Efficiency Assessment of Stormwater Treatment Vaults in the Round Hill General Improvement District – Draft Final Report

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EXECUTIVE SUMMARY

The Round Hill General Improvement District submitted a grant proposal for an extensive erosion control and water quality improvement project in 2001. The Desert Research Institute and the Tahoe Research Group were contracted to provide environmental monitoring for this project. The goal of the monitoring program was to perform an effectiveness evaluation of several proprietary stormwater treatment vaults that receive stormwater runoff from low-density residential neighborhoods near the southeast side of the Lake Tahoe Basin.

To meet the goals of the monitoring program, a meteorological station was installed at the office of the general improvement district to provide storm intensity and duration data. A treatment vault monitoring and sampling system was established to provide stormwater runoff volume data and to collect water quality samples from the influent and effluent portion of each treatment vault. Monitoring wells were also installed downstream of the treatment vaults to investigate the fate of nutrients discharged from the vaults. To better investigate the performance of the CDS and Vortechnics treatment vaults, they were cleaned at the end of water years 2003 and 2004. The material removed by this cleaning was analyzed for total mass, nutrient content and sediment size.

Flow measurement instrumentation and automatic sampling equipment provided characterization of urban runoff in the Round Hill subdivision. Pollutant concentrations of influent runoff are similar to those observed in other localities in the Lake Tahoe Basin with similar land uses. Attempts were made to determine treatment vault efficiencies by subtracting outflow loads of pollutants from the inflow loads. While this method is viable for the dissolved nutrients, it underestimated the removal efficiencies of sediment and particulate nutrients. There are several explanations for the underestimation of vault efficiencies by this method. The most important reason is that autosamplers do not effectively sample large sediment. This under accounts for larger particulates delivered to, and retained by the vaults. Additionally, sampling only occurs during large runoff or storm events. Small events and gradual snow-melt which have very low runoff rates could not be sampled with the selected equipment.

Results from treatment vault cleanout showed that flow measurements and automatic sampling equipment can not provide all the information necessary to assess treatment vault efficiency. At the end of the water year in 2003 and 2004, the Vortechnics and CDS vaults were cleaned of accumulated sediment, pine needles, and debris. Vault accumulation estimates from the site instrumentation were very different from the actual mass of material removed from the vaults. However, the data from the site instrumentation is critical to assessing how efficiently the treatment vaults retain sediment and nutrients.

Vault retention efficiencies were estimated using information derived from flow monitoring and the use of autosamplers combined with the information derived from analysis of material removed from treatment vaults at the end of each water year. A key assumption made in this assessment is that although autosamplers do not adequately sample influent waters because of their inability to sample the larger particles, they do describe the effluent waters since the larger particles are removed by the treatment vaults. The retention efficiencies are estimated using the following formula:

$$\text{Retention efficiency} = \frac{(\text{mass of vault constituent})}{(\text{mass of vault constituent} + \text{calculated outflow load of constituent})}$$

Using this formula, the research team estimated that the vaults were between 59 and 95 percent efficient at removing solids, 23 to 75 percent efficient at removing total nitrogen, and 7 to 18 percent efficient at removing total phosphorus. The vaults successfully retained 6 to 24 percent of soluble phosphorous species. Dissolved nitrogen species retentions were highly variable and sometimes negative. This result agrees with other recent studies in the Basin which indicate that biologic activity within stormwater vaults is a likely contributor to the occasionally increased nitrogen loads coming from these vaults.

The monitoring project has shown that water discharged from the stormwater treatment vaults meets standards for discharge to groundwater for almost all events. It should be noted that the stormwater entering the vaults also usually meets these standards. Discharge from the Vortechnics and CDS treatment vaults quickly infiltrates the permeable soils in this region. Chemical analyses from monitoring wells downgradient of the discharge from the vaults show that the vegetation and soils significantly reduce nutrient concentrations. Median concentrations for dissolved nitrogen species within these wells were 52-59% of vault effluent concentrations. Median concentrations of dissolved phosphorous species were 16-18% of vault effluent concentrations. However, these treatment levels may be temporary and more work is needed to assess this reduction process and determine how long these soils can adsorb these nutrients.

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INTRODUCTION

Lake Tahoe has been losing its water clarity at a long-term rate of about 0.25 meters per year. This is due to an excess loading of nutrients and fine sediment particles to the lake over the last several decades (Jassby *et al.*, 1999).

In an effort to control these excess loadings, resource management agencies in the Lake Tahoe Basin have adopted a variety of measures, including source control and erosion control projects, purchase of sensitive lands, construction of structural best management practices (BMPs), and implementation of nonstructural BMPs (strategic programs). Efficiency of many of these BMPs at removing nutrients and sediments from stormwater runoff in the Lake Tahoe Basin has not been evaluated. While these practices may perform well in other parts of the country, they may be less effective in the subalpine environment at Lake Tahoe, where winter storms account for the bulk of annual precipitation.

Stormwater vaults are one of the most common structural BMPs used in urbanized areas, including the Tahoe Basin. Typically installed underground or under pavement, these vaults provide stormwater treatment with a relatively small footprint. There are several different proprietary configurations of the stormwater treatment vault, and it is unclear to what degree they can provide treatment for dissolved nutrients and fine sediments, which are the primary pollutants affecting lake clarity.

Infiltration of stormwater runoff is another important strategy for the Lake Tahoe Basin restoration program. Both on-site and engineered infiltration are promoted as BMPs due to the natural filtration and adsorption properties of many soils. These are the same processes that naturally deliver clean water to supply wells, springs, rivers, and lakes. It is known, however, that these processes are not equally effective for all pollutants, and additional studies are needed in the Tahoe Basin to assess impacts from long-term urban stormwater infiltration.

In February 2001, the Round Hill General Improvement District (RHGID) submitted a grant application for extensive erosion control and water quality improvements within subdivision Unit No. 4 of its jurisdiction. The proposed elements of this project included slope stabilization, storm drain, curb and gutter, revegetation, stormwater treatment vaults, stormwater treatment basins, and SEZ restoration. The Desert Research Institute (DRI) and the Tahoe Research Group at the University of California, Davis (TRG UCD), were asked to submit a proposal to the Nevada Division of State Lands (NDSL) for a License Plate grant to provide monitoring as the Round Hill project was implemented. During the course of the Round Hill water quality improvement project the objectives of the monitoring project changed several times. The history of this project is presented in Appendix 1.

The data in this report primarily address the effectiveness of stormwater treatment vaults in reducing nutrient and sediment loads of stormwater runoff from a residential development in the RHGID, located on the southeast side of the Lake Tahoe Basin (Figure 1). Additional data on the soils and groundwater characteristics of the area downgradient from these vaults are also presented.

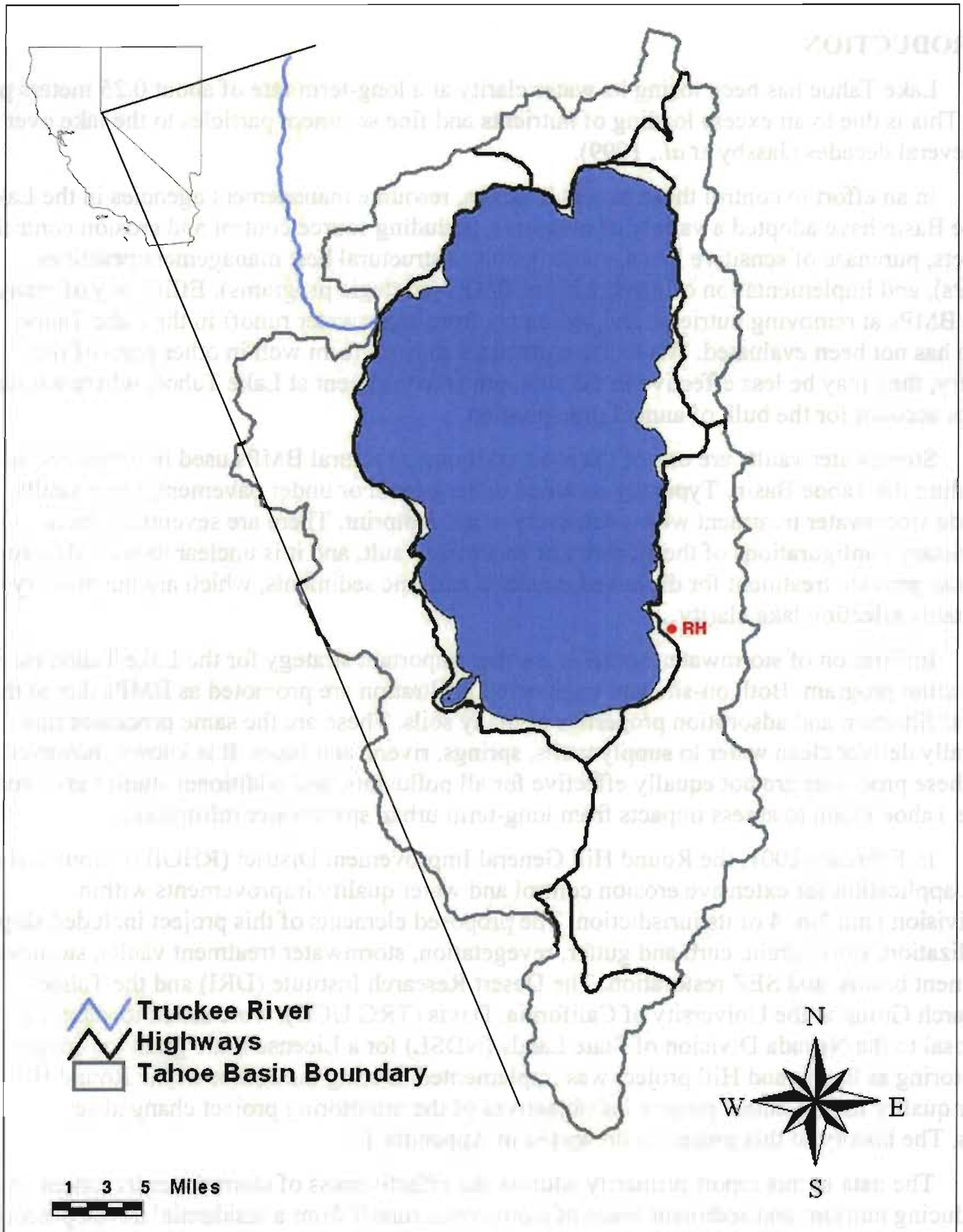

Figure 1. Location of the study area, Round Hill General Improvement District Subdivision Unit No. 4.

OBJECTIVES

This study focused on evaluating the nutrient and sediment retention characteristics of stormwater treatment vaults in the Round Hill residential area at Lake Tahoe. It was not designed to provide a comparative assessment of performance by each vault. Although both the CDS and the Vortechnics vaults were installed adjacent to each other in the drainage, they receive neither the same volumes of inflow, nor the same source runoff influent. Rather, the intent of this work was to provide data on the effectiveness of hydrodynamic treatment vaults in general at removing nutrients and sediment from stormwater runoff in this area, and to make a contribution toward more comprehensive characterization of stormwater runoff from low-density residential areas in the Lake Tahoe Basin. Just prior to the final year of stormwater monitoring the Jensen stormwater treatment vault was installed at the junction of Elks Point Road and McFaul Lane. Although the time of installation and budgetary constraints did not allow the same level of investigation on the Jensen vault, monitoring and sampling equipment were installed during WY2004 to characterize influent and effluent waters.

The four primary objectives were:

1) Quantitatively describe the nutrient and sediment concentrations of stormwater influent to the treatment vaults and compare to stormwater effluent concentrations after vault treatment under a variety of runoff conditions throughout two complete water years (WY2003 and WY2004).
2) Measure the mass retention of sediments and nutrients by cleaning each vault and quantifying the total sediment accumulation after each water year. Determine the annual retention of total sediment and nutrients, and compare to retention estimates from water quality monitoring in a mass-balance approach.
3) Measure nutrient concentrations in groundwater downgradient of the treatment vaults. Compare these values to vault effluent concentrations and assess relative to land treatment discharge standards.
4) Characterize soil in the stormwater infiltration area at the lower Round Hill boundary of the McFaul and Devaux drainage. Describe particle size, infiltration rates, and nutrient concentration of soil samples collected from within this terminal infiltration area.

DESCRIPTION OF DRAINAGE AREAS

The overall watershed of the RHGID project area contains about 290 acres of forested and shrub-covered lands, interspersed with residential areas. The area of interest in this report is focused on those drainages that contribute to the three stormwater treatment vaults monitored during WY2003 and WY2004, as shown in Figure 2.

The Jensen stormwater treatment vault receives runoff primarily from Elks Point Road. There is no significant residential development along this drainage, and the adjoining forested area has not been observed to add much volume to total runoff.

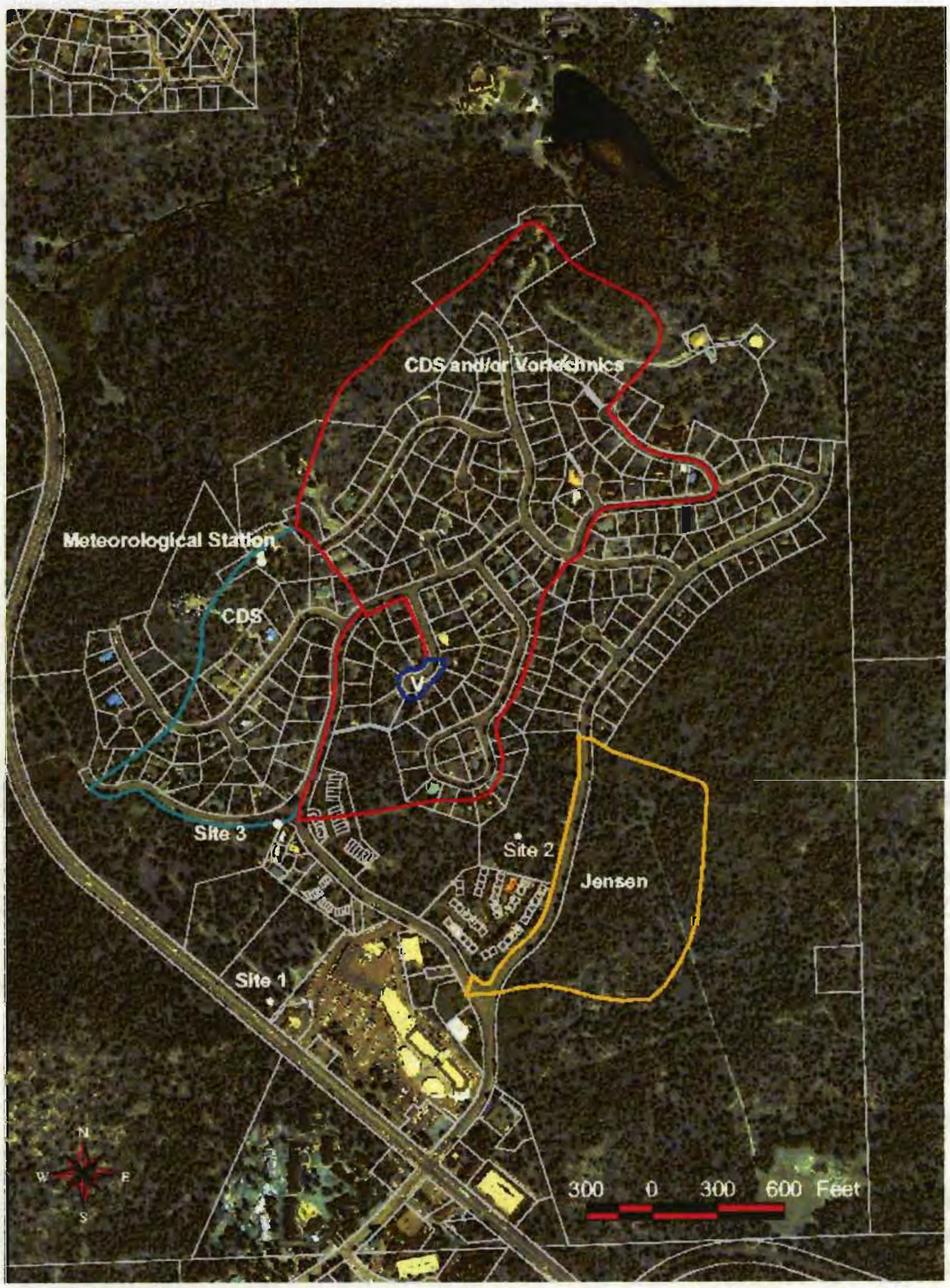

Figure 2. Round Hill GID, showing Hwy 50, instrument sites 1, 2, and 3, meteorological station and stormwater treatment vault drainage areas. Area contributing to the CDS vault is outlined in green, the area contributing to the Vortechnics vault is outlined in blue, the area contributing to either or both the CDS and Vortechnics vaults is outlined in red, and the area contributing to the Jensen vault is outlined in yellow.

Runoff to the CDS stormwater treatment vault and the Vortechnics stormwater treatment vault is more complicated. A significant portion of the total runoff is from a drainage that contributes to either or both stormwater treatment vaults. Whether runoff goes to the CDS vault, the Vortechnics vault or distributed between the vaults depends on conditions in the distribution vault and cannot be refined any better than what is shown in Figure 2. However, from individual vault monitoring in WY2004, it appears that the CDS vault receives about three times the runoff volume of the Vortechnics vault, suggesting that a larger area of the mixed drainage contributes runoff to the CDS vault. The land use in the drainage areas for the Vortechnics and CDS vaults consist primarily of single family residents with a few multifamily residential lots and several vegetated undeveloped lots (Figure 3).

Water Year 2002

The meteorological station was installed at the Round Hill GID on December 12, 2001. Althought this record does not cover the entire water year it likely represents the majority of the precipitation that fell that water year. Figure 4 shows the precipitation and cumulative precipitation that was recorded that year. A total of 26 events occurred (Appendix 2) that produced a 6.93 inches of precipitation during this period of record. Of the three years that precipitation was monitored at Round Hill, this was the smallest accumulation the site received (See Table 1). The highest accumulation rate was recorded during a convective storm event which occurred on July 17 and 18, 2002. This event began in the evening of the July 17 but most of the precipitation occurred in the late morning and early afternoon of the July 18. The total accumulation of this event was 0.39 inches, however, 0.2 inches fell within one hour on the morning of the July 18.

Water Year 2003

Water year 2003 received substantially more precipitation than measured during WY2002, including several high-intensity summer storms (Figure 5). The highest rainfall rate was 0.28 inches in a 0.5-hour period on August 21, 2003, during a thunderstorm that lasted 13.5 hours and delivered 1.21 inches of precipitation. Total precipitation during the water year was 20.9 inches. A total of 40 precipitation events were measured in WY2003, where individual events are defined as separated by a minimum 24-hour period without precipitation. Note that five events during this period measured only 0.01 inch of total precipitation, which may represent spurious data points instead of actual precipitation (Appendix 2).

Water Year 2004

Water year 2004 produced 17.69 inches of precipitation, with relatively few summer convective storms (Figure 6) compared to WY2003. An extended data gap exists in the meteorological record at Round Hill from July 21, 2004 through September 8, 2004, when power was inadvertently disconnected at the site. However, a review of the data record from a meteorological station 6 km to the west (Fire House) indicates that no precipitation fell in South Lake Tahoe during the period of this data gap at Round Hill. The highest rainfall rate during WY2004 was 0.20 inches per 0.5-hour period on July 1, 2004, during a summer storm that lasted 28.5 hours and delivered 0.27 inches of precipitation. A total of 32 precipitation events were measured during WY2004, with three events during this period measuring only 0.01 inch of precipitation (Appendix 2).

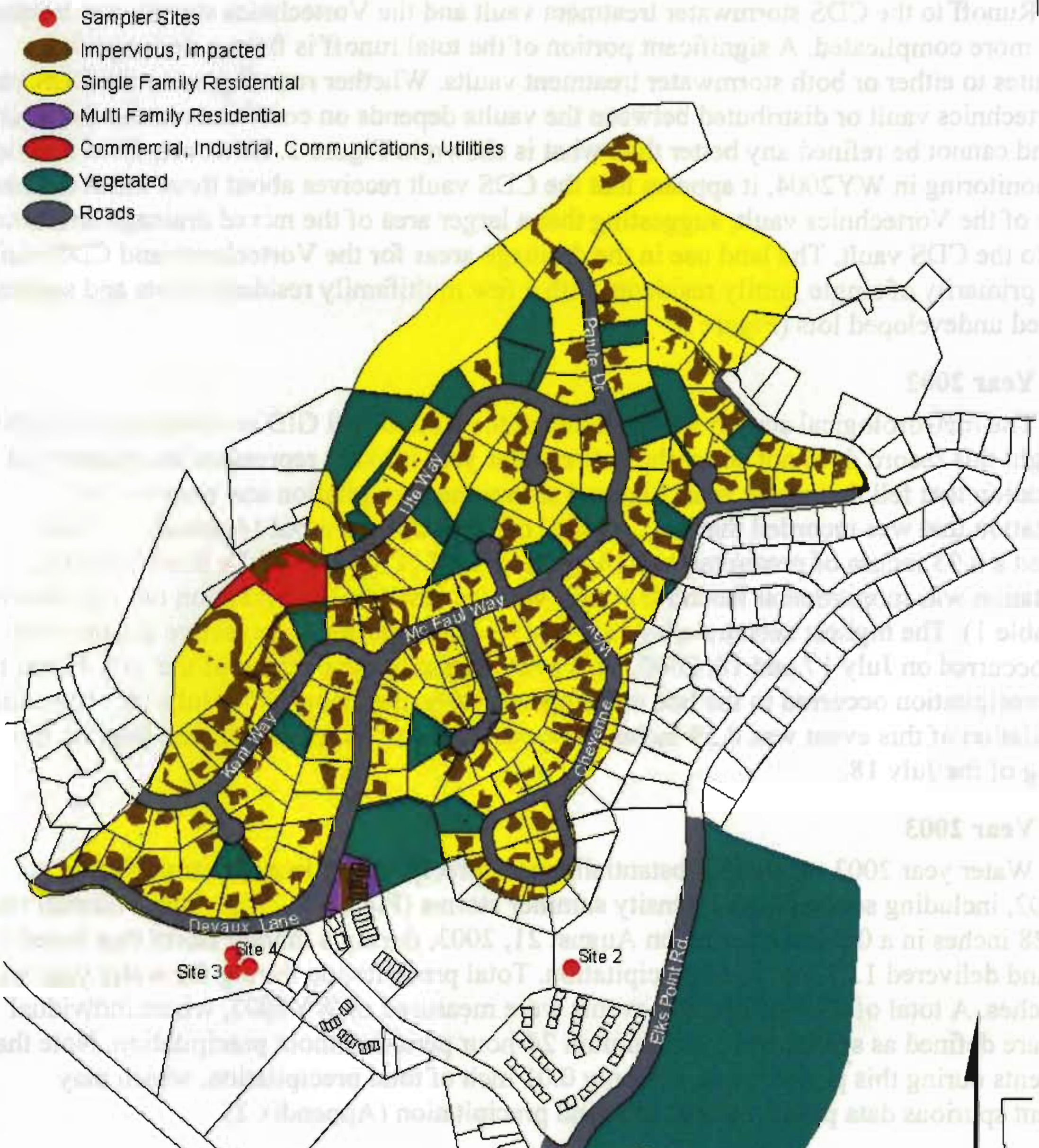

Figure 3. Distribution of land-use types in drainages contributing to the CDS, Vortechnics and Jensen stormwater vaults. Sampler locations are labeled with red dots.

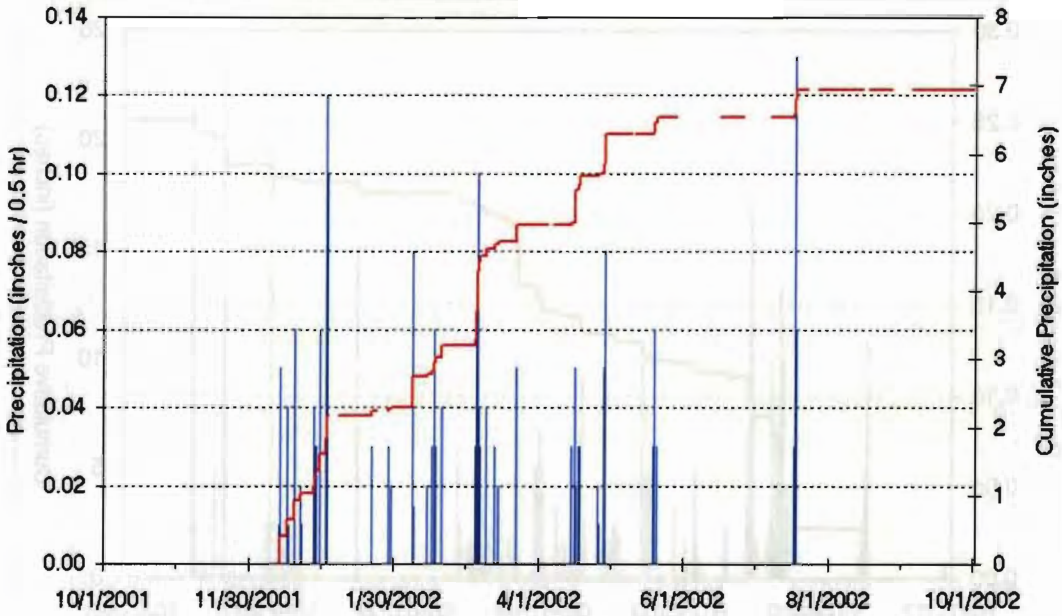

Figure 4. Precipitation event intensity and cumulative precipitation during WY2002 (December 12, 2001 through September 30, 2002).

Table 1. Round Hill meteorological station event summary for WY2002, WY2003, and WY2004.

Water Year	Number of events	Total Precipitation (inches)	Maximum intensity (in/30 min)	Average event peak intensity (in/30 min)	Average Event Length (hr)	Average Event Accumulation (inches)	Maximum Event Accumulation (inches)
2002*	26	6.93	0.13	0.05	11	0.27	1.3
2003	40	20.90	0.28	0.07	22.5	0.52	5.11
2004	32	17.69	0.2	0.07	17	0.55	2.76

*Data record began 12/12/2001

It is worth noting that despite several relatively large events during both WY2003 and WY2004, there was never any observed runoff into the proposed infiltration basin areas, where monitoring Site 1 and monitoring Site 2 had been installed during the initial phase of this project. This illustrates the permeable nature of soils in the lower drainage areas of the RHGID.

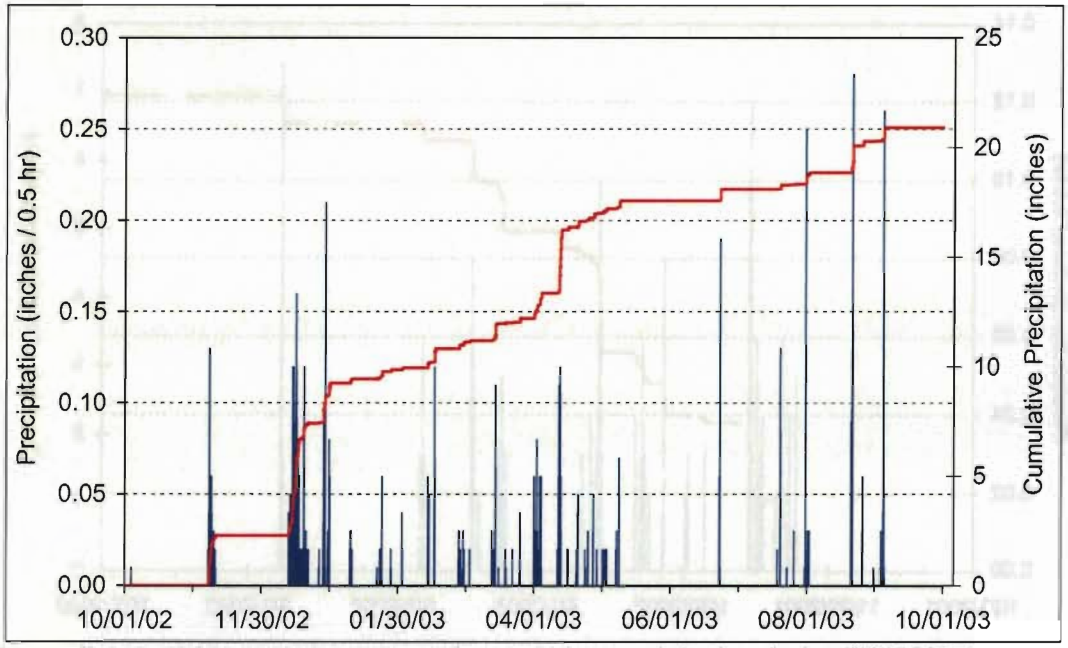

Figure 5. Precipitation event intensity and cumulative precipitation during WY2003 (October 1, 2002 through September 31, 2003).

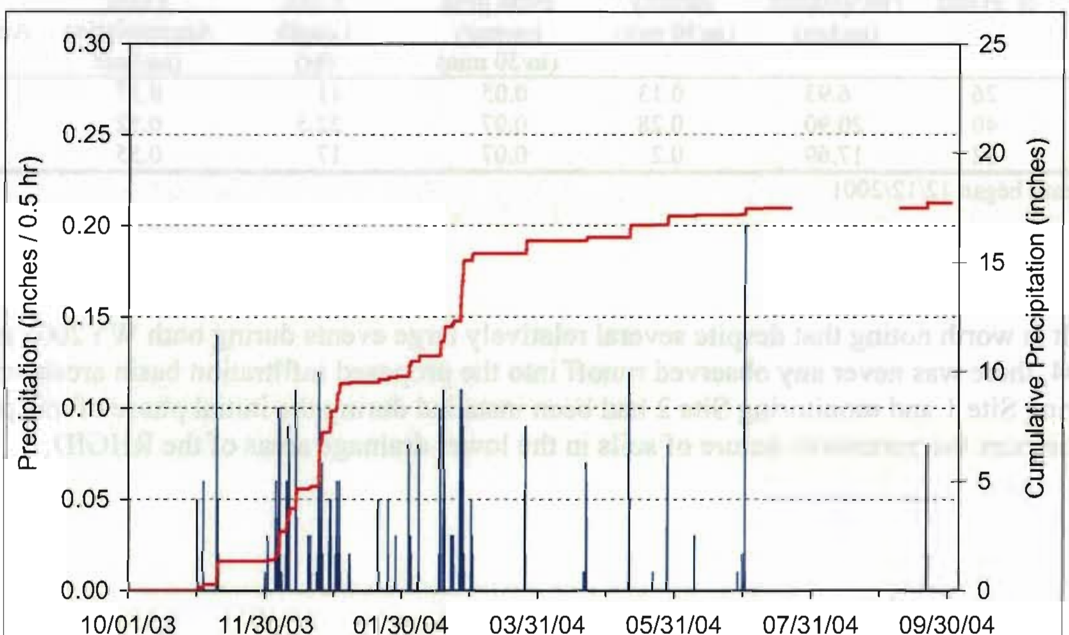

Figure 6. Precipitation event intensity and cumulative precipitation during WY2004 (October 1, 2003 through September 31, 2004).

VAULT DESCRIPTIONS

CDS Stormwater Treatment Vault

The CDS stormwater treatment vault at Round Hill was designed to treat a maximum flow of 14 ft^3/s. It has a sump volume of 150.8 ft^3 or 1,128 gallons and the separation chamber has a volume of 297.6 ft^3 or 2,226 gallons. Water from the stormwater drain flows through the diversion weir which allows bypass to occur when discharge exceeds the capacity of the stormwater treatment vault. The diversion weir diverts water into the separation chamber where the induced vortex separates suspended and fine sediments to the center of the chamber for eventual settling to the sump (See Figure 7). The separation chamber is fitted with a stainless steel screen which is continuously cleaned by the vortex and filtered water is allowed to pass through. After flowing beneath the oil baffle, the filtered water is discharged to the environment. More detailed descriptions and pictures can be obtained from their web site at cds@cdstech.com. During the course of the projects several questions arose concerning the design and operation of the stormwater treatment vaults. The questions and answers are presented in Appendix 3.

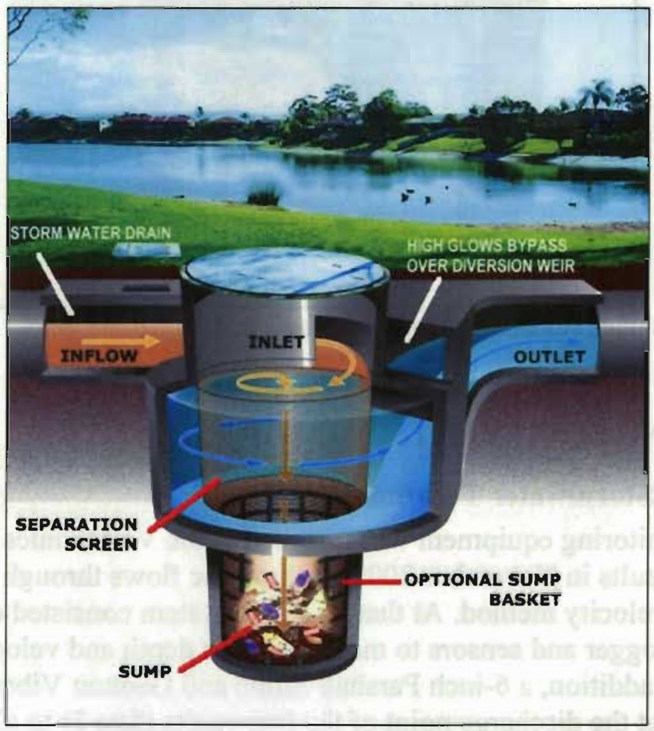

Figure 7. The CDS stormwater treatment vault conceptual diagram.

Vortechnics Stormwater Treatment Vault

The Vortechnics stormwater treatment vault at Round Hill is designed for a peak flow of 14 ft^3/s. The treatment vault has internal dimensions of 9' by 15' with a 3' sump. This gives it a volume of aproximatley 380 ft^3 or 2,842 gallons. Stormwater enters the unit tangentially to the grit chamber, which promotes a gentle swirling motion. As water circles within the grit chamber, pollutants migrate toward the center of the unit where velocities are the lowest. The majority of settlable solids are left behind as stormwater exits the grit chamber through two apertures on the perimeter of the chamber. Buoyant debris, oil and grease are separated from water flowing under the baffle wall due to their relatively low specific gravity. Stormwater exits the system through the flow control wall and ultimately to the environment.

The flow control wall is extremely important in the design of the Vortechnics stormwater treatment vault. The low flow orifice is configured to submerge the inlet pipe during storm events to reduce the velocity and energy in the system. At peak flows, the Cippoletti weir is used to gradually raise the upstream water surface elevation to prevent washout at peak flows (Figure 8). More detailed descriptions and pictures of the Vortechnics stormwater treatment vault can be obtained from their web site at www.vortechnics.com. As with the CDS stormwater treatment vault installation, several questions arose concerning the design and operation of the Vortechnics stormwater treatment vault. These questions and answers are presented in Appendix 4.

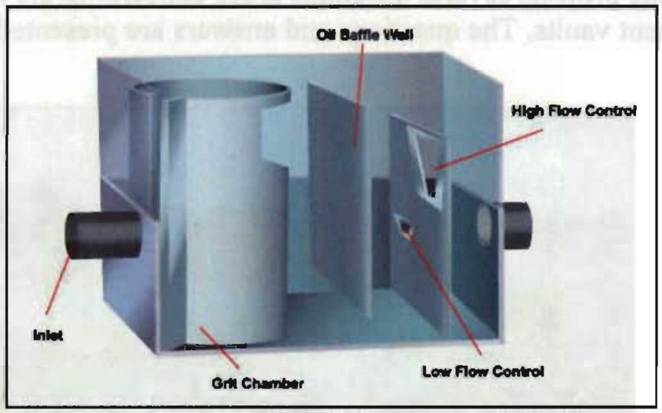

Figure 8. The Vortechnics stormwater treatment vault conceptual diagram.

VAULT MONITORING EQUIPMENT

CDS and Vortechnics Stormwater Treatment Vaults

Stormwater monitoring equipment was installed at the Vortechnics and the CDS stormwater treatment vaults in November 2002. Volumetric flows through each vault were to be calculated by the area-velocity method. At that time, the system consisted of a Campbell Scientific CR23X datalogger and sensors to measure water depth and velocity in the influent pipes of both vaults. In addition, a 6-inch Parshall flume and Geokon Vibrating wire weir monitor were installed at the discharge point of the two vaults (Site 3) to allow more accurate determination of total volumetric discharge. The individual flows through each vault were to be determined by measuring water velocities with Rocky Mountain Instruments GEOtivity VMT-1 ultrasonic doppler velocity sensors, and by calculating flow areas from depth measurements with Druck PDCR 1830 pressure transducers. However, turbulent flow in the stormwater pipes and large sediment accumulations where the sensors were installed made determination of water velocity a difficult parameter to measure.

Due to these difficulties, the system was reconfigured for the 2003-2004 monitoring season (WY2004). An additional Campbell Scientific CR10X datalogger was installed to allow monitoring of each vault separately. A new 3-inch Parshall flume was installed at the outflow of the Vortechnics vault, and the original 6-inch Parshall flume was reset to measure flow from the

CDS vault. These two outflow flumes replaced the original Site 3 flume configuration at this same location, and were thereafter designated as Site 4 outflow flumes, to distinguish from earlier data produced at this location with the original Site 3 flume. Figure 9 is a schematic of the site showing the placement of the sampler inlet strainers, vaults, auto samplers, and monitoring wells.

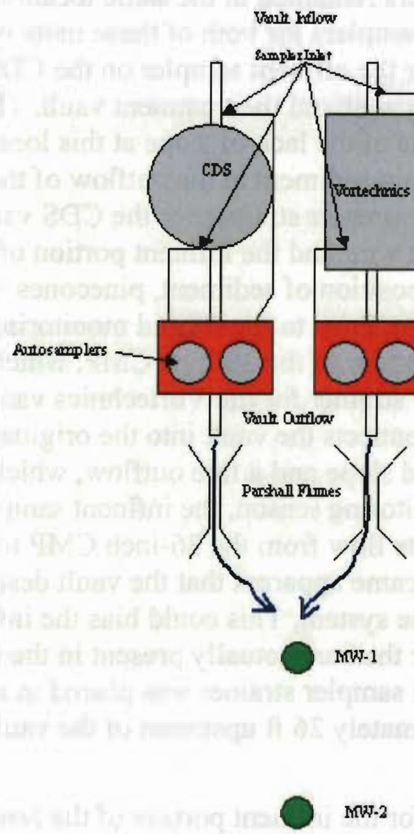

Figure 9. Schematic showing location of sampler inlet strainers, vaults, auto samplers, and monitoring wells. Monitoring Well 1 (MW-1) is located 79 feet downstream of vault outflow and MW-2 is located 157 feet downstream. Note diagram is not to scale.

Jensen Stormwater Treatment Vault

The Jensen stormwater treatment vault was instrumented in January 2004. This monitoring site was also instrumented with a Campbell Scientific CR10X datalogger, a Druck PDCR 1830 pressure transducer, and a GEOtivity VMT-1 ultrasonic doppler velocity sensor. Discharge was determined by the area velocity method with sensors installed in the 12-inch-diameter pipe that connects the collection vault with the treatment vault. Although this method to determine discharge is not the most accurate, there were no locations in the Jensen vault configuration that would allow monitoring with a flume.

Campbell Scientific CS547A water temperature and specific conductance probes were installed at the influent and effluent portion of all three vaults. Data from these sensors were used to verify when discharge was occurring at each location.

Water samples were collected at each monitoring site with Isco 3700 autosamplers, which use a peristaltic pump to draw water from an inlet strainer. One of the more important aspects of using autosamplers to monitor stormwater is the placement of the autosampler inlet strainer. This placement is important so as not to bias samples and pull the most representative sample possible. During the two years of monitoring the CDS and Vortechnics vaults at Round Hill, the strainer for the effluent samplers remained in the same location for both vaults, however, the strainers for the influent samplers for both of these units were relocated after the first monitoring season. The strainer for the effluent sampler on the CDS vault was located in the plastic connector between the diversion weir and the treatment vault. This placement allowed sampling small flow events, but because of the lack of slope at this location, samples could be biased because of deposition of fine-grain sediment at the outflow of the treatment vault. During the first monitoring season the influent sampler strainer for the CDS vault was placed in the plastic connector between the diversion weir and the influent portion of the treatment vault. However, this location experienced deposition of sediment, pinecones, pine needles, and garbage, which clogged the inlet strainer. Prior to the second monitoring season, the influent sampler strainer was relocated in the bottom of the 36-inch CMP, which was away from any active deposition. The effluent sampler strainer for the Vortechnics vault was installed in the 12-inch-diameter discharge pipe that connects the vault into the original 36-inch corrugated metal pipe (CMP). This pipe has a good slope and a free outflow, which would preclude deposition in the pipe. In the first monitoring season, the influent sampler strainer was placed in the 12-inch-diameter pipe, which directs flow from the 36-inch CMP to the Vortechnics vault. After the first year of monitoring, it became apparent that the vault design caused water and sediment to back up in this region of the system. This could bias the inflow samples; that is, the influent concentrations could be higher than are actually present in the influent waters. In the second year of monitoring, the influent sampler strainer was placed in a 2-inch-diameter pipe that received stormwater from approximately 26 ft upstream of the vault inlet. This reduced the potential for sample bias.

The autosampler inlet strainer for the influent portion of the Jensen vault was located in the 12-inch-diameter pipe that connects the collection vault with the treatment vault. The effluent autosampler strainer was located in the 12-inch-diameter discharge pipe which conveyed treated effluent under the road to a detention pond located 600 ft south of the vault.

VOLUMETRIC DISCHARGE

During the two years of monitoring at the CDS and Vortechnics stormwater treatment vaults in the RHGID, data were collected to determine discharge through the system. For the 2002-2003 monitoring season (WY2003), discharge from both vaults was directed into a 6-inch Parshall flume. Figure 10 shows the annual hydrograph for that monitoring season. During WY2003, a total of 676,115 gallons (90,397 ft^3) passed through the vaults.

For the 2003-2004 monitoring season (WY2004), a second Parshall flume was added to the monitoring system. Figure 11 shows the annual discharge hydrographs from each vault over this monitoring period. During WY2004, a total of 496,000 gallons (66,298 ft^3) passed through these treatment vaults. This volume is somewhat less than the volume from the previous water year, because WY2003 produced more precipitation than WY2004. Also, during WY2003, over 270,000 gallons (36,090 ft^3) of runoff were produced by summer thunderstorms, which were almost absent during WY2004. The bulk of precipitation during WY2004 fell as winter snow.

Compared to summer thunderstorms, the winter snowfalls are much less likely to produce equivalent runoff due to prolonged infiltration and sublimation of the snowpack.

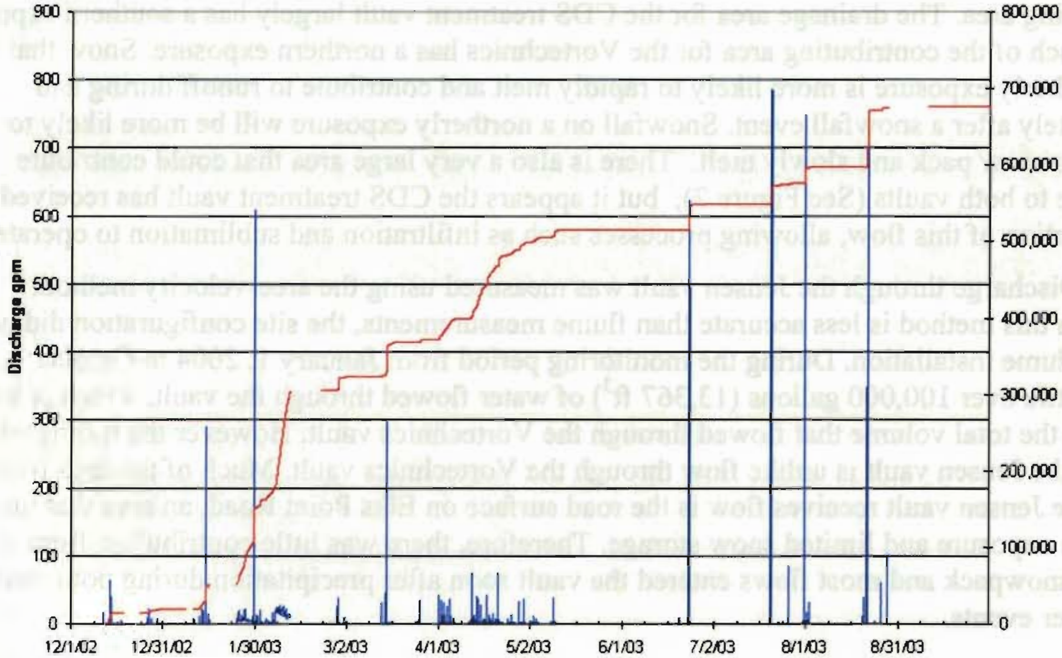

Figure 10. Hydrograph of discharge from the CDS and Vortechnics stormwater treatment vaults, WY2003. Blue lines show instantaneous discharge and red lines indicate cumulative discharge.

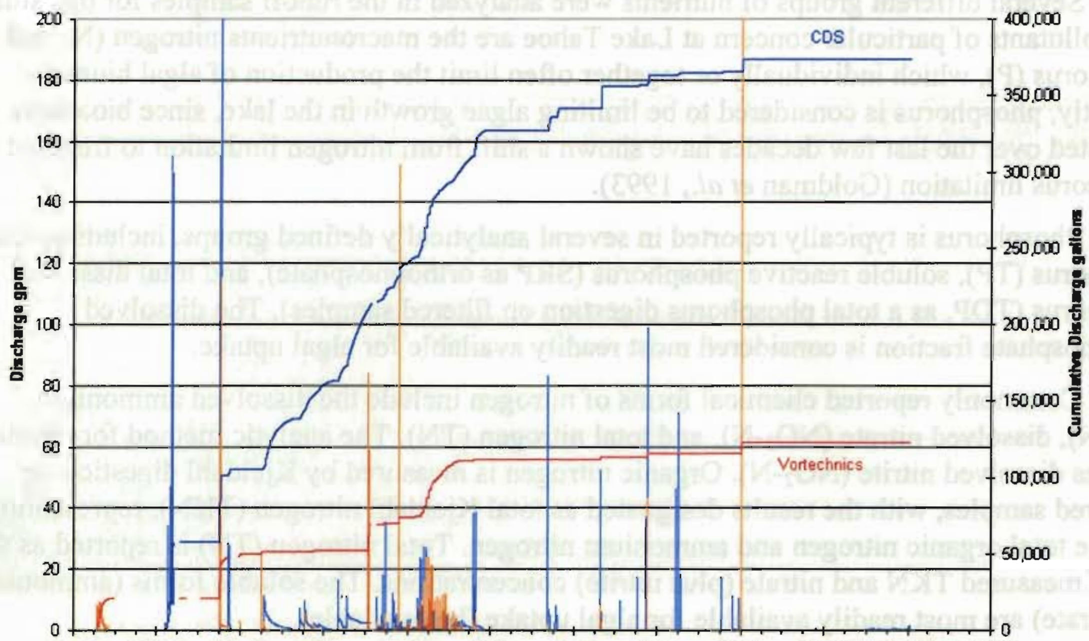

Figure 11. Hydrograph showing separate discharge records for the CDS and Vortechnics stormwater treatment vaults during WY2004.

Another important aspect of the hydrograph for the 2003-2004 monitoring season is distribution of flow through each vault. The CDS treatment vault received three times the volumetric discharge of the Vortechnics vault. There are many factors that contribute to the different flow regimes for each vault, but one major influencing factor would be the aspect of the contributing area. The drainage area for the CDS treatment vault largely has a southern exposure, while much of the contributing area for the Vortechnics has a northern exposure. Snow that falls on a southerly exposure is more likely to rapidly melt and contribute to runoff during and immediately after a snowfall event. Snowfall on a northerly exposure will be more likely to remain as snow pack and slowly melt. There is also a very large area that could contribute discharge to both vaults (See Figure 2), but it appears the CDS treatment vault has received the larger portion of this flow, allowing processes such as infiltration and sublimation to operate.

Discharge through the Jensen vault was measured using the area-velocity method. Although this method is less accurate than flume measurements, the site configuration did not allow a flume installation. During the monitoring period from January 1, 2004 to October 1, 2004 a little over 100,000 gallons (13,367 ft^3) of water flowed through the vault, which is a little less than the total volume that flowed through the Vortechnics vault. However the timing of flow through the Jensen vault is unlike flow through the Vortechnics vault. Much of the area from which the Jensen vault receives flow is the road surface on Elks Point Road, an area that has good sun exposure and limited snow storage. Therefore, there was little contribution from a melting snowpack and most flows entered the vault soon after precipitation during both summer and winter events.

WATER QUALITY SAMPLING AND ANALYSIS

Nutrient Analysis

Several different groups of nutrients were analyzed in the runoff samples for this study. Two pollutants of particular concern at Lake Tahoe are the macronutrients nitrogen (N) and phosphorus (P), which individually or together often limit the production of algal biomass. Currently, phosphorus is considered to be limiting algae growth in the lake, since bioassays conducted over the last few decades have shown a shift from nitrogen limitation to frequent phosphorus limitation (Goldman *et al.*, 1993).

Phosphorus is typically reported in several analytically defined groups, including total phosphorus (TP), soluble reactive phosphorus (SRP as orthophosphate), and total dissolved phosphorus (TDP, as a total phosphorus digestion on filtered samples). The dissolved orthophosphate fraction is considered most readily available for algal uptake.

Commonly reported chemical forms of nitrogen include the dissolved ammonium (NH_4-N), dissolved nitrate (NO_3-N), and total nitrogen (TN). The analytic method for nitrate includes dissolved nitrite (NO_2-N). Organic nitrogen is measured by Kjeldahl digestion on unfiltered samples, with the results designated as total Kjeldahl nitrogen (TKN), representing both the total organic nitrogen and ammonium nitrogen. Total nitrogen (TN) is reported as the sum of measured TKN and nitrate (plus nitrite) concentrations. The soluble forms (ammonium and nitrate) are most readily available for algal uptake (bioavailable).

In this report, total suspended solids (TSS) represent the concentration of particles greater than 1.2 microns (Whatman GF/C filter nominal pore size) but less than 1 mm (pre-screening). Recently, it has been shown that fine suspended sediment particles less than 10 microns in size substantially degrade the water clarity of Lake Tahoe (Swift, 2004). Sample storage conditions and subsequent analytic methods are shown in (Table 2), along with the detection and reporting limits for methods in use at TRG laboratories.

Table 2. Sample storage and analytic methods, with Method Detection Limits (MDL) and Reported Detection Levels (RDL) for the UCD TRG laboratory.

Analyte	Preferred Holding	Analytic Method	Analysis Description	MDL	RDL
Orthophosphate (OP or SRP)	In dark at 4°C, up to 7 days	EPA 365.1 SM 4500-PE	Colorimetric, phosphomolybdate	0.5 μg/L	1.0 μg/L
Total Phosphorus (TP or TDP)	In dark at 4°C, up to 28 days or freeze	EPA 365.3 USGS I-4600-85	Colorimetric, persulfate digestion, phosphomolybdate	0.5 μg/L	2.0 μg/L
Nitrate + Nitrite (NO_3-N+NO_2-N)	In dark at 4°C, up to 7 days	EPA 353.2 EPA 353.1	Colorimetric, cadmium reduction or hydrazine	0.5 μg/L	2.0 μg/L
Ammonium (NH_4-N)	In dark at 4°C, up to 7 days	EPA 350.1	Colorimetric, phenate	0.5 μg/L	3.0 μg/L
Total Kjeldahl Nitrogen (TKN)	In dark at 4°C, up to 28 days or freeze	EPA 351.2	Colorimetric, block digestion, phenate	25 μg/L	40 μg/L
Total Suspended Solids (TSS)	In dark at 4°C, up to 7 days	EPA 160.2	Gravimetric	0.1 mg/L	1 mg/L
Turbidity	In dark at 4°C, up to 48 hours	EPA 180.1 EPA 2130B	Nephelometric	0.1 NTU	1 NTU

Sample Collection

To determine treatment efficiency of the stormwater treatment vaults, autosamplers were used to collect samples from the influent and effluent portion of each vault. Sampling for this program was initiated when volumetric discharge rose above a predetermined trigger level. Sampling then continued at a set time interval until discharge dropped below the trigger level. The time interval used between sample collection during winter months was nominally 1 hour and during the summer months it was 10 minutes. The time interval of 1 hour used in the winter allowed continuous sampling during a typical Pacific frontal system storm, with sufficient time to retrieve samples and reload the autosamplers with clean bottles to continue sampling longer events. The 10-minute interval used during summer months allowed collection of several samples during the short-duration, convective events typical of summer storms.

Samples were collected on an event basis and transported to the UCD TRG laboratory in Tahoe City, CA, for processing and analysis. Analytic data were then compiled with flow data for the calculation of event mean concentration (EMC), as described below for a typical winter runoff event with the usual 1-hour sampling interval.

Sample Compositing

To calculate the EMC of a runoff event, samples were composited using the flow-weighted method. First, data were collected from the datalogger and the cumulative flow volume was tabulated for that event. This cumulative flow volume was then used to calculate incremental volumes (the volume of vault discharge that represents one sample) of water that passed through the monitoring site within one-half hour before and one-half hour after each sample was collected (Figure 12). Therefore, the incremental volume passing through the monitoring site is calculated from 30 minutes before to 30 minutes after the storm samples are collected. Note that this interval was 5 minutes before and after sample collection for summer convective storms. The incremental flow volumes (representing either 1 hour or 10 minutes of runoff volume) are then divided by the total flow volume for the runoff event. This fractional result is multiplied by 1,000 mL to determine the actual volume of incremental sample that should be included in the 1,000-mL composite sample representing the entire event.

This method was used to create event composite samples in proportion to the volumes of water that passed through the monitoring site during each incremental time period that surrounded individual sample collection. Thus, a sample taken at the peak (high-flow period) of a runoff event contributes proportionally more volume to the event composite than a sample taken during the low-flow period of that event.

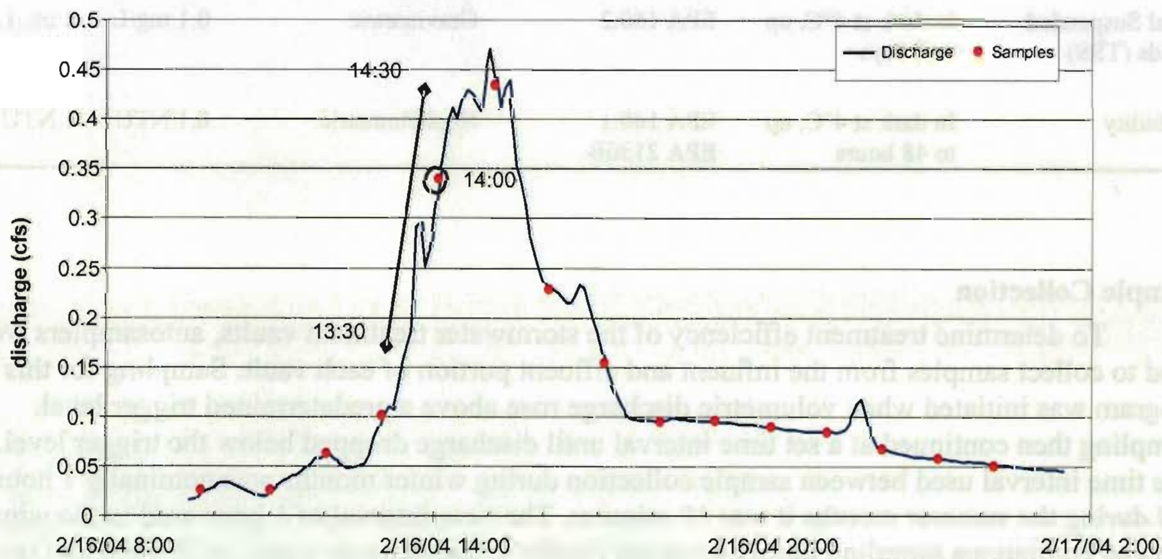

Figure 12. Example of a sample interval representing the 1-hour flow volume portion of the total event. For the sample collected at 14:00, the incremental flow volume was accumulated between 13:30 and 14:30.

RUNOFF VOLUMES AND EVENT CHARACTERIZATION

Discharge Characterization

Most runoff in the Round Hill drainage was derived from rain or snowmelt events, or from a mix of rain with snow. During WY2003, a total of 19 runoff events were monitored and sampled at the CDS vault, while 15 events were monitored and sampled at the Vortechnics vault.

Since the drainage areas to each vault are different, with larger volumes passing through the CDS vault, matched sampling events did not always occur. Runoff events tended to be of short duration (median 10 hours, mean 15.6 hours) and runoff volumes were relatively small, especially at the Vortechnics vault (Appendix 5). Note that WY2003 total runoff volumes have been scaled proportional to the individual vault runoff volumes measured during WY2004, when continuous flow monitoring was conducted separately on each vault (75 percent to CDS and 25 percent to Vortechnics).

The largest runoff volume during WY2003 was 5,951 ft^3 through the CDS vault during a summer thunderstorm runoff event on July 20, 2003, that lasted 4 hours and 10 minutes. Peak flow during this event was 2.3 ft^3/s, well below the vault design capacity of 14 ft^3/s. The Vortechnics runoff volume during this event was calculated at 1,955 ft^3 with a peak flow of only 0.8 ft^3/s. This was considered a high-intensity convective precipitation event for the area, and was observed to have moved large quantities of suspended material and debris, such as pine needles, pinecones and other large materials not sampled by the monitoring equipment.

As discussed earlier, the flow monitoring installations were modified for WY2004 such that each vault was monitored individually. Seven runoff events were monitored and sampled at the CDS vault during WY2004, while nine events were monitored and sampled at the Vortechnics vault, and eight events were monitored and sampled at the Jensen vault. Most of these were from different runoff dates at each vault, and are thus not directly comparable. The largest runoff event of both water years was a rainstorm that occurred on May 28, 2004. Total volume from this event was 9,297 ft^3 at the CDS vault and peak runoff was 2.2 ft^3/s. This event was not captured at the other two vaults, because the intake strainers became clogged with debris and did not function properly.

Event Characterization

Indeed, monitoring and sampling were inherently difficult. Equipment malfunctions were common, and it was difficult to collect enough samples to adequately represent runoff events. Operating procedures suggested a sampling density of 12 discrete samples during each event of 24 hours duration or less. Mean sampling density, however, only averaged five samples per event with an average runoff duration of about 14 hours. In some cases, the sampling was of high quality and sufficient samples were taken to represent the event (Figure 13), while in other cases, the sampling density was too low (usually fewer than two or three samples) or poorly distributed. One example of poor sample distribution was the event of August 21, 2003 (Figure 14). It would have been better if these five samples had been distributed throughout the event, instead of clustered on the first peak of the hydrograph.

The sampling quality of each event was rated at each site based on distribution of sampling points throughout the event, as well as the number of sample points representing that event. Note that even sparse sampling, if well distributed, was deemed to represent the event moderately well, especially if it was a low-flow event or of short duration. These event ratings, although subjective, are based upon professional judgment and range from good to moderate to poor (Appendix 5). Those events that were rated as poorly sampled were not included in subsequent data analyses.

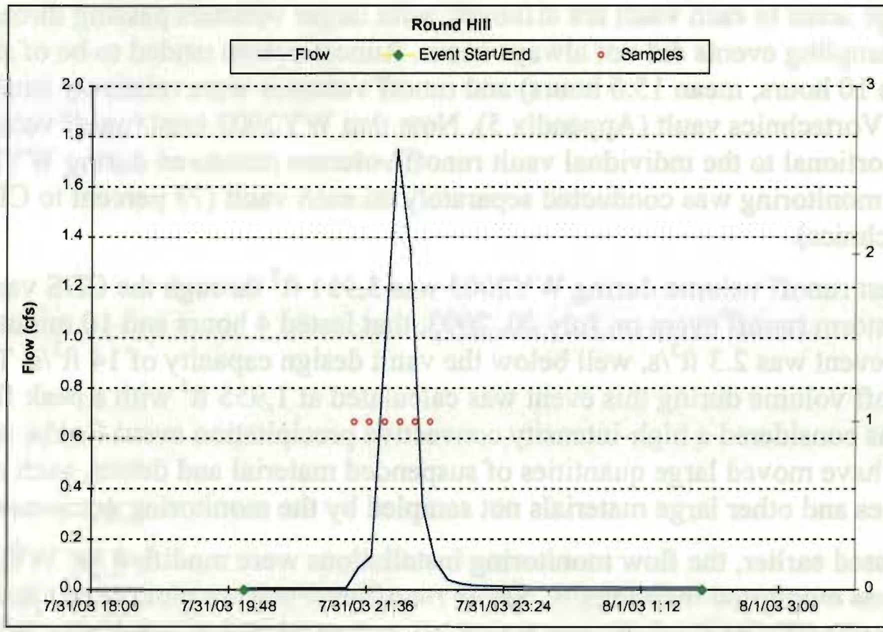

Figure 13. Example of an event rated "good" for sampling quality. The blue line is the discharge hydrograph for the stormwater treatment vault, and the red circles indicate times when samples were collected. Six field samples were used in flow-proportioned amounts to create one lab composite sample for analysis.

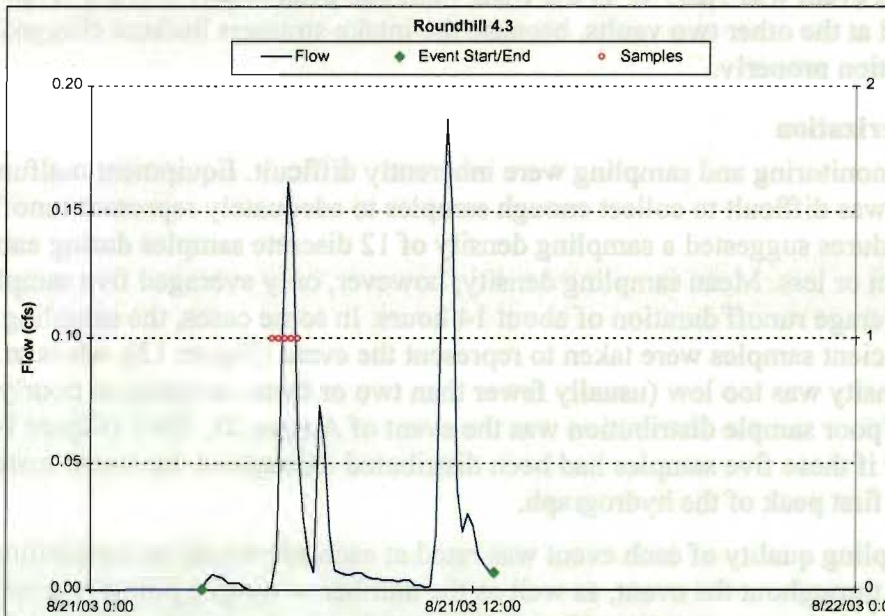

Figure 14. Example of an event rated "poor" for sampling quality. The blue line is the discharge hydrograph for the stormwater treatment vault, and the red circles indicate times when samples were collected. One composite sample was analyzed, but it represented a relatively small portion of the event hydrograph.

Total runoff volume through the CDS and Vortechnics vaults combined in WY2003 was 676,115 gallons (90,397 ft^3). As described previously, the instrumentation in these vaults for WY2003 did not function as anticipated to monitor flows separately through each vault. As a consequence, the instrumentation was changed in WY2004 and the subsequent data were used to estimate a ratio of flow at each vault to separate the combined flows of WY2003. These calibrated data for WY2003 were then used in load calculations (Appendix 6) and will be used in the subsequent discussion of event flows from WY2003.

It is estimated that the CDS vault received about 75 percent of the total runoff of the two vaults (CDS and Vortechnics) in WY2003 (67,798 ft^3). Nineteen events were sampled, of which nine were considered of good quality and six were considered to be of moderate quality. The four events that were poorly sampled are not included in subsequent discussion or in the calculations. Thus, 15 events are considered in the summary of EMCs (Table 3).

Table 3. Summary statistics of event mean concentrations at CDS vault for WY2003.

WY2003 RH CDS	EMCs	TN (µg/L)	TKN (µg/L)	NO3-N (µg/L)	NH4-N (µg/L)	TP (µg/L)	TDP (µg/L)	SRP (µg/L)	TSS (mg/L)	Turbidity (NTU)
Inflow	Median	1,579	1,546	45	13	512	95	69	88	28
	75% quartile	3,191	2,947	161	33	1,172	146	105	149	123
	25% quartile	1,357	1,282	15	8	231	58	47	45	23
	Mean	2,605	2,463	108	44	804	110	81	292	126
	Stdev	2,302	2,177	153	83	870	62	42	547	196
	CV	0.88	0.88	1.42	1.86	1.08	0.56	0.51	1.88	1.56
	n	14	15	14	13	14	14	14	14	12
Outflow	Median	1,621	1,583	64	13	478	103	68	93	44
	75% quartile	4,512	4,422	114	34	1,108	146	91	529	141
	25% quartile	1,134	1,090	19	9	259	76	62	55	29
	Mean	3,177	3,089	88	27	948	123	79	441	157
	Stdev	3,079	3,029	102	33	1,035	80	34	672	209
	CV	0.97	0.98	1.17	1.24	1.09	0.65	0.43	1.52	1.33
	n	15	15	15	14	15	15	15	15	15

WY03 sampled volume (cf): 24,742 — Note: this table is not an efficiency assessment.

WY03 cumulative volume (cf): 67,798

Percent of total volume represented: 37

Of these 15 sampled events, the median runoff volume through the CDS vault was 1,058 ft^3 with a median peak flow of 0.07 ft^3/s. The highest peak flow during sampled events in WY2003 was 2.3 ft^3/s. This is well below the 14 ft^3/s for which both vaults were designed.

Of total runoff through both stormwater vaults in WY2003, it is estimated that about 25 percent flowed through the Vortechnics vault (22,599 ft^3). Fifteen events were sampled, of which five were considered of good quality and five were considered to be of moderate quality. Two events were mixed in terms of sampling quality, with good quality sampling at one of the sites (either inflow or outflow) and moderate quality sampling at the other site. Similarly, one event was mixed in terms of good and poor quality. Two other events were poorly sampled and are not included in subsequent discussion or calculations. Thus, data from 13 events are considered in the summary of EMCs (Table 4), but only 12 events will be considered in the subsequent calculations of load reduction.

Of these 12 sampled events, the median runoff volume through the Vortechnics vault was 410 ft^3, with a median peak flow of 0.020 ft^3/s. The highest peak flow during sampled events in WY2003 was 0.76 ft^3/s. Again, this is well below the 14 ft^3/s to which both vaults were designed.

In WY2004, total runoff volume through the CDS and Vortechnics vaults combined was 66,316 ft^3, about two-thirds the volume measured in WY2003. The CDS vault received about 75 percent of this total runoff. Seven events were sampled at the CDS vault, with three considered as good quality sampling events and four considered as moderate quality. The summary EMC data from these seven runoff events are shown in Table 5.

Median runoff volume for these seven events at the CDS vault was 1,578 ft^3, with a median peak flow of 0.09 ft^3/s. The highest peak flow observed during these monitored events was 0.35 ft^3/s, substantially less than the peak flow in WY2003.

The Vortechnics vault received about one-quarter the volume of runoff compared to the CDS vault in WY2004, most likely reflecting differences in drainage area, impervious coverage, slope and aspect. Nine events were sampled at the Vortechnics vault in WY2004, with seven rated as good, one rated as a mixed moderate/good, and one event rated as poorly sampled. The EMC summary considers the eight good to moderate events (Table 6).

Of these eight sampled events, the median runoff volume through the Vortechnics vault was 622 ft^3, with a median peak flow of 0.05 ft^3/s in WY2004. The highest peak flow during sampled events in WY2004 was 0.25 ft^3/s. These values are much reduced from the peak flows and event volumes of WY2003.

Event mean concentration data for the Jensen vault are only available for WY2004, when eight events were sampled. Of these sampled events, six were rated as good, one was rated moderate, and one received a mixed good/poor rating for inflow/outflow sampling quality.

Runoff volumes to the Jensen vault tended to be very small, with a median of only 14 ft^3 and a mean of 1,261 ft^3. The mean peak flow was 0.31 ft^3/s. All five of the low-flow events were warm weather snowmelt periods in March. The median EMCs for most constituents through the Jensen vault (Table 7) were relatively similar to values from the CDS and the Vortechnics vaults in WY2004.

Table 4. Summary statistics of event mean concentrations at Vortechnics vault for WY2003.

WY2003 RH Vortech	EMCs	TN (µg/L)	TKN (µg/L)	NO3-N (µg/L)	NH4-N (µg/L)	TP (µg/L)	TDP (µg/L)	SRP (µg/L)	TSS (mg/L)	Turbidity (NTU)
Inflow	Median	1,123	1,065	49	19	287	99	80	60	25
	75% quartile	2,947	2,493	182	30	941	165	129	375	73
	25% quartile	920	749	29	12	231	41	33	33	17
	Mean	3,239	3,062	177	44	1,496	123	88	1,307	230
	Stdev	4,391	4,327	243	62	2,963	95	60	3,553	511
	CV	1.36	1.41	1.38	1.41	1.98	0.77	0.68	2.72	2.22
	n	12	12	12	12	12	12	12	12	10
Outflow	Median	1,343	694	79	14	197	96	80	24	23
	75% quartile	5,775	5,468	307	26	487	117	110	135	113
	25% quartile	563	536	27	9	154	70	50	11	8
	Mean	3,418	3,241	178	26	1,040	111	84	308	195
	Stdev	4,592	4,584	209	25	1,960	57	44	640	420
	CV	1.34	1.41	1.18	0.99	1.88	0.51	0.53	2.08	2.16
	n	13	13	13	13	13	13	13	13	12

WY03 sampled volume (cf): 7,433

Note: this table is not an efficiency assessment.

WY03 cumulative volume (cf): 22.599

Percent of total volume represented: 33

Table 5. Summary statistics of event mean concentrations at CDS vault for WY2004.

WY2004 RH CDS	EMCs	TN (µg/L)	TKN (µg/L)	NO3-N (µg/L)	NH4-N (µg/L)	TP (µg/L)	TDP (µg/L)	SRP (µg/L)	TSS (mg/L)	Turbidity (NTU)
Inflow	Median	2,353	2,183	50	25	428	157	123	45	58
	75% quartile	2,544	2,458	86	38	476	205	181	76	88
	25% quartile	902	876	36	17	284	54	41	34	44
	Mean	1,849	1,782	68	57	468	141	117	159	108
	Stdev	1,069	1,052	55	88	350	93	77	295	133
	CV	0.58	0.59	0.81	1.53	0.75	0.66	0.66	1.85	1.23
	n	7	7	7	7	7	7	7	7	7
Outflow	Median	1,790	1,686	66	35	378	140	104	41	45
	75% quartile	2,281	2,260	85	38	471	162	119	58	71
	25% quartile	1,272	1,150	22	23	217	63	50	34	42
	Mean	1,745	1,671	75	43	435	118	88	85	94
	Stdev	814	844	73	37	342	58	39	116	115
	CV	0.47	0.50	0.98	0.85	0.79	0.50	0.44	1.36	1.23
	n	7	7	7	7	7	7	7	7	7

WY04 sampled volume (cf): 15,750

Note: this table is not an efficiency assessment.

WY04 cumulative volume (cf): 49,917

Percent of total volume represented: 32

Table 6. Summary statistics of event mean concentrations at Vortechnics vault for WY2004.

WY2004 RH Vortech	EMCs	TN (µg/L)	TKN (µg/L)	NO3-N (µg/L)	NH4-N (µg/L)	TP (µg/L)	TDP (µg/L)	SRP (µg/L)	TSS (mg/L)	Turbidity (NTU)
Inflow	Median	450	300	118	25	140	64	57	33	35
	75% quartile	562	426	184	30	213	74	67	53	64
	25% quartile	406	284	66	16	126	61	55	17	19
	Mean	643	525	118	25	247	70	62	53	63
	Stdev	499	507	71	14	231	14	11	60	75
	CV	0.78	0.97	0.60	0.55	0.94	0.19	0.18	1.14	1.18
	n	8	8	8	8	8	8	8	8	8
Outflow	Median	686	257	149	24	131	63	59	37	36
	75% quartile	781	473	471	24	226	69	60	49	52
	25% quartile	458	233	79	20	128	54	50	17	18
	Mean	729	485	245	24	240	65	59	48	57
	Stdev	430	478	223	9	212	14	10	51	64
	CV	0.59	0.99	0.91	0.37	0.89	0.22	0.17	1.06	1.12
	n	8	8	8	8	8	8	8	8	8

WY04 sampled volume (cf): 8,262

Note: this table is not an efficiency assessment.

WY04 cumulative volume (cf): 16,399

Percent of total volume represented: 50

Table 7. Summary statistics of event mean concentrations at Jensen vault for WY2004.

WY2004 RH Jensen	EMCs	TN (µg/L)	TKN (µg/L)	NO3-N (µg/L)	NH4-N (µg/L)	TP (µg/L)	TDP (µg/L)	SRP (µg/L)	TSS (mg/L)	Turbidity (NTU)
Inflow	Median	704	665	42	25	321	24	13	83	65
	75% quartile	3,772	3,525	133	170	706	43	23	169	149
	25% quartile	286	264	20	20	112	12	11	50	34
	Mean	2,456	2,274	182	183	479	106	41	120	93
	Stdev	3,158	2,886	320	317	476	222	72	94	75
	CV	1.29	1.27	1.76	1.73	0.99	2.10	1.77	0.79	0.80
	n	8	8	8	8	8	8	8	8	8
Outflow	Median	294	250	37	20	76	18	16	24	14
	75% quartile	1,650	1,616	46	84	168	45	27	32	23
	25% quartile	257	220	36	17	74	17	15	13	14
	Mean	1,132	1,049	83	180	133	51	24	24	35
	Stdev	1,314	1,216	123	378	90	68	16	12	50
	CV	1.16	1.16	1.48	2.10	0.68	1.34	0.69	0.52	1.40
	n	7	7	7	7	7	7	7	7	7

WY04 sampled volume (cf): 10,084

Note: this table is not an efficiency assessment.

WY04 cumulative volume (cf): 13,367 (from January 1, 2004 through September 31, 2004)

Percent of total volume represented: 75

EVENT POLLUTANT CONCENTRATIONS

About 25 percent of the total runoff volume in WY2003 occurred during event sampling periods, while 50 to 75 percent of the total runoff volume in WY2004 occurred during event sampling periods. A comparison of the EMC tables (Tables 3 through 7) shows that runoff concentrations at each vault were relatively similar. These stormwater runoff concentrations in the RHGID are typical of runoff from other residential land use areas in the Tahoe Basin (Heyvaert *et al.*, 2004a, in review).

The coefficient of variation (CV) indicates that greatest variability in RHGID runoff concentrations tended to be associated with ammonium as nitrogen (NH_4-N), total suspended solids (TSS), nitrate as nitrogen (NO_3-N), turbidity (as NTUs), and total phosphorus (TP).

The medians of runoff EMCs between water years at each vault tended to vary by less than a factor of two, except for TKN at the Vortechnics vault, where median TKN in WY2004 was less than one-third of the median for EMCs from WY2003. Overall, the variation of inflow concentrations at each vault between water years was generally greater than the between vault variation within a water year.

At each vault and for each water year, the medians of outflow EMCs for both TKN and TDP were lower than the medians of their inflow EMCs, suggesting a reduction in the outflow concentrations of these pollutants by the vaults. In most other cases, the analyte medians were more variable between water years and vaults. However, these medians for analyte EMCs are not based on matched inflow and outflow event data, so they are not the best indicators of treatment efficiency. A better assessment of vault efficiency to be developed in the following section of this report will use matched inflow and outflow event data to determine cumulative net loadings at each vault.

One other important constraint in vault efficiency assessment that should be noted here is that autosamplers do not representatively collect the larger particles of sediment and debris suspended in stormwater flows. There is a bias toward underestimation of particulate concentrations in the inflow samples. At the end of both WY2003 and WY2004, the RHGID stormwater vaults were partially filled with sediment, pine needles, pine cones and other debris that were not representatively sampled by the autosamplers, due to orifice restrictions on the intake strainers.

This sampling bias is less of a problem with the vault outflow samples, however, since stormwater treatment vaults intercept much of this coarse material, at least until vault retention capacity is exceeded. Since the RHGID vaults were cleaned out at the start of each water year, these outflow samples are considered representative of concentrations for both particulate and soluble fractions in the vault discharge. This will be an important assumption for the approach developed to estimate vault retention efficiencies for the particulate constituents presented later.

In any case, for all the reasons discussed above, the EMC summary Tables 3 through 7 are not to be used as an assessment of vault performance. Rather, they describe the typical concentrations of soluble nutrients and fine particulates in the inflow and outflow samples at these vaults. Another representation of EMC distributions is shown in the following box plots (Figures 15 through 22). These box plots show the combined EMC data from both WY2003 and WY2004, except at the Jensen vault, where sampling data were only available after January 2004.

A box plot represents the population of the data set. The line within the box represents the median value and the upper and lower portion of the box represents the 25th and 75th percentiles, thus the box represents the middle 50 percent of the data or the interquartile range (IQR). The upper adjacent value (t shaped lines extending from the box) is the largest observation that is less than or equal to the 75th percentile plus 1.5 times the IQR. The lower adjacent value is the smallest observation that is greater than or equal to the 25th percentile minus 1.5 times IQR. Outliers in the data set are represented by the circles. If the outlier is colored red, it is considered a severe outlier. On several of the box plots, some of the outliers were removed to change the y-scale to allow better assessment of the data. These instances are noted in the captions. Each box plot represents a different chemical constituent with the different sampling location represented on the x-axis. C-in and C-out are the inflow and outflow for the CDS vault, respectively, V-in and V-out are the inflow and outflow for the Vortechnics vault, respectively, and J-in and J-out are the inflow and outflow for the Jensen vault, respectively.

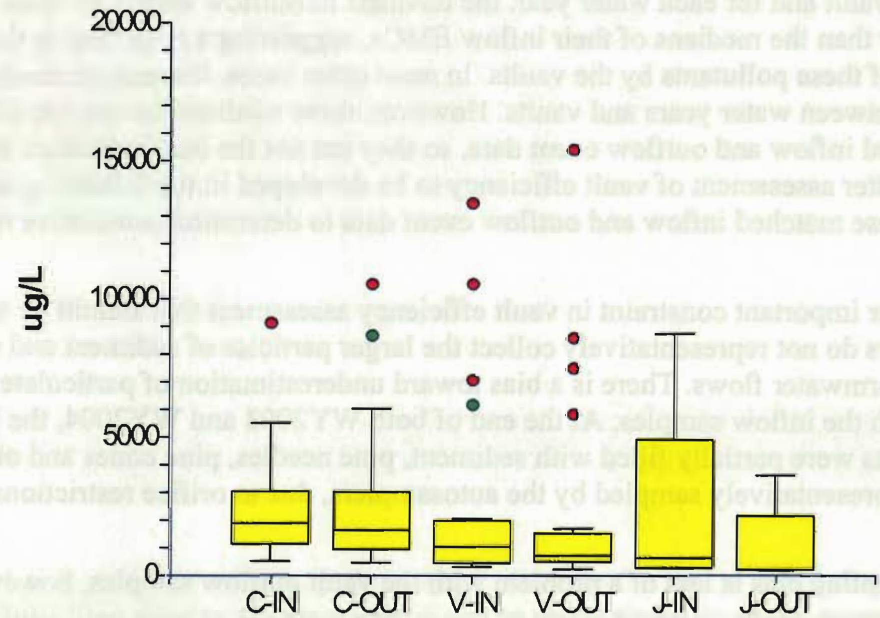

Figure 15. Box plot showing the distribution of event mean concentration for total nitrogen.

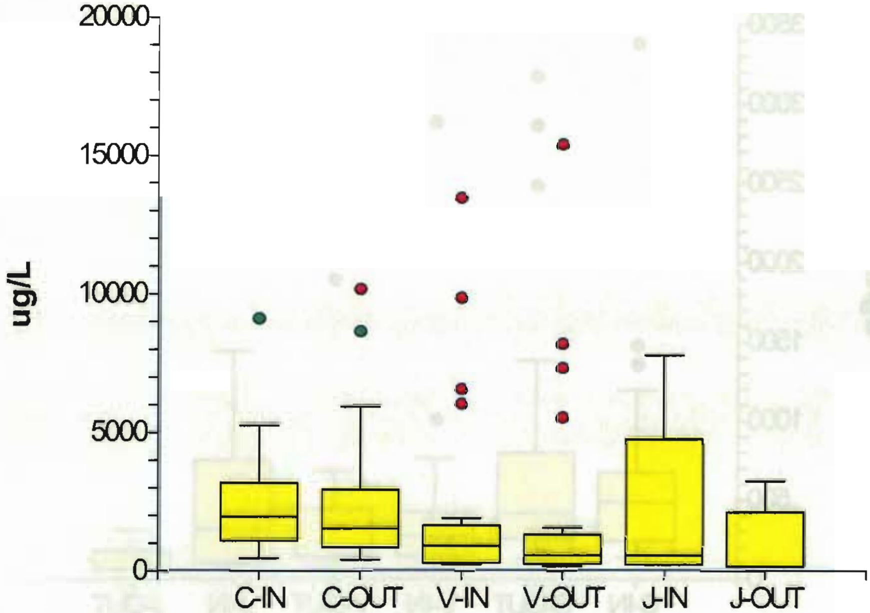

Figure 16. Box plot showing the distribution of event mean concentration for total Kjeldahl nitrogen.

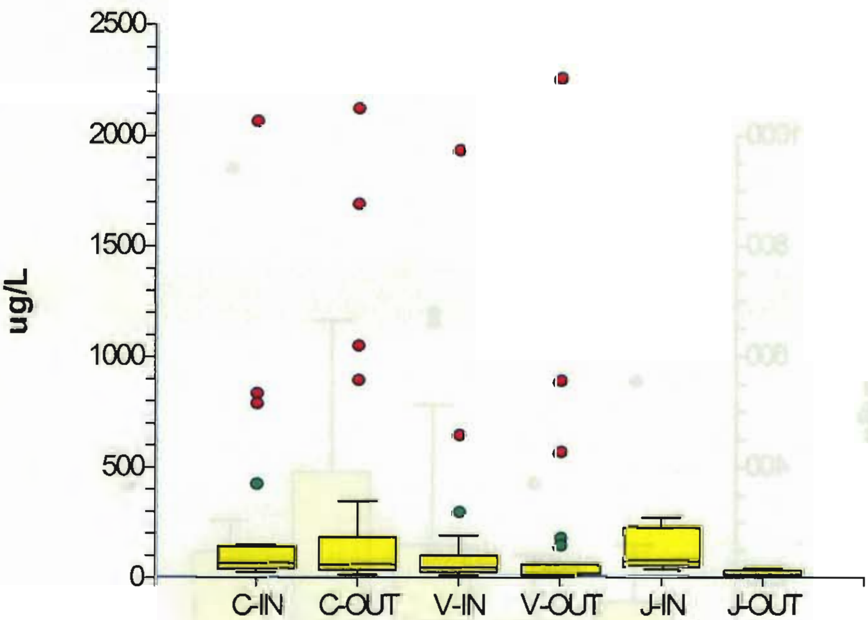

Figure 17. Box plot showing the distribution of event mean concentration for total suspended sediment. One outlier from the V-In plot was removed.

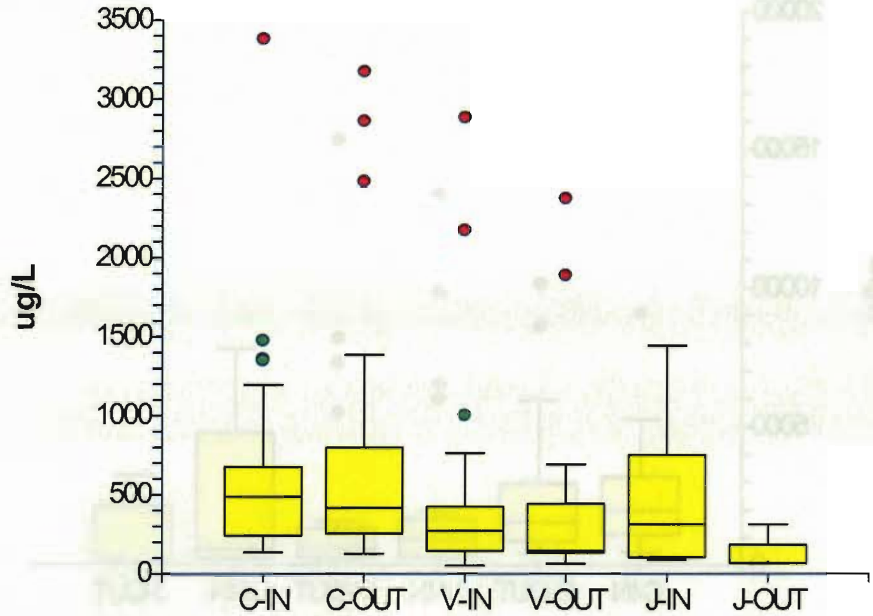

Figure 18. Box plot showing the distribution of event mean concentration for total phosphorus. Two outliers were removed, one from V-In and one from V-Out

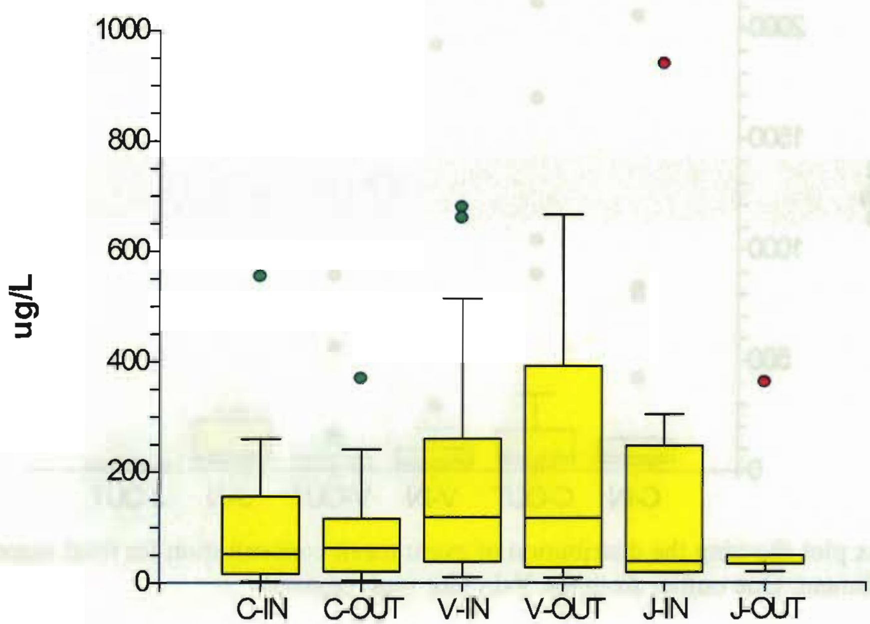

Figure 19. Box plot showing the distribution of event mean concentration for nitrate as nitrogen.

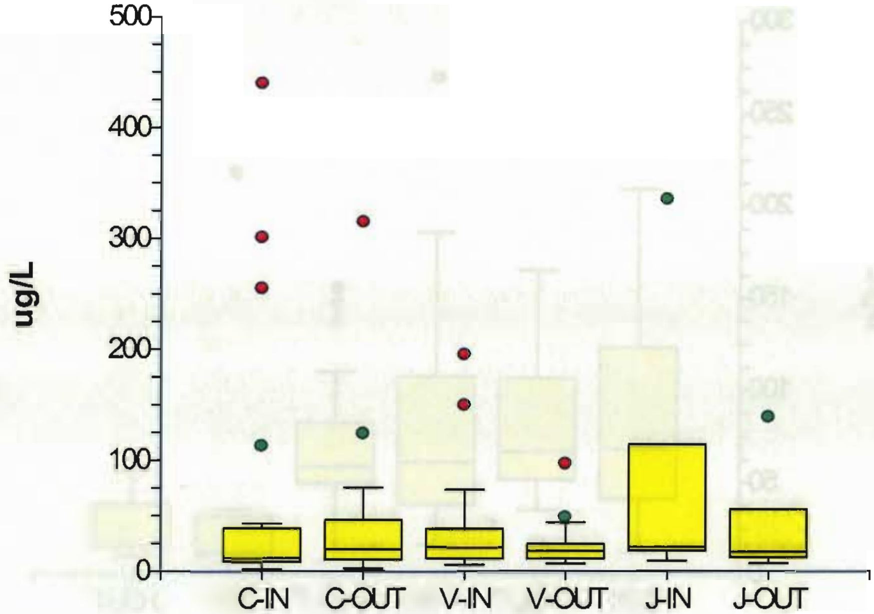

Figure 20. Box plot showing the distribution of event mean concentration for ammonium as nitrogen. Two outliers were removed, one from V-In and one from V-Out.

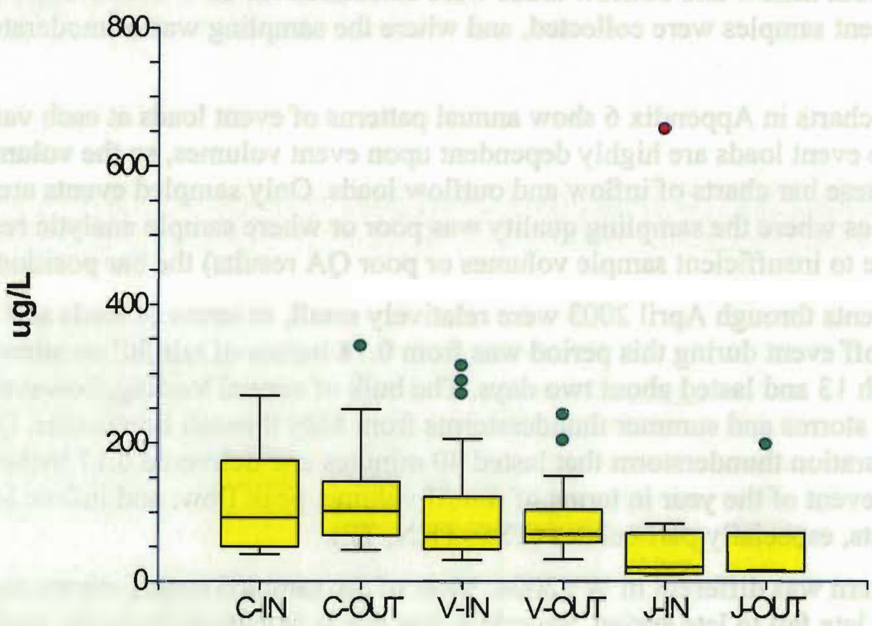

Figure 21. Box Plot showing the distribution of event mean concentration for total dissolved phosphorus.

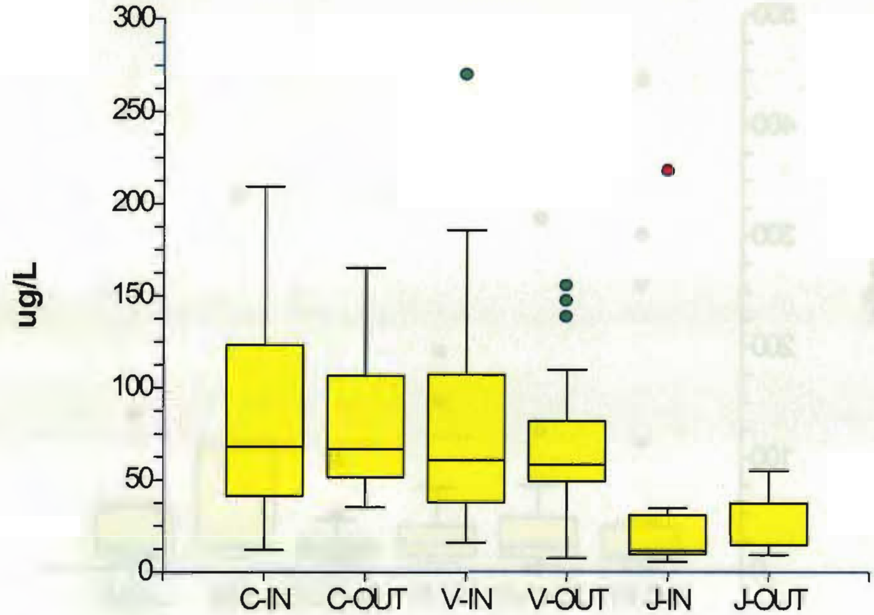

Figure 22. Box plot showing the distribution of event mean concentration for soluble reactive phosphorus.

EVENT LOADING ESTIMATES

Estimates of event pollutant loadings are calculated as the product of total event volume and the EMC. Both inflow and outflow loads were calculated for all events at each vault where influent or effluent samples were collected, and where the sampling was of moderate or good quality.

The bar charts in Appendix 6 show annual patterns of event loads at each vault. By definition, these event loads are highly dependent upon event volumes, so the volumes are included with these bar charts of inflow and outflow loads. Only sampled events are represented, and in those cases where the sampling quality was poor or where sample analytic results were unavailable (due to insufficient sample volumes or poor QA results) the bar positions are blank.

Most events through April 2003 were relatively small, in terms of loads and volumes. The largest runoff event during this period was from 0.78 inches of rainfall on snowpack that started on March 13 and lasted about two days. The bulk of annual loading, however, occurred with late spring storms and summer thunderstorms from May through September. On July 20, 2003, a short-duration thunderstorm that lasted 40 minutes and delivered 0.17 inches of rainfall was the largest event of the year in terms of runoff volume, peak flow, and inflow loading of most constituents, especially particulates (TSS, TKN, TP).

The pattern was different in WY2004. Most of the sampled runoff events occurred during the period from late fall to late spring. Sampling was not as consistent between vaults as in WY2003, because the monitoring equipment had been separated for each vault. But a comparison of the inflow and outflow loads shows a more consistent pattern of retention than observed in the WY2003 data.

Theoretically, the net vault retention could be determined by subtracting effluent load from influent load for the various nutrients and sediment. As can be seen from the graphs of event inflow and outflow loads, however, there were many events with net positive outflow loads. This may seem counterintuitive, but there are a number of factors that could contribute to estimates of larger event outflow loads compared to event inflow loads. These factors include:

- Event size, where low-volume events simply displace water already stored in the vault at higher concentrations than the inflow water.
- Internal loading, which can enrich the overlying water from biodegradation of accumulated solids in the vault.
- Sampling density, where synchronous sampling at the inflow and outflow may not capture the same portions of an event hydrograph and are not thus entirely equivalent, especially if the sampling density was sparse, incomplete, or did not sample the entire hydrograph.
- Sampling bias, particularly for the particulate constituents. This effect occurs when the sampling methods do not collect a representative sample, as discussed previously.
- Inadequate maintenance, when accumulated material is not cleaned out (vactored) and exceeds the vault capacity, and can be resuspended and increase the discharge loads.
- Analytic variation, where small differences in concentrations due to analytic variability or inaccurate assays can result in large loading differences at higher flow volumes.

Charts for effluent reductions in the CDS vault (Figures 23 and 24) and the Vortechnics vault (Figures 25 and 26) show the percent change in cumulative effluent loads relative to inflow loads for all events where sampling was at least good to moderate at both the inflow and outflow sites to that vault. Also shown in these figures are the medians of event reductions for all matched inflow and outflow EMCs, where event reduction is the event inflow EMC minus the event outflow EMC. The median of these event reductions for each analyte is shown in these charts, along with cumulative load reductions. The same type of data are shown in Figure 27 from the Jensen vault for WY2004.

The chart of load accumulation in the Jensen vault suggests significant retention in WY2004. This was an incomplete sampling year, however, and only represents the period from January 1 through September 31, 2004. Most runoff events during this period were very small, with only two events greater than 2,000 ft^3.

When cumulative load reductions are negative, it suggests a net release of nutrients or sediment from the vault. This was observed in several cases, particularly for TN, TKN, NO_3-N, and NH_4-N. Several of the factors that may contribute to this effect were discussed above.

For the soluble nutrients, there could be a net cumulative release from internal loading. This mechanism would not be applicable, however, for sediment export, as observed with the excess TSS released from the CDS vault during WY2003, since sediment would be considered a relatively conservative constituent (i.e., not transformed from particulate to soluble forms). Although some of the large particulate material not collected by autosamplers could be degraded into smaller particles in the vault and then exported, it seems likely that this would be a minor effect.

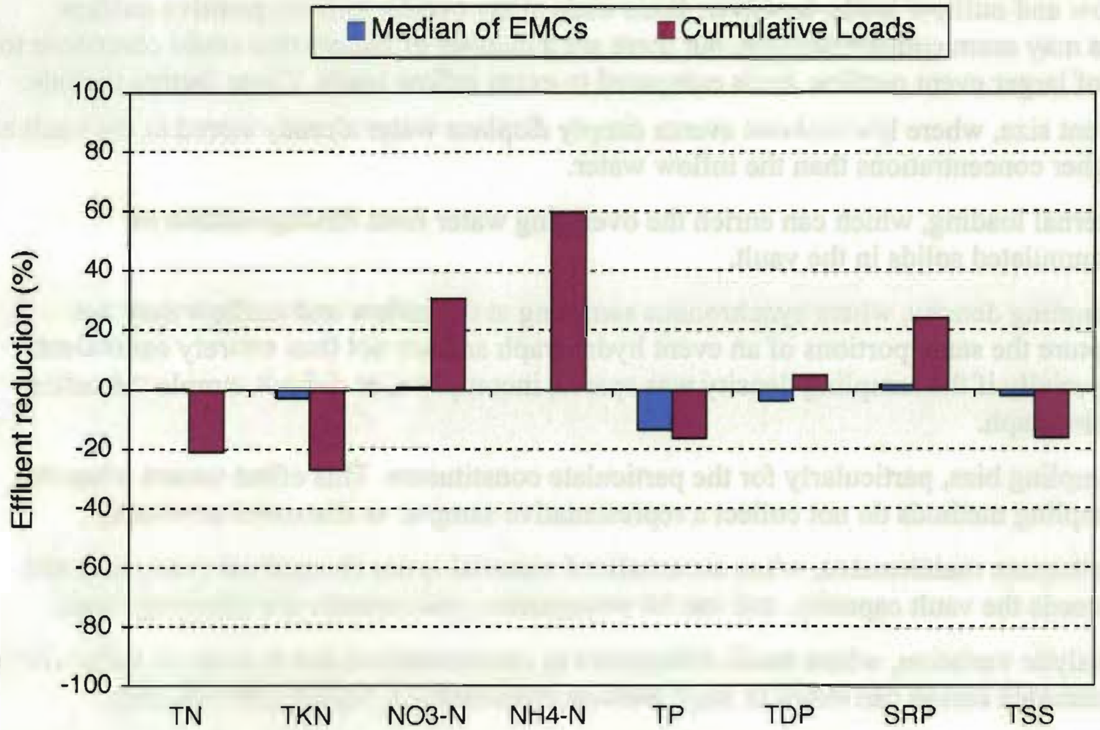

Figure 23. Effluent reduction for sampled events at RH CDS in WY2003.

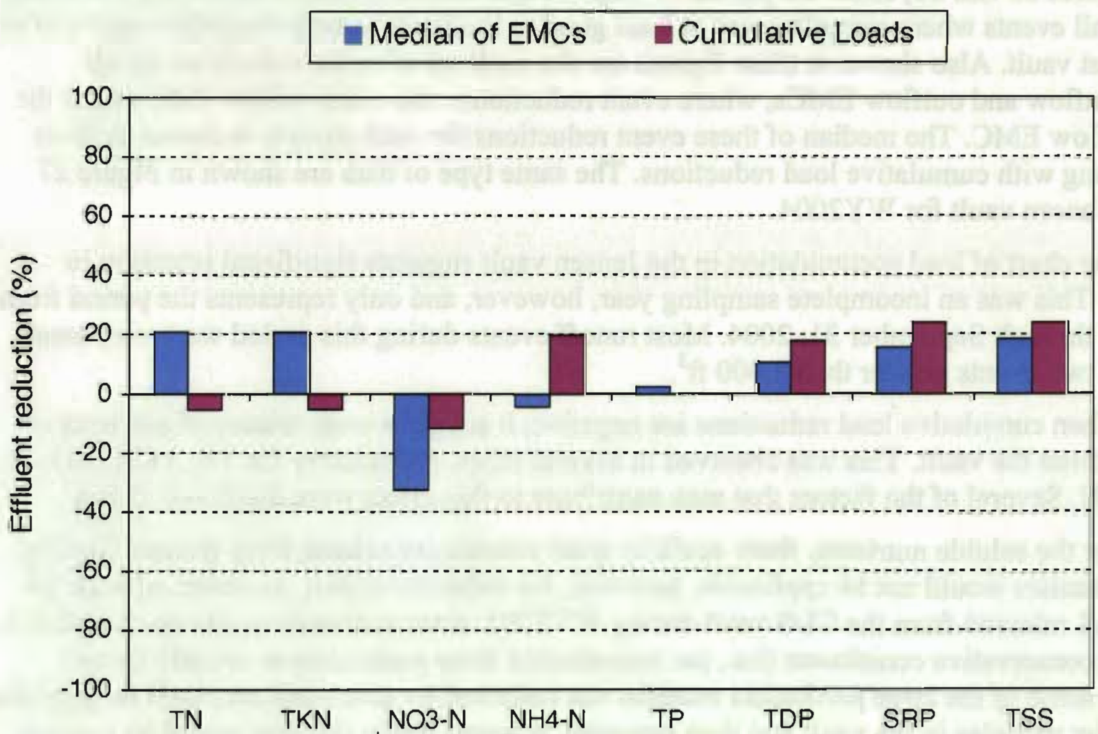

Figure 24. Effluent reduction for sampled events at RH CDS in WY2004.

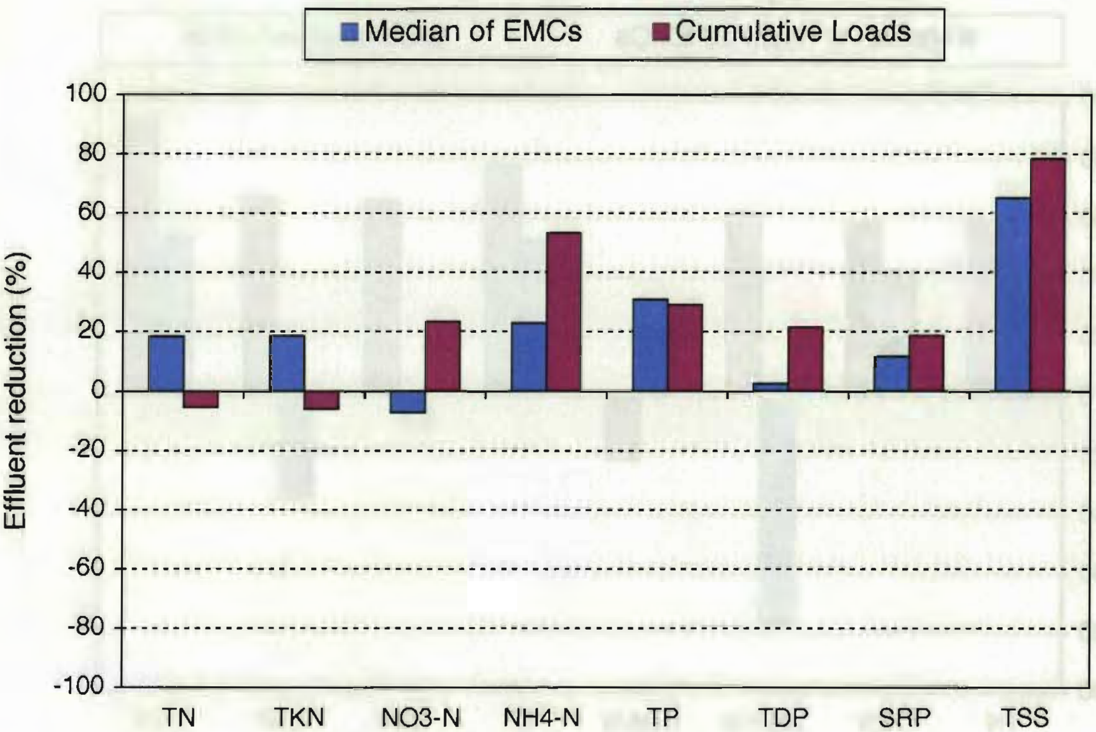

Figure 25. Effluent reduction for sampled events at RH Vortechnics in WY2003.

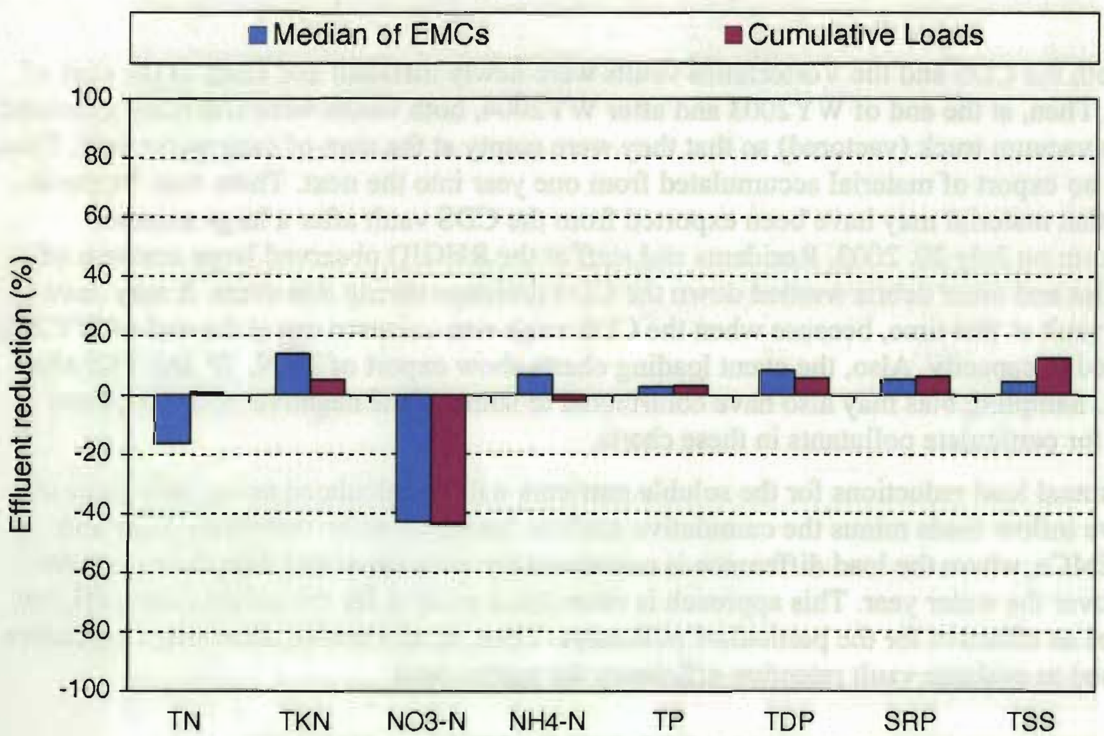

Figure 26. Effluent reduction for sampled events at RH Vortechnics in WY2004.

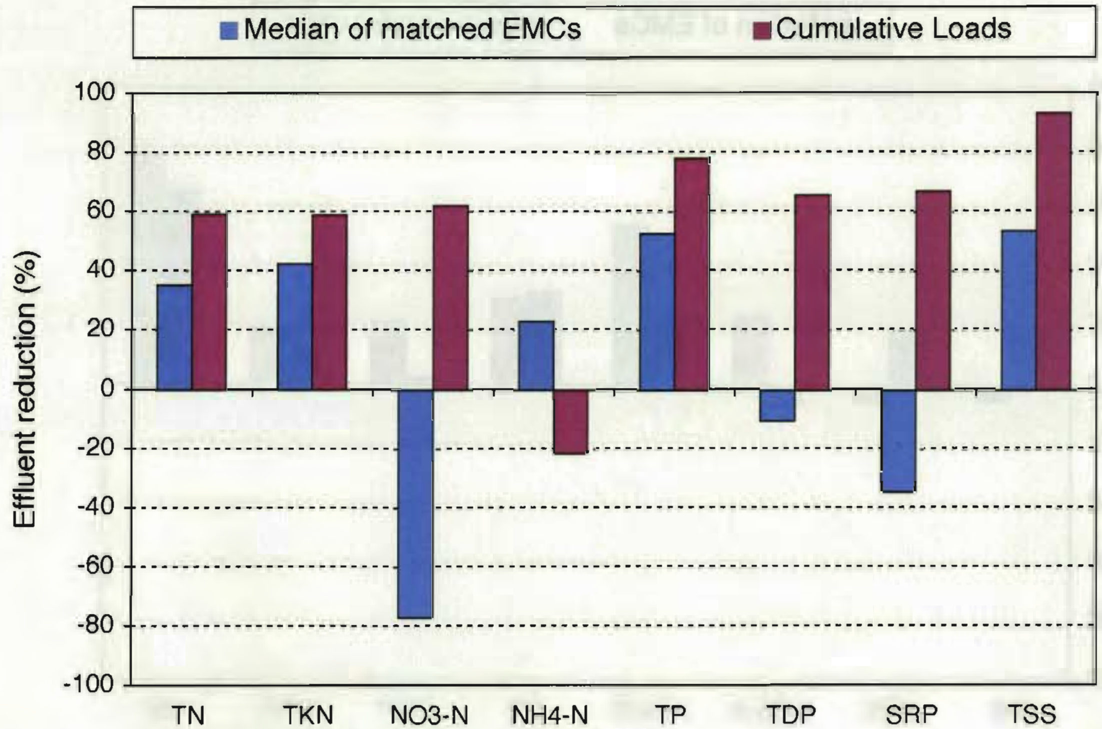

Figure 27. Effluent reduction for sampled events at RH Jensen in WY2004.

Both the CDS and the Vortechnics vaults were newly installed and clean at the start of WY2003. Then, at the end of WY2003 and after WY2004, both vaults were completely cleaned out with a vacuum truck (vactored) so that they were empty at the start of each water year. Thus, there was no export of material accumulated from one year into the next. There was, however, evidence that material may have been exported from the CDS vault after a large summer thunderstorm on July 20, 2003. Residents and staff at the RHGID observed large amounts of pine needles and other debris washed down the CDS drainage during this event. It may have filled the vault at that time, because when the CDS vault was vactored out at the end of WY2003, it was filled to capacity. Also, the event loading charts show export of TKN, TP and TSS after this event. Sampling bias may also have contributed to some of the negative load reductions observed for particulate pollutants in these charts.

Annual load reductions for the soluble nutrients will be calculated as the difference in cumulative inflow loads minus the cumulative outflow loads, based on matched inflow and outflow EMCs, where the load difference is calculated for each event and then the events are summed over the water year. This approach is considered reliable for the soluble nutrients, but may not be as effective for the particulate pollutants. Thus, an alternative assessment procedure will be used to evaluate vault retention efficiency for particulates.

VAULT RETENTION EFFICIENCY FOR SOLUBLE POLLUTANTS

The cumulative loads for each water year were calculated from all sampled events with both inflow and outflow data of good or moderate quality at each vault. These inflow and outflow loads, and the retention amounts, are shown in Appendix 7. As discussed previously, however, the inflow loads calculated for particulate fractions (TKN, TP, TSS) are likely to be underestimated. Assuming, for example, that sampled events were relatively representative of runoff for the entire year, there should not have been any solids in the CDS vault after WY2003. Yet this vault was filled with accumulated solids by the end of that year.

It seems most likely that inflow sampling was not representative of all the particulate material coming into these vaults, since the larger particle sizes, pine needles, trash, etc. are not collected by the autosampling equipment. While this sampling bias may be important for the sampling of inflow particulates, it probably does not have much effect on the sampling of soluble constituents or on the sampling of outflow particulates, since coarse materials are retained by the vaults. Therefore an assessment of vault retention efficiency for the soluble nutrients can be taken from the load retentions in Appendix 7 as summarized in Table 8.

Table 8. Estimates of vault retention efficiency for the soluble nutrients, based on annual inflow and outflow loadings calculated from EMC data.

Vault Retention Efficiency	WY	NO_3-N (%)	NH_4-N(%)	TDP (%)	SRP (%)
CDS Technology, Inc.	2003	31	60	5	24
CDS Technology, Inc.	2004	-12	20	18	24
Jensen Precast*	2004	62	-22	66	67
Vortechnics Systems	2003	23	53	21	19
Vortechnics Systems	2004	-44	-2	6	6

*partial year monitoring

The load retention efficiencies are positive for TDP in each vault and for each water year, as previously surmised from the EMC tables. There was also annual load retention of SRP. The mechanism of soluble phosphorus retention is unclear, although surface sorption onto sediments in the vaults is one plausible explanation. For the soluble nitrogen species, various biological transformations are possible, resulting in export of nitrate and ammonium in some cases.

About 25 percent of the total vault flow for WY2003 occurred during event sampling periods. During WY2004, about 50 percent of the total vault flow occurred during event sampling periods. While not all runoff events that occurred at these sites are represented in the dataset of sampled events, it is reasonable as a first approximation to assume that sampled events are sufficiently representative of the water year that these results could be scaled appropriately for estimates of total annual loads. Note, however, that annual loads calculated in this manner are sensitive to large volume events. If large events are not sampled or are not adequately represented in the dataset, it could have a substantial affect on the estimates of annual load.

An alternative approach in estimating the mass retention of particulate pollutants is to calculate it based on quantifying the material removed from a vault during cleanout operations. This was done for both the CDS and the Vortechnics vaults at the end of WY2003 and WY2004, and these results are discussed in the next section.

VAULT SOLIDS ACCUMULATION

Methods

By design, stormwater treatment vaults remove sediments and other coarse material from stormwater runoff. Over a period of time, depending on watershed and runoff conditions, these vaults accumulate material and must be vactored regularly to remove this material and prevent its subsequent loading to downstream catchments. As part of the monitoring program, this maintenance action was performed on the CDS and the Vortechnics vaults at the end of each water year.

Typical vault maintenance would specify a vactoring of each vault seasonally, depending on the solids accumulation rate. In this case, each vault was vactored at the end of the water year and considerable effort was invested in collecting and quantifying the material removed. The following briefly explains this cleanout procedure:

1. Overlying water was pumped out of each vault (and sampled);
2. The residual solid materials were then removed by vactor truck from each vault;
3. These materials were emptied into large holding tanks for settling;
4. Overlying water in the holding tanks was pumped out (and sampled) after settling;
5. The volume of remaining solids was measured;
6. Residual solids were sampled;
7. These samples were mixed then subsampled twice for replicate analysis; and
8. Samples were analyzed for bulk density, moisture content, total phosphorus, total nitrogen, total metals, and for particle size distributions.

The results of these analyses are provided below. Solids samples were analyzed in duplicate for a measure of analytic and sample variability. Bulk density was determined at the TRG laboratories, and sample analyses were conducted by the Soil Control Laboratory, Watsonville, CA. Relative standard deviations (RSD) were generally quite reasonable (< 20 percent) for most duplicates. The averages from these duplicate samples were used in the calculations of the annual vault accumulations.

Characterization of 2003 Vault Accumulation

During vault cleanout in 2003, there were four sets of samples produced that represented the accumulated solids and nutrients removed from the CDS vault. The sources were:

1. Vault decant water (overlying the solids in the vault)
2. Transport truck containing the CDS vault cleanout water taken to Reno, NV, for disposal
3. Decant water from the solids settling tank
4. Vault solids remaining in the settling tank after decant of overlying water

The two main sources of sediment and nutrients were residual solids after settling, and the 1,500 gallons of vault cleanout water. Analytic results from these two sets of samples are shown in Tables 9 and 10. The vault decant water contained 0.4 kg of solids, while the decant water from the solids settling tank contained an additional 9.3 kg of solids. Taken together, these four sets of samples, representing the vault cleanout after WY2003, account for a total of 3,797 kg of solids removed from the CDS vault.

Table 9. CDS vault solids sampled from settling tank in 2003. Volume and mass are shown for total material. Two replicate samples were analyzed; RSD = relative standard deviation.

CDS-1 2003	#3	#5	Average	RSD
Moisture	26.7%	27.3%	27.0%	2%
Volatile Solids	6.6%	7.1%	6.9%	5%
	(mg/kg)	(mg/kg)	(mg/kg)	
Total Phosphorus	275	299	287	6%
Total Nitrogen	1120	1010	1065	7%
Total Copper	11	12	12	6%
Total Lead	4	4	4	0%
Total Zinc	222	227	225	2%
Total Cadmium	2	2	2	0%

CDS-1 2003			
Volume (L):	2503	Density (kg/L):	1.57
Mass (kg):	3930	Solids (kg):	2869

CDS-1 2003	(mg/kg)	(g)
Total Phosphorus	287	823
Total Nitrogen	1065	3055
Total Copper	12	33
Total Lead	4	11
Total Zinc	225	644
Total Cadmium	2.0	6

Table 10. CDS vault cleanout water from transport truck holding tank in 2003. Volume and mass are shown for total material. Only one sample of this material was available for analysis.

CDS-HT 2003	#1
Moisture	85.3%
Volatile Solids	28.0%
	(mg/kg)
Total Phosphorus	123
Total Nitrogen	523
Total Copper	9.3
Total Lead	3.5
Total Zinc	151
Total Cadmium	0.4

CDS-HT 2003			
Volume (L):	5678	Density (kg/L):	1.10
Mass (kg):	6246	Solids (kg):	918

CDS-HT 2003	(mg/kg)	(g)
Total Phosphorus	123	113
Total Nitrogen	523	480
Total Copper	9	9
Total Lead	3.5	3
Total Zinc	151	139
Total Cadmium	0.4	0.4

From the Vortechnics cleanout in 2003, there were three sets of samples produced that represented accumulated solids and nutrients removed from the vault.

1. Vault decant water (overlying the solids in the vault)
2. Decant water from the solids settling tank
3. Grit chamber solids remaining in the settling tank after decant of overlying water.

However, the Vortechnics vault consists of three chambers, and only the main grit chamber was cleared of sediments in 2003. When the two other chambers were cleaned in 2004, there was a significant amount of additional material, representing two water years of accumulation. Thus, to account for this missing component in 2003, the total material removed from Vortechnics chambers 2 and 3 in 2004 will be parsed. This is mostly easily and reasonably done by using the proportion of total cumulative runoff volumes from both water years, WY2003 and WY2004 (30,440 ft^3 and 16,399 ft^3, respectively). Thus, of the 230 kg of solids removed from chambers 2 and 3 in 2004, it was estimated that about 149 kg represents accumulation from WY2003.

Analytic results on the residual solids collected from the Vortechnics grit chamber in 2003 are shown in Table 11. The vault decant water contained 0.8 kg of solids, while the decant water from the solids settling tank contained an additional 0.4 kg of solids. Adding the estimated 149 kg from chambers 2 and 3, and 861 kg from chamber 1, yields a total of 1,011 kg representing accumulated solids in the Vortechnics vault during WY2003.

Table 11. Vortechnics vault solids in 2003. Volume and mass are for total material (including portions lost to overflow of settling tank and ground storage). Two replicate samples were analyzed.

Vortechnics-1 2003	#2	#7	Average	RSD
Moisture	74.4%	81.1%	77.8%	6%
Volatile Solids	6.4%	4.8%	5.6%	20%
	(mg/kg)	(mg/kg)	(mg/kg)	
Total Phosphorus	595	438	517	21%
Total Nitrogen	1100	950	1025	10%
Total Copper	41	24	33	37%
Total Lead	61	15	38	86%
Total Zinc	398	257	328	30%
Total Cadmium	1.6	1.3	1.5	15%

Vortechnics-1 2003			
Volume (L):	2185	Density (kg/L):	1.77
Mass (kg):	3867	Solids (kg):	861

Vortechnics-1 2003	(mg/kg)	(g)
Total Phosphorus	517	444
Total Nitrogen	1025	882
Total Copper	33	28
Total Lead	38	33
Total Zinc	328	282
Total Cadmium	1.5	1

Characterization of 2004 Vault Accumulation

The vault cleanout procedures in 2004 were equivalent to the procedures followed in 2003, with a few minor variations. One difference was that decant water from the solids settling tanks was not sampled, since these volumes were relatively low and the water was clear.

The CDS vault cleanout at the end of WY2004 produced three sets of samples:

1. Vault decant water (overlying the solids in the vault)
2. Sump chamber solids remaining in settling tank 1 after decanting of overlying water
3. Solids collected from outside the CDS separation screen remaining in settling tank 2 after decanting of overlying water.

The vault decant water contained 1.7 kg of solids. Adding an estimated 931 kg from the CDS sump (Table 12), and another 336 kg from the area outside the CDS separation screen (Table 13), yields a total of 1,269 kg solids representing WY2004 accumulation in the CDS vault.

The Vortechnics vault cleanout at the end of WY2004 produced four sets of samples:

1. Vault decant water from main grit chamber 1 (overlying solids in the vault)
2. Vault decant water from chambers 2 and 3 (overlying solids in the vault)
3. Grit chamber 1 solids remaining in settling tank 1 after decanting of overlying water
4. Chamber 2 and 3 solids remaining in settling tank 2 after decanting of overlying water

The chamber 1 vault decant water contained 0.5 kg of solids, while chambers 2 and 3 vault decant water contained 0.4 kg of solids. Adding an estimated 67 kg from the Vortechnics grit chamber (Table 14), and another 80 kg from chambers 2 and 3 solids removed (Table 15), yields a total of 148 kg of solids representing WY2004 accumulation in the Vortechnics vault.

In 2004, the solids greater than 4 mm removed from each vault were quantified and described:

- Vortechnics Grit Chamber 1 – The > 4 mm size fraction was 33 percent of the sample (dry weight) with 57 percent of the material organic and 43 percent mineral. Pine needles composed 51 percent of the > 4 mm fraction.
- Vortechnics Chambers 2 and 3 – The > 4 mm size fraction was 15.2 percent of the sample (dry weight) with 40 percent of that material organic and 60 percent mineral. Pine needles composed 34 percent of the > 4 mm fraction.
- CDS Sump – The > 4 mm size fraction was 5.1 percent of the sample (dry weight) with 16 percent of the material organic and 84 percent mineral. Pine needles composed 11 percent of the > 4 mm fraction.
- CDS Area Outside Separation Chamber – The > 4 mm size fraction was 2.3 percent of the sample (dry weight) with 17 percent of the material organic and 83 percent mineral. Pine needles composed 12 percent of the > 4 mm fraction.

Somewhat puzzling is the considerable difference in total phosphorus concentrations in the recovered vault solids between WY2003 and WY2004. These values were verified with the Soil Control Laboratory, who checked their records and calculations and confirmed these values.

At this time, an explanation for the large difference in TP concentrations between years cannot be provided.

Table 12. CDS sump (vault) solids in 2004. Two replicate samples from settling tank 1.

CDS-1 2004	#1	#2	Average	RSD
Moisture	30.6%	32.8%	31.7%	5%
Volatile Solids	5.9%	4.5%	5.2%	19%
	(mg/kg)	(mg/kg)	(mg/kg)	
Total Phosphorus	15.5	17.7	16.6	9%
Total Nitrogen	790	880	835	8%
Total Copper	13.6	16.0	14.8	11%
Total Lead	3.6	3.8	3.7	4%
Total Zinc	313	344	329	7%
Total Cadmium	1.5	1.4	1.45	5%

CDS-1 2004			
Volume (L):	821	Density (kg/L):	1.66
Mass (kg):	1363	Solids (kg):	931

CDS-1 2004	(mg/kg)	(g)
Total Phosphorus	16.6	15
Total Nitrogen	835	777
Total Copper	14.8	14
Total Lead	3.7	3
Total Zinc	329	306
Total Cadmium	1.5	1

Table 13. Solids collected from outside the CDS separation screen in 2004. Two replicate samples from settling tank 2.

CDS-2 2004	#1	#2	Average	RSD
Moisture	32.0%	32.3%	32.2%	1%
Volatile Solids	7.3%	8.0%	7.7%	6%
	(mg/kg)	(mg/kg)	(mg/kg)	
Total Phosphorus	20.0	19.0	19.5	4%
Total Nitrogen	1200	1000	1100	13%
Total Copper	17.4	17.0	17.2	2%
Total Lead	4.7	6.4	5.6	22%
Total Zinc	377	388	383	2%
Total Cadmium	1.8	1.8	1.8	0%

CDS-2 2004			
Volume (L):	315	Density (kg/L):	1.57
Mass (kg):	495	Solids (kg):	336

CDS-2 2004	(mg/kg)	(g)
Total Phosphorus	19.5	7
Total Nitrogen	1100	369
Total Copper	17.2	6
Total Lead	5.6	2
Total Zinc	383	128
Total Cadmium	1.8	1

Table 14. Vortechnics chamber 1 solids in 2004. Two replicate samples from settling tank 3.

Vortechnics-1 2004	#1	#2	Average	RSD
Moisture	63.0%	63.5%	63.3%	1%
Volatile Solids	22.9%	27.8%	25.4%	14%
	(mg/kg)	(mg/kg)	(mg/kg)	
Total Phosphorus	37.0	34.0	35.5	6%
Total Nitrogen	3300	3100	3200	4%
Total Copper	33.8	33.0	33.4	2%
Total Lead	13.5	10.6	12.1	17%
Total Zinc	782	688	735	9%
Total Cadmium	2.1	2.4	2.3	9%

Vortechnics-1 2004			
Volume (L):	156	Density (kg/L):	1.16
Mass (kg):	181	Solids (kg):	67

Vortechnics-1 2004	(mg/kg)	(g)
Total Phosphorus	35.5	8
Total Nitrogen	3200	735
Total Copper	33.4	8
Total Lead	12.1	3
Total Zinc	735	169
Total Cadmium	2.3	1

Table 15. Vortechnics chambers 2 and 3 solids in 2004. Two replicate samples from settling tank 4. *

Vortechnics-23 2004	#1	#2	Average	RSD
Moisture	52.5%	50.3%	51.4%	3%
Volatile Solids	20.6%	19.0%	19.8%	6%
	(mg/kg)	(mg/kg)	(mg/kg)	
Total Phosphorus	40.7	39.3	40.0	2%
Total Nitrogen	3100	3500	3300	9%
Total Copper	38.8	38.0	38.4	1%
Total Lead	15.6	15.0	15.3	3%
Total Zinc	797	847	822	4%
Total Cadmium	3.0	2.9	3.0	2%

Vortechnics-23 2004			
Volume (L):	372	Density (kg/L):	1.27
Mass (kg):	472	Solids (kg):	230

Vortechnics-23 2004	(mg/kg)	(g)
Total Phosphorus	40.0	9
Total Nitrogen	3300	758
Total Copper	38.4	9
Total Lead	15.3	4
Total Zinc	822	189
Total Cadmium	3.0	1

* Note: it is estimated that 65 percent of this material is from WY2003 and 35 percent from WY2004.

Particle Sizes Captured by Vaults

Samples from the vault cleanouts were analyzed for particle size distribution. These results are shown in Table 16 for the percent solids in sand (4 mm to 62 μm), silt (62 μm to 2 μm), and clay (> 2 μm) size categories. The samples referenced are those shown in Tables 9 through 15, including the total mass of solids from each table.

Table 16. Percent by mass in particle size group of material removed from vaults during annual cleanout.

Year	Unit	Source	Sample #	Sand (%)	Silt (%)	Clay (%)	Mass (kg)
2003	CDS	1	3 and 5	86.8	12.4	0.9	2869
2003	CDS	HT	1	21.0	68.6	10.5	918
2003	Vort	1	2 and 7	88.3	10.8	1.0	861
2004	CDS	1	1 and 2	89.9	9.3	0.8	931
2004	CDS	2	1 and 2	84.6	14.6	0.9	336
2004	Vort	1	1 and 2	65.3	32.3	2.5	67
2004	Vort	23	1 and 2	48.0	47.8	4.3	230

Based on these data, the mass of solids captured in different size categories by each vault chamber (Table 17) was calculated. The CDS vault captured a total of 984 kg of silts in WY2003 and 122 kg of clays. Less total material was captured in WY2004, so the relative amounts of silts and clays are also correspondingly lower. About 100 kg of silt and clay were removed from the Vortechnics vault after WY2003. This was less than that removed from the CDS vault because the Vortechnics vault receives about one-quarter the runoff volume that passes through the CDS vault; also chambers 2 and 3 of the Vortechnics vault were not cleaned out until after WY2004. The mass of material removed from Vortechnics chambers 2 and 3 in WY2004 was proportioned to both water years for a more accurate assessment of total retention in each year.

Table17. Total mass of solids captured by size classification that was removed from the vaults during annual cleanout.

Year	Unit	Source	Sample #	Sand (kg)	Silt (kg)	Clay (kg)
2003	CDS	1	3 and 5	2489	354	26
2003	CDS	HT	1	193	630	96
2003	Vort	1	2 and 7	760	93	8
2004	CDS	1	1 and 2	837	87	7
2004	CDS	2	1 and 2	284	49	3
2004	Vort	1	1 and 2	44	22	2
2004	Vort	23	1 and 2	110	110	10

At this time, it is not possible to do an assessment of relative retention efficiency for the different particle size classes, primarily due to the sampling bias discussed previously.

VAULT RETENTION EFFICIENCY FOR PARTICULATE POLLUTANTS

Two approaches toward evaluating the mass retention efficiency of these stormwater treatment vaults have been applied in this study. The first approach estimated mass retention from the difference between inflow and outflow loads for each water year (Appendices 6 and 7). As discussed previously, it is obvious that this method does not provide an accurate assessment for particulates, since estimates of mass retention are significantly different from the known quantities of material removed from each vault in both water years (Table 18), even if one is to account for the amount of material greater than 4 mm that was not sampled by the autosamplers.

Table 18. Total mass (dry weight) of solids and nutrients removed during vault cleanout.

RHGID (inflow - outflow)	WY	Solids (kg)	TN (g)	TP (g)	TN/TP
CDS Technology, Inc.	2003	-796	-204	252	-0.8
CDS Technology, Inc.	2004	271	111	2	52.0
Vortechnics Systems	2003	2,489	-292	892	-0.3
Vortechnics Systems	2004	5	-15	5	-3.3
Jensen Precast	2004	59	1,499	327	4.6

The second approach for evaluating vault retention efficiency is based on measuring the mass of vault material removed (after cleanout) and calculating the outflow loads (from monitoring data), under assumptions that sampling at the outflow is not subject to particle discrimination, that it is representative for the entire year and is not subject to internal loading. Then, retention efficiency (RE) is calculated by the formula:

RE = mass of vault constituent / (mass of vault constituent + outflow load of constituent).

This mass-retention approach was used with the data from Table 18 and the data from Appendix 7 (scaled to the full water year) to produce the retention efficiency estimates shown in Table 19.

Table 19. Estimates of vault retention efficiency based on the mass-retention approach.

Vault Retention Efficiency	WY	Solids (%)	TN (%)	TP (%)
CDS Technology, Inc.	2003	68	23	18
CDS Technology, Inc.	2004	95	40	7
Vortechnics Systems	2003	59	20	17
Vortechnics Systems	2004	84	75	11

There was some variability in treatment efficiency between water years and vaults, but overall, the data indicate that 59 to 95 percent of the total mass of solids washed into these vaults was captured. The vaults were less effective at retention of TN and TP, ranging from 20 to 75 percent retention for TN and 7 to 18 percent retention for TP. Overall, the results were quite similar between water years and vaults.

SOIL CHARACTERIZATION AT INFILTRATION SITE

The Round Hill infiltration area is at the terminal end of residential drainage from Devaux Lane and McFaul Way. This infiltration area is located on the northeast corner of the intersection of Highway 50 and the Round Hill Shopping Center. It is the site of this project's first water quality monitoring installation at Round Hill (Site 1, Figure 2), where no runoff was ever observed. That monitoring equipment was later removed, and the area has been retrofitted recently to improve soil stability and infiltration features, as part of the RHGID Water Quality Improvement Project.

Soils were collected from this site in late October 2003, before the site improvements had occurred. This was also before winter storms arrived and while the sampling area was dry. Soil samples were collected after removing the surface duff layer and then augering to a depth of approximately 1 m at three randomly selected points within the central basin of the infiltration site.

These soils showed a general mottling of oxidized and reduced zones beginning at a depth of 0.5 to 1 m, which is characteristic of seasonal high groundwater levels. Soils collected from the three auger holes were aggregated, thoroughly mixed, and screened to remove coarse material greater than 0.63 cm. The aggregated sample was then analyzed for particle size distribution, soil pH, cation exchange capacity, nutrient content, and metals (Appendix 8).

Chemical characteristics of this soil were similar to soils collected at two other infiltration areas in the Tahoe Basin, although the Round Hill sample tended to be somewhat higher in cations and metals, especially zinc (Heyvaert *et al.*, 2004b, in review).

The Round Hill soil sample was classified as a loamy sand, based on particle size distribution, with 83 percent sand, 15.4 percent silt, and 1.6 percent clay (sand < 4 mm, silt < 62 μm, clay < 2 μm). All exposed soil surfaces at these sites were extremely hydrophobic at the time of sampling, but underlying soils seemed relatively permeable from tests conducted by NRCS personnel on the day of sample collection. Exact infiltration rates were difficult to measure, however, and highly variable due to uneven permeability of the soils.

LAND TREATMENT OF RUNOFF

Two monitoring wells were installed downstream from the outlet of the two vaults on Devaux Lane. Monitoring Well 1 (MW-1) was located approximately 79 ft. downstream of the vault outlet. It was drilled to a total depth of 13.8 ft. Monitoring Well 2 (MW-2) was located approximately 157 ft. downstream of the outlet, and was drilled to a total depth of 15.5 ft. Both wells were drilled to bedrock. The purpose of these wells was to determine if nutrients in stormwater discharged from the stormwater treatment vaults contributed to nutrient loading in groundwater. During WY2003 and WY2004, periodic water level measurements were made and water samples collected for nutrient analyses. These activities were conducted at approximately one-month intervals during times when runoff was occurring.

In March 2004, a pressure transducer and datalogger were installed in MW-1 to observe the groundwater response to drainage from the stormwater treatment vaults. Figure 28 is a plot of the data collected. The left y-axis shows the depth to water in MW-1, while the right y-axis shows discharge from the two stormwater treatment vaults. This figure shows that there is a very rapid groundwater response to discharge from the vaults. However, it should be noted that this is a pressure response, and the actual molecules of water leaving the vault take a longer time period to arrive at the well. It also demonstrates that without stormwater input, water slowly drains from this small groundwater reservoir. Water-level measurements from MW-2 show that this well is usually dry from mid-summer to late-fall, indicating how small this groundwater basin is.

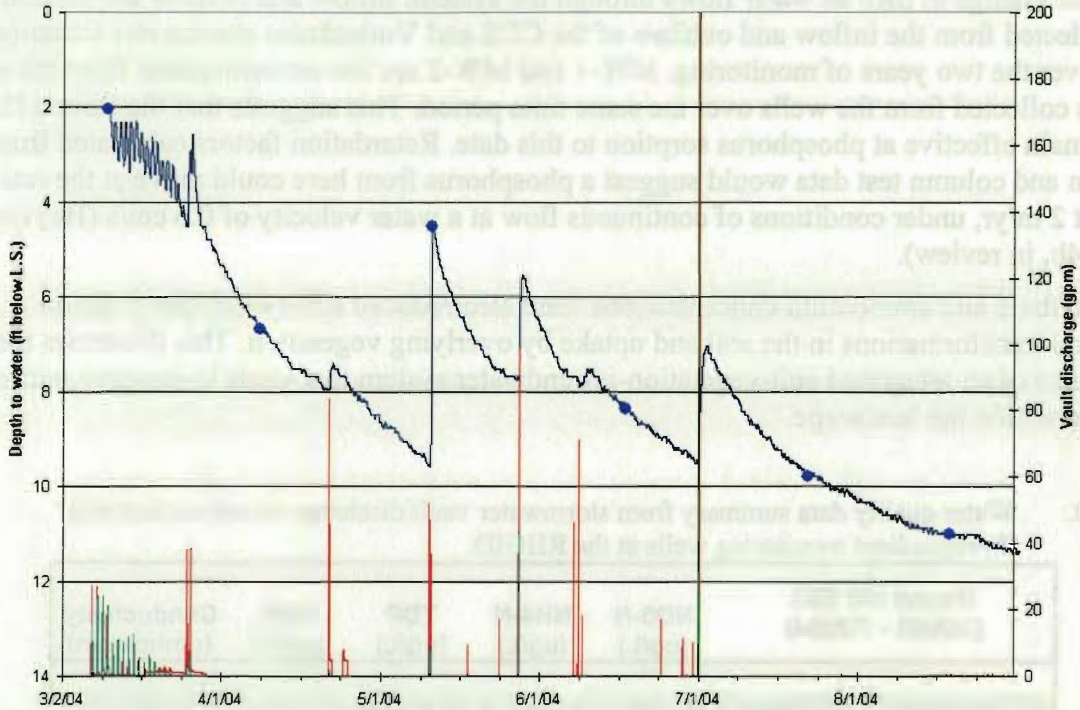

Figure 28. Plot of depth to water in MW-1 and drainage from stormwater treatment vaults. Blue dots indicate when water samples were collected and manual water level measurements were made.

Table 20 presents a summary of the water quality data from the monitoring wells and from the stormwater treatment vaults for WY2003 and WY2004. The raw monitoring well data are presented in Appendix 9. As shown above the discharge from the stormwater treatment vaults is the dominant source to groundwater in this small groundwater basin. Also, because the monitoring wells were drilled to bedrock, it is likely that they represent the bulk of the water passing through this soil from the vault surface water discharge. The surface discharge concentrations are typical of residential runoff from other areas of the Tahoe Basin (Heyvaert *et al.*, 2004a, in review), as are the groundwater concentrations (ACOE, 2003).

Stormwater treatment vaults remove most coarse material from runoff, so TSS and turbidity are quite low in the surface discharge to groundwater. Indeed, there is a net increase in TSS and turbidity in the groundwater wells compared to surface water samples taken during the same time period, from March 2003 to June 2004. Also, on occasion, it is possible that well sampling equipment disturbed sediments in the bottom of these monitoring wells. That would explain the anomalously high maximum values listed in the statistical summary. This was a rare occurrence, however.

Soluble concentrations of phosphorus (TDP and SRP) are much reduced compared to the upgradient, surface-water discharge. The median of measurements for TDP concentration from monitoring wells is only 18 percent of the upgradient surface-water median concentration. Similarly, the median groundwater orthophosphate concentration is only 16 percent of the upgradient surface-water concentration. This is illustrated graphically in Figure 29. This figure shows the change in SRP as water flows through the system. Inflow and outflow are the EMC data collected from the inflow and outflow of the CDS and Vortechnics stormwater treatment vaults over the two years of monitoring. MW-1 and MW-2 are the concentrations from the water samples collected from the wells over the same time period. This suggests that the Round Hill soils remain effective at phosphorus sorption to this date. Retardation factors calculated from isotherm and column test data would suggest a phosphorus front here could move at the rate of about 2 m/yr, under conditions of continuous flow at a water velocity of 0.6 cm/s (Heyvaert *et al.*, 2004b, in review).

Nitrate and ammonium concentrations were also reduced somewhat, likely due to biological transformations in the soil and uptake by overlying vegetation. This illustrates the importance of an integrated soil-vegetation-groundwater system that tends to improve nutrient retention within the landscape.

Table 20. Water quality data summary from stormwater vault discharge to soil surface and downgradient monitoring wells at the RHGID.

Round Hill GID (3/2003 - 7/2004)		NO3-N (ug/L)	NH4-N (ug/L)	TDP (ug/L)	SRP (ug/L)	Conductivity (umhos/cm)
Surface:	Median	77	23	84	67	60
	Minimum	7.3	7.3	31.7	7.6	28.0
	Maximum	1,969	2,860	240	1,041	163
	Mean	178	115	100	100	67
	Stdev	324	439	49	151	32
	CV	1.82	3.82	0.49	1.51	0.48
	n	43	43	43	43	19
MW-1:	Median	49	14	13	8	110
	Minimum	7.8	7.9	8.9	3.3	95.0
	Maximum	829	17	24	14	200
	Mean	182	13	15	8	120
	Stdev	302	3	5	3	37
	CV	1.66	0.26	0.30	0.38	0.31
	n	12	11	12	12	7
MW-2:	Median	31	13	17	13	108
	Minimum	12	7	14	3	100
	Maximum	46	23	30	15	110
	Mean	30	14	20	11	106
	Stdev	13	5	6	4	5
	CV	0.43	0.37	0.30	0.37	0.05
	n	8	7	8	8	4
MW_{avg} / Surface:	Median	52%	59%	18%	16%	181%
	Mean	59%	12%	17%	10%	169%

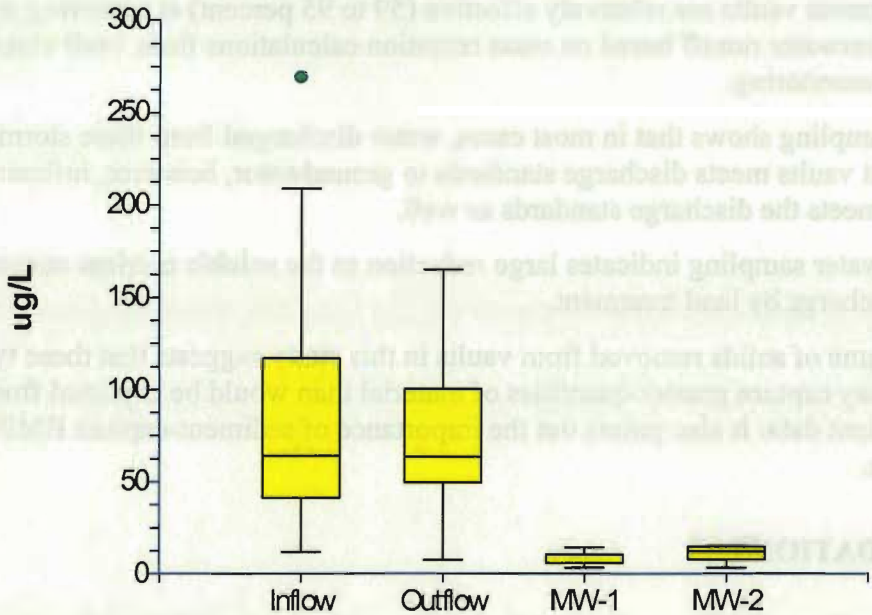

Figure 29. Box plot showing soluble reactive phosphorus data. The inflow and outflow represents the EMCs from the Vortechnics and CDS vaults over the two years of monitoring. MW-1 and MW-2 represents the water samples collected from the two monitoring wells over the two years of monitoring.

FINDINGS

- Stormwater monitoring in the Tahoe Basin is inherently difficult. Access to below-ground equipment during winter months is limited by accumulated snow. Short-duration, high-intensity summer events can move large quantities of material that clog sampling equipment making it inoperable.
- It is very difficult to assess performance based only on inflow and outflow sampling, unless the sample collection includes larger particulate materials and debris that are moved as bed load.
- Assessments based on inflow and outflow sampling are probably fairly reliable for the soluble nutrients, but do not account for reactions in treatment vaults that can change the chemical form.
- Total nitrogen retention by the vaults ranged from 20 to 75 percent, based on retention efficiency calculations from vault cleanouts and outflow monitoring.
- Retention of soluble nitrogen species was highly variable and sometimes negative, likely due to biological and chemical transformations in the vaults.
- Total phosphorus retention by the vaults ranged from 7 to 18 percent, based on mass retention calculations from vault cleanouts and outflow monitoring.
- Soluble phosphorus species were retained at about the same efficiency (6 to 24 percent) as total phosphorus in the CDS and Vortechnics vaults.

- The treatment vaults are relatively effective (59 to 95 percent) at removing total solids from stormwater runoff based on mass retention calculations from vault cleanouts and outflow monitoring.
- Water sampling shows that in most cases, water discharged from these stormwater treatment vaults meets discharge standards to groundwater, however, influent water usually meets the discharge standards as well.
- Groundwater sampling indicates large reduction in the soluble nutrient concentrations of vault discharge by land treatment.
- The volume of solids removed from vaults in this study suggests that these types of BMPs may capture greater quantities of material than would be expected from influent and effluent data. It also points out the importance of sediment-capture BMPs in front of wetlands.

RECOMMENDATIONS

- Water quality sampling equipment should be installed to avoid sampling from locations where sediment accumulates. This practice can seriously bias monitoring results, leading to overestimates of sediment load. It can also produce frequent mechanical failures in monitoring and sampling equipment.
- The volume of solids removed from vaults in this study suggests that these types of BMPs may capture greater quantities of material than would be expected from influent and effluent data. This indicates that more frequent cleaning may be required on these BMPs and of detention basins in general.
- Vault cleanouts are fairly expensive and labor intensive. Cleanouts should be performed at intervals determined by regular monitoring. A single, large event can move sufficient material to fill some vaults, especially when pine needles make up 50 percent or more of the load.
- Vaults are ideal for breeding mosquitoes. Considering the threat of West Nile virus and other mosquito-borne diseases, it is important to actively manage this problem.
- Given the large number of stormwater treatment vaults installed in the Tahoe Basin, the region may benefit from a treatment vault/BMP monitoring program and a maintenance facility. The monitoring program should address mosquitoes as well as sediment accumulation.
- Stormwater treatment vaults should not generally be installed in locations where suitable sites are available for land treatment of runoff water, especially for runoff from low-density residential areas or similar low-intensity land uses. Management is much easier where open space is available for access and maintenance, rather than keeping a vault at optimal performance by removing solids on a frequent basis.
- Groundwater sampling indicates large reduction in the soluble nutrient concentrations of vault discharge runoff by land treatment. This indicates the importance of considering a

treatment train approach in stormwater management. Few BMPs are likely to reduce all the pollutants of concern, but in sequence can provide targeted treatment.

- Routine seasonal groundwater sampling should continue at the two RHGID monitoring wells to watch for phosphorus breakthrough from surface runoff discharge at the vaults.

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APPENDIX 1: Background

In February 2001, the Round Hill General Improvement District (RHGID) submitted a grant application for extensive erosion control and water quality improvements within subdivision Unit No. 4 of its jurisdiction. The proposed elements of this project included slope stabilization, storm drain, curb and gutter, revegetation, stormwater treatment vaults, stormwater treatment basins, and SEZ restoration.

The Desert Research Institute (DRI) and the Tahoe Research Group at the University of California, Davis (TRG), were asked to submit a proposal to the Nevada Division of State Lands (NDSL) for a License Plate grant to provide monitoring as the Round Hill project was implemented. In particular, preliminary project designs proposed the construction of two water quality treatment basins for the detention, settlement, and infiltration of stormwater runoff. The monitoring program was initially designed to study effectiveness and potential impacts resulting from large-scale implementation of stormwater infiltration and source control measures. Monitoring was to consist of surface water flow measurements, groundwater observations, soil testing, and water quality characterization.

Toward that goal, a meteorological station was installed at the RHGID office and placed into operation on December 12, 2001. Two water quality monitoring stations were also installed at this time (Figure 1.1), one at each site of the two proposed infiltration basins. Instrumentation consisted of an in-channel flume with stage monitoring for continuous flow measurements during runoff events, and automated sampling equipment for water quality monitoring.

It soon became apparent, however, that runoff flows were insufficient to reach the monitoring stations located in these lower drainages of the RHGID. By spring 2002, neither site had recorded any overland flow during runoff events, despite several significant storms and spring snowmelt during this period (Figure 1.2). Therefore, a third station was established at the intersection of McFaul Way with Devaux Lane and brought online in May 2002. This monitoring site receives substantial stormwater runoff from roads and properties on the west side of the RHGID, and is upgradient from the larger of the two stormwater infiltration basins.

As evident in the precipitation chart of Water Year 2002 (WY02), however, only one precipitation event occurred after the Site 3 monitoring station started recording data. This was a relatively large summer convective storm that occurred on July 18, 2002. Unfortunately, the autosampler battery had drained to a voltage inadequate to activate automatic sampling at the start of this event, however grab samples were collected. Notably, monitoring stations in the lower drainages at the treatment basin sites did not receive flow during this event despite 0.35 inches of rain within an 8-hour period, demonstrating that soils upgradient from the area proposed for the infiltration basin have substantial infiltration capacity. Subsequently, the monitoring equipment was decommissioned at the two infiltration basin sites in anticipation of a more favorable monitoring site.

In discussions with RHGID and NDSL staff, it was determined that the monitoring program should be adjusted to focus instead on two new stormwater treatment vaults scheduled for installation at the McFaul and Devaux site in late summer 2002 (Figure 1.3). Additional funding was provided by the NDSL and the U.S. Forest Service CURTEM program to provide two years of monitoring (WY2003 and WY2004) for evaluation of treatment efficiency by two different stormwater treatment vaults. These are hydrodynamic treatment systems, of which there are several proprietary configurations. They have the advantage of being underground installations, thus providing treatment capacity in locations where there may be limited opportunity for other types of best management practices (BMPs), such as a detention basin or wetland system. The efficiency of these hydrodynamic treatment systems for removing sediments and nutrients from stormwater runoff in the Tahoe Basin was unknown, so the focus of the RHGID monitoring was shifted to an assessment of these treatment vaults.

Figure 1.1. Round Hill GID, showing Hwy 50, instrument sites 1, 2, and 3, meteorological station and stormwater treatment vault drainage areas.

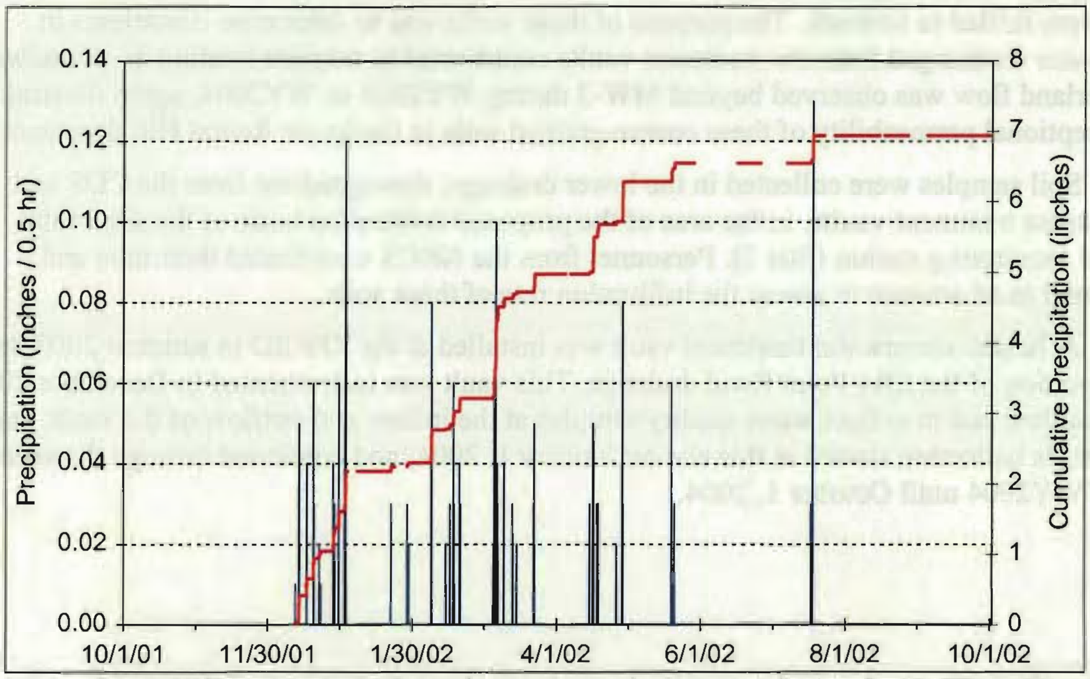

Figure 1.2. Precipitation event intensity and annual cumulative precipitation during Water Year 2002 (October 1, 2001 through September 31, 2002). Open spaces on the cumulative precipitation line indicate data gaps in the meteorological record.

Figure 1.3. Installation site of stormwater treatment vaults and outflow culverts at Devaux Lane and McFaul Way in September 2002 showing the CDS vault in this photo.

Two monitoring wells were installed downstream from the outlet of the two vaults on Devaux Lane. Monitoring Well 1 (MW-1) was located approximately 79 ft. downstream of the vault outlet. It was drilled to a total depth of 13.8 ft. Monitoring Well 2 (MW-2) was located approximately 157 ft. downstream of the outlet, and was drilled to a total depth of 15.5 ft. Both wells were drilled to bedrock. The purpose of these wells was to determine if nutrients in stormwater discharged from the treatment vaults contributed to nutrient loading in groundwater. No overland flow was observed beyond MW-2 during WY2003 or WY2004, again illustrating the exceptional permeability of these coarse-grained soils in the lower Round Hill drainages.

Soil samples were collected in the lower drainage, downgradient from the CDS and Vortechnics treatment vaults, in the area of the proposed infiltration basin at the site of the original monitoring station (Site 1). Personnel from the NRCS contributed their time and equipment in an attempt to assess the infiltration rate of these soils.

A Jensen stormwater treatment vault was installed at the RHGID in summer 2003, in the lower portion of the Elks Point Road drainage. This vault was instrumented in December 2004 to measure flow and to collect water quality samples at the inflow and outflow of the vault. Data and sample collection started at this site on January 1, 2004, and continued through the second half of WY2004 until October 1, 2004.

APPENDIX 2: Precipitation events at RHGID meteorological station during WY2002. Some small events (e.g., 0.01 in) may be spurious data points.

WY02 Precip Event (#)	Project	Event start	Event end	Event duration (hr:mm)	Interevent duration (hr:mm)	Event cumulative precip (inches)	Event peak precip (inch/30min)	Event minimum temp (°C)	Event maximum temp (°C)	Type of Precipitation
1	Round Hill	12/13/2001 23:00	12/14/2001 10:00	11:10	0:00	0.4	0.05	-3.082	-0.478	Snow
2	Round Hill	12/17/2001 7:00	12/17/2001 11:30	4:40	69:00	0.24	0.04	0.64	0.941	Rain
3	Round Hill	12/20/2001 5:30	12/20/2001 10:30	5:10	66:00	0.29	0.06	-3.443	0.58	Snow
4	Round Hill	12/22/2001 13:30	12/23/2001 7:30	18:10	51:00	0.1	0.02	-2.141	0.847	Snow
5	Round Hill	12/28/2001 11:30	12/29/2001 4:00	16:40	124:00	0.33	0.04	0.806	3.381	Rain
6	Round Hill	12/30/2001 19:30	12/30/2001 23:00	3:40	39:30	0.24	0.06	2.099	3.18	Rain
7	Round Hill	1/2/2002 7:00	1/2/2002 23:00	16:10	56:00	0.57	0.12	0.928	6.289	Rain
8	Round Hill	1/21/2002 18:00	1/21/2002 19:00	1:10	451:00	0.06	0.03	-1.08	-0.718	Snow
9	Round Hill	1/28/2002 15:00	1/29/2002 10:30	19:40	164:00	0.06	0.03	-13.18	-7.22	Snow
10	Round Hill	2/7/2002 17:00	2/8/2002 0:00	7:10	222:30	0.46	0.08	0.677	1.616	Rain
11	Round Hill	2/13/2002 21:30	2/13/2002 21:30	0:10	141:30	0.02	0.02	1.264	1.264	
12	Round Hill	2/15/2002 15:30	2/15/2002 18:00	2:40	183:30	0.06	0.03	3.197	5.859	Rain
13	Round Hill	2/17/2002 0:00	2/17/2002 12:00	12:10	30:00	0.19	0.06	-2.53	0.675	Snow
14	Round Hill	2/19/2002 15:00	2/19/2002 23:00	8:10	51:00	0.18	0.04	2.665	4.463	Rain
15	Round Hill	3/5/2002 20:30	3/7/2002 22:30	50:10	333:30	1.3	0.1	-5.403	4.893	Rain/snow
16	Round Hill	3/10/2002 8:00	3/10/2002 10:00	2:10	57:30	0.12	0.04	-0.969	0.41	Snow
17	Round Hill	3/14/2002 2:30	3/14/2002 4:30	2:10	88:30	0.06	0.03	-6.165	-5.594	Snow
18	Round Hill	3/15/2002 17:00	3/15/2002 18:00	1:10	36:30	0.03	0.02	-5.054	-4.399	Snow
19	Round Hill	3/22/2002 23:00	3/23/2002 9:00	10:10	173:00	0.25	0.05	-1.6	1.197	Snow
20	Round Hill	4/15/2002 9:00	4/15/2002 9:00	0:10	552:00	0.03	0.03	-2.723	-2.723	Snow
21	Round Hill	4/16/2002 16:00	4/17/2002 4:30	12:40	31:00	0.5	0.05	-3.972	-0.342	Snow
22	Round Hill	4/18/2002 12:30	4/19/2002 1:00	12:40	32:00	0.18	0.03	-3.267	0.654	Snow
23	Round Hill	4/26/2002 11:30	4/26/2002 18:00	6:40	178:30	0.04	0.02	4.021	7.22	Rain
24	Round Hill	4/29/2002 3:30	4/29/2002 12:30	9:10	57:30	0.57	0.08	0.864	4.717	Rain
25	Round Hill	5/19/2002 22:30	5/21/2002 3:30	29:10	490:00	0.26	0.06	-1.629	6.272	Rain/snow
26	Round Hill	7/17/2002 15:30	7/18/2002 14:30	23:10	1380:00	0.39	0.13	10.98	25.91	Thunderstorm

Data gap	Gap start	Gap end	Gap duration (hr:mm)
Data Gap	1/3/2002 15:30	1/7/2002 11:30	92:10
Data Gap	1/23/2002 9:30	1/28/2002 13:30	124:10
Data Gap	4/5/2002 9:30	4/7/2002 8:30	47:10
Data Gap	5/10/2002 12:30	5/11/2002 10:00	21:40
Data Gap	5/29/2002 13:00	6/16/2002 12:00	431:10
Data Gap	6/26/2002 12:30	7/7/2002 13:00	264:40
Data Gap	7/23/2002 8:00	7/27/2002 12:30	100:40
Data Gap	8/15/2002 15:00	8/17/2002 13:30	46:40
Data Gap	8/27/2002 14:30	9/4/2002 16:00	193:40

APPENDIX 2 (continued): Precipitation events at RHGID meteorological station during WY2003. Some small events (e.g., 0.01 in) may be spurious data points.

WY03 Precip Event (#)	Project	Event start	Event end	Event duration (hr:mm)	Inter-event duration (hr:mm)	Event cumulative precip (inches)	Event peak precip (inch/30min)	Event minimum temp (°C)	Event maximum temp (°C)	Type of Precipitation
1	Round Hill	10/3/2002 22:00	10/3/2002 23:00	1:10	na	0.02	0.01	8	9	Rain
2	Round Hill	11/7/2002 6:00	11/10/2002 12:30	78:40	823:00	2.29	0.13	0	8	Rain
3	Round Hill	12/13/2002 6:00	12/21/2002 22:30	208:40	785:30	5.11	0.16	-8	10	Rain/Snow
4	Round Hill	12/26/2002 18:00	12/26/2002 21:00	3:10	115:30	0.03	0.02	2	3	Rain
5	Round Hill	12/28/2002 18:30	12/29/2002 17:30	23:10	45:30	1.20	0.21	-4	1	Snow
6	Round Hill	12/30/2002 17:30	12/31/2002 13:00	19:40	24:00	0.59	0.08	-4	2	Snow
7	Round Hill	1/9/2003 11:30	1/10/2003 13:00	25:40	214:30	0.20	0.03	0	4	Rain
8	Round Hill	1/21/2003 13:30	1/21/2003 13:30	0:10	264:30	0.01	0.01	4	6	Rain
9	Round Hill	1/22/2003 18:30	1/23/2003 20:00	25:40	29:00	0.32	0.06	2	9	Rain
10	Round Hill	1/27/2003 15:30	1/27/2003 20:30	5:10	91:30	0.09	0.02	4	8	Rain
11	Round Hill	2/1/2003 15:00	2/1/2003 21:30	6:40	114:30	0.09	0.04	-3	4	Rain/Snow
12	Round Hill	2/13/2003 5:00	2/13/2003 19:30	14:40	271:30	0.24	0.06	1	8	Rain
13	Round Hill	2/16/2003 4:00	2/16/2003 11:30	7:40	56:30	0.63	0.12	-2	1	Snow
14	Round Hill	2/27/2003 0:00	3/1/2003 12:30	60:40	252:30	0.30	0.03	-6	4	Snow
15	Round Hill	3/3/2003 21:00	3/4/2003 1:30	4:40	56:30	0.06	0.02	-2	-1	Snow
16	Round Hill	3/13/2003 21:00	3/15/2003 12:00	39:10	235:30	0.78	0.11	0	10	Rain
17	Round Hill	3/17/2003 1:00	3/17/2003 1:00	0:10	37:00	0.01	0.01	-1	-1	Snow
18	Round Hill	3/19/2003 23:00	3/20/2003 3:00	4:10	70:00	0.03	0.02	0	1	Rain
19	Round Hill	3/23/2003 5:00	3/23/2003 5:00	0:10	74:00	0.02	0.02	2	2	Rain
20	Round Hill	3/26/2003 6:30	3/26/2003 10:30	4:10	73:30	0.18	0.04	5	6	Rain
21	Round Hill	4/1/2003 17:00	4/5/2003 2:00	81:10	150:30	1.15	0.08	-8	3	Snow
22	Round Hill	4/12/2003 6:30	4/13/2003 19:30	37:10	172:30	2.87	0.12	-2	7	Rain/Snow
23	Round Hill	4/16/2003 15:30	4/16/2003 23:00	7:40	68:00	0.15	0.02	0	3	Rain
24	Round Hill	4/20/2003 17:30	4/21/2003 11:30	18:10	90:30	0.25	0.05	1	5	Rain
25	Round Hill	4/24/2003 14:30	4/24/2003 18:00	3:40	75:00	0.06	0.02	1	4	Rain
26	Round Hill	4/25/2003 20:00	4/26/2003 0:30	4:40	26:00	0.11	0.03	-1	0	Snow
27	Round Hill	4/28/2003 4:30	4/28/2003 8:00	3:40	52:00	0.18	0.05	-2	1	Snow
28	Round Hill	4/29/2003 19:30	4/30/2003 0:00	4:40	35:30	0.04	0.02	-1	1	Rain/Snow
29	Round Hill	5/2/2003 9:30	5/4/2003 5:00	43:40	57:30	0.20	0.02	0	10	Rain
30	Round Hill	5/8/2003 9:30	5/9/2003 21:30	36:10	100:30	0.36	0.07	-3	6	Rain/Snow
31	Round Hill	6/23/2003 13:30	6/23/2003 20:30	7:10	1072:00	0.52	0.19	3	10	Rain
32	Round Hill	7/19/2003 7:00	7/19/2003 7:00	0:10	610:30	0.02	0.02	16	16	Rain
33	Round Hill	7/20/2003 17:00	7/20/2003 17:30	0:40	34:00	0.17	0.13	18	23	Rain
34	Round Hill	7/23/2003 17:00	7/23/2003 17:30	0:40	71:30	0.02	0.01	19	20	Rain
35	Round Hill	7/26/2003 18:00	7/26/2003 18:00	0:10	72:30	0.03	0.03	18	18	Rain
36	Round Hill	7/31/2003 14:00	8/2/2003 15:00	49:10	116:00	0.53	0.25	12	25	Rain
37	Round Hill	8/21/2003 6:30	8/21/2003 19:30	13:10	447:30	1.21	0.28	14	18	Rain
38	Round Hill	8/26/2003 4:30	8/26/2003 10:00	5:40	105:00	0.20	0.06	12	17	Rain
39	Round Hill	8/31/2003 10:00	8/31/2003 11:30	1:40	120:00	0.02	0.01	14	18	Rain
40	Round Hill	9/3/2003 13:30	9/5/2003 3:00	37:40	74:00	0.61	0.26	12	25	Rain

Data gap	Gap start	Gap end	Gap duration (hr:mm)	Comment
data gap	11/8/2002 9:00	11/8/2002 12:00	3:10	No precip at CSLT

Appendix 2 (continued). Precipitation events at RHGID meteorological station during WY2004. Some small events (e.g., 0.01 in) may be spurious data points.

Data gap	Gap start	Gap end	Gap duration (hr:mm)	Comment
data gap	7/21/04 14:30	9/8/04 9:30	1171:10	Power inadvertently disconnected
eof				

Note: no precipitation was recorded at the Fire House meteorological station in South Lake Tahoe during the RH data gap from 7/21/04 to 9/8/04.

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APPENDIX 3: Questions and answers about the CDS stormwater treatment vault.

April 13, 2005

Alan C. Heyvaert, Ph.D.
UCD Tahoe Research Group
P.O. Box 633
2400 Lake Forest Road
Tahoe City, CA 96145

Dear Dr. Heyvaert,

Following are the responses to your questions regarding CDS Storm Water Treatment Unit installed at the Round Hill GID.

Once again, we appreciate the opportunity to assist you in achieving the storm water objectives of your project. If we can offer any further assistance or if you would like to discuss any of the responses, please do not hesitate to call us at (916) 486-1736 or email: glippner@cdstech.com.

Respectfully,

Gary Lippner, P.E.
Regional Manager
CDS Technologies, Inc.

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1. The Round Hill CDS 14-cfs unit has a 51-inch tall weir to divert flow into the CDS unit. It would seem this height is excessive. Does the weir bypass flows greater than 14 cfs? If not, what is the expected consequence on treatment effectiveness of flows greater than 14 cfs through the treatment chamber? Please provide detailed hydraulic calculations showing that a 51-inch tall weir was needed to divert 14-cfs.

The weir has been sized to divert flows up to 14-cfs to the CDS unit. The flows greater than 14-cfs will be bypassed over the weir. Height of the CDS weir needed to divert flows in to the treatment unit is a function of following parameters:

1. ***Water Surface Elevation & Specific Energy downstream of CDS unit during the treatment flow rate***
2. ***Head loss through the CDS unit during the treatment flow rate.***

For this project the at the treatment rate of 14-cfs,

Critical Depth, Y_c = 1.19-ft
Critical Velocity, V_c = 5.34-cfs
Specifc Energy = $Y_c + V_c^2/2g$ = 1.63-ft
Head Loss through CDS PSWC56_53 at 14-cfs = 2.35-ft

Therefore,

Weir Height required = 1.63 + 2.35 + 0.5* $V_c^2/2g$ (Exit loss at weir chamber)
= 4.20-ft or 51-inches

2. The orientation of the CDS diversion weir is significantly different than that of Vortechnics system. Please explain the reasoning behind this orientation of the diversion weir angle, as opposed to a 90 degree weir orientation, for example.

The CDS weir is oriented approximately 60-degrees to the flow direction. This orientation ensures that hydraulic energy is utilized to maintain CDS functionality in terms in terms of self cleaning of the CDS screen and vortex motion inside the separation chamber. A bend or change in direction results in a distortion of the velocity distribution, thereby causing additional stresses within the fluid resulting in a head loss. The CDS weir orientation reduces the losses due to change in direction (compared to a 90-degrees orientation).

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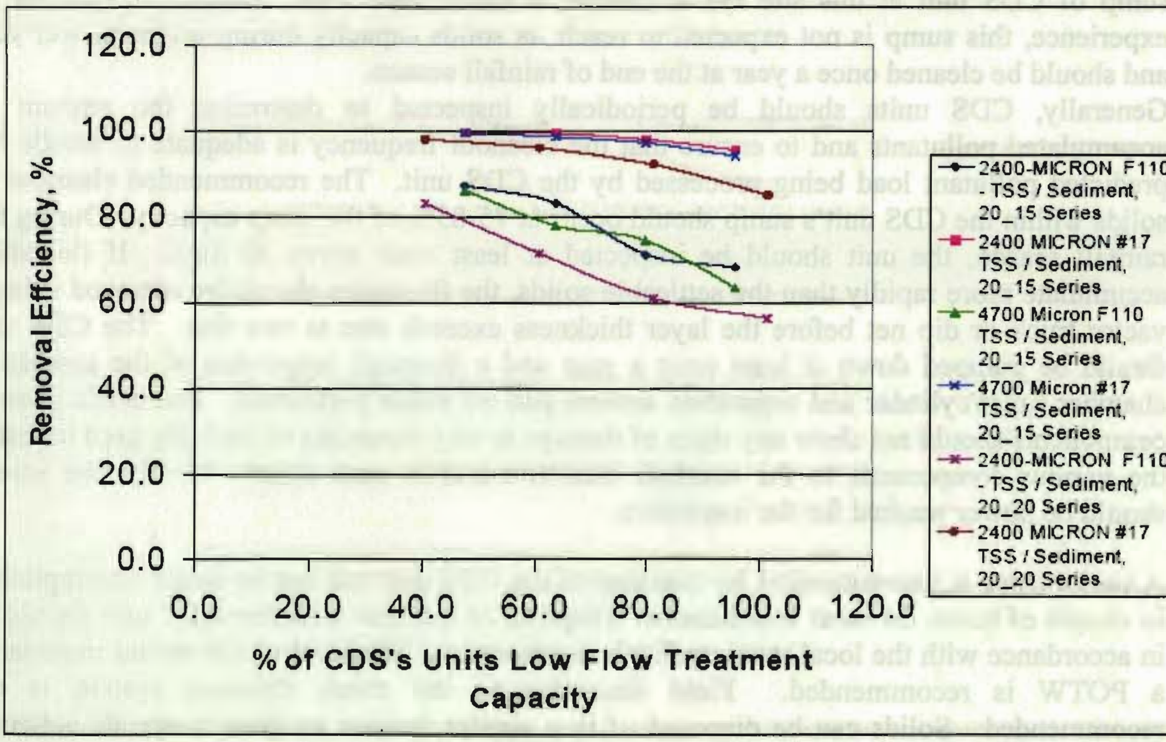
3. Would you expect improved, reduced or no change in treatment effectiveness across the range of flows from 0 to 14 cfs? In particular, would you expect good treatment at the low flow rates typical of snowmelt and other low intensity runoff events (0.05 to 0.5 cfs), or does the hydrodynamic action become less effective at these lower flows?

CDS units are designed to balance the hydraulics such that flow entering the screen has tangential forces greater than the normal forces on the screen surface over the entire range of treatment flows. This design ensures indirect screening and hence the non-blocking functionality of the screen for all the flows expected during any wet year from the smallest flows to the capacity of the treatment unit. In general, hydrodynamic separation is more effective during lower flows as compared to higher treatment flow. This is supported by laboratory testing of CDS unit at Portland State University that indicated removal efficiency of CDS is a function of operating rate of the system. Under the direction of Professor Scott Wells, multiple tests were performed to establish the removal efficiencies achieved by a full-scale CDS device. The study was organized to evaluate the effectiveness of the CDS device for various operating levels up to 100 percent. The operating level is expressed as a percentage of device's design treatment capacity. The removal was found to be higher for low operating rates and decreased as flow rate increased. Following figure illustrates the results from these tests.



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4. Do you expect anaerobic conditions to occur between events in the sump of the CDS or Vortechnics unit as solids acccumulate?

Anaerobic conditions may or may not occur depending on the time period between events, temperature, and organic content of the sump solids. Bottom part of accumulated solids in the sump would most likely go anaerobic at the end of the rainfall season due to accumulated material and warmer temperatures. Cleanout of the CDS unit at the end of a rainfall season is therefore recommended because of this potential.

5. What is your recommended inspection and maintenance procedure and schedule for this vault?

The frequency of cleaning the CDS unit depends upon the generation of trash and debris and sediments at the particular project site. Cleanout and preventive maintenance schedules are normally determined based on operating experience unless precise pollutant loadings have been determined. Monitoring performed over the last two years at the Round Hill site indicates that amount of floatables in runoff from this watershed is very small. Therefore, frequency of cleanout will largely depend on amount of solids captured in the sump. The sump of CDS unit at this site has a volume of more than 5-yd^3. Based on monitoring experience, this sump is not expected to reach its solids capacity during a typical wet year and should be cleaned once a year at the end of rainfall season.
Generally, CDS units should be periodically inspected to determine the amount of accumulated pollutants and to ensure that the cleanout frequency is adequate to handle the predicted pollutant load being processed by the CDS unit. The recommended cleanout of solids within the CDS unit's sump should occur at 75-85% of the sump capacity. During the rainfall season, the unit should be inspected at least once every 30 days. If floatables accumulate more rapidly than the settleable solids, the floatables should be removed using a vactor truck or dip net before the layer thickness exceeds one to two feet. The CDS unit should be pumped down at least once a year and a thorough inspection of the separation chamber (inlet/cylinder and separation screen) and oil baffle performed. The unit's internal components should not show any signs of damage or any loosening of the bolts used to fasten the various components to the manhole structure and to each other. Ideally, the screen should be power washed for the inspection.

A vactor truck is recommended for cleanout of the CDS unit and can be easily accomplished in couple of hours for most installations. Disposal of material from the CDS unit should be in accordance with the local municipality's requirements. Disposal of the decant material to a POTW is recommended. Field decanting to the storm drainage system is not recommended. Solids can be disposed of in a similar fashion as those materials collected from street sweeping operations and catch-basin cleanouts.

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6. Please provide an estimate of the vault volume, that is retention volume (water + solids) that would remain in the treatment chamber between storms.

Diameter of the CDS Separation Chamber/Sump = 8-ft
Depth from pipe invert to the separation slab = 5.92-ft
Depth of the Sump = 3-ft

Sump Volume = $(3.14/4)*(8)^2*(3) = 150.79\text{-ft}^3$ = 1128 gallons
Separation Chamber Volume = $(3.14/4)*(8)^2*(5.92) = 297.57\text{-ft}^3$ = 2226 gallons
Total Volume of water + Solids = Separation Chamber Volume + Sump Volume
= (150.79 + 297.57) = 448.4-ft³ = 3354 gallons

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APPENDIX 4: Questions and answers about the Vortechnics stormwater treatment vault.

February 16, 2005

UCD Tahoe Research Group
Attn: Alan C. Heyvaert, Ph.D.
P.O. Box 633
2400 Lake Forest Road
Tahoe City, CA 96145

Dear Dr. Heyvaert,

I have gone through your questions and provided my responses below. For information on how the vault design works you can reference our Technical Design Manual (attached). If you have any questions, please feel free to contact me at my office or on my mobile phone number below. Please see the attached documents on product description, removal efficiency (Technical Bulletin #1), site specific sediment removal estimate, stage discharge curve and our Technical Design Manual which offers some information on maintenance.

Thanks for your time and hard work on this project Alan.

Regards,

John P. Stiver, P.E.
Western Zone Manager, Vortechnics, Inc.
(207) 885-9830 x291 Office
(916) 212-7539 Cell

Committed to Clean Water™

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1. The Vortechnics *System Technical Design Manual* available online has an example that shows the Vortechs 5000 as an 8.50-cfs unit with 24-inch inlet and outlet pipes. Why would the Roundhill unit with a higher peak capacity (14-cfs) have 12-inch inlet and outlet pipes?

The Vortechs System that was used on this project was a Vortechs Model 9000. It has a treatment capacity of 14 cfs. The design engineer, who worked on this project, chose the 12" pipe size into our system based on his hydraulic calculations, and determined that they were adequate to send the 14 cfs to our system. We feel that the pipe is undersized.

2. The orientation of the diversion weir that directs flow into the treatment chamber is such that it causes the flow to make a 115 degrees reverse bend before it enters the chamber through the 12-inch pipe. Please explain the reasoning behind this orientation of the weir, as opposed to a weir that would direct flow toward the 12-inch inlet pipe with no reversal.

The Vortechs System on this project was designed without our knowledge. We had no input into this design, as we weren't contacted. The first we saw of this design was the day that the system went out to bid. We informed the engineer that the system configuration was not ideal and that we would like to see it moved. He told us that there wasn't enough room to rotate our system 90 degrees to accommodate this request. This was the best solution to meet the site conditions. Since I was there for the installation, I recommended to the contractor to rotate the system as much as possible. This minimized the degree of flow direction change in the manhole. It was actually much worse before the field adjustment. This situation however, is clearly not ideal for the proper functioning of the Vortechs System.

3. Is the 1.5-ft tall weir intended to divert a full 14-cfs of flow into the treatment chamber? It would seem this height is insufficient. From our estimates, the velocity in a full flowing pipe (Q/A) at 14-cfs would be approximately 17.8-ft/s, and the velocity head (V2/2g) at this peak flow would be 4.9-ft. Using a very conservative contraction and expansion loss coefficient of 0.2 yields a headloss at the inlet and outlet of the system of at least 2-ft. Based upon these head loss calculations, it is unclear how a 1.5-ft tall weir upstream of the system could divert 14-cfs into the treatment chamber.

Once again, your observations are correct. The 1.5-ft tall weir is much too small and much too short. The engineer used an existing 3-ft diameter manhole to divert flows into our system to save on costs. The existing manhole should have been replaced with a 6-ft diameter manhole to divert flows 90-degrees into our system.

4. Would you expect improved, reduced or no change in treatment effectiveness across the range of flows from 0 to 14 cfs? In particular, would you expect good treatment at the low flow rates typical of snowmelt and other low intensity runoff events (0.05 to 0.5 cfs), or does the hydrodynamic action become less effective at these lower flows?

As is true with all hydrodynamic treatment devices, the removal efficiency is greatest at the lowest flows. We don't typically rely on the "vortex" motion in our swirl chamber at low flows as much as we rely on the flow controls in our system to slow that water down and submerge our inlet pipe, which in turn will keep our velocities and energies low. See Technical Bulletin #1 (attached) for removal efficiencies based on operating rate and particle sizes.

5. Do you expect anaerobic conditions to occur between events in the sump of the CDS or Vortechnics unit as solids acccumulate?

Anaerobic conditions are possible in any system if organic material is present and there is a substantial dry period between storm events. In contrast to our Vortechs System with a 3-ft sump (depth below invert), the CDS unit has a much deeper sump. It would appear that the low flow through the CDS unit would not displace much of any water in the sump, making it an easier target for anaerobic conditions than a shallow sump Vortechs System.

6. What is your recommended inspection and maintenance procedure and schedule for this vault?

Since we don't know what the sediment loading rate is for every site, we would typically recommend quarterly inspections during the first year to determine sediment accumulation rates. Our typical design would allow for enough storage for annual maintenance. More frequent maintenance would be required for sites with high sediment accumulations.

7. Please provide an estimate of the vault volume, that is retention volume (water + solids) that would remain in each treatment chamber between storms.

The Vortechs Model 9000 has internal dimensions of 9' x 15'. The system typically has a 3' sump and the swirl chamber (can also call it the sediment chamber) at the inlet has a 9' diameter and 3' sump. The sediment storage capacity in this chamber will be approximately 130 cubic feet or 4.8 cubic yards using a cone shaped geometry to the top of pile, which is typically how the sediment pile forms. Since there are two walls inside the system, the baffle wall and the flow control wall, the internal volume at rest is 9' x 15' x 3' (minus some volume for the baffle and flow control wall) or approximately 380 cubic feet, or 14 cubic yards. If the sediment chamber were full of sediment, then the amount of water in the system would be about 250 cubic yards of water (9.26 cy).

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APPENDIX 5: Runoff event summaries for stormwater treatment vaults, WY2003 and WY2004.

WY2003 CDS stormwater treatment vault event summary, inflow (4.2) and outflow (4.1).

Project	Site	Location	Event ID	Runoff Start (Date Time)	Runoff End (Date Time)	Runoff Duration (hh:mm)	Event Type	Runoff Volume (cf)	Peak Flow (cfs)	Sample Pacing Set	Samples Collected	Singles or Composites Analyzed	Field Notes and Sampling Quality
Round Hill	4.1	1	na	10/01/02	na	na	site active	na	na	na	na	na	na
Round Hill	4.1	1	RH-03-1	12/13/02 7:00	12/14/02 7:00	24:00	rain on snow	1,372	0.107	62min	10	10	Good
Round Hill	4.1	1	RH-03-2	12/27/02 11:00	12/27/02 21:00	10:00	snowmelt	169	0.012	62min	3	3	Moderate
Round Hill	4.1	1	RH-03-3	1/12/03 12:30	1/13/03 21:45	33:15	rain on snow	1,011	0.036	62min	8	2	Good
Round Hill	4.1	1	RH-03-4	2/27/03 5:15	2/28/03 1:45	20:30	rain on snow	1,663	0.063	62min	3	3	Poor
Round Hill	4.1	1	RH-03-5	3/13/03 20:00	3/15/03 21:45	49:45	rain on snow	4,156	0.499	62min	8	8	Moderate
Round Hill	4.1	1	RH-03-6	3/26/03 6:00	3/26/03 16:30	10:30	snowmelt, rain on snow	313	0.056	62min	2	2	Moderate
Round Hill	4.1	1	RH-03-7	4/1/03 16:15	4/3/03 15:20	47:05	rain on snow	1,444	0.070	62min	4	4	Moderate
Round Hill	4.1	1	RH-03-8	4/12/03 16:10	4/12/03 19:30	3:00	snowmelt, rain on snow	580	0.126	62min	1	1	Poor
Round Hill	4.1	1	RH-03-9	4/14/03 8:30	4/15/03 7:10	22:40	snowmelt	1,438	0.067	62min	4	4	Moderate
Round Hill	4.1	1	RH-03-10	4/15/03 10:40	4/15/03 20:10	9:10	snowmelt	635	0.047	62min	3	3	Good
Round Hill	4.1	1	RH-03-11	4/17/03 10:40	4/17/03 20:40	10:00	snowmelt	1,058	0.069	62min	5	5	Good
Round Hill	4.1	1	RH-03-12	4/21/03 7:50	4/21/03 15:50	8:00	rain on snow	923	0.124	62min	4	4	Poor
Round Hill	4.1	1	RH-03-13	4/28/03 3:40	4/28/03 11:50	8:10	rain on snow	487	0.056	62min	2	2	Poor
Round Hill	4.1	1	RH-03-15	5/9/03 17:40	5/10/03 0:40	7:00	rain on snow	554	0.063	62min	3	3	Good
Round Hill	4.1	1	RH-03-16	6/23/03 12:20	6/23/03 18:10	5:50	rain on snow	3,200	1.045	12min	15	1	Moderate
Round Hill	4.1	1	RH-03-17	7/20/03 15:50	7/20/03 20:00	4:10	thunderstorm	5,951	2.318	10min	5	1	Good
Round Hill	4.1	1	RH-03-18	7/31/03 20:00	8/1/03 2:00	6:00	thunderstorm	2,302	1.317	10min	6	1	Good
Round Hill	4.1	1	RH-03-19	8/21/03 3:30	8/21/03 12:40	9:10	thunderstorm	631	0.141	10min	19	2	Good
Round Hill	4.1	1	RH-03-20	8/26/03 3:30	8/26/03 13:30	10:00	thunderstorm	509	0.071	12min	11	3	Good
Round Hill	4.2	2	na	10/01/02	na	na	site active	na	na	na	na	na	na
Round Hill	4.2	2	RH-03-1	12/13/02 7:00	12/14/02 7:00	24:00	rain on snow	1,372	0.107	62min	10	10	Good
Round Hill	4.2	2	RH-03-2	12/27/02 11:00	12/27/02 21:00	10:00	snowmelt	169	0.012	62min	3	3	Moderate
Round Hill	4.2	2	RH-03-3	1/12/03 12:30	1/13/03 21:45	33:15	rain on snow	1,011	0.036	62min	8	2	Good
Round Hill	4.2	2	RH-03-4	2/27/03 5:15	2/28/03 1:45	20:30	rain on snow	1,663	0.063	62min	1	1	Poor
Round Hill	4.2	2	RH-03-5	3/13/03 20:00	3/15/03 21:45	49:45	rain on snow	4,156	0.499	62min	6	6	Moderate
Round Hill	4.2	2	RH-03-6	3/26/03 6:00	3/26/03 16:30	10:30	snowmelt, rain on snow	313	0.056	62min	2	2	Moderate
Round Hill	4.2	2	RH-03-7	4/1/03 16:15	4/3/03 15:20	47:05	rain on snow	1,444	0.070	62min	5	5	Moderate
Round Hill	4.2	2	RH-03-8	4/12/03 16:10	4/12/03 19:30	3:00	snowmelt, rain on snow	580	0.126	62min	1	1	Poor
Round Hill	4.2	2	RH-03-9	4/14/03 8:30	4/15/03 7:10	22:40	snowmelt	1,438	0.067	62min	3	3	Moderate
Round Hill	4.2	2	RH-03-10	4/15/03 10:40	4/15/03 20:10	9:10	snowmelt	635	0.047	62min	3	3	Good
Round Hill	4.2	2	RH-03-11	4/17/03 10:40	4/17/03 20:40	10:00	snowmelt	1,058	0.069	62min	5	5	Good
Round Hill	4.2	2	RH-03-12	4/21/03 7:50	4/21/03 15:50	8:00	rain on snow	923	0.124	62min	1	1	Poor
Round Hill	4.2	2	RH-03-13	4/28/03 3:40	4/28/03 11:50	8:10	rain on snow	487	0.056	62min	1	1	Poor
Round Hill	4.2	2	RH-03-15	5/9/03 17:40	5/10/03 0:40	7:00	rain on snow	554	0.063	62min	3	3	Good
Round Hill	4.2	2	RH-03-16	6/23/03 12:20	6/23/03 18:10	5:50	rain on snow	3,200	1.045	12min	10	1	Moderate
Round Hill	4.2	2	RH-03-17	7/20/03 15:50	7/20/03 20:00	4:10	thunderstorm	5,951	2.318	10min	5	1	Good
Round Hill	4.2	2	RH-03-18	7/31/03 20:00	8/1/03 2:00	6:00	thunderstorm	2,302	1.317	10min	6	1	Good
Round Hill	4.2	2	RH-03-19	8/21/03 3:30	8/21/03 12:40	9:10	thunderstorm	631	0.141	10min	19	2	Good
Round Hill	4.2	2	RH-03-20	8/26/03 3:30	8/26/03 13:30	10:00	thunderstorm	509	0.071	12min	11	3	Good

APPENDIX 5: Runoff event summaries for stormwater treatment vaults, WY2003 and WY2004 (continued).

WY2003 CDS stormwater treatment vault event summary, inflow (4.2) and outflow (4.1) (continued).

Project	Site	Location	Event ID	Sampling Start (Date Time)	Average or EMC	Sampling End (Date Time)	TN EMC (µg/L)	TKN EMC (µg/L)	NO3-N EMC (µg/L)	NH4-N EMC (µg/L)	TP EMC (µg/L)	TDP EMC (µg/L)	SRP EMC (µg/L)	TSS EMC (mg/L)	Turbidity EMC (NTU)	Conductivity EMC (µmhos/cm)	Field Notes and Sampling Quality
Round Hill	4.1	1	na	10/01/03	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	4.1	1	RH-03-1	12/13/02 7:02	EMC	12/14/02 6:10	2,027	2,024	3	3	263	115	81	73	44	na	Good
Round Hill	4.1	1	RH-03-2	12/27/02 16:54	EMC	12/27/02 18:58	774	623	151	3	420	46	35	93	79	na	Moderate
Round Hill	4.1	1	RH-03-3	1/12/03 13:10	EMC	1/13/03 16:14	696	666	29	3	123	56	45	24	20	na	Good
Round Hill	4.1	1	RH-03-4	2/27/03 12:40	EMC	2/27/03 14:44	879	810	69	22	185	107	64	15	10	na	Poor
Round Hill	4.1	1	RH-03-5	3/13/03 20:06	EMC	3/15/03 13:14	3,534	3,503	31	9	1,382	106	83	885	139	na	Moderate
Round Hill	4.1	1	RH-03-6	3/26/03 8:06	EMC	3/26/03 9:08	1,357	1,349	8	9	617	87	96	172	113	na	Moderate
Round Hill	4.1	1	RH-03-7	4/1/03 16:20	EMC	4/2/03 10:50	966	957	9	10	160	77	60	62	44	na	Moderate
Round Hill	4.1	1	RH-03-8	4/12/03 16:16	avg	4/12/03 16:16	464	450	14	14	276	66	43	36	34	na	Poor
Round Hill	4.1	1	RH-03-9	4/14/03 12:58	EMC	4/14/03 16:04	1,591	1,583	7	13	254	54	40	44	28	na	Moderate
Round Hill	4.1	1	RH-03-10	4/15/03 12:16	EMC	4/15/03 14:12	852	783	69	12	255	75	67	34	22	na	Good
Round Hill	4.1	1	RH-03-11	4/17/03 11:50	EMC	4/17/03 15:58	1,302	1,223	79	18	478	84	67	113	39	na	Good
Round Hill	4.1	1	RH-03-12	4/21/03 7:56	EMC	4/21/03 11:02	2,479	2,301	178	76	784	78	53	221	85	na	Poor
Round Hill	4.1	1	RH-03-13	4/28/03 7:30	EMC	4/28/03 8:32	4,180	4,097	83	315	433	129	123	68	29	na	Poor
Round Hill	4.1	1	RH-03-15	5/9/03 17:50	EMC	5/9/03 21:48	2,307	2,243	64	ck	545	340	165	48	17	na	Good
Round Hill	4.1	1	RH-03-16	6/23/03 12:20	EMC	6/23/03 16:54	10,486	10,117	369	59	2,860	249	65	1,041	486	na	Moderate
Round Hill	4.1	1	RH-03-17	7/20/03 16:00	EMC	7/20/03 16:48	8,625	8,593	32	23	3,173	151	68	2,111	671	90	Good
Round Hill	4.1	1	RH-03-18	7/31/03 21:26	EMC	7/31/03 22:26	6,021	5,944	77	55	2,480	141	105	1,680	478	50	Good
Round Hill	4.1	1	RH-03-19	8/21/03 5:40	EMC	8/21/03 12:10	5,491	5,342	149	38	834	103	85	149	142	na	Good
Round Hill	4.1	1	RH-03-20	8/26/03 3:40	EMC	8/26/03 9:08	1,621	1,381	240	124	378	160	122	90	30	108	Good
Round Hill	4.2	2	na	10/01/03	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	4.2	2	RH-03-1	12/13/02 7:02	EMC	12/14/02 6:10	1,547	1,545	2	4	186	118	98	84	29	na	Good
Round Hill	4.2	2	RH-03-2	12/27/02 16:54	EMC	12/27/02 18:54	1,325	1,120	205	4	385	48	42	91	71	na	Moderate
Round Hill	4.2	2	RH-03-3	1/12/03 13:10	EMC	1/13/03 16:14	666	648	18	2	na	57	45	37	22	na	Good
Round Hill	4.2	2	RH-03-4	2/27/03 14:14	avg	2/27/03 14:14	971	872	100	13	294	84	37	44	na	na	Poor
Round Hill	4.2	2	RH-03-5	3/13/03 20:06	EMC	3/15/03 13:14	na	1,994	na	na	1,357	na	na	na	na	na	Moderate
Round Hill	4.2	2	RH-03-6	3/26/03 8:06	EMC	3/26/03 9:08	1,494	1,483	11	14	511	105	112	144	na	na	Moderate
Round Hill	4.2	2	RH-03-7	4/1/03 17:22	EMC	4/3/03 10:36	1,453	1,444	9	9	513	47	35	91	na	na	Moderate
Round Hill	4.2	2	RH-03-8	4/12/03 16:16	AVG	4/12/03 16:16	2,479	2,464	15	14	701	39	12	137	41	na	Poor
Round Hill	4.2	2	RH-03-9	4/14/03 14:00	EMC	4/1/03 16:04	1,091	1,074	17	13	216	47	41	41	20	na	Moderate
Round Hill	4.2	2	RH-03-10	4/15/03 12:16	EMC	4/15/03 4:12	610	529	81	9	250	62	53	49	28	na	Good
Round Hill	4.2	2	RH-03-11	4/17/03 11:50	EMC	4/17/03 15:58	1,611	1,546	65	8	555	77	65	151	85	na	Good
Round Hill	4.2	2	RH-03-12	4/21/03 7:56	avg	4/21/03 7:56	5,446	5,265	181	440	601	177	123	97	30	na	Poor
Round Hill	4.2	2	RH-03-13	4/28/03 7:30	avg	4/28/03 7:30	na	3,856	na	na	541	na	na	na	na	na	Poor
Round Hill	4.2	2	RH-03-15	5/9/03 17:50	EMC	5/9/03 21:48	3,398	3,338	60	ck	646	181	164	76	25	na	Good
Round Hill	4.2	2	RH-03-16	6/23/03 12:20	EMC	6/23/03 16:30	5,505	4,951	554	301	1,473	227	73	416	272	na	Moderate
Round Hill	4.2	2	RH-03-17	7/20/03 16:00	EMC	7/20/03 16:48	9,082	9,051	31	33	3,378	213	151	2,055	683	63	Good
Round Hill	4.2	2	RH-03-18	7/31/03 21:26	EMC	7/31/03 22:26	3,807	3,548	259	113	1,347	155	106	780	236	47	Good
Round Hill	4.2	2	RH-03-19	8/21/03 5:40	EMC	8/21/03 12:10	2,570	2,556	14	25	224	116	101	44	24	na	Good
Round Hill	4.2	2	RH-03-20	8/26/03 3:40	EMC	8/26/03 9:08	2,308	2,121	187	43	209	86	52	27	15	82	Good

APPENDIX 5: Runoff event summaries for stormwater treatment vaults, WY2003 and WY2004 (continued).

WY2003 Vortechnics stormwater treatment vault event summary, inflow (4.3) and outflow (4.4).

Project	Site	Location	Event ID	Runoff Start (Date Time)	Runoff End (Date Time)	Runoff Duration (hh:mm)	Event Type	Runoff Volume (cf)	Peak Flow (cfs)	Sample Pacing Set	Samples Collected	Singles or Composites Analyzed	Field Notes and Sampling Quality
Round Hill	4.3	3	na	10/01/02	na	na	site active	na	na	na	na	na	na
Round Hill	4.3	3	RH-03-2	12/27/02 11:00	12/27/02 21:00	10:00	snowmelt	224	0.016	62min	7	7	Good
Round Hill	4.3	3	RH-03-5	3/13/03 20:00	3/15/03 21:45	49:45	rain on snow	5,522	0.663	62min	8	8	Good
Round Hill	4.3	3	RH-03-6	3/26/03 6:00	3/26/03 16:30	10:30	snowmelt, rain on snow	416	0.075	62min	2	2	Moderate
Round Hill	4.3	3	RH-03-7	4/1/03 16:15	4/3/03 15:20	47:05	rain on snow	1,919	0.093	62min	2	2	Moderate
Round Hill	4.3	3	RH-03-8	4/12/03 16:10	4/12/03 19:30	3:00	snowmelt, rain on snow	771	0.167	62min	1	1	Poor
Round Hill	4.3	3	RH-03-9	4/14/03 8:30	4/15/03 7:10	22:40	snowmelt	1,910	0.089	62min	4	4	Good
Round Hill	4.3	3	RH-03-11	4/17/03 10:40	4/17/03 20:40	10:00	snowmelt	1,405	0.092	62min	4	4	Moderate
Round Hill	4.3	3	RH-03-12	4/21/03 7:50	4/21/03 15:50	8:00	rain on snow	1,226	0.165	62min	4	4	Good
Round Hill	4.3	3	RH-03-13	4/28/03 3:40	4/28/03 11:50	8:10	rain on snow	647	0.074	62min	2	2	Moderate
Round Hill	4.3	3	RH-03-14	4/29/03 18:20	4/29/03 20:00	1:40	snowmelt, rain on snow	109	0.079	62min	1	1	Poor
Round Hill	4.3	3	RH-03-15	5/9/03 17:40	5/10/03 0:40	7:00	rain on snow	736	0.084	62min	2	2	Moderate
Round Hill	4.3	3	RH-03-16	6/23/03 12:20	6/23/03 18:10	5:50	rain on snow	4,251	1.388	12min	15	1	Good
Round Hill	4.3	3	RH-03-17	7/20/03 15:50	7/20/03 20:00	4:10	thunderstorm	7,906	3.080	10min	3	1	Moderate
Round Hill	4.3	3	RH-03-18	7/31/03 20:00	8/1/03 2:00	6:00	thunderstorm	3,058	1.750	10min	6	1	Good
Round Hill	4.3	3	RH-03-19	8/21/03 3:30	8/21/03 12:40	9:10	thunderstorm	838	0.187	10min	5	1	Poor
Round Hill	4.4	4	na	10/01/02	na	na	site active	na	na	na	na	na	na
Round Hill	4.4	4	RH-03-2	12/27/02 11:00	12/27/02 21:00	10:00	snowmelt	224	0.016	62min	7	7	Good
Round Hill	4.4	4	RH-03-5	3/13/03 20:00	3/15/03 21:45	49:45	rain on snow	5,522	0.663	62min	8	8	Good
Round Hill	4.4	4	RH-03-6	3/26/03 6:00	3/26/03 16:30	10:30	snowmelt, rain on snow	416	0.075	62min	2	2	Moderate
Round Hill	4.4	4	RH-03-7	4/1/03 16:15	4/3/03 15:20	47:05	rain on snow	1,919	0.093	62min	2	2	Moderate
Round Hill	4.4	4	RH-03-8	4/12/03 16:10	4/12/03 19:30	3:00	snowmelt, rain on snow	771	0.167	62min	1	1	Poor
Round Hill	4.4	4	RH-03-9	4/14/03 8:30	4/15/03 7:10	22:40	snowmelt	1,910	0.089	62min	4	4	Good
Round Hill	4.4	4	RH-03-11	4/17/03 10:40	4/17/03 20:40	10:00	snowmelt	1,405	0.092	62min	4	4	Moderate
Round Hill	4.4	4	RH-03-12	4/21/03 7:50	4/21/03 15:50	8:00	rain on snow	1,226	0.165	62min	4	4	Good
Round Hill	4.4	4	RH-03-13	4/28/03 3:40	4/28/03 11:50	8:10	rain on snow	647	0.074	62min	2	2	Moderate
Round Hill	4.4	4	RH-03-14	4/29/03 18:20	4/29/03 20:00	1:40	snowmelt, rain on snow	109	0.079	62min	1	1	Poor
Round Hill	4.4	4	RH-03-15	5/9/03 17:40	5/10/03 0:40	7:00	rain on snow	736	0.084	62min	2	2	Moderate
Round Hill	4.4	4	RH-03-16	6/23/03 12:20	6/23/03 18:10	5:50	rain on snow	4,251	1.388	12min	14	1	Good
Round Hill	4.4	4	RH-03-17	7/20/03 15:50	7/20/03 20:00	4:10	thunderstorm	7,906	3.080	10min	5	1	Good
Round Hill	4.4	4	RH-03-18	7/31/03 20:00	8/1/03 2:00	6:00	thunderstorm	3,058	1.750	10min	4	1	Moderate
Round Hill	4.4	4	RH-03-19	8/21/03 3:30	8/21/03 12:40	9:10	thunderstorm	838	0.187	10min	16	2	Good

APPENDIX 5: Runoff event summaries for stormwater treatment vaults, WY2003 and WY2004 (continued).

WY2003 Vortechnics stormwater treatment vault event summary, inflow (4.3) and outflow (4.4) (continued).

Project	Site	Location	Event ID	Sampling Start (Date Time)	Average or EMC	Sampling End (Date Time)	TN EMC (µg/L)	TKN EMC (µg/L)	NO3-N EMC (µg/L)	NH4-N EMC (µg/L)	TP EMC (µg/L)	TDP EMC (µg/L)	SRP EMC (µg/L)	TSS EMC (mg/L)	Turbidity EMC (NTU)	Conductivity EMC (µmhos/cm)	Field Notes and Sampling Quality
Round Hill	4.3	3	na	10/01/03	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	4.3	3	RH-03-2	12/27/02 13:24	EMC	12/27/02 18:58	1,889	1,229	660	40	414	37	30	119	80	na	Good
Round Hill	4.3	3	RH-03-5	3/13/03 20:06	EMC	3/15/03 13:14	1,345	1,335	10	10	532	125	118	288	52	na	Good
Round Hill	4.3	3	RH-03-6	3/26/03 8:06	EMC	3/26/03 9:08	1,121	1,078	43	14	293	151	165	57	25	na	Moderate
Round Hill	4.3	3	RH-03-7	4/1/03 17:22	EMC	4/1/03 18:56	1,064	1,052	12	6	242	95	75	35	14	na	Moderate
Round Hill	4.3	3	RH-03-8	4/12/03 17:18	avg	4/12/03 17:18	2,048	1,930	118	14	310	35	16	56	20	na	Poor
Round Hill	4.3	3	RH-03-9	4/14/03 12:58	EMC	4/14/03 16:04	491	455	35	13	249	64	48	25	16	na	Good
Round Hill	4.3	3	RH-03-11	4/17/03 11:50	EMC	4/17/03 15:58	410	355	54	8	199	102	86	28	4	na	Moderate
Round Hill	4.3	3	RH-03-12	4/21/03 7:56	EMC	4/21/03 11:02	1,101	959	142	27	282	42	20	64	26	na	Good
Round Hill	4.3	3	RH-03-13	4/28/03 7:30	EMC	4/28/03 8:32	1,124	847	278	12	176	31	34	37	18	na	Moderate
Round Hill	4.3	3	RH-03-14	4/29/03 18:20	avg	4/29/03 18:20	1,593	1,176	417	9	354	35	33	97	25	na	Poor
Round Hill	4.3	3	RH-03-15	5/9/03 20:46	EMC	5/9/03 21:48	306	277	29	150	48	37	20	13	na	na	Moderate
Round Hill	4.3	3	RH-03-16	6/23/03 12:20	EMC	6/23/03 16:54	10,484	9,804	680	195	2,170	311	111	636	na	na	Good
Round Hill	4.3	3	RH-03-17	7/20/03 16:00	EMC	7/20/03 16:20	13,411	13,382	30	26	10,471	270	185	12,456	1,640	65	Moderate
Round Hill	4.3	3	RH-03-18	7/31/03 21:50	EMC	7/31/03 22:26	6,118	5,968	150	24	2,882	206	161	1,922	425	60	Good
Round Hill	4.3	3	RH-03-19	8/21/03 5:40	EMC	8/21/03 6:28	7,012	6,498	514	39	1,001	289	269	101	67	na	Poor
Round Hill	4.4	4	na	10/01/03	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	4.4	4	RH-03-2	12/27/02 13:24	EMC	12/27/02 18:58	1,551	1,115	436	14	276	105	80	37	28	na	Good
Round Hill	4.4	4	RH-03-5	3/13/03 20:06	EMC	3/15/03 13:14	1,417	1,405	11	8	440	104	95	135	42	na	Good
Round Hill	4.4	4	RH-03-6	3/26/03 8:06	EMC	3/26/03 9:08	425	346	79	9	154	93	110	11	6	na	Moderate
Round Hill	4.4	4	RH-03-7	4/1/03 17:22	EMC	4/1/03 18:56	713	694	19	12	171	96	82	13	10	na	Moderate
Round Hill	4.4	4	RH-03-8	4/12/03 17:18	avg	4/12/03 17:18	865	856	9	14	197	72	58	17	10	na	Poor
Round Hill	4.4	4	RH-03-9	4/14/03 12:58	EMC	4/14/03 16:04	340	327	13	14	197	62	50	24	18	na	Good
Round Hill	4.4	4	RH-03-11	4/17/03 12:52	EMC	4/17/03 15:58	563	536	27	8	132	89	69	9	5	na	Moderate
Round Hill	4.4	4	RH-03-12	4/21/03 7:56	EMC	4/21/03 11:02	771	650	121	24	154	70	49	18	9	na	Good
Round Hill	4.4	4	RH-03-13	4/28/03 7:30	EMC	4/28/03 8:32	1,343	677	666	8	101	50	49	6	5	na	Moderate
Round Hill	4.4	4	RH-03-14	4/29/03 18:20	EMC	4/29/03 18:20	928	576	352	7	112	32	42	15	na	na	Poor
Round Hill	4.4	4	RH-03-15	5/9/03 20:46	avg	5/9/03 21:48	224	186	38	97	60	57	8	10	na	na	Moderate
Round Hill	4.4	4	RH-03-16	6/23/03 12:20	EMC	6/23/03 16:54	8,533	8,142	392	44	1,885	117	57	556	326	na	Good
Round Hill	4.4	4	RH-03-17	7/20/03 16:00	EMC	7/20/03 16:48	15,344	15,313	31	21	7,093	240	147	2,245	1,460	80	Good
Round Hill	4.4	4	RH-03-18	7/31/03 21:50	EMC	7/31/03 22:26	7,441	7,269	172	26	2,370	203	155	878	396	55	Moderate
Round Hill	4.4	4	RH-03-19	8/21/03 6:04	EMC	8/21/03 12:10	5,775	5,468	307	49	487	152	138	57	31	na	Good

APPENDIX 5: Runoff event summaries for stormwater treatment vaults, WY2003 and WY2004 (continued).

WY2004 CDS stormwater treatment vault event summary, inflow (4.2) and outflow (4.1).

Project	Site	Location	Event ID	Runoff Start (Date Time)	Runoff End (Date Time)	Runoff Duration (hh:mm)	Event Type	Runoff Volume (cf)	Peak Flow (cfs)	Sample Pacing Set	Samples Collected	Singles or Composites Analyzed	Field Notes and Sampling Quality
Round Hill	4.1	1	na	10/01/03	na	na	site active	na	na	na	na	na	na
Round Hill	4.1	1	RC-04-01	11/9/03 14:20	11/10/03 12:00	21:40	snowmelt	1,939	0.048	12min	4	4	Moderate
Round Hill	4.1	1	RC-04-02	12/5/03 8:29	12/7/03 9:39	49:19	rain	7,213	0.345	12min	24	5	Moderate
Round Hill	4.1	1	RC-04-03	3/6/04 7:00	3/7/04 10:10	3:10	snowmelt	956	0.053	61min	4	1	Good
Round Hill	4.1	1	RC-04-04	3/7/04 10:10	3/8/04 10:15	24:05	snowmelt	1,142	0.061	61min	9	2	Good
Round Hill	4.1	1	RC-04-05	3/25/04 16:05	3/26/04 14:20	22:15	snowmelt	1,578	0.086	61min	3	3	Moderate
Round Hill	4.1	1	RC-04-06	5/11/04 2:00	5/11/04 11:10	11:10	snowmelt	1,992	0.116	61min	6	6	Good
Round Hill	4.1	1	RC-04-07	5/28/04 0:50	5/28/04 7:25	6:35	rain	930	0.220	11min	10	2	Good
Round Hill	4.2	2	na	10/01/03	na	na	site active	na	na	na	na	na	na
Round Hill	4.2	2	RC-04-01	11/9/03 14:20	11/10/03 12:00	21:40	snow	1,939	0.048	12min	4	4	Moderate
Round Hill	4.2	2	RC-04-02	12/5/03 8:29	12/7/03 9:39	49:19	rain	7,213	0.345	12 min	24	5	Moderate
Round Hill	4.2	2	RC-04-03	3/6/04 7:00	3/7/04 10:10	3:10	snowmelt	956	0.053	61min	4	1	Good
Round Hill	4.2	2	RC-04-04	3/7/04 10:10	3/8/04 10:15	24:05	snowmelt	1,142	0.061	61min	9	2	Good
Round Hill	4.2	2	RC-04-05	3/25/04 16:05	3/26/04 14:20	22:15	snowmelt	1,578	0.086	61min	3	3	Moderate
Round Hill	4.2	2	RC-04-06	5/11/04 2:00	5/11/04 11:10	11:10	snowmelt	1,992	0.116	61min	6	6	Good
Round Hill	4.2	2	RC-04-07	5/28/04 0:50	5/28/04 7:25	6:35	rain	930	0.220	11min	5	2	Moderate

Project	Site	Location	Event ID	Sampling Start (Date Time)	Average or EMC	Sampling End (Date Time)	TN EMC (µg/L)	TKN EMC (µg/L)	NO3-N EMC (µg/L)	NH4-N EMC (µg/L)	TP EMC (µg/L)	TDP EMC (µg/L)	SRP EMC (µg/L)	TSS EMC (mg/L)	Turbidity EMC (NTU)	Conductivity EMC (µmhos/cm)	Field Notes and Sampling Quality
Round Hill	4.1	1	na	10/01/03	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	4.1	1	RC-04-01	11/9/03 14:52	EMC	11/9/03 15:28	1,420	1,400	20	20	443	185	111	34	44	163	Moderate
Round Hill	4.1	1	RC-04-02	12/5/03 10:32	EMC	12/6/03 19:10	2,042	2,019	23	22	498	143	128	73	84	45	Moderate
Round Hill	4.1	1	RC-04-03	3/6/04 12:17	EMC	3/6/04 15:20	2,840	2,774	66	35	189	59	46	34	45	28	Good
Round Hill	4.1	1	RC-04-04	3/7/04 11:50	EMC	3/7/04 15:54	483	417	66	23	141	48	43	24	32	25	Good
Round Hill	4.1	1	RC-04-05	3/25/04 16:35	EMC	3/26/04 11:13	1,124	899	225	38	245	67	54	41	58	93	Moderate
Round Hill	4.1	1	RC-04-06	5/11/04 2:05	EMC	5/11/04 8:03	1,790	1,686	104	124	378	181	127	44	40	55	Good
Round Hill	4.1	1	RC-04-07	5/28/04 1:05	EMC	5/28/04 4:40	2,520	2,502	18	38	1,149	140	104	346	353	77	Good
Round Hill	4.2	2	na	10/01/03	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	4.2	2	RC-04-01	11/9/03 14:52	EMC	11/9/03 15:28	2,505	2,444	60	11	454	241	208	26	33	140	Moderate
Round Hill	4.2	2	RC-04-02	12/5/03 10:32	EMC	12/6/03 19:10	1,284	1,274	10	12	428	169	155	45	58	36	Moderate
Round Hill	4.2	2	RC-04-03	3/6/04 12:17	EMC	3/6/04 15:20	519	469	50	39	167	45	41	41	48	20	Good
Round Hill	4.2	2	RC-04-04	3/7/04 11:50	EMC	3/7/04 15:54	520	478	43	25	133	42	38	27	39	20	Good
Round Hill	4.2	2	RC-04-05	3/25/04 16:35	EMC	3/26/04 11:13	2,584	2,472	112	22	401	63	41	73	116	88	Moderate
Round Hill	4.2	2	RC-04-06	5/11/04 2:05	EMC	5/11/04 8:03	2,353	2,183	170	255	497	269	209	78	60	43	Good
Round Hill	4.2	2	RC-04-07	5/28/04 1:15	EMC	5/28/04 4:40	3,181	3,152	29	37	1,193	157	123	826	405	63	Moderate

APPENDIX 5: Runoff event summaries for stormwater treatment vaults, WY2003 and WY2004 (continued).

WY2004 Vortechnics stormwater treatment vault event summary, inflow (4.3) and outflow (4.4).

Project	Site	Location	Event ID	Runoff Start (Date Time)	Runoff End (Date Time)	Runoff Duration (hh:mm)	Event Type	Runoff Volume (cf)	Peak Flow (cfs)	Sample Pacing Set	Samples Collected	Singles or Composites Analyzed	Field Notes and Sampling Quality
Round Hill	4.3	3	na	10/01/03	na	na	site active	na	na	na	na	na	na
Round Hill	4.3	3	RV-04-01	12/24/03 5:50	12/24/03 19:50	14:00	rain, snow	3,045	0.257	61min	3	3	Moderate
Round Hill	4.3	3	RV-04-02	2/16/04 9:45	2/17/04 1:40	14:10	rain on snow	2,278	0.187	61min	7	1	Good
Round Hill	4.3	3	RV-04-03	3/8/04 12:25	3/9/04 0:50	11:10	snowmelt	701	0.053	61min	6	1	Good
Round Hill	4.3	3	RV-04-04	3/9/04 12:25	3/10/04 3:20	13:10	snowmelt	793	0.053	61min	6	1	Good
Round Hill	4.3	3	RV-04-05	3/10/04 11:45	3/10/04 19:40	12:15	snowmelt	622	0.047	61min	5	1	Good
Round Hill	4.3	3	RV-04-06	3/11/04 13:20	3/11/04 18:55	5:35	snowmelt	212	0.022	61min	3	1	Good
Round Hill	4.3	3	RV-04-07	3/14/04 12:55	3/14/04 19:20	12:45	snowmelt	287	0.026	61min	4	1	Good
Round Hill	4.3	3	RV-04-08	3/15/04 12:10	3/15/04 19:05	11:45	snowmelt	324	0.027	61min	4	1	Good
Round Hill	4.3	3	RV-04-09	5/11/04 4:55	5/11/04 11:10	6:20	snowmelt	199	0.018	61min	1	1	Poor
Round Hill	4.4	4	na	10/01/03	na	na	site active	na	na	na	na	na	na
Round Hill	4.4	4	RV-04-01	12/24/03 5:50	12/24/03 19:50	14:00	rain, snow	3,045	0.257	61min	6	6	Good
Round Hill	4.4	4	RV-04-02	2/16/04 9:45	2/17/04 1:40	14:10	rain on snow	2,278	0.187	61min	7	1	Good
Round Hill	4.4	4	RV-04-03	3/8/04 12:25	3/9/04 0:50	11:10	snowmelt	701	0.053	61min	6	1	Good
Round Hill	4.4	4	RV-04-04	3/9/04 12:25	3/10/04 3:20	13:10	snowmelt	793	0.053	61min	6	1	Good
Round Hill	4.4	4	RV-04-05	3/10/04 11:45	3/10/04 19:40	12:15	snowmelt	622	0.047	61min	5	1	Good
Round Hill	4.4	4	RV-04-06	3/11/04 13:20	3/11/04 18:55	5:35	snowmelt	212	0.022	61min	3	1	Good
Round Hill	4.4	4	RV-04-07	3/14/04 12:55	3/14/04 19:20	12:45	snowmelt	287	0.026	61min	4	1	Good
Round Hill	4.4	4	RV-04-08	3/15/04 12:10	3/15/04 19:05	11:45	snowmelt	324	0.027	61min	4	1	Good
Round Hill	4.4	4	RV-04-09	5/11/04 4:55	5/11/04 11:10	6:20	snowmelt	199	0.018	61min	1	1	Poor

APPENDIX 5: Runoff event summaries for stormwater treatment vaults, WY2003 and WY2004 (continued).
WY2004 Vortechnics stormwater treatment vault event summary, inflow (4.3) and outflow (4.4) (continued).

Project	Site	Location	Event ID	Sampling Start (Date Time)	Average or EMC	Sampling End (Date Time)	TN EMC (µg/L)	TKN EMC (µg/L)	NO3-N EMC (µg/L)	NH4-N EMC (µg/L)	TP EMC (µg/L)	TDP EMC (µg/L)	SRP EMC (µg/L)	TSS EMC (mg/L)	Turbidity EMC (NTU)	Conductivity EMC (µmhos/cm)	Field Notes and Sampling Quality
Round Hill	4.3	3	na	10/01/03	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	4.3	3	RV-04-01	12/24/03 11:22	EMC	12/24/03 13:24	768	753	14	12	420	96	82	71	94	24	Moderate
Round Hill	4.3	3	RV-04-02	2/16/04 11:51	EMC	2/16/04 17:57	1,835	1709	126	49	760	87	74	192	237	200	Good
Round Hill	4.3	3	RV-04-03	3/8/04 13:12	EMC	3/8/04 18:17	360	314	46	27	143	69	65	46	16	25	Good
Round Hill	4.3	3	RV-04-04	3/9/04 12:50	EMC	3/9/04 17:55	360	287	72	24	141	62	58	47	20	32	Good
Round Hill	4.3	3	RV-04-05	3/10/04 13:10	EMC	3/10/04 17:14	421	312	109	37	139	66	55	13	16	33	Good
Round Hill	4.3	3	RV-04-06	3/11/04 14:11	EMC	3/11/04 16:13	437	250	187	6	119	62	55	12	54	38	Good
Round Hill	4.3	3	RV-04-07	3/14/04 13:43	EMC	3/14/04 16:46	491	285	206	18	128	61	53	20	36	40	Good
Round Hill	4.3	3	RV-04-08	3/15/04 13:14	EMC	3/15/04 16:17	464	280	184	26	120	60	52	18	33	45	Good
Round Hill	4.3	3	RV-04-09	5/11/04 4:59	EMC	5/11/04 4:59	2,001	1574	427	74	379	117	96	60	58	110	Poor
Round Hill	4.4	4	na	10/01/03	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	4.4	4	RV-04-01	12/24/03 7:18	EMC	12/24/03 12:23	771	762	8	21	445	91	80	60	83	44	Good
Round Hill	4.4	4	RV-04-02	2/16/04 11:51	EMC	2/16/04 17:57	1,694	1574	120	43	688	81	63	168	204	60	Good
Round Hill	4.4	4	RV-04-03	3/8/04 13:12	EMC	3/8/04 18:17	287	242	45	24	152	62	58	45	16	42	Good
Round Hill	4.4	4	RV-04-04	3/9/04 12:50	EMC	3/9/04 17:55	466	376	90	23	131	65	59	45	17	40	Good
Round Hill	4.4	4	RV-04-05	3/10/04 13:10	EMC	3/10/04 17:14	436	259	177	24	130	65	59	14	33	36	Good
Round Hill	4.4	4	RV-04-06	3/11/04 14:11	EMC	3/11/04 16:13	706	200	506	13	131	52	49	9	40	62	Good
Round Hill	4.4	4	RV-04-07	3/14/04 13:43	EMC	3/14/04 16:46	807	256	551	16	117	50	49	29	42	71	Good
Round Hill	4.4	4	RV-04-08	3/15/04 13:14	EMC	3/15/04 16:17	666	207	459	25	122	54	51	18	18	63	Good
Round Hill	4.4	4	RV-04-09	5/11/04 4:59	EMC	5/11/04 4:59	1,031	1031	na	na	148	na	na	na	na	na	Poor

APPENDIX 5: Runoff event summaries for stormwater treatment vaults, WY2003 and WY2004 (continued).

WY2004 Jensen stormwater treatment vault event summary, inflow (5.1) and outflow (5.2).

Project	Site	Location	Event ID	Runoff Start (Date Time)	Runoff End (Date Time)	Runoff Duration (hh:mm)	Event Type	Runoff Volume (cf)	Peak Flow (cfs)	Sample Pacing Set	Samples Collected	Singles or Composites Analyzed	Field Notes and Sampling Quality
Round Hill	5.1	1	na	01/01/04	na	na	site active	na	na	na	na	na	na
Round Hill	5.1	1	RJ-04-01	2/16/04 11:05	2/16/04 16:55	5:50	rain on snow	1,389	0.347	61min	3	3	Good
Round Hill	5.1	1	RJ-04-02	3/7/04 13:40	3/7/04 16:20	2:40	snowmelt	2	0.000	61min	3	3	Good
Round Hill	5.1	1	RJ-04-03	3/8/04 12:55	3/8/04 16:50	3:55	snowmelt	15	0.002	61min	4	1	Good
Round Hill	5.1	1	RJ-04-04	3/9/04 13:05	3/9/04 16:35	3:30	snowmelt	12	0.002	61min	3	1	Good
Round Hill	5.1	1	RJ-04-05	3/12/04 13:05	3/12/04 15:40	2:35	snowmelt	2	0.002	61min	3	1	Good
Round Hill	5.1	1	RJ-04-06	3/25/04 16:05	3/26/04 15:35	6:25	snowmelt	6	0.002	61min	4	4	Good
Round Hill	5.1	1	RJ-04-07	6/30/04 13:25	7/1/04 23:00	33:35	thunderstorm	3,366	0.563	61min	24	3	Good
Round Hill	5.1	1	RJ-04-08	9/20/04 11:30	9/20/04 13:35	2:05	snow	5,292	1.560	61min	3	3	Moderate
Round Hill	5.2	2	na	01/01/04	na	na	site active	na	na	na	na	na	na
Round Hill	5.2	2	RJ-04-01	2/16/04 11:05	2/16/04 16:55	5:50	rain on snow	1,389	0.347	na	na	na	na
Round Hill	5.2	2	RJ-04-02	3/7/04 13:40	3/7/04 16:20	2:40	snowmelt	2	0.000	61min	3	3	Good
Round Hill	5.2	2	RJ-04-03	3/8/04 12:55	3/8/04 16:50	3:55	snowmelt	15	0.002	61min	4	1	Good
Round Hill	5.2	2	RJ-04-04	3/9/04 13:05	3/9/04 16:35	3:30	snowmelt	12	0.002	61min	3	1	Good
Round Hill	5.2	2	RJ-04-05	3/12/04 13:05	3/12/04 15:40	2:35	snowmelt	2	0.002	61min	3	1	Good
Round Hill	5.2	2	RJ-04-06	3/25/04 16:05	3/26/04 15:35	6:25	snowmelt	6	0.002	61min	4	4	Good
Round Hill	5.2	2	RJ-04-07	6/30/04 13:25	7/1/04 23:00	33:35	thunderstorm	3,366	0.563	61min	24	3	Good
Round Hill	5.2	2	RJ-04-08	9/20/04 11:30	9/20/04 13:35	2:05	snow	5,292	1.560	61min	3	3	Moderate

APPENDIX 5: Runoff event summaries for stormwater treatment vaults, WY2003 and WY2004 (continued).

WY2004 Jensen stormwater treatment vault event summary, inflow (5.1) and outflow (5.2) (continued).

Project	Site	Location	Event ID	Sampling Start (Date Time)	Average or EMC	Sampling End (Date Time)	TN EMC (µg/L)	TKN EMC (µg/L)	NO3-N EMC (µg/L)	NH4-N EMC (µg/L)	TP EMC (µg/L)	TDP EMC (µg/L)	SRP EMC (µg/L)	TSS EMC (mg/L)	Turbidity EMC (NTU)	Conductivity EMC (µmhos/cm)	Field Notes and Sampling Quality
Round Hill	5.1	1	na	01/01/04	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	5.1	1	RJ-04-01	2/16/04 13:34	EMC	2/16/04 15:36	1,038	979	60	19	482	30	20	140	132	16	Good
Round Hill	5.1	1	RJ-04-02	3/7/04 13:51	EMC	3/7/04 15:53	292	269	23	25	82	9	9	31	25	11	Good
Round Hill	5.1	1	RJ-04-03	3/8/04 13:12	EMC	3/8/04 16:15	264	243	21	24	93	10	12	49	37	12	Good
Round Hill	5.1	1	RJ-04-04	3/9/04 13:16	EMC	3/9/04 15:18	266	248	18	20	119	13	13	65	23	9	Good
Round Hill	5.1	1	RJ-04-05	3/12/04 13:06	EMC	3/12/04 15:08	370	352	18	10	161	18	13	50	44	21	Good
Round Hill	5.1	1	RJ-04-06	3/25/04 16:04	EMC	3/26/04 11:53	3,203	2,900	304	114	685	30	6	253	200	169	Good
Round Hill	5.1	1	RJ-04-07	6/30/04 17:28	EMC	7/1/04 20:21	5,477	5,400	77	919	770	83	35	271	198	113	Good
Round Hill	5.1	1	RJ-04-08	9/20/04 11:34	EMC	9/20/04 13:36	8,738	7,799	939	335	1,438	653	217	101	86	na	Moderate
Round Hill	5.2	2	na	01/01/04	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	5.2	2	RJ-04-01	na	na	na	na	na	na	na	na	na	na	na	na	na	na
Round Hill	5.2	2	RJ-04-02	3/7/04 13:51	EMC	3/7/04 15:53	294	250	43	19	61	18	16	14	14	30	Good
Round Hill	5.2	2	RJ-04-03	3/8/04 13:12	EMC	3/8/04 16:15	273	236	37	28	76	16	16	42	14	22	Good
Round Hill	5.2	2	RJ-04-04	3/9/04 13:16	EMC	3/9/04 15:18	199	164	35	20	73	18	15	32	12	20	Good
Round Hill	5.2	2	RJ-04-05	3/12/04 13:06	EMC	3/12/04 15:08	240	203	37	7	76	19	17	33	14	15	Good
Round Hill	5.2	2	RJ-04-06	3/25/04 16:04	EMC	3/26/04 11:53	1,136	1,088	49	15	156	16	9	24	29	75	Good
Round Hill	5.2	2	RJ-04-07	6/30/04 17:28	EMC	7/1/04 20:21	2,163	2,144	20	139	180	70	37	11	147	249	Good
Round Hill	5.2	2	RJ-04-08	9/20/04 11:34	EMC	9/20/04 13:36	3,620	3,258	362	1,030	308	197	55	11	18	na	Moderate

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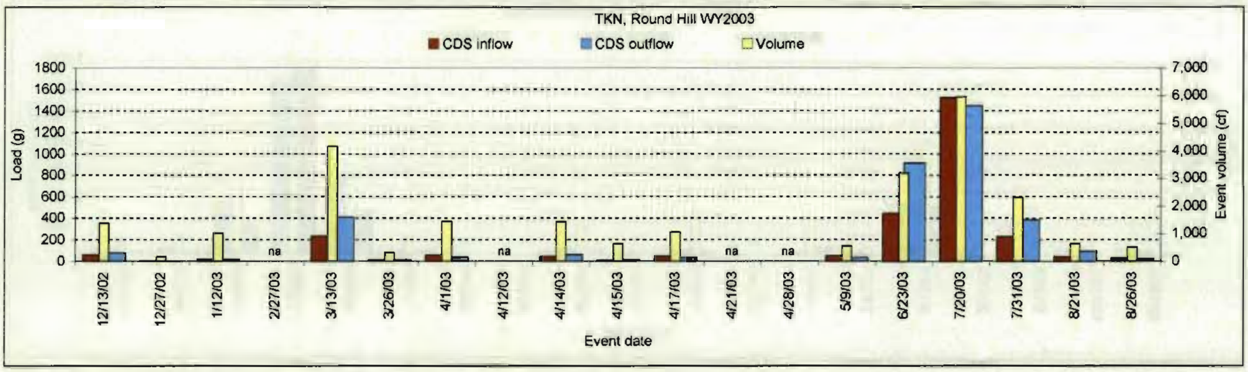
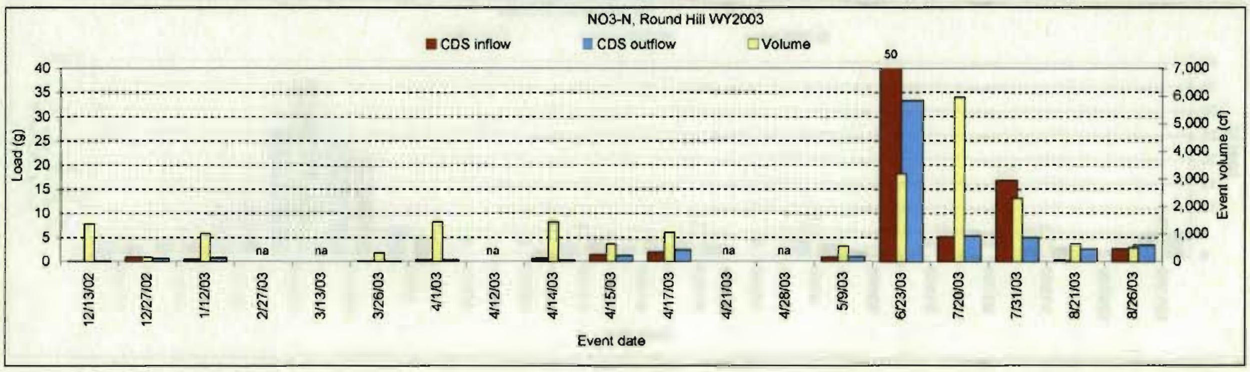
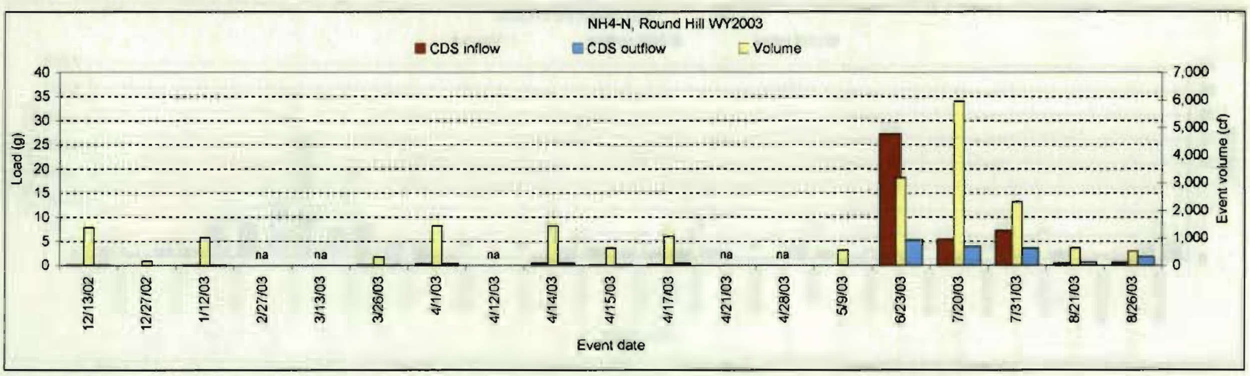
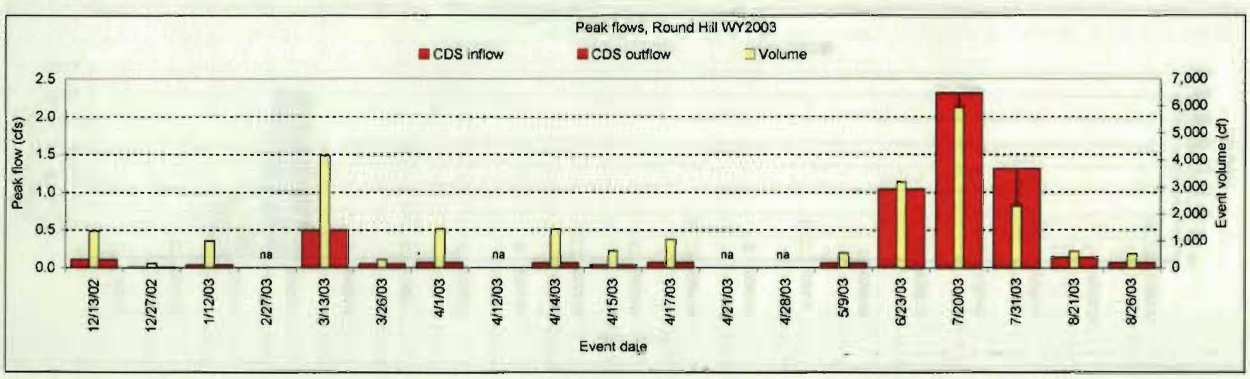
APPENDIX 6: Event loads during monitored events of WY2003 and WY2004. Flows are calibrated (see text).

WY2003 CDS stormwater vault event loads during monitored events.



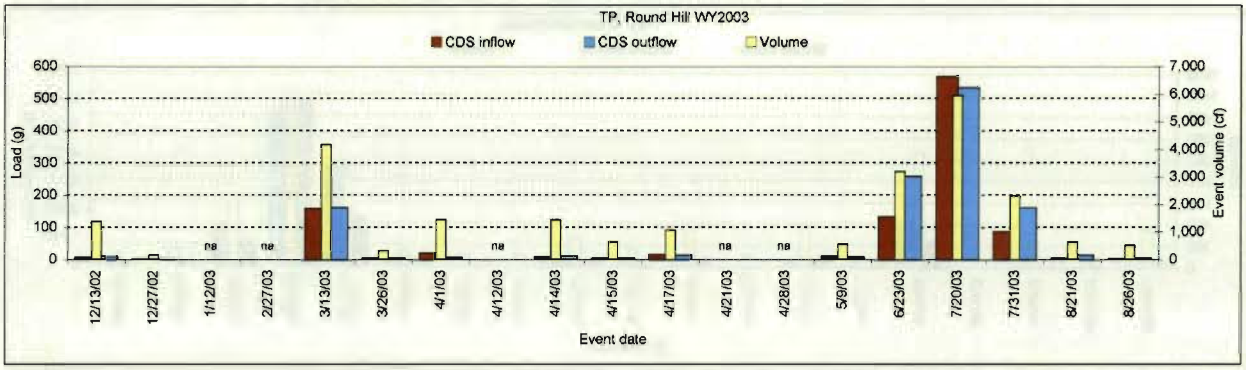


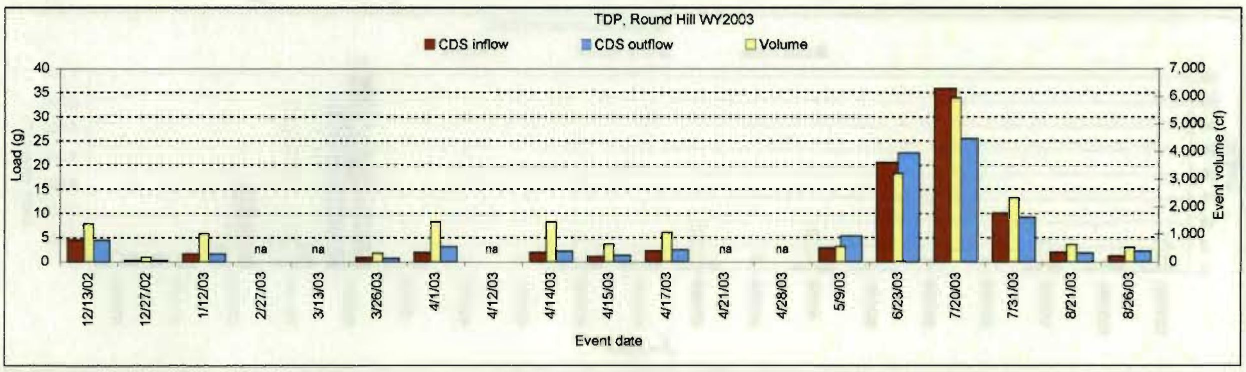


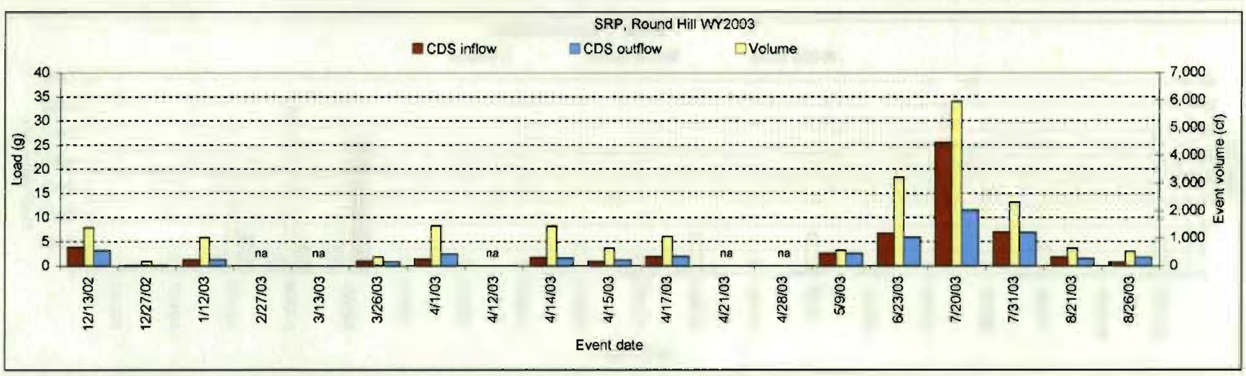


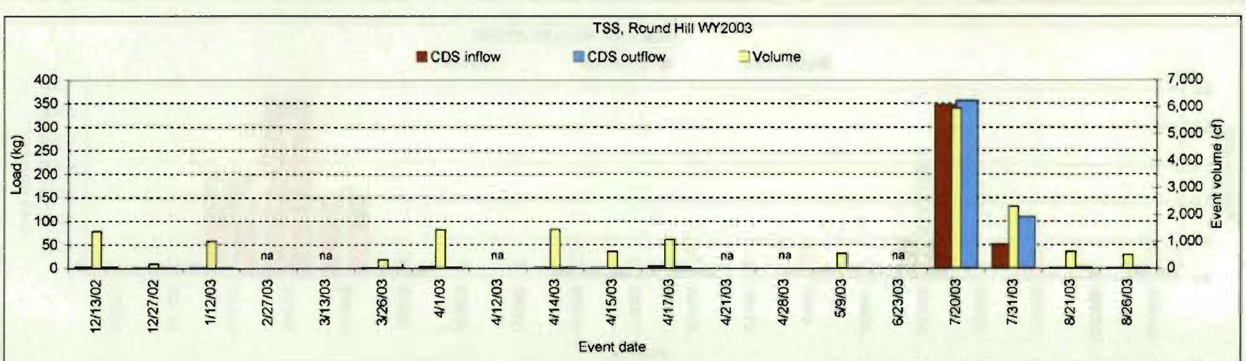
APPENDIX 6: Event loads during monitored events of WY2003 and WY2004. Flows are calibrated (see text) (continued).

WY2003 CDS stormwater vault event loads during monitored events (continued)



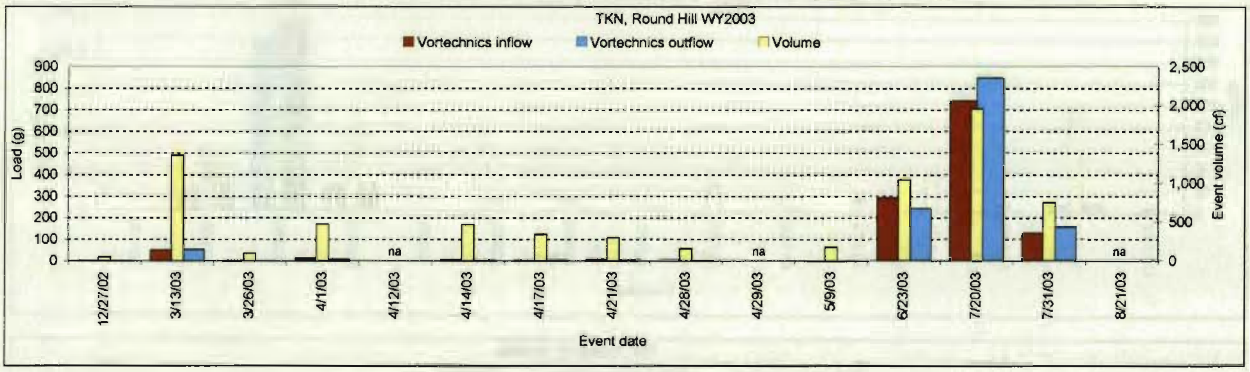


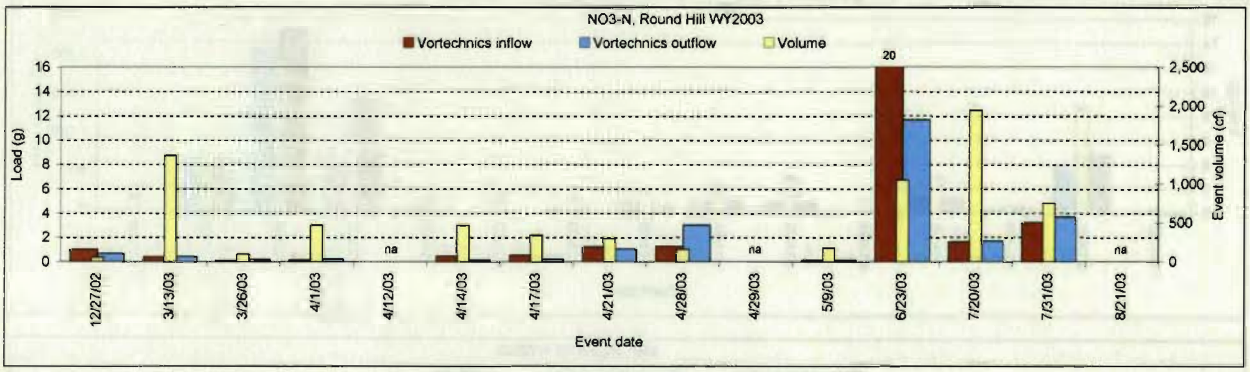


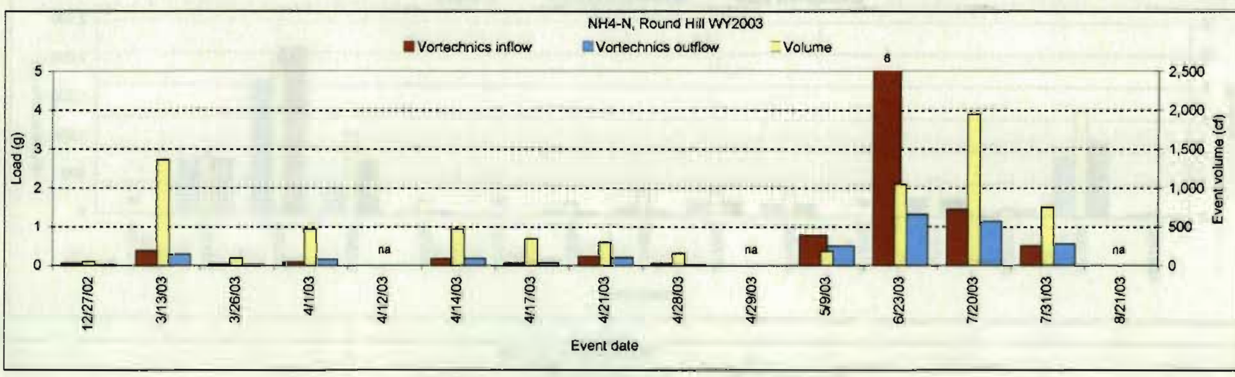


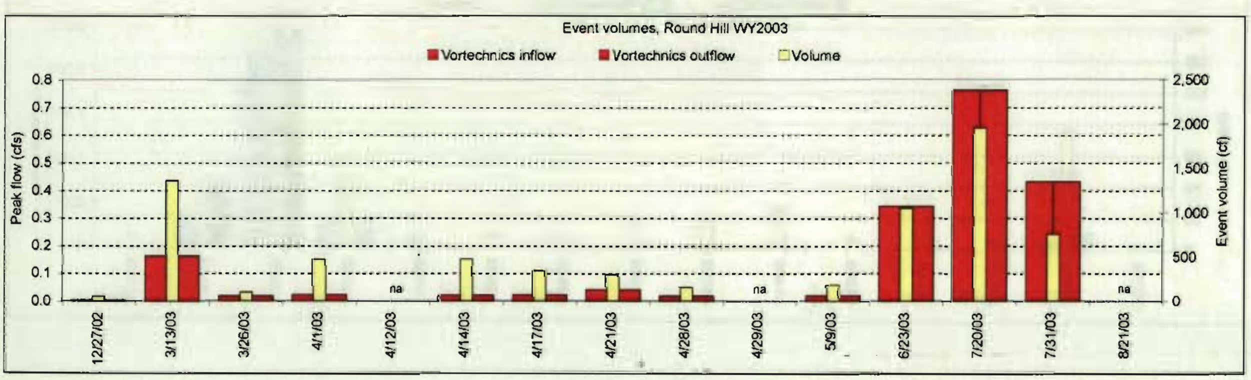
APPENDIX 6: Event loads during monitored events of WY2003 and WY2004. Flows are calibrated (see text) (continued).

WY2003 Vortechnics stormwater vault loads during monitored events



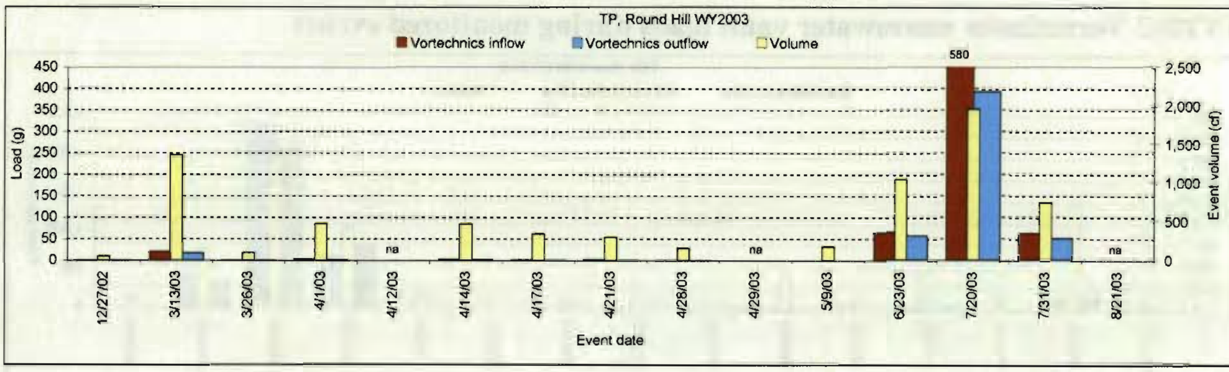


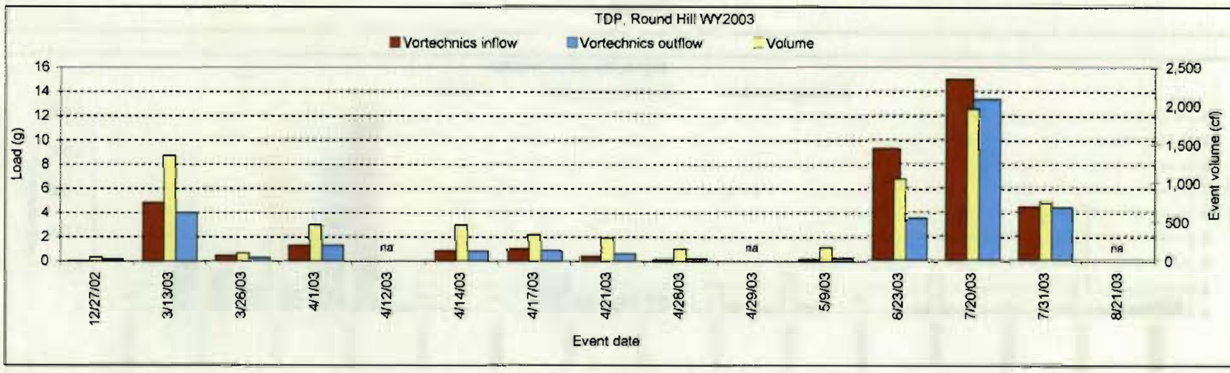


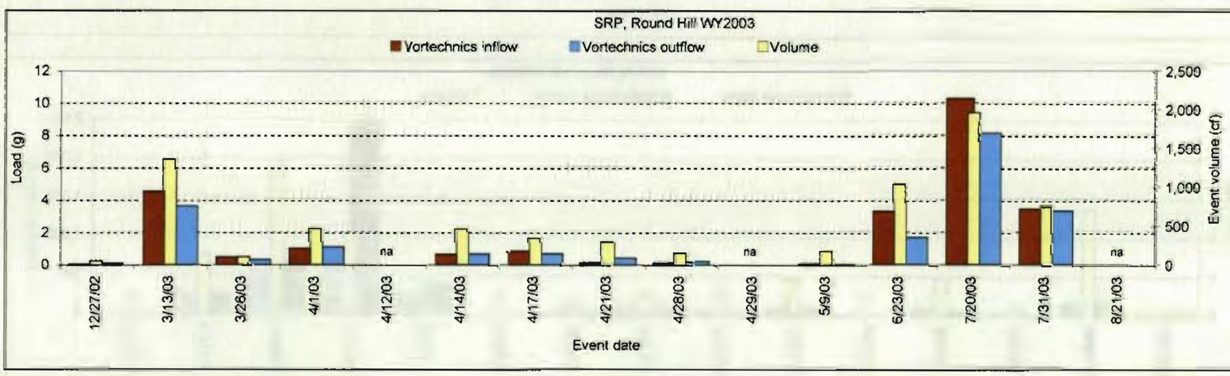


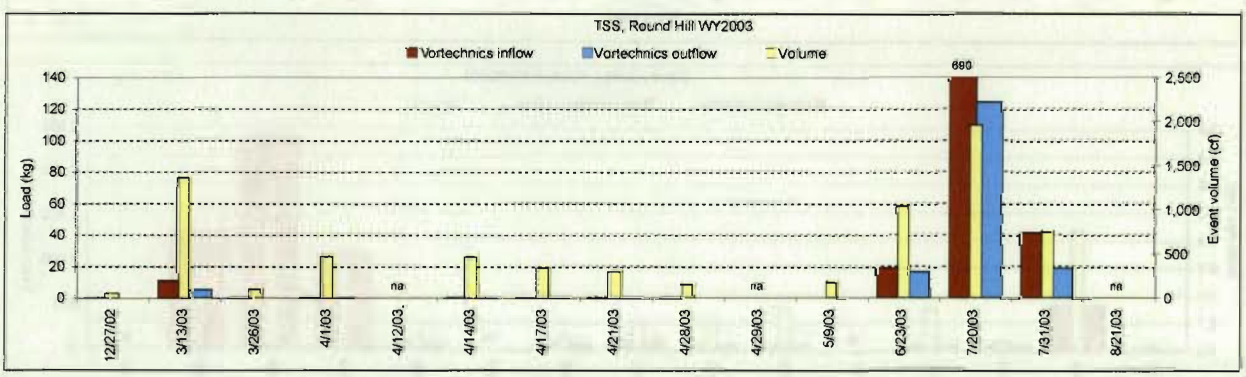
APPENDIX 6: Event loads during monitored events of WY2003 and WY2004. Flows are calibrated (see text) (continued).

WY2003 Vortechnics stormwater vault loads during monitored events



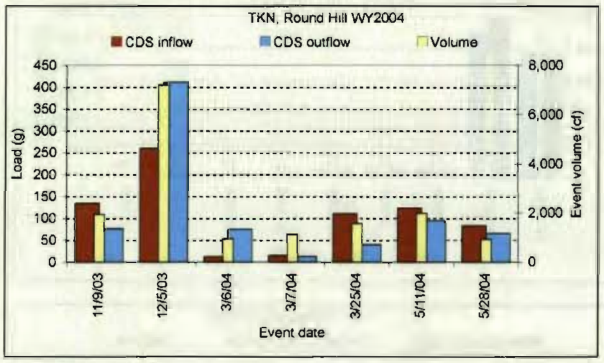


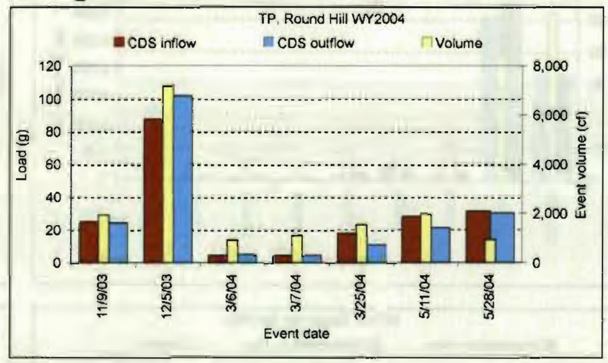


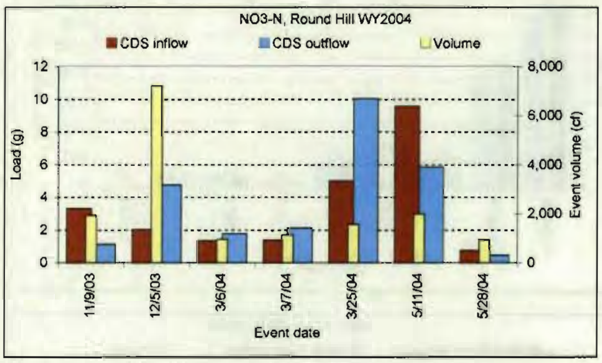


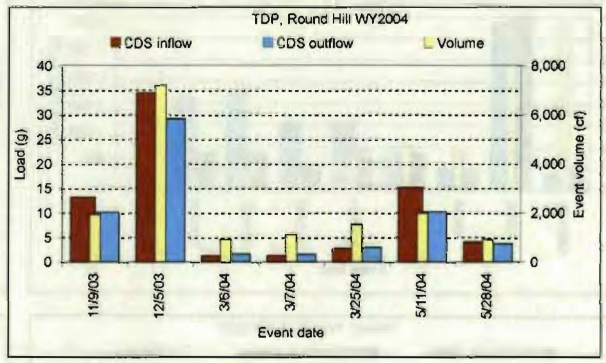
APPENDIX 6: Event loads during monitored events of WY2003 and WY2004 (continued).

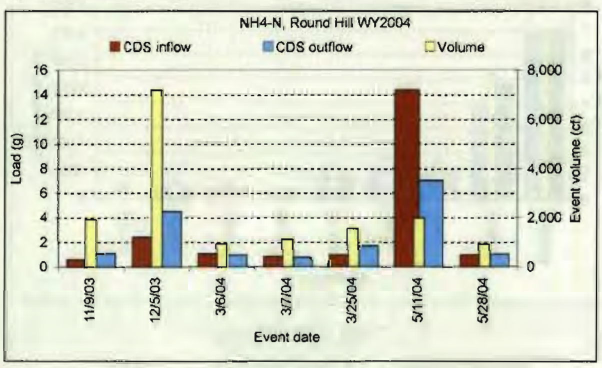
WY2004 CDS stormwater vault event loads during monitored events

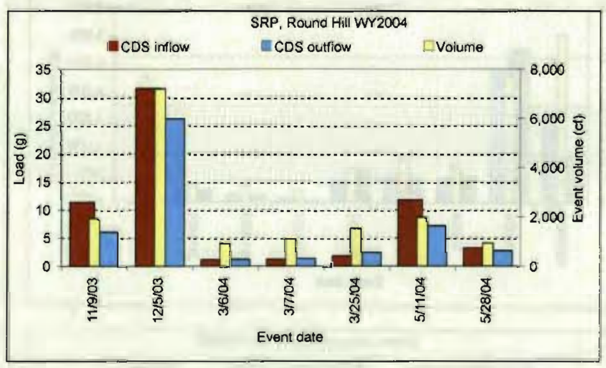


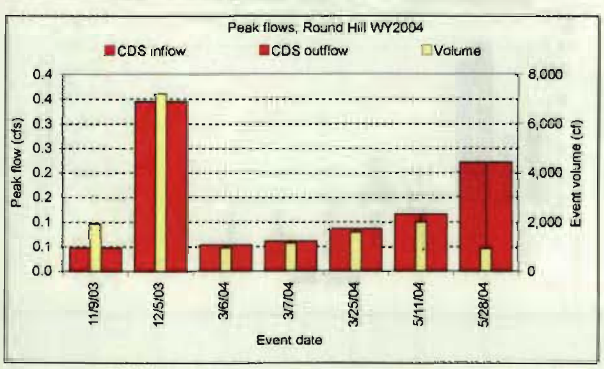


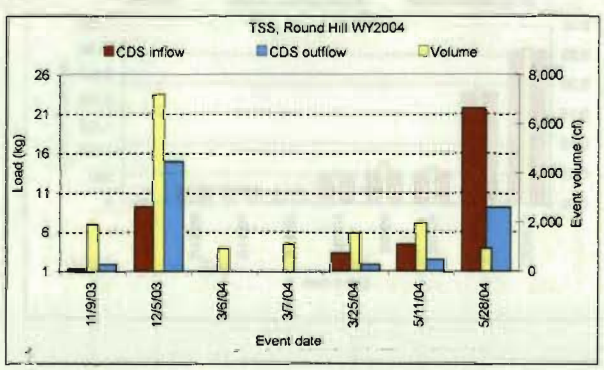






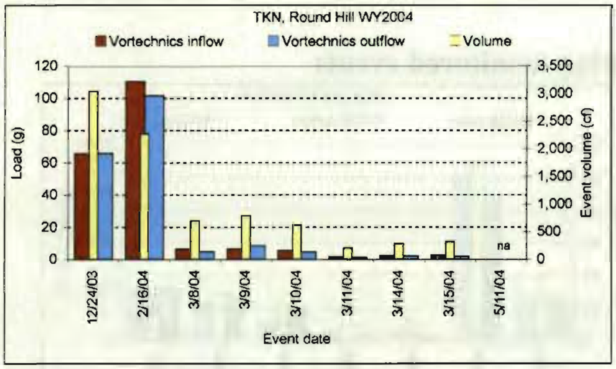


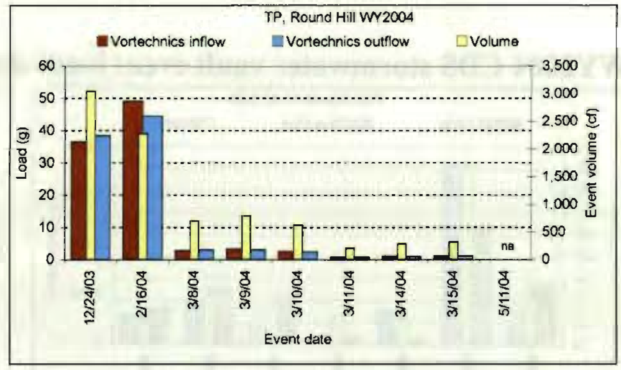


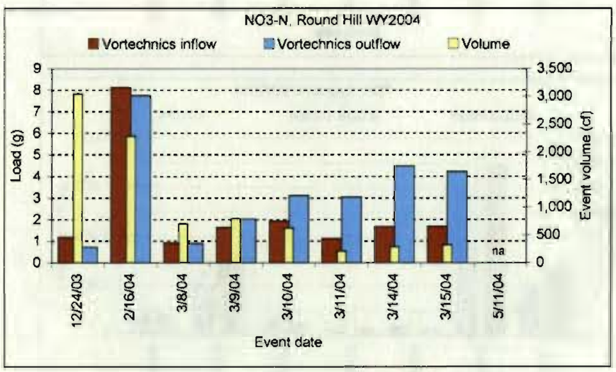


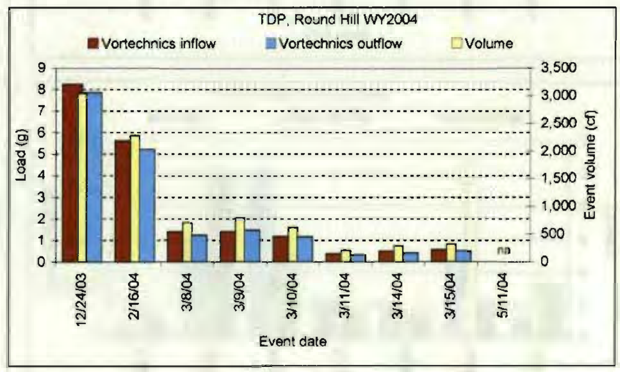
APPENDIX 6: Event loads during monitored events of WY2003 and WY2004 (continued).

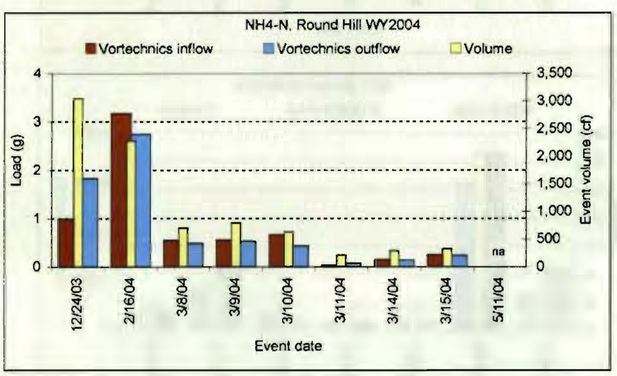
WY2004 Vortechnics stormwater vault loads during monitored events

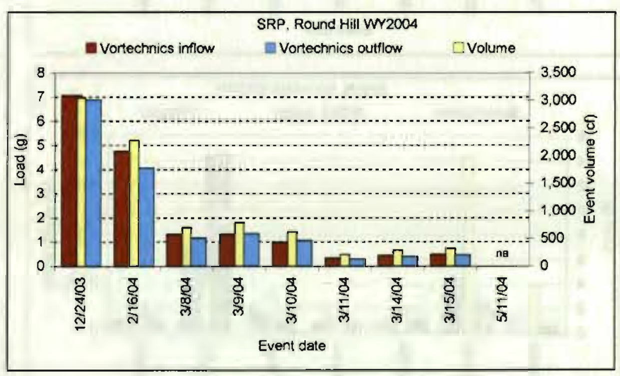


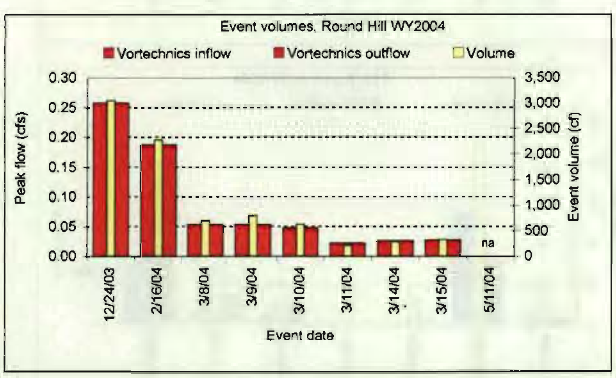


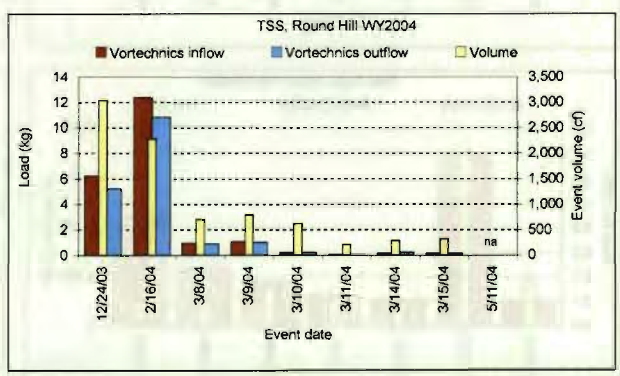






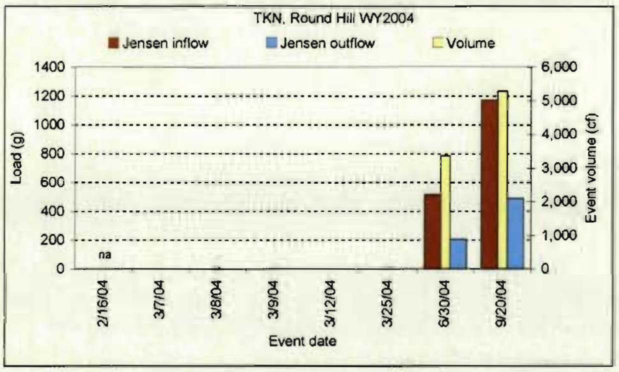


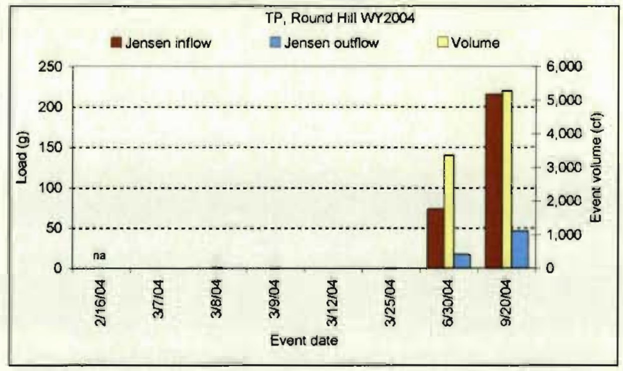


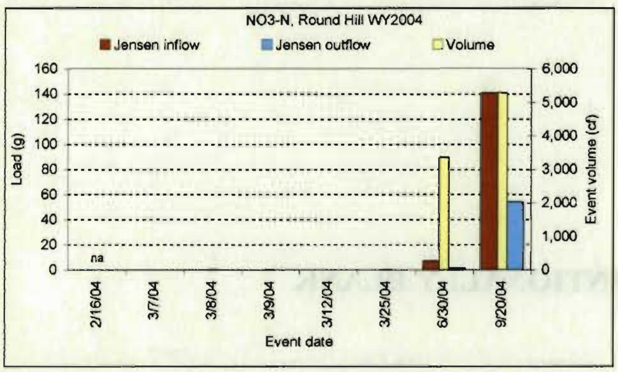


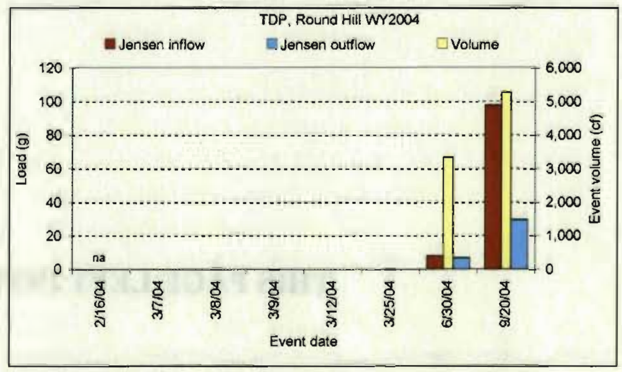
APPENDIX 6: Event loads during monitored events of WY2003 and WY2004 (continued).

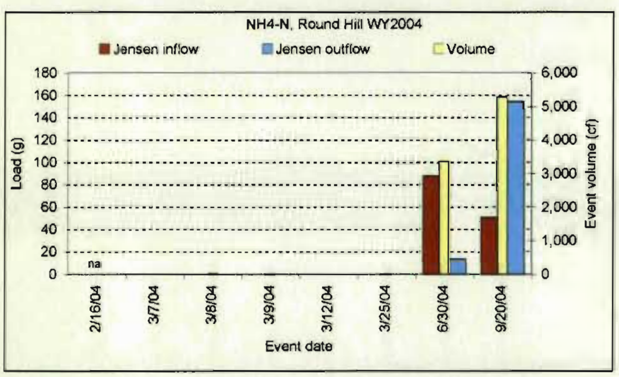
WY2004 Jensen stormwater vault loads during monitored events

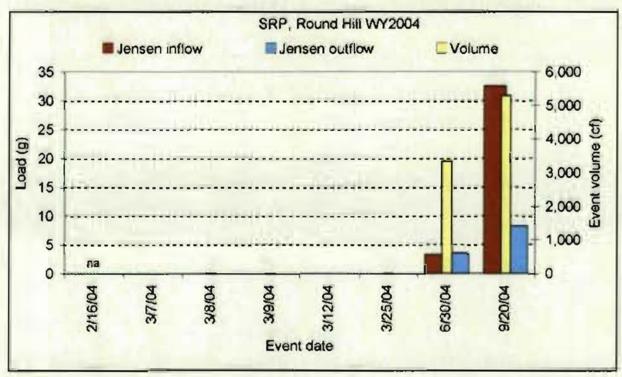


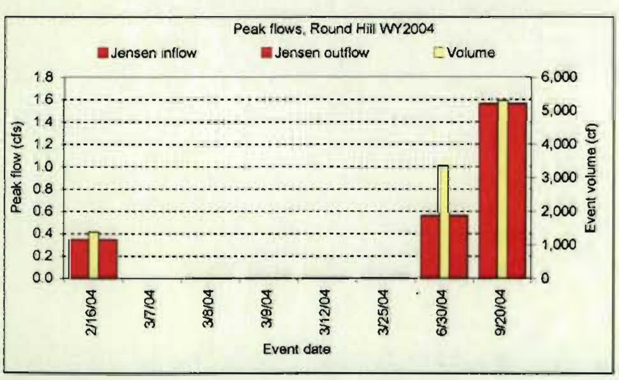


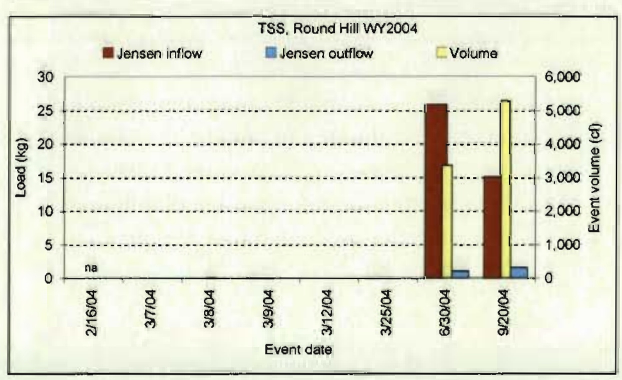












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APPENDIX 7: Cumulative event loads calculated from the monitored events of WY2003 and WY2004.

WY2003 CDS stormwater vault cumulative event loads calculated from monitored events

WY2003 RH CDS	TN (g)	TKN (g)	NO3-N (g)	NH4-N (g)	TP (g)	TDP (g)	SRP (g)	TSS (kg)
Inflow Mass	2,672	2,824	82	43	1,032	87	57	416
Outflow Mass	3,227	3,582	57	17	1,201	83	43	484
Mass Retention	-555	-758	25	26	-169	4	14	-67
Load Reduction	-21%	-27%	31%	60%	-16%	5%	24%	-16%

WY03 sampled volume (cf):	24,742	
WY03 cumulative volume (cf):	67,798	
Percent of total volume represented:		37

WY2003 Vortechnics stormwater vault cumulative event loads calculated from monitored events

WY2003 RH Vortechnics	TN (g)	TKN (g)	NO3-N (g)	NH4-N (g)	TP (g)	TDP (g)	SRP (g)	TSS (kg)
Inflow Mass	1,285	1,254	30	10	740	38	25	763
Outflow Mass	1,355	1,332	23	5	526	30	20	166
Mass Retention	-70	-77	7	5	214	8	5	597
Load Reduction	-5%	-6%	23%	53%	29%	21%	19%	78%

WY03 sampled volume (cf):	7,433	
WY03 cumulative volume (cf):	30,440	
Percent of total volume represented:		24

APPENDIX 7: Cumulative event loads calculated from the monitored events of WY2003 and WY2004 (continued).

WY2004 CDS stormwater vault cumulative event loads calculated from monitored events

WY2004 RH CDS	TN (g)	TKN (g)	NO3-N (g)	NH4-N (g)	TP (g)	TDP (g)	SRP (g)	TSS (kg)
Inflow Mass	763	739	23	21	198	72	62	42
Outflow Mass	805	779	26	17	198	59	47	32
Mass Retention	-42	-40	-3	4	0	13	15	10
Load Reduction	-6%	-5%	-12%	20%	0%	18%	24%	24%

WY04 sampled volume (cf): 15,750

WY04 cumulative volume (cf): 49,917

Percent of total volume represented: 32

WY2004 Vortechnics stormwater vault cumulative event loads calculated from monitored events

WY2004 RH Vortechnics	TN (g)	TKN (g)	NO3-N (g)	NH4-N (g)	TP (g)	TDP (g)	SRP (g)	TSS (kg)
Inflow Mass	219	200	18	6	97	19	17	21
Outflow Mass	217	190	26	6	94	18	16	19
Mass Retention	2	10	-8	0	3	1	1	3
Load Reduction	1%	5%	-44%	-2%	3%	6%	6%	12%

WY04 sampled volume (cf): 8,262

WY04 cumulative volume (cf): 16,399

Percent of total volume represented: 50

APPENDIX 7: Cumulative event loads calculated from the monitored events of WY2003 and WY2004 (continued).

WY2004 Jensen stormwater vault cumulative event loads calculated from monitored events

WY2004 RH Jensen	TN (g)	TKN (g)	NO3-N (g)	NH4-N (g)	TP (g)	TDP (g)	SRP (g)	TSS (kg)
Inflow Mass	1,873	1,723	150	139	308	107	37	47
Outflow Mass	749	693	56	168	63	36	12	3
Mass Retention	1,124	1,030	94	-29	245	71	25	44
Load Reduction	60%	60%	63%	-21%	79%	66%	68%	94%

WY04 sampled volume (cf): 10,084

WY04 cumulative volume (cf): 13,367 (from January 1, 2004 through September 31, 2004)

Percent of total volume represented: 75

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APPENDIX 8: Laboratory analysis of soil sample from Round Hill infiltration area.

ANALYTICAL CHEMISTS and BACTERIOLOGISTS Approved by State of California

SOIL CONTROL LAB

42 HANGAR WAY WATSONVILLE CALIFORNIA 95076 USA

Tel: 831 724-5422
FAX: 831 724-3188

Account Number:
185302-3-58

UC Davis / Tahoe Research Group
P.O. Box 633
Tahoe City, CA 96145
Attn: Alan Hayvaert

Reporting Date:
August 17, 2004

Date Received:	August 4, 2004
Project #/Name:	None / BMP monitoring and research
Sample Identification:	Round Hill Perc Soil 10/24/03
Matrix:	Soil
Laboratory #:	185302-3/3

Analysis	Results	Units
pH value	5.3	pH units
Moisture Content	18	%
Cation Exchange Capacity	7.8	meq/100g
Total Carbon (C)	10000	mg/Kg
Total Organic Carbon (C)	10000	mg/Kg
Total Nitrogen (N)	460	mg/Kg
Extractable Phosphorus (P)	45	mg/Kg
Total Phosphorus (P)	540	mg/Kg
Total Iron (Fe)	24000	mg/Kg
Total Aluminum (Al)	18000	mg/Kg
Total Magnesium (Mg)	7400	mg/Kg
Total Calcium (Ca)	1200	mg/Kg
Total Potassium (K)	5800	mg/Kg
Total Copper (Cu)	16	mg/Kg
Total Lead (Pb)	4.9	mg/Kg
Total Zinc (Zn)	270	mg/Kg
Total Cadmium (Cd)	1.8	mg/Kg

A Division of Control Laboratories Inc.

Mike Galloway

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APPENDIX 9: Analytic results from water samples taken at two groundwater monitoring well sites located downstream from the CDS and Vortechnics stormwater treatment vaults.

Project	Sample ID	Date Time		Water depth below ground surface (inches)	TKN (μg/L)	NO3-N (μg/L)	NH4-N (μg/L)	TP (μg/L)	TDP (μg/L)	SRP (μg/L)	TSS (mg/L)	Turbidity (NTU)	Conductivity (μmhos/cm)
Round Hill	MW1	10/10/2002	14:50	na	lost	lost	lost	lost	47	5	1,538	no sample	na
Round Hill	MW1	3/13/2003	0:00	na	432	30	9	29	14	7	559	4	na
Round Hill	MW1	4/3/2003	14:00	6.66	315	12	14	32	12	3	8	no sample	na
Round Hill	MW1	5/2/2003	13:30	3.21	882	9	14	58	13	6	11	6	na
Round Hill	MW1	7/21/2003	16:00	5.33	823	808	17	101	23	9	34	20	100
Round Hill	MW1	8/14/2003	0:00	6.23	110	97	na	21	18	7	na	na	na
Round Hill	MW1	10/8/2003	15:15	12.04	303	8	11	343	13	13	60	62	200
Round Hill	MW1	12/9/2003	11:54	6.85	647	829	10	128	15	14	56	58	97
Round Hill	MW1	3/10/2004	12:00	3.62	116	83	17	57	13	11	39	9	125
Round Hill	MW1	4/8/2004	13:45	7.35	95	36	8	88	12	9	36	37	110
Round Hill	MW1	5/11/2004	13:00	7.58	73	8	16	14	9	6	4	3	110
Round Hill	MW1	6/17/2004	12:00	11.30	132	62	10	62	17	6	23	12	95
Round Hill	MW1	7/22/2004	11:06	11.01	--	207	15	113	24	11	38	20	na
Round Hill	MW1	8/18/2004	12:00	11.04	120	139	na	220	11	10	115	42	na
Round Hill	MW2	10/10/2002	14:50	DRY	--	--	--	--	--	--	--	--	--
Round Hill	MW2	3/13/2003	0:00	na	868	41	13	1,262	25	11	7	110	na
Round Hill	MW2	4/3/2003	14:10	9.29	337	28	23	58	15	3	16	no sample	na
Round Hill	MW2	5/2/2003	13:35	8.33	775	12	11	250	14	7	86	30	na
Round Hill	MW2	7/21/2003	16:00	DRY	--	--	--	--	--	--	--	--	--
Round Hill	MW2	8/14/2003	0:00	11.70	80	40	na	31	25	15	na	na	na
Round Hill	MW2	10/8/2003	15:15	DRY	--	--	--	--	--	--	--	--	--
Round Hill	MW2	12/9/2003	12:25	16.81	1,488	34	7	1,245	30	15	505	93	110
Round Hill	MW2	3/10/2004	12:40	5.28	246	19	17	374	16	13	194	170	110
Round Hill	MW2	4/8/2004	14:00	9.50	196	17	18	293	16	14	134	103	105
Round Hill	MW2	5/11/2004	13:05	15.87	191	46	13	313	17	14	117	61	100
Round Hill	MW2	6/17/2004	12:00	DRY	--	--	--	--	--	--	--	--	--
Round Hill	MW2	7/22/2004	11:06	DRY	--	--	--	--	--	--	--	--	--
Round Hill	MW2	8/18/2004	12:00	DRY	--	--	--	--	--	--	--	--	--