redundancy where multiple drive failures can occur without data loss. Refer to Appendix C (RAID Guide) for more information.

Category Type: Sequential Write Intensive

Application types in this category include Web and SQL Server Logs. Web Server and SQL server log servers are mission critical systems that require availability and redundancy to be able to recover from power failure or hardware malfunction.

Depending on size of server, web and SQL logs servers typically require large amounts of capacity to log events from daily transactions. For instance, a database server writes to its log device before a transaction result is served. These logs are typically used to rebuild the database during a critical event. Without these logs, the database will no longer be consistent and data loss unrecoverable for those transactions being executed during the event.

Table 7 provides the typical I/O profile for Web and SQL Server applications.

Application	I/O Profile		
	Read/Write	Random/Sequential	Size
Webserver Log	100% Writes	100% Sequential	8k
SQL Server Log	100% Writes	100% Sequential	64k

Table 7. Typical Webserver and SQL Log Server I/O Profile

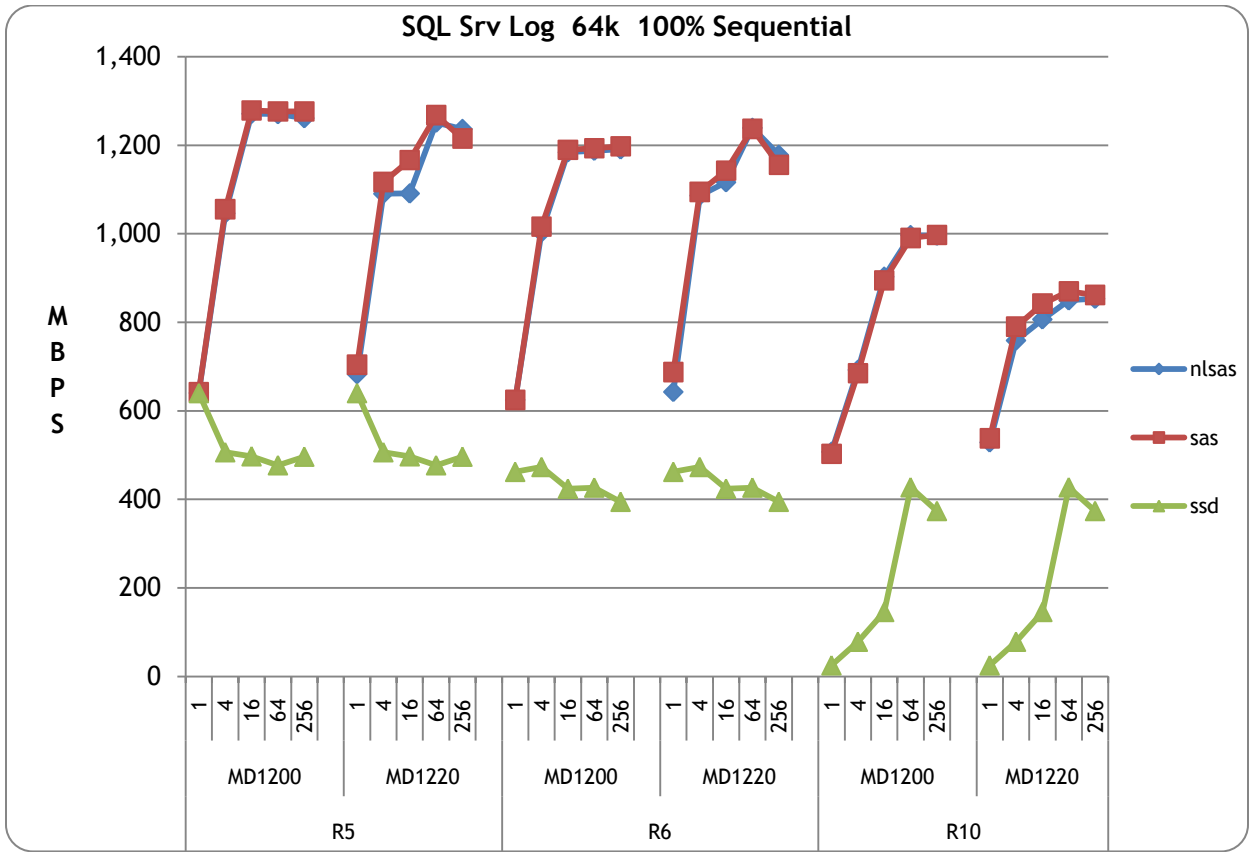

Figure 3. RAID performance comparison of Sequential Writes of 12/24-drive NL-SAS/ SAS and 8-drive SSD arrays

RAID TYPE	ENCLOSURE	QUEUE DEPTH	NL-SAS	SAS	SSD
RAID 5	MD1200	256	1261.3	1276.4	496.4
	MD1220	256	1236.8	1215.3	496.4
RAID 6	MD1200	256	1190.7	1197.3	394.4
	MD1220	256	1178.3	1155.4	394.4
RAID 10	MD1200	256	995.6	997.5	373.7
	MD1220	256	853.3	861.7	373.7

Table 8. Results: Max MBPS - SQL Server Log server applications

SEQUENTIAL WRITE INTENSIVE: RECOMMENDED STORAGE CONFIGURATION		
Component	**Recommendation**	**Rationale**
Enclosure	MD1200 Large capacity and Best streaming performance -OR- MD1220 Typical Capacity and Performance	• For servers where capacity is a priority, Powervault™ MD1200 is our recommended enclosure. 3.5'' form factor HDDs provide better streaming performance compared to 2.5'' form factor HDDs • For servers with typical capacities where performance and power efficiency are more a priority, the Powervault™ MD1220 is our recommended enclosure
Drive Type	HDDs [NL-SAS or SAS] combination performance and capacity	• Webserver log and SQL Server log workloads are sequential in nature. For Sequential applications, traditional hard drives provide a potent combination of performance and capacity which cannot be matched by SSDs
RAID Level	RAID 6	• If drive count per array is small, RAID 10 is best. If array is spread across 6 drives or more, RAID 6 will deliver optimal performance. For more detail, refer to Appendix C (RAID Guide)

Category Type: Large Block Size, Random Read Intensive

Applications in this category include Video On Demand Server (VOD) and Decision Support System Server (DSS). A typical VOD server must be capable of streaming several different movies at the same time. A good example is Netflix online streaming service. Decision Support Systems (DSS) are used by decision makers to gather useful information from a combination of inputs to solve problems and make decisions. A good example of DSS is the loan processing system used by a bank to verify the credit of the applicant. In both VOD and DSS servers, bandwidth is of prime importance.

Table 9 provides the typical I/O profiles for VOD and DSS.

Application	I/O Profile		
	Read/Write	Random/Sequential	Size
Video On Demand (VOD)	100% Reads	100% Random	512K
Decision Support Systems (DSS)	100% Reads	100% Random	1M

Table 9. Typical Video On-Demand and Decision Support System I/O Profile

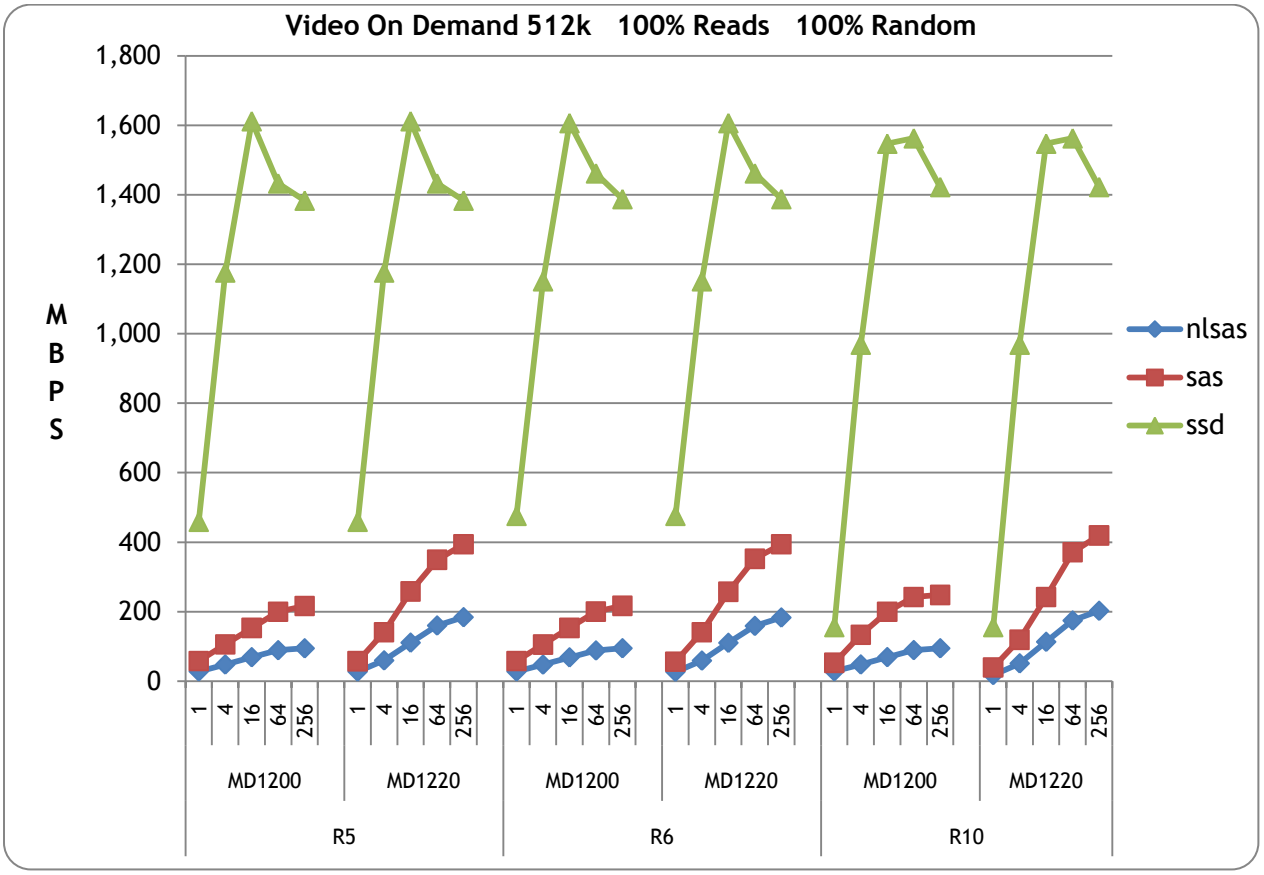

Figure 4. **Comparison of 12/24-drive NL-SAS / SAS and 8-drive SSD Virtual Drives of random read intensive workload**

RAID TYPE	ENCLOSURE	QUEUE DEPTH	NL-SAS	SAS	SSD
RAID 5	MD1200	256	94.3	216.2	1383.5
	MD1220	256	184.0	394.0	1383.5
RAID 6	MD1200	256	94.5	216.7	1388.0
	MD1220	256	183.1	393.9	1388.0
RAID 10	MD1200	256	94.4	248.0	1422.7
	MD1220	256	202.4	419.4	1422.7

Table 10. Results: Max MBPS - Video on Demand Servers

LARGE BLOCK SIZE, RANDOM READ INTENSIVE: RECOMMENDED STORAGE CONFIGURATION		
Component	**Recommendation**	**Rationale**
Enclosure	MD1220	• Since performance is the priority in VOD/DSS servers, spreading data across more spindles improves random performance
Drive Type	SSDs max performance **-OR-** HDDs [NLSAS or SAS] combination performance and capacity	• Video on Demand and Decision Support System Engine servers have huge payload sizes (512K and 1M respectively) and typically require large amounts of storage capacity • SSDs provide the best performance with limited storage capacity • NLSAS / SAS HDDs provide a combination of storage capacity and two distinct levels of performance that make them possibly a better solution
RAID Level	RAID 10	• As workloads are 100% reads, RAID 5, 6, and 10 deliver similar performance. For more detail, refer to Appendix C (RAID Guide)

Category Type: Large Block Size Sequential Read Intensive

Applications in this category include streaming media servers. Streaming media servers are systems that provide web-casting, video conferencing, Internet entertainment (for example, Internet TV or Internet radio), and multimedia services. These systems generally require a balance between storage capacity, availability, redundancy, and performance. Like web servers, they may also be part of a group of systems that work together to provide content.

Table 11 provides the typical media streaming I/O profile.

Application	I/O Profile		
	Read/Write	Random/Sequential	Size
Media Streaming	98/2	100% Sequential	64k

Table 11. Typical Media Streaming Server I/O Profile

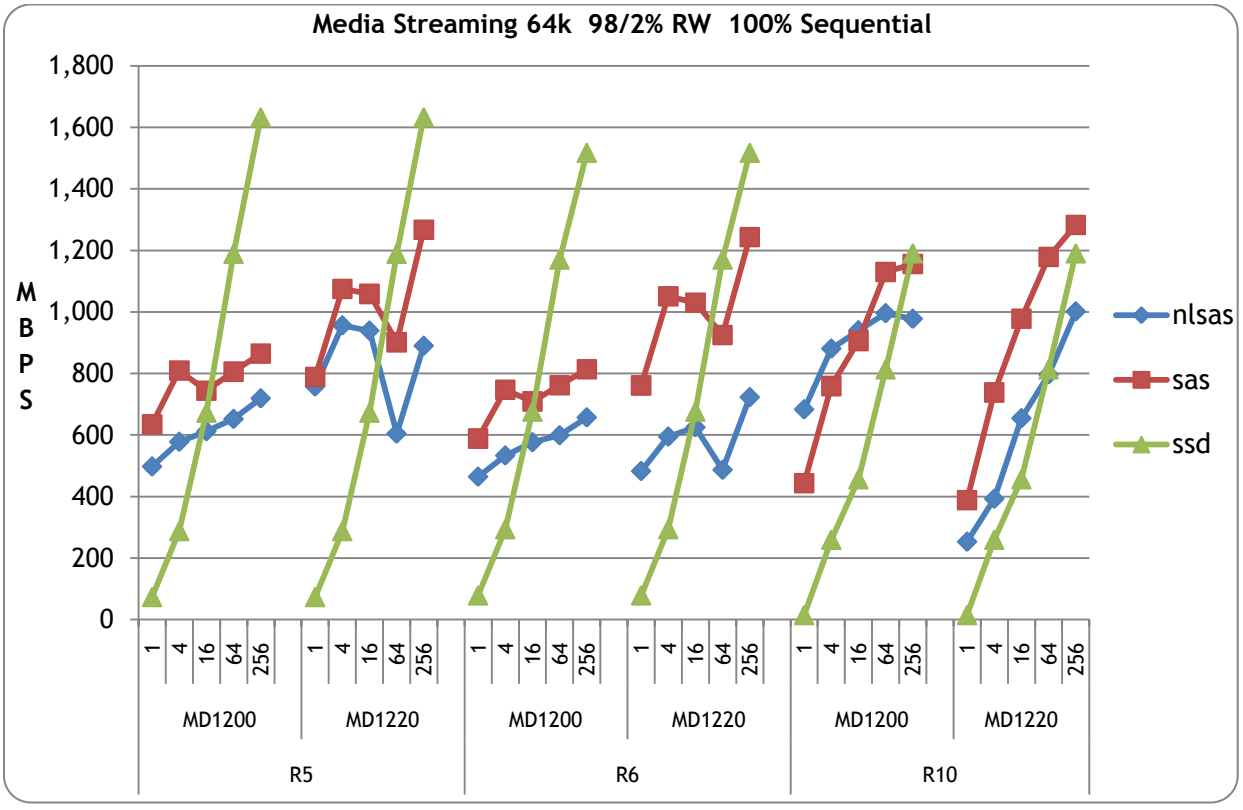

Figure 5. RAID performance comparison of Large Sequential Reads of 12/24-drive NLSAS/SAS and 8-drive SSD arrays

RAID TYPE	ENCLOSURE	QUEUE DEPTH	NL-SAS	SAS	SSD
RAID 5	MD1200	256	718.9	864.5	1633.4
	MD1220	256	889.6	1267.5	1633.4
RAID 6	MD1200	256	656.9	813.8	1518.0
	MD1220	256	722.7	1243.2	1518.0
RAID 10	MD1200	256	977.3	1155.9	1190.8
	MD1220	256	1001.3	1282.9	1190.8

Table 12. Results: Max MBPS - Media Streaming Server

LARGE BLOCK SIZE, SEQUENTIAL READ INTENSIVE: RECOMMENDED STORAGE CONFIGURATION		
Component	**Recommendation**	**Rationale**
Enclosure	MD1220 maximum performance limited capacity MD1200 capacity and performance	• Spreading data across more drives increases throughput as more spindles are being accessed concurrently. MD1220 offers up to 24 drives per enclosure • MD1200 offers less drives (12) but provides greater storage capacity with larger 3.5'' form factor drives capable of up to 2TBs per drive
Drive Type	HDDs [NL-SAS or SAS] capacity and performance	• Media Streaming applications are primarily focused on storage capacity. SSDs may perform better than HDDs at larger queue depths but cannot match the capacity of NL-SAS or SAS Drives. Until capacity of SSDs increase, HDDs are the better option
RAID Level	RAID 6	• RAID 6 is the recommended RAID level based on performance; however, RAID 5 also offers similar performance but with less redundancy protection. More details can be found in Appendix C (RAID Guide)

Summary

Performance metrics collected from various PowerVault storage solutions configured using different RAID levels, drive and enclosure types, and PERC H800 adapter settings show that each solution can achieve different performance levels depending on application type. Both traditional HDDs and recently introduced enterprise SSDs offer unique benefits depending upon I/O load profile. Each drive type offers a different combination of storage performance and capacity. If the application type is 100% random I/O, combining the PERC H800 with either the MD1220 or MD1200 matched with SSDs will deliver a new era of performance that hard drives cannot match. If the application type is switched to 100% sequential I/O, the 7.2k NL-SAS and 15k SAS drives deliver a powerful combination of optimal performance and storage capacities (up to 2TBs per 3.5'' drive w/ MD1200 enclosure) that current generation SSDs cannot match.

Table 13 summarizes the Solution Recommendations based on Application Type that will achieve maximum I/O performance.

Table 13. Solution Recommendations based on Application Type

Application		Storage Recommendations			
Server	**Key Focus**	**Enclosure**	**Drive Type**	**Controller Cache Settings**	**RAID Level***
Small Random Reads *Web Server*	Performance	**MD1220**	**SSDs**	Write Through No Read Ahead	5,6,***10**
Random Read and Writes *DB OLTP*	Performance and Scalability	**MD1220**	**SSDs**	Write Through No Read Ahead	5,6,***10**
Sequential Writes *SQL/Web Logs*	Capacity and Performance	**MD1200** Capacity and Performance	**HDDs** NL-SAS or SAS	Write Back Adaptive Read Ahead	5,***6**,10
		MD1220 Typical Capacity and Performance			
Large Random Reads *Video On Demand*	Capacity and Performance	**MD1200**	**SSDs** Max Performance Limited Capacity	No Read Ahead Write Through	5,6,***10**
			HDDs Combination performance and Capacity	Write Back Adaptive Read Ahead	
Sequential Reads *Media Streaming*	Capacity and Performance	**MD1220** max spindles max performance -OR- **MD1200** Max capacity and performance	**HDDs** NLSAS or SAS	Write Back Adaptive Read Ahead	5,***6**,10
*** RAID level that achieved max performance**					

Appendix A: About the Hardware Used

PERC H800 SATA/SAS Adapter

The PERC H800 controller is the 3rd generation SATA/SAS controller designed for a mature 6Gbps end-to-end solution with increased flexibility, scalability and I/O performance capabilities when attached to the PowerVault MD1200 and MD1200 expansion array enclosures.

Key Feature List

- PCI-Express Gen2.0 support
- 6Gb/s SAS (SAS 2.0) host interface
- Doubles throughput performance capability from previous generation of PERC
- Connectivity to a mixture of both PowerVault MD1200 and MD1220 storage enclosures

For a complete overview of the features of the H800, see the User's Guide:
http://support.dell.com/support/edocs/storage/Storlink/H700H800/en/UG/PDF/H700H800.pdf

http://www.dell.com/content/topics/topic.aspx/global/products/pvaul/topics/en/us/raid_controller?c=us&cs=555&l=en&s=biz

PowerVault MD1200/MD1220 Expandable Array Enclosure

PowerVault MD1200 and MD1220 array enclosures are the 2nd generation of Dell's energy-efficient, small-form-factor (SFF), drive expansion enclosures. The MD1200 supports a combination of twelve (12) 3.5-inch or 2.5-inch drives while the MD1220 can hold twenty-four (24) 2.5-inch drives in the same chassis. Both 3.0Gb/s and 6.0Gb/s drive types are supported by both enclosures.

The modular designs of the PowerVault MD1200 and MD1220 are designed for easy expansion for more room to store data from your server. Both enclosures can be daisy-chained together for a combination of up to 8 enclosures on one PERC H800 adapter. Up to six PowerVault MD1220 24 mixed drive expansion enclosures can be daisy-chained together on one PERC Series 7 H800 controller, giving you up to 144 mixed disk drives options. To simplify management, both PowerVault enclosures connect to and can be controlled by a single PERC H800 RAID controller-equipped PowerEdge server.

Key Feature List

- 6Gb/s SAS: 35% increase in IOPS and twice the throughput of last generation arrays
- Solid State Drives: Support for solid state drives (SSD) which have 3x the IOPs performance
- over 15K SAS2 drives , an ideal solution for applications that rely on random block access.

For a complete overview of the features of the PowerVault MD1200 and MD1220, see the User's Guide:

http://support.dell.com/support/edocs/systems/md1200/multlang/GSG/DAO_BCC/K356M.pdf

http://www.dell.com/us/en/enterprise/storage/sas/cp.aspx?refid=sas&s=biz&cs=555

http://support.dell.com/support/edocs/systems/md1200/en/index.htm

Disk Drive Technologies Measured

The 7.2k NL-SAS and 15k SAS were the first two drive types measured. Both are traditional hard disk drives (HDDs) that are built on the same internal design which is composed of rotating platters, arms, and mechanical components. SSDs are the third drive type tested. Internally, SSDs are composed of memory chips versus electro-mechanical parts found in the first two drive types, and introduce a new era of I/O performance.

7.2k NL-SAS drive

The 7.2k Nearline SAS (NL-SAS) drive is Dell's enterprise class SATA drive engineered to withstand the business operation cycle while leveraging large storage capacities from the consumer grade version. Out of the three drive types, the NL-SAS drive offers the best dollar per Gigabyte ($/GB) ratio. It is a popular choice when server applications require large amounts of capacity while still achieving good I/O performance.

15k SAS drive

The 15k SAS drive is the 2nd HDD measured inside both PowerVault enclosures. Similar in design to the 7.2k NL-SAS disk drive, the internal platters of the 15k SAS disk drive rotate twice as fast. This translates to 20-30% improvement in I/O performance over the 7.2k NL-SAS drive. This drive type is suited for mission critical applications requiring the highest reliability and the best I/O performance out of the traditional drive types offered.

Solid State Drives (SSDs)

The newest drive technology tested is the 2.5" SSD drive, Dell's first enterprise level flash drive. SSDs deliver the best I/O performance because I/O latencies are now comparable to memory access times. Results collected from applications that issue random I/Os show that SSDs are able to achieve the best I/O performance out of all the drive types measured. Additionally, the number of SSDs required to achieve this level of performance is only a fraction of the number of traditional drives needed.

Appendix B: Testing Details

Methodology

IOmeter was configured to simulate 5 workload types that represent popular I/O application patterns used by Dell customers. IOmeter generates I/O commands of different transaction sizes, queue depth and read / write ratios to the PERC RAID controller. Table 4 provides a summary of the application patterns used.

Application Pattern	Payload size	Percent Read/Write	Percent Random(R)/Sequential(S)
Web File Server	8K	95/5	75/25
DB OLTP	8K	70/30	100% Random
SQL Srv Logs	64K	100% Writes	100% Sequential
Video On Demand	512K	100% Reads	100% Random
MediaStreaming	64K	98/2	100% Sequential

Table 14. IOmeter Application Profiles

PERC H800 Cache Settings

The PERC controller uses a small amount of high performance cache memory to hold data for both reads and writes. The controller offers both read and write cache modes that can help increase application I/O performance.

Adaptive Read Ahead vs. No Read Ahead: When data is read from disk with Adaptive Read Ahead Enabled, the controller transfers data to its cache from the logical drive equal to the stripe size. I/O performance is best when the workload is mainly sequential reads and the I/O request size is larger than the stripe size. In No Read Ahead mode, the controller reads the I/O request size without reading ahead to the end of the stripe. Random read workloads or I/O requests smaller than the stripe size benefit the most from this mode.

Write Through vs. Write Back: In Write Through mode, the data bypasses cache memory and the controller must wait for the data to be written to the physical disk before returning write complete to the operating system. This is a slow process affecting I/O performance as the server thread must wait for the entire write operation to take place synchronously. In write-back mode, the RAID controller responds with write complete as soon as the data is transferred into cache. The server can continue processing additional commands instantly while the controller completes the write asynchronously. When the workload is write intensive and mostly random, Write Back mode usually results in increased performance.

For all IOmeter measurements where rotational media was used, the PERC H800 default cache modes of ***Write Back*** with ***Adaptive Read Ahead*** were used. This was done to show "out of the box" performance that can be achieved with the PERC H800, the PowerVault enclosures, and the 7.2k NL-SAS and 15k SAS drive types. Due to the high performance results of SSDs, the controller's default cache modes were set to ***No Read Ahead*** with ***Write Through*** to bypass all caching logic. Results showed that with caching logic enabled with SSDs, overall I/O performance was reduced.

Appendix C – RAID Guide

Which RAID Level is best for My Application Type?

Selecting the appropriate RAID level to implement across a storage sub-system can be a challenge. Each of the PERC H800-supported RAID levels offers a different level of redundancy, available/useable capacity, and I/O performance. Table 5 is a guide to select the best RAID level based on number of drives that can fail before data is lost, available storage capacity after the array is created, and what application type is best suited for each RAID level.

RAID Level	Available Capacity (N = total number of disks)	# of Drives that can fail	Sequential Reads (MB/s)	Sequential Writes (MB/s)	Random Reads (IOPS)	Random Writes (IOPS)
RAID 0*	N	0	Best	Best	Best	Best
RAID 5	N-1	1	Best	Better	Best	Good

RAID 6	N-2	2	Better	Better	Better	Good
RAID 10	N/2	multiple	Good	Good	Better	Better
RAID 50	N-2	2	Best	Better	Best	Good
RAID 60	N-4	4	Better	Better	Better	Good
***While RAID 0 offers the best MB/sec and IOs/sec performance, it offers no fault tolerance.**						

Table 15. Raid Guide

RAID I/O Amplification: To help understand RAID performance, it is useful to know how many physical reads and/or writes must occur when a logical read or write is issued to the RAID array. As we know RAID 0 offers no data integrity, one (1) logical read or write maps to one (1) physical read/write. Logical reads on RAID5, RAID6, RAID 10, RAID50, and RAID60 arrays all translate to one (1) physical read as no data is being written to the arrays. Once a single write is issued to the same RAID levels, their performance is impacted by the parity calculation write penalty. Table 16 summarizes RAID I/O amplification for RAID levels measured in this paper.

	RAID 0	RAID 5	RAID 6	RAID 10	
1 Logical Read	1	1	1	1	Physical Read I/O
	0	0	0	0	Physical Write I/O
1 Logical Write	0	2	3	0	Physical Read I/O
	1	2	3	2	Physical Write I/O

Table 16. I/O Amplification

RAID Levels Measured and Analyzed

The PERC H800 offers hardware RAID support with the following RAID levels: RAID 0,1,5,6,10,50, and 60. All performance metrics collected in these tests were with virtual drives implementing the four RAID levels: RAID 0, RAID 5, RAID 6 and RAID 10.

RAID 0 - RAID 0 offers the highest throughput rates amongst all other RAID levels no fault tolerance as data is only striped across the disk array. The group reliability decreases as more disks are added to the RAID 0 disk array. RAID 0 should only be considered where performance is critical and data loss is acceptable. The throughput of the array will be the aggregate transfer capacity of all the disks, limited only by the throughput of the PERC Adapter.

RAID 5 - RAID 5 offers fault tolerance by generating and using block level parity information. All drives participate and store parity information. If a disk should fail in the array, data is reconstructed from parity with the surviving disks data blocks "on the fly"; I/O continues to the array seamlessly, though with some performance degradation. Once the failed drive is replaced, array rebuilding can begin and the performance degradation disappears once complete.

RAID 6 - RAID 6 provides protection against double disk failures as well as failures while a single disk is rebuilding, by using striping in combination with parity information; each stripe maintains two disk blocks with parity. RAID 6 is not as efficient as RAID 5 or 10 when used with a small number of drives, as a significant amount of storage capacity is lost. However, as arrays become bigger and consist of more drives, the loss of storage capacity is not as great. In the case where there is only one array, it may make more sense to use RAID 6 over having a dedicated hot spare disk.

RAID 10 - RAID 10 helps ensure fault tolerance and availability with a striped and mirrored disk pair sub-system. As every disk has a mirrored copy, this RAID level uses more physical disks to provide redundancy than other RAID levels as half of the drives in the array are being used as only mirrored copies. Unlike RAID 0, RAID10 volumes must write data twice due to mirroring but are written simultaneously.

Appendix D. Hardware Description

Test Platform – PowerEdge R610	
Processor	(2) E5530 2.4Ghz, 8M Cache, Turbo, HT
System BIOS	1.0.4
Memory	16GB
OS	Microsoft Windows Server 2008 R2
IOmeter Version	2006.07.27

PowerEdge RAID Controller H800	
Raid on chip	LSI 2108
Data Transfer Rate	Up to 6Gb/s per port
Cache Memory Size	512MB
Caching Methods	Read: No/Always/Adaptive Write: Write Back/Write Through
Battery Backup	Yes
Firmware Version	12.3.0-0031
Driver	Dell 4.23.0.64

Hard Drives used in PowerVault MD1220			
	7.2k NL-SAS	15k SAS	SSD
Manufacturer	Seagate	Seagate	Pliant
Model	ST9500430SS	ST9146852SS	LB150
Drive Firmware	DS63	HT62	D011
Capacity	500GB	146GB	150GB

Hard Drives used in PowerVault MD1200			
	7.2k NL-SAS	15k SAS	SSD
Manufacturer	Seagate	Seagate	Pliant
Model	ST32000444SS	ST3600057SS	LB150
Drive Firmware	KS68	ES62	D011
Capacity	2TB	600GB	150GB

Appendix E. Results of Configuration 1: PERC H800 Attached to PowerVault MD1220

IOPS	Queue Depth	R0 nlsas	R0 sas	R0 ssd	R5 nlas	R5 sas	R5 ssd	R6 nlsas	R6 sas	R6 ssd	R10 sas	R10 sas	R10 ssd
WebFileSvr 4K; 95/5 RW; 75/25% Random	1	87.07	214.55	666.03	95.92	226.40	435.67	97.04	224.63	958.24	73.78	173.94	2506.25
	4	294.62	719.87	11534.73	297.99	721.75	6612.12	294.77	718.69	10339.28	244.02	622.40	11690.04
	16	900.55	2260.40	23646.27	871.55	2186.07	19459.67	859.41	2141.66	27016.92	842.23	1984.46	25892.32
	64	2234.53	5604.81	66165.91	2033.06	5067.18	56956.69	1928.07	4882.84	60056.39	2261.88	5572.54	66130.33
	256	3819.74	9324.43	185586.36	3442.83	8322.15	73574.01	3199.79	7791.23	66107.86	4154.96	9850.94	114274.04
WebFileSvr 8K; 95/5 RW; 75/25% Random	1	87.99	211.60	426.63	90.76	221.20	626.93	92.02	221.03	1525.67	72.44	171.98	1323.28
	4	291.16	710.75	8955.39	291.78	705.02	5290.48	286.00	704.45	7910.91	245.53	616.91	7000.64
	16	849.91	2204.16	19957.68	846.10	2132.72	15549.19	832.66	2078.19	19711.89	814.47	1936.47	16582.29
	64	2094.04	5237.94	50506.09	1944.00	4789.53	46962.70	1860.07	4575.51	48347.31	2170.96	5303.54	50132.23
	256	3550.76	8626.75	150745.32	3207.70	7719.60	68691.64	2979.05	7278.92	61486.73	3859.69	9116.71	112889.50
WebFileSvr 64K; 95/5 RW; 75/25% Random	1	67.61	176.17	176.92	71.19	177.86	195.24	70.48	178.11	556.71	56.76	139.95	300.31
	4	241.15	581.58	2677.16	234.94	578.40	1895.13	233.73	574.15	2636.56	203.96	481.81	2435.75
	16	616.89	1561.62	6784.89	608.58	1498.23	5933.66	574.40	1456.37	6991.10	581.32	1385.70	5936.76
	64	1219.97	2939.63	19240.35	1140.84	2735.76	17461.82	1097.93	2651.58	15771.14	1269.06	2998.60	17855.12
	256	1835.09	4322.55	29015.47	1699.30	3962.66	24488.66	1617.74	3796.23	20860.82	1963.63	4518.14	27001.22
DB OLTP 8K; 70/30 RW; 100% Random	1	100.65	263.47	1035.57	106.60	259.28	1266.57	107.24	260.96	1763.73	100.23	279.40	1385.37
	4	382.13	982.07	3288.98	350.21	896.06	4097.05	329.69	852.86	6703.24	345.58	1010.26	4080.53
	16	1023.62	2615.82	12106.09	810.39	1962.22	15212.65	712.60	1760.31	14609.16	940.78	2318.29	10460.54
	64	2165.98	5316.18	48208.32	1487.54	3604.12	26387.75	1257.33	3050.77	21005.59	2062.69	4852.22	37310.61
	256	3318.65	7937.82	131387.72	2090.08	4907.26	21549.67	1665.66	3983.64	19524.30	2991.08	6704.40	95514.67
Exch Email 4k; 67/33 RW; 100% Random	1	102.59	280.21	2203.64	111.50	279.14	2899.22	117.42	276.99	2957.33	92.47	223.85	2153.18
	4	406.90	1021.12	7585.03	368.13	945.00	9577.30	347.98	902.21	8992.11	349.56	951.79	7065.34
	16	1095.52	2774.90	22952.62	833.22	2042.07	19955.36	742.77	1817.65	17962.41	993.84	2405.59	17362.84
	64	2327.05	5714.58	58168.25	1528.79	3727.08	26748.57	1271.89	3118.75	21223.53	2173.74	5081.33	46591.80
	256	3548.92	8496.98	148423.13	2118.33	4946.63	22126.50	1671.15	3920.74	19768.25	3132.15	7081.02	106121.70
OS Drive 4K; 70/30 RW; 100% Random	1	98.01	270.36	698.00	108.13	263.68	1039.22	105.91	267.59	1815.79	88.79	212.62	1667.59
	4	393.92	989.54	4801.50	370.96	905.38	3987.73	359.25	874.14	6238.64	355.88	940.90	5676.63
	16	1074.48	2728.85	13588.92	839.62	2053.74	15154.95	741.40	1831.27	14708.17	971.39	2363.78	13351.32
	64	2286.37	5620.15	48172.00	1549.16	3814.81	26359.43	1293.33	3213.61	20951.20	2179.59	5105.83	38704.56
	256	3505.84	8469.82	131576.65	2174.46	5220.16	21512.03	1738.43	3989.68	19503.55	3181.42	7308.49	95740.98

MBPS	Queue Depth	R0 nlsas	R0 sas	R0 ssd	R5 nlsas	R5 sas	R5 ssd	R6 nlsas	R6 sas	R6 ssd	R10 nlsas	R10 sas	R10 ssd
Websvr log 8K 0/100 RW 100% Sequential	1	186.32	174.04	2.98	186.32	205.36	178.11	164.12	196.48	194.82	162.91	184.11	2.30
	4	368.13	364.82	13.65	368.13	391.38	349.66	370.80	389.15	344.92	286.46	321.00	8.44
	16	619.37	604.56	27.45	619.37	682.29	574.03	650.27	674.65	547.75	466.60	484.21	20.85
	64	887.58	904.10	75.51	887.58	971.94	493.99	948.53	975.40	455.10	664.36	689.74	62.19
	256	1099.15	1031.04	329.82	1099.15	1186.21	491.85	1144.90	1161.99	427.58	811.19	838.24	271.59
Sqlsvr log 64K 0/100 RW; 100% Sequential	1	682.96	629.12	13.49	682.96	704.07	639.84	642.84	687.61	462.06	528.73	537.90	25.15
	4	1090.61	1091.38	78.44	1090.61	1116.86	506.42	1086.46	1094.62	473.05	759.05	790.09	78.45
	16	1091.13	1085.77	153.86	1091.13	1166.67	497.29	1116.51	1142.44	424.00	806.73	842.20	145.70
	64	1251.09	1254.47	605.39	1251.09	1268.01	476.98	1239.28	1236.96	426.55	849.56	870.05	427.21
	256	1236.79	1219.98	964.04	1236.79	1215.25	496.38	1178.27	1155.44	394.43	853.28	861.72	373.65
OS Paging 64K 90/10 RW; 100% Sequential	1	453.80	637.22	20.65	453.80	617.25	19.48	280.97	577.95	52.15	175.83	296.97	61.88
	4	551.03	846.35	199.92	551.03	704.67	135.06	322.60	648.88	186.05	276.01	506.34	213.34
	16	528.80	844.88	428.38	528.80	708.43	261.07	326.24	655.78	356.19	466.88	606.52	442.81
	64	313.42	574.36	1063.27	313.42	476.33	688.92	244.24	453.60	698.81	548.13	747.04	705.47
	256	482.10	884.90	1812.95	482.10	703.52	1342.39	381.62	662.63	1146.41	706.59	814.17	1154.09
Media Streaming 64K; 98/2 RW; 100% Sequential	1	757.33	772.45	10.94	757.33	788.43	73.46	482.62	761.14	78.76	253.11	387.99	14.87
	4	955.79	1309.59	212.53	955.79	1074.43	287.83	594.49	1050.61	294.05	392.48	738.23	259.59
	16	938.84	1254.03	515.90	938.84	1058.80	672.93	624.93	1029.90	676.31	654.35	977.77	456.36
	64	604.13	1028.60	1204.84	604.13	901.55	1189.43	486.56	924.84	1170.76	796.37	1179.04	813.62
	256	889.60	1455.92	1800.66	889.60	1267.53	1633.37	722.73	1243.19	1517.95	1001.29	1282.99	1190.82
VOD; 512K; 100/0 RW; 100% Random	1	27.32	51.42	55.38	27.32	57.20	458.90	26.79	55.92	476.02	17.23	39.39	155.79
	4	59.43	139.86	1040.62	59.43	141.01	1176.63	58.86	140.58	1151.34	50.87	119.20	968.86
	16	110.62	257.69	1630.20	110.62	258.05	1612.12	110.11	257.17	1606.72	113.03	242.19	1547.47
	64	159.99	349.53	1560.15	159.99	349.33	1433.16	158.87	352.21	1462.01	174.45	370.75	1562.89
	256	183.99	394.11	1488.61	183.99	393.96	1383.48	183.06	393.87	1387.95	202.44	419.47	1422.66
DSS 1M; 100/0 RW; 100% Random	1	32.24	65.50	444.03	32.24	66.50	512.24	33.07	67.90	647.48	32.24	66.50	576.29
	4	47.94	111.88	1380.92	47.94	124.72	1373.81	55.57	146.20	1363.06	47.94	124.72	1144.31
	16	138.38	314.30	1737.12	138.38	315.09	1719.51	138.30	315.29	1711.74	138.38	315.09	1678.37
	64	186.25	396.73	1508.18	186.25	396.64	1409.49	184.53	398.16	1410.70	186.25	396.64	1445.45
	256	194.80	415.98	1508.05	194.80	417.27	1410.32	194.48	417.48	1409.35	194.80	417.27	1445.28

Appendix F. Results of Configuration 2: PERC H800 Attached to PowerVault MD1200

IOPS	Queue Depth	R0 nlsas	R0 sas	R0 ssd	R5 nlsas	R5 sas	R5 ssd	R6 nlsas	R6 sas	R6 ssd	R10 nlsas	R10 sas	R10 ssd
WebFileSvr 4K 95/5 RW; 75/25%Random	1	86.57	203.84	666.03	93.09	205.81	435.67	90.05	204.24	958.24	153.87	235.04	2506.25
	4	277.18	629.98	11534.73	283.78	636.35	6612.12	282.05	631.76	10339.28	246.74	718.54	11690.04
	16	753.60	1723.23	23646.27	740.31	1643.46	19459.67	726.45	1602.36	27016.92	386.86	1832.53	25892.32
	64	1448.07	3273.11	66165.91	1330.60	3011.09	56956.69	1265.63	2885.58	60056.39	556.57	3487.28	66130.33
	256	2067.84	4710.60	185586.36	1856.68	4233.83	73574.01	1748.32	3979.58	66107.86	694.06	4888.78	114274.04
WebFileSvr 8K 95/5 RW 75/25%Random	1	79.36	196.59	426.63	87.48	195.47	626.93	87.33	198.40	1525.67	501.11	226.29	1323.28
	4	270.01	597.96	8955.39	263.76	599.30	5290.48	256.78	587.81	7910.91	707.52	687.00	7000.64
	16	735.15	1674.81	19957.68	696.48	1571.57	15549.19	667.72	1539.20	19711.89	834.68	1764.34	16582.29
	64	1377.07	3097.62	50506.09	1250.30	2811.59	46962.70	1195.37	2701.44	48347.31	840.98	3290.81	50132.23
	256	1923.70	4382.53	150745.32	1727.26	3942.36	68691.64	1620.98	3701.04	61486.73	839.65	4512.27	112889.50
WebFileSvr 64K 95/5 RW 75/25%Random	1	69.56	160.10	176.92	68.68	157.17	195.24	69.22	158.68	556.71	151.89	184.75	300.31
	4	208.60	481.19	2677.16	203.87	462.27	1895.13	199.51	448.20	2636.56	313.59	538.37	2435.75
	16	463.62	1059.16	6784.89	435.17	989.60	5933.66	418.52	959.76	6991.10	362.97	1093.77	5936.76
	64	754.75	1687.23	19240.35	700.22	1574.70	17461.82	682.82	1525.13	15771.14	494.19	1794.97	17855.12
	256	994.29	2265.80	29015.47	911.87	2091.05	24488.66	860.34	2006.45	20860.82	481.01	2321.45	27001.22
DB OLTP 8K; 70/30 RW 100% Random	1	100.73	235.30	1035.57	98.46	232.63	1266.57	97.32	219.54	1763.73	361.91	265.33	1385.37
	4	331.65	765.46	3288.98	298.85	676.96	4097.05	268.26	634.28	6703.24	555.64	786.65	4080.53
	16	764.88	1739.93	12106.09	583.42	1325.10	15212.65	518.25	1178.46	14609.16	626.11	1681.97	10460.54
	64	1316.74	3047.09	48208.32	878.83	2025.16	26387.75	743.30	1714.78	21005.59	776.23	2801.42	37310.61
	256	1750.44	4145.90	131387.72	1031.78	2460.66	21549.67	927.87	2108.66	19524.30	903.18	3446.90	95514.67
Exch Email 4k 67/33 RW 100% Random	1	107.30	249.79	2203.64	105.00	244.06	2899.22	109.94	240.44	2957.33	24.46	272.83	2153.18
	4	357.25	830.64	7585.03	310.43	710.95	9577.30	277.36	652.62	8992.11	61.82	828.63	7065.34
	16	806.08	1853.24	22952.62	601.45	1381.09	19955.36	530.11	1207.19	17962.41	95.20	1787.55	17362.84
	64	1411.68	3282.28	58168.25	910.37	2106.91	26748.57	754.26	1751.14	21223.53	117.32	2964.24	46591.80
	256	1872.90	4507.70	148423.13	1057.78	2471.69	22126.50	841.87	1994.73	19768.25	119.13	3678.39	106121.70
OS Drive 4K 70/30 RW 100% Random	1	102.39	238.83	698.00	96.35	231.75	1039.22	96.74	227.50	1815.79	60.31	267.73	1667.59
	4	346.94	792.40	4801.50	301.15	705.97	3987.73	271.78	651.64	6238.64	123.89	814.39	5676.63
	16	792.82	1821.50	13588.92	612.03	1388.17	15154.95	542.12	1227.16	14708.17	173.20	1758.40	13351.32
	64	1400.20	3237.72	48172.00	927.30	2146.03	26359.43	787.03	1797.74	20951.20	196.14	2955.98	38704.56
	256	1857.36	4466.97	131576.65	1106.89	2612.23	21512.03	982.99	2048.53	19503.55	197.52	3628.87	95740.98

MBPS	Queue Depth	R0 nlsas	R0 sas	R0 ssd	R5 nlsas	R5 sas	R5 ssd	R6 nlsas	R6 sas	R6 ssd	R10 nlsas	R10 sas	R10 ssd
Websvr log 8K 0/100 RW 100% Sequential	1	171.62	175.44	2.98	177.04	185.30	178.11	175.35	180.49	194.82	171.62	158.13	2.30
	4	309.58	322.49	13.65	324.58	339.07	349.66	332.97	332.92	344.92	309.58	275.85	8.44
	16	505.55	487.59	27.45	514.85	525.83	574.03	438.52	474.06	547.75	505.55	401.13	20.85
	64	658.45	718.64	75.51	653.89	661.68	493.99	668.48	732.77	455.10	658.45	584.30	62.19
	256	889.82	969.21	329.82	874.34	857.95	491.85	800.04	920.07	427.58	889.82	721.33	271.59
Sqlsvr log 64k 0/100 RW 100% Sequential	1	655.83	650.40	13.49	640.54	642.51	639.84	624.75	624.62	462.06	517.22	502.60	25.15
	4	1067.03	1069.05	78.44	1046.20	1055.38	506.42	1003.61	1016.03	473.05	750.32	684.86	78.45
	16	1401.07	1391.97	153.86	1271.35	1278.74	497.29	1184.22	1189.75	424.00	808.79	894.81	145.70
	64	1464.50	1765.24	605.39	1270.32	1276.18	476.98	1187.69	1193.17	426.55	803.30	990.47	427.21
	256	1447.35	1775.63	964.04	1261.25	1276.41	496.38	1190.69	1197.34	394.43	806.18	997.49	373.65
OS Paging 64K 90/10 RW 100% Sequential	1	415.05	639.66	20.65	281.36	407.66	19.48	249.10	343.45	52.15	415.05	184.06	61.88
	4	475.38	741.49	199.92	304.33	434.44	135.06	261.96	364.75	186.05	475.38	463.11	213.34
	16	451.19	632.85	428.38	293.76	403.52	261.07	258.31	345.00	356.19	451.19	545.61	442.81
	64	573.58	746.48	1063.27	365.84	468.92	688.92	327.81	411.04	698.81	573.58	730.46	705.47
	256	666.25	648.19	1812.95	388.97	471.83	1342.39	336.30	417.60	1146.41	666.25	708.64	1154.09
MediaStreaming 64K 98/2 RW 100% Sequential	1	683.01	781.96	10.94	497.47	634.98	73.46	464.44	588.50	78.76	683.01	443.62	14.87
	4	880.43	1116.72	212.53	577.62	809.56	287.83	533.18	746.84	294.05	880.43	759.21	259.59
	16	939.98	987.12	515.90	611.88	743.87	672.93	576.18	709.04	676.31	939.98	905.87	456.36
	64	995.58	1102.54	1204.84	651.99	805.99	1189.43	598.88	761.31	1170.76	995.58	1129.85	813.62
	256	977.27	1185.45	1800.66	718.97	864.53	1633.37	656.98	813.82	1517.95	977.27	1155.90	1190.82
VOD; 512K 100/0 RW 100% Random	1	28.07	58.47	55.38	27.75	57.98	458.90	27.72	51.42	476.02	28.07	52.71	155.79
	4	47.66	105.40	1040.62	47.57	105.96	1176.63	47.26	139.86	1151.34	47.66	133.23	968.86
	16	68.92	152.91	1630.20	68.69	153.01	1612.12	68.15	257.69	1606.72	68.92	199.68	1547.47
	64	89.15	200.16	1560.15	88.79	199.90	1433.16	88.02	349.53	1462.01	89.15	241.85	1562.89
	256	94.41	215.95	1488.61	94.29	216.25	1383.48	94.52	394.11	1387.95	94.41	248.07	1422.66
DSS 1M 100/0 RW 100% Random	1	43.11	91.82	444.03	43.32	89.82	512.24	42.11	65.50	647.48	43.11	127.65	576.29
	4	77.60	165.25	1380.92	76.57	166.62	1373.81	77.14	111.88	1363.06	77.60	254.97	1144.31
	16	103.30	216.23	1737.12	102.16	217.48	1719.51	104.99	314.30	1711.74	103.30	347.33	1678.37
	64	121.41	255.43	1508.18	121.04	258.12	1409.49	124.21	396.73	1410.70	121.41	374.16	1445.45
	256	119.40	255.46	1508.05	119.07	257.09	1410.32	122.84	415.98	1409.35	119.40	373.42	1445.28