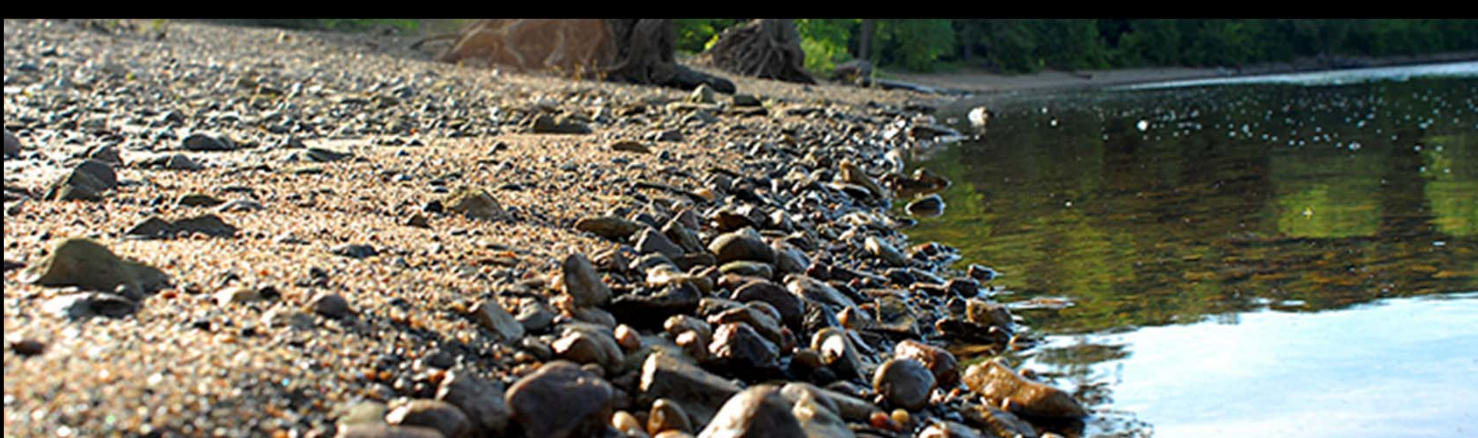
# Capitol Region Watershed District

## BMP Performance and Cost-Benefit Analysis:

### Arlington Pascal Project
### 2007-2010

March 9, 2012



Capitol Region Watershed District

1410 Energy Park Dr., Suite 4 St. Paul, MN 55108
Phone: (651) 644-8888 Fax: (651) 644-8894 www.capitolregionwd.org

March 9, 2012

Dear Stakeholders and Interested Parties:

Eighteen stormwater best management practices (BMPs) were constructed for the Arlington Pascal Stormwater Improvement Project, which aimed to reduce the incidence of localized flooding and improve the water quality of Como Lake, a 303(d) impaired water in St. Paul, Minnesota. Construction of the BMPs was completed in 2007. Since their completion, CRWD has conducted and tracked operation and maintenance activities and has also extensively monitored and modeled the performance of the BMPs. This data was utilized to ascertain and track overall BMP operation and performance. This *BMP Performance and Cost-Benefit Analysis: Arlington Pascal Project 2007-2010*, presents a comprehensive analysis of that data, for the individual project BMPs as well as for the entire Arlington Pascal Project.

I would like to recognize staff which contributed to data collection and the preparation of this report. Melissa Baker had a major role in both monitoring and maintaining the BMPs but also in analyzing and reporting the data. Bob Fossum and Anna Eleria assisted with analysis and report development. Matt Loyas and Britta Suppes assisted with data collection and report preparation. The following staff also assisted with data collection and/or analysis: Andrea Bolks, Peter Brumm, Katie Huser, Christopher Lundeen, Selina Pradhan, Carrie Robertson, Freya Rowland, Nissa Rudh, and John Woodside.

I would also like to thank those that provided a peer review of this report. Those individuals include Bruce Wilson (Minnesota Pollution Control Agency), Andy Erickson (University of Minnesota), Steve Klein (Barr Engineering), Cecilio Olivier (Emmons & Olivier Resources), and Ed Mathiesen (Wenck Associates).

CRWD's BMP program was enhanced by the contributions of numerous agencies and individuals including: Conservation Corps Minnesota and Iowa, St. Paul Parks and Recreation, Steve Dinger, Nathan Johnson, and Adam Robbins for assistance with maintenance of the BMPs; St. Paul Public Works, Anne Weber, and Pat Cahonous, for assistance with city storm sewer monitoring; and Metropolitan Council Environmental Services, for lab analysis on water samples. I would also like to thank Beth Cebilinski, Valerie Cunningham, Sharon Shinomiya, and the numerous other volunteers which assisted with maintenance of the BMPs.

The supporting data used in this assessment is available upon request from CRWD. This report is also available on the District's website: www.capitolregionwd.org. If you have any questions pertaining to the enclosed report do not hesitate to contact me or our staff at 651.644.8888.

Sincerely,

Mark Doneux

Mark Doneux
Administrator

enc: *BMP Performance and Cost-Benefit Analysis: Arlington Pascal Project 2007-2010*

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# BMP Performance and Cost-Benefit Analysis:

## Arlington Pascal Project
## 2007-2010

**Prepared by:**

Capitol Region Watershed District
1410 Energy Park Drive, Suite 4
St. Paul, MN  55108
(651) 644-8888
www.capitolregionwd.org

March 9, 2012

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**Appendices**

# Acronyms and Abbreviations

| | |
|---|---|
| Ac | Acre |
| ANOVA | Analysis of Variance |
| BMP | Best management practice |
| BWSR | Minnesota Board of Soil and Water Resources |
| Cd | Cadmium |
| cf | Cubic feet |
| cfs | Cubic feet per second |
| Cl | Chloride |
| CN | Curve Number |
| Cr | Chromium |
| CRWD | Capitol Region Watershed District |
| Cu | Copper |
| *E. coli* | *Escherichia coli* |
| EPA | US Environmental Protection Agency |
| ET | Evapotranspiration |
| ft | Foot |
| FWA | Flow weighted average |
| GP | Gottfried's Pit |
| ha | Hectare |
| IDDE | Illicit discharge detection and elimination |
| in | Inch |
| IQR | Interquartile range |
| kg | Kilogram |
| L | Liter |
| LID | Low Impact Development |
| Lb | Pound |
| m | Meter |
| MCES | Metropolitan Council Environmental Services |
| mg | Milligram |
| mL | Milliliter |
| MnDOT | Minnesota Department of Transportation |
| MPCA | Minnesota Pollution Control Agency |
| MPN | Most probable number |
| NA | Not available |
| NWS | National Weather Service |
| O & M | Operation and maintenance |
| P8 | Modeling Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds |
| Ortho-P | Ortho-phosphate |
| Pb | Lead |

| | |
|---|---|
| PCB | Polychlorinated Biphenyls |
| Q | Discharge |
| s | Second |
| SM | Standard Methods |
| TDS | Total dissolved solids |
| TKN | Total Kjeldahl Nitrogen |
| TMDL | Total maximum daily load |
| TP | Total phosphorus |
| TSS | Total suspended solids |
| UMN | University of Minnesota |
| VSS | Volatile suspended solids |
| Zn | Zinc |

# Definitions

**ANOVA** – an Analysis of Variance (ANOVA) is a statistical test used for determining whether there is a statistically significant difference among three or more group sample means.

**Amortize –** to reduce a debt by making payments against the principal balance in installments. Calculated over the life expectancy of the best management practice.

**Annual operating cost –** the yearly cost of operation of the stormwater best management practice. It includes the annual capital cost and the annual operation and maintenance cost.

**Annual projected –** term used to refer to the amount of stormwater runoff volume, pollutant load, or cost incurred during a year with an average annual precipitation amount. For the purposes of this report, the 1995 water year was used as the average precipitation year (annual projected).

**As-built –** drawing or certification of conditions (of stormwater best management structures) as they were actually constructed.

**Baseflow** – water flowing through the pipe during non-storm events, usually at a relatively constant, low discharge.

**Best management practice (BMP) –** activities or behaviors that prevent or reduce the impacts of stormwater runoff. Stormwater BMPs are structural and non-structural practices intended to manage the quantity and/or quality of stormwater runoff.

**Bioretention (rain garden) –** a stormwater best management practice structure that utilizes a depressional storage area, native landscaping, and soils to capture and treat stormwater runoff. Stormwater runoff accumulates in the depression areas where it is filtered through the soil media and/or utilized by native plants.

**Boxplot –** a statistical method for graphically depicting groups of numerical data through their five-number summaries, or their interquartile range (IQR). A boxplot may also indicate which observations might be considered outliers. Also known as a “box and whisker plot”.

**Bulk density –** the measure of the mass of soil per unit volume, commonly expressed in lbs/cf. Bulk density is dependent upon the mineral composition of the soil and its degree of compaction.

**Capital cost** – the total cost of construction, engineering, and bond interest of a best management practice.

**Catch basin –** a chamber, typically constructed at the curb line of a street, which captures and conveys stormwater runoff to a storm sewer or sub-drain. A sediment sump, designed to retain gravel and detritus below the point of overflow, may be incorporated at the base of a catch basin.

**Composite sample** – a water sample that is composed of two or more discrete samples taken at specified discharge/time intervals. The aggregate sample reflects the average water quality covering the sample period.

**Conveyance** – a mechanism for transporting water from one point to another including pipes, ditches, and channels.

**Curve number –** a numerical representation of a given watershed area's impervious cover. This is a unitless number used in the P8 Model to represent overall watershed land use based on total pervious area. A pervious curve number (CN) ranges from 30 (indicating high infiltration) to 100 (indicating high runoff).

**Cumulative total phosphorous load –** the combined load of total phosphorus (TP) removed by a best management practice, including: 1) the TP load removed through the infiltration of stormwater runoff and settlement of suspended particles, and 2) the TP load associated with the gross solids load which accumulated within the BMPs themselves and/or were captured by any pretreatment devices.

**Dead storage –** the permanent pool volume located below the outlet structure of a stormwater best management practice. Dead storage allows for water quality treatment, however, it does not provide water quantity treatment.

**Detention** – the temporary storage of stormwater runoff in a stormwater best management practice structure with the goal of controlling peak discharge rates and providing gravity settling of pollutants.

**Detention facility/structure** – an above or below ground facility, such as a pond or holding area, that temporarily collects and stores stormwater runoff and subsequently releases it at a slower rate than was collected, allowing for infiltration of the collected stormwater and gravity settling of pollutants. The facility is not designed to create a permanent pool of water.

**Discharge** – rate of flow, in a pipe or stream; commonly expressed as a volume per unit time, i.e. cubic feet per second (cfs).

**Drainage –** refers to the collection, containment, conveyance, and/or discharge of surface and stormwater runoff.

**Drainage area (watershed) –** the total area contributing runoff to a single point/area. A watershed boundary is typically delineated by topography or other landscape features.

**Drainage basin (sub-watershed) –** a geographic and hydrologic sub-unit of a watershed.

**Evapotranspiration –** describes the sum of both evaporation and plant transpiration from a land surface to the atmosphere. Evapotranspiration (ET) is dependent on climatic factors, vegetation types, and soil types.

**Flow-weighted concentration –** the total pollutant load divided by total flow, often expressed as mg/L.

**Grab sample** – a water sample obtained on a one-time basis. The sample may be collected without consideration of the flow rate and/or without consideration of the time.

**Gross solids –** all litter, organic debris, and coarse sediments (greater than 75 µm) that are transported in urban stormwater runoff. Litter includes all human derived trash (e.g. paper, plastic, Styrofoam, metal). Organic debris consists of detritus from leaves, branches, twigs, and grass clippings. Coarse sediments include inorganic materials greater than 75 µm, including soil particles, pavement breakdown, and building materials.

**Growing season –** the annual period of time in which plant growth occurs. The length of a growing season is dependent on regional climate (temperature and precipitation) and location (elevation and total daylight hours). In Minnesota, the growing season generally spans from June through September.

**Hydrodynamic structure** – an engineered structure designed to separate sediments and oils from stormwater runoff through gravitational separation and/or hydraulic flow.

**Hydrograph** – a graph of runoff rate, inflow rate, or discharge rate past a specific point over time.

**Impaired water body** – a water body that does not meet water quality standards and designated uses because of pollutant(s), pollution, or unknown causes of impairment.

**Impervious surfaces –** a hard surface that prevents the entry of water into the soil which results in direct stormwater runoff during a precipitation or melting event. Common types of impervious surfaces include roads, sidewalks, driveways, parking lots, or rooftops covered by asphalt, concrete, roofing materials, or compacted earthen materials.

**Infiltration** – the downward movement of water from the surface to the subsoil.

**Infiltration facility (or system)** – a drainage facility designed to use the hydrologic process of stormwater runoff soaking into the ground, referred to as percolation, to dispose of stormwater runoff.

**Life expectancy –** the anticipated length of time for a best management practice facility to perform at its maximum expected treatment capacity.

**Low impact development (LID) –** a comprehensive land planning and engineering design approach with a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds.

**Manhole –** an underground structure or chamber connected to a storm sewer that is capped with a manhole cover. The structure can be sumped to act as a pretreatment device to remove gross solids and other pollutants from stormwater.

**Monitoring season –** the annual time period, generally from April through November, in which CRWD collects data on the quantity and quality of its water resources at designated monitoring stations. Monitoring includes routine measurements of water quality and quantity in water bodies (i.e. lakes, ponds, and wetlands) and stormwater discharges through the municipal storm sewer system. The duration of the monitoring season is dependent on annual variations in temperature and precipitation.

**Nutrients –** chemical elements, such as nitrogen and phosphorus, that naturally occur in the environment and are essential to plant growth and animal populations. In excess, elevated concentrations of nutrients from land use activity can become water quality contaminants because they promotes algal growth, eutrophication, and hypoxic conditions which are detrimental to aquatic health.

**Operation and maintenance (O & M) cost –** the sum of labor, equipment and materials, and contract services costs for inspecting and maintaining stormwater best management practices.

**P8 model –** The P8 Model (Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds) is used for modeling stormwater runoff and pollutant production in small urbanized watersheds. The model generates continuous water-balance and mass-balance calculations to determine BMP performance and removal efficiency for flow and pollutants.

**Particle size distribution –** a measurement designed to determine the size and range of a set of particles within a representative sample extracted from a material (e.g. soil, debris, bedload).

**Pollutant load –** the total mass of a pollutant, often expressed in lbs or kg.

**Post-hoc Tukey Test** – a statistical test that uses the results of ANOVA to perform a pairwise comparison of the sample means to see where the statically significant differences are.

**Performance efficiency –** an analysis aimed at determining volume and pollutant load reductions and volume and pollutant removal efficiencies (performance) by a stormwater BMPs using monitored and modeled data. Efficiency is typically expressed as a percentage. Performance efficiency calculations assist in verifying overall BMP project success.

**Pretreatment unit** – a device incorporated into the design of a stormwater BMP that is intended to capture stormwater and remove pollutants prior to the stormwater discharging in to the BMP facility. Pretreatment units prolong the life expectancy of the BMP by removing excess debris that would otherwise flow directly into the BMP.

**Probability plot** – a statistically generated graph that shows the distribution of all data and the probability of occurrence for a parameter by percentile.

**R –** a computer programming language and software package for statistical computing and graphics.

**Retrofit** – modifying or upgrading stormwater management systems/practices in existing developed areas.

**Riparian buffer –** a vegetated area adjacent to a stream or water body that plays a critical role in water quality by intercepting sediment and pollutants in surface runoff. Riparian buffers also provide bank stabilization, water temperature moderation, aquatic species abundance, and terrestrial wildlife habitat.

**Removal efficiency** – the ability of a stormwater best management practice to reduce stormwater runoff and remove pollutants. Efficiency is typically expressed as a percentage. It is calculated by dividing the total volume or pollutant load removed by the best management practice by the total volume or pollutant load which flowed into the best management practice.

**Storm flow** – water flowing through the pipe during and after storm events. Storm flow usually occurs for a short amount of time and has higher velocities than baseflow.

**Stormwater** – water that is not infiltrated (runoff) into the soil during a precipitation or snowmelt event.

**Stormwater pond** – a land depression or impoundment created for detaining or retaining stormwater runoff.

**Stormwater quality** – a term used to describe the chemical, physical, and biological characteristic of stormwater runoff.

**Stormwater quantity** – A term used to describe the volume characteristics of stormwater runoff.

**Sump** – a design element, incorporated at the base of a catch basin or manhole, used to retain gravel and detritus below the point of overflow.

**SYSTAT –** a software package used for statistics and statistical graphics.

**Total impervious fraction –** an input parameter utilized in the calibration of the P8 Model that represents the percentage of the total area of the watershed being modeled covered by impervious surfaces.

**Total Maximum Daily Load (TMDL) –** a calculation of the maximum amount of a pollutant that a water body can receive and still safely meet water quality standards as established by the EPA under section 303(d) of the Clean Water Act.

**Total phosphorus (TP) –** a measure of both inorganic and organic forms of phosphorus within the water column, where it can be present as both dissolved and particulate matter. Commonly reported in mg/L. Phosphorus is the most limiting nutrient to plant growth in fresh water. In excess, total phosphorus can cause algal growth and eutrophication in surface waters.

**Total solids load** – includes the total amount of solids (gross and suspended) captured by a stormwater best management practice as well as the amount of gross solids removed by any pretreatment devices discharging to the best management practice. Total solids loads are expressed in pounds (lbs).

**Total suspended solids (TSS) –** all particles (< 63 μm in size), both organic and inorganic, suspended in and carried by the water. Commonly reported in mg/L. High levels of TSS in surface waters can be detrimental to aquatic species by reducing dissolved oxygen levels and burying benthic communities.

**Treatment train –** a flow network of connected stormwater treatment facilities nested in line at various positions within a subwatershed to capture runoff and successively remove pollutants.

**Vacting –** the process of removing debris, organic matter, and sediment from pretreatment devices with suction through the use of a vactor truck.

**Water year –** any 12-month period usually selected to begin and end during a relatively dry season that is used as a basis for processing stream flow and other hydrologic data. In general, the period from October 1 to September 30 is most widely used in the United States.

# 1. Executive Summary

There has been a recent shift in watershed management approaches and concepts such as green infrastructure, innovative stormwater best management practices (BMPs), and low impact development (LID) have become increasingly more prevalent; particularly in the development/re-development of urban watersheds for stormwater quality improvements.

The importance of staying current on new and innovative stormwater management approaches, given the urbanized nature of the District and limitations of traditional stormwater management practices, was identified in the Capitol Region Watershed District's (CRWD) *2010 Watershed Management Plan* (CRWD, 2010[a]). Urban stormwater management is the primary focus for improving the quality of CRWD's water resources; with efforts focused on investigating new stormwater management techniques and approaches including green infrastructure practices such as rain gardens, pervious pavement, green roofs, and integrated tree trenches. Opportunities for BMP retrofits, which incorporate those innovative concepts, are being explored and incorporated in to CRWD projects.

Como Lake (in St. Paul, MN) is a 303(d) impaired water (MPCA, 2011) and a key feature of one of the region's largest and most visited parks; Como Park. The Como Park Zoo and Conservatory offers a variety of activities and amenities to meet the recreational needs of the residents of St. Paul and surrounding communities; an estimated 3.5 million individuals visit the park annually (Metropolitan Council, 2011). Como Lake has historically served a stormwater function and has been plagued by degraded water quality since development of the Como Subwatershed. Documented problems such as poor water quality, sedimentation, and excessive vegetation have altered the ecological function and natural resource value of the lake; reducing its recreational value and ultimately that of Como Park.

In an effort to improve the water quality of Como Lake and address intercommunity flooding issues, the cities of Falcon Heights, Roseville, and St. Paul along with Ramsey County and CRWD formed a partnership to conduct a hydrologic evaluation of the Como 7 Subwatershed in 2003 (CRWD, 2003). The Como 7 Subwatershed is one of eight smaller subwatersheds that comprise the larger Como Subwatershed and was prioritized for pollutant load reductions due to the intensive land uses and lack of existing structures to pretreat stormwater runoff. The results of that study prompted the partnership to implement the Arlington Pascal Stormwater Improvement Project (Arlington Pascal Project).

The Arlington Pascal Project was the first large-scale capital improvement project ($2.7 million), implemented by CRWD. The goals of the project, which included reducing the frequency of localized flooding and reducing the pollutant loading to Como Lake, were achieved through the construction of eighteen stormwater BMPs in the Como 7 Subwatershed. Construction of the project BMPs commenced in 2005 and was completed in 2007. The BMPs constructed included:

- An underground stormwater storage and infiltration facility (Arlington-Hamline Underground Stormwater Facility/Arlington-Hamline Facility
- A regional stormwater pond (Como Park Regional Pond)
- Eight underground infiltration trenches
- Eight rain gardens

Extensive monitoring and modeling efforts have been conducted by CRWD since the project BMPs became operational, to ascertain and track the overall operation and performance of the individual BMPs and the project as a whole. Specifically, monitoring and modeling activities have aimed to determine BMP performance with regards to volume reduction, total phosphorous (TP) load removal, and total suspended solids (TSS) load removal.

This report presents analysis on only modeled BMP performance results and actual maintenance data collected on the Arlington Pascal Project BMPs, from 2007 through 2010. The analysis of actual monitoring data was excluded from this report; however, it was utilized for the calibration of the model. Overall, this report aims to present a comprehensive analysis on BMP performance and for determining overall project success to those decision makers, regulators, and practitioners interested or involved with stormwater management.

Performance results, from 2007 to 2010 and for a year with an average precipitation amount (annual projected), for each BMP are presented in the individual chapters. BMP performance results include annual volume and pollutant load reductions and annual removal efficiencies for volume, TP, and TSS by the BMPs only. In addition, annual cumulative TP and total solids loads are also presented. Cumulative TP and total solids loads incorporate the TP and TSS loads removed through the infiltration of stormwater runoff and settlement of suspended solids, as well as, the loads removed through the accumulation of gross solids within the BMPs and any pretreatment units. Gross solids include all litter, organic debris, and coarse sediments (greater than 75 µm) that are transported in urban stormwater runoff.

On average 9.3 million cubic feet (cf) of stormwater runoff flowed to all Arlington Pascal Project BMPs annually, from 2007 through 2010. Of that volume, on average of 20% (1.9 million cf) was removed each year; which was slightly less than the annual projected amount (2.1 million cf). Annual stormwater volume reduction was strongly dependent on precipitation trends, especially in 2010, when a 24% increase in precipitation (above the 30-year normal amount) was observed. Runoff flowing to and removed, by all BMPs in 2010; was more than one and one-half times greater than those amounts observed in previous years, which were drier than 2010. Volume reduction costs for the entire project were consistent from 2007 to 2009 ($0.06 per cubic foot). That cost was 50% less in 2010 ($0.03 per cubic foot); primarily due to the large volume reduction which occurred.

The TSS load flowing to all BMPs, averaged 70,800 lbs each year from 2007 to 2010; of which an average of 57,100 lbs (81%) was removed. This reduction exceeded the annual projected amount (38,300 lbs) by 39%. The total solids load (includes TSS removed through infiltration and settling, as well as, gross solids captured by the pretreatment units and the BMPs) removed by all BMPs, averaged 224,000 lbs each year from 2007 to 2010. However, this did not exceed the annual projected load (232,400 lbs). Although results vary annually for each individual BMP, the majority of the total solids load removed (75%) was due to gross solids captured by the BMPs and pretreatment units. Project total solids removal costs have decreased since 2007; from $1.07 per pound to$0.34 per pound in 2010, which is more than three times less.

From 2007 to 2010, on average, 159 pounds (lbs) of cumulative TP (collective amount of TP removed through infiltration and settling and TP in gross solids captured by the BMPs and pretreatment units) was removed by all BMPs, annually. The portions of that reduction due to the various mechanisms, including TP removed through infiltration of stormwater runoff and settling of suspended particles and TP contained in gross solids which accumulated in pretreatment units and the BMPs were fairly comparable. An average of 82 lbs (52%) of TP was removed through infiltration and settling and 77 lbs (48%) of TP was removed through the accumulation of gross solids each year. The average annual cumulative TP load (159 lbs) removed by all project BMPs was slightly greater than the annual projected load (155 lbs). Like the total solids removal costs, the annual cumulative TP removal costs for the Arlington Pascal Project decreased from $1,100 per pound in 2007 to $395 per pound in 2010.

In general, the overall performance of the project BMPs were exceptional, with nearly all annual volume and pollutant load reductions meeting or exceeding annual projected load reductions. Volume reduction and pollutant removal costs for the individual BMPs have fluctuated annually, due to fluctuations in annual operating costs and in the amount of volume and pollutant load reductions occurring each year. However, pollutant removal costs for the entire project have illustrated a decreasing trend.

The cost-benefit analysis was expanded to normalize capital (construction) costs and 35-year project operation and maintenance (O & M) costs by the contributing watershed area and amount of impervious surfaces. These costs will serve as a base for District programs and processes. The capital costs of all Arlington Pascal Project BMPs were $14,300 per watershed acre and $32,600 per acre impervious surfaces. The 35-year projected O & M costs for all project BMPs were $5,400 per watershed area and $12,300 per acre impervious surfaces.

The Arlington Pascal Project has been highly successful at volume and pollutant load reductions from the Como 7 Subwatershed. The project has consistently exceeded the target annual TP load reduction goal for Como Lake since 2008; which represents the first year in which all project BMPs were operational (Table E-1). Quantifiable results and impacts on the water quality of Como Lake, specifically related to these volume and load reductions, have yet to be extensively examined (measureable results may not be seen for many years). However, the Arlington Pascal Project has been proven to be a cost-effective strategy, in comparison to the original proposal, for achieving target volume and pollutant load reduction goals.

**Table E-1. Arlington Pascal Project annual TP load reductions in comparison to the target load reduction.**

| | TP Load Reduction (lbs) |
|---|---|
| 2007 | 56 |
| 2008 | 151 |
| 2009 | 173 |
| 2010 | 256 |
| Projected | 155 |
| **Target** | **77** |

# 2. Introduction

In recent years, there has been a shift in watershed management approaches and innovative concepts such as green infrastructure, innovative stormwater best management practice (BMP) structures, and low impact development (LID).

The importance of staying current on new and innovative stormwater management approaches given the urbanized nature of the District and limitations of traditional stormwater management practices was identified in the Capitol Region Watershed District's (CRWD) *2010 Watershed Management Plan* (CRWD, 2010[a]). Urban stormwater management is the primary focus for improving the quality of CRWD's water resources, with efforts focused on investigating new stormwater management techniques and approaches including green infrastructure practices such as rain gardens, pervious pavement, green roofs, and integrated tree trenches. Opportunities for BMP retro-fits which incorporate those innovative concepts are being explored and incorporated in to CRWD projects.

## 2.1. Report Overview

This report represents an expansion of the CRWD *Stormwater BMP Performance and Cost-Benefit Analysis* (CRWD, 2010[b]). This report also achieves the same four objectives as the previous report:

- Describe the BMPs constructed and explain why they were built
- Determine the volume and pollutant load reductions and volume and pollutant removal efficiencies (performance) of the BMPs
- Determine the costs to design, construct, operate, and maintain the BMPs
- Estimate the costs to remove pollutants (cost-benefit analysis)

In addition, this report presents analysis on only modeled performance results and actual maintenance data collected on stormwater BMP structures monitored and maintained by CRWD (those BMPs constructed as part of the Arlington Pascal Stormwater Improvement Project), from 2007 through 2010. This report was also further expanded to include:

- A synopsis of methodologies used to collect and analyze data obtained through monitoring from 2007 through 2010
- A more detailed overview of the modeling analysis completed
- A statistical analysis of water quality data collected through monitoring
- Refined results on gross solids, total solids, and total phosphorous loads accumulation within the BMPs and their respective pretreatment units

## 2.2. Capitol Region Watershed District

CRWD is a special purpose local unit of government that was formed in 1998 to manage and protect the water resources within its boundaries. CRWD is located in Ramsey County, Minnesota and has a population of approximately 245,000. The District encompasses 41 square miles, including portions of five metropolitan communities (Falcon Heights, Lauderdale, Maplewood, Roseville, and St. Paul) (Figure 2-1). Within the watershed, CRWD actively manages the integrity of four lakes (Como, Loeb, McCarrons, and Crosby), multiple wetlands, and stormwater runoff which drains from the watershed and flows to the Mississippi River.

Historical development and current redevelopment have placed a significant burden on the health and sustainability of the water resources in CRWD. Many natural areas in the watershed were developed over time and those that remain have been significantly degraded through development. Many historical surface waters have also been altered, placed in underground pipes, or filled to make way for development.

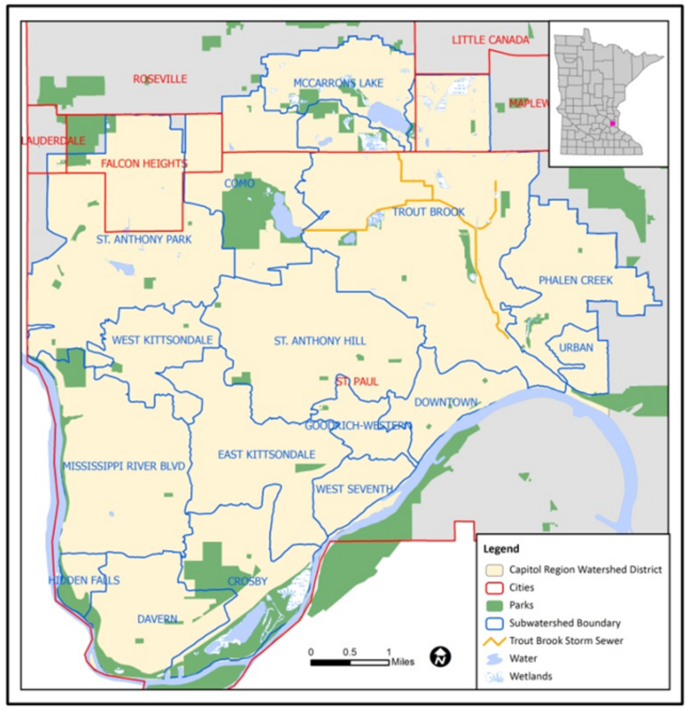


**Figure 2-1. Map of the Capitol Region Watershed District.**

At present, CRWD is highly urbanized; 42% of the watershed is covered by impervious surfaces. Residential and impervious roadways are the two dominant land uses in the watershed. Impervious surfaces generate polluted stormwater runoff which causes environmental impacts such as poor water quality, increased peak storm flows, increased volumes of stormwater runoff, decreased groundwater recharge, increased flooding, and loss of aquatic and wildlife habitat.

Stormwater runoff is the most significant source of water pollution in CRWD. It carries and delivers detergents, fertilizers, pesticides, pet and wildlife waste, trash, nutrients, heavy metals, sediment, and other anthropogenic pollutants to local water bodies and wetlands. Runoff is collected and conveyed through an extensive network of underground storm sewers, which replaced creeks and streams that formerly drained the watershed and flowed directly into the Mississippi River. A total of 55 known outlet pipes discharge into the thirteen mile stretch of the Mississippi River bordering CRWD.

## 2.3. Pollutants of Concern

Two primary water quality constituents of concern in the District are phosphorous and sediment. In excess, these two constituents have the potential to limit the effectiveness of biological processes and alter ecological processes through eutrophication and sedimentation.

Phosphorous is a biological nutrient that limits the growth of algae in most lakes and streams. It is often found in high concentrations in stormwater runoff. In excess, it can cause the overgrowth of algae and aquatic plants in lakes and rivers, reducing dissolved oxygen levels and increasing turbidity of the water column.  Phosphorus contributes to nutrient impairments in water bodies, including Como Lake and the Mississippi River. Common sources of phosphorus include fertilizers from lawns and gardens, leaves and grass clippings, pet and wildlife waste, detergents used for car washing and laundry, automobile emissions, and wastewater treatment plant discharges.

Sediment is another major constituent of stormwater runoff that negatively impacts water clarity and impairs benthic aquatic habitat.  The reduction or removal of sediment from stormwater is essential because other pollutants such as phosphorus adhere to soil particles.  Sediment contributes to turbidity impairments in water bodies, including Como Lake and the Mississippi River. Sediment originates from erosion of soil particles from construction sites, stream banks, and lake shores as well as sand applied to streets, highways, and parking lots for deicing in the winter months.

Both historical and current water quality data of two District water resources, Como Lake and the Mississippi River, indicate that these water bodies are impaired for various pollutants, including nutrients, turbidity, and bacteria.  Como Lake and the Mississippi River are listed on the Minnesota Pollution Control Agency's (MPCA) 2008 303(d) list of impaired waters (MPCA, 2008) for not meeting their designated uses for fishing, aquatic habitat, and recreation.  Additionally, both are listed on the draft 2010 303(d) list of impaired waters (MPCA, 2011).  These impaired waters require a total maximum daily load (TMDL) study, or pollution budget, for pollutants including bacteria, mercury, nutrients, polychlorinated biphenyls (PCBs), and turbidity.

## 2.4. Stormwater Best Management Practices

Stormwater BMPs are structural and non-structural practices intended to manage the quantity and/or quality of stormwater runoff.  Structural practices include a wide variety of practices such as green roofs, rain barrels, rain gardens, and stormwater ponds.  These practices rely on a combination of processes (biological, chemical, hydraulic, hydrologic, physical, etc.) to manage the quantity and improve the quality of stormwater runoff.

Non-structural practices include pollution prevention (i.e. good housekeeping practices), education, and regulations.  Examples of pollution prevention and source control measures include street sweeping and debris removal from sumped devices (i.e. catch basin and manholes). The effectiveness of non-structural BMPs such as education and regulations are dependent upon behavioral change or enforcement.

CRWD, in partnership with local units of government and other entities within the watershed, has been designing and implementing structural and non-structural stormwater BMPs to minimize the impacts of stormwater runoff and improve the water quality of CRWD water resources.  CRWD also operates and maintains several structural BMPs within the watershed and monitors their effectiveness at pollutant removal and stormwater volume reduction.  In addition, as a part of CRWD's water quality and stormwater management rules, construction projects which disturb one-acre or more of land have to adhere to one or more rules regarding stormwater management, flood control ,wetland management, erosion and sediment control, and illicit discharge and connection.

## 2.5. Arlington Pascal Stormwater Improvement Project

Como Lake is a key feature of one of the region's largest and most visited parks, Como Park. Como Park, adjacent to and buffering Como Lake, was established in 1873 and further developed to incorporate a zoo (in 1897) and a conservatory (in 1915). Today the Como Park Zoo and Conservatory is comprised of 384 acres and offers a variety of activities and amenities (boating, fishing, golfing, conservatory, pavilion, zoo, etc.) to meet the recreational needs of the residents of St. Paul and surrounding communities. The park receives an estimated 3.5 million visitors annually (Metropolitan Council, 2011).

Como Lake has historically served a stormwater function and has been plagued by degraded water quality since development of the Como Subwatershed. Early development consisted of agricultural land uses and continued through the mid 1900's with the conversion of agricultural land to residential. Agricultural runoff and direct impacts by livestock gave way to an increase in the amount of impervious surfaces and a more direct hydrologic connection between the landscape and the lake. Stormwater runoff, carrying nutrients and sediment, pose the most serious threat to water quality of the lake. Documented problems including poor water quality, sedimentation, and excessive vegetation have altered the ecological function and natural resource value of Como Lake. In addition, the degraded water quality of Como Lake has reduced its recreational value and ultimately, that of Como Park.

In an effort to improve the water quality of Como Lake and address intercommunity flooding issues, the cities of Falcon Heights, Roseville, and St. Paul along with Ramsey County and CRWD formed a partnership to conduct a hydrologic evaluation of the Como 7 Subwatershed in 2003 (CRWD, 2003). The Como 7 Subwatershed (298 acres) is one of eight smaller subwatersheds that comprise the larger Como Subwatershed (Figure 2-2) and was prioritized for treatment and pollutant load reductions due to the intensive land uses and lack of existing pretreatment.

The results of the 2003 evaluation provided a framework from which to implement a plan (Arlington Pascal Stormwater Improvement Project) to meet outlined goals. The goals of the Arlington Pascal Stormwater Improvement Project were to:

1. Reduce the frequency and duration of flooding in Como 7 and adjacent subwatersheds
2. Address needed improvements in the storm sewer infrastructure within the subwatershed
3. Improve water quality by reducing the amount of phosphorous that reaches Como Lake
4. Determine an equitable distribution of costs for necessary improvements

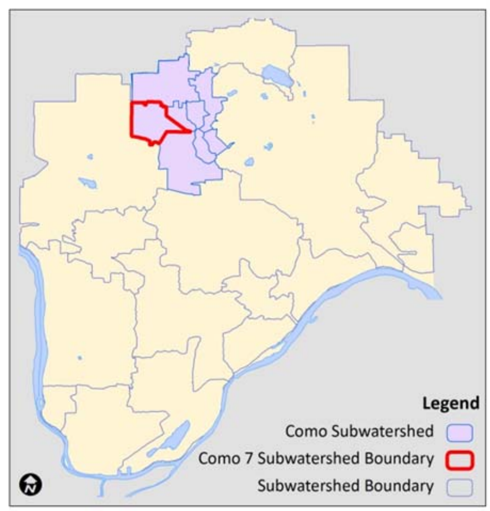


**Figure 2-2. Como 7 Subwatershed project area.**

Initially, the proposed solution included the construction of a second 60-inch storm sewer pipe through the Como Park Golf Course that would convey untreated stormwater runoff to Como Lake. This solution had an estimated cost of $2.5 million which did not include financing costs. Instead, CRWD and the project partners designed and constructed eighteen stormwater BMPs located throughout the Como 7 Subwatershed (Figure 2-3) that achieved the project goals and included water quality benefits, at a lower cost of approximately $2.0 million (financing costs not included).

The eighteen BMPs constructed in the Como 7 Subwatershed were:

- Eight rain gardens
- Eight underground infiltration trenches
- An underground stormwater storage and infiltration system (Arlington-Hamline Underground Stormwater Facility/Arlington-Hamline Facility)
- A regional stormwater pond (Como Park Regional Pond)

The BMPs form a treatment train of stormwater BMPs nested within the Como 7 Subwatershed (Figure 2-4). The drainage areas to the stormwater BMPs cover 64% (190 acres) of the Como 7 Subwatershed (Figure 2-3). Construction of BMPs commenced in 2005 and was completed in late December 2007 when the Como Park Regional Pond became operational.

CRWD monitors the performance of these BMPs and also conducts regular inspections and maintenance to ensure they are functioning properly. The inlets and outlets of the Arlington-Hamline Facility, Como Park Regional Pond, and two out of the eight infiltration trenches (Trenches 4 and 5) are monitored for water quality and/or flow while the rain gardens are monitored for peak water levels only.

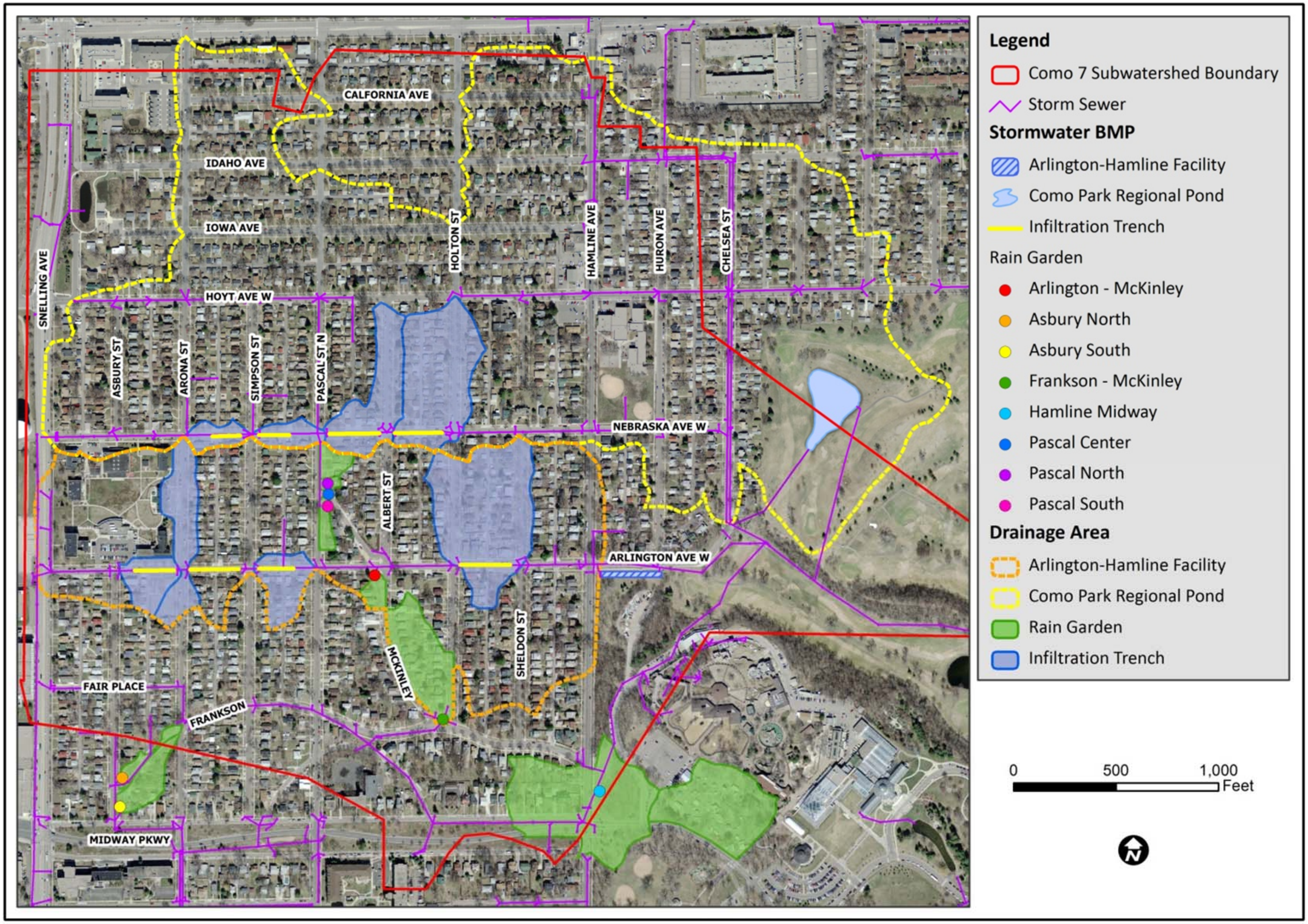


**Figure 2-3. Arlington Pascal Stormwater Improvement Project BMPs and drainage area locations.**

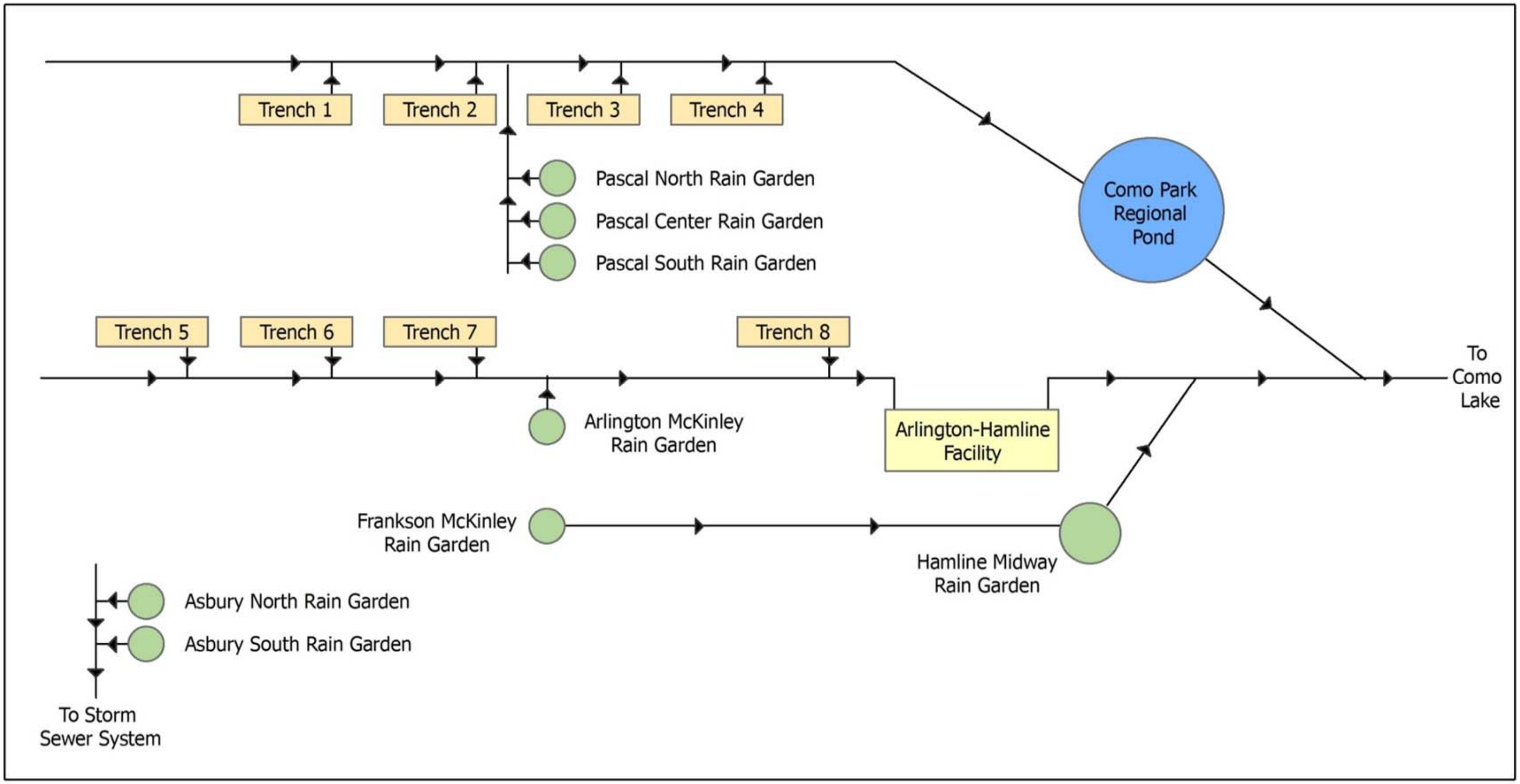


**Figure 2-4. Arlington Pascal Project BMP flow network.**

# 3. Arlington Pascal Stormwater Improvement Project

## 3.1. Project Foundations

In 1998, a group of Saint Paul citizens petitioned to the Minnesota Board of Soil and Water Resources (BWSR) to create CRWD for the purpose of addressing local watershed management issues. A list of watershed management issues was compiled in the initial petition (CRWD, 1998), including:

- **Gottfried's Pit Flooding**
  Stormwater runoff from the City of Falcon Heights and the City of Roseville was identified as the main source of floodwaters to Gottfried's Pit. Floodwater damage was frequently sustained by property owners on the south side of Larpenteur Avenue, adjacent to Gottfried's Pit. It was noted that a number of BMPs existed; however, even with those improvements flooding remained problematic.

- **Water Quality of Como Lake**
  The citizens noted that target pollution loads for Como Lake had not been developed and they expressed concern about the quality and quantity of stormwater discharges entering the water body. It was identified that large portions of the stormwater discharges entering Como Lake (over 800 acres) were generated from the City of Falcon Heights and the City of Roseville.

  Additionally, the formation of large sediment deltas in Como Lake was noted as an issue of concern. The sediment creating the plumes was stated to be from a variety of sources in the Cities of Falcon Heights, Roseville, and St. Paul.

  It was also stated that two stormwater ponds, located on the Como Park Golf Course, were inadequately sized to provide sufficient treatment of stormwater runoff which flowed into the ponds and discharged to Como Lake.

### 3.1.1. Gottfried's Pit

Gottfried's Pit is a stormwater retention pond located on the north side of Larpenteur Avenue at Chelsea Street in the City of Roseville (Figure 3-1). Gottfried's Pit has a 522 acre drainage area and a storage volume of approximately 500,000 cubic feet. Collectively, the retention pond receives stormwater runoff from the Cities of Falcon Heights, Roseville, and St. Paul. Gottfried's Pit is equipped with a lift station that pumps water out of the pit and into storm sewers in the City of St. Paul; ultimately discharging to the Como Park Regional Pond and then to Como Lake. Normal water level of Gottfried's Pit is 894 feet. The lift station is activated to pump out water when the water elevation reaches 897 feet.

Gottfried's Pit itself is not a main focus of this report; however, it is important to mention when discussing the Como Park Regional Pond because Gottfried's Pit discharges into the pond.

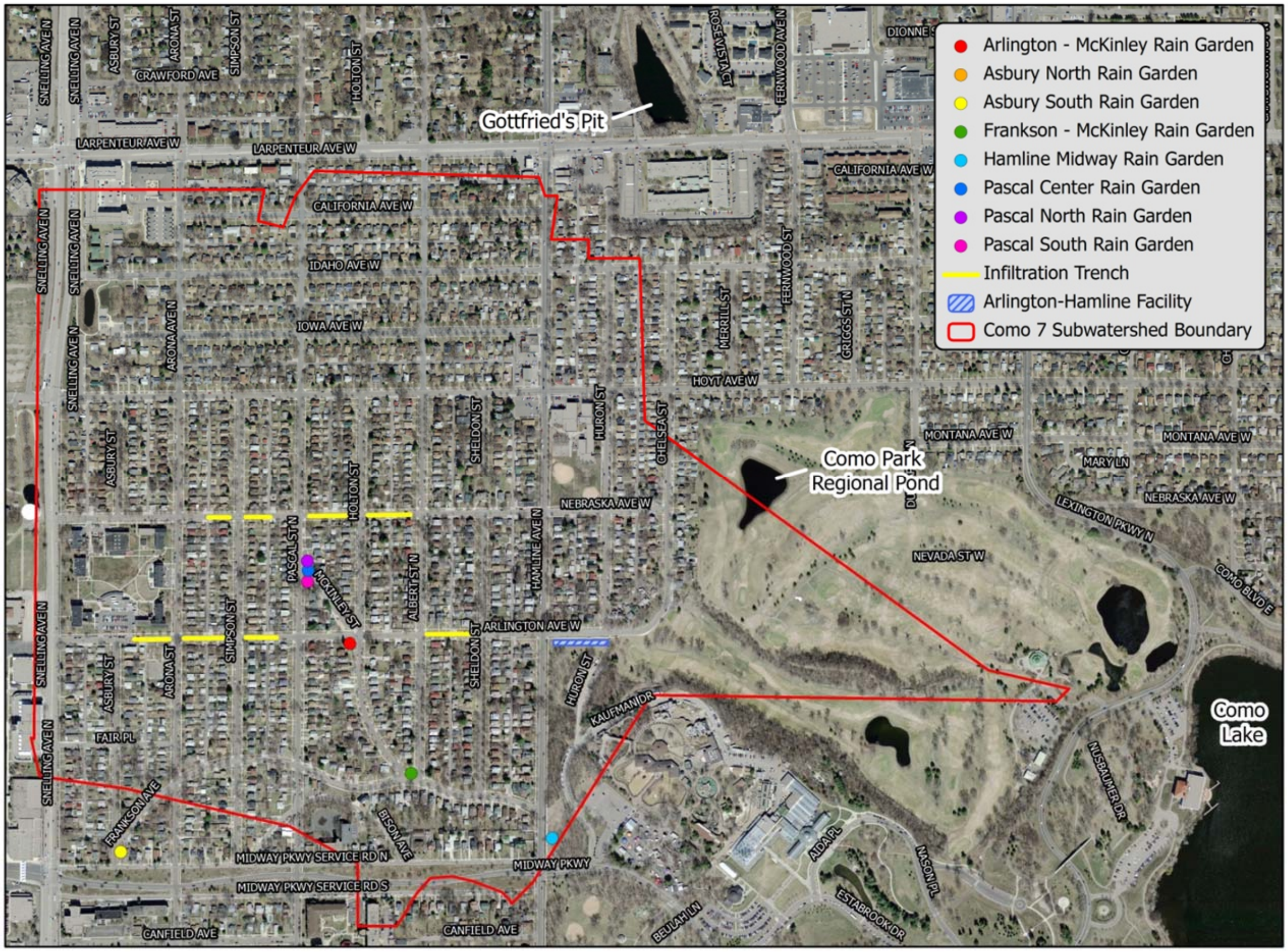


**Figure 3-1. Location of Como Lake and Gottfried's Pit in relation to the Arlington Pascal Stormwater Improvement Project location.**

## 3.1.2. Como Lake

Como Lake is a 67 acre lake with a maximum depth of 15.5 feet. This shallow urban lake is located in the City of St. Paul where surrounding land uses are primarily residential and open space. Como Lake is classified as a shallow lake because nearly 100% of the lake is in the littoral zone. Como Lake is listed on the Minnesota Pollution Control Agency's 303(d) list of impaired waters due to excessive nutrients (MPCA, 2011).

Como Lake has historically served a stormwater function and has been plagued by degraded water quality since development of the Como Subwatershed. Early development in the Como Subwatershed consisted of primarily agriculture land uses and continued through the mid 1900's with the conversion of agriculture land to residential land, with an extensive network of roads. The water quality of Como Lake was likely impacted by early development due to agricultural runoff and was directly impacted by livestock. Additionally, later development and an increase in the amount of impervious surfaces resulted in increased stormwater runoff and a more direct hydrologic connection between the landscape and the lake. Stormwater runoff, carrying nutrients and sediment, pose the most serious threat to water quality of the lake. Documented problems, including poor water quality, sedimentation, and excessive vegetation have altered the ecological function and natural resource value of Como Lake.

Como Lake is a key feature of one of the region's largest and most visited parks, Como Park. Como Park, adjacent to and buffering Como Lake, was established in 1873. The park was further developed to incorporate a zoo (in 1897) and a conservatory (in 1915). Today the Como Park Zoo and Conservatory is comprised of 384 acres and offers a variety of activities and amenities (boating, fishing, pavilion, zoo, conservatory, fishing, boating, golfing, etc.) to meet the recreation needs of the residents of St. Paul and surrounding communities. The park receives over an estimated 3.5 million visitors annually (Metropolitan Council, 2011). The degraded water quality of Como Lake has reduced its recreational value and ultimately that of Como Park.

To further emphasize the historical water quality issues and importance of this resource, in CRWD's *2000 Watershed Management Plan*, it was stated that Como Lake is a major recreation amenity and community resource that is afflicted with poor water quality, sedimentation, and excess vegetation (CRWD, 2000). It was identified in Section IV-I that CRWD would propose a management program to implement the *Como Lake Strategic Lake Management Plan*, which was being developed alongside the watershed management plan.

The *Como Lake Strategic Management Plan* was completed in 2002 (CRWD, 2002). The goals of the report were to identify important lake management issues and implementation activities. The report ultimately described an implementation work plan for stakeholder groups to achieve a goal of 60% annual phosphorous load reduction by remediating surface runoff with stormwater BMPs. The stakeholders involved included the following organizations:

- CRWD
- The City of Falcon Heights
- The City of Roseville
- The City of St. Paul
- The Minnesota Department of Natural Resources
- Ramsey County
- The St. Paul Community Council – District 10

CRWD prioritized several activities for implementation within the first five years following adoption of the plan. One of those activities was the 'Subwatershed Loading Plan' (CRWD, 2002). The loading plan focused on maximizing phosphorous load reductions in the individual Como Subwatersheds. Using a variety of combinations of stormwater BMPs, phosphorous load reductions were modeled in order to maximize the nutrient load reductions within the smaller Como Subwatersheds. The Como 3, 4, and 7 Subwatersheds were prioritized for treatment and pollutant load reductions due to the intensive land uses and lack of existing stormwater pretreatment. The end result provided a framework for general BMP selection, construction costs, and operation and maintenance costs for each Como Subwatershed to achieve the target 60% phosphorous load reduction.

## 3.2. Project Planning

Since 1996, the City of St. Paul has been implementing a residential street vitality program. The program aims at improving and upgrading 10-15 miles of unpaved and older streets each year. In addition to street upgrades, tree and lighting improvements are completed as well as upgrades to public and private utilities and the incorporation of stormwater management techniques.

Neighborhoods within the Como 7 Subwatershed were on the street improvement project schedule for 2005. In preparation for the upcoming street project, the City of St. Paul completed a hydrologic model. The model identified several under capacity storm sewer pipes and several areas with potential for localized flooding due to storm sewer surcharge and overland flow from the Como 7 Subwatershed. The City of St. Paul developed a preliminary plan (constructing a 60-inch storm sewer parallel to an existing 60-inch storm sewer through the Como Park Golf Course) to address these issues. This solution had an estimated cost of $2.5 million which did not include any financing costs.

Other communities were also contributors to the drainage and flooding problems in St. Paul. The City of Falcon Heights, the City of Roseville, and Ramsey County recognized their roles and agreed to be involved in resolving the issues. These four local government units approached CRWD to facilitate the process. CRWD's role was to resolve the inter-community flow issues and manage the quantity and quality of stormwater runoff discharging to Como Lake.

All of these entities formed a partnership to conduct a hydrologic evaluation of the Como 7 Subwatershed in 2003 to achieve four primary goals:

1. Reduce the frequency and duration of flooding in Como 7 and adjacent subwatersheds
2. Address needed improvements in the storm sewer infrastructure within the subwatershed
3. Improve water quality by reducing the amount of phosphorous that reaches Como Lake
4. Determine an equitable distribution of costs for necessary improvements

The hydrologic evaluation model was completed for two watersheds; the Como 7 Subwatershed and the Gottfried's Pond Subwatershed (which discharges into Gottfried's Pit). The results of the evaluation provided a framework from which to implement a project (the Arlington Pascal Stormwater Improvement Project) designed to meet the evaluation goals.

Through discussion and public participation, CRWD and partners further refined the evaluation solutions and implemented the Arlington Pascal Stormwater Improvement Project. The project detailed the design and construction of eighteen stormwater BMPs, all retro-fits of developed areas, spread throughout the Como 7 Subwatershed (Figure 2-3). These BMPs not only achieved the project goals at a lower cost than the original solution (the project cost was approximately $2.0 million which does not include financing costs), but also provided water quality benefits consistent with the phosphorous reduction goals outlined in the *Como Lake Strategic Management Plan* (CRWD, 2002).

The 18 BMPs constructed through the Arlington Pascal Stormwater Improvement Project were:

- Eight rain gardens
- Eight underground infiltration trenches
- An underground stormwater storage and infiltration system (Arlington-Hamline Underground Stormwater Facility/Arlington-Hamline Facility)
- A regional stormwater pond (Como Park Regional Pond)

## 3.3. Project Costs and Features

The Arlington Pascal Stormwater Improvement Project had a total capital cost of approximately $2.7 million, which included the cost of design and construction and also bond interest paid by CRWD (Table 3-1).

The BMPs are nested together and form a treatment train that cumulatively has a drainage area of approximately 190 acres (Table 3-2, Figure 2-3). Combined, the BMPs have a storage area of 141,553 square feet ($ft^2$) and 444,390 cubic feet (cf) of dead storage volume.

Of all the BMPs, the Como Park Regional Pond has the largest drainage area, storage area, and storage volume. It alone accounted for 50% of the total project capital cost, primarily due to higher costs for design and construction than any other BMP. However, the pond had the lowest unit capital cost per storage volume at $4.52/cf (Table 3-3). The infiltration trenches combined had the highest unit capital cost per storage volume of the BMPs at $10.71/cf. Collectively, the eight rain gardens have the smallest drainage area and storage volume and lowest capital cost. The unit capital costs for all rain gardens were some of the lowest of all of the BMPs; the lowest cost per area and the second lowest cost per storage volume. However, unit capital costs for each individual rain garden varies.

Construction of the Arlington Pascal Project BMPs began in 2005. The last BMP to be constructed, the Como Park Regional Pond, was completed in 2007. CRWD assesses the performance of all 18 BMPs and conducts regular inspections and maintenance to ensure proper function.

Table 3-1. Capital costs of the Arlington Pascal Project and individual BMPs.

| | Design | Construction | Bond Interest[a] | Total Cost |
|---|---|---|---|---|
| **Arlington-Hamline Facility** | **$86,636** | **$487,488** | **$224,963** | **$799,087** |
| **Como Park Regional Pond** | **$147,926** | **$832,357** | **$384,063** | **$1,364,346** |
| Infiltration Trench 1 | $2,400 | $11,998 | $5,642 | $20,039 |
| Infiltration Trench 2 | $3,569 | $17,846 | $8,392 | $29,807 |
| Infiltration Trench 3 | $10,583 | $52,916 | $24,884 | $88,383 |
| Infiltration Trench 4 | $10,369 | $51,845 | $24,380 | $86,595 |
| Infiltration Trench 5 | $3,091 | $15,454 | $7,267 | $25,812 |
| Infiltration Trench 6 | $4,163 | $20,815 | $9,788 | $34,766 |
| Infiltration Trench 7 | $3,479 | $17,397 | $8,181 | $29,058 |
| Infiltration Trench 8 | $10,250 | $51,249 | $24,100 | $85,599 |
| **Infiltration Trenches Total** | **$47,904** | **$239,521** | **$112,635** | **$400,060** |
| Arlington-McKinley Rain Garden | $494 | $2,471 | $1,150 | $4,116 |
| Asbury North Rain Garden | $1,106 | $5,532 | $2,607 | $9,246 |
| Asbury South Rain Garden | $1,433 | $7,164 | $3,374 | $11,970 |
| Frankson-McKinley Rain Garden | $1,309 | $6,545 | $3,067 | $10,921 |
| Hamline Midway Rain Garden | $12,365 | $61,824 | $28,983 | $103,172 |
| Pascal Center Rain Garden | $648 | $3,239 | $1,533 | $5,421 |
| Pascal North Rain Garden | $806 | $4,028 | $1,917 | $6,750 |
| Pascal South Rain Garden | $1,032 | $5,162 | $2,454 | $8,648 |
| **Rain Gardens Total** | **$19,193** | **$95,966** | **$45,085** | **$160,244** |
| **Project Total:** | **$301,659** | **$1,655,332** | **$766,746** | **$2,723,737** |

[a] Does not include bond interest paid by project partners.

**Table 3-2. Features of the BMPs.**

| | Drainage Area (acre)[a] | Percent Impervious | Storage Area ($ft^2$) | Storage Volume (cf) |
|---|---|---|---|---|
| **Arlington-Hamline Facility** | **50.00** | **44%** | **11,761** | **85,813** |
| **Como Park Regional Pond** | **128.00** | **39%** | **91,912** | **301,871** |
| Infiltration Trench 1 | 0.74 | 47% | 1,507 | 1,871 |
| Infiltration Trench 2 | 0.84 | 49% | 2,169 | 2,783 |
| Infiltration Trench 3 | 3.21 | 36% | 5,066 | 8,252 |
| Infiltration Trench 4 | 5.29 | 37% | 4,883 | 8,085 |
| Infiltration Trench 5 | 1.28 | 40% | 1,725 | 2,410 |
| Infiltration Trench 6 | 2.60 | 40% | 2,209 | 3,246 |
| Infiltration Trench 7 | 1.63 | 44% | 1,982 | 2,713 |
| Infiltration Trench 8 | 7.08 | 39% | 4,870 | 7,992 |
| **Infiltration Trenches Total** | **22.67** | **39%** | **24,411** | **37,352** |
| Arlington-McKinley Rain Garden | 0.37 | 41% | 767 | 349 |
| Asbury North Rain Garden | 0.40 | 43% | 945 | 1,045 |
| Asbury South Rain Garden | 1.08 | 31% | 1,712 | 2,113 |
| Frankson-McKinley Rain Garden | 2.81 | 33% | 2,078 | 2,492 |
| Hamline Midway Rain Garden | 10.47 | 18% | 6,364 | 12,576 |
| Pascal Center Rain Garden | 0.13 | 46% | 536 | 227 |
| Pascal North Rain Garden | 0.46 | 28% | 357 | 209 |
| Pascal South Rain Garden | 0.36 | 24% | 710 | 344 |
| **Rain Gardens Total** | **16.08** | **23%** | **13,469** | **19,354** |
| **Project Total:** | **189.95** | **44%** | **141,553** | **444,390** |

[a] BMPs are nested and have overlapping drainage areas. The total project drainage area does not include overlapped drainage areas.

**Table 3-3. Arlington Pascal Project and individual BMP capital costs per unit.**

| | Cost/ft² | Cost/cf |
|---|---|---|
| **Arlington-Hamline Facility** | **$67.94** | **$9.31** |
| **Como Park Regional Pond** | **$14.84** | **$4.52** |
| Infiltration Trench 1 | $13.30 | $10.71 |
| Infiltration Trench 2 | $13.74 | $10.71 |
| Infiltration Trench 3 | $17.45 | $10.71 |
| Infiltration Trench 4 | $17.73 | $10.71 |
| Infiltration Trench 5 | $14.96 | $10.71 |
| Infiltration Trench 6 | $15.74 | $10.71 |
| Infiltration Trench 7 | $14.66 | $10.71 |
| Infiltration Trench 8 | $17.58 | $10.71 |
| **Infiltration Trenches Total** | **$16.39** | **$10.71** |
| Arlington-McKinley Rain Garden | $5.37 | $11.81 |
| Asbury North Rain Garden | $9.78 | $8.84 |
| Asbury South Rain Garden | $6.99 | $5.67 |
| Frankson-McKinley Rain Garden | $5.26 | $4.38 |
| Hamline Midway Rain Garden | $16.21 | $8.20 |
| Pascal Center Rain Garden | $10.12 | $23.93 |
| Pascal North Rain Garden | $18.90 | $32.28 |
| Pascal South Rain Garden | $12.18 | $25.13 |
| **Rain Gardens Total** | **$11.90** | **$8.28** |
| **Project Total:** | **$19.24** | **$6.13** |

## 3.4. Target Total Phosphorus Load Reductions

The 2003 hydraulic evaluation of the Como 7 Subwatershed determined target TP load reductions for the project BMPs that were consistent with the phosphorous load reduction goals outlined in the *Como Lake Strategic Management Plan* (CRWD, 2002). Table 3-4 presents the target TP load reductions by BMP type.

Preliminary plans of the Arlington Pascal Project BMPs initially depicted a series of boulevard rain gardens instead of the underground infiltration trenches. Also, the plan detailed a stormwater pond instead of the underground Arlington-Hamline Facility. The underground infiltration trenches and Arlington-Hamline Facility were designed and constructed to meet the target TP load reductions outlined in the 2003 hydraulic study. The target TP load reduction for the infiltration trenches and rain gardens reflects a combined TP load reduction for all preliminarily designed rain gardens.

**Table 3-4. 2003 target Arlington Pascal Project and individual BMP TP load reductions.**

| BMP | TP Load In (lbs)[a] | TP Load Removed (lbs)[a] | % TP Removal[a] |
|---|---|---|---|
| Arlington-Hamline Facility | 29 | 12 | 42% |
| Como Park Regional Pond | 76 | 41 | 54% |
| Rain Gardens and Underground Infiltration Trenches | NA | 24 | NA |
| **Annual Project TP Load Reduction:** | | **77** | |

[a] Represents annual loads and reductions.

# 4. Methods

## 4.1. Monitoring Methods

CRWD began monitoring BMPs constructed for the Arlington Pascal Stormwater Improvement Project in 2007. First year monitoring activities evaluated water quality and/or quantity data from the Arlington-Hamline Facility, two underground infiltration trenches (Trenches 4 and 5), and eight constructed rain gardens. In 2008, BMP monitoring expanded to include the Como Park Regional Pond. Table 4-1 lists current BMP monitoring sites.

Water quantity and quality data has been consistently collected from 2007 through 2010 for the monitored Arlington Pascal Project BMPs. Data collection generally occurred during the monitoring season (April through November) of each year, however, actual dates varied annually based on weather conditions.

**Table 4-1. 2011 BMP monitoring sites.**

| Monitoring Site Name | Monitoring Period | Monitoring Site Type[a] | Monitoring Equipment |
|---|---|---|---|
| ***Arlington-Hamline Facility*** | | | |
| Arlington-Hamline Facility Inlet | 2007-2010 | Water Quantity & Quality | ISCO 6712 |
| Arlington-Hamline Facility Outlet | 2007-2010 | Water Quantity & Quality | ISCO 6712 |
| ***Como Park Regional Pond*** | | | |
| Como Park Regional Pond | 2008-2010 | Continuous Level | Global Water |
| Como Park Regional Pond Inlet | 2008-2010 | Water Quantity & Quality | ISCO 6712 |
| Como Park Regional Pond Oulet | 2008-2010 | Water Quantity & Quality | ISCO 6712 |
| ***Underground Infiltration Trenches*** | | | |
| Trench 4 East | 2007-2010 | Water Quantity & Quality | ISCO 6712 |
| Trench 4 East Overflow | 2007-2010 | Water Quantity | ISCO 2150 |
| Trench 4 West | 2007-2010 | Water Quantity | ISCO 2150 |
| Trench 4 West Overflow | 2007-2010 | Water Quantity | ISCO 2150 |
| Trench 5 East | 2007-2010 | Water Quantity | ISCO 2150 |
| Trench 5 East Overflow | 2007-2010 | Water Quantity | ISCO 2150 |
| ***Rain Gardens*** | | | |
| Arlington-McKinley | 2007-2010 | Peak Level | Crest Gauge |
| Asbury North | 2007-2010 | Peak Level | Crest Gauge |
| Asbury South | 2007-2010 | Peak Level | Crest Gauge |
| Frankson-McKinley | 2007-2010 | Peak Level | Crest Gauge |
| Hamline Midway | 2007-2010 | Peak Level | Crest Gauge |
| Pascal Center | 2007-2010 | Peak Level | Crest Gauge |
| Pascal North | 2007-2010 | Peak Level | Crest Gauge |
| Pascal South | 2007-2010 | Peak Level | Crest Gauge |

[a] 'Peak Level' sites have a manual crest gauge which records peak water level of a storm event. 'Continuous Level' sites have a level logger which records continuous water level data. 'Water Quantity' sites have a flow logger which records continuous flow data. 'Water Quantity and Quality' sites have an automated sampler and flow logger which records continuous flow data and collects water quality samples.

### 4.1.1. Data Collection Methods

Data collection methods and equipment at each monitoring site were dependent on site characteristics and specific data needs. Each BMP monitoring site had a flow module and/or water quality sampler installed during the monitoring season. The following water quantity and water quality sampling equipment were used to collect data at one or more of the Arlington Pascal Project BMPs:

- ISCO 6712 Portable Sampler with ISCO 750 Area Velocity Flow Module;
- ISCO 2150 Area Velocity Flow Module;
- ISCO 4120 Level Logger;
- Global Water Level Logger.

An ISCO 6712 portable sampler includes an ISCO 750 Area Velocity Flow Module, automated water sampling capability, and flow data storage. An area-velocity sensor is secured to the bottom of the main pipe and connected to the flow module. Once in place, the sampler is programmed to record water depth (level) and velocity every ten minutes.

The sampler is also programmed to take water quality samples during a storm event by setting a trigger. The trigger can be a specific high water level or velocity that indicates to the sampler that a storm event is occurring. Once triggered, the sampler begins extracting samples at a pre-programmed, flow-paced rate; meaning a sample is taken after a specified quantity of water has passed over the sensor. The purpose of flow-paced sampling is to collect samples over the entire rise and fall of the storm hydrograph in order to extract a fully representative sample of a storm event, rather than taking a single grab sample.

Two different ISCO 6712 sampler sizes were used: a compact sampler and a full-size sampler. A compact sampler can collect up to 48- 200 milliliter (mL) discrete samples, and a full-size sampler can collect up to 96- 200 mL discrete samples. Following a storm event, all samples were collected and composited to produce one 4,000 mL composite sample for lab analysis.

Water quality samples collected, were submitted to the Metropolitan Council Environmental Services (MCES) Laboratory for analysis. A list of chemical parameters analyzed, method of analysis used, and holding times are shown in Table 4-2. If sample collection occurred after the holding time of a given chemical parameter had expired, lab analysis for the expired parameter(s) was not completed. Grab water samples for *Escherichia coli* (*E. coli*) were collected directly into sterilized containers during storm events.

ISCO 2150 Area Velocity Flow Modules were utilized at the infiltration trench monitoring sites to record continuous water level and velocity data throughout the monitoring seasons. An ISCO 2150 unit has a sensor that is installed in a pipe and uses acoustic Doppler technology to determine water level and velocity by bouncing sound waves off suspended particles in the water. Once a sensor was secured in a trench pipe, the flow module was programmed to record water depth (level) and velocity.

**Table 4-2. Water quality sample parameters, analysis methods, reporting limits, and holding times analyzed by MCES laboratory.**

| Parmeter | Abbreviation | MCES Method | Reference Method | Reporting Limit | Units | Holding Time |
|---|---|---|---|---|---|---|
| Ortho-Phosphate | Ortho-P | ORTHO_P_1 | SM 4500-P E | 0.01 | mg/L | 48 hours |
| Chloride | Cl | CHLORIDE_AA_1 | SM 4500-Cl E | 2.00 | mg/L | 28 days |
| Cadmium | Cd | MET_ICPMSV_1 | MNPBMS 003 (EPA 200.8) | 0.50 | µg/L | 6 months |
| Chromium | Cr | MET_ICPMSV_1 | MNPBMS 003 (EPA 200.8) | 5.00 | µg/L | 6 months |
| Copper | Cu | MET_ICPMSV_1 | MNPBMS 003 (EPA 200.8) | 0.50 | µg/L | 6 months |
| Lead | Pb | MET_ICPMSV_1 | MNPBMS 003 (EPA 200.8) | 0.10 | µg/L | 6 months |
| Nickel | Ni | MET_ICPMSV_1 | MNPBMS 003 (EPA 200.8) | 0.50 | µg/L | 6 months |
| Zinc | Zn | MET_ICPMSV_1 | MNPBMS 003 (EPA 200.8) | 5.00 | µg/L | 6 months |
| Ammonia | $NH_3$ | NH3_AA_1 | EPA 350.1 | 0.50 | mg/L | 7 days |
| Total Kjeldahl Nitogen | TKN | NUT_AA_1 | EPA 351.2 | 0.10 | mg/L | 7 days |
| Total Phosphorus | TP | NUT_AA_1 | MNPBMS 014 (365.4) | 0.05 | mg/L | 28 days |
| Nitrate | $NO_2$ | N-N_AA_1 | SM 4500 NO3- H/MNPBMS 025 (EPA 323.1) | 0.05 | mg/L | 28 days |
| Nitrite | $NO_3$ | N-N_AA_1 | SM 4500 NO3- H/MNPBMS 025 (EPA 323.1) | 0.01 | mg/L | 28 days |
| Total Dissolved Solids | TDS | TDS180_1 | SM 2540 C | 10.00 | mg/L | 7 days |
| Total Suspended Solids | TSS | TSSVSS_1 | SM 2540 E | 1.00 | mg/L | 7 days |
| Volatile Suspended Solids | VSS | TSSVSS_2 | SM 2540 E | 1.00 | mg/L | 7 days |
| Hardness | Hardness | HARD-TITR_1 | SM 2340 C | 5.00 | mg/L | 30 days |
| *Escherichia coli* | *E. coli* | COLI-Q_1 | Coliert-18 Quanti-Tray | 1.00 | MPN/100 mL | 6 hours |

EPA: Environmental Protection Agency, MCES: Metropolitan Council Environmental Services, MNPBMS: Minnesota Performance Based Methods, SM: Standard Method

An ISCO 4120 Level Logger was installed at one location: the Arlington-Hamline Facility Pipe Gallery. This unit uses a pressure transducer to record continuous water level through a sensor that is mounted at the base of a pipe. Similarly, a Global Water Level Logger unit (used at Como Park Regional Pond) has an internal pressure transducer, which is submerged to a stake in the pond, to monitor continuous water levels.

In addition, manual crest gauges were used to monitor peak levels of storm events in all eight rain gardens. Each crest gauge consists of a PVC pipe with perforations in the bottom portion and caps on both ends, a wooden stick marked out in measurements in tenths of feet, and granulated cork. Figure 4-1 details a schematic of a manual crest gauge.

The crest gauges were placed at the lowest elevation in each rain garden. As the rain garden fills with runoff, the water flows into the perforations on the PVC pipe causing the granulated cork to float. At the peak water level, the granulated cork sticks to the wooden stick and remains as the water level recedes.

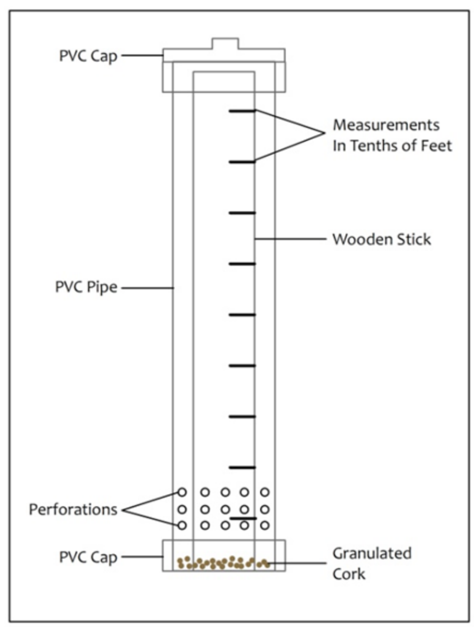


**Figure 4-1. An illustration of a manual crest gauge.**

All samplers and continuous monitoring equipment used by CRWD, is maintained in accordance to manufacturer recommendations. In addition, area velocity sensors and flow modules are tested for accuracy on a flume with a controlled flow rate prior to installation at a monitoring site.

#### *4.1.1.1. Data Collection: Arlington-Hamline Underground Stormwater Facility*

CRWD began monitoring the Arlington-Hamline Facility in 2007. Both water quality and quantity were monitored at two locations: the west-end inlet and the east-end outlet (Figure 4-2). Compact ISCO 6712 samplers were suspended in manholes at each location. The samplers were programmed to take water quality samples during a storm event when it was triggered by water level (ft) in the pipe. Flow to this BMP only occurs during storm events.

During the 2007 and 2008 monitoring seasons, the outlet was monitored using an ISCO 3700 portable sampler with an ISCO 4150 Flow Logger. The combination of the two units perform the same function as an ISCO 6712 unit with a 750 flow module, but are older equipment models.

In addition to the inlet and outlet sites, a level logger was installed inside of the pipe gallery at the northeast end of the facility from 2007 to 2009 and 2011 (Figure 4-2). The ISCO 4120 level logger was installed to monitor continuous water level inside the pipe gallery by recording measurements every 10 minutes. The data collected was utilized to assist in correlating water inflow rates (from inlet site) to water volumes inside the pipe gallery. Data currently collected at this location is used to assist with determining infiltration rates inside the facility and for model calibration. This station was not in commission during the 2010 monitoring season.

Future monitoring of the Arlington-Hamline Facility will be expanded to include continuous flow monitoring of stormwater runoff which bypasses the facility; the flow which over tops the diversion weir in Arlington Avenue.


**Figure 4-2. Arlington-Hamline Facility monitoring locations.**

#### *4.1.1.2. Data Collection: Como Park Regional Pond*

In 2008, CRWD began monitoring the Como Park Regional Pond inlet and outlet (Figure 4-3). Both water quantity and quality data were collected at the inlet and outlet using ISCO 6712 compact samplers. The samplers were suspended in manholes and were programmed to take flow-paced water quality samples when triggered by a high water level (ft).

The inlet site does not typically have base flow and only flows if a storm event is occurring. However, the inlet also receives stormwater flow from the pumping of Gottfried's Pit; an upstream stormwater pond. Non-storm flow may occur depending on the timing of Gottfried's Pit pumping. Flows at the outlet site are observed when water level in the pond is high enough to spill into the pond overflow.

In 2008, a Global Water level logger was placed in the Como Park Regional Pond to track pond elevation in relationship to precipitation. The logger location was surveyed relative to a known benchmark which allowed for level data to be converted to elevation.

Due to limitations of the data collection equipment (accuracy of velocity data during very low flow rates), the total discharge from the Como Park Pond Outlet is likely to be underestimated and the volume reduction efficiency of the pond may be slightly less than calculated. In addition, when the level of the pond exceeds the normal water level, infiltration most likely occurs within the banks around the perimeter of the pond.

Future monitoring of discharge from the Como Park Pond Outlet will include the collection of instantaneous velocity measurements during periods of dry weather (base flow) throughout the monitoring season. Those measurements will be compared to and/or possibly incorporated in continuous flow data collected at the monitoring site, if accurate data is not collected by the sensor and flow module.


**Figure 4-3. Como Park Regional Pond monitoring locations.**

### *4.1.1.3. Data Collection: Infiltration Trenches*

Following the installation of the eight infiltration trenches, CRWD began monitoring Trenches 4 and 5 in July 2007 (Figure 4-4). Trench 4 is representative of a double-ended trench. A double-ended trench receives runoff from catch basins connected to both ends of the trench. Trench 5 is representative of a single-ended trench. It receives flow from catch basins draining to only one end of the trench.

From 2007 to 2010, storm flow was monitored in the east and west ends of Trench 4 and the east end of Trench 5 using ISCO 2150 flow modules. Area-velocity sensors were placed in the overflow pipes on both ends of Trench 4 and in the east end of Trench 5 and in the lower, perforated infiltration trench pipe on the west end of Trench 4 and east end of Trench 5 (2010 only). The flow module recorded continuous water level and velocity data every 5 minutes (generally) in all pipes; therefore inflow, outflow, and infiltration rates could be determined.

Additionally, water quality samples were taken at the east end of Trench 4 from 2007 through 2010 and at the east end of Trench 5 from 2007 through 2009 using ISCO 6712 compact samplers. Area-velocity sensors were connected to the samplers and placed in the lower, perforated infiltration trench pipe on the east ends of Trenches 4 and 5. The samplers were housed in metal boxes on the boulevard adjacent to both trenches and were programmed to take water quality samples, during storm events, when triggered by a high water level (ft). The collection of water quality samples from stormwater flowing to the east end of Trench 5 was discontinued in 2010 because it was determined that there was no significant statistical difference in the quality of stormwater runoff flowing to Trench 4 than that flowing into Trench 5.

Obtaining accurate flow data from the trench sites has been difficult due to a variety of factors (e.g. equipment sensitivity, pipe grades, size of sampling location). Thus, equipment type and placement has changed frequently over the 2007 through 2010 monitoring seasons, in an attempt to improve data quality. Future monitoring efforts may be expanded to include the collection of water quality data from the trench overflows. However, this effort has been hindered by monitoring equipment space limitations and infrequent and low overflow discharges.

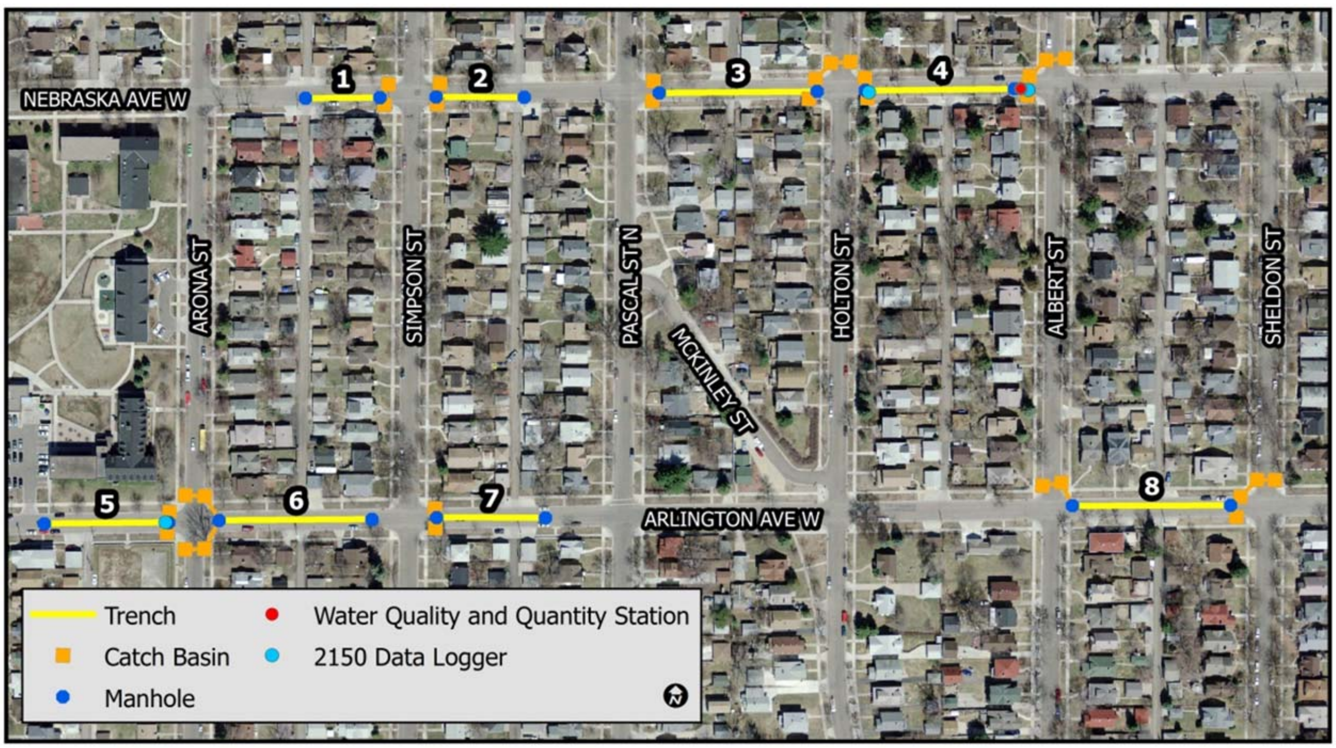


**Figure 4-4. Infiltration trench monitoring locations.**

#### *4.1.1.4. Data Collection: Rain Gardens*

CRWD has monitored peak water levels of storm events, in the eight rain gardens using manual crest gauges (Figure 2-3; Figure 4-1). Two rain gardens (Frankson-McKinley and Hamline-Midway) have been monitored since 2006 and the remaining other six rain gardens since 2007. Crest gauges were installed at the lowest point in each rain garden and recorded peak water level reached in the rain garden, during a storm event. Peak level data collected is used in model calibration.

## 4.2. Monitoring Data Analysis Methods

### 4.2.1. Data Quality Assurance

In general, CRWD monitored the Arlington Pascal Project BMPs from April to November during the 2007 through 2010 monitoring seasons (actual dates varied annually depending on weather conditions).

Following each monitoring season, continuous water quantity data collected (level and velocity data) were quality checked. Bad data points (e.g. missing data periods or negative values) were removed and replaced with a corrected value, which was interpolated based on periods of good data. If there were extended periods of missing data (due to equipment failure, vandalism, etc.), level data (from within the same monitoring season) was used to interpolate velocity by developing a regression relationship between level and velocity. If this was not possible, the data was left as missing. Once level and velocity data were quality checked and any regression analysis was completed, discharge (volume) was calculated based on site specific flow calculations (typically area-velocity equations). Water quality data was quality checked and suspected erroneous parameter values were flagged.

Monitoring efficiencies for each site were determined by calculating a percentage based on the number of total missing monitoring hours for a specific monitoring site divided by the number of total possible monitoring hours for a specific monitoring site. The total possible monitoring hours for each site were determined based site specific equipment installation (spring) and removal (fall) dates/times. Missing data may be caused by equipment failure, power failure, or vandalism.

In 2007 and 2008, CRWD achieved average monitoring efficiencies of approximately 100% and 99% respectively (CRWD, 2010 [b]). In 2008, the Arlington-Hamline Facility Inlet site had approximately ten days of missing data which reduced the efficiency average by 1%.

The monitoring efficiency in 2009 averaged almost 100% with small amounts of missing data occurring at the Arlington-Hamline Facility Inlet and the Como Park Pond Inlet and Outlet sites (Appendix A: Table A-1).

In 2010, the monitoring efficiency was 98%, the lowest average in all four years of monitoring due to data loss at the Arlington-Hamline Facility Inlet and the Como Park Pond Outlet (Appendix A: Table A-2). At the Arlington-Hamline Facility Inlet, a total of 248 hours (10 days) of data were missing in 2010.

Similarly, the Como Park Pond Outlet had 607 hours (25 days) of missing data in 2010. Both sites experienced extended periods of data loss due to equipment and power failures.

## 4.2.2. Discharge, TP, and TSS Loading Calculations

### *4.2.2.1 Discharge, TP, TSS Loading Calculations: From Monitoring Data*

The total discharge, for each storm event, was determined at each monitoring site (except for the rain gardens) and TP and TSS loads were calculated. Discharge is expressed in cubic feet (cf) and loads are expressed in pounds (lbs).

TP and TSS concentrations collected for sampled storm events were used to calculate loads for their corresponding storm events. Monitoring season average concentrations of TP and TSS were calculated and used to calculate pollutant loads for non-sampled storm events. TP and TSS loads were calculated for each storm event using the following equation:

$$\text{Storm Event TP/TSS Load (lbs)} =$$
$$\text{(Storm Event Total Q)} * \text{(Total TP / TSS FWA)} * 28.316 \text{ (L/cf)} * 1 \text{ lb} / 453{,}592 \text{ mg}$$

Where Q=discharge (cf) and FWA=flow weighted average (mg/L)

**(Equation 1)**

The loading calculations for discharge, TP, and TSS are only representative of the monitoring period, which is generally April through November. Flow and pollutant loading does occasionally occur throughout the winter at the monitoring sites; however, CRWD does not operate equipment at these sites during winter months due to the problems associated with freezing temperatures (e.g. frozen samples, frozen sample lines, loss in battery life).

For each monitoring site, the total discharge and total TP and TSS loads from each storm event were summed to calculate a total monitoring season discharge and pollutant loads of TP and TSS. Loading tables, for each monitoring site, are available on the data CD accompanying this report.

# 4.3. Statistical Analysis

Statistical methods were used to demonstrate the effectiveness of the monitored Arlington Pascal Project BMPs at removing TP and TSS through the infiltration and/or treatment of stormwater runoff during the monitoring season. Statistical analysis was also utilized to identify annual variations and trends in TP and TSS concentrations.

Water quality samples collected at the inlet of the Arlington-Hamline Facility, the inlet and outlet of the Como Park Regional Pond, and at the inlets of two infiltration trenches (Trenches 4 and 5) for the parameters TP and TSS, from 2007 to 2010, were used in statistical analysis (Table 4-3).

The sample size of data used for the statistical analysis was in excess of 300 samples. Although there is variability in the number of water quality samples collected by site location and by year, overall, the sample size was fairly extensive. Lab results for water quality samples collected at each monitoring site, from 2007 to 2010, are available on the data CD accompanying this report.

**Table 4-3. Number of water quality samples collected, from 2007 to 2010, at monitoring sites used in the statistical analysis.**

| | Number of Samples Collected | | | | |
|---|---|---|---|---|---|
| **Site Location** | 2007 | 2008 | 2009 | 2010 | **TOTAL** |
| Arlington-Hamline Facility Inlet | 15 | 16 | 20 | 18 | **69** |
| Arlington-Hamline Facility Outlet | 0 | 0 | 0 | 0 | **0** |
| Como Park Regional Pond Inlet - Storm Flow | | 10 | 21 | 18 | **49** |
| Como Park Regional Pond Inlet - Gottfried's Pit Flow | | 9 | 6 | 9 | **24** |
| Como Park Regional Pond Outlet | | 12 | 18 | 13 | **43** |
| Trench 4 | 23 | 16 | 20 | 15 | **74** |
| Trench 5 | 19 | 17 | 13 | | **49** |
| | | | | **TOTAL:** | **308** |

Note: The Como Park Regional Pond was not operational in 2007; samples were not collected at Trench 5 in 2010; and no flow has been observed discharging from the Arlington-Hamline Facility.

## 4.3.1. Analysis Methods

Box and whisker plots (boxplots) were used to show variations in TP and TSS concentrations for each BMP from 2007 to 2010 (Figure 4-5). Boxplots are useful for looking at the spread and skew of data, as well as general trends over time.

For each boxplot, the box represents the interquartile range (IQR) or the middle 50% of the data; the lower line of the box is the 25$^{th}$ percentile, and the upper line is the 75$^{th}$ percentile. The horizontal line which cuts across the box represents the median value. The 'whiskers' (vertical lines extending off the top and bottom of the box) extend out to the lowest and highest values, unless the distance from the minimum value to the first quartile is more than one and one-half times the IQR. In this case the lowest whisker represents one and one-half times the IQR and points beyond that are considered outliers. A similar rule is used if the highest value is more than one and one-half times the third quartile. Data falling below or above one and one-half times the IQR are marked as outliers and are represented by open circles.

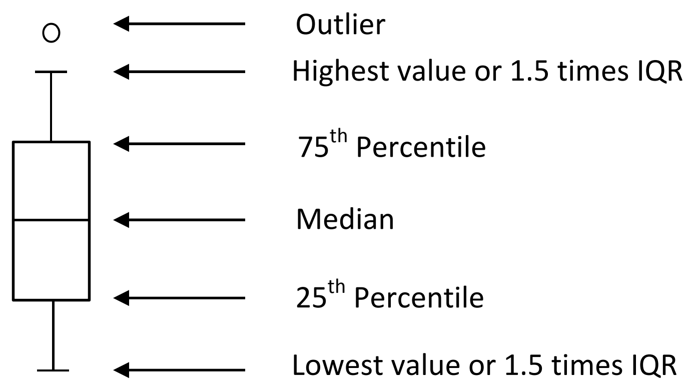


**Figure 4-5. Diagram of a boxplot.**

Generally, more compact boxes with short “whiskers” and few outliers indicate low yearly variability. Long-term TP and TSS trends may be seen by the boxplot moving in an up or down direction over the years. All TP and TSS concentrations, from 2007 to 2010, were graphed as boxplots using the statistical program R (R Project, 2011).

In addition, TP and TSS concentrations from the Arlington-Hamline Facility Inlet and the Como Park Regional Pond sites were graphed in SYSTAT (SYSTAT 13, 2009) as probability plots. A probability plot illustrates the distribution of all data, in a given dataset, and the probability of occurrence of a parameter concentration by percentile.

All TP and TSS samples collected at the Arlington-Hamline Facility and Como Park Regional Pond were plotted on graphs using different symbols to distinguish each sampling site. Probability plots are useful for comparing the distribution of TP and TSS concentrations between sites, as all sites may be plotted together on the same graph. If the points from each site do not overlap on the graph, there is evidence the sites have different statistically different concentrations from each other.

An analysis of variance (ANOVA) test was employed to determine the effectiveness of the Como Park Regional Pond at removing TP and TSS from the inlet and outlet from 2008 to 2010. ANOVA is a useful test for determining whether there is a statistically significant difference among three or more group sample means. For our purposes, ANOVA was utilized to test whether site location (the two inflow types for the Como Park Regional Pond Inlet (direct storm runoff or discharge from Gottfried’s Pit or the Como Park Regional Pond Outlet), year in which samples were collected, or the combination of site and year were good predictors of TP and TSS concentrations in stormwater runoff flowing to and from the Como Park Regional Pond. All data were log-transformed to meet the assumptions of ANOVA (constant variance and normality), and then analyzed within the statistical software R.

To expand upon the results of the ANOVA test, a post-hoc Tukey test was used to test for significant differences between sites, in annual differences in TP and TSS concentrations. A post-hoc Tukey test uses the results of ANOVA to perform a pairwise comparison of the sample means to see where the statically significant differences are. Using the post-hoc Tukey test allowed for a comparison of site location and years, to identify any statistically significant differences (if any existed). Both ANOVA and the post-hoc Tukey test compared TP and TSS concentrations from paired storms between the Como Park Regional Pond Inlet, Gottfried's Pit, and the Como Park Regional Pond Outlet.

## 4.4. Performance Modeling

### 4.4.1. Performance Modeling of the Arlington Pascal Project BMPs

CRWD conducted a performance assessment of the Arlington Pascal Project BMPs from 2007 through 2010 using the P8 Urban Catchment Model to simulate the annual performance for volume, TP, and TSS loading. The subsequent discussion provides a brief summary of the P8 model and calibration methods and analysis completed. A full summary of the input parameters, calibration methods, and modeling results may be found in the *Arlington Pascal P8 Model Calibration Report* in Appendix C (CRWD, 2011[a]).

The P8 Model (Program for Predicting Polluting Particle Passage through Pits, Puddles, and Ponds) is used for modeling stormwater runoff and pollutant production in small urbanized watersheds. The model generates continuous water-balance and mass-balance calculations to determine BMP performance (removal efficiency) for flow and pollutants.

CRWD specifically utilized the model to predict annual stormwater volume reductions and TP and TSS load reductions for all eighteen BMPs. To calculate removal efficiency, the P8 Model requires several input parameters, including:

- Air temperature (annual time series)
- BMP infiltration rates (inches/hour)
- BMP input pipe orifice diameter and/or weir length
- Detention ponds/depressional storage (area)
- Growing season length/antecedent moisture conditions (evapotranspiration)
- Impervious runoff coefficient (fixed)
- Particle size distribution (TSS, gross solids)
- Precipitation (annual)
- Subwatershed area
- Total impervious fraction (area)

The model requires calibration using existing monitoring data. When the model was created in 2008 for the previous report, it was calibrated using two years of monitoring data. The model has since been recalibrated using four years of monitoring data (2007 through 2010); prior to which, all four years of data underwent a rigorous quality assurance/quality control. This led to better calibration of the model.

The following monitoring data was utilized for the model calibration:

- Annual precipitation
- Annual temperatures
- BMP subwatershed land use
- Infiltration rates

- Water quality data
- Water quantity data

Water quantity data collected from the monitoring sites, from 2007 to 2010, were used for stormwater runoff volume calibrations. The models were calibrated based on annual volume during the monitoring season and hourly model output was compared to monitored data to ensure adequate annual distribution of loading volume. Also, the peak water levels measured in the eight rain gardens, from 2008 to 2010, assisted in selecting the model volume infiltration rates. Calibration was completed by adjusting rain garden infiltration rates within the model, until they closely matched observed crest gauge peak elevations.

Water quality data collected from the monitoring sites, from 2007 to 2010, were used for stormwater pollutant loading calibrations. Based on the water quality data, the TP and TSS loading factors were globally modified to better represent overall watershed characteristics. Annual monitored loads of TP and TSS were compared to the modeled loads, and the pollutant scale factor for particle loads were adjusted accordingly to match. The TSS scale factor was modified from 1.0 to 2.0, which increased the model output of TSS loading to more closely match concentrations regularly observed at the monitoring sites. Similarly, the TP scale factor was increased during model calibration, so modeled values were more representative of typical concentrations.

For annual precipitation calibration, 15-minute rainfall data from the University of Minnesota-St. Paul Campus rain gauge, from 2007 to 2010, were used and corresponded to actual monitoring days. Annual precipitation and storm intensity were important inputs to the model because they assisted in calculating depressional storage, runoff generation rates, and total runoff volumes. To calibrate the model, a continuous hydrograph was constructed for 2007 to 2010, and daily precipitation values and smaller storm events were evaluated to determine the amount of rainfall required to produce runoff. From this, runoff generation typically occurred after 0.01 inches to 0.03 inches of rainfall; therefore, the depressional storage parameter was calibrated to 0.02 inches.

Annual temperatures were calibrated by averaging daily highs and lows from the climatology record from 2007 to 2010. The annual average temperature data, along with the precipitation data, assisted in calibrating evapotranspiration (ET) rates of stormwater from rain gardens. Water volumes lost to ET in the rain gardens affect the overall volume of stormwater infiltrated.

The land uses of each BMP's individual subwatershed were calibrated in the model to reflect variations in impervious surface coverage. Although land uses are similar between each subwatershed, the monitoring data indicated that hydrological differences were present between drainage areas. Thus, each subwatershed was individually delineated for total drainage area and percent land use coverage. Based on overall watershed land use, a standard pervious curve number (CN) of 61 was used in the model. A pervious CN is a unit-less value ranging from 30 (indicating high infiltration) to 100 (indicating high runoff). A CN of 61 represents a moderately developed watershed with a moderate amount of total pervious area.

Following calibration, the model was run for years 2007 through 2010 and the 1995 water year (a year with an average precipitation amount). The monitoring data used to calibrate the model is only representative of the 2007 to 2010 monitoring seasons (generally April through November). Thus, the data needed to be extrapolated to portray an accurate annual prediction. The 1995 water year, which had an average precipitation amount, was considered the annual projected year.

The model was able to predict BMP volume reduction and pollutant removal efficiencies, for TP and TSS, for all BMPs. Modeled results were compared to the monitoring data and adjustments were made until the actual and modeled data were similar. Calibration adjustments were made to the parameters defining the watersheds and/or the individual BMPs. Performance results and analysis for the individual BMPs and the entire Arlington Pascal Project, from 2007 to 2010, and also performance results for the annual projected year may be found in the subsequent sections.

#### *4.4.1.1. Modeling of the Arlington-Hamline Facility*

For the Arlington-Hamline Facility, the model was calibrated using monitoring data from the 2007 through 2010 monitoring seasons. Annual volumes were calibrated using the 10-minute flow data from the inlet monitoring location. To calculate runoff volumes, the nested drainage areas of the upstream infiltration trenches were removed from the annual runoff depth calculation for the Arlington-Hamline Facility, since the trenches have generally had 100% removal efficiencies.

Over the period of the monitoring record, the discharge has never been observed at the outlet of the Arlington-Hamline Facility; therefore, all stormwater runoff which flowed to the pipe gallery was first stored and then infiltrated. The infiltration rate of the Arlington-Hamline Facility was initially calibrated to the average long-term model design value of 0.5 inches/hour. This value was found to be highly conservative; thus the value was modified and recalibrated using continuously monitored level data measured within the pipe gallery. Also, the facility was reclassified in the model to be a 'general device' rather than a dry pond.

#### *4.4.1.2. Modeling of the Como Park Regional Pond*

For the Como Park Regional Pond, the model was calibrated using monitoring data from the 2008 to 2010 monitoring seasons. The projected annual volumes and TP and TSS loads for the Como Park Regional Pond were altered to reflect zero stormwater infiltration by the pond. Debris and sediment accumulation in the pond will eventually cause the pond to seal allowing for no infiltration of stormwater runoff (although the vegetated fringe buffering the pond may allow for some infiltration). Therefore, projected annual discharge flowing from the pond was adjusted to equal the discharge flowing into the pond.

There was speculation that the monitored volumes used to calibrate the pond may be overestimated due to flow contributions from Gottfried's Pit. Thus, Gottfried's Pit was calibrated to the annual volumes calculated from the monitoring data. Also, Gottfried's Pit was calibrated in conjunction with the inlet since they flow through the same point. Infiltration rates in Gottfried's Pit were altered to match recorded flows and pumping rates.

#### 4.4.1.3. *Modeling of the Rain Gardens*

The model was used to determine the volume of water infiltrated and pounds of pollutants (TP and TSS) removed by each rain garden for 2007 to 2010. The model was calibrated using the crest gauge data collected from 2008 to 2010. The water quality and quantity data collected at the other monitoring sites were used to interpolate loads flowing in to the rain gardens.

#### 4.4.1.4. *Modeling of the Infiltration Trenches*

Water quantity and quality data collected from Trenches 4 and 5, from 2008 to 2010, were used for model calibration. Based on the 2007 to 2010 monitoring data, the runoff depths to the trenches were found to be highly variable. Consequently, the runoff parameters of the trench drainage areas were modified to match those of the Arlington-Hamline Facility.

## 4.5. Gross Solids and Associated TP Loading Calculations

In the previous BMP report (CRWD, 2010[b]), it was recommended that further research and monitoring be conducted to better quantify the annual rate of gross solids accumulation and to characterize the content of the material being deposited. Gross solids refers to all litter, organic debris, and coarse sediments (greater than 75 µm) that are transported in urban stormwater runoff. These solids are captured by pretreatment units discharging to the BMPs and also accumulate within the BMPs themselves. It was also recommended that the TP load in those gross solids be quantified.

Based on the recommendations, a consultant was hired to conduct a supplementary study (*Sump Monitoring Study;* CRWD, 2011[b]) to determine average bulk density and TP concentrations of gross solids in sumped catch basins and manholes and develop methodologies from which to calculate annual gross solids and associated TP loads for all BMPs (Appendix D). The results of that study proved to be inconclusive. In 2011, CRWD expanded upon methodologies from that study and conducted *The Arlington Pascal Project: Gross Solids Accumulation Study* (CRWD, 2011[c]), which may be found in Appendix E.

Data and sample collection methodologies for the gross solids study were developed and refined in order to determine annual gross solids and TP load accumulations, from 2007 to 2010, for all pretreatment units connected to the BMPs and/or the BMPs themselves. Ultimately, samples were collected from thirty sumped catch basins discharging to the eight underground infiltration trenches and from fifteen locations within the pipe gallery of the Arlington-Hamline Facility, in June 2011. Samples were analyzed for bulk density, TP concentration, and particle size. Average bulk density and TP concentration values were determined appropriately and annual gross solids and associated TP loads were calculated. Those methods and calculations are briefly described below. A complete discussion on the methods and analysis may be found in Appendix E.

## 4.5.1. Arlington-Hamline Facility

The Arlington-Hamline Facility pipe galley consists of three west-east oriented 10-foot diameter round pipes that are each 270-feet in length. The east and west ends also each have a 36-foot north-south oriented, 10-foot diameter pipe that connects all three east-west pipes on both ends of the system. The width and depth of total debris in each pipe was measured, every 10-feet, using the methods described in the full report in Appendix E. Gross solids samples were collected from 15 locations within the pipe gallery (five at incremental locations throughout each pipe).

In addition, the Arlington-Hamline Facility also has a pretreatment unit. The pretreatment unit consists of a large Contech Vortech® Model 7000 pretreatment device. The Vortech® is a hydrodynamic separator which is designed to effectively treat low flows by removing sediment, oil, and debris before discharging into the pipe gallery of the Arlington-Hamline Facility.

Gross solids and associated total phosphorous loads were calculated for both the pipe gallery and the pretreatment unit and also for the facility as a whole. Those calculations are described below.

### *4.5.1.1. Gross Solids Loads: Arlington-Hamline Facility Pipe Gallery*

Several calculations were necessary to determine the gross solids load, expressed in pounds (lbs), which accumulated within the pipe gallery. The volume of gross solids which accumulated in the pipe gallery was calculated for each 10-foot section of pipe, in each pipe (Pipe 1, 2, 3, and East End). There was no debris accumulation in the West End Pipe of the pipe gallery. The following equation was used to calculate gross solids volume:

$$\text{Gross Solids Volume per 10-foot Section (cf)} =$$
$$(L * [R^2 \cos^{-1}((R - h) / R) - (R - h)\ \sqrt{2Rh - h}\ ^2])$$

Where L=length (10 ft), R=radius (5 ft), h=height of debris (ft)

**(Equation 2)**

Bulk density lab results for the samples collected at the sample points in the pipe gallery and the volumes of gross solids for each 10-foot section were used to calculate the gross solids load for each 10-foot pipe section. Because there were only five sample points in each pipe (Pipe 1, 2, and 3), the bulk densities of sample material collected from the sample points were applied to the volume of gross solids in the preceding 10-foot pipe sections.

For example, the bulk density at Point 1 represented the material in the previous 10-foot sections (those sections between 0 ft and 60 ft), in each respective pipe (Pipe 1, 2, or 3). The bulk density at Point 2 represented 70 ft through 130 ft. The bulk density at Point 3 represented 140 ft through 190 ft and so forth. The bulk densities at Point 5 were used to calculate the gross solids load for the East End Pipe. The following equation was applied to the 10-foot pipe sections to calculate the gross solids load:

$$\text{Gross Solids Load per 10-foot Section (lbs)} = \\ ((\text{Total Solids Volume per 10-foot Section (cf)}) * (28.3\ \text{L} / 1\ \text{cf}) * (1{,}000\ \text{mL} / 1\ \text{L}) * \\ (\text{Bulk Density per 10-foot Section (g/mL)}) * (2.2\ \text{lbs} / 1{,}000\ \text{g}))$$

**(Equation 3)**

The gross solids loads for all 10-foot sections, in each pipe, were summed to produce a total gross solids load per pipe (Pipe 1, 2, 3, and East End). The gross solids load for the entire pipe gallery was finally determined by summing the gross solids load in all pipes (Pipe 1, 2, 3, and East End).

#### *4.5.1.2. TP Loads: Arlington-Hamline Facility Pipe Gallery*

The TP load (expressed in lbs) in gross solids, captured in the pipe gallery, was also calculated. TP concentrations of the samples collected, from the sampling points, were applied to the mass of gross solids in the preceding 10-foot pipe sections to determine the TP load, for each 10-foot pipe section, in all pipes (Pipe 1, 2, 3, and East End). The following equation was applied to the gross solids load, determined for each 10-foot pipe section, to calculate TP load:

$$\text{TP Load per 10-foot Section (lbs)} = \\ ((\text{Gross Solids Load per 10-foot Section (lbs)}) * (\text{TP Concentration per 10-foot Section (mg/kg)}) \\ / (1{,}000{,}000\ \text{mg/kg})$$

**(Equation 4)**

The TP loads in gross solids for all 10-foot sections, in a specific pipe (Pipe 1, 2, 3, and East End), were summed to produce a TP load per pipe. TP loads for all pipes were then summed to produce a TP load in gross solids captured by the entire pipe gallery.

#### *4.5.1.3. Annual Gross Solids and TP Loads: Arlington-Hamline Facility Pipe Gallery*

No discharge has been observed overflowing from the outlet of the pipe gallery, thus no debris and sediment have been transported out of the pipe gallery. In addition, debris and sediment have never been removed from the pipe gallery. Therefore, the gross solids and TP loads calculated above are representative of four years (2007 to 2010) of accumulation.

Annual gross solids loads and annual TP loads in gross solids which accumulated in the pipe gallery were determined by multiplying the gross solids or TP load by the percentage of annual precipitation per year, from the 2007 to 2010 total precipitation amounts (Table 4-4). This method was determined to be a representative estimation of annual accumulation based on the assumption that sediment transport and TP loading is proportional to precipitation amounts and associated runoff volumes.

**Table 4-4. The annual percentages of precipitation based on the four-year total (2007 to 2010) total.**

| Monitoring Year | Annual Precipitation (in) | Total 4-Year Precipitation Amount (%) |
|---|---|---|
| 2007 | 25.0 | 24% |
| 2008 | 21.7 | 21% |
| 2009 | 22.3 | 21% |
| 2010 | 36.3 | 34% |
| **Total:** | **105.3** | **100%** |

#### *4.5.1.4. Gross Solids Loads: Arlington-Hamline Facility Pretreatment Unit*

The Arlington-Hamline Facility pretreatment unit receives regular maintenance and debris and sediment is removed bi-annually (spring and fall). Prior to debris removal, depth measurements of the accumulated gross solids were taken. The volume of gross solids which accumulated bi-annually in the pretreatment unit was calculated using the record of depth measurements, from 2007 to 2010. The volume of gross solids captured by the pretreatment unit was calculated using the following equation:

Pretreatment Unit Annual Gross Solids Volume (cf) =
(*Length* of Pretreatment Unit (ft)) * (*Width* of Pretreatment Unit (ft)) * (*Depth* of Gross Solids (ft))

**(Equation 5)**

It was not possible to extract samples of the gross solids which had accumulated within the pretreatment unit due several factors. First, the proximity of the access point caused difficulties because the pretreatment unit is located over the swirl chamber (sample collection from the chamber between the flow control walls would be more ideal). Next, the overall size of the pretreatment unit was problematic because the distance between the access point and the solids deposit (15-18 feet) was too great to extract a sample with the equipment available. Also, the amount of standing water inside the unit made sampling difficult because it was not possible to decant the large volume of water present and extract a complete sample with the equipment available.

The bulk density and TP concentration sampling results from the Arlington-Hamline Facility pipe gallery were utilized to calculate the annual load of gross solids removed by the pretreatment unit. The overall average bulk density value (1.43 g/mL) determined for the entire pipe gallery was used to calculate annual gross solids loads. It is recognized that the gross solids captured by the pretreatment unit are likely heavier, coarser, and have higher bulk densities than the material which accumulated in the pipe gallery. Future monitoring should incorporate sample collection of material captured by the pretreatment unit.

The following equation was used to calculate the annual gross solids load:

Pretreatment Unit Annual Gross Solids Load (lbs) =
(Gross Solids Volume Pretreatment Unit (cf)) * (28.3 L / 1 cf) * (1,000 mL / 1 L) *
(Average Bulk Density (g/mL) from Arlington-Hamline Facility Pipe Gallery) * (2.2 lbs / 1,000 g)

**(Equation 6)**

#### *4.5.1.5. TP Loads: Arlington-Hamline Facility Pretreatment Unit*

The annual TP loads in gross solids loads captured by the pretreatment unit, from 2007 to 2010, were calculated using the annual gross solids loads captured by the pretreatment unit and TP concentrations from the Arlington-Hamline Facility pipe gallery. Specifically, the TP concentrations from samples taken at sample Point 1 in all three pipes (Pipe 1, 2, and 3) were averaged to determine an average TP concentration (568 mg/kg).

This average TP concentration was assumed to be representative of the material in the pretreatment unit because the sample points reside closest to the outlet of the pretreatment unit. Additionally, the composition of the material at these three sample locations generally consisted of coarser particles (e.g. sands, gravels). However, it is again likely that the material captured by the pretreatment unit is larger and coarser than what was assumed. Therefore, it is probable that TP concentrations are lower than the average concentration used in the calculation.

The following equation was used to determine annual TP loads:

Pretreatment Unit Annual TP Load (lbs) =
((Pretreatment Unit Annual Gross Solids Load (lbs))*
(Average TP (mg/kg) from Arlington-Hamline Facility Pipe Gallery Sampling Points 1) /
(1,000,000 mg/kg)

**(Equation 7)**

The same values for average bulk density and TP concentration were used to calculate annual gross solids and TP loads for all years, from 2007 to 2010. This was done in order to determine annual loadings using the data that was available. It is recognized that gross solids load accumulations and composition of material varies from year-to-year. These annual loadings will most likely be refined if additional sampling is conducted.

#### *4.5.1.6. Annual Gross Solids and TP Loads: Arlington-Hamline Facility*

Annual gross solids and associated TP loads were calculated for the entire Arlington-Hamline Facility (pipe gallery and pretreatment unit) from 2007 to 2010. The annual gross solids load which accumulated within the pipe gallery was added to the corresponding annual gross solids load which accumulated within the pretreatment unit; resulting in an annual gross solids loads for the entire Arlington-Hamline Facility, from 2007 to 2010. The same process was used to calculate annual TP loads for the entire Arlington-Hamline Facility from 2007 to 2010.

## 4.5.2. Underground Infiltration Trenches

Eight underground infiltration trenches were constructed beneath the roadbed of Arlington and Nebraska Avenues. Each trench is comprised of two ten-inch perforated pipes that run parallel to each other in an aggregate backfill.

Sixteen sumped manholes and thirty sumped catch basins pretreat stormwater runoff before flowing into the infiltration trenches. Sumped catch basins drain to one/both ends of an infiltration trench. Stormwater runoff discharging from the sumped catch basins next flows into sumped manholes before flowing into the actual infiltration trench. The manholes are located on both ends of each infiltration trench.

Gross solids and associated total phosphorous loads were calculated for both infiltration trench pretreatment unit types (catch basins and manholes). Those calculations are described below.

### *4.5.2.1 Gross Solids Load: Infiltration Trench Pretreatment Units*

Accumulated material within the catch basins and manholes is removed twice a year (spring and fall). Prior to removal, inspections of the pretreatment units were performed and debris depth measurements of the accumulated material were taken. Combined, the two volume calculations (spring and fall) for each unit (catch basin or manhole) will yield the volume of gross solids captured by unit annually, from 2007 to 2010. The following equation was used to calculate the gross solids volume in each catch basin:

$$\text{Catch Basin Gross Solids Volume (cf)} = (\textit{Length}\ \text{(ft)}) * (\textit{Width}\ \text{(ft)}) * (\textit{Depth}\ \text{of Gross Solids (ft)})$$

**(Equation 8)**

The volume of gross solids which accumulated within each sumped manhole was calculated using the following equation:

$$\text{Manhole Gross Solids Volume (cf)} = (\pi) * (\text{manhole radius (ft)})^2 * (\textit{Depth}\ \text{of Gross Solids (ft)})$$

**(Equation 9)**

The average bulk density (1.28 g/mL or 79.91 lbs/ $ft^3$) of all samples collected from the catch basins and the volumes of gross solids captured by each pretreatment unit were used to determine the load of gross solids captured by each unit. This same value for average bulk density was used to calculate gross solids loads captured by all units, in all years (2007 to 2010). This was done in order to determine loadings using the data that was available. It is recognized that gross solids load accumulations and composition of material varies from year-to-year.

Gross solids loads were calculated using the following equation:

Gross Solids Load (per Catch Basin or Manhole) (lbs) =
(Gross Solids Volume (cf) * Average Debris Bulk Density (lb/cf))

**(Equation 10)**

#### *4.5.2.2. TP Load: Infiltration Trench Pretreatment Units*

Annual TP loads in gross solids captured by each pretreatment unit (catch basin and manhole), from 2007 to 2010, were determined by using the gross solids loads captured by each unit and an average TP concentration (402 mg/kg) of samples collected from all catch basins. (Note: The TP concentration of one sample collected was excluded from the average calculation due to being an extreme outlier.). The following equation was used to calculate the TP loads in gross solids captured by the catch basins and manholes:

Total Phosphorus (TP) load (per Catch Basin or Manhole) (lbs) =
((Gross Solids Load per unit (lbs))* (TP per unit (mg/kg)) / (1,000,000 mg/kg)

**(Equation 11)**

Like bulk density, the same value for average TP concentration was used to calculate TP loads for all years, from 2007 to 2010. It is recognized that gross solids load accumulations and composition of material varies from year-to-year.

#### *4.5.2.3. Annual Gross Solids and TP Loads: Infiltration Trenches*

Due to removal of material from the catch basins and manholes generally twice each year, two gross solids and TP loads were calculated for each unit, annually. Those two gross solids and TP loads per unit were summed to determine the total annual loads (gross solids or TP) captured by each catch basin and manhole, from 2007 to 2010. This then enabled the calculation of annual loads captured by each infiltration trench, which included the sum of the gross solids or TP loads for all catch basins and manholes connected to a particular trench (Trench 1 through 8).

### 4.5.3. Como Park Regional Pond and Rain Gardens

The annual gross solids and TP loads in gross solids cumulatively removed by all sumped catch basins and manholes discharging to the infiltration trenches were used to extrapolate annual gross solids loads and TP loads accumulating within the Como Park Regional Pond and all eight rain gardens.

The drainage areas to the pond and the rain gardens have fairly similar land uses and coverage by impervious surfaces as the drainage area to the infiltration trenches. Due to the similarities in drainage area characteristics, it was assumed that the drainage areas of the rain gardens and pond would yield similar pollutant loads as those to the infiltration trenches.

#### *4.5.3.1 Gross Solids Loads*

The annual gross solids yield (lbs/acre) for the infiltration trenches was used to extrapolate the annual gross solids loads for the Como Park Regional Pond and all rain gardens. The annual gross solids yield for the infiltration trenches was calculated by dividing the annual gross solids loads captured by all pretreatment units (all 30 sumped catch basins and 16 sumped manholes), from 2007 to 2010, by the portion of the total drainage area to all infiltration trenches covered by impervious surfaces (Table 4-5).

**Table 4-5. 2007 to 2010 gross solids yields for the infiltration trenches drainage area covered by impervious surfaces.**

| | | Gross Solids | |
|---|---|---|---|
| Year | Acres Impervious | Load (lbs) | Yield (lbs/ac) |
| 2007 | 8.93 | 14,536 | 1,628 |
| 2008 | 8.93 | 26,080 | 2,920 |
| 2009 | 8.93 | 32,200 | 3,606 |
| 2010 | 8.93 | 19,448 | 2,178 |

The annual gross solids load captured by the Como Park Regional Pond and by each rain garden, from 2007 to 2010, was calculated by multiplying the annual gross solids yield for the infiltration trenches by the portion of drainage area to each BMP (pond and each rain garden) covered by impervious surfaces. The total drainage area and percentage covered by impervious surfaces, for the pond and each rain garden, are listed in Table 4-6.

**Table 4-6. Como Park Regional Pond and individual rain garden drainage areas and impervious surfaces coverage.**

| BMP | Drainage Area (acres) | Impervious Surfaces (acres) | % Impervious Surfaces |
|---|---|---|---|
| Como Park Regional Pond | 128.00 | 49.92 | 39% |
| Arlington-McKinley Rain Garden | 0.37 | 0.15 | 41% |
| Asbury North Rain Garden | 0.40 | 0.17 | 43% |
| Asbury South Rain Garden | 1.08 | 0.33 | 31% |
| Frankson-McKinley Rain Garden | 2.81 | 0.94 | 33% |
| Hamline Midway Rain Garden | 10.47 | 1.86 | 18% |
| Pascal Center Rain Garden | 0.13 | 0.06 | 46% |
| Pascal North Rain Garden | 0.46 | 0.13 | 28% |
| Pascal South Rain Garden | 0.36 | 0.09 | 24% |

#### *4.5.3.2. Total Phosphorous Loads*

Annual TP loads in gross solids which accumulated in the Como Park Regional Pond and each rain garden, from 2007 to 2010, were extrapolated by multiplying the annual TP yield for the infiltration trenches by the portion of drainage area (for the pond and each rain garden) covered by impervious surfaces (Table 4-7).

**Table 4-7. The TP yields for the infiltration trenches drainage area covered by impervious surfaces.**

| | | Total Phosphorous | |
|---|---|---|---|
| **Year** | **Acres Impervious** | Load (lbs) | Yield (lbs/ac) |
| 2007 | 8.93 | 5.84 | 0.65 |
| 2008 | 8.93 | 10.48 | 1.17 |
| 2009 | 8.93 | 12.94 | 1.45 |
| 2010 | 8.93 | 7.82 | 0.88 |

## 4.6. Annual Projected Gross Solids and Associated TP Loads

Annual projected gross solids and TP loads in gross solids captured by each project BMP were also calculated. Annual projected gross solids and TP loads for each component of the Arlington-Hamline Facility (pipe gallery and pretreatment unit) and for the entire Arlington-Hamline Facility are the average of the annual gross solids and associated TP loads captured from 2007 to 2010. Similarly, the annual projected gross solids and associated TP loads for the rain gardens are also equal to the average of the annual gross solids and associated TP loads captured by the rain gardens from 2007 to 2010.

The annual projected gross solids and associated TP loads for the Como Park Regional Pond is equal to the average of the annual gross solids and associated TP loads captured by the pond from 2008 to 2010. The pond was not operational in 2007.

The annual gross solids and associated TP loads from 2008 to 2010 were used to determine the annual projected gross solids and associated TP loads for each component of the infiltration trenches (sumped catch basins and manholes) as well as for each infiltration trench. Gross solids and associated TP load accumulations for the infiltration trenches in 2007 were only representative one-half of a year of operation and were therefore excluded from the average calculation.

## 4.7. Annual Total Solids Loading Calculations

Annual total solids loads, from 2007 to 2010, were also calculated for the BMPs. The total solids load removed from each BMP includes: 1) the TSS load removed through the infiltration of stormwater and settlement of suspended particles, and 2) the gross solids load which accumulated within the BMPs themselves and/or were captured by pretreatment devices. The 2007 through 2010 annual modeled results for TSS loads removed through the infiltration of stormwater runoff and settlement of suspended particles were used in the total solids load calculations.

The variables used in annual total solids load calculations for each Arlington Pascal Project BMP are as follows:

- Arlington-Hamline Facility. Includes the:
    1. TSS load removed through infiltration of stormwater runoff and settlement of suspended particles;
    2. Gross solids load accumulated within the pipe gallery;
    3. Gross solids load captured by the pretreatment unit.

- Infiltration Trenches. Includes the:
    1. TSS load removed through infiltration of stormwater runoff and settlement of suspended particles;
    2. Gross solids load captured by sumped catch basins;
    3. Gross solids load captured by sumped manholes.

- Como Park Regional Pond and the Rain Gardens. Includes the:
    1. TSS load removed through infiltration of stormwater runoff and settlement of suspended particles;
    2. Gross solids load accumulated within the BMP.

## 4.8. Annual Cumulative TP Loading Calculations

Annual cumulative TP loads, from 2007 through 2010, were also calculated for the BMPs. The cumulative TP load removed from each BMP includes: 1) the TP load removed through the infiltration of stormwater and settlement of suspended particles, and 2) the TP load associated with the gross solids load which accumulated within the BMPs themselves and/or were captured by pretreatment devices. The 2007 through 2010 annual modeled performance results for TP loads removed through the infiltration of stormwater runoff and settlement of suspended particles were used in the cumulative TP load calculations.

Annual cumulative TP loads were calculated similarly to annual total solids loads for the BMPs. The variables used in annual cumulative TP load calculations for each BMP are as follows:

- Arlington-Hamline Facility. Includes the:
    1. TP load removed through infiltration of stormwater runoff and settlement of suspended particles;
    2. TP load associated with the gross solids load which accumulated within the pipe gallery;
    3. TP load associated with the gross solids load captured by the pretreatment unit.

- Infiltration Trenches. Includes the:
    1. TP load removed through infiltration of stormwater runoff and settlement of suspended particles;
    2. TP load associated with the gross solids load captured by sumped catch basins;
    3. TP load associated with the gross solids load captured by sumped manholes.

- Como Park Regional Pond and the Rain Gardens. Includes the:
    1. TP load removed through infiltration of stormwater runoff and settlement of suspended particles;
    2. TP load associated with the gross solids load which accumulated within the BMP.

## 4.9. BMP Performance Calculations

The percent removal efficiencies were calculated for discharge, TP, and TSS from the inlet to outlet of each BMP. The removal efficiencies for total solids were not calculated for any of the BMPs. The percent volume reduction efficiency was calculated using the following equation:

% Volume Reduction Efficiency =
(Total Discharge Inlet (cf) – Total Discharge Outlet (cf)) / (Total Discharge Inlet (cf))

**(Equation 12)**

The percent removal efficiencies for TP and TSS were calculated using the following equation:

% Removal Efficiency (TP or TSS) =
(Total TP/TSS Load Inlet (lbs) – Total TP/TSS Load Outlet (lbs)) / (Total TP/TSS Load Inlet (lbs))

**(Equation 13)**

## 4.10. Cost-Benefit Analysis

### 4.10.1. Operation and Maintenance

Construction of stormwater BMPs for the Arlington Pascal Project began in 2005 and all BMPs were constructed and operational by 2008. CRWD has full maintenance responsibility and/or ownership of the Arlington Pascal Project BMPs. For effective management and long term success of these facilities, CRWD has developed and implemented a program to assess their performance and conduct maintenance.

In 2007, an inspection and maintenance schedule was developed to identify the type and frequency of inspections and maintenance activities to be completed for each BMP. A manual of standard operating procedures for all inspections and maintenance activities was also developed using information from the MPCA Stormwater Manual (MPCA, 2005) and the University of Minnesota Assessment of Stormwater

Best Management Practices (UMN, 2010). The inspection schedule and the manual of standard operating procedures are reviewed annually and updated as necessary.

In 2007, CRWD initiated inspections and maintenance on the eight rain gardens, the eight underground infiltration trenches, and the Arlington-Hamline Facility. In 2008, the Como Park Regional Pond was added to the inspections and maintenance routine. Routine inspections and maintenance have continued on schedule, each year, for all BMPs through 2010. All activities are documented and tracked.

### 4.10.2. Total Capital Costs

Total capital costs were calculated for each BMP. The total capital cost was calculated by summing the actual costs of design, construction, and bond interest of an individual BMP. Design and construction costs reflect the amount paid by CRWD and project partners. The bond interest cost only reflects the amount of the interest cost paid by CRWD and does not include any interest paid by project partners.

To derive a total capital cost for the Arlington Pascal Project, the individual capital costs for each BMP were summed to determine the total project cost. Again, this cost does not include interest paid by project partners.

### 4.10.3. Annual Capital Costs

Annual capital costs were calculated for the individual Arlington Pascal Project BMPs. The total capital cost for each BMP was amortized over the life expectancy of each BMP. A life expectancy of 35 years, an approximate average life expectancy of an individual BMP, was assumed for each BMP to allow for side-by-side comparisons. An annual project capital cost was also calculated by summing the annual capital costs of each BMP.

### 4.10.4. Total Annual Operation and Maintenance Costs

Total annual operation and maintenance (O & M) costs were calculated for each BMP, for 2007 through 2010, and were based on the total cost of labor, equipment and materials, and contract services. Labor incorporates time and associated costs spent maintaining the BMPs by CRWD staff, City of St. Paul and Minnesota Conservation Corps staff, and volunteers. Equipment and materials costs include the costs spent on tools and items used to maintain the BMPs. Contract services include the costs for hiring a consultant to conduct maintenance services (e.g. removing debris from pretreatment units).

To maintain an accurate record of O & M activities, CRWD used electronic field forms to document all BMP site visits. Each site visit recorded the BMP being inspected or maintained, the inspection or maintenance activity occurring, time on and off site, and staff present on site. The table of the staff rates used to calculate O & M labor costs may be found in Appendix A: Table A-3. Itemized O & M activities and costs for 2007 through 2010 for each BMP may be found in Appendix A: Table A-34 through A-56.

Projected annual O & M costs were also determined for each Arlington Pascal Project BMP. Projected annual costs are a reflection of expected labor, equipment and materials, and contract services costs of an average year. The cost estimates were based on CRWD observations and estimations of large scale maintenance activities that occur irregularly, such as debris removal from proprietary structures, dredging, and bathymetric surveys. The costs of these irregular, large scale maintenance activities were summed for each BMP and amortized over the life expectancy of the BMP. Amortized costs of the large scale maintenance activities are reflected in the annual projected O & M costs and are detailed in subsequent individual BMP sections.

Cumulative O & M costs for the entire Arlington Pascal Project were also calculated for 2007 through 2010 by summing the individual BMPs annual O & M costs.

### 4.10.5. Annual Operating Costs

The annual operating cost for each Arlington Pascal Project BMP was calculated for 2007 through 2010 and a projected annual year. The annual operating cost was determined by adding the annual capital cost of each BMP and the total O & M cost for each year from 2007 to 2010, and the projected annual year. The Arlington Pascal Project annual operating costs were calculated by summing the annual capital cost with the total annual O & M cost.

### 4.10.6. Cost-Benefit Analysis: Volume and Pollutant Removal

Annual volume reduction and pollutant removal costs were calculated for each Arlington Pascal Project BMP for 2007 through 2010, and a projected annual year. Pollutant removal costs are driven by two factors: fluctuations in annual operating costs (which is directly affected by fluctuations in annual O & M costs) and by fluctuations in the amount of pollutants removed by the BMP. Although other climatic factors have influence, generally, an increase in precipitation will result in an increase in stormwater runoff flowing to the BMPs. Increased runoff and pollutant loading offers a greater opportunity for discharge and associated pollutants to be removed by the BMP. Typically, the greater the volume infiltrated and pollutants removed by the BMP, the lower the pollutant removal cost.

The volume reduction and pollutant removal costs were determined by dividing the annual operating cost of each BMP for a given year by the total volume of runoff infiltrated or by the cumulative TP or total solids load removed in that same year. This provided the costs for removing a pound of TP and TSS, the cost for reducing a cubic foot of stormwater volume, and allowed for a side-by-side comparison of BMP removal costs. Modeled annual volume and pollutant load reductions were used in the removal cost calculations since they represent total annual loads. Actual monitoring results are only representative of a portion of the year.

### 4.10.7. Cost-Benefit Analysis: Drainage Area

Analysis was also conducted to calculate the total capital costs and the 35-year O & M costs on a per acre basis. The total capital costs for the individual BMPs and the Arlington Pascal Project as a whole were divided by the corresponding drainage area of each (individual BMP or entire project). In addition, construction (capital) costs per acre of impervious surfaces coverage (the amount of the drainage area covered by impervious surfaces) were also calculated for each BMP and the project as a whole.

The 35-year O & M costs for each BMP were calculated by multiplying the annual projected O & M cost (which includes irregular maintenance activities such as dredging, debris removal, etc.) of each BMP by 35; the estimated average life expectancy of all Arlington Pascal Project BMPs. The 35-year O & M cost for the entire Arlington Pascal Project was determined by first summing the annual projected O & M cost for each BMP and then multiplying that cost by 35. The 35-year O & M costs for the entire project and each BMP were also normalized by drainage area and amount of impervious surface coverage resulting in 35-year O & M costs per acre (drainage area and impervious surfaces coverage).

# 5. Arlington Pascal Stormwater Improvement Project Data Summary

## 5.1. Introduction

This section presents an analysis of stormwater BMP performance, a summary of O & M costs, and a volume reduction and pollutant removal cost-benefit analysis for the entire Arlington Pascal Stormwater Improvement Project.

BMP performance with regards to volume and pollutant load reductions, were simulated by a P8 Water Quality Model, for 2007 to 2010 and for a year with an average precipitation amount (annual projected), for all Arlington Pascal Project BMPs. The model was calibrated to water quantity and quality data collected during the 2007 through 2010 monitoring seasons. An analysis of the performance data is presented below.

BMP performance data was simulated for the entire calendar year from 2007 through 2010. The Como Park Regional Pond was not operational until 2008; therefore, performance data was not simulated for this BMP for 2007. Although, the eight underground infiltration trenches did not become operational until June 2007. Performance data was simulated for all infiltration trenches for the entire calendar year in 2007 in order to conduct consistent year-to-year comparisons.

BMP capital costs and annual O & M costs are also presented for 2007 to 2010. These represent actual construction costs and documented O & M activities and actual costs incurred during that time period. Capital and O & M costs for an annual projected year are also presented and were based on staff recommendations for costs during a normal maintenance year.

The cost-benefit analysis utilized simulated BMP performance results and annual operating costs to determine volume reduction and pollutant removal costs for the individual BMPs, as well as, for the project as a whole for 2007 through 2010 and for an annual projected year.

More detailed data and information about the P8 Model may be found in Chapter 4.4 and Appendix C. More detailed analysis for the individual BMPs may be found in subsequent sections. Actual monitoring data collected on individual the BMPs is provided on the accompanying data CD.

## 5.2. Performance Analysis

### 5.2.1. Volume Reduction

In 2007, approximately 1.1 million cf of stormwater runoff flowed to the Arlington Pascal Project BMPs (Table 5-1). All BMPs were operational in 2007 except the Como Park Regional Pond. The BMPs that were operational were highly efficient at volume reduction; less than one-half of one percent of stormwater runoff flowing to the BMPs overflowed. All operational BMPs had volume reduction efficiencies between 99% and 100% (Figure 5-1, Appendix A: Table A-4).

The 2008 results represent the first full year of operation of all project BMPs. In 2008 and 2009, there were comparable amounts of annual precipitation. This led to fairly comparable annual volumes of stormwater runoff flowing to and from the BMPs; approximately 8.7 million cf and 8.6 million cf of runoff flowed to the BMPs in 2008 and 2009 (Figure 5-2, Table 5-1). Of that runoff, 1.7 million cf was removed each year (19% and 20% of annual inflow, respectively). Annual runoff flowing to all of the BMPs in 2008 and 2009 were less than the annual projected amount.

The majority of the BMPs were highly efficient at volume reduction in 2008 and 2009. The Arlington-Hamline Facility, underground infiltration trenches, and rain gardens all exhibited volume reduction efficiencies of 100% in 2008 and 2009 (Figure 5-1, Appendix A: Tables A-6 and A-8). All runoff which flowed to those BMPs was removed. Although annual runoff flowing to the BMPs in 2008 and 2009 were less than the annual projected amount, the volume reduction efficiencies of the Arlington-Hamline Facility, trenches, and rain gardens were consistent with annual projected volume reduction efficiencies.

The Como Park Regional Pond has the largest watershed area of all the BMPs and received the majority of runoff, flowing to all BMPs, in 2008 and 2009; 89% and 88% of annual flow to the BMPs. Overflow from the pond was attributable to the entire portion of runoff overflowing from all BMPs, in 2008 and 2009; approximately 7 million cf and 6.9 million cf of runoff overflowed from the pond in 2008 and 2009 (Figure 5-2). The pond was not designed for infiltration of stormwater runoff but rather for settling of pollutants. The volume reduction efficiency of the pond in 2008 and 2009 was 9% and 10% respectively, which is consistent with the annual projected removal efficiency (Appendix A: Tables A-6, A-8 and A-12). Although there is some infiltration, it is expected that as sedimentation occurs within the pond over time, the volume reduction efficiency will gradually decrease until sediment is removed from the pond. Some amount of infiltration is likely to occur at the fringes of the pond.

In 2010, a greater amount of annual precipitation occurred than in previous years; 24% more precipitation fell in comparison to the 30-year normal amount. This precipitation generated a substantial amount of stormwater runoff flowing to the BMPs; approximately 18.9 million cf (Figure 5-2, Table 5-1). This was more than two times as much runoff than in 2008 or 2009. Of the runoff which flowed to the BMPs in 2010, 16% (approximately 3 million cf) was removed. This was almost double the amount which was removed in 2008 or 2009. The volume of stormwater runoff flowing to the BMPs in 2010 was more than one and one-half times that of the annual projected amount and the volume of runoff removed was almost one and one-half times that of the annual projected amount.

Overall, individual BMP volume reduction efficiencies were lower in 2010 than those observed from 2007 through 2009 with the exception of the Arlington-Hamline Facility (Figure 5-1, Table 5-3). The Arlington-Hamline Facility was 100% efficient in 2010. The lower volume reduction efficiencies were most likely due to a combination of factors that led to BMP capacities being exceeded; such as more frequent storm events, more intense storm events, and storm events with overall higher precipitation totals. In 2010, the volume reduction efficiencies of the other BMPs were as follows: the pond 5%, the trenches 77%, and the rain gardens 88%. With the exception of the Arlington-Hamline Facility, volume reduction efficiencies for the BMPs were significantly less than the annual projected efficiencies.

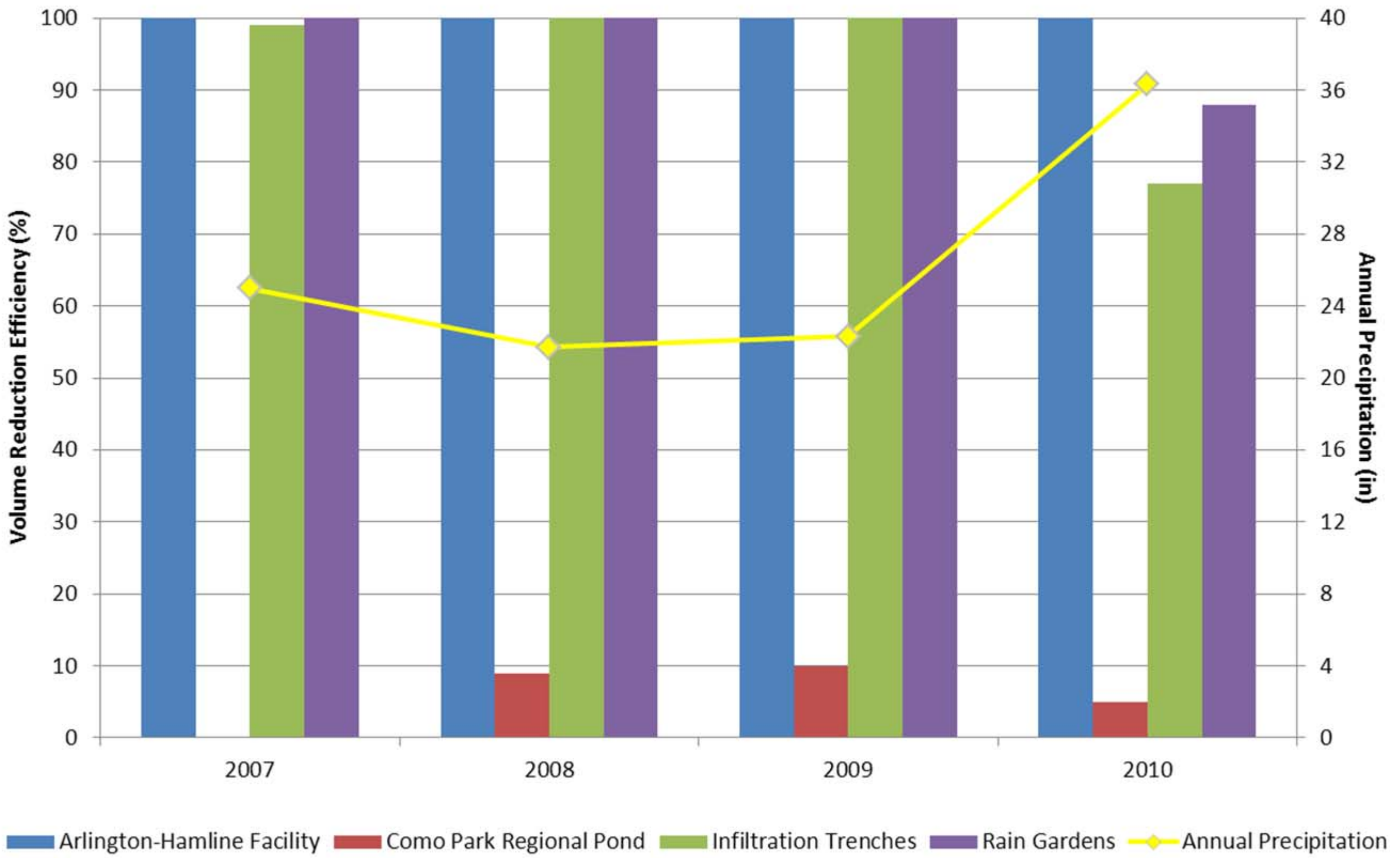


**Figure 5-1. Volume reduction efficiencies of the Arlington Pascal Project BMPs from 2007 to 2010.**

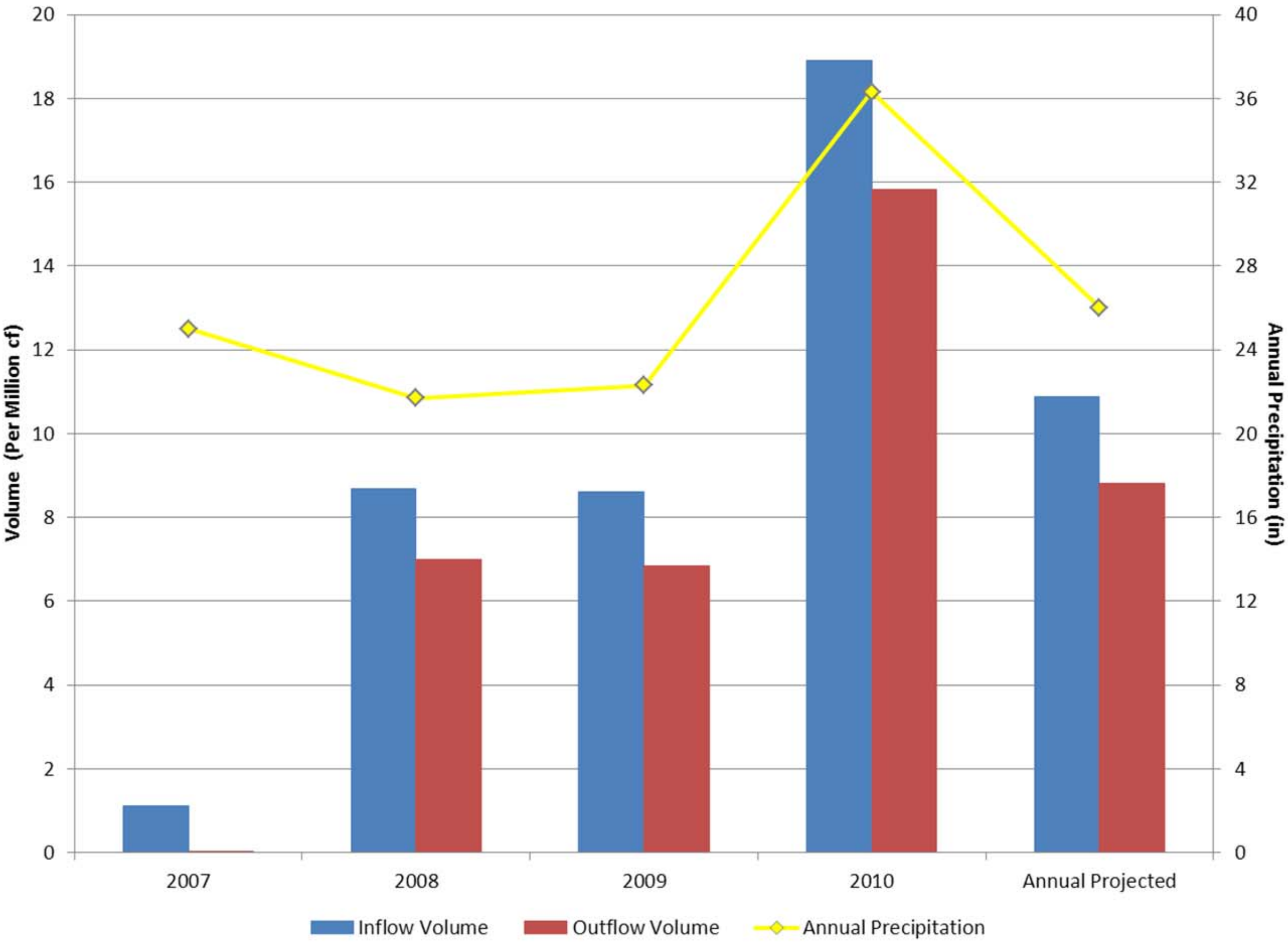


**Figure 5-2. Annual stormwater runoff flowing to and discharging from all Arlington Pascal Project BMPs from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

## 5.2.2. Total Phosphorous

A cumulative TP load was calculated which includes: 1) the TP load removed through the infiltration of stormwater and settlement of suspended solids, 2) the TP load removed through the accumulation of the gross solids load within any pretreatment unit(s), and 3) the TP load removed through the accumulation of the gross solids load within the BMP itself.

### *5.2.2.1 TP Load Reductions and Removal Efficiencies: Due to Infiltration and Settling of Suspended Solids*

The immediate discussion focuses on annual TP loads with regards to stormwater runoff, infiltration of that runoff, and settling of suspended particles in that runoff. Discussions regarding annual cumulative TP loads occur following this discussion.

The annual TP load flowing to all BMPs in 2007 was approximately 28 lbs; almost all of which was removed (Table 5-1). Less than one-half of one percent of the annual TP load was not removed and was attributable to the TP load in a small amount of runoff overflowing from the infiltration trenches (Appendix A: Table A-4). All operational BMPs were highly efficient; exhibiting TP removal efficiencies of 99% and 100% (Figure 5-3). While annual TP loads flowing to the individual BMPs were slightly less than the annual projected loads, the TP removal efficiencies were similar to the annual projected efficiencies (Table 5-1)

Annual TP loads flowing to and from the BMPs in 2008 and 2009 were similar; 133 lbs and 136 lbs of TP flowed to the BMPs and 76 lbs and 77 lbs overflowed respectively (Table 5-1). Approximately 57 lbs and 60 lbs of TP (43% and 44% of the annual TP load flowing to all BMPs) were removed by the BMPs in 2008 and 2009. Similar to stormwater runoff trends, the largest portion of the annual TP loads flowing to the BMPs in 2008 and 2009 were attributable to annual TP loads flowing to the Como Park Regional Pond (Table 5-3).

Of annual TP loads flowing to all BMPs, in 2008 and 2009, 82% (109 lbs) and 80% (110 lbs) of those annual loads flowed to the pond (Appendix A: Tables A-6 and A-8). These amounts were at least eight times the annual TP load flowing to any other BMP. The pond was also attributed with removing the largest portion of annual TP loads to all BMPs in those same years; 32 lbs and 33 lbs of TP were removed by the pond in 2008 and 2009. This equates to 57% and 55% of annual TP loads removed by all BMPs.

While the pond removed the largest portion of annual TP loads in 2008 and 2009, it had the lowest TP removal efficiencies (30% each year) of any of the BMPs. The pond's mechanism for TP removal, settling of suspended solids, achieved its maximum (30%) in 2008 and 2009. Annual TP loads flowing to the pond, from 2008 to 2010, were variable. Regardless of that variability and of the TP load flowing to the pond, a maximum of 30% of the annual load will be removed. TP removal efficiencies for the other BMPs were all 100% in those same years.

Although annual TP loads flowing to and from the BMPs in 2008 and 2009 were less than the annual projected loads, the TP removal efficiencies for all BMPs observed in 2008 and 2009 exceeded or were the same as the projected TP removal efficiencies (Table 5-1).

Annual TP loads flowing to and removed by all BMPs in 2010 were substantially greater than annual TP loads of previous years (Table 5-1). This is largely due to more precipitation in 2010 than in previous years. The annual TP load flowing to all BMPs was 406 lbs, of which, 183 lbs (45%) was removed. This was more than three times the annual loads flowing to, from, and being removed by the BMPs in previous years and more than two times the annual projected loads.

TP removal efficiencies for the BMPs in 2010 were generally lower than TP removal efficiencies observed in previous years for the BMPs and were also lower than annual projected TP removal efficiencies; with the exception of the Arlington-Hamline Facility (Figure 5-3, Appendix A: Tables A-10 and A-12). The Arlington-Hamline Facility was 100% efficient at TP removal. TP removal efficiencies for the trenches and the rain gardens were 75% and 86%, respectively. The pond's TP removal efficiency was the same as previous years (30%).

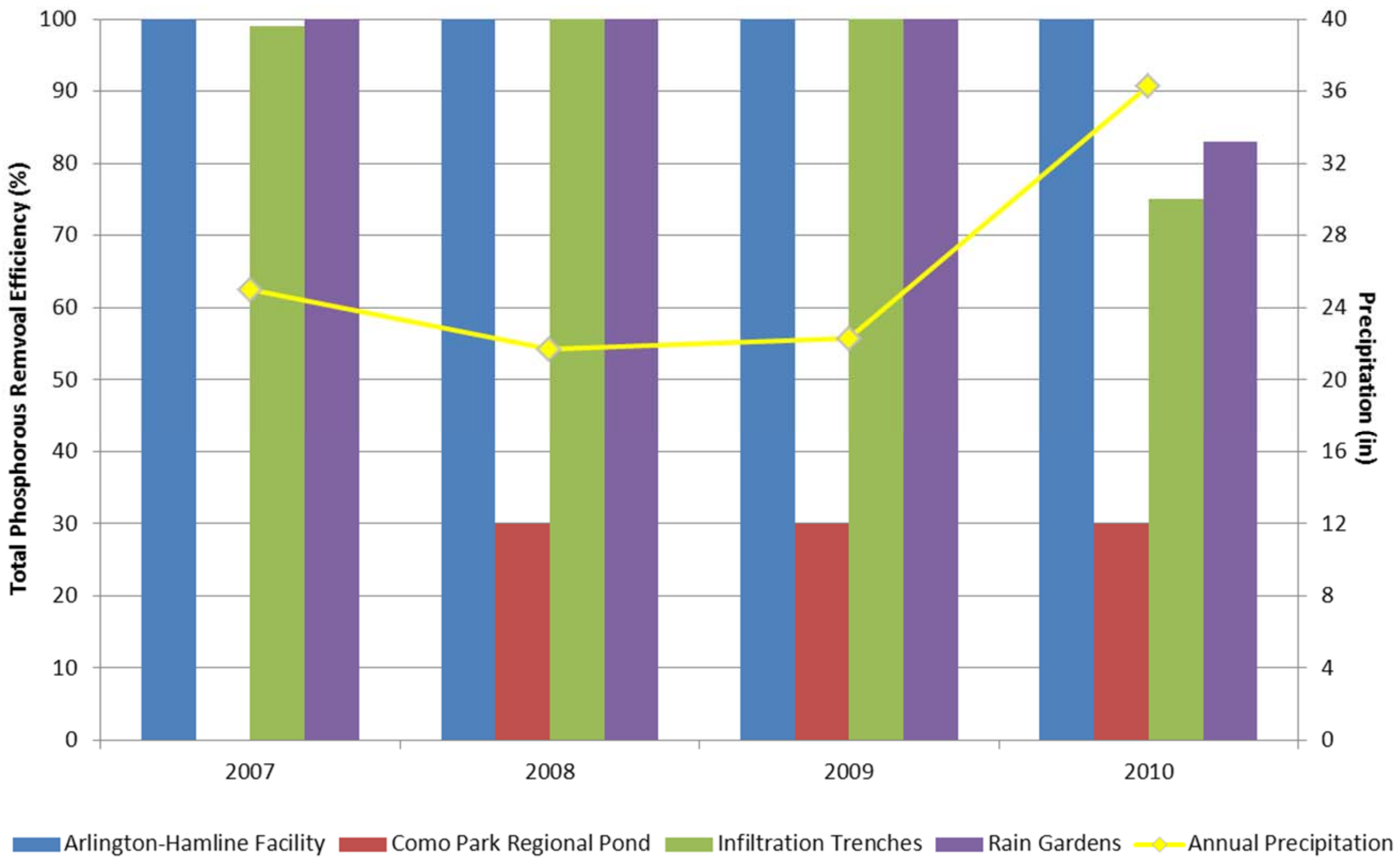


**Figure 5-3. TP removal efficiencies of the Arlington Pascal Project BMPs from 2007 to 2010.**

### *5.2.2.2 Cumulative TP Load Reductions*

As stated at the beginning of the phosphorous load discussion, annual cumulative TP loads were determined for all BMPs. Cumulative TP loads include the TP load removed through infiltration and settling of suspended particles and the TP loads removed through the accumulation of gross solids within the BMP and/or any pretreatment units. Note that not all BMPs have pretreatment units.

The Como Park Regional Pond and the rain gardens do not pretreat stormwater runoff before it flows into the BMPs. Therefore, TP loads in gross solids accumulations are representative of the gross solids loads which accumulated within those BMPs. The Arlington-Hamline Facility and the infiltration trenches have pretreatment units. A large swirl-separator pretreats low flow runoff flowing into the Arlington-Hamline Facility before it flows into the pipe gallery where it is infiltrated. TP loads in gross solids load accumulations for the Arlington-Hamline Facility include the gross solids loads which accumulated within the swirl-separator and the pipe gallery. Thirty sumped catch basins and sixteen sumped manholes serve as pretreatment units for all infiltration trenches. TP loads in the gross solids loads for the trenches include the gross solids which were captured by all catch basins and manholes.

In 2007, 56 lbs of cumulative TP was removed by all BMPs (Table 5-2). The cumulative TP load removed by the Arlington-Hamline Facility accounted for 62% of the annual cumulative TP load removed by all BMPs (Table 5-3). Of the annual cumulative TP load removed by all BMPs in 2007, nearly half (49%) was attributable to the TP load in gross solids captured by the BMPs and pretreatment units (Figure 5-4, Table 5-2). Annual cumulative TP loads removed by the individual BMPs that were operational in 2007), were less than the annual projected cumulative TP loads.

2008 represents the first year in which all BMPs were operational and in 2008, the annual cumulative TP load removed by all BMPs was 151 lbs (Table 5-2). The majority of that cumulative TP load was removed by the Como Park Regional Pond (60%) (Table 5-3). The Arlington-Hamline Facility also removed a sizeable portion (22%). The majority (62%) of the annual cumulative TP load removed by all BMPs in 2008 was due to TP in gross solids; approximately 94 lbs (Figure 5-4, Table 5-2). Annual cumulative TP loads removed by the individual BMPs were similar or greater than the annual projected cumulative TP loads (Table 5-3).

Although annual precipitation amounts in 2008 and 2009 were fairly similar, the annual cumulative TP load removed by the BMPs in 2009 was 22 lbs (14%) greater than the cumulative TP load removed in 2008 (Figure 5-4, Table 5-2). The cumulative TP load removed by all BMPs in 2009 was 173 lbs. This difference is attributable to TP loads in gross solids; a greater load was captured in 2009 than in 2008. Annual TP loads due to infiltration and settling of suspended particles were similar in 2008 and 2009.

Similar to trends observed in previous years, the Como Park Regional Pond and the Arlington-Hamline Facility removed the largest portions of the annual cumulative TP load in 2009; 61% (105 lbs) and 21% (36 lbs), respectively (Table 5-3). The annual cumulative TP load removed by all BMPs in 2009 as well as annual cumulative TP loads removed by the individual BMPs exceeded the annual projected loads (Table 5-2, Table 5-3).

The greatest quantity of cumulative TP was removed by all BMPs in 2010; 256 lbs (Figure 5-4, Table 5-2). This is largely attributable to an increase in precipitation which produced more stormwater runoff in 2010 than in previous years. The 2010 annual cumulative TP load removed by all BMPs was at least one and one-half times that of the annual cumulative TP load observed in any other year (2007 through 2009 as well as the annual projected year). In addition, annual cumulative TP loads removed by the individual BMPs were one and one-half to two times more than the individual BMP annual projected cumulative TP loads (Table 5-3).

In 2010, a minimum of 20 lbs of cumulative TP was removed by each BMP (Arlington-Hamline Facility, pond, trenches, and rain gardens). The Arlington-Hamline Facility and the Como Park Regional Pond removed the largest portions of the annual cumulative TP load in 2010; 73 lbs and 133 lbs (29% and 52% of annual cumulative TP load) respectively. Unlike trends observed in previous years, the largest portion of the cumulative TP load removed in 2010 was due to the TP load removed through infiltration and settling of suspended particles; 71% of the annual cumulative TP load (183 lbs) (Figure 5-4, Table 5-2).

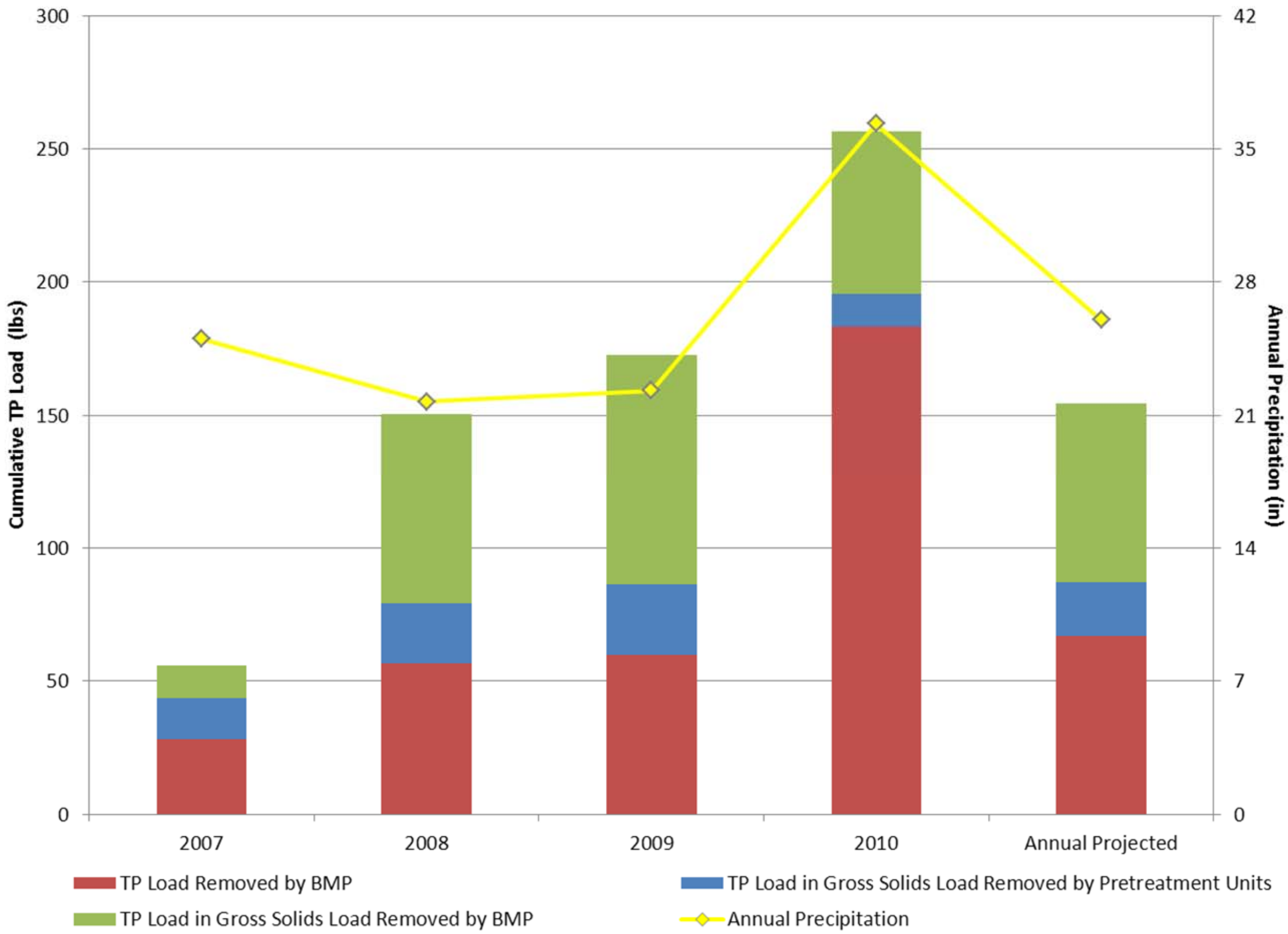


**Figure 5-4. Annual cumulative TP loads removed by the Arlington Pascal Project BMPs from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

### 5.2.3. Total Suspended Solids

The TSS load removed by all Arlington Pascal Project BMPs was approximately 12,400 lbs in 2007 (Table 5-1). Of this amount, less than one-half of one percent overflowed. All BMPs which were operational (Arlington-Hamline Facility, infiltration trenches, and rain gardens) were highly efficient. The Arlington-Hamline Facility and the rain gardens all had TSS removal efficiencies of 100% and the trenches 99% (Figure 5-5). The Arlington-Hamline Facility removed more than one-half of the TSS load removed by all BMPs in 2007; 6,600 lbs (Appendix A: Table A-4). The 2007 annual TSS loads removed by the individual BMPs as well as 2007 TSS removal efficiencies for the individual BMPs, exceeded the annual projected TSS loads and removal efficiencies (Appendix A: Tables A-4 and A-12).

In 2008 and 2009, the TSS loads flowing to the BMPs was approximately 39,200 lbs and 42,200 lbs respectively; of which approximately 34,200 lbs in 2008 and 36,000 lbs in 2009 were removed (Table 5-1). This equates to 87% and 85% of the annual TSS loads, respectively. Overall, the annual TSS load to all BMPs, in 2008 and 2009, as well as the TSS loads to each individual BMP were all less than annual projected loads (Appendix A: Tables A-6, A-8, and A-12). Also, TSS removal efficiencies were very high for the Arlington-Hamline Facility, trenches, and rain gardens in 2008 and 2009 (100%) and were consistent with annual projected TSS removal efficiencies. The Como Park Regional Pond had a higher TSS removal efficiency in 2008 (82%) than in 2009 (79%); however, both were still high and consistent with the annual projected TSS removal efficiency (80%).

The Arlington-Hamline Facility and the Como Park Regional Pond removed the largest proportion of the total TSS loads removed by all BMPs in 2008 and 2009; 85% (29,200 lbs) in 2008 and 84% (30,200 lbs) in 2009. These two BMPs have the two largest watershed areas of all the BMPs.

The TSS load which flowed to and was removed by all BMPs in 2010 was at a minimum four times the annual TSS load in any other year, including the annual projected year (Table 5-1). Approximately 189,200 lbs of TSS flowed to all BMPs, of which, 145,800 lbs (77%) was removed. The Arlington-Hamline Facility had a TSS removal efficiency of 100%. This is consistent with removal efficiencies observed in previous years as well as the annual projected TSS removal efficiency (Figure 5-5, Appendix A: Tables A-10 and A-12). The TSS removal efficiencies for the infiltration trenches (82%), rain gardens (87%), and pond (69%) were lower than TSS removal efficiencies observed in previous years and were lower than annual projected removal efficiencies. However, the TSS removal efficiencies for the trenches and the rain gardens were still high.

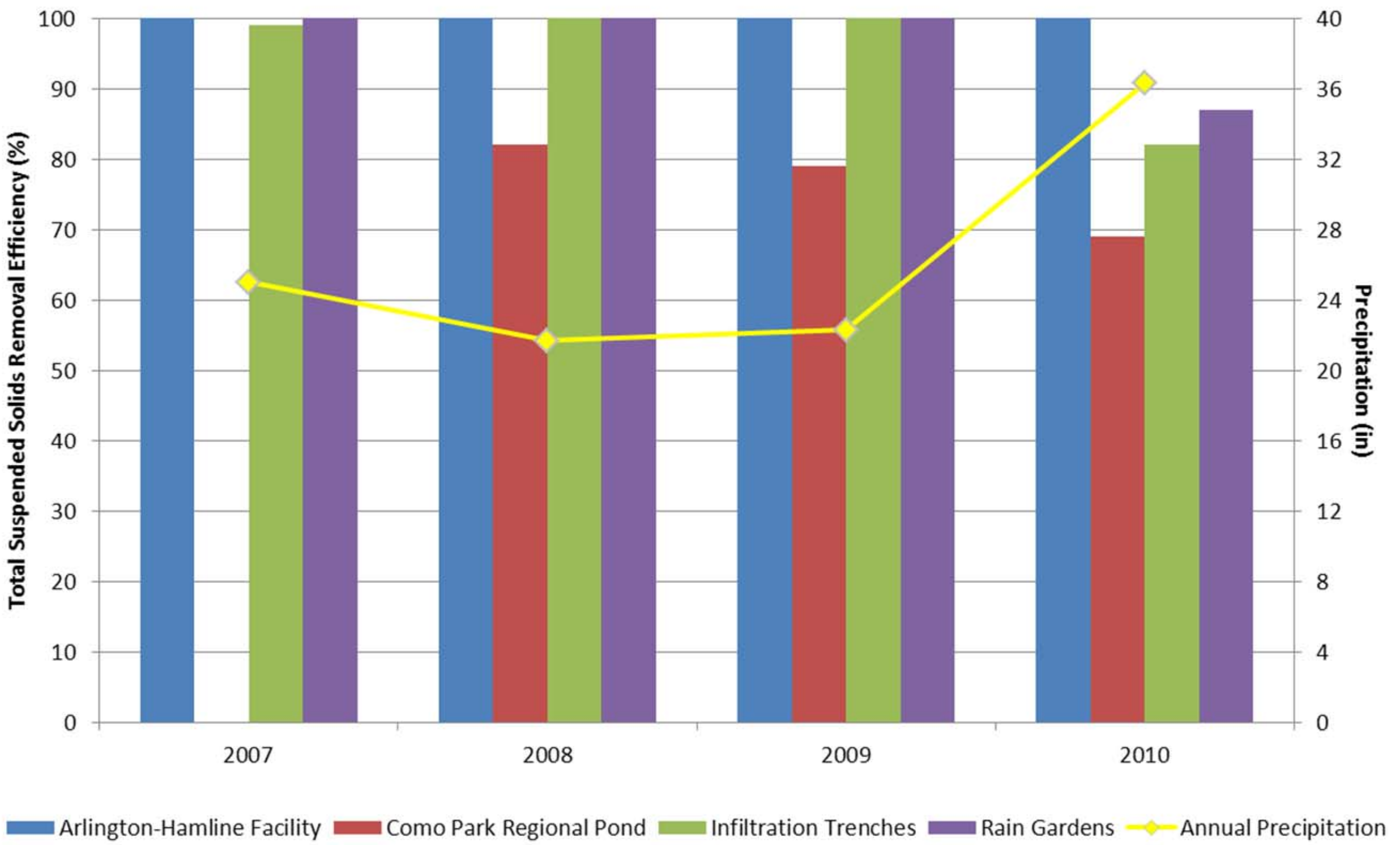


**Figure 5-5. TSS removal efficiencies of the Arlington Pascal Project BMPs from 2007 to 2010.**

## 5.2.4. Total Solids

A comprehensive total solids load was determined for the BMPs. It incorporates: 1) the TSS load removed by the BMP through the infiltration of stormwater and settlement of suspended particles, 2) the gross solids load which accumulated within any pretreatment units, and 3) the gross solids load which accumulated within the BMPs.

The total solids load removed by all BMPs in 2007 was approximately 57,700 lbs (Figure 5-6, Table 5-2). The majority of that load (45,000 lbs or 78%) was attributable to the accumulation of gross solids loads in the BMPs and pretreatment units. Of the BMPs which were operational in 2007, more than one-half of the annual total solids load removed by all BMPs was due to total solids removed by the Arlington-Hamline Facility (Table 5-3). Total solids loads removed by the Arlington-Hamline Facility and the infiltration trenches in 2007 were similar to or greater than the annual projected total solids loads removed (Table 5-3). The total solids load removed by the rain gardens (8,400 lbs) in 2007 was significantly less than the annual projected load removed (13,200 lbs).

Annual total solids loads removed by all BMPs in 2008 and 2009 totaled approximately 244,700 lbs and 292,600 lbs, respectively (Figure 5-6, Table 5-2). The majority of those annual loads (86% in 2008 and

88% in 2009) were due to the accumulation of gross solids in the BMPs and pretreatment units; 210,500 lbs and 256,600 lbs, respectively. The amount of the annual total solids loads removed in 2008 and 2009, due to TSS removal by the BMPs, were fairly consistent. The 2008 and 2009 annual total solids loads removed by all BMPs exceeded the annual projected load removed. Annual total solids loads removed by the individual BMPs also generally exceeded the annual projected total solids loads removed (Table 5-3).

The largest portion of the annual total solids loads removed by all BMPs, in 2008 and 2009, was due to total solids captured by the Como Park Regional Pond; 69% (169,300 lbs) and 70% (203,600 lbs) of the total solids load to all BMPs were removed by the pond. Significant total solids loads, 13,000 lbs to 37,600 lbs, were removed by the other BMPs (Arlington-Hamline Facility, trenches, and rain gardens) even though they accounted for a smaller portion of the annual total solids loads in both years.

In 2010, approximately 301,000 lbs of total solids was removed by all BMPs (Figure 5-6, Table 5-2). This was the largest amount removed than in any other year, including the annual projected year. The proportion of that load which was removed through infiltration and settling and the proportion due to accumulation of gross solids were nearly the same; 48% of the annual total solids load was due to infiltration and settling of suspended solids while 52% was due to accumulation of gross solids. Annual total solids loads removed by each BMP in 2010 exceeded the annual projected total solids loads removed.

Similar to previous years, the Como Park Regional Pond removed the largest portion (65%) of the annual total solids load removed by all BMPs in 2010; approximately 194,400 lbs were removed by the pond. Annual total solids load removed by the other BMPs in 2010 were also significant; ranging from 19,000 lbs to 52,800 lbs.

Annual total solids loads that are captured by each BMP are largely dependent upon the BMP's watershed area. Since the Como Park Regional Pond has the largest watershed area, it consistently accumulated the largest portion of annual total solids loads than any other BMP.

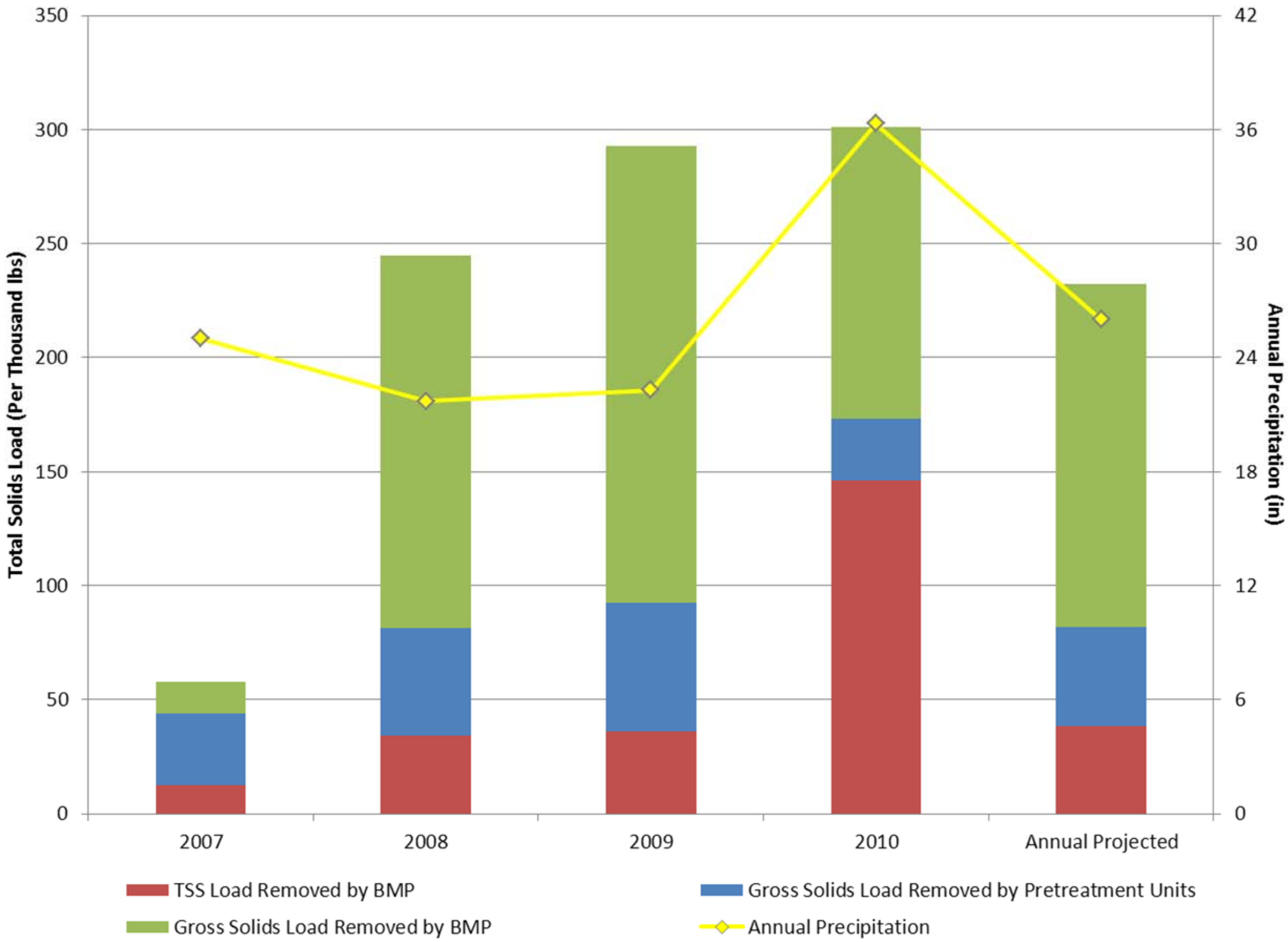


**Figure 5-6. Annual total solids loads removed by the Arlington Pascal Project BMPs from 2007 to 2010 and for a year with an average Precipitation amount (annual projected).**

**Table 5-1. Annual volume reduction and pollutant removal efficiencies for the Arlington Pascal Project BMPs from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected[a] |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 21.7 | 22.3 | 36.3 | 26.0 |
| Subwatershed Area (ac) | 217 | 217 | 217 | 217 | 217 |
| ***VOLUME REDUCTION*** | | | | | |
| Inflow Volume (cf) | 1,103,549 | 8,677,153 | 8,596,609 | 18,896,546 | 10,881,025 |
| Outflow Volume (cf) | 3,005 | 6,992,905 | 6,851,204 | 15,829,922 | 8,814,322 |
| Volume Removed by BMP (cf) | **1,100,544** | **1,684,248** | **1,745,405** | **3,066,624** | **2,066,703** |
| ***TOTAL PHOSPHOROUS LOAD REDUCTION*** | | | | | |
| Inflow TP Load (lbs) | 28.4 | 133.1 | 136.4 | 406.4 | 162.9 |
| Outflow TP Load (lbs) | 0.1 | 76.4 | 76.8 | 223.1 | 96.1 |
| TP Load Removed by BMP (lbs) | **28.3** | **56.7** | **59.6** | **183.3** | **66.8** |
| ***TOTAL SUSPENDED SOLIDS LOAD REDUCTION*** | | | | | |
| Inflow TSS Load (lbs) | 12,382 | 39,242 | 42,208 | 189,196 | 44,916 |
| OutflowTSS Load (lbs) | 29 | 5,079 | 6,221 | 43,430 | 6,609 |
| TSS Load Removed by BMP (lbs) | **12,353** | **34,163** | **35,987** | **145,766** | **38,307** |

[a] Annual projected results derived using the 1995 water year.

**Table 5-2. Annual cumulative TP and total solids load reductions for the Arlington Pascal Project BMPs from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 21.7 | 22.3 | 36.3 | 26.0 |
| Subwatershed Area (ac) | 217 | 217 | 217 | 217 | 217 |
| ***VOLUME REMOVED*** | | | | | |
| Total Volume Removed by BMP (cf) | **1,100,544** | **1,684,248** | **1,745,405** | **3,066,624** | **2,066,703** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | |
| TP Load Removed by BMP (lbs) | 28.3 | 56.7 | 59.6 | 183.3 | 66.8 |
| TP Load in Gross Solids Load Removed by BMP (lbs) | 12.2 | 71.5 | 86.3 | 60.8 | 67.5 |
| TP Load in Gross Solids Load Removed by Pretreatment Units (lbs) | 15.4 | 22.3 | 26.6 | 12.3 | 20.3 |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | **55.9** | **150.6** | **172.6** | **256.4** | **154.6** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | |
| TSS Load Removed by BMP (lbs) | 12,353 | 34,163 | 35,987 | 145,766 | 38,307 |
| Gross Solids Load Removed by BMP (lbs) | 13,885 | 163,569 | 200,340 | 127,980 | 150,788 |
| Gross Solids Load Removed by Pretreatment Units (lbs) | 31,416 | 46,949 | 56,274 | 27,282 | 43,324 |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | **57,654** | **244,681** | **292,601** | **301,028** | **232,420** |

**Table 5-3. Total annual volume and pollutant load reductions for the Arlington Pascal Project and individual BMPs.**

| | | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|---|
| Volume Reduction (cf) | 2007 | 526,248 | NA | 317,248 | 257,048 | 1,100,544 |
| | 2008 | 458,600 | 718,914 | 281,616 | 225,118 | 1,684,248 |
| | 2009 | 475,675 | 747,490 | 291,721 | 230,519 | 1,745,405 |
| | 2010 | 1,245,032 | 737,994 | 582,354 | 501,245 | 3,066,625 |
| | Projected | 566,149 | 876,341 | 346,562 | 277,651 | 2,066,703 |
| Cumulative TP Load Removed[a] (lbs) | 2007 | 34.4 | NA | 13.3 | 8.2 | 55.9 |
| | 2008 | 33.4 | 90.9 | 17.1 | 9.3 | 150.7 |
| | 2009 | 36.4 | 105.3 | 20.1 | 10.7 | 172.6 |
| | 2010 | 73.2 | 133.4 | 29.4 | 20.4 | 256.4 |
| | Projected | 35.5 | 90.4 | 18.3 | 10.4 | 154.6 |
| Total Solids Load Removed[b] (lbs) | 2007 | 31,347 | NA | 17,871 | 8,433 | 57,651 |
| | 2008 | 33,414 | 169,293 | 28,977 | 12,997 | 244,681 |
| | 2009 | 37,575 | 203,627 | 35,584 | 15,815 | 292,600 |
| | 2010 | 52,819 | 194,446 | 34,722 | 19,042 | 301,029 |
| | Projected | 32,071 | 157,953 | 29,217 | 13,178 | 232,419 |

[a] Includes the TP load removed through infiltration of stormwater and settlement of suspended particles and the TP load associated with the gross solids load(s) captured by the BMP and/or any pretreatment units.

[b] Includes the TSS load removed through infiltration of stormwater and settlement of suspended particles and the gross solids load(s) captured by the BMP and/or any pretreatment units.

NA: Not available. The Como Park Park Regional Pond was not operational in 2007.

### 5.2.5. 2003 Arlington Pascal Project Target TP Load Reductions

The 2003 hydraulic evaluation of the Como 7 Subwatershed determined target TP load reduction goals for the Arlington Pascal Project overall and for each individual BMP (CRWD, 2003). This evaluation established target reductions based on original, preliminary plans of the BMPs. The preliminary plan had the Arlington-Hamline Facility as a stormwater pond and the underground infiltration trenches as a series of boulevard rain gardens. Over the course of development of the Arlington Pascal Project, those preliminary plans were modified based on further planning and public input to feature the stormwater BMPs ultimately constructed. Although the BMP types were altered from the original plan, the BMPs constructed were still designed to meet the load reductions outlined in the 2003 evaluation.

From 2007 to 2010, annual cumulative TP load reductions for the Arlington Pascal Project averaged 159 lbs per year. Since 2008, when all project BMPs were operational, individual BMP and project cumulative TP load reductions far exceeded the 2003 target TP load reductions (Table 5-4). Cumulative TP load reductions, from 2008 to 2010, were more than one and one-half times the target load reduction. The annual projected cumulative TP load reduction for the entire Arlington Pascal Project was slightly more than two times the 2003 target load reduction for the entire project.

Since the BMPs have been operational, annual cumulative TP load reductions for the Arlington-Hamline Facility and the Como Park Regional Pond were more than two times greater than the 2003 target load reductions. The annual cumulative TP load removed by the infiltration trenches and rain gardens in 2007 was slightly less than the 2003 target load reduction. However, since 2008, annual cumulative TP load reductions for the trenches and the rain gardens exceeded the 2003 target load reductions.

**Table 5-4. Comparison of the Arlington Pascal Project annual cumulative TP load reductions, from 2007 to 2010 and for a year with an average precipitation amount (annual projected), to the 2003 target TP load reduction.**

| BMP | 2003 (Target) | 2007 | 2008 | 2009 | 2010 | Annual Projected |
|---|---|---|---|---|---|---|
| Arlington-Hamline Facility | **12** | 34 | 33 | 36 | 73 | 35 |
| Como Park Regional Pond | **41** | NA | 91 | 105 | 133 | 90 |
| Rain Gardens and Underground Infiltration Trenches | **24** | 22 | 26 | 31 | 50 | 29 |
| **Project Total TP Load Reduction:** | **77** | **56** | **151** | **173** | **257** | **155** |

*All loads are expressed in pounds (lbs).

NA: Not Available

## 5.3. Operation and Maintenance

CRWD is responsible for the overall operation and maintenance the Arlington Pascal Project BMPs. Additional assistance is received by other parties for maintenance of some BMPs. The City of St. Paul Parks and Recreation Department provided maintenance assistance with debris removal around the perimeter of the Como Park Regional Pond following storm events and general maintenance of one rain garden. Citizen volunteers also provided assistance with general maintenance of the rain gardens.

From 2007 to 2010, on average, approximately $22,000 and 554 labor hours have been spent annually on the O & M of all Arlington Pascal Project BMPs. The majority of that cost has been spent on O & M of the infiltration trenches and the rain gardens. Although the overall O & M cost has varied annually, the actual total annual labor hours have steadily decreased. The annual costs for labor, equipment and materials, and contract services for each project BMP are shown in Table 5-5.

Generally, from 2007 to 2010 almost half of the total annual O & M costs have been attributable to debris removal from the sumped catch basins and manholes connected to the infiltration trenches. Also, the rain gardens require more labor intensive maintenance in comparison to other BMP types. A significant portion of labor was spent establishing the rain gardens in 2007; however, annual labor costs have greatly decreased over time from approximately $11,500 in 2007 to $3,200 in 2010. The rain garden O & M cost would have been at its lowest in 2010 if not for the purchase and installation of educational signage at the rain gardens; 2010 equipment and materials cost were approximately $4,400.

In 2007, the infiltration trenches became fully operational mid-year resulting in lowered O & M costs since a full calendar year of operation and maintenance was not represented. Also, the Como Park Regional Pond was not completed until 2008 and did not contribute to the overall O & M cost for 2007. However, the initial O & M costs spent establishing the rain gardens in 2007 offset these overall reductions.

The highest annual O & M costs for the individual BMPs and project as a whole occurred in 2008 (Table 5-5). The high O & M cost is primarily due to the development of an individual O & M plan for the Como Park Regional Pond and the additional maintenance needs for the infiltration trenches. A higher frequency of inspections occurred for the infiltration trenches in 2008 in comparison to other years. In addition, labor intensive maintenance of the steel hoods in the catch basins occurred in 2008 and contributed to the increased costs. In general, annual O & M costs in 2009 and 2010 decreased from 2007 and 2008 because all BMPs were established and only routine maintenance of the BMPs was necessary.

The projected annual O & M cost for the BMPs was approximately $29,400. This was significantly higher than the average O & M cost ($22,000), as well as any annual O & M cost observed for the BMPs from 2007 to 2010 (Table 5-5). The projected O & M cost accounts for not only routine maintenance activities but also incorporates the cost for large scale maintenance needs for the Arlington-Hamline Facility, Como Park Regional Pond, and infiltration trenches (i.e. bathymetric surveys, dredging/removal of sediment, etc). Those irregular costs were amortized over the life expectancy (35 years) of the BMPs and incorporated into the projected annual O & M cost. In years when the irregular maintenance activities occur, the annual O & M costs will be substantially higher than in normal maintenance years. Detailed O & M activities and costs on each BMP may be found in subsequent individual sections as well as in Appendix A: Tables A-34 through A-56.

**Table 5-5. Annual O & M costs and labor hours spent maintaining the Arlington Pascal Project BMPs from 2007 through 2010 and for an annual projected year.**

| | | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|---|
| **2007** | Labor | $267 | NA | $2,373 | $11,469 | **$14,108** |
| | Equipment & Materials | $264 | NA | $0 | $2,621 | **$2,885** |
| | Contract Services | $0 | NA | $3,136 | $761 | **$3,897** |
| | Annual O & M Cost | $531 | NA | $5,509 | $14,851 | **$20,891** |
| | Total Labor Hours[a] | 12.8 | NA | 138.0 | 640.0 | **790.8** |
| **2008** | Labor | $296 | $983 | $1,768 | $5,142 | **$8,189** |
| | Equipment & Materials | $0 | $31 | $323 | $1,755 | **$2,109** |
| | Contract Services | $1,729 | $5,544 | $10,314 | $648 | **$18,234** |
| | Annual O & M Cost | $2,025 | $6,558 | $12,405 | $7,544 | **$28,532** |
| | Total Labor Hours[a] | 13.9 | 77.8 | 87.8 | 431.6 | **611.2** |
| **2009** | Labor | $211 | $915 | $337 | $3,790 | **$5,253** |
| | Equipment & Materials | $0 | $0 | $0 | $1,006 | **$1,006** |
| | Contract Services | $1,729 | $0 | $10,314 | $0 | **$12,042** |
| | Annual O & M Cost | $1,940 | $915 | $10,651 | $4,796 | **$18,301** |
| | Total Labor Hours[a] | 13.0 | 75.2 | 23.3 | 380.2 | **491.7** |
| **2010** | Labor | $168 | $1,152 | $675 | $3,185 | **$5,180** |
| | Equipment & Materials | $0 | $0 | $0 | $4,430 | **$4,430** |
| | Contract Services | $1,728 | $0 | $10,314 | $0 | **$12,042** |
| | Annual O & M Cost | $1,896 | $1,152 | $10,988 | $7,615 | **$21,652** |
| | Total Labor Hours[a] | 10.0 | 94.1 | 43.2 | 243.2 | **390.5** |
| **Annual Projected** | Labor | $250 | $1,000 | $1,000 | $5,010 | **$7,260** |
| | Equipment & Materials | $0 | $50 | $100 | $1,350 | **$1,500** |
| | Contract Services | $2,900 | $5,500 | $11,400 | $800 | **$20,600** |
| | Annual O & M Cost | $3,150 | $6,550 | $12,500 | $7,160 | **$29,360** |

[a] Includes CRWD staff, CRWD volunteer, and City of St. Paul staff hours.

NA: Not Available

## 5.4. Cost-Benefit Analysis: Volume and Pollutant Removal

The annual capital cost of the total Arlington Pascal Project increased from approximately $40,600 in 2007 to $79,600 in 2008 and subsequent years (Table 5-6). This increase was due to the completion of the Como Park Regional Pond which became operational in 2008. Since 2008, annual capital costs have remained constant. The annual capital costs of the individual BMPs are fixed values, which will only be modified if the 35-year life expectancy is to be modified (this is the value in which the total capital costs are amortized by).

Since 2008 which represents the first year in which all BMPs were operational, the Como Park Regional Pond was accountable for the greatest majority of the annual capital cost. Individually, the pond accounts for nearly half of the total project annual capital cost.

**Table 5-6. Annual capital costs for the Arlington Pascal Project from 2007 through 2010 and for a year with an average precipitation amount (annual projected).**

| | 2007 | 2008-2010 | Annual Projected |
|---|---|---|---|
| Arlington-Hamline Facility | $24,605 | $24,605 | $24,605 |
| Como Park Regional Pond | NA | $38,981 | $38,981 |
| Infiltration Trenches | $11,430 | $11,430 | $11,430 |
| Rain Gardens | $4,578 | $4,578 | $4,578 |
| **Project Total:** | **$40,614** | **$79,595** | **$79,595** |

NA: Not Applicable

Annual operating costs are comprised of the total annual capital costs and the total annual O & M costs. Annual operating costs are primarily driven by increases or decreases in annual O & M costs since annual capital costs generally remain constant.

From 2007 to 2010, the annual operating cost for the Arlington Pascal Project averaged approximately $88,200. Since the Como Park Regional Pond was still under construction in 2007, the 2007 annual operating cost for the Arlington Pascal Project was significantly less than any other year; roughly $61,500. This greatly reduced the overall average project annual operating cost. Annual operating costs for all BMPs from 2008 through 2010 are more representative of actual project costs because all of the BMPs were fully operational. From 2008 to 2010, the average annual operating cost was approximately $97,200. Annual operating costs are shown in Table 5-7.

The overall Arlington Pascal Project annual projected operating cost is higher than any annual operating cost from 2007 to 2010. This is again due to irregular, large scale maintenance needs of the individual BMPs.

**Table 5-7. Annual operating costs for the Arlington Pascal Project and individual BMPs from 2007 through 2010 and for a year with an average precipitation amount (annual projected).**

| Year | | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|---|
| **2007** | Annual Capital Cost | $24,605 | NA | $11,430 | $4,578 | **$40,614** |
| | Annual O & M Cost | $531 | NA | $5,509 | $14,851 | **$20,891** |
| | Annual Operating Cost | $25,136 | NA | $16,939 | $19,429 | **$61,504** |
| **2008** | Annual Capital Cost | $24,605 | $38,981 | $11,430 | $4,578 | **$79,595** |
| | Annual O & M Cost | $2,025 | $6,558 | $12,405 | $7,544 | **$28,532** |
| | Annual Operating Cost | $26,630 | $45,539 | $23,835 | $12,122 | **$108,127** |
| **2009** | Annual Capital Cost | $24,605 | $38,981 | $11,430 | $4,578 | **$79,595** |
| | Annual O & M Cost | $1,940 | $915 | $10,651 | $4,796 | **$18,301** |
| | Annual Operating Cost | $26,545 | $39,897 | $22,081 | $9,374 | **$97,896** |
| **2010** | Annual Capital Cost | $24,605 | $38,981 | $11,430 | $4,578 | **$79,595** |
| | Annual O & M Cost | $1,896 | $1,152 | $10,988 | $7,615 | **$21,652** |
| | Annual Operating Cost | $26,502 | $40,134 | $22,418 | $12,193 | **$101,247** |
| **Annual Projected** | Annual Capital Cost | $24,605 | $38,981 | $11,430 | $4,578 | **$79,595** |
| | Annual O & M Cost | $3,150 | $6,550 | $12,500 | $7,160 | **$29,360** |
| | Annual Operating Cost | $27,755 | $45,531 | $23,930 | $11,738 | **$108,955** |

NA: Not Available

A cost-benefit analysis was completed to determine volume reduction and pollutant removal costs for the Arlington Pascal Project and individual BMPs (Table 5-8). It incorporated BMP performance data and actual construction and O & M costs to determine the unit cost for removing a single pound of pollutants (TP and total solids) and one cubic foot of volume reduction. This cost-benefit analysis serves as a basis of comparison for BMP types and has the potential to be a tool for decision makers in future projects.

Volume reduction and pollutant removal costs are directly affected by two factors: fluctuations in annual operating costs and fluctuations in the amount of volume reduction and pollutant load reductions occurring. In general, the amount of volume and pollutant load reductions occurring has a larger impact than the fluctuations in the annual operating costs.

Annual operating costs for the BMPs fluctuated greatly from 2007 to 2010. In general, the lowest annual operating costs occurred in 2007 and the highest in 2008. However, there was a decreasing trend in volume reduction and pollutant removal costs, from 2007 to 2010, across the individual BMPs and the Arlington Pascal Project as a whole (Table 5-8). The highest volume reduction and pollutant removal costs occurred in 2007 and the lowest in 2010. The lower volume reduction and pollutant removal costs in 2010 were mostly due to the higher amount of annual precipitation in 2010. This increased precipitation generated more stormwater runoff and pollutants flowing to the BMPs and also allowed for substantially more volume and pollutants to be removed than in any other year.

Volume reduction costs for the entire Arlington Pascal Project from 2007 to 2010 were between $0.03 and $0.06 per cubic foot (Table 5-8). The volume reduction cost in 2010 for the entire project was one-half the volume reduction costs from 2007 to 2010. Again, this was due to significantly more stormwater runoff being removed in 2010 than in previous years. Volume reduction costs for the individual BMPs varied annually; individual BMP volume reduction costs were between $0.02 and $0.08 per cubic foot from 2007 to 2010.

From 2007 to 2010, annual cumulative TP removal costs for the Arlington Pascal Project were between $395 and $1,100 per pound and for the individual BMPs were between $301 and $2,372 per pound (Table 5-8). The total solids removal costs for the overall project and individual BMPs were between $0.33 and $1.07 per pound and $0.20 and $2.30 per pound, respectively.

The infiltration trenches and the rain gardens consistently had the highest cumulative TP and total solids removal costs of the BMPs from 2007 to 2010 (Table 5-8). From 2007 to 2010, on average the cost to remove one pound of cumulative TP by the trenches and the rain gardens were $1,140 and $1,089, respectively and the average total solids removal cost for each was $0.73 and $0.94 per pound, respectively. This was due to a combination of the overall lower amounts of pollutants being removed (because of their smaller drainage areas in comparison to the pond or the Arlington-Hamline Facility) and more frequent and intensive O & M schedule; because of their BMP type they require more annual maintenance than the pond and the Arlington-Hamline Facility.

The Arlington-Hamline Facility and the Como Park Regional Pond had the lowest cumulative TP and total solids removal costs of the BMPs from 2007 to 2010 (Table 5-8). The average cost to remove one pound of cumulative TP was lower for the Como Park Regional Pond ($381) than the Arlington-Hamline Facility ($590). The average cost to removed one pound of total solids was more than three times lower for the Arlington-Hamline Facility ($0.22) than the Como Park Regional Pond ($0.68).

The 2007 to 2010 average volume reduction costs for the Arlington-Hamline Facility and the rain gardens were the same ($0.04 per cubic foot) and were lower than the volume reduction costs for the Como Park Regional Pond and the infiltration trenches, which were also identical ($0.06 per cubic foot).

**Table 5-8. Volume reduction and pollutant removal costs for the Arlington Pascal Project and individual BMPs.**

| | | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|---|
| Annual Operating Cost | 2007 | $25,136 | NA | $16,939 | $19,429 | $61,504 |
| | 2008 | $26,630 | $45,539 | $23,835 | $12,122 | $108,127 |
| | 2009 | $26,545 | $39,897 | $22,081 | $9,374 | $97,896 |
| | 2010 | $26,502 | $40,134 | $22,418 | $12,193 | $101,247 |
| | Projected | $27,755 | $45,531 | $23,930 | $11,738 | $108,955 |
| Volume Reduction Cost ($/cf) | 2007 | $0.05 | NA | $0.05 | $0.08 | $0.06 |
| | 2008 | $0.06 | $0.06 | $0.08 | $0.05 | $0.06 |
| | 2009 | $0.06 | $0.05 | $0.08 | $0.04 | $0.06 |
| | 2010 | $0.02 | $0.05 | $0.04 | $0.02 | $0.03 |
| | Projected | $0.05 | $0.05 | $0.07 | $0.04 | $0.05 |
| Cumulative TP Removal Cost [a] ($/lb) | 2007 | $732 | NA | $1,269 | $2,372 | $1,100 |
| | 2008 | $797 | $501 | $1,395 | $1,301 | $718 |
| | 2009 | $729 | $379 | $1,096 | $880 | $567 |
| | 2010 | $362 | $301 | $762 | $599 | $395 |
| | Projected | $782 | $504 | $1,307 | $1,129 | $705 |
| Total Solids Removal Cost [b] ($/lb) | 2007 | $0.80 | NA | $0.95 | $2.30 | $1.07 |
| | 2008 | $0.80 | $0.27 | $0.82 | $0.93 | $0.44 |
| | 2009 | $0.71 | $0.20 | $0.62 | $0.59 | $0.33 |
| | 2010 | $0.50 | $0.21 | $0.65 | $0.64 | $0.34 |
| | Projected | $0.87 | $0.29 | $0.82 | $0.89 | $0.47 |

[a] Represents the removal cost for the cumulative TP load removed. Includes the TP load removed through infiltration of stormwater and settlement of suspended solids and the TP load associated with the accumulation of gross solids load(s) within the BMP and/or any pretreatment units.

[b] Represents the removal cost for the total solids load removed. This includes the TSS load removed through infiltration of stormwater and settlement of suspended solids and the gross solids load(s) captured by the BMP and/or any pretreatment units.

## 5.5. Cost-Benefit Analysis: Drainage Area

In addition to the results of the cost-benefit analysis described above, additional analysis was conducted to determine the capital costs and the 35-year projected O & M costs, of each BMP and the Arlington Pascal Project as a whole, on a per acre basis. Capital costs and O & M costs were normalized by the drainage area (of the project or specific BMP) and by the portion of that drainage area covered by impervious surfaces. The results of that analysis are presented in Table 5-9.

**Table 5-9. Capital Costs and 35-Year Annual Projected O & M Costs, for the Arlington Pascal Project and BMPs, normalized by drainage area and impervious surfaces coverage.**

| | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | Project Total |
|---|---|---|---|---|---|
| Drainage Area (ac) | 50.00 | 128.00 | 22.67 | 16.08 | **189.95** |
| Impervious Surface Coverage (%) | 44% | 39% | 39% | 23% | **0.44** |
| Impervious Surface Coverage (ac) | 22.00 | 49.92 | 8.84 | 3.70 | **83.58** |
| **Capital Cost Per Acre** | | | | | |
| Capital Cost | $ 799,087 | $ 1,364,346 | $ 400,060 | $ 160,244 | **$ 2,723,737** |
| Cost per Acre Drainage Area ($/ac) | $ 15,982 | $ 10,659 | $ 17,647 | $ 9,965 | **$ 14,339** |
| Cost per Acre Impervious ($/ac) | $ 36,322 | $ 27,331 | $ 45,249 | $ 43,328 | **$ 32,589** |
| **35-Year O & M Cost Per Acre** | | | | | |
| 35-Year Projected O & M Cost[a] | $ 110,250 | $ 229,250 | $ 437,500 | $ 250,600 | **$ 1,027,600** |
| Cost per Acre Drainage Area ($/ac) | $ 2,205 | $ 1,791 | $ 19,299 | $ 15,585 | **$ 5,410** |
| Cost per Acre Impervious ($/ac) | $ 5,011 | $ 4,592 | $ 49,491 | $ 67,730 | **$ 12,295** |

[a]Annual projected O & M costs were multiplied by the life expectancy of the BMPs (35 years) to derive the 35-year O & M cost.

# 6. Climatological Summary

## 6.1. Background

Over the four-year monitoring period (2007 to 2010) of the Arlington Pascal Project BMPs, weather conditions and precipitation trends varied significantly over the District. The annual precipitation totals over the four-year monitoring period reflected both very dry and very wet conditions. For example, a 24% precipitation increase was observed in 2010 in comparison to the National Weather Service (NWS) 30-year normal precipitation amount. The consequence of variations in precipitation trends on BMP performance were observed in the monitoring results. Thus, understanding the effects of climatological factors to watershed response, are critical for BMP performance analysis.

## 6.2. Data Summary

Climatological data (temperature and precipitation) collected by the Minnesota Climatology Research Group (University of Minnesota- St. Paul) and by the National Weather Service (NWS) were also used in model calibration and performance data modeling for the Arlington Pascal Project BMPs.

The Minnesota Climatology Research Group records precipitation every fifteen minutes from an automatic rain gauge located on the University of Minnesota-St. Paul Campus (UMN). This rain gauge is located approximately two miles directly west of the Arlington Pascal Project area. The data is reported on a public website (http://climate.umn.edu/). The 15-minute precipitation data was used to calculate hourly precipitation totals, monthly precipitation totals, and annual precipitation totals. The hourly precipitation was used for model calibration. Table 6-1 lists the summed annual precipitation totals for 2007 through 2010.

Additionally, precipitation and daily temperatures collected from a NWS weather station, located at the Minneapolis-St. Paul International Airport, were retrieved from a public website (http://www.nws.noaa.gov/climate/index.php?wfo=mpx). This weather station is located approximately ten miles south of the Arlington Pascal Project area. The 2007 to 2010 climate data was compared to the NWS 30-year normal values. Table 6-1 lists the annual mean temperature and annual precipitation departures from the 30-year normal values for the Minneapolis-St. Paul region. Figure 6-1 graphically compares the 30-year normal precipitation values to 2007 to 2010 observed precipitation data.

Over the four-year period that the BMPs were monitored, the 2007 annual precipitation total at the UMN weather station was closest to the NWS 30-year normal value of 29.4 inches with the mean temperature being two and one-half degrees higher than normal. In 2008, approximately eight inches of precipitation less than the NWS 30-year normal value were recorded, showing the greatest departure from normal during the 2007 through 2010 monitoring record. Similarly, 2009 recorded six fewer inches of precipitation than normal. By far, 2010 was the wettest year in the BMP monitoring record, yielding seven more inches of rain than normal with a mean temperature nearly three degrees hotter.

The rainfall amounts in 2010 represented a 24% increase in annual precipitation in comparison to the NWS 30-year normal amount.

**Table 6-1. 2007 to 2010 annual precipitation totals and annual mean temperatures as compared to the NWS 30-year normal.**

| Year | Precipitation (inches)[a] | Mean Temperature (°F) | Departure from Normal |
|---|---|---|---|
| 2007 | 29.72 | 47.8 | 0.3" higher, 2.5° higher |
| 2008 | 21.67 | 44.7 | 7.7" lower, 0.6° lower |
| 2009 | 23.24 | 45.4 | 6.2" lower, 0.1° higher |
| 2010 | 36.32 | 48.2 | 6.9" higher, 2.9° higher |
| NWS 30-Year Normal | 29.41 | 45.3 | |

[a] Annual precipitation reported by UMN.

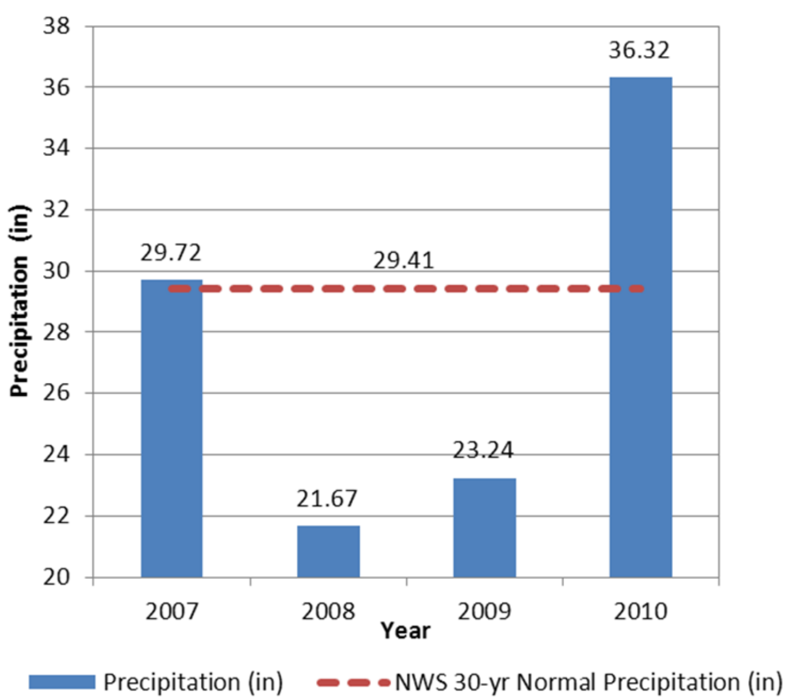


**Figure 6-1. Annual precipitation totals, from 2007 to 2010, as compared to the NWS 30-year normal.**

# 7. Arlington-Hamline Underground Stormwater Facility

## 7.1 Background

The Arlington-Hamline Underground Stormwater Facility (Arlington-Hamline Facility) is a large underground stormwater retention and infiltration system (Figure 7-1). It is located beneath parkland at the southeast corner of Hamline Avenue North and Arlington Avenue West intersection in St. Paul.

**Figure 7-1. Construction of the Arlington-Hamline Facility.**

The Arlington-Hamline Facility has a watershed area of 50 acres with impervious surfaces covering 22 acres (44%) of that area. Primarily, the facility only receives flow resulting from stormwater runoff. It receives untreated runoff from 33 acres within the BMP's 50 acre watershed, which drain directly to the facility. The other 17 acres of the BMP's watershed receive treatment by other Arlington Pascal Project BMPs, nested within the Arlington-Hamline Facility's watershed. Four underground infiltration trenches (on Arlington Avenue) treat stormwater runoff from 13 acres, with any overflows from those four BMPs flowing to the Arlington-Hamline Facility. Additionally, five rain gardens also treat runoff from 4 acres; however, overflow from those BMPs do not flow to the Arlington-Hamline Facility.

The Arlington-Hamline Facility consists of two components: a pipe gallery and a pretreatment unit. The pipe gallery consists of 861-feet of ten-foot diameter, perforated, corrugated metal pipes which store and infiltrate stormwater (Figure 7-1). The pipe gallery has a storage capacity of nearly two-acre feet. A Contech Vortech® Model 7000 functions as a pretreatment unit. The Vortech® is a hydrodynamic separator which is designed to effectively treat low flows by removing sediment, oil, and debris before discharging into the pipe gallery (Appendix B: Figure B-1). A series of flow controls (i.e. large swirl chamber, baffle, and flow control walls) reduce turbulent velocities, decreasing the probability of re-suspension of debris and sediment and increasing the residence time for treatment of stormwater runoff in the device.

Inflow is diverted from a 60-inch storm sewer located in Arlington Avenue to the facility by a diversion weir (Figure 7-2). A short distance from the diversion weir, water then flows to a second diversion weir 2.4 feet in height. During low flow periods (less than 2.4 feet), water is diverted into the pretreatment unit before flowing into the pipe gallery. In instances of high flow (greater than 2.4 feet), water flows directly into the pipe gallery, bypassing the pretreatment unit. When the water depth inside the pipe gallery exceeds 3 feet, water flows out of the pipe gallery through a 12-inch orifice and back into the 60-inch storm sewer in Arlington Avenue. This storm sewer ultimately flows to Como Lake.

Figure 7-2 depicts a diagram of the Arlington-Hamline Facility. Detailed schematics of the facility (as-built) may be found in Appendix B: Figure B-1.

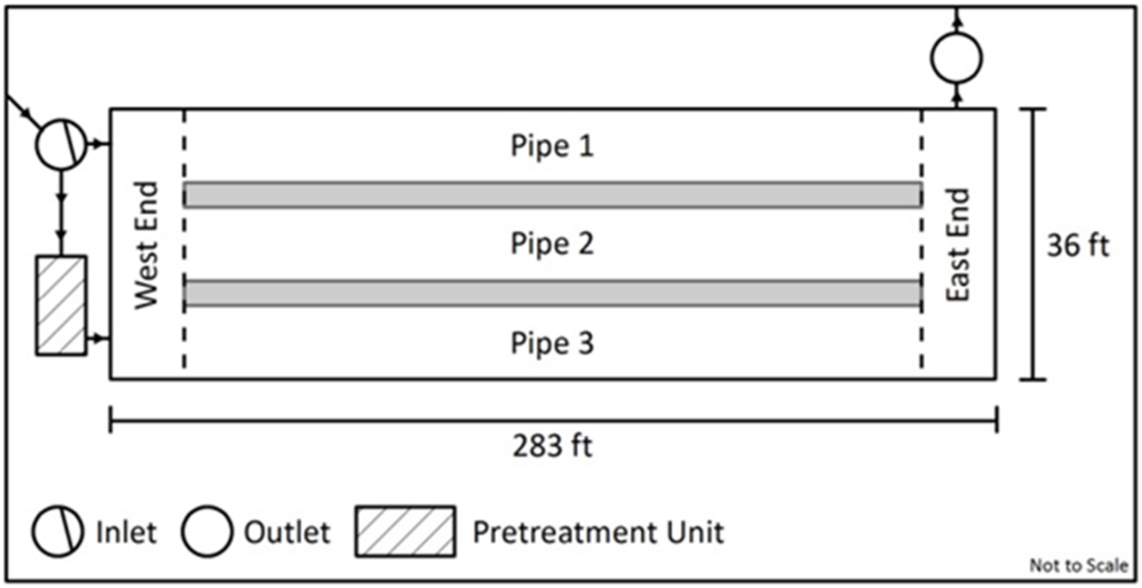


**Figure 7-2. Diagram of the Arlington-Hamline Facility.**

Construction of the Arlington-Hamline Facility began in August 2006 and was completed by October 2006. The total capital cost for the facility was $799,087 which includes the cost of design, construction, and bond interest (Table 7-1). The Arlington-Hamline Facility is owned, operated, and maintained by CRWD.

**Table 7-1. Total capital cost of the Arlington-Hamline Facility.**

| | Cost |
|---|---|
| Design | $86,636 |
| Construction | $487,488 |
| Bond Interest[a] | $224,963 |
| **Capital Cost** | **$799,087** |

[a]Does not include bond interest paid by project partners.

## 7.2. Performance Analysis

Since the Arlington-Hamline Facility became operational, no discharge has overflowed from the system. All stormwater runoff that entered the pipe gallery was stored and infiltrated. Infiltration rates of up to 37 inches per hours were observed within the pipe gallery.

The total volume of stormwater runoff infiltrated by the Arlington-Hamline Facility from 2007 to 2009 was fairly consistent; on average, approximately 486,800 cf of runoff was infiltrated each year (Figure 7-3, Table 7-2). This is significantly lower than the volume of stormwater runoff infiltrated in 2010; on average approximately 758,000 cf more stormwater runoff flowed to and was infiltrated in 2010 than in previous years. In 2010, there was a substantial increase in annual precipitation which generated a greater amount of stormwater runoff in comparison to previous years. From 2007 to 2010, on average 676,400 cf of runoff flowed to and was infiltrated by the BMP each year.

In comparison to the annual projected amount of runoff infiltrated by the Arlington-Hamline Facility (which represents the amount of runoff flowing to and infiltrated during an average precipitation year), the actual amount of stormwater runoff received and infiltrated, from 2007 through 2009, was less than the annual projected amount (Figure 7-3, Table 7-2). The amount of stormwater which flowed to and infiltrated in 2010, was more than double the annual projected amounts. The quantity of stormwater runoff generated by a storm event is largely dictated by the amount of precipitation. Generally, a larger storm event will generate a greater amount stormwater runoff that transported to the BMP. Annual precipitation amounts, from 2007 through 2009, were less than the annual projected precipitation amount (26.0 inches). Annual precipitation in 2010 was significantly higher than the annual projected amount.

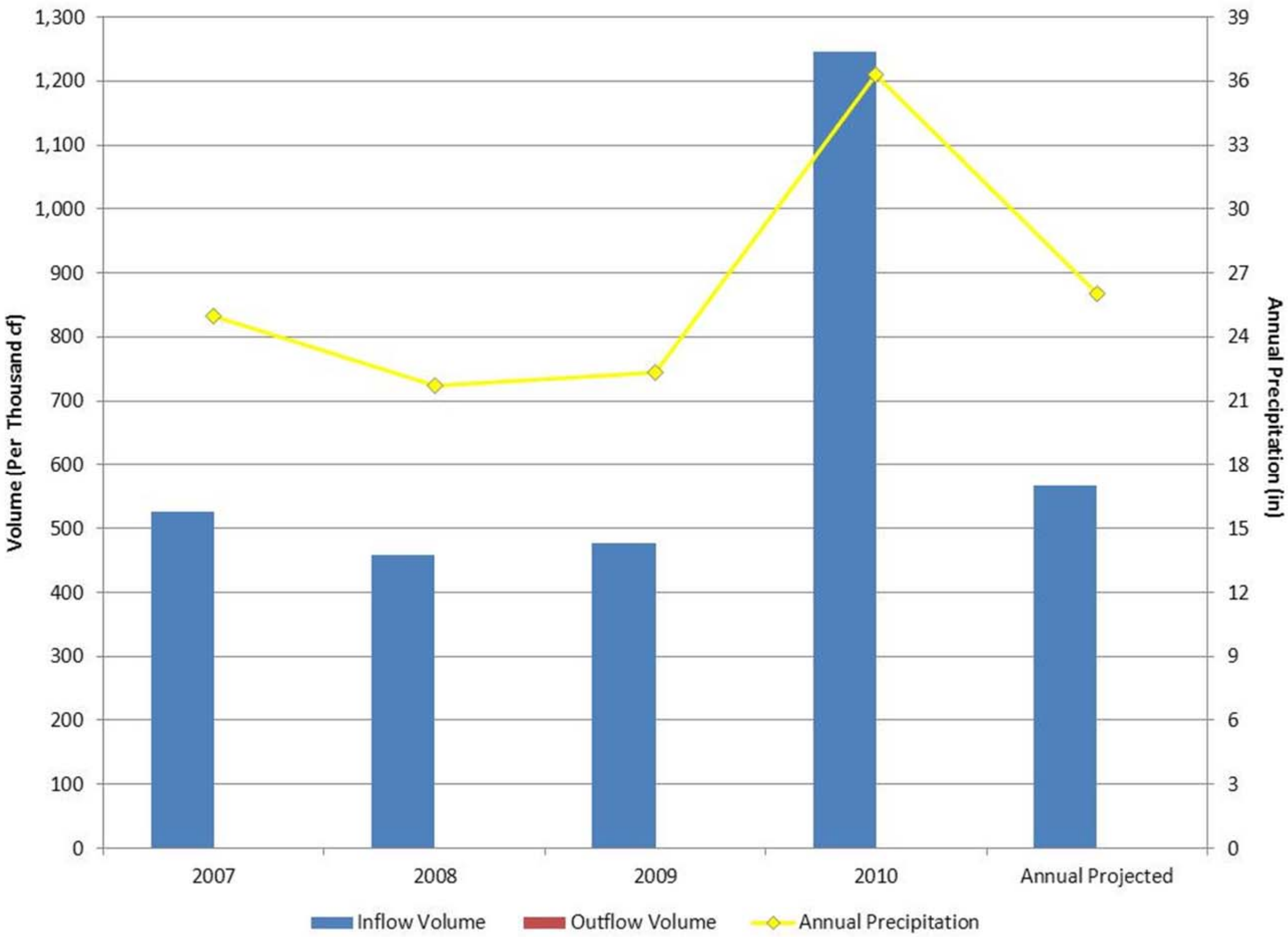


**Figure 7-3. Annual stormwater runoff flowing to and discharging from the Arlington-Hamline Facility from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

There were two types of TP loads determined: 1) the TP load associated with the infiltration of stormwater runoff and settlement of suspended particles and 2) the TP load in the gross solids loads captured by the pretreatment unit and within the pipe gallery. The model did not simulate the gross solids load captured by the pretreatment unit, the gross solids load which accumulated inside the pipe gallery, or the TP load associated with either gross solids load. Instead, it only simulated results for the TP load associated with runoff entering/discharging from the system and the load being removed through infiltration of stormwater and settlement of suspended solids. However, annual cumulative TP loads removed by the entire facility (all components of the BMP), from 2007 to 2010, were calculated.

The cumulative TP load for the Arlington-Hamline Facility includes: 1) the TP load removed through the infiltration of stormwater and 2) the settlement of suspended solids and the TP loads associated with the gross solids captured by both the pretreatment unit and the pipe gallery.

Annual TP loads removed through the infiltration of stormwater runoff from 2007 through 2009 were comparable, averaging 14 pounds (lbs) of TP removed each year (Table 7-2). The TP load removed in

2010 was significantly higher; an increase four times greater in comparison to the loads removed in previous years. From 2007 to 2010, on average, approximately 24 lbs of TP was removed each year. Annual TP loads removed through infiltration of runoff from 2007 to 2009 were less than the annual projected TP load (15.4 lbs). The TP load removed through infiltration in 2010 was two and one-half times that of the annual projected TP load.

Similar to results observed with volume reduction, annual TP loads removed by the BMP through infiltration are greatly dependent upon annual precipitation amounts. With increased precipitation, a greater amount of stormwater runoff and pollutant loads flow to the Arlington-Hamline Facility.

From 2007 through 2010, the TP load associated with the gross solids load captured by both the pretreatment unit and the pipe gallery accounted for, on average, an additional 20 lbs of TP removal each year. The resulting cumulative TP load removed, from 2007 to 2010, was an average of 44 lbs, each year. The cumulative TP load removed in 2010 was double the amount removed in any other year, approximately 72 lbs (Tables 7-2 and 7-3).

When taking into consideration the TP load associated with gross solids, the annual cumulative TP loads from 2007 to 2009 are more comparable to the annual projected TP load than those annual TP loads attributable to just infiltration of stormwater runoff alone. The 2010 annual cumulative TP load removed was still significantly higher than the annual projected cumulative TP load; more than two times as much cumulative TP was removed in 2010 than in the annual projected year.

Figure 7-4 illustrates the amounts of the annual cumulative TP loads removed for the entire Arlington-Hamline Facility attributable to the infiltration of stormwater and gross solids captured within the pretreatment unit and the pipe gallery from 2007 to 2010 and for a year with an average precipitation amount (annual projected).

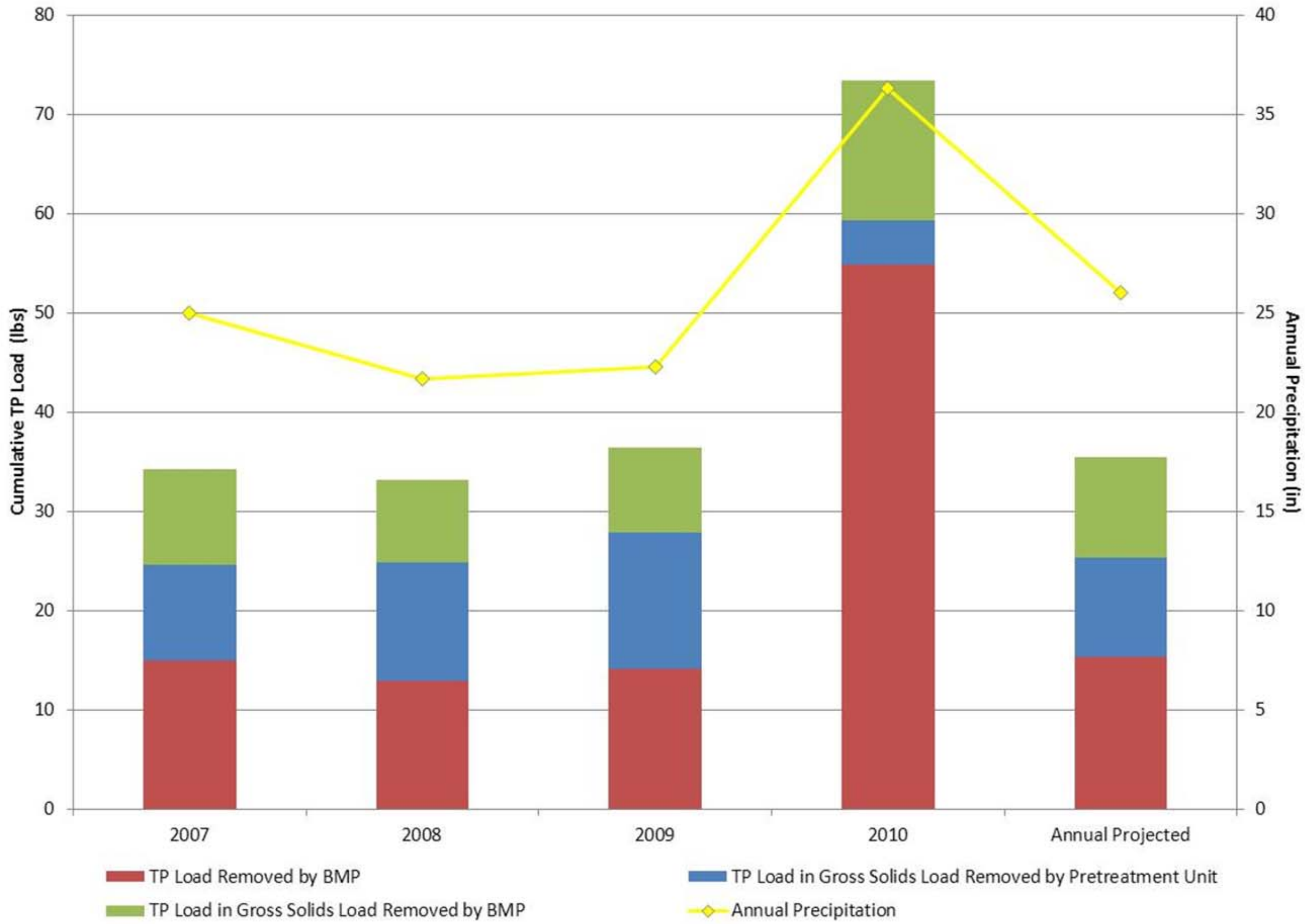


**Figure 7-4. Annual cumulative TP loads removed by the Arlington-Hamline Facility from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

A total solids load was determined which included 1) the gross solids load captured by the pretreatment unit and the pipe gallery and 2) the TSS load removed through the infiltration of stormwater runoff and settlement of suspended particles. On average, approximately 38,800 lbs of total solids were removed by the Arlington-Hamline Facility, annually, from 2007 to 2010 (Table 7-3). On average, 25,600 lbs of gross solids was captured by the pretreatment unit and pipe gallery each year.

In comparison to the annual projected total solids load removed, the annual total solids loads removed by the BMP in 2007 is slightly less than the annual projected load. Also, the annual total solids loads in 2008 and 2009 were slightly greater than the annual projected load (Table 7-3). The annual total solids load for 2010 was one and one-half times greater than the annual projected total solids load.

Figure 7-5 depicts the amount of annual total solids loads attributable to each component of the BMP (the gross solids loads captured by the pretreatment and pipe gallery and the TSS load removed by the BMP). From 2007 to 2009, the gross solids removed by the pretreatment unit accounted for the majority of the total solids load; generally gross solids loads captured by the BMP accounted for the second largest majority. In 2010 there was a noticeable shift from that trend in that the removal of TSS through infiltration of stormwater accounted for the majority of the total solids load removed. Gross solids captured within the BMP, was the second largest majority. This shift in trend may be due to the significant increase in precipitation in 2010. Increased frequency of storm events, higher storm intensities, and more frequent high total precipitation events may have generated higher volumes of stormwater runoff which overtopped the secondary diversion weir causing runoff and associated debris to bypass the pretreatment unit and flow directly into the pipe gallery.

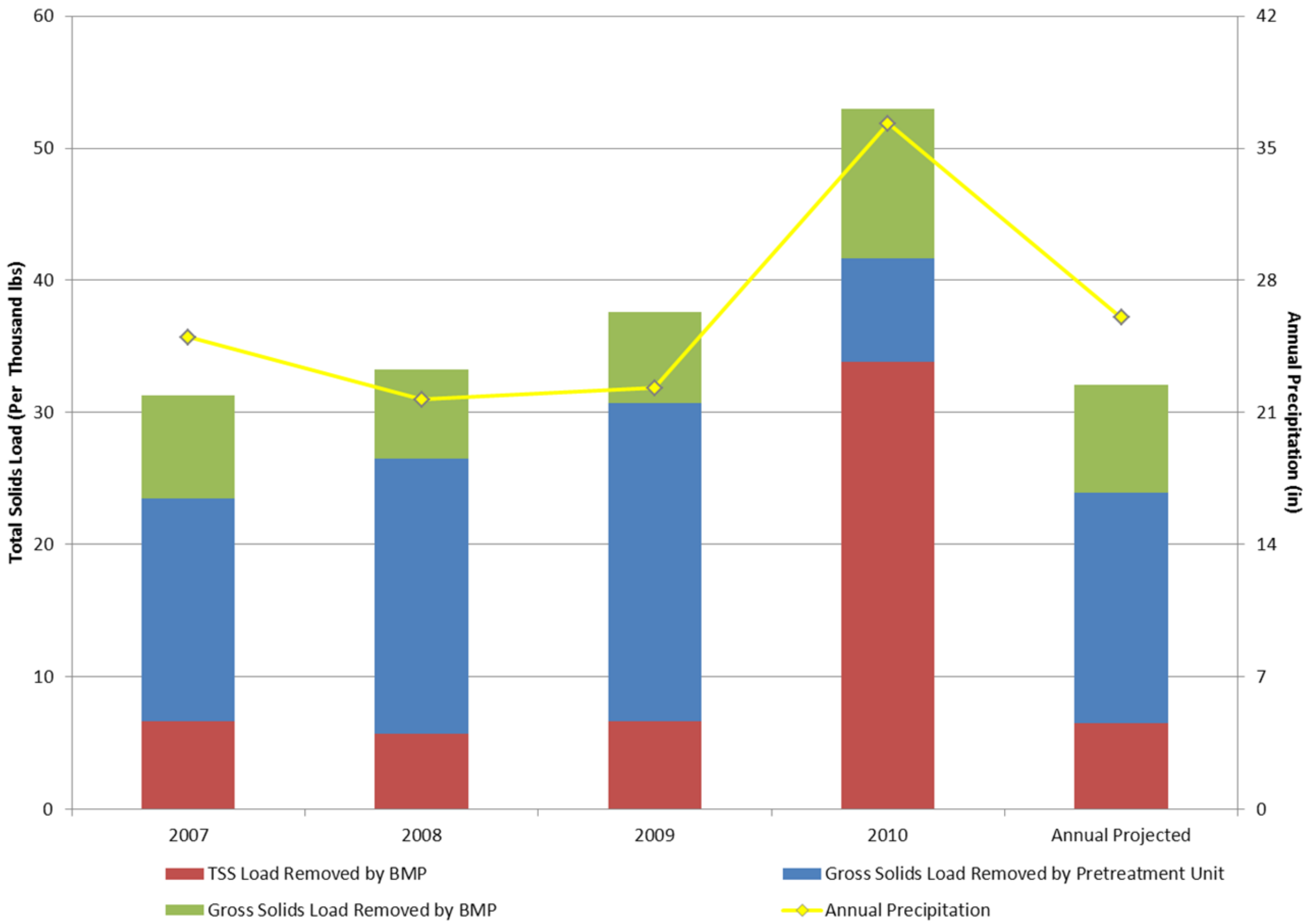


**Figure 7-5. Annual total solids loads removed by the Arlington-Hamline Facility from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

**Table 7-2. Arlington-Hamline Facility annual volume reduction and pollutant removal efficiencies from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected[a] |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 21.7 | 22.3 | 36.3 | 26.0 |
| Subwatershed Area (ac) | 50 | 50 | 50 | 50 | 50 |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | |
| Inflow Volume (cf) | 526,248 | 458,600 | 475,675 | 1,245,032 | 566,149 |
| Outflow Volume (cf) | 0 | 0 | 0 | 0 | 0 |
| Volume Removed by BMP (cf) | 526,248 | 458,600 | 475,675 | 1,245,032 | 566,149 |
| Volume Removal Efficiency (%) | **100%** | **100%** | **100%** | **100%** | **100%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | |
| Inflow TP Load (lbs) | 15.0 | 13.0 | 14.2 | 54.9 | 15.4 |
| Outflow TP Load (lbs) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| TP Load Removed by BMP (lbs) | 15.0 | 13.0 | 14.2 | 54.9 | 15.4 |
| TP Removal Efficiency (%) | **100%** | **100%** | **100%** | **100%** | **100%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | |
| Inflow TSS Load (lbs) | 6,608 | 5,669 | 6,625 | 33,851 | 6,470 |
| Outflow TSS Load (lbs) | 0 | 0 | 0 | 0 | 0 |
| TSS Load Removed by BMP (lbs) | 6,608 | 5,669 | 6,625 | 33,851 | 6,470 |
| TSS Removal Efficiency (%) | **100%** | **100%** | **100%** | **100%** | **100%** |

[a] Annual projected results derived using the 1995 water year.

**Table 7-3. Arlington-Hamline Facility annual cumulative TP and total solids load reductions from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 21.7 | 22.3 | 36.3 | 26.0 |
| Subwatershed Area (ac) | 50 | 50 | 50 | 50 | 50 |
| ***VOLUME REMOVED*** | | | | | |
| Total Volume Removed by BMP (cf) | **526,248** | **458,600** | **475,675** | **1,245,032** | **566,149** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | |
| TP Load Removed by BMP (lbs) | 15.0 | 13.0 | 14.2 | 54.9 | 15.4 |
| TP Load in Gross Solids Load Removed by Pretreatment Unit (lbs) | 9.6 | 11.9 | 13.7 | 4.5 | 9.9 |
| TP Load in Gross Solids Load Removed by BMP (lbs) | 9.8 | 8.6 | 8.6 | 13.8 | 10.2 |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | **34.4** | **33.4** | **36.4** | **73.2** | **35.5** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | |
| TSS Load Removed by BMP (lbs) | 6,608 | 5,669 | 6,625 | 33,851 | 6,470 |
| Gross Solids Load Removed by Pretreatment Unit (lbs) | 16,880 | 20,869 | 24,074 | 7,835 | 17,415 |
| Gross Solids Load Removed by BMP (lbs) | 7,859 | 6,876 | 6,876 | 11,133 | 8,186 |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | **31,347** | **33,414** | **37,575** | **52,819** | **32,071** |

## 7.3 Operation and Maintenance

In consideration of its size, the Arlington-Hamline Facility has been a fairly low maintenance BMP during regular maintenance years; requiring on average 12 hours of staff time and $1,600 annually. The primary O & M costs CRWD has incurred since the BMP became operational have been associated with labor and contract services costs.

Labor costs are attributable to staff time spent conducting routine field inspections of debris and sediment accumulation within the pipe gallery and pretreatment unit. The majority of the annual O & M cost is due to contract services which includes the removal of debris and sediment from within the pretreatment unit. In years that debris removal occurred (2008 to 2010), those services accounted for an average of 88% of the total annual O & M cost. Annual O & M costs and staff hours are listed in Table 7-4.

**Table 7-4. Annual O & M costs and labor hours from 2007 to 2010 for the Arlington-Hamline Facility.**

| Year | Labor | Equipment & Materials | Contract Services | Total | Labor Hours |
|---|---|---|---|---|---|
| 2007 | $267 | $264 | $0 | $531 | 12.8 |
| 2008 | $296 | $0 | $1,729 | $2,025 | 13.9 |
| 2009 | $211 | $0 | $1,729 | $1,940 | 13.0 |
| 2010 | $168 | $0 | $1,728 | $1,896 | 10.0 |
| **Total:** | **$942** | **$264** | **$5,185** | **$6,392** | **49.7** |

Table 7-5 illustrates the current inspection and maintenance schedule for the Arlington-Hamline Facility. This schedule is expected to remain the same in the immediate future. Inspections were conducted by CRWD semi-annually (once in the spring and once in the fall) of the second inlet diversion structure, the pretreatment chamber, the pipe gallery, and the outlet structure. The overall conditions of the structures were noted as well as the composition and depth of any debris which may have accumulated in each structure. A contractor was hired to remove the debris and sediment from the pretreatment unit semi-annually.

**Table 7-5. Inspection and maintenance schedule for the Arlington-Hamline Facility.**

| Activity | Frequency |
|---|---|
| Manhole Sediment Inspection | Semi-Annual |
| Pipe Gallery Inspection | Semi-Annual |
| Pretreatment Unit Sediment Inspection | Semi-Annual |
| Debris Removal from the Pretreatment Unit | Semi-Annual |

In future years, staff hours spent on inspections and maintenance is not expected to substantially deviate from the average. The cost associated with debris removal from the pretreatment unit is expected to increase due to the cost of inflation, as well as the potential change in costs (increase or decrease) associated with a change in the vendor providing the service.

The Arlington-Hamline Facility is a relatively new type of stormwater BMP; consequently, long term maintenance data is not available.  It is expected that some amount of irregular maintenance and costs will be incurred over the life expectancy of the BMP.  Removing the accumulated debris and sediment within the pipe gallery is an example of a future activity necessary to keep the BMP functioning.

CRWD estimates that removal of the debris from within the pipe gallery will need to occur three times over the life expectancy of the BMP (35 years), with an estimated cost of $10,000 per time. The total cost of the estimated three debris removals was amortized over the life expectancy of the BMP and incorporated into the annual projected O & M costs in Table 7-6.  The cost was amortized in order to keep annual O & M costs comparable.  CRWD acknowledges and fully expects that the annual O & M cost for those years in which irregular maintenance activities occur will be substantially higher than the O & M costs from those regular maintenance years.

Itemized annual O & M activities and costs for 2009 and 2010 for the Arlington-Hamline Facility may be found in Appendix A: Tables A-34 and A-35.

## 7.4 Cost-Benefit Analysis

From 2007 to 2010, the Arlington-Hamline Facility has had a very consistent annual operating cost averaging approximately $26,000 per year (Table 7-6).  The annual operating cost is directly related to increases or decreases in the annual O & M cost; the annual capital cost is a fixed value.

The 2007 annual operating cost was lower than any other year (Table 7-6).  In 2007, the debris was not removed from the pretreatment unit which occurred twice a year in 2008, 2009, and 2010.  The annual projected operating cost for the Arlington-Hamline Facility is slightly higher than the 2007 through 2010 annual operating costs.  The projected operating cost is an estimated future annual operating cost based on a year with average precipitation and maintenance.  The projected operating cost incorporates costs for those irregular maintenance activities described above, therefore the cost should be higher.

**Table 7-6. Arlington-Hamline Facility annual operating costs.**

| | Annual Capital Cost[a] | Annual O & M Cost | Annual Operating Cost |
|---|---|---|---|
| 2007 | $24,605 | $531 | $25,136 |
| 2008 | $24,605 | $2,025 | $26,630 |
| 2009 | $24,605 | $1,940 | $26,545 |
| 2010 | $24,605 | $1,896 | $26,502 |
| Annual Projected | $24,605 | $3,150 | $27,755 |

[a] Capital cost amortized over 35 years.

In 2010, there was a significant increase in annual precipitation in comparison to annual precipitation amounts observed in 2007, 2008, and 2009. Thus, total discharge and pollutant loads removed by the Arlington-Hamline Facility in 2010 were substantially greater than the volume reduction and pollutant loads removed by the BMP from 2007 through 2009. Consequently, volume reduction and pollutant removal costs in 2010 were lower than any other year (Table 7-7). The 2010 volume reduction and pollutant removal costs are also substantially lower than the annual projected removal costs which represent removal costs during an average precipitation year. Removal costs for 2007 through 2009 are fairly consistent with annual projected volume reduction and pollutant removal costs, more so than the 2010 costs.

The cumulative TP load removed includes the amount of TP removed by the BMP through infiltration of stormwater runoff and settlement of suspended particles and the amount of TP removed through gross solids accumulation within the pretreatment unit and the pipe gallery. The TP removal cost tends to be significantly higher than the other pollutant removal costs (TSS and total solids) because the amount of TSS and gross solids removed is often three orders of magnitude higher than the amount of TP removed. The average cost to remove a pound of TP was $591.

Total solids include the amount of TSS removed through the infiltration of stormwater and settlement of suspended particles and the amount of gross solids captured by the pretreatment unit and the pipe gallery. Total solids removal costs should be lower than TSS removal costs alone. The average removal cost per pound of TSS was $1.99 and the average removal cost per pound of total solids was $0.70 (Table 7-7).

Volume reduction costs from 2007 to 2009 were comparable and more consistent with the annual projected cost than the 2010 cost (Table 7-7). The 2010 volume reduction cost was two to three times less than those costs from 2007 to 2009. On average, the cost to remove one cubic foot of stormwater runoff was $0.05.

**Table 7-7. Arlington-Hamline Facility annual volume reduction and pollutant removal and costs.**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected |
|---|---|---|---|---|---|
| Annual Operating Cost | $25,136 | $26,630 | $26,545 | $26,502 | $27,755 |
| Volume Reduction (cf/year) | 526,248 | 458,600 | 475,675 | 1,245,032 | 566,149 |
| Volume Reduction Cost ($/cf) | $0.05 | $0.06 | $0.06 | $0.02 | $0.05 |
| Cumulative TP Load Removed (lbs/year)[a] | 34.4 | 33.4 | 36.4 | 73.2 | 35.5 |
| Cumulative TP Removal Cost ($/lb) | $732 | $797 | $729 | $362 | $782 |
| TSS Load Removed (lbs/year) | 6,608 | 5,669 | 6,625 | 33,851 | 6,470 |
| TSS Removal Cost ($/lb) | $3.80 | $4.70 | $4.01 | $0.78 | $4.29 |
| Total Solids Load Removed (lbs/year)[b] | 31,347 | 33,414 | 37,575 | 52,819 | 32,071 |
| Total Solids Removal Cost ($/lb) | $0.80 | $0.80 | $0.71 | $0.50 | $0.87 |

a Includes the TP load removed through infiltration of stormwater runoff and settlement of suspended particles and the TP load associated with the gross solids load captured by the BMP.

[b] Includes the TSS load removed through infiltration of stromwater and settlement of suspended particles as well as the gross solids load captured by the BMP.

# 8. Como Park Regional Pond

## 8.1. Background

The Como Park Regional Pond is a regional stormwater pond that was constructed on the Como Golf Course in St. Paul, between the 3rd and 11th fairways, in 2007 (Figure 2-3, Figures 8-1 and 8-2). Construction of the pond involved re-grading an existing depression to allow for the storage and treatment of runoff via a multi-stage gravity outlet.

The Como Park Regional Pond has a direct drainage area of 128 acres, of which, 39% is covered by impervious surfaces. The pond also receives runoff from the City of Roseville (522 acres) via discharges from Gottfried's Pit (Figure 2-4, Figure 3-1). Gottfried's Pit is a stormwater basin which has an automatic pumping system. When the water level in Gottfried's Pit reaches an elevation greater than 897 feet, typically achieved during storm events, water is automatically pumped out and drains to the Como Park Regional Pond.

Stormwater inflow from both Gottfried's Pit and the direct drainage area is diverted to the Como Park Regional Pond by a 3.4 feet tall, concrete weir located in a diversion structure at the corner of Chelsea Street and Arlington Avenue. Flow into the pond is regulated by a 42-inch sluice gate in the diversion structure. If the water level inside of the diversion structure exceeds 3.4 feet, it flows over a concrete weir bypassing the pond and into a 60-inch storm sewer that drains to Como Lake.

Water flows out of the pond through an 8-inch PVC drain pipe in the outlet structure when the water level of the pond exceeds an elevation of 888.8 feet. If the water level of the pond exceeds an elevation of 891.8 feet, the discharge flows over a notch which serves as a secondary overflow in the outlet structure. If the water level exceeds 893.2 feet, the discharge then also flows into an emergency overflow (grate at the top of the outlet structure). Flow can be regulated through opening or closing a gate valve in the outlet structure. All discharge eventually flows into a 60-inch storm sewer that drains to Como Lake. A detailed schematic of the Como Park Regional Pond as-built may be found in Appendix B: Figure B-2.

Construction of the Como Park Regional Pond began in March 2007 and was completed in November 2007. The pond became operational in late December 2007. The total capital cost for the pond was $1,364,346 which includes the cost of design, construction, and bond interest (Table 8-1). The Como Park Pond is owned by the City of St. Paul. CRWD is ultimately responsible for the overall operation and maintenance of the pond, but receives assistance from the City of St. Paul Parks and Recreation Department with general maintenance.

**Table 8-1. Total capital cost of the Como Park Regional Pond.**

| | Cost |
|---|---|
| Design | $147,926 |
| Construction | $832,357 |
| Bond Interest[a] | $384,063 |
| **Capital Cost** | **$1,364,346** |

[a]Does not include bond interest paid by project partners.

**Figure 8-1. Normal water level of the Como Park Regional Pond in September 2009.**

**Figure 8-2. The Como Park Regional Pond after a rainfall in August 2010.**

## 8.2. Performance Analysis

The Como Park Regional Pond is a stormwater storage system that was designed to provide short-term storage of stormwater runoff, allowing time for suspended sediments to settle out of the water column, rather than through infiltration. On average, the pond received 10.6 million cf of stormwater runoff and infiltrated 7% (735,000 cf), annually, from 2008 to 2010 (Table 8-2). However, as sedimentation continues, infiltration rates are expected to gradually decrease over time until sediment is removed from the pond. A small amount of infiltration would likely occur at the fringes of the pond.

Annual precipitation in 2008 and 2009 was fairly comparable and stormwater runoff flowing to the Como Park Pond averaged 7.65 million cf (Figure 8-3, Table 8-2). Annual precipitation in 2010 was substantially more than the amounts in 2008 and 2009. In 2010, stormwater runoff flowing to the pond was more than double that of previous years at 16.3 million cf. Although there was more runoff flowing to the pond in 2010, the total volume infiltrated was the lowest; only 5% of runoff to the pond was infiltrated in comparison to 9% in 2008 and 10% in 2009.

In a year with an average precipitation amount (annual projected), approximately 9.7 million cf of stormwater runoff is expected to flow to the pond, with 9% of that runoff being lost through infiltration and evapotranspiration. Stormwater runoff flowing to the pond in 2008 and 2009 are lower than the annual projected amount (Table 8-2). Although the annual amounts of runoff flowing to the pond in 2008 and 2009 were less than the annual projected amount, the portion of that flow which was infiltrated was the same (2008) or higher (2009) than the annual projected amount. Runoff flowing to the pond in 2010 was significantly higher than that annual projected amount; more than one and one-half times more runoff flowed to the pond in 2010 than in the annual projected year. However, the volume reduction efficiency of the pond in 2010 (5%) was lower than the annual projected volume reduction efficiency (9%).

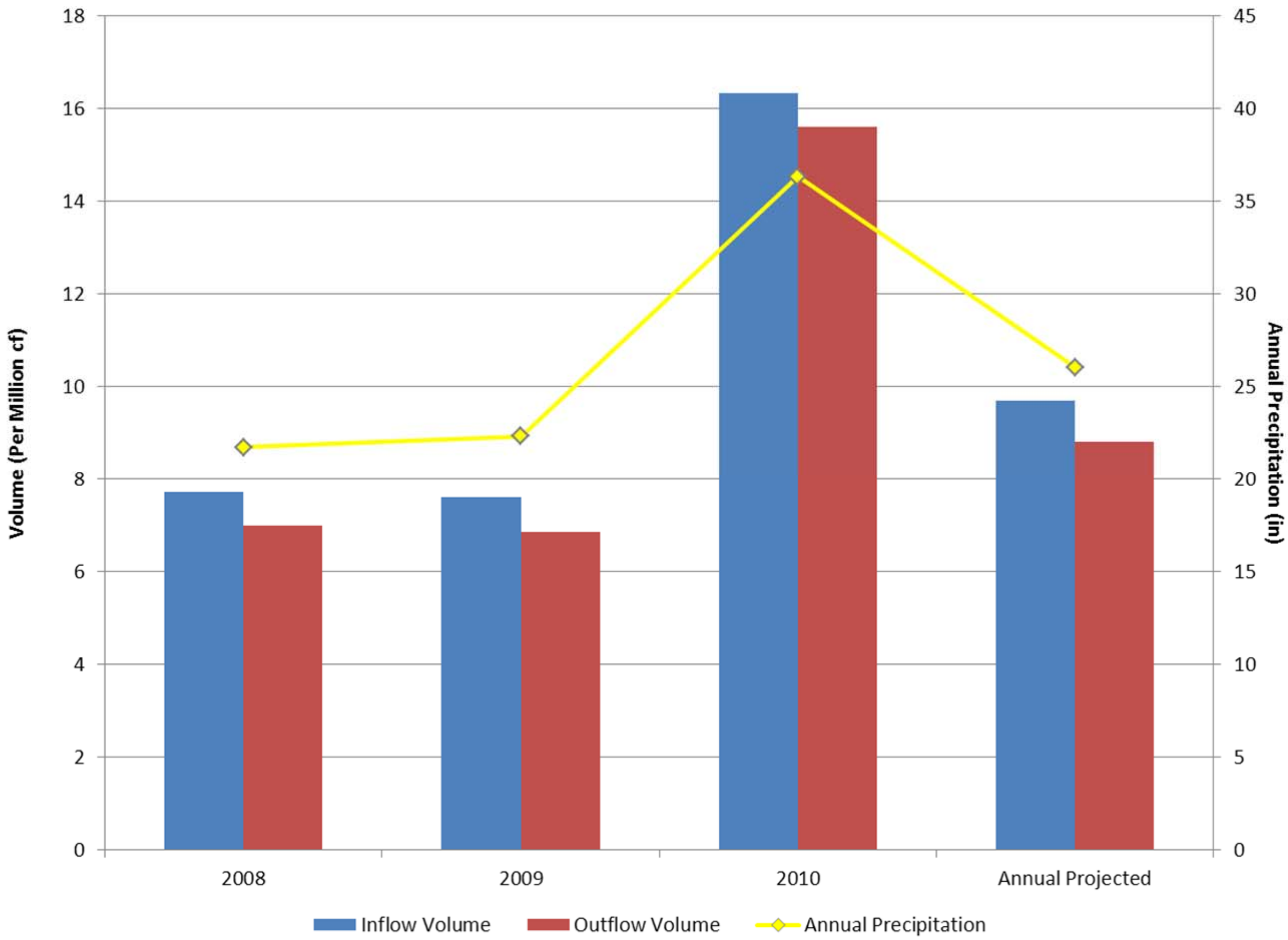


**Figure 8-3. Annual stormwater runoff flowing to and discharging from the Como Park Regional Pond from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

From 2008 to 2010, the pond has more efficiently removed TSS than TP (Note: load reductions in this immediate discussion, refers to the loads removed through the infiltration and settlement of suspended solids). On average, 73% of the TSS load was removed each year in comparison to only 30% of the TP load (Table 8-2).

From 2008 to 2010, the pond's efficiency at removing TSS has decreased each year; falling from 82% in 2008 to 69% in 2010 (Table 8-2). Annual TSS loads flowing to and from the pond in 2008 and 2009 were consistent with the annual projected loads. In addition, the TSS removal efficiencies for those two years are also comparable to the annual projected TSS removal efficiency.

The 2010, TSS loads were significantly higher than the annual projected loads; TSS loads flowing to and from the pond in 2010 were more than three and one-half times and five and one-half times greater than the annual projected loads flowing to and from the pond, respectively (Table 8-2). Although the pond removed more than three times the TSS load in 2010 than in the annual projected year, the removal efficiency was significantly less; 69% in 2010 and 80% in the annual projected year.

Variations in annual precipitation amounts equate to variations in the amount of stormwater runoff and associated pollutant loading. Greater amounts of precipitation generally tend to generate greater amounts of stormwater runoff and associated pollutant loads flowing to the pond than in those years with less precipitation. However, greater amounts of runoff and pollutant loads flowing to the pond do not necessarily equate to greater volume and pollutant load reductions.

The decrease in TSS removal efficiencies may be caused in part by sedimentation of the pond, which decreases the amount of storage volume available. However, it is most likely due to shorter residence times for stormwater runoff which may be caused by one or a combination of more frequent storm events, storm events with more precipitation and/or higher intensities, and saturated soil moisture conditions. It should be noted that pumping capabilities of Gottfried's Pit (which pumps water to the Como Park Pond) were upgraded in late 2010, allowing for more stormwater to be pumped at a higher rate. This additional flow may also have contributed to shorter holding times in the pond.

Annual TP removal efficiencies from 2008 to 2010 were higher (30%) than the annual projected TP removal efficiency (28%) (Table 8-2). Although the 2008 through 2010 TP removal efficiencies were slightly higher than the annual projected efficiency, the amount of annual TP loads (flowing into and being removed by the pond) in 2008 and 2009 were less than the annual projected load. The 2010 TP loads flowing into and being removed by the pond were significantly higher. The annual projected TP load flowing to and being removed by the pond was 133 lbs and 96 lbs, respectively (Table 8-2).

Although the volume of stormwater runoff and pollutant loads flowing to and from the pond has varied annually from 2008 to 2010, the TP removal efficiency of the pond has remained constant at 30%. In 2010 there was almost three times as much TP load flowing to the pond than in 2008 or 2009. Although there was three times as much TP load, only 30% of that load was removed. Regardless of the amount of stormwater runoff which flowed to the pond from 2008 to 2010, the pond's mechanism for TP removal (settling of suspended particles) reached a maximum (30%) each year.

An annual cumulative TP load was calculated which includes 1) the TP load removed by the infiltration of stormwater and settlement of suspended solids and 2) the TP load removed by the BMP through accumulation of gross solids (all litter, organic debris, and coarse sediments (>75 µm). On average, an additional 58 lbs of TP was removed, annually, through accumulation of gross solids; which in 2008 and 2009 accounted for the majority of the annual cumulative TP load removed by the pond (Figure 8-4, Table 8-3). In 2010, the TP load removed through infiltration accounted for the majority and may be due to less gross solids accumulation caused by shorter holding times. From 2008 to 2010, on average 110 lbs of cumulative TP was removed by the pond each year.

In comparison to the annual projected cumulative TP load, annual cumulative TP loads removed from 2008 through 2010 all exceeded the annual projected cumulative TP load. The 2008 and 2009 annual TP loads removed through the accumulation of gross solids both exceeded the annual projected TP load associated with gross solids and the 2010 annual TP load was less (Table 8-3).

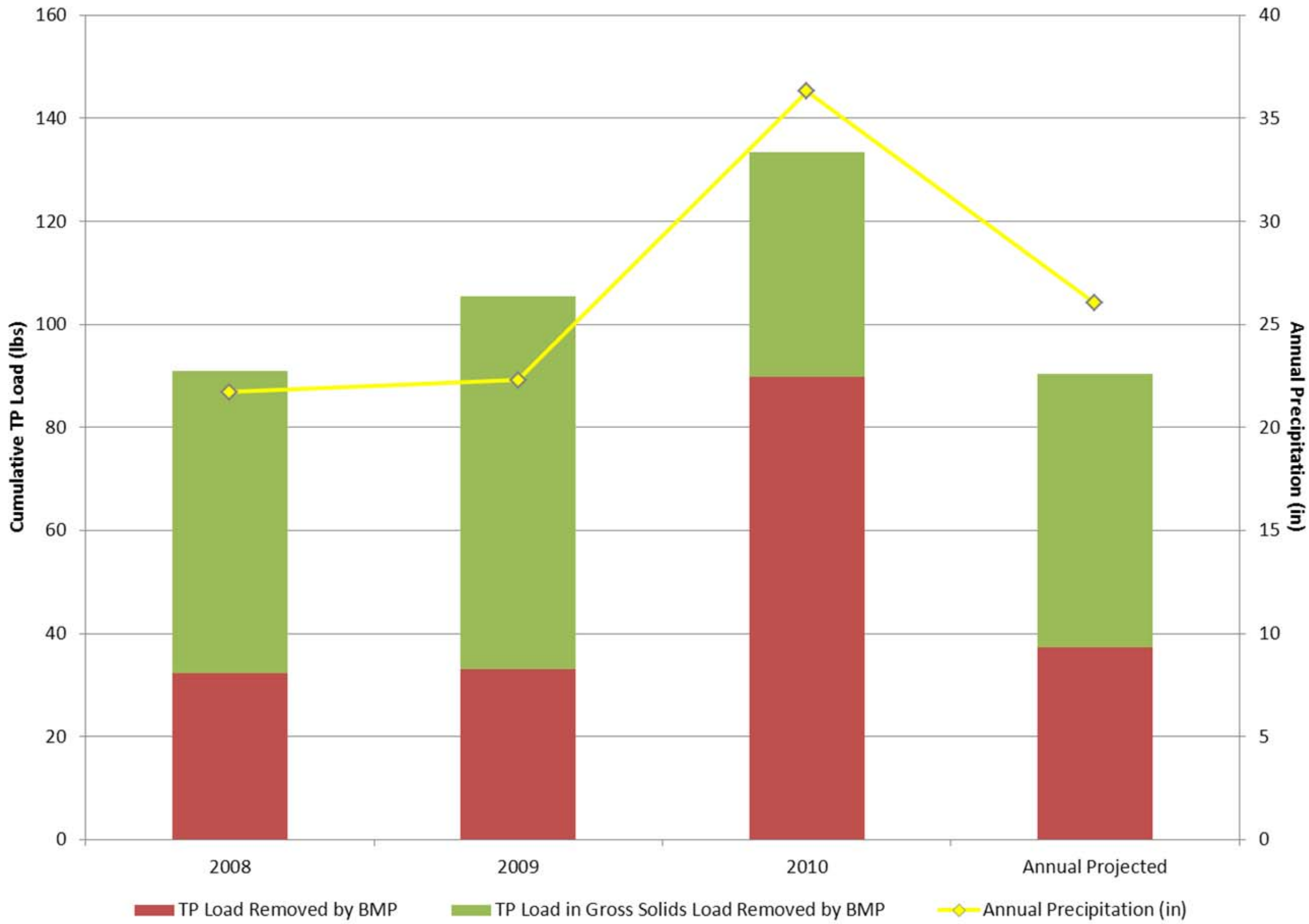


**Figure 8-4. Annual cumulative TP loads removed by the Como Park Regional Pond from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

A total solids load was also calculated which incorporates: 1) the total TSS load removed through infiltration and settlement of suspended particles and 2) the amount of gross solids which accumulated in the pond. From 2008 through 2010, an average of 145,000 lbs of gross solids accumulated in the pond annually (Figure 8-5, Table 8-3). Combined with the TSS load removed, the total solids load removed by the pond averaged 189,000 lbs annually. In 2008 and 2009, accumulation of gross solids accounted for the majority of the total solids load. From 2008 through 2010 the annual total solids loads removed by the pond all exceeded the annual projected total solids load.

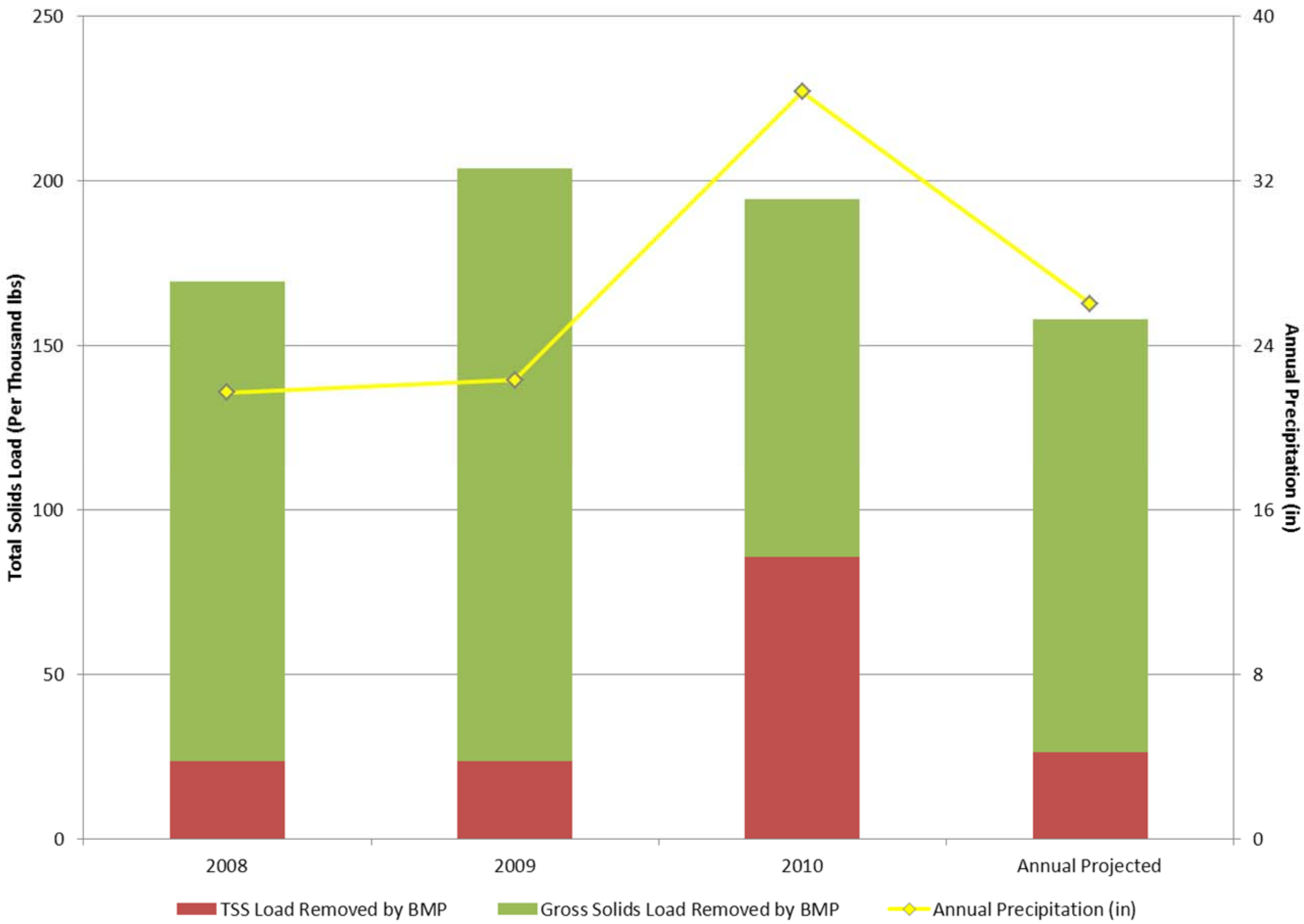


**Figure 8-5. Annual total solids loads removed by the Como Park Regional Pond from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

**Table 8-2. Como Park Regional Pond annual volume reduction and pollutant removal efficiencies from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

| | 2008 | 2009 | 2010 | Annual Projected[a] |
|---|---|---|---|---|
| Annual Precipitation (in) | 21.7 | 22.3 | 36.3 | 26.0 |
| Subwatershed Area (ac) | 128 | 128 | 128 | 128 |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | |
| Inflow Volume (cf) | 7,711,819 | 7,598,694 | 16,327,464 | 9,690,663 |
| Outflow Volume (cf) | 6,992,905 | 6,851,204 | 15,589,471 | 8,814,322 |
| Volume Removed by BMP (cf) | 718,914 | 747,490 | 737,994 | 876,341 |
| Volume Removal Efficiency (%) | **9%** | **10%** | **5%** | **9%** |
| ***TP REMOVAL EFFICIENCY*** | | | | |
| Inflow TP Load (lbs) | 108.6 | 109.8 | 302.2 | 133.5 |
| Outflow TP Load (lbs) | 76.4 | 76.8 | 212.5 | 96.1 |
| TP Load Removed by BMP (lbs) | 32.3 | 33.0 | 89.7 | 37.4 |
| TP Removal Efficiency (%) | **30%** | **30%** | **30%** | **28%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | |
| Inflow TSS Load (lbs) | 28,581 | 29,845 | 124,242 | 32,782 |
| Outflow TSS Load (lbs) | 5,079 | 6,221 | 38,513 | 6,609 |
| TSS Load Removed by BMP (lbs) | 23,502 | 23,624 | 85,729 | 26,173 |
| TSS Removal Efficiency (%) | **82%** | **79%** | **69%** | **80%** |

[a] Annual projected results derived using the 1995 water year.

**Table 8-3. Como Park Regional Pond annual cumulative TP and total solids load reductions from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

| | 2008 | 2009 | 2010 | Annual Projected |
|---|---|---|---|---|
| Annual Precipitation (in) | 21.7 | 22.3 | 36.3 | 26.0 |
| Subwatershed Area (ac) | 128 | 128 | 128 | 128 |
| ***VOLUME REMOVED*** | | | | |
| Total Volume Removed by BMP (cf) | **718,914** | **747,490** | **737,994** | **876,341** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | |
| TP Load Removed by BMP (lbs) | 32.3 | 33.0 | 89.7 | 37.4 |
| TP Load in Gross Solids Load Removed by BMP (lbs) | 58.6 | 72.3 | 43.7 | 53.0 |
| Cumulative TP Load Removed: BMP (lbs) | **90.9** | **105.3** | **133.4** | **90.4** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | |
| TSS Load Removed by BMP (lbs) | 23,502 | 23,624 | 85,729 | 26,173 |
| Gross Solids Load Removed by BMP (lbs) | 145,791 | 180,003 | 108,717 | 131,780 |
| Total Solids Load Removed: BMP (lbs) | **169,293** | **203,627** | **194,446** | **157,953** |

## 8.3. Operation and Maintenance

CRWD is responsible for the O & M of the Como Park Regional Pond. However, due to the pond's location between fairways on the Como Park Golf Course (which is operated by the City of St. Paul), City of St. Paul Parks and Recreation staff frequently completed maintenance, including trash removal from the pond's perimeter, inlet, and outlet and provided updates to CRWD on the performance of the pond. Their time is reflected in staff hours and labor costs in Table 8-4.

**Table 8-4. Annual O & M costs and labor hours for the Como Park Regional Pond.**

| Year | Labor | Equipment & Materials | Contract Services | Total | Labor Hours[a] |
|---|---|---|---|---|---|
| 2008 | $983 | $31 | $5,544 | $6,558 | 77.8 |
| 2009 | $915 | $0 | $0 | $915 | 75.2 |
| 2010 | $1,152 | $0 | $0 | $1,152 | 94.1 |
| **Total:** | **$3,051** | **$31** | **$5,544** | **$8,625** | **247.1** |

[a] Includes both CRWD and City of Saint Paul staff hours.

With the exception of a one-time cost to develop an inspection and maintenance manual for the pond ($5,544 in 2008), annual O & M costs have almost all been attributed to labor costs for inspections and maintenance. Labor costs and staff time has been fairly consistent from 2008 to 2010. The 2010 staff hours and labors costs were slightly higher than 2008 and 2009 because there were more storm events which required additional debris cleanup along the pond perimeter.

As indicated above, CRWD receives assistance from the City of St. Paul staff for maintenance or the pond. CRWD also conducts post-rain inspections, general inspections, and maintenance of the inlet and outlet control structures. Table 8-5 illustrates the current inspection and maintenance schedule for the pond. It is expected that in the immediate future this inspection and maintenance schedule will not substantially change and that debris removal following storm events will vary year-to-year depending on the amount of precipitation.

**Table 8-5. Inspection and maintenance schedule for the Como Park Regional Pond.**

| Activity | Frequency |
|---|---|
| Debris Removal from Pond Perimeter and Control Structures | After Every Storm Event |
| Post-Rain Inspection | After Major Rainfall |
| General Inspection | Quarterly |
| Maintenance of Inlet and Outlet Control Structures | Semi-Annual |

Post-rain inspections are visual site evaluations completed after major rainfall events (those storm events totaling two inches or more of precipitation). The pond perimeter is inspected for erosion, bank failures, and any other notable anomalies.  The pond inlet, outlet, and overflow structures are also inspected for damage and overall structure condition in observed.  General inspections are identical to post-rain inspections with the only difference being that general inspections are completed on a quarterly basis during dry weather periods.

Maintenance of control structures at the inlet and outlet of the pond was also completed on a semi-annual basis.  The sluice gate at the inlet diversion structure and the gate valve in the outlet structure, both of which control flow in and out of the pond, were maintained.  The sluice gate tracks were cleaned of debris and old grease, new grease was applied to the sluice gate tracks, and the sluice gate was lowered and raised several times.  Grease was also applied to the control structure at the outlet of the pond if necessary and was closed and opened several times.

It is expected that some amount of irregular maintenance and costs will be incurred over the life expectancy of the pond including completion of bathymetric surveys, sediment dredging, muskrat control improvements, and riparian buffer establishment.  The total cost of irregular maintenance activities was estimated, amortized over the life expectancy of the BMP (to keep annual O & M costs comparable), and incorporated into the annual projected O & M costs in Table 8-6 .  The estimated costs or the irregular maintenance activities are outlined below.

In accordance with the inspection and maintenance manual completed for the pond, CRWD will be completing bathymetric surveys every five year to monitor the sedimentation rates.  CRWD estimates that it will cost roughly $10,000 to complete a bathymetric survey and analyze the data.  A total of seven surveys will be conducted over the lifetime of the BMP, resulting in a total cost of $70,000.

It is estimated that dredging of sediment near the inlet of the stormwater pond will need to occur twice over the 35-year life expectancy (approximately once every 15 years). CRWD estimates that it will cost a total of $100,000 ($50,000 per dredge).

A barrier was installed along the pond perimeter, during the pond’s construction, to prevent muskrats from burrowing into the bank (see Como Park Regional Pond As-Builts for more detail, Appendix B: Figure B-2).  During the winter of 2010, this control practice became dislodged from the bank.  It was deemed essential to restore the control and install a shoreline buffer to prevent the barrier from becoming displaced in the future.  CRWD expects that the installation of the barrier and buffer to occur one-time over the life expectancy of the BMP at an estimated cost of $15,000.

Itemized annual O & M activities and costs for 2009 and 2010 for the Como Park Regional Pond may be found in Appendix A: Tables A-36 and A-37.

## 8.4.  Cost-Benefit Analysis

From 2008 to 2010, the annual operating cost of the Como Park Regional Pond averaged $41,856 each year (Table 8-6).  This is slightly more than the annual projected operating cost which is an anticipated annual operating cost which also incorporates costs for those large scale maintenance activities described above. The annual operating cost is directly related to increases or decreases in annual O & M costs. The annual capital cost is a fixed value.

**Table 8-6. Como Park Regional Pond annual operating costs.**

| | Annual Capital Cost[a] | Annual O & M Cost | Annual Operating Cost |
|---|---|---|---|
| 2008 | $38,981 | $6,558 | $45,539 |
| 2009 | $38,981 | $915 | $39,897 |
| 2010 | $38,981 | $1,152 | $40,134 |
| Annual Projected | $38,981 | $6,550 | $45,531 |

[a] Capital cost amortized over 35 years.

The TP removal cost for the Como Park Pond averaged $381 per pound (Table 8-7). This includes the TP load removed through infiltration of stormwater and settlement of suspended particles and the TP load removed through the accumulation of gross solids. The lowest TP removal cost was in 2010; which had a relatively low annual operating cost and the largest TP load removed.

TSS removal costs for the pond were low, averaging $0.95 per pound (Table 8-7). When incorporating the annual gross solids loads also removed by the pond, the removal costs dropped significantly (over four times less); averaging $0.22 per pound of total solids per year.

Significant variations were not observed in the volume reduction costs from 2008 to 2010 (Table 8-7). The volume of stormwater runoff removed each year was fairly comparable as well as no substantial differences in annual operating costs. Volume reduction costs averaged just $0.06 per cubic foot.

The highest pollutant removal and volume reduction costs occurred in 2008 which can be attributed to the highest annual operating costs, the lowest amount of pollutants removed, and the lowest volume infiltrated from 2008 through 2010 (Table 8-7). Generally, 2010 had the lowest pollutant removal and volume reduction costs except for total solids. The lowest annual operating costs occurred in 2009 because the largest amounts of total solids were removed, resulting in the lowest total solids removal cost.

The annual projected volume reduction and pollutant removal costs are representative of a year with an average amount of precipitation and also incorporated the costs for irregular maintenance activities. The higher projected annual operating costs drives higher annual projected volume reduction and pollutant removal costs.

**Table 8-7. Como Park Regional Pond annual volume reduction and pollutant removal costs.**

| | 2008 | 2009 | 2010 | Annual Projected |
|---|---|---|---|---|
| Annual Operating Cost | $45,539 | $39,897 | $40,134 | $45,531 |
| Volume Reduction (cf/year) | 718,914 | 747,490 | 737,994 | 876,341 |
| Volume Reduction Cost ($/cf) | $0.06 | $0.05 | $0.05 | $0.05 |
| Cumulative TP Load Removed (lbs/year)[a] | 90.9 | 105.3 | 133.4 | 90.4 |
| Cumulative TP Removal Cost ($/lb) | $501 | $379 | $301 | $504 |
| TSS Load Removed (lbs/year) | 23,502 | 23,624 | 85,729 | 26,173 |
| TSS Removal Cost ($/lb) | $1.94 | $1.69 | $0.47 | $1.74 |
| Total Solids Load Removed (lbs/year)[b] | 169,293 | 203,627 | 194,446 | 157,953 |
| Total Solids Removal Cost ($/lb) | $0.27 | $0.20 | $0.21 | $0.29 |

[a] Includes the TP load removed through infiltration of stormwater runoff and settlement of suspended particles and the TP load associated with the gross solids load captured by the BMP.

[b] Includes the TSS load removed through infiltration of stromwater and settlement of suspended particles as well as the gross solids load captured by the BMP.

# 9. Underground Infiltration Trenches

## 9.1. Background

Eight underground infiltration trenches were constructed beneath the roadbed of Arlington and Nebraska Avenues in 2006 (Figure 3-1). This was the first time in St. Paul that an infiltration BMP was implemented beneath the city's streets. The trenches have a combined drainage area of approximately 23 acres; of which 39% is covered by impervious surfaces (Figure 2-3, Table 9-1, and Table 9-2).

**Figure 9-1. Construction of an infiltration trench.**

Each trench is comprised of two 10-inch, perforated pipes (with an approximate one-foot offset in elevation) which run parallel to each other, in an aggregate backfill (Figure 9-1). The trenches total 3,220 feet in length and have a combined storage volume of 37,352 cubic feet. The trenches provide stormwater rate and volume control as well as water quality benefits.

Runoff enters the trenches through sumped catch basins which connect to one or both ends of each trench and serve as pretreatment devices. There are a total of 30 catch basins connected to the eight trenches and all have standard dimensions of two by three feet. Sump depth of the catch basins varies; however, all catch basins have a minimum two foot sump. The minimum storage volume of a sumped catch basin is twelve cubic feet. The outlet leaving each catch basin is equipped with a steel hood which minimizes the amount of trash and debris entering the trenches.

Flow from the catch basins is directed into sumped manholes (16 in total) which are connected to both ends of an infiltration trench. The diameter of the manholes varies, from four to six feet, and the manholes have a minimum sump depth of two and one-half feet. The sumped manholes provide additional pretreatment of stormwater runoff before flowing into the perforated pipes. The perforations of the two pipes are situated above the invert of the pipe to allow for fine sediment to settle and prevent it from entering the aggregate backfill. The runoff then enters the aggregate backfill through the perforations in the pipe and is infiltrated into the ground.

Once runoff volume in the trenches reaches capacity, the stormwater flows through an overflow pipe which discharges into the main storm sewer system. Overflow from the four Nebraska Avenue trenches flows into the Como Park Regional Pond, and overflow from the four Arlington Avenue trenches flows into the Arlington-Hamline Facility where it is treated again. Stormwater runoff flow from both the Como Park Regional Pond and the Arlington-Hamline Facility ultimately flows to Como Lake. As-builts of the underground infiltration trenches may be found in Appendix B: Figure B-3.

Construction of the trenches began in May 2006 and was completed in November 2006. All eight trenches became operational in June 2007. The total capital cost for the infiltration trenches was $400,060 (Table 9-3). The total cost includes the cost of design and construction and bond interest paid by CRWD. The infiltration trenches are owned, operated, and maintained by CRWD.

**Table 9-1. Drainage area and storage volume of the infiltration trenches.**

| | Drainage Area (acres) | Storage Area ($ft^2$) | Storage Volume (cf) |
|---|---|---|---|
| Trench 1 | 0.74 | 1,507 | 1,871 |
| Trench 2 | 0.84 | 2,169 | 2,783 |
| Trench 3 | 3.21 | 5,066 | 8,252 |
| Trench 4 | 5.29 | 4,883 | 8,085 |
| Trench 5 | 1.28 | 1,725 | 2,410 |
| Trench 6 | 2.60 | 2,209 | 3,246 |
| Trench 7 | 1.63 | 1,982 | 2,713 |
| Trench 8 | 7.08 | 4,870 | 7,992 |
| **Total:** | **22.67** | **24,411** | **37,352** |

**Table 9-2. Drainage areas and impervious surface characteristics for the infiltration trenches.**

| | Drainage Area (acres) | Acres Impervious | Percent Impervious |
|---|---|---|---|
| Trench 1 | 0.74 | 0.35 | 47% |
| Trench 2 | 0.84 | 0.41 | 49% |
| Trench 3 | 3.21 | 1.15 | 36% |
| Trench 4 | 5.29 | 1.97 | 37% |
| Trench 5 | 1.28 | 0.51 | 40% |
| Trench 6 | 2.60 | 1.05 | 40% |
| Trench 7 | 1.63 | 0.72 | 44% |
| Trench 8 | 7.08 | 2.77 | 39% |
| **Total:** | **22.67** | **8.93** | **39%** |

**Table 9-3. Total capital cost of the infiltration trenches.**

| | Design | Construction | Bond Interest[a] | Total Cost |
|---|---|---|---|---|
| Trench 1 | $2,400 | $11,998 | $5,642 | $20,039 |
| Trench 2 | $3,569 | $17,846 | $8,392 | $29,807 |
| Trench 3 | $10,583 | $52,916 | $24,884 | $88,383 |
| Trench 4 | $10,369 | $51,845 | $24,380 | $86,595 |
| Trench 5 | $3,091 | $15,454 | $7,267 | $25,812 |
| Trench 6 | $4,163 | $20,815 | $9,788 | $34,766 |
| Trench 7 | $3,479 | $17,397 | $8,181 | $29,058 |
| Trench 8 | $10,250 | $51,249 | $24,100 | $85,599 |
| **Total:** | **$47,904** | **$239,521** | **$112,635** | **$400,060** |

[a]Does not include bond interest paid by project partners.

## 9.2. Performance Analysis

The infiltration trenches did not become operational until June 2007. The performance results represent annual volumes and pollutant loads, from 2007 to 2010, to allow for year-to-year comparisons. It should be noted that in the immediate discussion references to TP are in regards to the TP load associated stormwater runoff flowing to and from the infiltration trenches, as well as the TP load removed through infiltration of runoff and settlement of suspended particles.

From 2007 to 2009, almost all infiltration trenches were 100% efficient at infiltrating stormwater runoff and removing TP and TSS (Table 9-4, Appendix A: Tables A-14, A-16, and A-18). In 2007, Trench 6 and Trench 8 had a small amount of runoff which overflowed; however, the efficiencies were still high (between 96% and 100%).

From 2007 to 2009, the total annual volumes of stormwater runoff which flowed to the trenches were fairly comparable (Figure 9-2, Table 9-4). On average, approximately 298,000 cf flowed to the trenches annually. In 2010, the annual volume of runoff which flowed to the trenches was substantially higher; more than double that of any other year. Although the volume of runoff flowing to the trenches was more than doubled that of any other year, all trenches were less efficient at infiltrating stormwater runoff and removing pollutants. Roughly 23% of the total flow to the trenches in 2010, overflowed along with 25% of the TP load and 18% of the TSS load.

Total annual flows to the trenches, in 2008 through 2009, were all less than the annual projected amount (Figure 9-2, Table 9-4). Although annual flow to the trenches in 2010 was substantially higher than the annual projected amount, there is no annual projected runoff flowing from the trenches. Thus, the annual projected volume reduction efficiency is 100%. The volume reduction efficiency in 2010 was much lower (77%).

Trends observed in TSS loads (inflow and outflow TSS loads and TSS loads removed) for all trenches mimic those trends observed with annual TP loads (Table 9-4). Annual TSS loads flowing to the trenches, from 2007 to 2009, were somewhat comparable; averaging 3,200 lbs each year. Annual TSS loads flowing to and being removed by the infiltration trenches from 2007 to 2009, were comparable to annual projected loads. In addition, the TSS removal efficiencies from 2007 to 2009 (99% to 100%) were comparable to the annual projected TSS removal efficiency for all infiltration trenches (100%).

The TSS load flowing to the trenches in 2010 was more than five times the annual TSS load of any other year (2007 through 2009 and the annual projected). Although the TSS load flowing to the trenches in 2010 was substantially greater than the annual projected load, the TSS removal efficiency in 2010 (85%) was much lower than the annual projected efficiency (100%) (Table 9-4).

Performance results for individual trenches varied, annually. In 2010, there was significantly more annual precipitation causing more stormwater runoff and pollutant loads flowing to the trenches than in previous years. Several factors associated with that elevated annual precipitation amount in 2010 (i.e. more frequent storm events, more intense storm events, higher precipitation storm events, etc.) may have been attributable to lower volume reduction and TP and TSS removal efficiencies for the individual trenches in 2010 than in previous years. Volume reduction and TP and TSS removal efficiencies for the individual trenches, varied from 67% to 93% in 2010 (Appendix A: Table A-20).

Trenches 1, 2, 5, 6, and 7 are all single ended trenches. A single ended trench receives flow from only one end of the trench. Double ended trenches receive flow into both ends. Trenches 3, 4, and 8 are all double ended trenches. The double ended trenches have the three largest drainage areas and received the largest volumes of stormwater runoff and TP and TSS loads. In 2010, when volume reduction and pollutant removal efficiencies were highly variable, single ended trenches performed more efficiently overall than the double ended trenches. Notably, the trenches on Nebraska Avenue (Trenches 1-4) performed more efficiently than those on Arlington Avenue (Trenches 5-8). Also, overall the infiltration trenches were more efficient at removing TSS than TP.

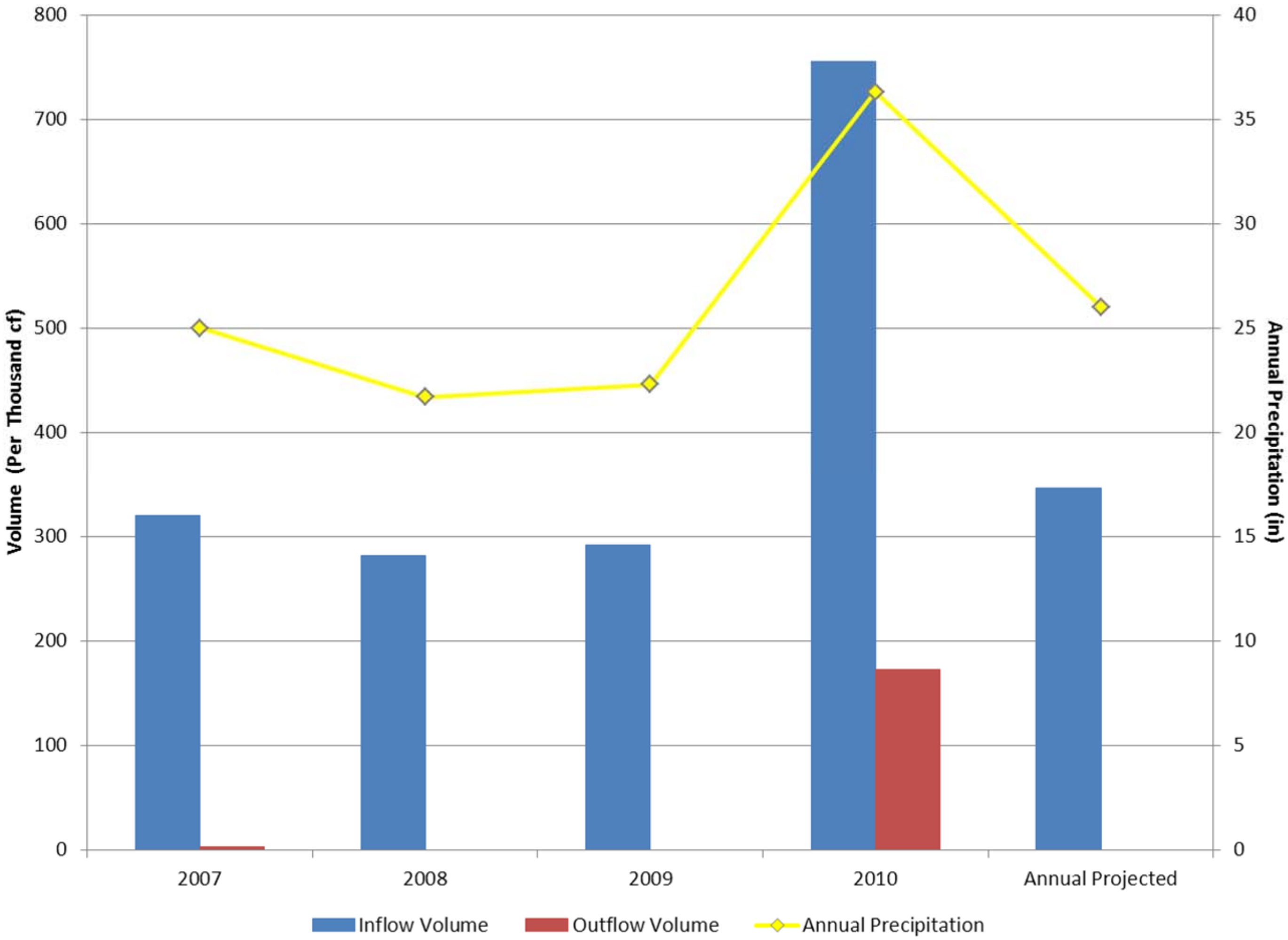


**Figure 9-2. Annual stormwater runoff flowing to and discharging/bypassing from all infiltration trenches from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

2007 to 2010 annual cumulative TP loads removed by the trenches were calculated. The annual cumulative TP load includes: 1) the TP load removed through the infiltration of stormwater runoff and settlement of suspended particles, 2) the TP load associated with the accumulation of gross solids within sumped catch basins, and 3) the TP load associated with accumulation of gross solids within the sumped manholes (Figure 9-3).

On average, the cumulative TP load removed by all infiltration trenches, from 2007 to 2010, was 20 lbs per year. Overall, annual cumulative TP loads removed by all infiltration trenches increased each year, from 2007 to 2010 (Figure 9-3, Table 9-4). However, annual TP loads for the three components of the cumulative TP load (described above) varied (Figure 9-3).

Annual cumulative TP loads removed by the trenches from 2008 to 2010, each represent full years of operation; the 2007 annual cumulative TP load only represents one-half year of operation (Table 9-5).

Annual cumulative TP loads removed by the trenches in 2008 and 2009 were comparable to the annual projected cumulative TP load removed.  The cumulative TP load removed in 2010 was more than one and one-half times the annual projected cumulative TP load.

Double ended trenches (Trenches 3, 4 and 8) collectively removed the largest portion of the annual cumulative TP loads removed by all trenches, from 2007 to 2010; 62% to 67% of the annual cumulative TP loads.

The TP load associated with the accumulation of gross solids accounted for a significant portion of the annual cumulative TP loads removed by all trenches (Table 9-5).  On average, 46% of the annual cumulative TP load removed by all trenches, from 2007 to 2010, was due to the TP load removed through the accumulation of gross solids in all pretreatment units.  From 2007 to 2010, on average, 9 lbs of TP was removed, by the trenches, through the accumulation of gross solids in all pretreatment units.

Annual TP loads in gross solids captured by the catch basins were greater than annual TP loads in gross solids removed by the manholes.  The catch basins serve as the first form of treatment for runoff; therefore, gross solids are generally captured in the catch basins before runoff receives secondary treatment in the manholes.  In addition, more floatables are retained in the catch basins than in the manholes as the catch basin outlets are equipped with steel hoods which prevent floatables from flowing out of the catch basins.

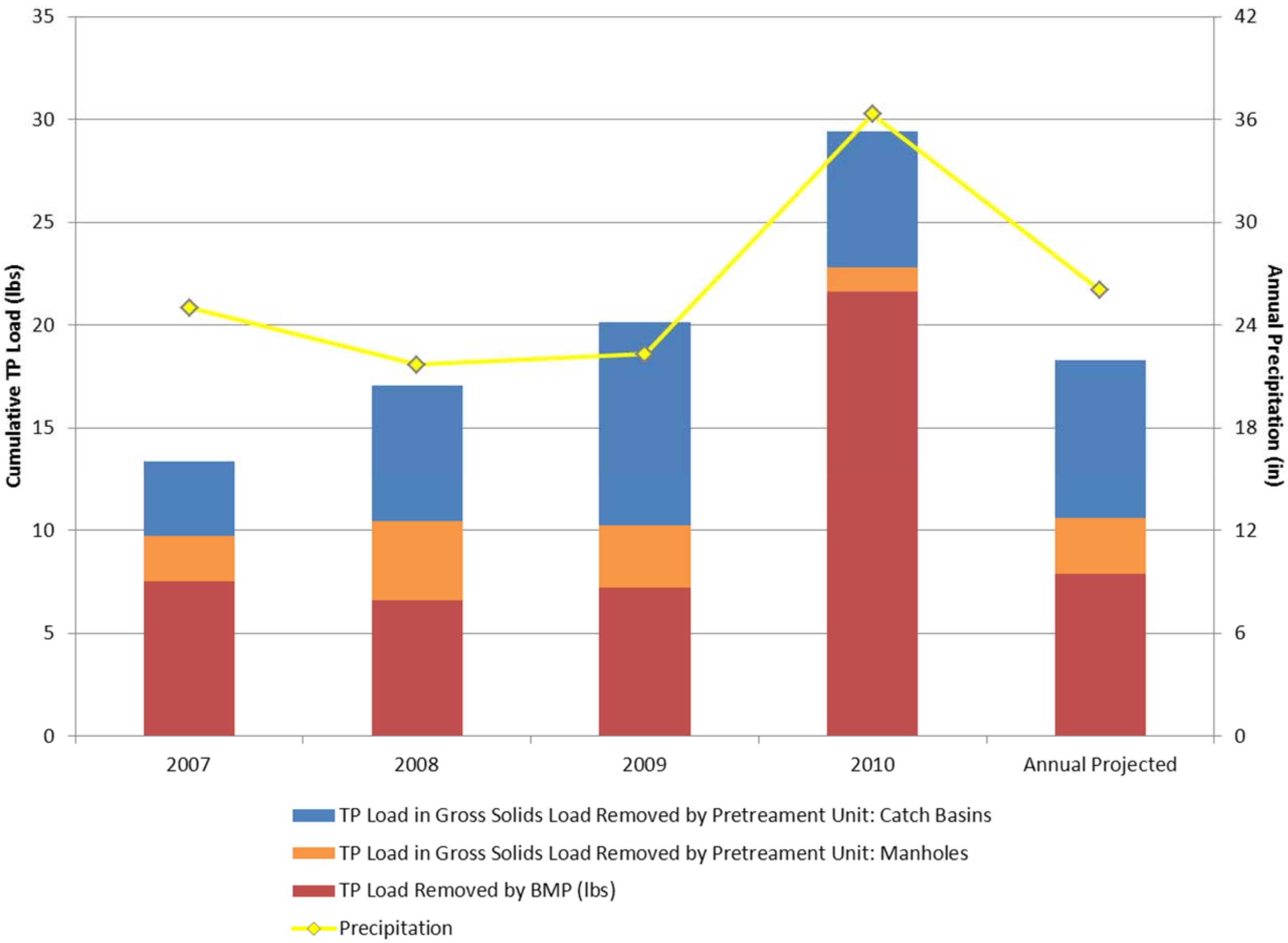


**Figure 9-3. Annual cumulative TP loads removed by all infiltration trenches from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

Annual total solids loads, from 2007 to 2010, were calculated for the trenches which include: 1) the annual TSS load removed through the infiltration of stormwater runoff and the settlement of suspended particles, 2) the annual gross solids load captured by sumped catch basins, and 3) the annual gross solids load captured by sumped manholes (Figure 9-4, Table 9-5).

From 2007 to 2009, on average 29,300 lbs of total solids was removed by all trenches each year. The majority of the annual total solids loads removed by the trenches were due to gross solids captured by all pretreatment units; on average 79% of annual total solids loads. In years when gross solids loads, captured by the pretreatment units, were representative of a full year of operation (2008 through 2010), annual total solids loads were similar or exceeded the annual projected load.

Annual gross solids loads captured by all catch basins were greater than the annual gross solids load captured by all manholes. Gross solids loads captured by the catch basins were attributable to 57% of the average annual total solids loads captured the trenches from 2007 to 2010; an average 16,700 lbs of gross solids was captured by all catch basins each year. This is an expected result because the catch basins serve as the first form of treatment and are equipped with steel hoods to retain floatables.

Annual gross solids loading results, from 2007 to 2010, for the individual trenches vary (Appendix A: Tables A-15, A-17, A-19, and A-21). Overall in 2007 and 2010, annual gross solids loads captured by single ended trenches were greater than those loads captured by double ended trenches. However, the opposite was true in 2008 and 2009; double ended trenches captured more annual gross solids loads than the single ended trenches.

In addition, annual gross solids loads captured by a particular pretreatment unit type (catch basins or manholes), for an individual trench, also varied. While the overall trend for all infiltration trenches (with regards to annual gross solids loads captured by pretreatment units) was that more annual gross solids loads were captured by catch basins than manholes; it was observed that for some trenches, manholes captured more annual gross solids loads than catch basins and vice versa.

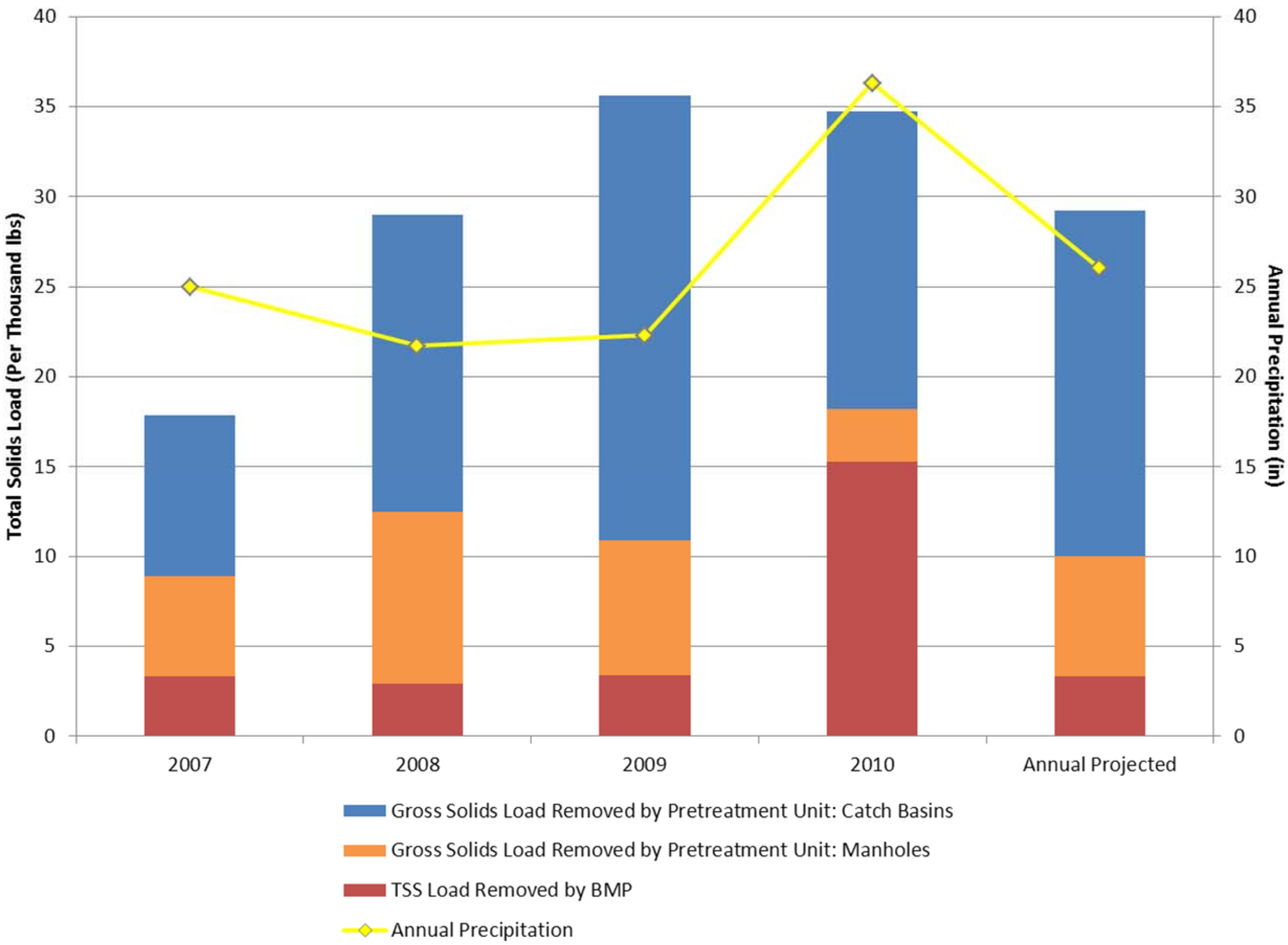


**Figure 9-4. Annual total solids loads removed by all infiltration trenches from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

**Table 9-4. Annual volume reduction and pollutant removal efficiencies for all infiltration trenches from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected[a] |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 21.7 | 22.3 | 36.3 | 26.0 |
| Watershed Area (ac) | 22.67 | 22.67 | 22.67 | 22.67 | 22.67 |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | |
| Inflow Volume (cf) | 320,166 | 281,616 | 291,721 | 755,069 | 346,562 |
| Outflow Volume (cf) | 2,918 | 0 | 0 | 172,715 | 0 |
| Volume Removed by BMP (cf) | 317,248 | 281,616 | 291,721 | 582,354 | 346,562 |
| Volume Removal Efficiency (%) | **99%** | **100%** | **100%** | **77%** | **100%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | |
| Inflow TP Load (lbs) | 7.6 | 6.6 | 7.2 | 28.8 | 7.9 |
| Outflow TP Load (lbs) | 0.1 | 0.0 | 0.0 | 7.2 | 0.0 |
| TP Load Removed by BMP (lbs) | 7.5 | 6.6 | 7.2 | 21.6 | 7.9 |
| TP Removal Efficiency (%) | **99%** | **100%** | **100%** | **75%** | **100%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | |
| Inflow TSS Load (lbs) | 3,363 | 2,897 | 3,384 | 18,538 | 3,308 |
| Outflow TSS Load (lbs) | 28 | 0 | 0 | 3,264 | 0 |
| TSS Load Removed by BMP (lbs) | 3,335 | 2,897 | 3,384 | 15,274 | 3,308 |
| TSS Removal Efficiency (%) | **99%** | **100%** | **100%** | **82%** | **100%** |

[a] Annual projected results derived using the 1995 water year.

**Table 9-5. Annual cumulative TP and total solids load reductions for all infiltration trenches from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 21.7 | 22.3 | 36.3 | 26.0 |
| Watershed Area (ac) | 22.67 | 22.67 | 22.67 | 22.67 | 22.67 |
| ***VOLUME REMOVED*** | | | | | |
| Total Volume Removed by BMP (cf) | **317,248** | **281,616** | **291,721** | **582,354** | **346,562** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | |
| TP Load Removed by BMP (lbs) | 7.5 | 6.6 | 7.2 | 21.6 | 7.9 |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Catch Basins (lbs) | 3.6 | 6.6 | 9.9 | 6.6 | 7.7 |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Manholes (lbs) | 2.2 | 3.8 | 3.0 | 1.2 | 2.7 |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | **13.3** | **17.1** | **20.1** | **29.4** | **18.3** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | |
| TSS Load Removed by BMP (lbs) | 3,335 | 2,897 | 3,384 | 15,274 | 3,308 |
| Gross Solids Load Removed by Pretreatment Unit: Catch Basins (lbs) | 9,000 | 16,513 | 24,683 | 16,513 | 19,236 |
| Gross Solids Load Removed by Pretreatment Unit: Manholes (lbs) | 5,536 | 9,568 | 7,517 | 2,935 | 6,673 |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | **17,871** | **28,977** | **35,584** | **34,722** | **29,217** |

## 9.3. Operation and Maintenance

CRWD maintains the eight infiltration trenches as well as the sixteen sumped manholes and 30 sumped catch basins. The total staff hours spent maintaining the trenches have been slightly variable from 2007 to 2010. However, from 2008 to 2010 the annual O & M costs have been fairly consistent. On average, CRWD spent $9,888 and 73 staff hours annually maintaining the infiltration trenches and pretreatment units. Table 9-6 lists annual O & M costs and staff hours for all eight infiltration trenches.

**Table 9-6. Annual O & M costs and labor hours for all infiltration trenches.**

| Year | Labor | Equipment & Materials | Contract Services | Total | Labor Hours |
|---|---|---|---|---|---|
| 2007 | $2,373 | $0 | $3,136 | $5,509 | 138.0 |
| 2008 | $1,768 | $323 | $10,314 | $12,405 | 87.8 |
| 2009 | $337 | $0 | $10,314 | $10,651 | 23.3 |
| 2010 | $675 | $0 | $10,314 | $10,988 | 43.2 |
| **Total:** | **$5,153** | **$323** | **$34,077** | **$39,553** | **292.3** |

On average, 83% of the annual O & M cost from 2007 to 2010 was attributed to contract services (Table 9-6). Generally, contract services consist of removing debris and sediment from the sumped catch basins and manholes semi-annually (spring and fall). In 2007, debris and sediment removal in the trenches only occurred once because the trenches and pretreatment units were not operational until June 2007. The cost associated with this debris removal outweighs the variability in labor costs, keeping the annual O & M costs fairly consistent from year-to-year. The costs to remove debris and sediment from the catch basins and manholes on average were approximately $144/manhole and $95/catch basin.

Labor costs and staff hours spent on inspections and maintenance have been variable from 2007 to 2010 (Table 9-6). Staff hours were high in 2007 due to the installation of steel hoods in each catch basin. Before the hoods could be installed, gaskets were attached to the edge of each hood to eliminate gaps and to provide a better seal. The particular type of gasket installed in 2007 degraded rapidly. In 2008, the original gaskets were removed and replaced with heavy rubber gaskets. This process was fairly labor intensive causing staff hours to remain high in 2008. In 2009 and 2010, staff hours were significantly lower than in previous years, primarily due to not replacing the gaskets on the hoods.

In addition to gasket replacement, inspections were also conducted to track sediment accumulation within the sumped catch basins and manholes and to also observe how quickly water infiltrated through the perforated pipes following rain events. Table 9-7 details the inspection and maintenance schedule for the infiltration trenches.

**Table 9-7. Inspection and maintenance schedule for the infiltration trenches.**

| Activity | Frequency |
|---|---|
| Catch Basin Sediment Inspection | Semi-Annual |
| Catch Basin Gasket Inspection | As Necessary |
| Catch Basin Maintenance | Semi-Annual/Annual |
| Manhole Sediment Inspection | Semi-Annual |
| Trench Post-Rain Infiltration Inspection | Quarterly/After Major Rainfall |
| Trench Maintenance | Semi-Annual/Annual |

Prior to removing debris and sediment from each catch basin and manhole, sediment inspections were conducted in the spring and fall. Inspections of each catch basin and manhole included the measurements of debris and water depth and note of the overall condition of the structure.

Post-rain inspections of the manholes were conducted 24 hours following a storm event which totaled two or more inches of precipitation. Additionally, manhole inspections were conducted on a quarterly basis to ensure proper function. The purpose of the inspection was to observe if the trenches were infiltrating properly following an event. If water was present in the lower pipe during an inspection, a visual approximation of water depth was recorded. Runoff drained from all trenches typically within 48 hours. Post-rain inspections were conducted on a more frequent schedule in 2007 and 2008 (after every storm event). It was determined that this frequency was no longer necessary and the frequency of post-rain inspections was decreased to a quarterly basis and following major rainfall events.

In future years, CRWD staff hours spent on inspections and maintenance is expected to remain somewhat consistent with 2010 hours. However, a significant increase in staff hours is expected for 2011, due to a labor intensive special project aimed at more accurately quantifying sediment and TP loads being captured by the catch basins and manholes. The cost associated with debris removal from the pretreatment unit is also expected to increase due to the cost of inflation. Additionally, the cost of contract services for debris removal may fluctuate due to an anticipated change in contractor.

Irregular trench maintenance and costs are expected to incur over the life expectancy of the BMP. For example, the perforated pipes of each trench will need to be cleaned out over time as sediment and other debris accumulates within. Proper maintenance of the infiltration trenches will ensure functionality over the life of the BMP.

CRWD estimates that the removal of accumulated debris in the trench pipes will need to occur three times over the course of the BMP life expectancy (35 years) with an estimated cost of $10,000 per cleaning. The total cost of the three debris removals was amortized over the life expectancy of the BMP and was incorporated into the annual projected O & M costs in Table 9-8. The cost was amortized in order to keep annual O & M costs comparable. CRWD acknowledges and fully expects the annual O & M cost for those years in which irregular maintenance activities occur will be substantially higher than the O & M costs from those regular maintenance years.

Itemized annual O & M activities and costs for 2009 and 2010 for the infiltration trenches may be found in Appendix A: Tables A-55 and A-56.

## 9.4. Cost-Benefit Analysis

From 2007 to 2010, the average annual operating cost for all infiltration trenches was approximately $21,000 per year (Table 9-8). The 2007 operating costs were the lowest since it was only represent O & M costs for one-half of the year. The annual operating costs from 2008 to 2010 were fairly consistent, averaging roughly $22,800 annually.

**Table 9-8. Annual operating costs for the infiltration trenches.**

| | Annual Capital Cost[a] | Annual O & M Cost | Annual Operating |
|---|---|---|---|
| 2007 | $11,430 | $5,509 | $16,939 |
| 2008 | $11,430 | $12,405 | $23,835 |
| 2009 | $11,430 | $10,651 | $22,081 |
| 2010 | $11,430 | $10,988 | $22,418 |
| Annual Projected | $11,430 | $12,500 | $23,930 |

[a] Capital cost amortized over 35 years.

The highest volume reduction and pollutant removal costs occurred in 2008 (Table 9-9). This was due to a high annual operating cost and lower volume and fewer amount of pollutants removed in 2008 than in any other year. Overall, volume reduction and pollutant removal costs were the lowest in 2010 than in any other year. However, there were significant variations in volume reduction and pollutant removal costs annually from 2007 to 2010. These variations were due to a combination of variability in annual operating costs and in the volume of runoff and amount of pollutants removed.

On average the cost to remove one cubic foot of stormwater runoff was $0.06 and the cost to remove one pound of TP and one pound of total solids was $1,066 and $0.73, respectively (Table 9-9). These average costs were less than the annual projected volume reduction and pollutant removal costs.

**Table 9-9. Annual volume reduction and pollutant removal costs for all infiltration trenches.**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected |
|---|---|---|---|---|---|
| Annual Operating Cost | $16,939 | $23,835 | $22,081 | $22,418 | $23,930 |
| Volume Reduction (cf/year) | 317,248 | 281,616 | 291,721 | 582,354 | 346,562 |
| Volume Reduction Cost ($/cf) | $0.05 | $0.08 | $0.08 | $0.04 | $0.07 |
| Cumulative TP Load Removed (lbs/year)[a] | 13.35 | 17.08 | 20.14 | 29.42 | 18.32 |
| Cumulative TP Removal Cost ($/lb) | $1,269 | $1,395 | $1,096 | $762 | $1,307 |
| TSS Load Removed (lbs/year) | 3,335 | 2,897 | 3,384 | 15,274 | 3,308 |
| TSS Removal Cost ($/lb) | $5.08 | $8.23 | $6.52 | $1.47 | $7.23 |
| Total Solids Load Removed (lbs/year)[b] | 17,871 | 28,977 | 35,584 | 34,722 | 29,217 |
| Total Solids Removal Cost ($/lb) | $0.95 | $0.82 | $0.62 | $0.65 | $0.82 |

[a] Includes the TP load removed through infiltration of stormwater runoff and settlement of suspended particles and the TP load associated with the gross solids load captured by the BMP.

[b] Includes the TSS load removed through infiltration of stromwater and settlement of suspended particles as well as gross solids load captured by the BMP.

# 10. Rain Gardens

## 10.1. Background

A component of the Arlington Pascal Project was the construction of eight rain gardens (Figure 2-3). CRWD owns and maintains the rain gardens which are named according to nearby street intersections. The rain gardens are:

- Arlington-McKinley
- Asbury North
- Asbury South
- Frankson-McKinley
- Hamline Midway
- Pascal Center
- Pascal North
- Pascal South

A majority of the rain gardens were built within the city street right-of-way during a street reconstruction project. The Hamline Midway Rain Garden was built between the wooded edge of Como Park and Hamline Avenue in an area that was disturbed by a storm sewer pipe replacement project. Following replacement of the storm sewer pipe, the rain garden was constructed above the new pipe.

**Figure 10-1. Pascal South Rain Garden.**

The purpose of the rain gardens is to contribute to water quality improvements as well as volume and rate control. They also increase groundwater recharge, improve aesthetics, and provide wildlife habitat and educational opportunities for the community.

The rain gardens were constructed in 2005 and 2006. When combined, the total drainage area is approximately 16 acres (Table 10-1) with approximately 25% impervious surface coverage (Table 10-2). The eight rain gardens have a combined area of 13,469 ft² and a total storage capacity of approximately 19,354 cf.

Seven of the gardens (except the Hamline Midway Rain Garden) receive runoff via curb-cuts which direct flow into the rain garden. If a rain garden reaches capacity, water will bypass the rain garden and flow down gradient to catch basins that are connected to the main storm sewer system. The Hamline Midway Rain Garden receives runoff from the storm sewer pipe mentioned above and also from a second 10-inch pipe which drains areas within Como Park and Como Zoo. When this rain garden reaches capacity, water flows out of the rain garden through an outlet structure and enters into the storm sewer system, ultimately discharging to Como Lake.

A majority of the rain gardens serve as the first form of treatment within the treatment train of stormwater best management practices (BMPs). Any runoff overflowing and bypassing the Pascal Rain Gardens (Center, North, and South) flows into a storm sewer which flows to the Como Park Regional

Pond where it is treated and eventually discharges to Como Lake. Stormwater runoff which overflows and bypasses the Arlington-McKinley Rain Garden flows to the Arlington-Hamline Facility, which discharges to Como Lake. Runoff which overflows and bypasses the Frankson-McKinley Rain Garden flows to the Hamline Midway Rain Garden which discharges to Como Lake.

All rain gardens were planted with a combination of perennial, native forbs and sedges, with the exception of the Hamline Midway Rain Garden which was planted with mostly trees and shrubs (Figure 10-2). Though plant species and abundance varies from garden to garden, the most commonly found plant species in the seven rain gardens are as follows:

- Black-eyed Susan (*Rudbeckia hirta*)
- Blue Lobelia (*Lobelia siphilitica*)
- Blueflag Iris (*Iris versicolor*)
- Butterfly Milkweed (*Asclepias tuberosa*)
- Canada Anemone (*Anemone canadensis*)
- Cardinal Flower (*Lobelia cardinalis*)
- Fox Sedge (*Carex vulpinoidea*)
- Little Bluestem (*Schizachyrium scoparium*)
- Meadow Blazingstar (*Liatris ligulistylis*)
- Pale Purple Coneflower (*Echinacea pallida)*
- Prairie Blazingstar (*Liatris pycnostachya*)
- Rattlesnake Master (E*ryngium yuccifolium*)
- Sneezeweed (*Helenium autumnale*)
- Wild Bergamot (*Monarda fistulosa*)


**Figure 10-2. Common rain garden plants species.**

The combined cost of all eight rain gardens was $160,244 which includes the cost of design, construction, and bond interest paid by CRWD (Table 10-3). The unit cost of all rain gardens was approximately $11.90/ft² (Table 3-3). The Hamline Midway Rain Garden, the largest garden with the largest drainage area, accounted for 64% of the total capital cost of all the rain gardens alone. The Pascal North Rain Garden has the smallest drainage area but had the highest cost per square foot of all the rain gardens. This was mainly due to the proportionately high construction cost for such a small rain garden area. Topographic surveys of all rain gardens may be found in Appendix B: Figure B-4.

## 10.1.1. Arlington-McKinley Rain Garden

The Arlington-McKinley Rain Garden is a 767 ft² shallow rain garden, located just southeast of the intersection of Arlington Avenue, Holton Street, and Frankson Street (Table 10-1, Figure 2-3). The rain garden has a water storage volume of 349 cf and also has a drainage area of 0.37 acres. The rain garden receives runoff from a curb-cut inlet on McKinley Street. The rain garden began operation in September 2006. Construction cost of the rain garden totaled $4,115 ($5.37/ft²) (Tables 10-3 and 3-3).

### 10.1.2. Asbury North Rain Garden

The Asbury North Rain Garden is located just north of the intersection of Asbury and Frankson Streets. The rain garden is 945 $ft^2$ and has a water storage volume of 1,045 cf (Table 10-1, Figure 2-3). It receives runoff from a curb-cut inlet on Frankson Street and has a drainage area of 0.40 acres. Asbury North became operational in 2006. Construction cost of the rain garden totaled $9,246 ($9.87/$ft^2$) (Tables 10-3 and 3-3).

### 10.1.3. Asbury South Rain Garden

The Asbury South Rain Garden is a large rain garden, located just south of the intersection of Asbury and Frankson Streets. The rain garden is 1,712 $ft^2$ and has a water storage volume of 2,113 cf (Table 10-1, Figure 2-3). Asbury South has a 1.08 acre drainage area and receives runoff from a curb-cut inlet on Frankson Street. It began operation in June 2006. Construction cost of the rain garden totaled $11,971 ($6.99/$ft^2$) (Tables 10-3 and 3-3).

### 10.1.4. Frankson-McKinley Rain Garden

The Frankson-McKinley Rain Garden is a large rain garden, located just north of the intersection of Frankson, McKinley, and Albert Streets. Its storage area is 2,078 $ft^2$, has a water storage volume of 2,492 cf, and drains 2.8 acres (Table 10-1, Figure 2-3). The rain garden receives runoff from two curb-cut inlets, one on McKinley Street and one on Albert Street. The rain garden became operational in June 2006. Construction cost of the rain garden totaled $10,921 ($5.26/$ft^2$) (Tables 10-3 and 3-3).

### 10.1.5. Hamline Midway Rain Garden

The Hamline Midway Rain Garden is the largest (6,364 $ft^2$) of CRWD owned rain gardens and is located just northeast of the intersection of Hamline Avenue and the Midway Parkway (Table 10-1, Figure 2-3). It is adjacent to Como Park and also the Como Zoo. The Hamline Midway Rain Garden is unlike the other rain gardens because it was planted primarily with shrubs and trees, rather than perennial native forbs and sedges. The planting design was in response to the large size of the rain garden as well as citizen concerns regarding the removal of oak trees during the construction of the rain garden.

Hamline Midway has a water storage volume of 12,576 cf and drains an area of 10.5 acres. It receives runoff from two storm sewer inlets: one at the south end and another on the east side of the rain garden. The rain garden is the only rain garden that has an outlet structure. Once water level in the rain garden reaches approximately three feet, water flows out through a raised PVC pipe. The outlet structure is also equipped with an emergency overflow which consists of a beehive grate which sits on top of the outlet structure. Once water levels in the rain garden reach approximately five feet, water flows into the emergency overflow and into the storm sewer system, ultimately discharging to Como Lake.

Hamline Midway began operation in 2006. The total cost of the rain garden was $103,172 ($16.21/$ft^2$) (Tables 10-3 and 3-3). CRWD owns and maintains the Hamline Midway Rain Garden. In addition, the

City of St. Paul Parks and Recreation Department as well as the Conservation Corps of Minnesota and Iowa (through a Clean Water Legacy Grant) provide additional assistance in maintenance of the rain garden.

### 10.1.6. Pascal Center Rain Garden

The Pascal Center Rain Garden is a 536 $ft^2$, shallow rain garden located just north of the intersection of Pascal and Frankson Streets (Table 10-1, Figure 2-3). It is one of three rain gardens built on Pascal Street. The rain garden has a water storage volume of 227 cf and a drainage area of 0.13 acres. It receives runoff from a curb-cut inlet on Pascal Street. It became operational in 2006. Construction cost of the rain garden totaled $5,421 ($10.12/$ft^2$) (Tables 10-3 and 3-3).

### 10.1.7. Pascal North Rain Garden

The Pascal North Rain Garden is a small, shallow rain garden (357 $ft^2$) located north of the intersection of Pascal and Frankson Streets (Table 10-1, Figure 2-3). It is the northern most of three rain gardens built on Pascal Street. The rain garden has a water storage volume of 209 cf, has a drainage area of 0.46 acres, and receives runoff from a curb-cut inlet on Pascal Street. Pascal North Rain Garden became operational in 2006. Construction cost of the rain garden totaled $6,750 ($18.90/$ft^2$) (Tables 10-3 and 3-3).

### 10.1.8. Pascal South Rain Garden

The Pascal South Rain Garden is a shallow rain garden (710 $ft^2$) located north of the intersection of Pascal and Frankson Streets (Table 10-1, Figure 2-3). It is the most southern of three rain gardens, built on Pascal Street. Pascal South has a water storage volume of 344 cf. It receives runoff from a curb-cut inlet on Pascal Street and has a drainage area of 0.36 acres. The rain garden began operation in 2006. Construction cost of the rain garden totaled $8,648 ($12.18/$ft^2$) (Tables 10-3 and 3-3).

**Table 10-1. Size and storage capacity of the rain gardens.**

| Raingarden | Drainage Area (acres) | Storage Area ($ft^2$) | Storage Volume (cf) |
|---|---|---|---|
| Arlington-McKinley | 0.37 | 767 | 349 |
| Asbury North | 0.40 | 945 | 1,045 |
| Asbury South | 1.08 | 1,712 | 2,113 |
| Frankson-McKinley | 2.81 | 2,078 | 2,492 |
| Hamline Midway | 10.47 | 6,364 | 12,576 |
| Pascal Center | 0.13 | 536 | 227 |
| Pascal North | 0.46 | 357 | 209 |
| Pascal South | 0.36 | 710 | 344 |
| **Total:** | **16.08** | **13,469** | **19,354** |

**Table 10-2. Rain garden drainage areas and impervious surfaces characteristics.**

| Raingarden | Drainage Area (acres) | Acres Impervious | Percent Impervious |
|---|---|---|---|
| Arlington-McKinley | 0.37 | 0.15 | 41% |
| Asbury North | 0.40 | 0.17 | 43% |
| Asbury South | 1.08 | 0.33 | 31% |
| Frankson-McKinley | 2.81 | 0.94 | 33% |
| Hamline Midway | 10.47 | 1.86 | 18% |
| Pascal Center | 0.13 | 0.06 | 46% |
| Pascal North | 0.46 | 0.13 | 28% |
| Pascal South | 0.36 | 0.09 | 24% |
| **Total** | **16.08** | **3.73** | **23%** |

**Table 10-3. Total capital cost of the rain gardens.**

| | Design | Construction | Bond Interest[a] | Total Cost |
|---|---|---|---|---|
| Arlington-McKinley | $494 | $2,471 | $1,150 | $4,116 |
| Asbury North | $1,106 | $5,532 | $2,607 | $9,246 |
| Asbury South | $1,433 | $7,164 | $3,374 | $11,970 |
| Frankson-McKinley | $1,309 | $6,545 | $3,067 | $10,921 |
| Hamline Midway | $12,365 | $61,824 | $28,983 | $103,172 |
| Pascal Center | $648 | $3,239 | $1,533 | $5,421 |
| Pascal North | $806 | $4,028 | $1,917 | $6,750 |
| Pascal South | $1,032 | $5,162 | $2,454 | $8,648 |
| **Total:** | **$19,193** | **$95,966** | **$45,085** | **$160,244** |

## 10.2. Performance Analysis

Since the rain gardens became operational, all have been performing very efficiently. From 2007 to 2009, almost all rain gardens had performance efficiencies of 100% for volume reduction, TP, and TSS (Table 10-4, Appendix A: Tables A-24, A-26, and A-28). All stormwater runoff and associated pollutants which flowed into the rain gardens was infiltrated and removed. In 2010, the rain gardens still performed well; however, overall performance efficiencies were slightly lower than those observed in previous years due to a higher than average precipitation year (Appendix A: Table A-30). Combined, the rain gardens infiltrated on average, 95% of total flow which flowed to the gardens and removed 91% of the TP and TSS loads associated with that flow. These efficiencies are slightly lower than the annual projected efficiencies (all of which are 100%); which are based on a year with an average amount of precipitation.

The volume of stormwater runoff that flowed to all of the rain gardens was fairly consistent from 2007 to 2009 (Figure 10-3, Table 10-4). There were no substantial differences in total annual precipitation during this time. Generally, greater amounts of precipitation resulted in larger volumes of runoff flowing to the rain gardens. In 2010, there was significantly more precipitation than in previous years. Total flow to all of the rain gardens was approximately 560,000 cf in 2010. This was more than two times greater than the total annual flow in any other year. Subsequently, 2010 annual TP and TSS loads were four to five times more than annual pollutant loads in previous years.

In comparison to the annual projected volume of stormwater runoff which flowed to the rain gardens; the annual volume of runoff flowing to the rain gardens from 2007 to 2009, were less than the annual projected amount. Annual overflow from the rain gardens, in 2007, was slightly more than the annual projected amount. In 2008 and 2009, there was no overflow from or runoff which bypassed the rain gardens; this is consistent with the annual projected results. In 2010, annual runoff flowing into the rain gardens was substantially more than the annual projected amount; more than two times as much runoff flowed to the rain gardens in 2010 than in the annual projected amount. However, the amount of runoff which discharged from/bypassed the rain gardens in 2010 (12%) was greater than the annual projected amount.

The Hamline Midway Rain Garden, which has the largest storage volume and drainage area, received and infiltrated more stormwater than any other rain garden from 2007 to 2010 (Appendix A: Tables A-24, A-26, A-28, and A-30). On average, the Hamline Midway Rain Garden received 69% of the total annual flow to all rain gardens and infiltrated 68% of that total annual flow. Generally, from 2007 to 2010, the Pascal Center Rain Garden consistently received the smallest amount of stormwater runoff and pollutant loads than any other rain garden. The Pascal Center Rain Garden has the smallest drainage area and storage volume than any other rain garden.

Volume reduction and TP and TSS removal efficiencies across individual rain gardens in 2010 varied significantly, from 65% to 100%. The Asbury North and Asbury South Rain Gardens performed the most efficiently of all rain gardens; with efficiencies between 93% and 100%. The Pascal Center Rain Garden had the lowest efficiencies (65% to 70%). All other rain gardens had an average volume reduction efficiency of 88% and average TP and TSS removal efficiencies of 83% and 87%, respectively.

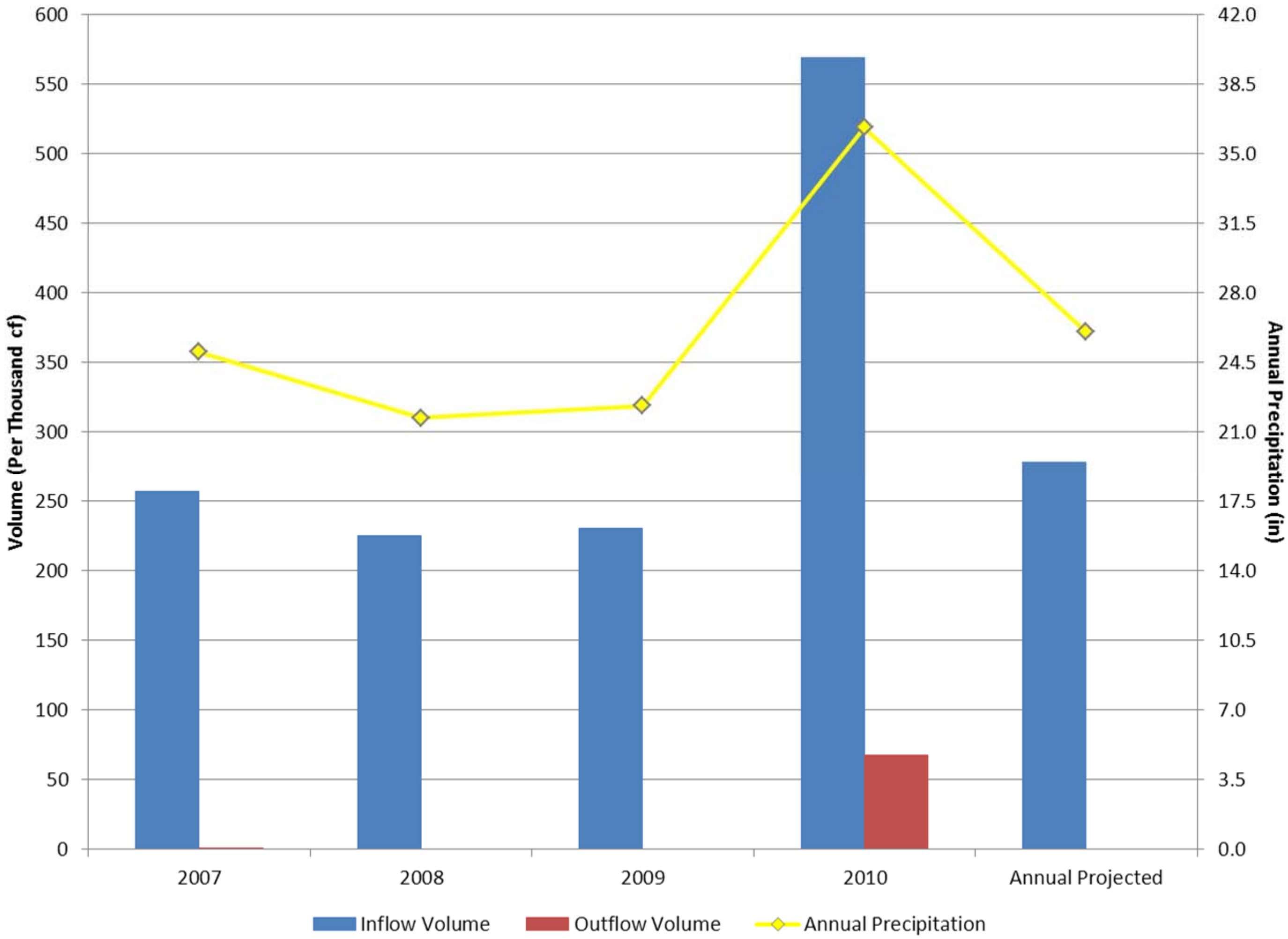


**Figure 10-3. Annual stormwater runoff flowing to and discharging/bypassing from all rain gardens from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

The annual cumulative TP load removed by the rain gardens was, on average, 12 lbs (Table 10-5). This includes the TP load removed through the infiltration of stormwater runoff and settlement of suspended solids and the TP load removed through accumulation of gross solids within the rain gardens. Annual cumulative TP loads removed by the rain gardens, from 2007 to 2009, were comparable or slightly less than the annual projected cumulative TP load. In 2010, the annual cumulative TP load was almost two times that of the annual projected cumulative TP load. These trends are primarily attributable to annual precipitation amounts. Generally the greater the annual precipitation amount, the greater amount of stormwater runoff and pollutant loads flowing to the rain gardens.

The Hamline Midway Rain Garden consistently removed the largest portion of the annual cumulative TP load of all the rain gardens from 2007 to 2010 (Appendix A: Tables A-24 through A-31). On average, 61% of the annual cumulative TP load of all rain gardens was removed by Hamline Midway Rain Garden. This is consistent with the annual projected cumulative TP load removed by the Hamline Midway Rain Garden (Appendix A: Tables A-32 and A-33). The Pascal Center Rain Garden, which has the smallest watershed area and storage volume, consistently removed the smallest annual cumulative TP load, from 2007 to 2010 (Appendix A: Tables A-24 through A-31).

Generally, annual TP load reductions attributable to the infiltration of stormwater runoff and settlement of suspended particles, has accounted for the majority of the annual cumulative TP loads removed by the rain gardens each year (Figure 10-4, Table 10-5). Annual TP loads remained fairly consistent, from 2007 to 2009, and all were slightly less than the annual projected load. The 2010 annual TP load removed through infiltration and settling was nearly three times greater than that of the annual projected TP load. On average, 8 lbs of TP was removed by the rain gardens through infiltration and settling each year.

Annual TP loads removed through the accumulation of gross solids averaged approximately 4 lbs. From 2007 to 2010, annual TP loads associated with the accumulation of gross solids has varied. An increase in annual TP loads was observed from 2007 to 2009 and decreased in 2010.

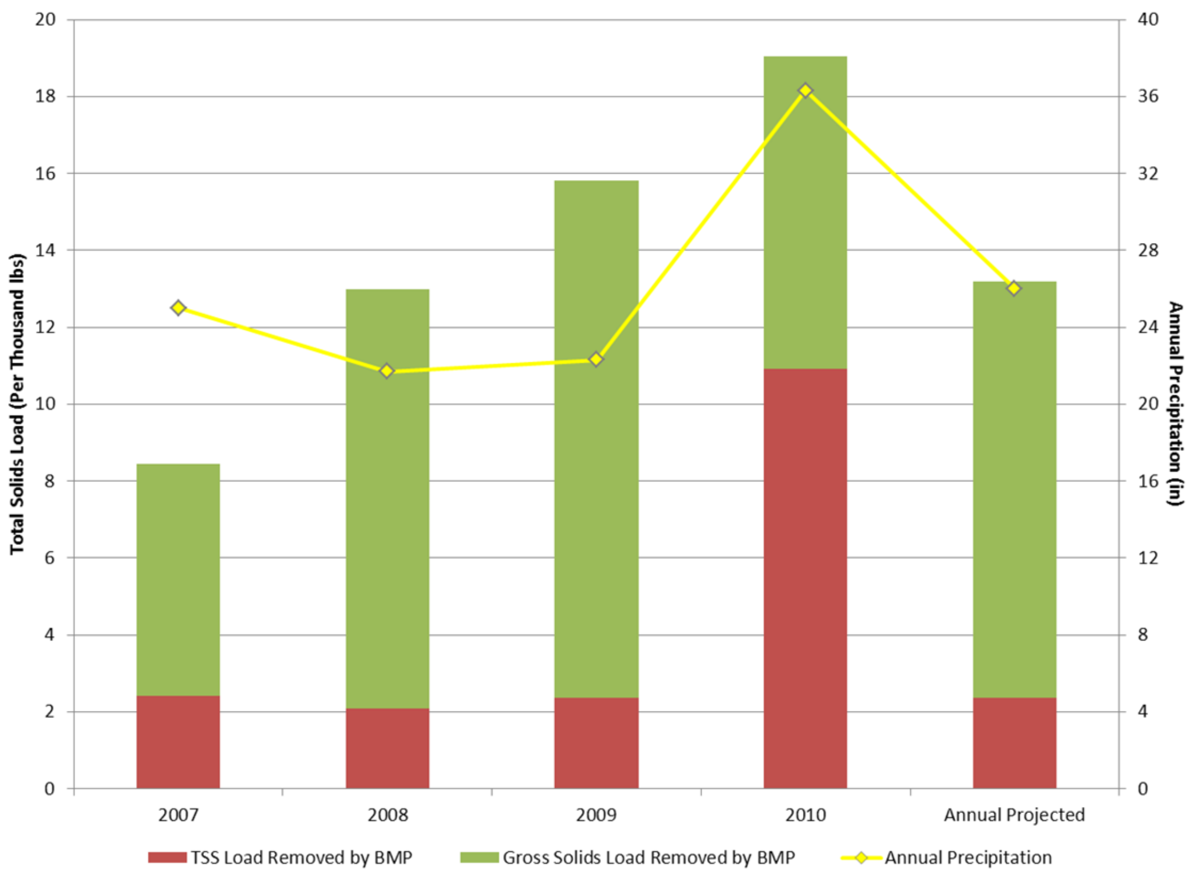


**Figure 10-4. Annual cumulative TP loads removed by all rain gardens from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

The average annual total solids load, removed by all of the rain gardens, was approximately 14,000 lbs (Table 10-5). The total solids load is comprised of 1) the total TSS load removed through the infiltration of stormwater and settlement of suspended solids and 2) the accumulation of gross solids. The Frankson-McKinley and the Hamline Midway Rain Gardens accumulated by far, the largest amount of total solids annually in comparison to the other rain gardens (Appendix A: Tables A-24 through A-31). Cumulatively, total solids loads captured by both rain gardens accounted for an average of 77% of the annual total solids load.

Annual total solids loads removed by all rain gardens increased from 2007 to 2010 (Figure 10-5, Table 10-5). While annual total solids loads have varied, the average annual total solids load is comparable to the annual projected total solids load.

From 2007 to 2009 the gross solids load which accumulated within the rain gardens, comprised the majority of the total solids load removed. In 2010, the TSS load removed through infiltration of stormwater runoff and settlement of suspended particles accounted for the majority of the total solids load removed by all rain gardens. However, these results vary for individual rain gardens each year (Appendix A- Tables A-24 through A-31). The gross solids load captured by all rain gardens averaged 9,600 lbs annually, from 2007 to 2010.

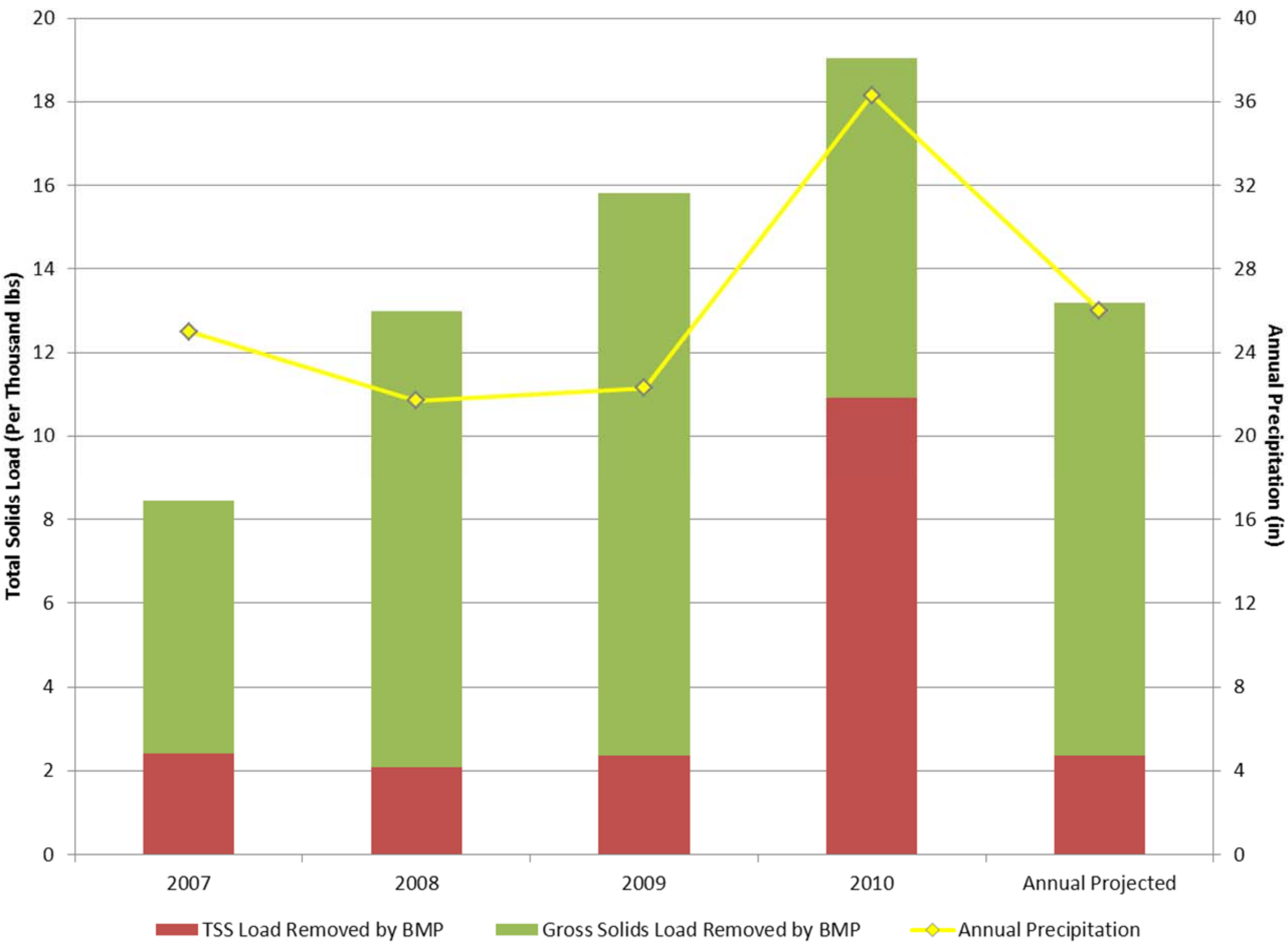


**Figure 10-5. Annual total solids loads removed by all rain gardens from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

**Table 10-4. Annual volume reduction and pollutant removal efficiencies for all rain gardens from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected[a] |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 21.7 | 22.3 | 36.3 | 26.0 |
| Watershed Area (ac) | 16.08 | 16.08 | 16.08 | 16.08 | 16.08 |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | |
| Inflow Volume (cf) | 257,135 | 225,118 | 230,519 | 568,981 | 277,651 |
| Outflow Volume (cf) | 87 | 0 | 0 | 67,736 | 0 |
| Volume Removed by BMP (cf) | 257,048 | 225,118 | 230,519 | 501,245 | 277,651 |
| Volume Removal Efficiency (%) | **100%** | **100%** | **100%** | **88%** | **100%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | |
| Inflow TP Load (lbs) | 5.75 | 4.94 | 5.24 | 20.50 | 6.05 |
| Outflow TP Load (lbs) | 0.00 | 0.00 | 0.00 | 3.40 | 0.00 |
| TP Load Removed by BMP (lbs) | 5.75 | 4.94 | 5.24 | 17.10 | 6.05 |
| TP Removal Efficiency (%) | **100%** | **100%** | **100%** | **83%** | **100%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | |
| Inflow TSS Load (lbs) | 2,411 | 2,095 | 2,354 | 12,565 | 2,356 |
| Outflow TSS Load (lbs) | 1 | 0 | 0 | 1,653 | 0 |
| TSS Load Removed by BMP (lbs) | 2,410 | 2,095 | 2,354 | 10,912 | 2,356 |
| TSS Removal Efficiency (%) | **100%** | **100%** | **100%** | **87%** | **100%** |

[a] Annual projected results derived using the 1995 water year.

**Table 10-5. Annual cumulative TP and total solids load reductions for all rain gardens from 2007 to 2010 and for a year with an average precipitation amount (annual projected).**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 21.7 | 22.3 | 36.3 | 26.0 |
| Watershed Area (ac) | 16.08 | 16.08 | 16.08 | 16.08 | 16.08 |
| ***VOLUME REMOVED*** | | | | | |
| Total Volume Removed by BMP (cf) | **257,048** | **225,118** | **230,519** | **501,245** | **277,651** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | |
| TP Load Removed by BMP (lbs) | 5.75 | 4.94 | 5.24 | 17.10 | 6.05 |
| TP Load in Gross Solids Load Removed by BMP (lbs) | 2.44 | 4.38 | 5.41 | 3.26 | 4.35 |
| Cumulative TP Load Removed: BMP (lbs) | **8.19** | **9.32** | **10.65** | **20.36** | **10.40** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | |
| TSS Load Removed by BMP (lbs) | 2,410 | 2,095 | 2,354 | 10,912 | 2,356 |
| Gross Solids Load Removed by BMP (lbs) | 6,023 | 10,902 | 13,461 | 8,130 | 10,822 |
| Total Solids Load Removed: BMP (lbs) | **8,433** | **12,997** | **15,815** | **19,042** | **13,178** |

## 10.3. Operation and Maintenance

Figure 10-6. CRWD staff and volunteers conducting maintenance in the Asbury South Rain Garden, 2008.

CRWD is responsible for the operation and maintenance of the eight rain gardens. In 2010, a Clean Water Legacy grant was awarded to CRWD in cooperation with the City of St. Paul Parks and Recreation Department for a Conservation Crew of Minnesota field crew. This crew was assigned to assist both CRWD and the City of St. Paul, to establish and maintain environmental practices which provide a direct benefit to the water quality of Como Lake.

The field crew exclusively provided maintenance assistance to the Hamline Midway Rain Garden. Since 2008, CRWD has also received assistance from neighborhood volunteers for maintenance of rain gardens. CRWD staff, City of St. Paul staff, Conservation Crew of Minnesota staff, and volunteer hours are reflected in annual labor hours and labor costs in Table 10-6. A labor rate of $0.00 was applied to volunteer hours in the labor cost calculation.

**Table 10-6. Annual O & M costs and labor hours for the rain gardens.**

| Year | Labor | Equipment & Materials | Contract Services | Total | Labor Hours[a] |
|---|---|---|---|---|---|
| 2007 | $11,469 | $2,621 | $761 | $14,851 | 640.0 |
| 2008 | $5,142 | $1,755 | $648 | $7,544 | 431.6 |
| 2009 | $3,790 | $1,006 | $0 | $4,796 | 380.2 |
| 2010 | $3,185 | $4,430 | $0 | $7,615 | 243.2 |
| **Total:** | **$23,586** | **$9,811** | **$1,409** | **$34,805** | **1695.0** |

[a] Includes CRWD staff, CRWD volunteer, and City of St. Paul staff hours.

From 2007 to 2009, annual O & M costs for the rain gardens decreased substantially. In 2010, the annual O & M cost increased; however, this increase was mainly due to the purchase and installation of signage at the rain gardens (equipment and materials cost). The maintenance of rain gardens is labor intensive. On average labor costs account for 67% of the annual O & M costs.

Since 2007, there has been an overall decrease in the number of labor hours and labor costs spent annually maintaining the rain gardens. As the rain gardens become more established, the need for maintenance should gradually decrease. Since 2008, various individuals and groups have volunteered their time to provide CRWD with assistance with maintenance of the rain gardens. In 2008 and 2009, volunteers accounted for almost 60% of the total labor hours, although in 2010 they accounted for only 8%. From 2008 to 2010, CRWD staff hours have remained fairly consistent, averaging 240 hours annually. CRWD staff hours are expected to drop significantly in future years, as maintenance of the rain gardens will be contracted out.

In 2009, approximately 70% of the total labor hours were spent maintaining four rain gardens: the Asbury South, Frankson-McKinley, Hamline Midway, and Pascal Center Rain Gardens (on average, 66 hours per rain garden). The Pascal Center Rain Garden is the second smallest rain garden; however, it has the largest immediate boulevard area. Maintenance of that boulevard area (grass re-establishment and mowing) accounted for the majority of its total labor hours. The Asbury South, Frankson-McKinley, and Hamline Midway Rain Gardens are the three largest rain gardens. They generally require more attention for maintenance due to their size. The remaining four rain gardens (Arlington-McKinley, Asbury North, Pascal North, and Pascal South Rain Gardens) averaged 29 hours of maintenance, per rain garden in 2009.

Approximately 43% of the total labor hours (approximately 105 hours) in 2010, were spent maintaining the Hamline Midway Rain Garden. The other seven rain gardens averaged 20 hours of maintenance per rain garden.

CRWD's rain garden inspection and maintenance schedule is outlined in Table 10-7. Routine maintenance of the rain gardens and the immediate surrounding boulevard was completed as deemed necessary. This included grass establishment and mowing of the boulevard areas immediately surrounding the rain garden. The more frequent types of rain garden maintenance activities included debris and trash removal from the rain garden and rain garden inlets, leaf removal, thinning plants, and weeding.

**Table 10-7. Inspection and maintenance schedule for the rain gardens.**

| Activity | Frequency |
|---|---|
| Inspection | Monthly, After Major Rainfall |
| Maintenance | Monthly or as Necessary |

CRWD also completed monthly inspections and post-rain inspections (after rain events totaling two or more inches of precipitation) for all rain gardens. Both inspections were qualitative and required the assessor to make observations on the health and abundance of plants, the presence of bare patches of soil, the occurrence of sediment buildup, the presence of debris in the inlet(s); and the initiation of erosion.

Itemized annual O & M activities and costs for each rain garden, for 2007 and 2008, may be found in CRWD's Stormwater *BMP Performance Assessment and Cost-Benefit Analysis* (CRWD, 2010[b]). Itemized annual O & M activities and costs, for 2009 and 2010, for each rain garden may be found in Appendix A: Tables A-38 through A-54.

## 10.4. Cost-Benefit Analysis

Annual operating costs for all of the rain gardens have varied, from 2007 to 2010, due to significant fluctuations in annual O & M costs. On average, the annual operating cost for all rain gardens is approximately $13,000; which is slightly higher than the projected annual operating cost (Table 10-8). 2007 had the highest annual operating cost due to the labor cost associated with maintenance of the rain gardens. This high annual operating cost had a large impact on the overall, 2007 through 2010, average. Excluding the 2007 operating cost, the 2008 through 2010 average annual operating cost is more on par with the annual projected operating cost at approximately $11,000.

**Table 10-8. Rain garden annual operating costs.**

| | Annual Capital Cost[a] | Annual O & M Cost | Annual Operating Cost |
|---|---|---|---|
| 2007 | $4,578 | $14,851 | $19,429 |
| 2008 | $4,578 | $7,544 | $12,122 |
| 2009 | $4,578 | $4,796 | $9,374 |
| 2010 | $4,578 | $7,615 | $12,193 |
| Annual Projected | $4,578 | $7,160 | $11,738 |

[a] Capital cost amortized over 35 years.

Volume reduction and pollutant removal costs have steadily decreased since 2007 (Table 10-9). The costs were at their lowest in 2010, primarily due to greater volumes of runoff being infiltrated and increased pollutant removal in 2010 than in previous years.

The 2010 removal costs generally indicate that the driving factors in volume reduction and pollutant removal costs are the volume of discharge and the quantity of pollutants being removed. Increases or decreases in discharge and pollutant loads directly impact the removal costs. Annual operating costs do not generally have a large impact on volume reduction and pollutant removal costs because generally there are no significant fluctuations in annual operating costs therefore the impact is not quite as extensive. However, the sizeable differences in annual operating costs, from 2007 to 2009 for the rain gardens, have an equal and perhaps an even greater impact on those corresponding volume reduction and pollutant removal costs. More so than the volume of discharge and quantity of pollutants being removed.

With the exception of the TSS removal cost, which is significantly lower, average volume reduction and pollutant removal costs are relatively comparable to annual projected costs. On average, the cost to remove one pound of TP and one pound of total solids is $1,107 and $0.91. The average cost to infiltrated one cubic foot of stormwater runoff is $0.04.

**Table 10-9. Annual volume reduction and pollutant removal costs for all rain gardens.**

| | 2007 | 2008 | 2009 | 2010 | Annual Projected |
|---|---|---|---|---|---|
| Annual Operating Cost | $19,429 | $12,122 | $9,374 | $12,193 | $11,738 |
| Volume Reduction (cf/year) | 257,048 | 225,118 | 230,519 | 501,245 | 277,651 |
| Volume Reduction Cost ($/cf) | $0.08 | $0.05 | $0.04 | $0.02 | $0.04 |
| Cumulative TP Load Removed (lbs/year)[a] | 8.19 | 9.32 | 10.65 | 20.36 | 10.40 |
| Cumulative TP Removal Cost ($/lb) | $2,372 | $1,301 | $880 | $599 | $1,129 |
| TSS Load Removed (lbs/year) | 2,410 | 2,095 | 2,354 | 10,912 | 2,356 |
| TSS Removal Cost ($/lb) | $8.06 | $5.79 | $3.98 | $1.12 | $4.98 |
| Total Solids Load Removed (lbs/year)[b] | 8,433 | 12,997 | 15,815 | 19,042 | 13,178 |
| Total Solids Removal Cost ($/lb) | $2.30 | $0.93 | $0.59 | $0.64 | $0.89 |

[a] Includes the TP load removed through infiltration of stormwater runoff and settlement of suspended particles and the TP load associated with the gross solids load captured by the BMP.

[b] Includes the TSS load removed through infiltration of stromwater and settlement of suspended particles as well as the gross solids load captured by the BMP.

# 11. Additional Analysis

Additional analysis was performed to further explore the performance trends of the Arlington Pascal Project BMPs from 2007 to 2010. Statistical methods were used to demonstrate the effectiveness of the Arlington-Hamline Facility, Como Park Regional Pond, and the two monitored infiltration trenches at removing TP and TSS loads. Statistical analysis was also utilized to identify annual variations and trends in TP and TSS concentrations.

## 11.1. Como Park Regional Pond

The Como Park Regional Pond receives stormwater runoff from two types of input source flow: the direct drainage area of the pond (denoted as Como Park Regional Pond Inlet) and from Gottfried's Pit. The discharge from the direct drainage area is sourced from a 128 acre watershed that is primarily residential in land use. Gottfried's Pit is a stormwater detention pond that receives runoff from a 522 acre watershed. Water is pumped from Gottfried's Pit and into a storm sewer which flows to the Como Park Regional Pond, when the water level of the pit reaches a specific level. Both types of input source flow, as well as overflow from the Como Park Regional Pond (Como Park Regional Pond Outlet), have been monitored for concentrations of TP and TSS since 2008, allowing for pollution retention and treatment in the pond to be assessed.

Using the data collected at these three monitoring points, an ANOVA test was performed to test the significance of monitoring site location and monitoring year in determining TP and TSS concentrations in the Como Park Regional Pond. From the ANOVA test, it was concluded with 95% confidence that monitoring site location was highly significant in determining TP and TSS concentrations; however, monitoring year was not significant.

Post-hoc Tukey tests indicate the flow resulting from the direct drainage area of the pond had significantly higher TP and TSS concentrations, than the flow pumped from Gottfried's Pit and overflow from the Como Park Regional Pond (Figure 11-1). Also, the Post-hoc Tukey tests showed that flow discharging from Gottfried's Pit and overflow from the Como Park Regional Pond, were not significantly different from each other. This strongly suggests that the primary influx of nutrients and sediment flowing to the pond is generated from runoff from the direct drainage area of the pond.

In consideration of the subwatershed conditions for the Como Park Regional Pond Inlet, this conclusion is supported because runoff discharging directly through the pond inlet is generated from a residential subwatershed that has only a small percentage (7%) of runoff treated by the Arlington Pascal Project BMPs. In comparison, flow to Como Park Regional Pond resulting from water discharging from Gottfried's Pit, has been pretreated by Gottfried's Pit itself; since the pit was designed to provide retention of stormwater. Thus, pollutant loads discharged in water from Gottfried's Pit are somewhat reduced prior to flowing to the Como Park Regional Pond.

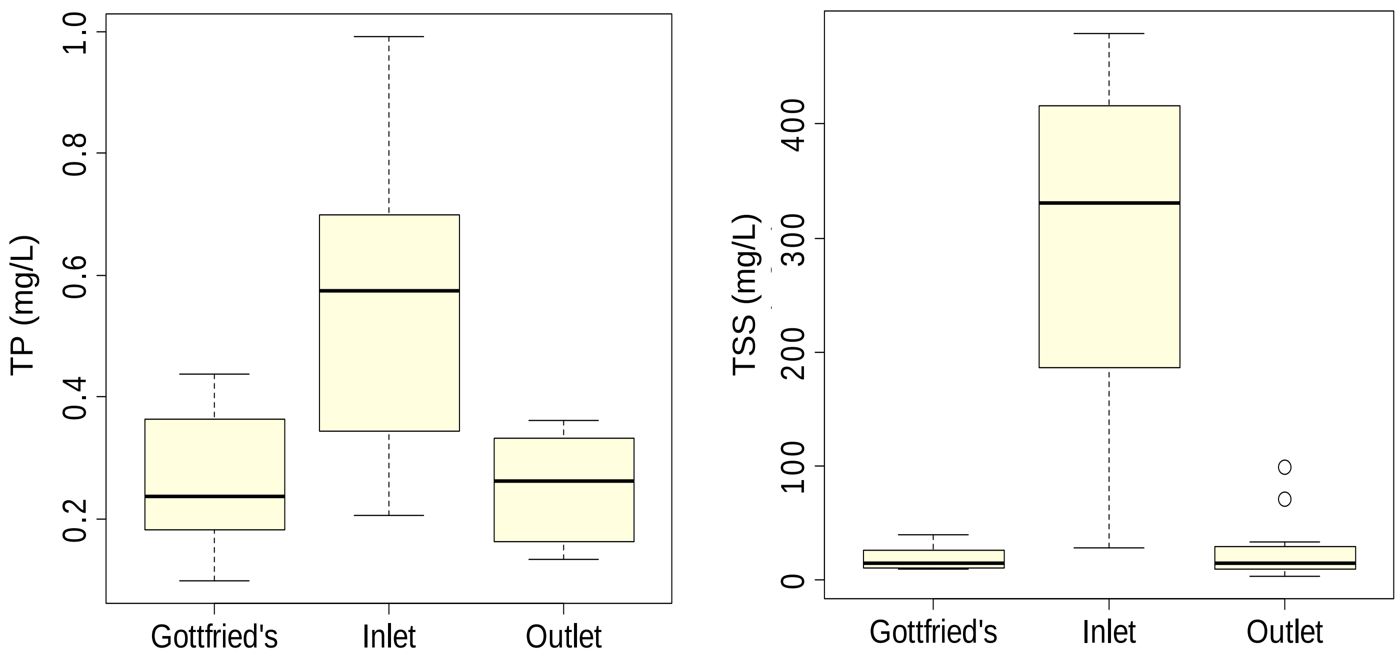


**Figure 11-1. Paired data from Gottfried's Pit, Como Park Regional Pond Inlet, and Como Park Regional Pond Outlet from 12 different paired storm events (2008 to 2010).**

To further examine the removal of TP and TSS during storms by the Como Park Regional Pond, paired storm data from the pond inlet and outlet were graphed using boxplots. Data from 31 paired storm events taken during the 2008 through 2010 monitoring seasons were used in the analysis; 8 paired events in 2008, 13 paired events in 2009, and 10 paired events in 2010. In each case, TP and TSS concentrations were significantly lower in discharge overflowing from the pond than in both types of runoff (direct drainage area, pumped water from Gottfried's Pit) flowing to the pond (Figures 11-2 and 11-3). This suggests that the pond is effective at removing both TP and TSS. In addition, probability plots of the data indicated that the runoff generated from the direct drainage area to the pond had higher TP and TSS concentrations than the water pumped from Gottfried's Pit and from overflow from the pond (Figure 11-4). Based on these results, it can be concluded that Como Park Regional Pond is an effective BMP for reducing TP and TSS.

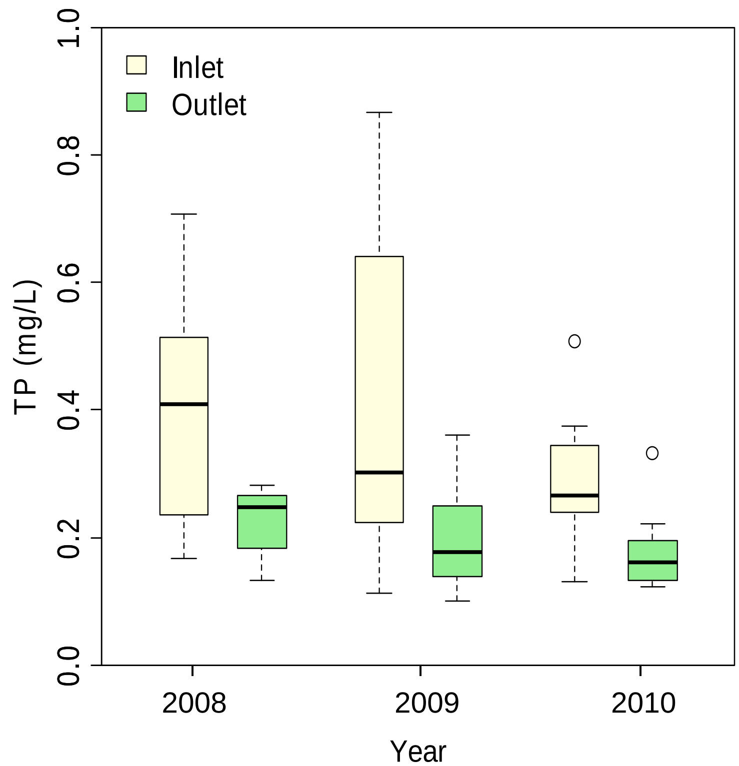


**Figure 11-2. Paired storm comparisons of Como Park Regional Pond Inlet versus Como Park Regional Pond Outlet TP concentrations between 2008 and 2010.**

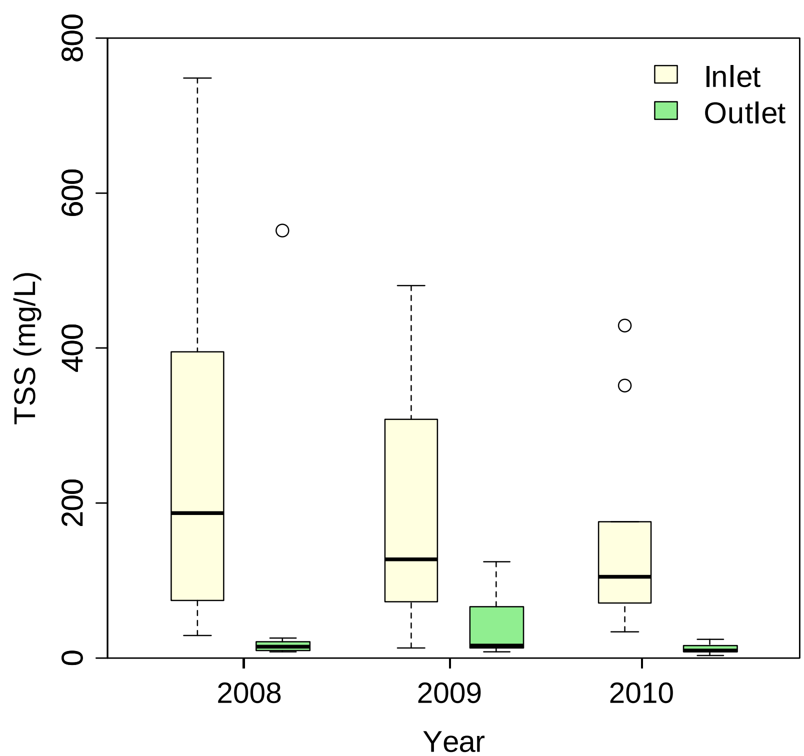


**Figure 11-3. Paired storm comparisons of Como Park Regional Pond Inlet versus Como Park Regional Pond Outlet TSS concentrations between 2008 and 2010.**

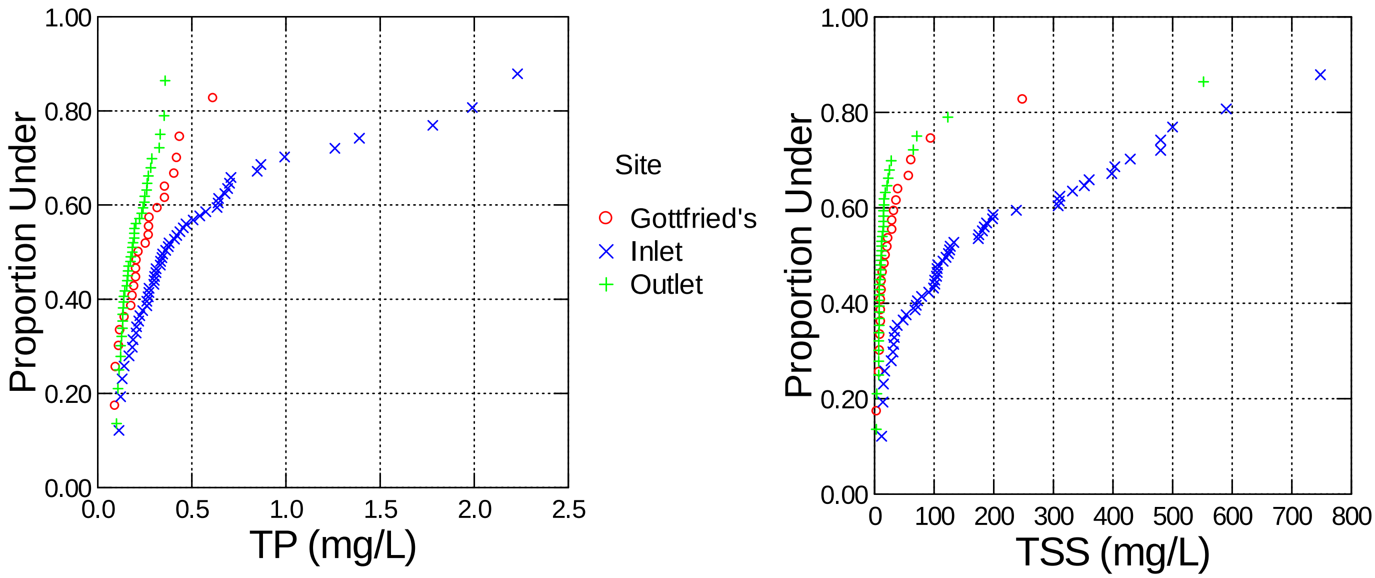


**Figure 11-4. TP (left) and TSS (right) probability plots for all data from 2008 to 2010, separated by site (Gottfried's Pit, Como Park Regional Pond Inlet, and Como Park Regional Pond Outlet).**

## 11.2. Arlington-Hamline Facility

Median TP and TSS concentrations of runoff flowing to the Arlington-Hamline Facility, from 2007 to 2010, did not differ significantly. Boxplots showed extreme outliers in TP and TSS concentrations. TP concentrations were generally below 1 mg/L and TSS concentrations were below 400 mg/L (Figure 11-5).

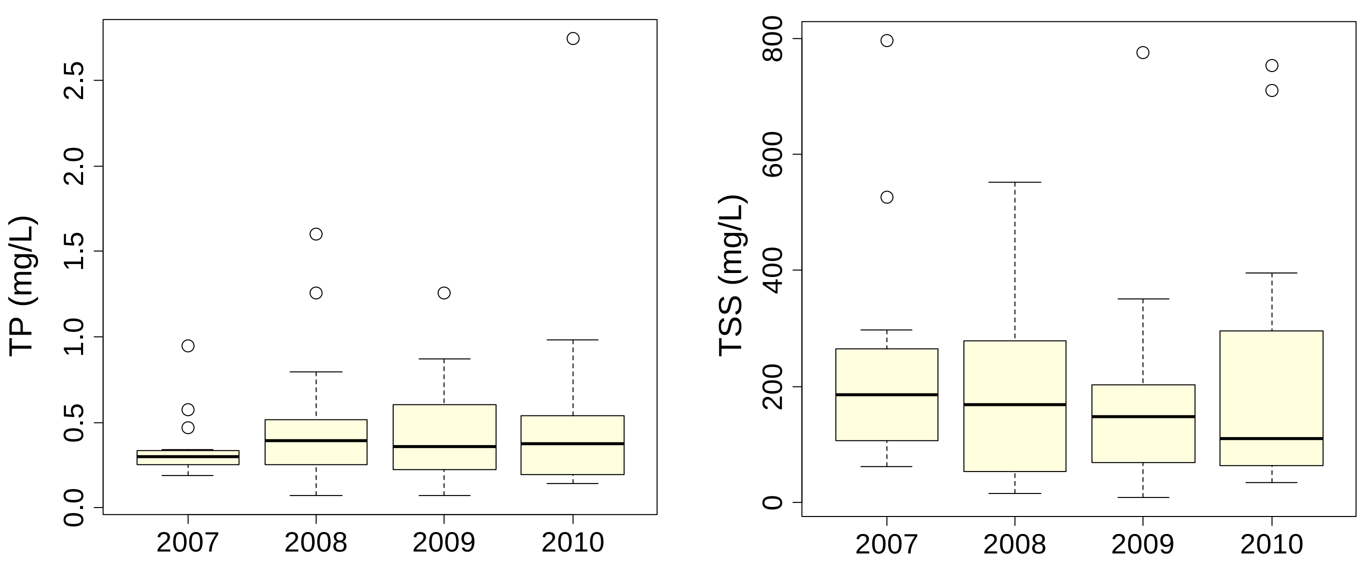


**Figure 11-5. Arlington-Hamline Facility Inlet TP (left) and TSS (right) concentrations from 2007 to 2010.**

The probability plot of TP concentrations of runoff flowing to the Arlington-Hamline Facility, from 2007 to 2010, indicated that TP concentrations did not differ greatly overtime.  This is evidenced by the high degree of overlap in the probability plot (Figure 11-6).  For TP, 80% of sample concentrations were under 1 mg/L.  TSS concentrations were more variable than TP (Figure 11-6).  For both TP and TSS, the 2010 monitoring year had some of the highest concentrations of TP and TSS ever recorded in runoff flowing to the Arlington-Hamline Facility.

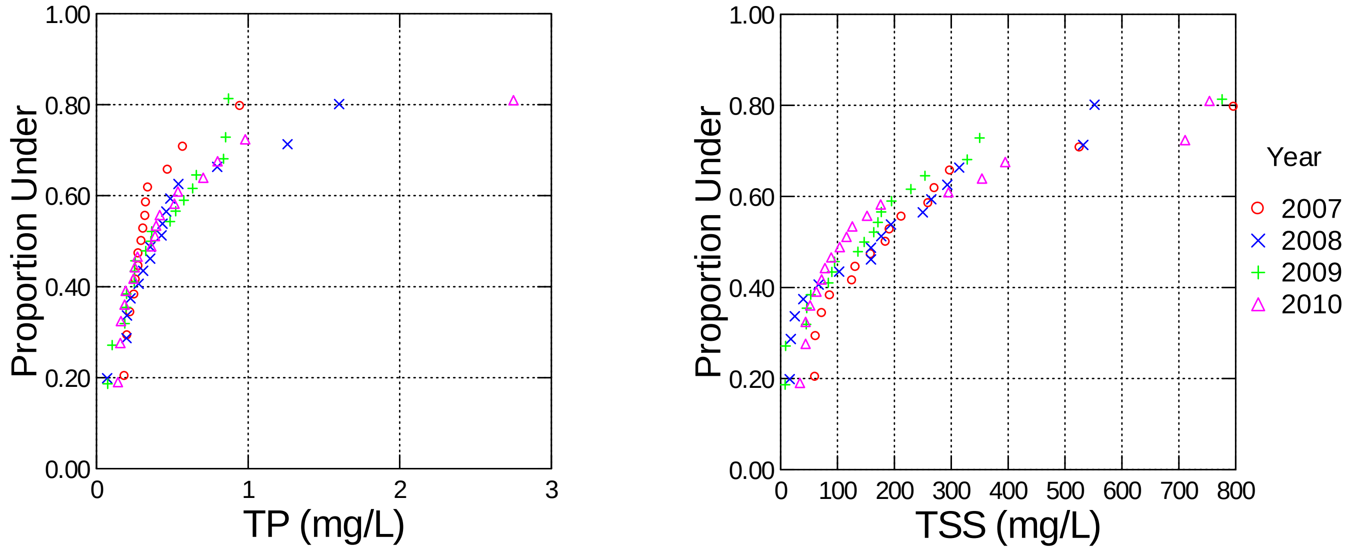


**Figure 11-6. Arlington-Hamline Facility Inlet TP (left) and TSS (right) probability plots for all data from 2007 to 2010, separated by year.**

## 11.3. Underground Infiltration Trenches

Of the eight infiltration trenches installed, two trenches (Trench 4 and 5) have been monitored for water quality.  Boxplots show a slight but non-significant trend of increasing TP concentrations in runoff flowing to Trench 4 from 2007 to 2010 (Figure 11-7), but no discernible trend for TSS concentrations (Figure 11-7).

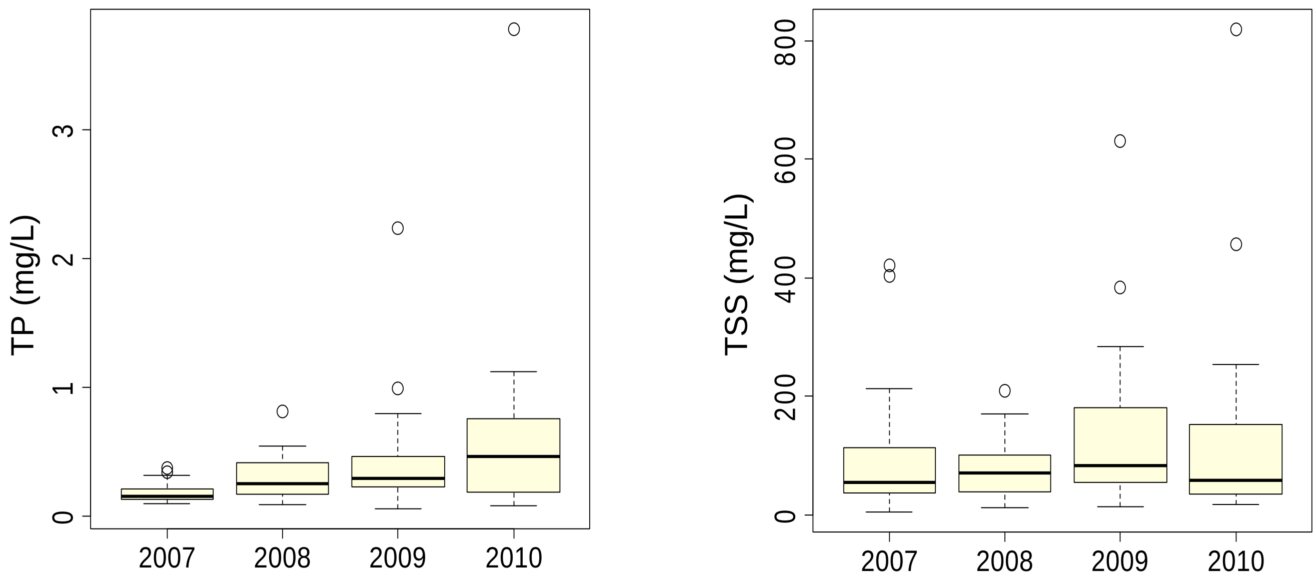


**Figure 11-7. Trench 4 TP (left) and TSS (right) concentrations from 2007 to 2010.**

TP and TSS concentrations of runoff flowing into Trench 5 did not change significantly between 2007 and 2009 (Figure 11-8). In 2009, TSS concentrations were skewed toward higher values in comparison to 2007 and 2008 (Figure 11-8), but an ANOVA test indicated that the trend was not significant.

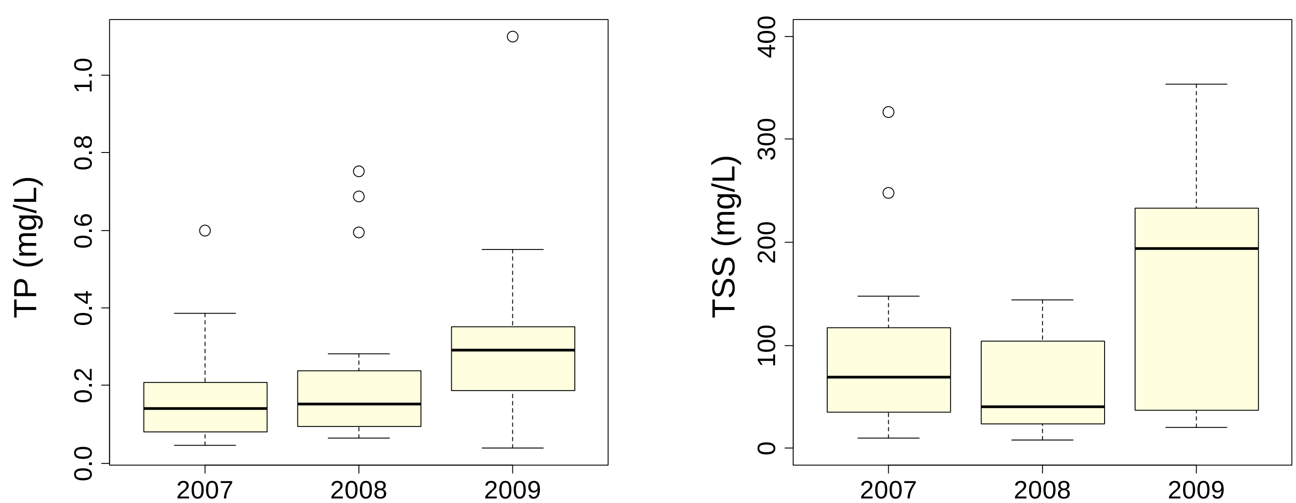


**Figure 11-8. Trench 5 TP (left) and TSS (right) concentrations from 2007 to 2009. Trench 5 was not monitored for water quality in 2010.**

## 11.4. Conclusions

The first objective was to assess the effectiveness of the Como Park Regional Pond for removing TP and TSS. Flow from Gottfried's Pit was found to be not significantly different from the water overflowing from the pond; suggesting that the primary source of nutrients and suspended solids comes from the runoff generated from the direct drainage area of the pond. TP and TSS concentrations of runoff flowing to and water overflowing from the pond were found to be significantly different. Based on these results, it can be concluded that the pond is an effective BMP for TP and TSS removal; most likely through pollutant retention and internal processing.

Results from statistical tests showed that TP and TSS concentrations of runoff flowing to the Arlington-Hamline Facility, Trench 4, and Trench 5 (from 2007 to 2010), were not significantly different. The datasets show that stormwater runoff entering these systems was not changed significantly in TP and TSS concentrations over time, which suggests that localized watershed conditions (e.g. land use, pollutant sources) have remained constant over a four-year period.

# 12. Conclusions and Future Work

CRWD assessed the annual performance of BMPs for the Arlington Pascal Project using a water quality model calibrated to actual water quantity and quality data collected from the BMPs from 2007 through 2010. During that time, CRWD also maintained the BMPs and documented maintenance activities and costs for each task. Using the BMP performance and O & M data, a cost-benefit analysis of those BMPs was conducted. Overall conclusions of that analysis are briefly summarized below.

## 12.1. BMP Performance Results

### 12.1.1. Annual Precipitation

Annual precipitation totals varied significantly from 2007 to 2010 ranging from very dry to very wet. Considerably more precipitation fell in 2010 than in previous years. A 24% precipitation increase was observed in 2010 (36 inches) in comparison to the National Weather Service (NWS) 30-year normal precipitation amount (29 inches). This increase in annual precipitation equated to substantially more stormwater runoff and pollutants flowing to and from the BMPs; as well as, greater amounts of runoff and pollutant loads being removed by the BMPs.

### 12.1.2. Volume Reduction

On average, from 2007 to 2010, 9.3 million cf of stormwater runoff flowed to all Arlington Pascal Project BMPs annually (Arlington-Hamline Facility, Como Park Regional Pond, infiltration trenches, and rain gardens). Of that inflow volume, an average 1.9 million cf (20%) was removed each year.

The Como Park Regional Pond has the largest drainage area of all other BMPs, and from 2008 to 2010 the pond has received the largest quantity of runoff which flowed to all BMPs; 87% of the total runoff flowing to all BMPs. Although the pond received the majority of runoff flowing to all BMPs from 2008 to 2010, the Arlington-Hamline Facility removed the same proportion of runoff (removed by all BMPs) as the pond; 34% of the total runoff removed. In addition, all runoff which flowed to the Arlington-Hamline Facility was infiltrated.

From 2007 to 2009, annual volume reduction efficiencies of the Arlington-Hamline Facility, infiltration trenches, and rain gardens were all extremely high. With the exception of the infiltration trenches in 2007, in which the volume reduction efficiency for the trenches was 99%, the Arlington-Hamline Facility, infiltration trenches, and rain gardens had annual volume reduction efficiencies of 100% from 2007 to 2009. All runoff which flowed to those BMPs was removed. The Como Park Regional Pond, which was not designed for infiltration but rather for settling, had much lower annual volume reduction efficiencies in 2008 and 2009; 9% and 10% respectively. Annual volume reduction efficiencies, for all BMPs from 2007 to 2009, were consistent with annual projected volume reduction efficiencies; which are based on volume reductions in a normal precipitation year.

In 2010, more stormwater runoff flowed to and was removed by the BMPs than in previous years; 18.9 million cf and 3.1 million cf, respectively. These amounts were more than one and one-half times greater than the amounts observed in previous years. Volume reduction efficiencies for the individual BMPs, except for the Arlington-Hamline Facility, were lower in 2010 than those observed in previous years. This was likely due to BMP capacities being exceeded by a combination of factors including: increased frequency of storm events, greater number of storm events producing high precipitation totals, an increased frequency of more intense storm events, and saturated soil moisture conditions. In 2010, the volume reduction efficiency of the pond was 5%, the infiltration trenches 77%, and the rain gardens 88%. These were all also lower than the annual projected efficiencies. In contrast, the volume reduction efficiency observed for the Arlington-Hamline Facility in 2010 was the same as those efficiencies observed in previous years (100%) and was consistent with the annual projected efficiency.

## 12.1.3. Total Phosphorous Reduction

### *12.1.3.1. TP Load Reductions and Removal Efficiencies: Due to Infiltration and Settling of Suspended Solids*

The average annual TP load in stormwater runoff flowing to all BMPs, from 2007 to 2010, was 176 lbs; of which, 82 lbs (47%) was removed through infiltration of runoff and settling of suspended solids. The largest portions of annual TP loads, in runoff flowing to all BMPs, were removed by the Como Park Regional Pond and the Arlington-Hamline Facility.

Similar to volume reduction efficiencies observed for the BMPs, from 2007 to 2009, the Arlington-Hamline Facility, infiltration trenches, and rain gardens had TP removal efficiencies of 100%; except for the infiltration trenches in 2007, which had a TP removal efficiency of 99%. These efficiencies were consistent with the annual projected TP removal efficiencies. In 2010, the TP removal efficiencies were lower for the infiltration trenches and the rain gardens; 75% and 83% respectively. The 2010 TP removal efficiency for the Arlington-Hamline Facility remained at 100% since no stormwater overflowed from the BMP.

The TP removal efficiency for the Como Park Regional Pond was constant (30%) from 2008 to 2010, which was slightly higher than the annual projected efficiency (28%). Regardless of the total annual amount of TP flowing to the pond from 2008 to 2010, it achieved a maximum removal efficiency of 30% through infiltration and settling.

### *12.1.3.2. Cumulative TP Load Reductions*

Annual cumulative TP loads were determined for each BMP which incorporated: 1) the annual TP load removed through infiltration and settlement of suspended particles, 2) the annual TP load removed through the accumulation of gross solids in any pretreatment units, and 3) the annual TP load removed through the accumulation of gross solids within the BMP.

On average, 159 lbs of cumulative TP was collectively removed by all BMPs each year. The majority of that amount was captured and removed by the Arlington-Hamline Facility (average 44 lbs per year) and the Como Park Regional Pond (average 110 lbs per year). Although the infiltration trenches and rain gardens removed a much smaller portion, the amount of cumulative TP removed was still significant; each year an average 20 lbs and 12 lbs, respectively. In general, annual cumulative TP loads removed by the BMPs, increased from 2007 to 2010. The annual cumulative TP loads removed by the BMPs in 2010 were at a minimum, one and one-half times greater than annual cumulative TP loads removed in any other year; due to increased loading.

Although annual TP loads removed through infiltration and settling of solids and through the accumulation of gross solids in the BMPs and/or any pretreatment units has varied annually and by BMP; overall, the majority of annual cumulative TP loads removed by all BMPs, from 2007 to 2009, were due to the TP loads removed through the accumulation of gross solids in the BMPs and pretreatment units. From 2007 to 2009, TP loads in gross solids captured accounted for 62% (234 lbs) of annual cumulative TP loads removed by all BMPs. In 2010, the TP loads in gross solids removed by the BMPs and pretreatment units accounted for just 29% (73 lbs) of the annual cumulative TP load removed.

### 12.1.4. Total Suspended Solids Reduction

From 2007 to 2010, the average annual TSS load flowing to all BMPs was 70,800 lbs; of which, 57,100 lbs (81%) were removed through infiltration and settling each year. The Como Park Regional Pond (average of 44,300 lbs) and the Arlington-Hamline Facility (average of 13,200 lbs) removed the largest amounts of TSS every year. The rain gardens removed the smallest load (average of 4,400 lbs), largely due to their smaller contributing drainage areas.

From 2007 to 2009, TSS removal efficiencies for the Arlington-Hamline Facility, infiltration trenches, and rain gardens were 100%; with the exception of the removal efficiency of the trenches in 2007 which was 99%. In 2008 and 2009, the Como Park Regional Pond also had high TSS removal efficiencies, 82% and 79%, respectively. TSS removal efficiencies observed for the individual BMPs from 2007 to 2009 were all consistent with annual projected results.

In 2010, the TSS load which flowed to and was removed by the BMPs was more than four times the TSS loads observed in any other year; 189,200 lbs of TSS cumulatively flowed to the BMPs and 145,800 lbs (77%) were removed. Similar to volume and TP efficiency trends, TSS removal efficiencies in 2010 were lower than those observed in previous years except for the Arlington-Hamline Facility. The Arlington-Hamline Facility remained 100% effective at removing TSS. The infiltration trenches and rain gardens were still effective at TSS removal (82% and 87% respectively). The pond had the lowest TSS removal efficiency of all the BMPs in 2010 (69%); however, it was still effective at TSS removal.

### 12.1.5. Total Solids Reduction

Annual total solids loads were determined for each BMP which incorporated: 1) the annual TSS load removed through infiltration and settlement of suspended particles, 2) the annual gross solids load removed through the accumulation of gross solids in any pretreatment units, and 3) the annual gross solids load removed through the accumulation of gross solids within the BMP.

From 2007 to 2010, on average, 224,000 lbs of total solids were removed by all BMPs each year. The vast majority (75%) of that total solids load removed, was due to accumulation of gross solids in the BMPs and by the pretreatment units. However, the proportion of annual loads removed, attributable to each component of the total solids load, for each individual BMP varied.

The largest amounts of total solids were removed by the BMPs in 2009 (293,000 lbs) and 2010 (301,000 lbs). Annual total solids loads removed by the Arlington-Hamline Facility and the Como Park Regional Pond accounted for the largest portions of total solids removed by all the BMPs from 2007 to 2010; on average 17% and 63% of the annual total solids load. The infiltration trenches and the rain gardens removed significantly less total solids than the Arlington-Hamline Facility and the pond. However, the annual total solids loads removed by both BMPs were still significant, considering their smaller contributing drainage areas. On average, the infiltration trenches removed 29,000 lbs and the rain gardens removed 14,000 lbs of total solids annually, from 2007 to 2010.

### 12.1.6. Meeting 2003 Target TP Load Reductions

Target TP load reductions for the Arlington Pascal Project and for the individual BMPs were set in accordance with a TP load reduction goal of 60% for Como Lake. The TP load reduction goal for the entire Arlington Pascal Project was determined to be 77 lbs of annually.

From 2007 to 2010, annual cumulative TP load reductions for the Arlington Pascal Project averaged 159 lbs per year. Since 2008, when all project BMPs were operational, individual BMP and project cumulative TP load reductions exceeded the 2003 target TP load reductions. Annual cumulative TP load reductions, from 2008 to 2010, were more than one and one-half times the target load reduction. The annual projected cumulative TP load reduction for the entire Arlington Pascal Project was slightly more than two times the 2003 target load reduction for the entire project.

Since they have been operational, annual cumulative TP load reductions for the Arlington-Hamline Facility and the Como Park Regional Pond were more than two times greater than the 2003 target load reductions of 12 lbs and 41 lbs, respectively. The annual cumulative TP load removed by the infiltration trenches and rain gardens in 2007 was slightly less than the 2003 target load reduction of 24 lbs. However, since 2008, annual cumulative TP load reductions for the trenches and the rain gardens exceeded the 2003 target load reductions.

Improvements in the water quality of Como Lake, directly related to phosphorous load reductions by the project BMPs, have yet to be extensively studied. The BMPs may need to be in operation for a longer time period before measureable results are observed. However, the Arlington Pascal Project has been proven to be a cost-effective strategy, in comparison to the original proposal, for achieving target volume and pollutant load reduction goals.

## 12.2. BMP Operation and Maintenance

From 2007 to 2010, on average $22,300 and 554 staff hours were spent maintaining the Arlington Pascal Project BMPs each year. Annual O & M costs and hours spent on maintenance, for individual BMPs, have varied. However, O & M costs and total hours spent on inspecting and maintaining the BMPs have decreased from 2007 to 2010. Although the annual O & M cost collectively spent on operation and maintenance of all BMPs has only slightly decreased from 2007 to 2010; total staff hours spent on operation and maintenance in 2010 was one and one-half times less than the hours spent in 2007. More labor intensive BMP types (i.e. rain gardens) require fewer hours of maintenance as they become more established.

## 12.3. Cost-Benefit Analysis

### 12.3.1. Volume and Pollutant Removal

Annual volume reduction costs for the entire Arlington Pascal Project from 2007 to 2010 were between $0.03 and $0.06 per cubic foot. The volume reduction cost in 2010 for the entire project was one-half less than the annual volume reduction costs for the project from 2007 to 2010. This was due to significantly more stormwater runoff being removed in 2010, than in previous years. Volume reduction costs for the individual BMPs varied annually; individual BMP volume reduction costs were between $0.02 and $0.08 per cubic foot from 2007 to 2010.

The 2007 to 2010 annual cumulative TP removal costs for the Arlington Pascal Project were between $395 and $1,100 per pound and for the individual BMPs were between $301 and $2,372 per pound. The total solids removal costs for the project and BMPs were between $0.33 and $1.07 per pound and $0.20 and $2.30 per pound respectively.

The infiltration trenches and the rain gardens consistently had the highest cumulative TP and total solids removal costs of the BMPs from 2007 to 2010. This was due to a combination of the overall lower amounts of pollutants being removed (because of their smaller drainage areas in comparison to the pond or the Arlington-Hamline Facility) and more intensive O & M schedules. The rain gardens require significantly more annual maintenance than the pond and the Arlington-Hamline Facility.

In general, the lowest annual operating costs occurred in 2007 and the highest in 2008. However, there was a decreasing trend in volume reduction and pollutant removal costs from 2007 to 2010 across the individual BMPs and the Arlington Pascal Project as a whole. The highest volume reduction and pollutant removal costs occurred in 2007 and the lowest in 2010. The lower volume reduction and pollutant removal costs in 2010 were mostly due to the higher amount of annual precipitation. Increased precipitation in 2010 generated more stormwater runoff and pollutants flowing to the BMPs and also allowed for substantially more volume and pollutants to be removed than in any other year.

### 12.3.2. Drainage Area

Additional analysis was also conducted to normalize construction (capital) costs and the 35-year projected O & M costs, for the project BMPs and project as a whole, by the contributing drainage area to each; as well as, by the amount of each contributing drainage area covered by impervious surfaces. This analysis will serve as a base, moving forward, for other District programs and processes.

The capital costs of all Arlington Pascal Project BMPs were $14,300 per watershed acre and $32,600 per acre impervious surfaces. The 35-year projected O & M costs for all project BMPs were $5,400 per watershed area and $12,300 per acre impervious surfaces.

## 12.4. General Conclusions

Since the stormwater pond became operational, the Como Park Regional Pond has accounted for the largest quantity of volume reduction and pollutants being removed of all BMPs. This is not surprising, as the pond has by far the largest contributing drainage area, in addition to also receiving discharge pumped from an upstream stormwater pond (Gottfried's Pit). Although it has infiltrated the largest quantity of stormwater runoff and removed the largest quantity of pollutants, it consistently had the lowest performance efficiencies of all BMPs.

The Arlington-Hamline Facility performed consistently, from 2007 to 2010, and had the highest performance efficiencies of all BMPs. All stormwater runoff and associated pollutants that flowed to the facility were infiltrated and removed from 2007 to 2010. The infiltration trenches and the rain gardens were also highly effective at removing runoff, TP, and TSS. Individual volume reduction and removal efficiencies were between 75% and 100% from 2007 to 2010.

In general, the BMPs performed as or better than expected. From 2007 to 2010, all BMPs overall were more effective at removing TSS than TP. Volume reduction and TP and TSS removal efficiencies for individual BMPs were consistent with projected removal efficiencies from 2007 to 2010. Removal efficiencies in 2010 were all slightly less than those observed in previous years as well as less than the annual projected removal efficiencies. This was primarily due to higher volumes of stormwater runoff, more pollutant loading to the BMPs, and greater volumes of runoff and loads of pollutants being removed by the BMPs in 2010 than in the 1995 water year used to simulate annual projected results.

The amounts of gross solids loads and TP loads in gross solids captured by the BMPs and pretreatment units were considerable. From 2007 to 2010, TP loads in gross solids and gross solids loads captured by the BMPs and pretreatment units accounted for the vast majority of the cumulative TP loads and total solids loads to all of the BMPs. The value of pretreatment devices in capturing debris and solids is substantial, as well as, the value of incorporating gross solids into total solid load estimates.

Volume reduction and pollutant removal costs were directly affected by two factors: fluctuations in annual operating costs and fluctuations in the amount of volume reduction and pollutant load reductions occurring. In general, the amount of volume and pollutant load reductions occurring had a greater impact on removal costs, than the fluctuations in the annual operating costs. It is expected that in years with large volume and pollutant load reductions, volume reduction and pollutant removal costs will be lower and vice versa.

## 12.5. Future Work

Monitoring BMPs is essential for determining and tracking overall BMP performance. CRWD expects to monitor the BMPs into the foreseeable future to observe their overall performance throughout subsequent years. This assessment is expected to be published on a bi-annual basis. During that time, CRWD will further explore and research questions and topics that arose during the production and peer review stages of this report. The following is a summary of the questions and topics which may be explored further.

- Currently, water quality samples are not taken from the discharge overflowing from the underground infiltration trenches. To better characterize the pollutant removal efficiencies of the infiltration trenches, it is recommended that sampling of this effluent be conducted.

- Additionally, water quantity is currently not monitored for that flow which bypasses the BMPs altogether. It is recommended that monitoring of this flow be conducted for use in model calibration.

- CRWD will continue to conduct additional research to further characterize the type and amount of solids and pollutants removed by the pretreatment devices. CRWD will also explore other methods on how to better estimate the total solids loads being captured within the BMPs (i.e. Como Park Regional Pond and rain gardens).

- While this report primarily focuses on BMP performance with regards to volume, TP, TSS, and total solids reductions, a full suite of water chemistry parameters were sampled and analyzed. CRWD will further analyze water quality data collected to determine additional impacts BMPs have on the reduction of other pollutants such as metals and bacteria.

- Due to the high volume reduction efficiency of the Arlington-Hamline Facility, CRWD will explore potential modifications to the bypass weir in Arlington Avenue which would allow more water to be diverted into the system. This relatively minimal modification could have great impacts on increasing volume and pollutant load reductions. While it is recognized that other modifications may also be made to other BMP structures (i.e. Como Park Regional Pond) to improve their performance, those options are not currently being explored.

- CRWD will continue to research comparable volume reduction and pollutant removal calculations and costs.

- The amount of volume reduction that occurred collectively by the BMPs was substantial. CRWD and others will work to assess what, if any, affect the infiltrated stormwater has on groundwater resources. This may include documenting what effects the

BMPs have on groundwater elevations, groundwater recharge, and/or the quality of groundwater.

In future reports, CRWD will incorporate additional performance results and analysis from other stormwater BMP structures implemented as part of subwatershed management plans and construction of capital improvement projects.

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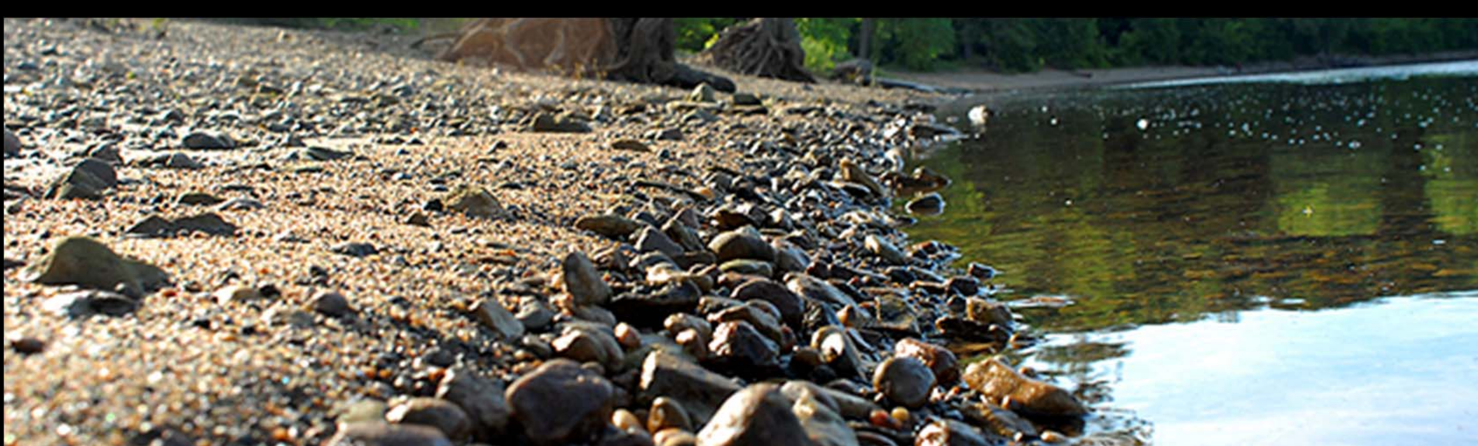
# Capitol Region Watershed District

## Appendices

BMP Performance and Cost-Benefit Analysis:

Arlington Pascal Project
2007-2010

March 9, 2012



# Appendix A

## Reference Tables

# Appendix A: Reference Tables

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**Table A-1. 2009 monitoring efficiencies for water quality and quantity BMP monitoring stations.**

| Site | Possible Days | Possible Hours | Hours Missing | Efficiency |
|---|---|---|---|---|
| Arlington-Hamline Facility Level | 222 | 5,328 | 0 | 100.0% |
| Arlington-Hamline Facility Inlet | 220 | 5,279 | 0 | 100.0% |
| Arlington-Hamline Facility Outlet | 195 | 4,687 | 0 | 100.0% |
| Como Park Regional Pond Level | 217 | 5,204 | 0 | 100.0% |
| Como Park Regional Pond Inlet | 214 | 5,135 | 76 | 98.5% |
| Como Park Regional Pond Outlet | 216 | 5,177 | 0 | 100.0% |
| Trench 4 East | 203 | 4,877 | 0 | 100.0% |
| Trench 4 East Overflow | 209 | 5,018 | 0 | 100.0% |
| Trench 4 West | 209 | 5,018 | 0 | 100.0% |
| Trench 4 West Overflow | 211 | 5,066 | 0 | 100.0% |
| Trench 5 East | 202 | 4,846 | 0 | 100.0% |
| Trench 5 East Overflow | 211 | 5,063 | 0 | 100.0% |
| **Total:** | **2,529** | **60,698** | **76** | **99.9%** |

**Table A-2. 2010 monitoring efficiencies for water quality and quantity BMP monitoring stations.**

| Site | Possible Days | Possible Hours | Hours Missing | Efficiency |
|---|---|---|---|---|
| Arlington-Hamline Facility Inlet | 204 | 4,897 | 248 | 94.9% |
| Arlington-Hamline Facility Outlet | 209 | 5,016 | 0 | 100.0% |
| Como Park Regional Pond Level | 183 | 4,391 | 236 | 94.6% |
| Como Park Regional Pond Inlet | 183 | 4,395 | 30 | 99.3% |
| Como Park Regional Pond Outlet | 183 | 4,391 | 607 | 86.2% |
| Trench 4 East | 183 | 4,390 | 0 | 100.0% |
| Trench 4 East Overflow | 205 | 4,916 | 0 | 100.0% |
| Trench 4 West | 210 | 5,041 | 0 | 100.0% |
| Trench 4 West Overflow | 209 | 5,017 | 0 | 100.0% |
| Trench 5 East | 197 | 4,728 | 0 | 100.0% |
| Trench 5 East Overflow | 183 | 4,396 | 0 | 100.0% |
| **Total:** | **2149** | **51,580** | **1121** | **97.8%** |

**Table A-3. CRWD employee salary rates used to calculate operation and maintenance labor costs.**

| Staffing Combinations | Ratio | Rate ($/hour) |
|---|---|---|
| Administrative | 1 | $30.00 |
| Administrative/Seasonal | 1:1 | $21.50 |
| Adminstrative/Seasonal/Technician | 1:1:1 | $21.33 |
| Adminstrative/Technician | 1:1 | $25.50 |
| Adminstrative/Technician | 2:1 | $27.00 |
| Seasonal | 1 | $13.00 |
| Seasonal/Technician | 2:1 | $15.67 |
| Seasonal/Technician | 1:1 | $17.00 |
| Technician | 1 | $21.00 |

**Table A-4. 2007 volume reduction and pollutant removal efficiencies for the Arlington Pascal Project BMPs.**

| | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Subwatershed Area (ac) | 50 | 128 | 23 | 16 | 217 |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | |
| Inflow Volume (cf) | 526,248 | NA | 320,166 | 257,135 | 1,103,549 |
| Outflow Volume (cf) | 0 | NA | 2,918 | 87 | 3,005 |
| Volume Removed by BMP (cf) | **526,248** | NA | **317,248** | **257,048** | **1,100,544** |
| Volume Removal Efficiency (%) | **100%** | NA | **99%** | **100%** | NA |
| ***TP REMOVAL EFFICIENCY*** | | | | | |
| Inflow TP Load (lbs) | 15.0 | NA | 7.6 | 5.8 | 28.4 |
| Outflow TP Load (lbs) | 0.0 | NA | 0.1 | 0.0 | 0.1 |
| TP Load Removed by BMP (lbs) | **15.0** | NA | **7.5** | **5.8** | **28.3** |
| TP Removal Efficiency (%) | **100%** | NA | **99%** | **100%** | NA |
| ***TOTAL SUSPENDED SOLIDS*** | | | | | |
| Inflow TSS Load (lbs) | 6,608 | NA | 3,363 | 2,411 | 12,382 |
| Outflow TSS Load (lbs) | 0 | NA | 28 | 1 | 29 |
| TSS Load Removed by BMP (lbs) | **6,608** | NA | **3,335** | **2,410** | **12,353** |
| TSS Removal Efficiency (%) | **100%** | NA | **99%** | **100%** | NA |

NA: Not Available

**Table A-5. 2007 cumulative TP and total solids load reductions for the Arlington Pascal Project BMPs.**

| | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Subwatershed Area (ac) | 50 | 128 | 23 | 16 | 217 |
| ***VOLUME REMOVED*** | | | | | |
| Total Volume Removed by BMP (cf) | **526,248** | NA | **317,248** | **257,048** | **1,100,544** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | |
| TP Load Removed by BMP (lbs) | 15.0 | NA | 7.5 | 5.8 | 28.3 |
| TP Load in Gross Solids Load Removed by BMP (lbs) | 9.8 | NA | NA | 2.4 | 12.2 |
| TP Load in Gross Solids Load Removed by Pretreatment Units (lbs) | 9.6 | NA | 5.8 | NA | 15.4 |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | **34.4** | NA | **13.3** | **8.2** | **55.9** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | |
| TSS Load Removed by BMP (lbs) | 6,608 | NA | 3,335 | 2,410 | 12,353 |
| Gross Solids Load Removed by BMP (lbs) | 7,859 | NA | NA | 6,023 | 13,885 |
| Gross Solids Load Removed by Pretreatment Units (lbs) | 16,880 | NA | 14,536 | NA | 31,416 |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | **31,347** | NA | **17,871** | **8,433** | **57,654** |

NA: Not Available

**Table A-6. 2008 volume reduction and pollutant removal efficiencies for the Arlington Pascal Project BMPs.**

| | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 |
| Subwatershed Area (ac) | 50 | 128 | 23 | 16 | 217 |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | |
| Inflow Volume (cf) | 458,600 | 7,711,819 | 281,616 | 225,118 | 8,677,153 |
| Outflow Volume (cf) | 0 | 6,992,905 | 0 | 0 | 6,992,905 |
| Volume Removed by BMP (cf) | **458,600** | **718,914** | **281,616** | **225,118** | **1,684,248** |
| Volume Removal Efficiency (%) | **100%** | **9%** | **100%** | **100%** | NA |
| ***TP REMOVAL EFFICIENCY*** | | | | | |
| Inflow TP Load (lbs) | 13.0 | 108.6 | 6.6 | 4.9 | 133.1 |
| Outflow TP Load (lbs) | 0.0 | 76.4 | 0.0 | 0.0 | 76.4 |
| TP Load Removed by BMP (lbs) | **13.0** | **32.2** | **6.6** | **4.9** | **56.7** |
| TP Removal Efficiency (%) | **100%** | **30%** | **100%** | **100%** | NA |
| ***TOTAL SUSPENDED SOLIDS*** | | | | | |
| Inflow TSS Load (lbs) | 5,669 | 28,581 | 2,897 | 2,095 | 39,242 |
| Outflow TSS Load (lbs) | 0 | 5,079 | 0 | 0 | 5,079 |
| TSS Load Removed by BMP (lbs) | **5,669** | **23,502** | **2,897** | **2,095** | **34,163** |
| TSS Removal Efficiency (%) | **100%** | **82%** | **100%** | **100%** | NA |

NA: Not Available

**Table A-7. 2008 cumulative TP and total solids load reductions for the Arlington Pascal Project BMPs.**

| | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 |
| Subwatershed Area (ac) | 50 | 128 | 23 | 16 | 217 |
| ***VOLUME REMOVED*** | | | | | |
| Total Volume Removed by BMP (cf) | **458,600** | **718,914** | **281,616** | **225,118** | **1,684,248** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | |
| TP Load Removed by BMP (lbs) | 13.0 | 32.3 | 6.6 | 4.9 | 56.7 |
| TP Load in Gross Solids Load Removed by BMP (lbs) | 8.6 | 58.6 | NA | 4.4 | 71.5 |
| TP Load in Gross Solids Load Removed by Pretreatment Units (lbs) | 11.9 | NA | 10.5 | NA | 22.3 |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | **33.4** | **90.9** | **17.1** | **9.3** | **150.6** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | |
| TSS Load Removed by BMP (lbs) | 5,669 | 23,502 | 2,897 | 2,095 | 34,163 |
| Gross Solids Load Removed by BMP (lbs) | 6,876 | 145,791 | NA | 10,902 | 163,569 |
| Gross Solids Load Removed by Pretreatment Units (lbs) | 20,869 | NA | 26,080 | NA | 46,949 |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | **33,414** | **169,293** | **28,977** | **12,997** | **244,681** |

NA: Not Available

**Table A-8. 2009 volume reduction and pollutant removal efficiencies for the Arlington Pascal Project BMPs.**

| | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 |
| Subwatershed Area (ac) | 50 | 128 | 23 | 16 | 217 |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | |
| Inflow Volume (cf) | 475,675 | 7,598,694 | 291,721 | 230,519 | 8,596,609 |
| Outflow Volume (cf) | 0 | 6,851,204 | 0 | 0 | 6,851,204 |
| Volume Removed by BMP (cf) | **475,675** | **747,490** | **291,721** | **230,519** | **1,745,405** |
| Volume Removal Efficiency (%) | **100%** | **10%** | **100%** | **100%** | NA |
| ***TP REMOVAL EFFICIENCY*** | | | | | |
| Inflow TP Load (lbs) | 14.2 | 109.8 | 7.2 | 5.2 | 136.4 |
| Outflow TP Load (lbs) | 0.0 | 76.8 | 0.0 | 0.0 | 76.8 |
| TP Load Removed by BMP (lbs) | **14.2** | **33.0** | **7.2** | **5.2** | **59.6** |
| TP Removal Efficiency (%) | **100%** | **30%** | **100%** | **100%** | NA |
| ***TOTAL SUSPENDED SOLIDS*** | | | | | |
| Inflow TSS Load (lbs) | 6,625 | 29,845 | 3,384 | 2,354 | 42,208 |
| Outflow TSS Load (lbs) | 0 | 6,221 | 0 | 0 | 6,221 |
| TSS Load Removed by BMP (lbs) | **6,625** | **23,624** | **3,384** | **2,354** | **35,987** |
| TSS Removal Efficiency (%) | **100%** | **79%** | **100%** | **100%** | NA |

NA: Not Available

**Table A-9. 2009 cumulative TP and total solids load reductions for the Arlington Pascal Project BMPs..**

| | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 |
| Subwatershed Area (ac) | 50 | 128 | 23 | 16 | 217 |
| ***VOLUME REMOVED*** | | | | | |
| Total Volume Removed by BMP (cf) | **475,675** | **747,490** | **291,721** | **230,519** | **1,745,405** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | |
| TP Load Removed by BMP (lbs) | 14.2 | 33.0 | 7.2 | 5.2 | 59.6 |
| TP Load in Gross Solids Load Removed by BMP (lbs) | 8.6 | 72.3 | NA | 5.4 | 86.3 |
| TP Load in Gross Solids Load Removed by Pretreatment Units (lbs) | 13.7 | NA | 12.9 | NA | 26.6 |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | **36.4** | **105.3** | **20.1** | **10.7** | **172.6** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | |
| TSS Load Removed by BMP (lbs) | 6,625 | 23,624 | 3,384 | 2,354 | 35,987 |
| Gross Solids Load Removed by BMP (lbs) | 6,876 | 180,003 | NA | 13,461 | 200,340 |
| Gross Solids Load Removed by Pretreatment Units (lbs) | 24,074 | NA | 32,200 | NA | 56,274 |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | **37,575** | **203,627** | **35,584** | **15,815** | **292,601** |

NA: Not Available

**Table A-10. 2010 volume reduction and pollutant removal efficiencies for the Arlington Pascal Project BMPs.**

| | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 |
| Subwatershed Area (ac) | 50 | 128 | 23 | 16 | 217 |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | |
| Inflow Volume (cf) | 1,245,032 | 16,327,464 | 755,069 | 568,981 | 18,896,546 |
| Outflow Volume (cf) | 0 | 15,589,471 | 172,715 | 67,736 | 15,829,922 |
| Volume Removed by BMP (cf) | **1,245,032** | **737,993** | **582,354** | **501,245** | **3,066,624** |
| Volume Removal Efficiency (%) | **100%** | **5%** | **77%** | **88%** | NA |
| ***TP REMOVAL EFFICIENCY*** | | | | | |
| Inflow TP Load (lbs) | 54.9 | 302.2 | 28.8 | 20.5 | 406.4 |
| Outflow TP Load (lbs) | 0.0 | 212.5 | 7.2 | 3.4 | 223.1 |
| TP Load Removed by BMP (lbs) | **54.9** | **89.7** | **21.6** | **17.1** | **183.3** |
| TP Removal Efficiency (%) | **100%** | **30%** | **75%** | **83%** | NA |
| ***TOTAL SUSPENDED SOLIDS*** | | | | | |
| Inflow TSS Load (lbs) | 33,851 | 124,242 | 18,538 | 12,565 | 189,196 |
| Outflow TSS Load (lbs) | 0 | 38,513 | 3,264 | 1,653 | 43,430 |
| TSS Load Removed by BMP (lbs) | **33,851** | **85,729** | **15,274** | **10,912** | **145,766** |
| TSS Removal Efficiency (%) | **100%** | **69%** | **82%** | **87%** | NA |

NA: Not Available

**Table A-11. 2010 cumulative TP and total solids load reductions for the Arlington Pascal Project BMPs.**

| | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 |
| Subwatershed Area (ac) | 50 | 128 | 23 | 16 | 217 |
| ***VOLUME REMOVED*** | | | | | |
| Total Volume Removed by BMP (cf) | **1,245,032** | **737,993** | **582,354** | **501,245** | **3,066,624** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | |
| TP Load Removed by BMP (lbs) | 54.9 | 89.7 | 21.6 | 17.1 | 183.3 |
| TP Load in Gross Solids Load Removed by BMP (lbs) | 13.8 | 43.7 | NA | 3.3 | 60.8 |
| TP Load in Gross Solids Load Removed by Pretreatment Units (lbs) | 4.5 | NA | 7.8 | NA | 12.3 |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | **73.2** | **133.4** | **29.4** | **20.4** | **256.4** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | |
| TSS Load Removed by BMP (lbs) | 33,851 | 85,729 | 15,274 | 10,912 | 145,766 |
| Gross Solids Load Removed by BMP (lbs) | 11,133 | 108,717 | NA | 8,130 | 127,980 |
| Gross Solids Load Removed by Pretreatment Units (lbs) | 7,835 | NA | 19,448 | NA | 27,282 |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | **52,819** | **194,446** | **34,722** | **19,042** | **301,028** |

NA: Not Available

**Table A-12. Annual projected volume reduction and pollutant removal efficiencies for the Arlington Pascal Project BMPs.**

| | Arlington-Hamline Facility | Como Park Regional Ponda | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 |
| Subwatershed Area (ac) | 50 | 128 | 23 | 16 | 217 |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | |
| Inflow Volume (cf) | 566,149 | 9,690,663 | 346,562 | 277,651 | 10,881,025 |
| Outflow Volume (cf) | 0 | 8,814,322 | 0 | 0 | 8,814,322 |
| Volume Removed by BMP (cf) | **566,149** | **876,341** | **346,562** | **277,651** | **2,066,703** |
| Volume Removal Efficiency (%) | **100%** | **9%** | **100%** | **100%** | NA |
| ***TP REMOVAL EFFICIENCY*** | | | | | |
| Inflow TP Load (lbs) | 15.4 | 133.5 | 7.9 | 6.1 | 162.9 |
| Outflow TP Load (lbs) | 0.0 | 96.1 | 0.0 | 0.0 | 96.1 |
| TP Load Removed by BMP (lbs) | **15.4** | **37.4** | **7.9** | **6.1** | **66.8** |
| TP Removal Efficiency (%) | **100%** | **28%** | **100%** | **100%** | NA |
| ***TOTAL SUSPENDED SOLIDS*** | | | | | |
| Inflow TSS Load (lbs) | 6,470 | 32,782 | 3,308 | 2,356 | 44,916 |
| Outflow TSS Load (lbs) | 0 | 6,609 | 0 | 0 | 6,609 |
| TSS Load Removed by BMP (lbs) | **6,470** | 26,173 | **3,308** | **2,356** | **38,307** |
| TSS Removal Efficiency (%) | **100%** | **80%** | **100%** | **100%** | NA |

NA: Not Available

**Table A-13. Annual projected cumulative TP and total solids load reductions for the Arlington Pascal Project BMPs.**

| | Arlington-Hamline Facility | Como Park Regional Pond | Infiltration Trenches | Rain Gardens | **Project Total** |
|---|---|---|---|---|---|
| Annual Precipitation (in) | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 |
| Subwatershed Area (ac) | 50 | 128 | 23 | 16 | 217 |
| ***VOLUME REMOVED*** | | | | | |
| Total Volume Removed by BMP (cf) | **566,149** | **876,341** | **346,562** | **277,651** | **2,066,703** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | |
| TP Load Removed by BMP (lbs) | 15.4 | 37.4 | 7.9 | 6.1 | 66.8 |
| TP Load in Gross Solids Load Removed by BMP (lbs) | 10.2 | 53.0 | NA | 4.4 | 67.5 |
| TP Load in Gross Solids Load Removed by Pretreatment Units (lbs) | 9.9 | NA | 10.4 | NA | 20.3 |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | **35.5** | **90.4** | **18.3** | **10.4** | **154.6** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | |
| TSS Load Removed by BMP (lbs) | 6,470 | 26,173 | 3,308 | 2,356 | 38,307 |
| Gross Solids Load Removed by BMP (lbs) | 8,186 | 131,780 | NA | 10,822 | 150,788 |
| Gross Solids Load Removed by Pretreatment Units (lbs) | 17,415 | NA | 25,909 | NA | 43,324 |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | **32,071** | **157,953** | **29,217** | **13,178** | **232,420** |

NA: Not Available

**Table A-14. 2007 volume reduction and pollutant removal efficiencies for the underground infiltration trenches.**

| | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | **25.0** |
| Watershed Area (ac) | 0.74 | 0.84 | 3.21 | 5.29 | 1.28 | 2.60 | 1.63 | 7.08 | **22.67** |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow Volume (cf) | 10,411 | 11,805 | 45,433 | 74,705 | 18,077 | 36,721 | 23,000 | 100,014 | **320,166** |
| Outflow Volume (cf) | 0 | 0 | 0 | 0 | 0 | 261 | 0 | 2,657 | **2,918** |
| Volume Removed by BMP (cf) | 10,411 | 11,805 | 45,433 | 74,705 | 18,077 | 36,460 | 23,000 | 97,357 | **317,248** |
| Volume Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 99% | 100% | 97% | **99%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TP Load (lbs) | 0.2 | 0.3 | 1.1 | 1.8 | 0.4 | 0.9 | 0.5 | 2.4 | **7.6** |
| Outflow TP Load (lbs) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | **0.1** |
| TP Load Removed by BMP (lbs) | 0.2 | 0.3 | 1.1 | 1.8 | 0.4 | 0.9 | 0.5 | 2.3 | **7.5** |
| TP Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 96% | **99%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TSS Load (lbs) | 109 | 124 | 477 | 785 | 190 | 386 | 242 | 1,050 | **3,363** |
| Outflow TSS Load (lbs) | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 25 | **28** |
| TSS Load Removed by BMP (lbs) | 109 | 124 | 477 | 785 | 190 | 383 | 242 | 1,025 | **3,335** |
| TSS Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 99% | 100% | 98% | **99%** |

**Table A-15. 2007 cumulative TP and total solids load reductions for the underground infiltration trenches.**

| | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | **25.0** |
| Watershed Area (ac) | 0.74 | 0.84 | 3.21 | 5.29 | 1.28 | 2.60 | 1.63 | 7.08 | **22.67** |
| ***VOLUME REMOVED*** | | | | | | | | | |
| Total Volume Removed by BMP (cf) | 10,411 | 11,805 | 45,433 | 74,705 | 18,077 | 36,460 | 23,000 | 97,357 | **317,248** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | | | | | |
| TP Load Removed by BMP (lbs) | 0.2 | 0.3 | 1.1 | 1.8 | 0.4 | 0.9 | 0.5 | 2.3 | **7.5** |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Catch Basins (lbs) | 0.1 | 0.2 | 0.9 | 0.8 | 0.5 | 0.4 | 0.0 | 0.8 | **3.6** |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Manholes (lbs) | 0.5 | 0.2 | 0.3 | 0.2 | 0.1 | 0.5 | 0.1 | 0.4 | **2.2** |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | 0.8 | 0.6 | 2.2 | 2.9 | 1.0 | 1.7 | 0.6 | 3.5 | **13.3** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | | | | | |
| TSS Load Removed by BMP (lbs) | 109 | 124 | 477 | 785 | 190 | 383 | 242 | 1,025 | **3,335** |
| Gross Solids Load Removed by Pretreatment Unit: Catch Basins (lbs) | 278 | 379 | 2,158 | 2,066 | 1,266 | 964 | 0 | 1,889 | **9,000** |
| Gross Solids Load Removed by Pretreatment Unit: Manholes (lbs) | 1,205 | 432 | 633 | 605 | 321 | 1,131 | 131 | 1,078 | **5,536** |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | 1,592 | 935 | 3,267 | 3,456 | 1,777 | 2,477 | 373 | 3,992 | **17,871** |

**Table A-16. 2008 volume reduction and pollutant removal efficiencies for the underground infiltration trenches.**

| | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | **21.7** |
| Watershed Area (ac) | 0.74 | 0.84 | 3.21 | 5.29 | 1.28 | 2.60 | 1.63 | 7.08 | **22.67** |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow Volume (cf) | 9,148 | 10,367 | 39,945 | 65,732 | 15,899 | 32,322 | 20,255 | 87,948 | **281,616** |
| Outflow Volume (cf) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Volume Removed by BMP (cf) | 9,148 | 10,367 | 39,945 | 65,732 | 15,899 | 32,322 | 20,255 | 87,948 | **281,616** |
| Volume Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TP Load (lbs) | 0.2 | 0.2 | 0.9 | 1.5 | 0.4 | 0.8 | 0.5 | 2.1 | **6.6** |
| Outflow TP Load (lbs) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| TP Load Removed by BMP (lbs) | 0.2 | 0.2 | 0.9 | 1.5 | 0.4 | 0.8 | 0.5 | 2.1 | **6.6** |
| TP Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TSS Load (lbs) | 94 | 107 | 411 | 676 | 164 | 332 | 208 | 905 | **2,897** |
| Outflow TSS Load (lbs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| TSS Load Removed by BMP (lbs) | 94 | 107 | 411 | 676 | 164 | 332 | 208 | 905 | **2,897** |
| TSS Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |

**Table A-17. 2008 cumulative TP and total solids load reductions for the underground infiltration trenches.**

| | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | **21.7** |
| Watershed Area (ac) | 0.74 | 0.84 | 3.21 | 5.29 | 1.28 | 2.60 | 1.63 | 7.08 | **22.67** |
| ***VOLUME REMOVED*** | | | | | | | | | |
| Total Volume Removed by BMP (cf) | 9,148 | 10,367 | 39,945 | 65,732 | 15,899 | 32,322 | 20,255 | 87,948 | **281,616** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | | | | | |
| TP Load Removed by BMP (lbs) | 0.2 | 0.2 | 0.9 | 1.5 | 0.4 | 0.8 | 0.5 | 2.1 | **6.6** |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Catch Basins (lbs) | 0.3 | 0.4 | 1.1 | 2.0 | 0.3 | 0.7 | 0.3 | 1.4 | **6.6** |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Manholes (lbs) | 0.2 | 0.4 | 0.7 | 0.8 | 0.1 | 0.6 | 0.2 | 0.9 | **3.8** |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | 0.7 | 1.0 | 2.8 | 4.3 | 0.8 | 2.1 | 1.0 | 4.4 | **17.1** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | | | | | |
| TSS Load Removed by BMP (lbs) | 94 | 107 | 411 | 676 | 164 | 332 | 208 | 905 | **2,897** |
| Gross Solids Load Removed by Pretreatment Unit: Catch Basins (lbs) | 815 | 921 | 2,829 | 5,068 | 801 | 1,860 | 743 | 3,476 | **16,513** |
| Gross Solids Load Removed by Pretreatment Unit: Manholes (lbs) | 392 | 994 | 1,777 | 1,940 | 221 | 1,470 | 580 | 2,194 | **9,568** |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | 1,301 | 2,022 | 5,017 | 7,684 | 1,185 | 3,663 | 1,531 | 6,575 | **28,977** |

**Table A-18. 2009 volume reduction and pollutant removal efficiencies for the underground infiltration trenches.**

| | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | **22.3** |
| Watershed Area (ac) | 0.74 | 0.84 | 3.21 | 5.29 | 1.28 | 2.60 | 1.63 | 7.08 | **22.67** |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow Volume (cf) | 9,496 | 10,759 | 41,382 | 68,084 | 16,466 | 33,454 | 20,952 | 91,128 | **291,721** |
| Outflow Volume (cf) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Volume Removed by BMP (cf) | 9,496 | 10,759 | 41,382 | 68,084 | 16,466 | 33,454 | 20,952 | 91,128 | **291,721** |
| Volume Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TP Load (lbs) | 0.2 | 0.3 | 1.0 | 1.7 | 0.4 | 0.8 | 0.5 | 2.3 | **7.2** |
| Outflow TP Load (lbs) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| TP Load Removed by BMP (lbs) | 0.2 | 0.3 | 1.0 | 1.7 | 0.4 | 0.8 | 0.5 | 2.3 | **7.2** |
| TP Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TSS Load (lbs) | 110 | 125 | 480 | 790 | 191 | 388 | 243 | 1,057 | **3,384** |
| Outflow TSS Load (lbs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| TSS Load Removed by BMP (lbs) | 110 | 125 | 480 | 790 | 191 | 388 | 243 | 1,057 | **3,384** |
| TSS Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |

**Table A-19. 2009 cumulative TP and total solids load reductions for the underground infiltration trenches.**

| | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | **22.3** |
| Watershed Area (ac) | 0.74 | 0.84 | 3.21 | 5.29 | 1.28 | 2.60 | 1.63 | 7.08 | **22.67** |
| ***VOLUME REMOVED*** | | | | | | | | | |
| Total Volume Removed by BMP (cf) | 9,496 | 10,759 | 41,382 | 68,084 | 16,466 | 33,454 | 20,952 | 91,128 | **291,721** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | | | | | |
| TP Load Removed by BMP (lbs) | 0.2 | 0.3 | 1.0 | 1.7 | 0.4 | 0.8 | 0.5 | 2.3 | **7.2** |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Catch Basins (lbs) | 0.6 | 0.6 | 2.1 | 1.8 | 0.6 | 1.3 | 0.7 | 2.1 | **9.9** |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Manholes (lbs) | 0.6 | 0.1 | 0.8 | 0.5 | 0.1 | 0.6 | 0.1 | 0.3 | **3.0** |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | 1.5 | 1.0 | 3.9 | 4.0 | 1.1 | 2.7 | 1.3 | 4.7 | **20.1** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | | | | | |
| TSS Load Removed by BMP (lbs) | 110 | 125 | 480 | 790 | 191 | 388 | 243 | 1,057 | **3,384** |
| Gross Solids Load Removed by Pretreatment Unit: Catch Basins (lbs) | 1,606 | 1,462 | 5,260 | 4,454 | 1,506 | 3,313 | 1,750 | 5,332 | **24,683** |
| Gross Solids Load Removed by Pretreatment Unit: Manholes (lbs) | 1,556 | 161 | 2,039 | 1,195 | 141 | 1,483 | 277 | 666 | **7,517** |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | 3,272 | 1,748 | 7,778 | 6,439 | 1,837 | 5,184 | 2,270 | 7,055 | **35,584** |

**Table A-20. 2010 volume reduction and pollutant removal efficiencies for the underground infiltration trenches.**

| | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | **36.3** |
| Watershed Area (ac) | 0.74 | 0.84 | 3.21 | 5.29 | 1.28 | 2.60 | 1.63 | 7.08 | **22.67** |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow Volume (cf) | 24,524 | 27,835 | 107,114 | 176,200 | 42,645 | 86,641 | 54,276 | 235,834 | **755,069** |
| Outflow Volume (cf) | 2,613 | 2,265 | 12,066 | 34,543 | 10,106 | 24,699 | 10,803 | 75,620 | **172,715** |
| Volume Removed by BMP (cf) | 21,911 | 25,570 | 95,048 | 141,657 | 32,539 | 61,942 | 43,473 | 160,214 | **582,354** |
| Volume Removal Efficiency (%) | 89% | 92% | 89% | 80% | 76% | 71% | 80% | 68% | **77%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TP Load (lbs) | 0.9 | 1.1 | 4.1 | 6.7 | 1.6 | 3.3 | 2.1 | 9.0 | **28.8** |
| Outflow TP Load (lbs) | 0.1 | 0.1 | 0.6 | 1.5 | 0.4 | 1.0 | 0.5 | 3.0 | **7.2** |
| TP Load Removed by BMP (lbs) | 0.8 | 1.0 | 3.5 | 5.2 | 1.2 | 2.3 | 1.6 | 6.0 | **21.6** |
| TP Removal Efficiency (%) | 89% | 91% | 85% | 78% | 75% | 70% | 76% | 67% | **75%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TSS Load (lbs) | 602 | 684 | 2,630 | 4,326 | 1,047 | 2,127 | 1,332 | 5,790 | **18,538** |
| Outflow TSS Load (lbs) | 56 | 47 | 266 | 713 | 167 | 445 | 205 | 1,365 | **3,264** |
| TSS Load Removed by BMP (lbs) | 546 | 637 | 2,364 | 3,613 | 880 | 1,682 | 1,127 | 4,425 | **15,274** |
| TSS Removal Efficiency (%) | 91% | 93% | 90% | 84% | 84% | 79% | 85% | 76% | **82%** |

**Table A-21. 2010 cumulative TP and total solids load reductions for the underground infiltration trenches.**

| | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | **36.3** |
| Watershed Area (ac) | 0.74 | 0.84 | 3.21 | 5.29 | 1.28 | 2.60 | 1.63 | 7.08 | **22.67** |
| ***VOLUME REMOVED*** | | | | | | | | | |
| Total Volume Removed by BMP (cf) | 21,911 | 25,570 | 95,048 | 141,657 | 32,539 | 61,942 | 43,473 | 160,214 | **582,354** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | | | | | |
| TP Load Removed by BMP (lbs) | 0.8 | 1.0 | 3.5 | 5.2 | 1.2 | 2.3 | 1.6 | 6.0 | **21.6** |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Catch Basins (lbs) | 0.5 | 0.4 | 1.2 | 1.3 | 0.4 | 0.9 | 0.4 | 1.5 | **6.6** |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Manholes (lbs) | 0.1 | 0.5 | 0.2 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | **1.2** |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | 1.4 | 1.8 | 5.0 | 6.5 | 1.6 | 3.3 | 2.1 | 7.6 | **29.4** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | | | | | |
| TSS Load Removed by BMP (lbs) | 546 | 637 | 2,364 | 3,613 | 880 | 1,682 | 1,127 | 4,425 | **15,274** |
| Gross Solids Load Removed by Pretreatment Unit: Catch Basins (lbs) | 1,242 | 892 | 3,102 | 3,232 | 887 | 2,349 | 1,088 | 3,721 | **16,513** |
| Gross Solids Load Removed by Pretreatment Unit: Manholes (lbs) | 302 | 1,175 | 573 | 20 | 30 | 207 | 267 | 360 | **2,935** |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | 2,090 | 2,704 | 6,039 | 6,865 | 1,797 | 4,238 | 2,482 | 8,506 | **34,722** |

**Table A-22. Annual projected volume reduction and pollutant removal efficiencies for the underground infiltration trenches.**

| | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | **26.0** |
| Watershed Area (ac) | 0.74 | 0.84 | 3.21 | 5.29 | 1.28 | 2.60 | 1.63 | 7.08 | **22.67** |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow Volume (cf) | 11,238 | 12,763 | 49,179 | 80,891 | 19,558 | 39,770 | 24,916 | 108,247 | **346,562** |
| Outflow Volume (cf) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Volume Removed by BMP (cf) | 11,238 | 12,763 | 49,179 | 80,891 | 19,558 | 39,770 | 24,916 | 108,247 | **346,562** |
| Volume Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TP Load (lbs) | 0.3 | 0.3 | 1.1 | 1.8 | 0.4 | 0.9 | 0.6 | 2.5 | **7.9** |
| Outflow TP Load (lbs) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| TP Load Removed by BMP (lbs) | 0.3 | 0.3 | 1.1 | 1.8 | 0.4 | 0.9 | 0.6 | 2.5 | **7.9** |
| TP Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TSS Load (lbs) | 107 | 122 | 469 | 772 | 187 | 380 | 238 | 1,033 | **3,308** |
| Outflow TSS Load (lbs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| TSS Load Removed by BMP (lbs) | 107 | 122 | 469 | 772 | 187 | 380 | 238 | 1,033 | **3,308** |
| TSS Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |

**Table A-23. Annual projected cumulative TP and total solids load reductions for the underground infiltration trenches.**

| | Trench 1 | Trench 2 | Trench 3 | Trench 4 | Trench 5 | Trench 6 | Trench 7 | Trench 8 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | **26.0** |
| Watershed Area (ac) | 0.74 | 0.84 | 3.21 | 5.29 | 1.28 | 2.60 | 1.63 | 7.08 | **22.67** |
| ***VOLUME REMOVED*** | | | | | | | | | |
| Total Volume Removed by BMP (cf) | 11,238 | 12,763 | 49,179 | 80,891 | 19,558 | 39,770 | 24,916 | 108,247 | **346,562** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | | | | | |
| TP Load Removed by BMP (lbs) | 0.3 | 0.3 | 1.1 | 1.8 | 0.4 | 0.9 | 0.6 | 2.5 | **7.9** |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Catch Basins (lbs) | 0.5 | 0.4 | 1.5 | 1.7 | 0.4 | 1.0 | 0.5 | 1.7 | **7.7** |
| TP Load in Gross Solids Load Removed by Pretreament Unit: Manholes (lbs) | 0.3 | 0.3 | 0.6 | 0.4 | 0.1 | 0.4 | 0.2 | 0.4 | **2.7** |
| Cumulative TP Load Removed: BMP + Pretreatment (lbs) | 1.1 | 1.1 | 3.2 | 3.9 | 0.9 | 2.3 | 1.2 | 4.6 | **18.3** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | | | | | |
| TSS Load Removed by BMP (lbs) | 107 | 122 | 469 | 772 | 187 | 380 | 238 | 1,033 | **3,308** |
| Gross Solids Load Removed by Pretreatment Unit: Catch Basins (lbs) | 1,221 | 1,092 | 3,730 | 4,251 | 1,064 | 2,508 | 1,194 | 4,176 | **19,236** |
| Gross Solids Load Removed by Pretreatment Unit: Manholes (lbs) | 750 | 777 | 1,463 | 1,052 | 131 | 1,053 | 375 | 1,073 | **6,673** |
| Total Solids Load Removed: BMP + Pretreatment (lbs) | 2,078 | 1,990 | 5,662 | 6,075 | 1,382 | 3,941 | 1,807 | 6,283 | **29,217** |

**Table A-24. 2007 volume reduction and pollutant removal efficiencies for the rain gardens.**

| | Arlington-McKinley | Asbury North | Asbury South | Frankson-McKinley | Hamline Midway | Pascal Center | Pascal North | Pascal South | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | **25.0** |
| Watershed Area (ac) | 0.37 | 0.40 | 1.08 | 2.81 | 10.47 | 0.13 | 0.46 | 0.36 | **16.08** |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow Volume (cf) | 5,184 | 5,663 | 15,246 | 39,727 | 177,855 | 1,917 | 6,490 | 5,053 | **257,135** |
| Outflow Volume (cf) | 0 | 0 | 0 | 0 | 0 | 0 | 87 | 0 | **87** |
| Volume Removed by BMP (cf) | 5,184 | 5,663 | 15,246 | 39,727 | 177,855 | 1,917 | 6,403 | 5,053 | **257,048** |
| Volume Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 99% | 100% | **100%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TP Load (lbs) | 0.1 | 0.1 | 0.4 | 0.9 | 3.9 | 0.1 | 0.2 | 0.1 | **5.8** |
| Outflow TP Load (lbs) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| TP Load Removed by BMP (lbs) | 0.1 | 0.1 | 0.4 | 0.9 | 3.9 | 0.1 | 0.2 | 0.1 | **5.8** |
| TP Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TSS Load (lbs) | 55 | 59 | 160 | 417 | 1,579 | 20 | 68 | 53 | **2,411** |
| Outflow TSS Load (lbs) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **1** |
| TSS Load Removed by BMP (lbs) | 55 | 59 | 160 | 417 | 1,579 | 20 | 67 | 53 | **2,410** |
| TSS Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 99% | 100% | **100%** |

**Table A-25. 2007 cumulative TP and total solids load reductions for the rain gardens.**

| | Arlington-McKinley | Asbury North | Asbury South | Frankson-McKinley | Hamline Midway | Pascal Center | Pascal North | Pascal South | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | **25.0** |
| Watershed Area (ac) | 0.37 | 0.40 | 1.08 | 2.81 | 10.47 | 0.13 | 0.46 | 0.36 | **16.08** |
| ***VOLUME REMOVED*** | | | | | | | | | |
| Total Volume Removed by BMP (cf) | 5,184 | 5,663 | 15,246 | 39,727 | 177,855 | 1,917 | 6,403 | 5,053 | **257,048** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | | | | | |
| TP Load Removed by BMP (lbs) | 0.1 | 0.1 | 0.4 | 0.9 | 3.9 | 0.1 | 0.2 | 0.1 | **5.8** |
| TP in Gross Solids Load Removed by BMP (lbs) | 0.1 | 0.1 | 0.2 | 0.6 | 1.2 | 0.0 | 0.1 | 0.1 | **2.4** |
| Cumulative TP Load Removed: BMP (lbs) | 0.2 | 0.2 | 0.6 | 1.5 | 5.1 | 0.1 | 0.3 | 0.2 | **8.2** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | | | | | |
| TSS Load Removed by BMP (lbs) | 55 | 59 | 160 | 417 | 1,579 | 20 | 67 | 53 | **2,410** |
| Gross Solids Load Removed by BMP (lbs) | 244 | 276 | 539 | 1,511 | 3,009 | 97 | 205 | 142 | **6,023** |
| Total Solids Load Removed: BMP (lbs) | 299 | 335 | 699 | 1,928 | 4,588 | 117 | 272 | 195 | **8,433** |

**Table A-26. 2008 volume reduction and pollutant removal efficiencies for the rain gardens.**

| | Arlington-McKinley | Asbury North | Asbury South | Frankson-McKinley | Hamline Midway | Pascal Center | Pascal North | Pascal South | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | **21.7** |
| Watershed Area (ac) | 0.37 | 0.40 | 1.08 | 2.81 | 10.47 | 0.13 | 0.46 | 0.36 | **16.08** |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow Volume (cf) | 4,574 | 4,966 | 13,416 | 34,935 | 155,466 | 1,612 | 5,706 | 4,443 | **225,118** |
| Outflow Volume (cf) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Volume Removed by BMP (cf) | 4,574 | 4,966 | 13,416 | 34,935 | 155,466 | 1,612 | 5,706 | 4,443 | **225,118** |
| Volume Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TP Load (lbs) | 0.1 | 0.1 | 0.3 | 0.8 | 3.4 | 0.0 | 0.1 | 0.1 | **4.9** |
| Outflow TP Load (lbs) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| TP Load Removed by BMP (lbs) | 0.1 | 0.1 | 0.3 | 0.8 | 3.4 | 0.0 | 0.1 | 0.1 | **4.9** |
| TP Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TSS Load (lbs) | 47 | 51 | 138 | 359 | 1,379 | 16 | 59 | 46 | **2,095** |
| Outflow TSS Load (lbs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| TSS Load Removed by BMP (lbs) | 47 | 51 | 138 | 359 | 1,379 | 16 | 59 | 46 | **2,095** |
| TSS Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |

**Table A-27.  2008 cumulative TP and total solids load reductions for the rain gardens.**

| | Arlington-McKinley | Asbury North | Asbury South | Frankson-McKinley | Hamline Midway | Pascal Center | Pascal North | Pascal South | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | **21.7** |
| Watershed Area (ac) | 0.37 | 0.40 | 1.08 | 2.81 | 10.47 | 0.13 | 0.46 | 0.36 | **16.08** |
| ***VOLUME REMOVED*** | | | | | | | | | |
| Total Volume Removed by BMP (cf) | 4,574 | 4,966 | 13,416 | 34,935 | 155,466 | 1,612 | 5,706 | 4,443 | **225,118** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | | | | | |
| TP Load Removed by BMP (lbs) | 0.1 | 0.1 | 0.3 | 0.8 | 3.4 | 0.0 | 0.1 | 0.1 | **4.9** |
| TP in Gross Solids Load Removed by BMP (lbs) | 0.2 | 0.2 | 0.4 | 1.1 | 2.2 | 0.1 | 0.2 | 0.1 | **4.4** |
| Cumulative TP Load Removed: BMP (lbs) | 0.3 | 0.3 | 0.7 | 1.9 | 5.6 | 0.1 | 0.3 | 0.2 | **9.3** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | | | | | |
| TSS Load Removed by BMP (lbs) | 47 | 51 | 138 | 359 | 1,379 | 16 | 59 | 46 | **2,095** |
| Gross Solids Load Removed by BMP (lbs) | 447 | 499 | 975 | 2,734 | 5,444 | 175 | 371 | 257 | **10,902** |
| Total Solids Load Removed: BMP (lbs) | 494 | 550 | 1,113 | 3,093 | 6,823 | 191 | 430 | 303 | **12,997** |

**Table A-28. 2009 volume reduction and pollutant removal efficiencies for the rain gardens.**

| | Arlington-McKinley | Asbury North | Asbury South | Frankson-McKinley | Hamline Midway | Pascal Center | Pascal North | Pascal South | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | **22.3** |
| Watershed Area (ac) | 0.37 | 0.40 | 1.08 | 2.81 | 10.47 | 0.13 | 0.46 | 0.36 | **16.08** |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow Volume (cf) | 4,748 | 5,140 | 13,896 | 36,198 | 158,384 | 1,655 | 5,881 | 4,617 | **230,519** |
| Outflow Volume (cf) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Volume Removed by BMP (cf) | 4,748 | 5,140 | 13,896 | 36,198 | 158,384 | 1,655 | 5,881 | 4,617 | **230,519** |
| Volume Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TP Load (lbs) | 0.1 | 0.1 | 0.3 | 0.9 | 3.6 | 0.0 | 0.1 | 0.1 | **5.2** |
| Outflow TP Load (lbs) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| TP Load Removed by BMP (lbs) | 0.1 | 0.1 | 0.3 | 0.9 | 3.6 | 0.0 | 0.1 | 0.1 | **5.2** |
| TP Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TSS Load (lbs) | 55 | 60 | 161 | 420 | 1,517 | 19 | 68 | 54 | **2,354** |
| Outflow TSS Load (lbs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| TSS Load Removed by BMP (lbs) | 55 | 60 | 161 | 420 | 1,517 | 19 | 68 | 54 | **2,354** |
| TSS Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |

**Table A-29. 2009 cumulative TP and total solids load reductions for the rain gardens.**

| | Arlington-McKinley | Asbury North | Asbury South | Frankson-McKinley | Hamline Midway | Pascal Center | Pascal North | Pascal South | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | **22.3** |
| Watershed Area (ac) | 0.37 | 0.40 | 1.08 | 2.81 | 10.47 | 0.13 | 0.46 | 0.36 | **16.08** |
| ***VOLUME REMOVED*** | | | | | | | | | |
| Total Volume Removed by BMP (cf) | 4,748 | 5,140 | 13,896 | 36,198 | 158,384 | 1,655 | 5,881 | 4,617 | **230,519** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | | | | | |
| TP Load Removed by BMP (lbs) | 0.1 | 0.1 | 0.3 | 0.9 | 3.6 | 0.0 | 0.1 | 0.1 | **5.2** |
| TP in Gross Solids Load Removed by BMP (lbs) | 0.2 | 0.3 | 0.5 | 1.4 | 2.7 | 0.1 | 0.2 | 0.1 | **5.4** |
| Cumulative TP Load Removed: BMP (lbs) | 0.3 | 0.4 | 0.8 | 2.3 | 6.3 | 0.1 | 0.3 | 0.2 | **10.7** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | | | | | |
| TSS Load Removed by BMP (lbs) | 55 | 60 | 161 | 420 | 1,517 | 19 | 68 | 54 | **2,354** |
| Gross Solids Load Removed by BMP (lbs) | 552 | 617 | 1,204 | 3,375 | 6,721 | 216 | 458 | 317 | **13,461** |
| Total Solids Load Removed: BMP (lbs) | 607 | 677 | 1,365 | 3,795 | 8,238 | 235 | 526 | 371 | **15,815** |

**Table A-30. 2010 volume reduction and pollutant removal efficiencies for the rain gardens.**

| | Arlington-McKinley | Asbury North | Asbury South | Frankson-McKinley | Hamline Midway | Pascal Center | Pascal North | Pascal South | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | **36.3** |
| Watershed Area (ac) | 0.37 | 0.40 | 1.08 | 2.81 | 10.47 | 0.13 | 0.46 | 0.36 | **16.08** |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow Volume (cf) | 12,240 | 13,329 | 35,981 | 93,698 | 380,279 | 6,229 | 15,246 | 11,979 | **568,981** |
| Outflow Volume (cf) | 1,481 | 435 | 1,264 | 12,067 | 46,914 | 2,178 | 1,960 | 1,437 | **67,736** |
| Volume Removed by BMP (cf) | 10,759 | 12,894 | 34,717 | 81,631 | 333,365 | 4,051 | 13,286 | 10,542 | **501,245** |
| Volume Removal Efficiency (%) | 88% | 97% | 96% | 87% | 88% | 65% | 87% | 88% | **88%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TP Load (lbs) | 0.5 | 0.5 | 1.4 | 3.6 | 13.1 | 0.3 | 0.6 | 0.5 | **20.5** |
| Outflow TP Load (lbs) | 0.1 | 0.0 | 0.1 | 0.7 | 2.2 | 0.1 | 0.1 | 0.1 | **3.4** |
| TP Load Removed by BMP (lbs) | 0.4 | 0.5 | 1.3 | 2.9 | 10.9 | 0.2 | 0.5 | 0.4 | **17.1** |
| TP Removal Efficiency (%) | 80% | 100% | 93% | 81% | 83% | 67% | 83% | 80% | **83%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TSS Load (lbs) | 301 | 327 | 883 | 2,300 | 7,927 | 158 | 375 | 294 | **12,565** |
| Outflow TSS Load (lbs) | 32 | 9 | 31 | 326 | 1,121 | 48 | 53 | 33 | **1,653** |
| TSS Load Removed by BMP (lbs) | 269 | 318 | 852 | 1,974 | 6,806 | 110 | 322 | 261 | **10,912** |
| TSS Removal Efficiency (%) | 89% | 97% | 96% | 86% | 86% | 70% | 86% | 89% | **87%** |

**Table A-31. 2010 cumulative TP and total solids load reductions for the rain gardens.**

| | Arlington-McKinley | Asbury North | Asbury South | Frankson-McKinley | Hamline Midway | Pascal Center | Pascal North | Pascal South | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | 36.3 | **36.3** |
| Watershed Area (ac) | 0.37 | 0.40 | 1.08 | 2.81 | 10.47 | 0.13 | 0.46 | 0.36 | **16.08** |
| ***VOLUME REMOVED*** | | | | | | | | | |
| Total Volume Removed by BMP (cf) | 10,759 | 12,894 | 34,717 | 81,631 | 333,365 | 4,051 | 13,286 | 10,542 | **501,245** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | | | | | |
| TP Load Removed by BMP (lbs) | 0.4 | 0.5 | 1.3 | 2.9 | 10.9 | 0.2 | 0.5 | 0.4 | **17.1** |
| TP in Gross Solids Load Removed by BMP (lbs) | 0.1 | 0.2 | 0.3 | 0.8 | 1.6 | 0.1 | 0.1 | 0.1 | **3.3** |
| Cumulative TP Load Removed: BMP (lbs) | 0.5 | 0.7 | 1.6 | 3.7 | 12.5 | 0.3 | 0.6 | 0.5 | **20.4** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | | | | | |
| TSS Load Removed by BMP (lbs) | 269 | 318 | 852 | 1,974 | 6,806 | 110 | 322 | 261 | **10,912** |
| Gross Solids Load Removed by BMP (lbs) | 333 | 372 | 727 | 2,038 | 4,059 | 131 | 277 | 192 | **8,130** |
| Total Solids Load Removed: BMP (lbs) | 602 | 690 | 1,579 | 4,012 | 10,865 | 241 | 599 | 453 | **19,042** |

**Table A-32. Annual projected volume reduction and pollutant removal efficiencies for the rain gardens.**

| | Arlington-McKinley | Asbury North | Asbury South | Frankson-McKinley | Hamline Midway | Pascal Center | Pascal North | Pascal South | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | **26.0** |
| Watershed Area (ac) | 0.37 | 0.40 | 1.08 | 2.81 | 10.47 | 0.13 | 0.46 | 0.36 | **16.08** |
| ***VOLUME REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow Volume (cf) | 5,619 | 6,098 | 16,509 | 42,994 | 191,969 | 1,960 | 7,013 | 5,489 | **277,651** |
| Outflow Volume (cf) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Volume Removed by BMP (cf) | 5,619 | 6,098 | 16,509 | 42,994 | 191,969 | 1,960 | 7,013 | 5,489 | **277,651** |
| Volume Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TP REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TP Load (lbs) | 0.1 | 0.1 | 0.4 | 1.0 | 4.1 | 0.1 | 0.2 | 0.1 | **6.1** |
| Outflow TP Load (lbs) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| TP Load Removed by BMP (lbs) | 0.1 | 0.1 | 0.4 | 1.0 | 4.1 | 0.1 | 0.2 | 0.1 | **6.1** |
| TP Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |
| ***TSS REMOVAL EFFICIENCY*** | | | | | | | | | |
| Inflow TSS Load (lbs) | 54 | 58 | 158 | 410 | 1,538 | 19 | 67 | 52 | **2,356** |
| Outflow TSS Load (lbs) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| TSS Load Removed by BMP (lbs) | 54 | 58 | 158 | 410 | 1,538 | 19 | 67 | 52 | **2,356** |
| TSS Removal Efficiency (%) | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | **100%** |

**Table A-33. Annual projected cumulative TP and total solids load reductions for the rain gardens.**

| | Arlington-McKinley | Asbury North | Asbury South | Frankson-McKinley | Hamline Midway | Pascal Center | Pascal North | Pascal South | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Annual Precipitation (in) | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | **26.0** |
| Watershed Area (ac) | 0.37 | 0.40 | 1.08 | 2.81 | 10.47 | 0.13 | 0.46 | 0.36 | **16.08** |
| ***VOLUME REMOVED*** | | | | | | | | | |
| Total Volume Removed by BMP (cf) | 5,619 | 6,098 | 16,509 | 42,994 | 191,969 | 1,960 | 7,013 | 5,489 | **277,651** |
| ***CUMULATIVE TP LOAD REMOVED*** | | | | | | | | | |
| TP Load Removed by BMP (lbs) | 0.1 | 0.1 | 0.4 | 1.0 | 4.1 | 0.1 | 0.2 | 0.1 | **6.1** |
| TP in Gross Solids Load Removed by BMP (lbs) | 0.2 | 0.2 | 0.4 | 1.1 | 2.2 | 0.1 | 0.2 | 0.1 | **4.4** |
| Cumulative TP Load Removed: BMP (lbs) | 0.3 | 0.3 | 0.8 | 2.1 | 6.3 | 0.1 | 0.4 | 0.2 | **10.4** |
| ***TOTAL SOLIDS LOAD REMOVED*** | | | | | | | | | |
| TSS Load Removed by BMP (lbs) | 54 | 58 | 158 | 410 | 1,538 | 19 | 67 | 52 | **2,356** |
| Gross Solids Load Removed by BMP (lbs) | 435 | 493 | 957 | 2,727 | 5,397 | 174 | 377 | 261 | **10,822** |
| Total Solids Load Removed: BMP (lbs) | 489 | 551 | 1,115 | 3,137 | 6,935 | 193 | 444 | 313 | **13,178** |

**Table A-34. 2009 itemized Arlington-Hamline Facility operation and maintenance costs.**

| Date | Activitiy | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/1/2009 | Pipe Gallery Inspection | 4 | $17.00 | 2.0 | 8.0 | $136 |
| 5/4/2009 | Manhole and Vortech Sediment Inspection | 2 | $13.00 | 0.5 | 1.0 | $13 |
| 10/14/2009 | Manhole and Vortech Sediment Inspection | 2 | $15.67 | 0.2 | 0.4 | $6 |
| 10/14/2009 | Pipe Gallery Inspection | 3 | $15.67 | 1.2 | 3.6 | $56 |
| | | | | **Total:** | **13.0** | **$211** |
| *Equipment and Materials* | | | | | | |
| | | | | | **Total:** | **$0** |

| Date | Activity | # of Units | Hour/Unit[a] | Total Hours | Rate | Cost |
|---|---|---|---|---|---|---|
| *Contract Services* | | | | | | |
| 5/20/09 - 5/26/09 | Vactored Vortech | 1 | 3.0 | 3.0 | $288 | $864 |
| 11/3/09 - 11/4/09 | Vactored Vortech | 1 | 3.0 | 3.0 | $288 | $864 |
| | | | | | **Total:** | **$1,729** |

[a] Time was approximated.

| | |
|---|---|
| **Total Labor Hours:** | **13** |
| **Total Cost:** | **$1,940** |

**Table A-35. 2010 itemized Arlington-Hamline Facility operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 4/21/2010 | Inspection: Manhole & Vortech Sediment | 4 | $17.00 | 0.3 | 1.0 | $17 |
| 6/22/2010 | Inspection: Pipe Gallery | 4 | $17.00 | 1.9 | 7.5 | $128 |
| 10/8/2010 | Inspection: Manhole & Vortech Sediment | 3 | $15.67 | 0.5 | 1.5 | $24 |
| | | | | **Total:** | **10.0** | **$168** |
| *Equipment and Materials* | | | | | | |
| | | | | | **Total:** | **$0** |

| Date | Activity | # of Units | Hour/Unit[a] | Total Hours | Rate | Cost |
|---|---|---|---|---|---|---|
| *Contract Services* | | | | | | |
| 05/2010 | Vactored Vortech | 1 | 3.0 | 3.0 | $288 | $864 |
| 11/2010 | Vactored Vortech | 1 | 3.0 | 3.0 | $288 | $864 |
| | | | | | **Total:** | **$1,728** |

[a] Time was approximated.

| | |
|---|---|
| **Total Labor Hours:** | **10** |
| **Total Cost:** | **$1,896** |

**Table A-36. 2009 Como Park Regional Pond operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/11/2009 | Suice Gate Maintenance | 3 | $15.67 | 0.8 | 2.3 | $35 |
| 10/14/2009 | Sluce Gate Maintenance | 2 | $17.00 | 0.5 | 0.9 | $16 |
| 04/2009-11/2009 | Debris Removal from Perimeter | 1 | $12.00 | 72.0 | 72.0 | $864 |
| | | | | **CRWD Labor Total:** | **3.2** | **$51** |
| | | | | **City of St. Paul Labor Total:** | **72.0** | **$864** |
| | | | | **Combined Total:** | **75.2** | **$915** |
| *Equipment and Materials* | | | | | | |
| | | | | | **Total:** | **$0** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

| | |
|---|---|
| **Total Labor Hours:** | **75** |
| **Total Cost:** | **$915** |

**Table A-37. 2010 Como Park Regional Pond operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/27/2010 | Suice Gate Maintenance | 3 | $18.33 | 1.1 | 3.3 | $60 |
| 10/13/2010 | Sluce Gate Maintenance | 3 | $15.67 | 0.3 | 0.8 | $12 |
| 04/2010-11/2010 | Debris Removal from Perimeter | 1 | $12.00 | 90.0 | 90.0 | $1,080 |
| | | | | **CRWD Labor Total:** | **4.1** | **$72** |
| | | | | **City of St. Paul Labor Total:** | **90.0** | **$1,080** |
| | | | | **Combined Total:** | **94.1** | **$1,152** |
| *Equipment and Materials* | | | | | | |
| | | | | | **Total:** | **$0** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

| | |
|---|---|
| **Total Labor Hours:** | **94** |
| **Total Cost:** | **$1,152** |

Table A-38. 2009 Arlington-McKinley Rain Garden operation and maintenance costs.

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/1/2009 | Dead Plant Removal, Debris Removal, Debris Removal from Inlet, Leaf Removal | 4 | $17.00 | 1.0 | 4.0 | $68 |
| 5/8/2009 | Inspection: Monthly | 3 | $15.67 | 0.3 | 1.0 | $16 |
| 6/3/2009 | Mulching, Weeding, Watering | 2 | $13.00 | 1.9 | 3.8 | $50 |
| 6/9/2009 | Debris Removal from Inlet | 2 | $17.00 | 0.2 | 0.4 | $7 |
| 6/10/2009 | Inspection: Post-Rain | 1 | $13.00 | 0.1 | 0.1 | $2 |
| 6/15/2009 | Seeding | 1 | $17.00 | 0.1 | 0.1 | $1 |
| 7/21/2009 | Debris Removal from Inlet | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 7/27/2009 | Mowing | 2 | $13.00 | 0.1 | 0.2 | $2 |
| 8/6/2009 | Mowing, Weeding | 1 | $17.00 | 1.1 | 1.1 | $19 |
| 8/11/2009 | Inspection: Monthly | 2 | $17.00 | 0.1 | 0.1 | $2 |
| 8/24/2009 | Debris Removal from Inlet, Inspection: Post-Rain, Weeding | 3 | $18.33 | 0.9 | 2.6 | $47 |
| 8/27/2009 | Inspection: Monthly | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 9/10/2009 | Signage Removal | 2 | $13.00 | 0.1 | 0.3 | $3 |
| 9/10/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.2 | 0.4 | $5 |
| 9/21/2009 | Inspection: Monthly | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 10/5/2009 | Inspection: Monthly | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 11/2/2009 | Inspection: Monthly | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 11/13/2009 | Leaf Removal | 4 | $17.00 | 1.0 | 4.0 | $68 |
| | | | | **CRWD Labor Total:** | **18.5** | **$296** |
| | | | | **Volunteer Labor Total:** | **0.0** | **$0** |
| *Equipment and Materials* | | | | | | |
| 4/1/2009 | Hydrant Meter | | | | | $78 |
| 5/1/2009 | Mulch | | | | | $17 |
| 5/1/2009 | Tools and Supplies | | | | | $3 |
| 6/1/2009 | Tools and Supplies | | | | | $40 |
| | | | | | **Total:** | **$138** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **19** |
| **Total Cost:** | **$434** |

**Table A-39. 2009 Asbury North Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/8/2009 | Debris Removal, Leaf Removal, Debris Removal from Inlet, Inspection: Monthly | 4 | $17.00 | 1.4 | 5.7 | $97 |
| 6/3/2009 | Mulching, Weeding | 2 | $13.00 | 0.4 | 0.8 | $11 |
| 6/4/2009 | Watering | 2 | $17.00 | 0.2 | 0.5 | $8 |
| 6/9/2009 | Debris Removal from Inlet | 2 | $17.00 | 0.1 | 0.2 | $4 |
| 6/11/2009 | Inspection: Monthly | 1 | $13.00 | 0.1 | 0.1 | $2 |
| 6/17/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.0 | 0.0 | $1 |
| 7/5/2009 | Weeding, Debris Removal from Inlet | 1 | $0.00 | 0.4 | 0.4 | $0 |
| 7/12/2009 | Weeding | 1 | $0.00 | 0.5 | 0.5 | $0 |
| 7/21/2009 | Debris Removal from Inlet | 1 | $13.00 | 0.2 | 0.2 | $2 |
| 8/9/2009 | Weeding | 1 | $0.00 | 0.8 | 0.8 | $0 |
| 8/10/2009 | Inspection: Monthly | 4 | $17.00 | 0.1 | 0.2 | $3 |
| 8/12/2009 | Dead Plant Removal,Weeding | 2 | $17.00 | 0.5 | 0.9 | $15 |
| 8/25/2009 | Dead Plant Removal, Weeding, Temporary Fencing: Installation, Inspection: Monthly | 4 | $17.00 | 0.5 | 2.1 | $35 |
| 9/8/2009 | Debris Removal, Inlet Cleaning, Weeding | 18 | $0.00 | 0.5 | 9.0 | $0 |
| 9/15/2009 | Mowing | 2 | $13.00 | 0.1 | 0.2 | $3 |
| 9/21/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 10/5/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 11/2/2009 | Inspection: Monthly | 2 | $13.00 | 0.1 | 0.2 | $3 |
| 11/5/2009 | Leaf Removal | 3 | $15.67 | 0.8 | 2.3 | $37 |
| 11/18/2009 | Pruning, Leaf Removal | 4 | $17.00 | 0.3 | 1.3 | $22 |
| | | | | **CRWD Labor Total:** | **15.2** | **$248** |
| | | | | **Volunteer Labor Total:** | **10.7** | **$0** |
| *Equipment and Materials* | | | | | | |
| 4/1/2009 | Hydrant Meter | | | | | $78 |
| 5/1/2009 | Mulch | | | | | $17 |
| 5/1/2009 | Tools and Supplies | | | | | $3 |
| 6/1/2009 | Tools and Supplies | | | | | $40 |
| | | | | | **Total:** | **$138** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **26** |
| **Total Cost:** | **$386** |

**Table A-40. 2009 Asbury South Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/8/2009 | Debris Removal, Dead Plant Removal | 3 | $15.67 | 2.1 | 6.4 | $100 |
| 5/8/2009 | Debris Removal, Inspection: Monthly, Leaf Removal | 3 | $15.67 | 1.1 | 3.2 | $49 |
| 5/8/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 5/11/2009 | Leaf Removal, Weeding | 3 | $15.67 | 0.9 | 2.8 | $43 |
| 5/27/2009 | Mowing, Weeding | 2 | $13.00 | 0.3 | 0.7 | $9 |
| 6/3/2009 | Mulching | 2 | $17.00 | 1.0 | 2.0 | $35 |
| 6/4/2009 | Watering | 2 | $17.00 | 0.6 | 1.1 | $19 |
| 6/9/2009 | Debris Removal from Inlet | 2 | $17.00 | 0.2 | 0.4 | $6 |
| 6/11/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 6/17/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.1 | 0.1 | $2 |
| 6/26/2009 | Weeding | 1 | $0.00 | 2.0 | 2.0 | $0 |
| 7/5/2009 | Debris Removal from Inlet, Weeding | 1 | $0.00 | 0.5 | 0.5 | $0 |
| 7/7/2009 | Mowing, Weeding | 2 | $13.00 | 0.2 | 0.5 | $6 |
| 7/12/2009 | Weeding | 1 | $0.00 | 0.5 | 0.5 | $0 |
| 7/21/2009 | Debris Removal from Inlet | 1 | $13.00 | 0.2 | 0.2 | $2 |
| 8/9/2009 | Weeding | 1 | $0.00 | 0.8 | 0.8 | $0 |
| 8/10/2009 | Inspection: Monthly | 4 | $17.00 | 0.1 | 0.2 | $3 |
| 8/12/2009 | Mowing | 2 | $17.00 | 0.2 | 0.4 | $6 |
| 8/12/2009 | Dead Plant Removal | 2 | $17.00 | 0.4 | 0.7 | $12 |
| 8/25/2009 | Debris Removal from Inlet, Inspection: Post-Rain, Mowing, Temporary Fencing: Installation, Weeding | 4 | $17.00 | 1.5 | 6.1 | $103 |
| 9/8/2009 | Debris Removal, Debris Removal From Inlet, Weeding | 18 | $0.00 | 1.0 | 18.0 | $0 |
| 9/10/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.0 | 0.0 | $0 |
| 9/21/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 10/5/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 11/2/2009 | Inspection: Monthly | 2 | $13.00 | 0.2 | 0.3 | $4 |
| 11/12/2009 | Leaf Removal | 3 | $15.67 | 1.7 | 5.2 | $81 |
| 11/13/2009 | Leaf Removal | 4 | $17.00 | 0.8 | 3.1 | $53 |
| 11/18/2009 | Pruned plants | 4 | $17.00 | 0.5 | 2.1 | $35 |
| | | | | **CRWD Labor Total:** | **36.1** | **$580** |
| | | | | **Volunteer Labor Total:** | **21.8** | **$0** |
| *Equipment and Materials* | | | | | | |
| 4/1/2009 | Hydrant Meter | | | | | $78 |
| 5/1/2009 | Mulch | | | | | $17 |
| 5/1/2009 | Tools and Supplies | | | | | $3 |
| 6/1/2009 | Tools and Supplies | | | | | $40 |
| | | | | | **Total:** | **$138** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **58** |
| **Total Cost:** | **$718** |

**Table A-41. 2009 Frankson-McKinley Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 4/16/2009 | Debris Removal | 2 | $0.00 | 1.3 | 2.5 | $0 |
| 4/19/2009 | Debris Removal | 2 | $0.00 | 1.3 | 2.7 | $0 |
| 4/22/2009 | Pruned plants, Leaf Removal | 2 | $0.00 | 1.5 | 3.0 | $0 |
| 5/15/2009 | Debris Removal, Debris Removal from Inlet, Inspection: Monthly, Leaf Removal, Weeding | 3 | $15.67 | 1.6 | 4.7 | $74 |
| 5/19/2009 | Debris Removal, Debris Removal from Inlet, Leaf Removal, Redistributed Mulch, Weeding | 3 | $15.67 | 1.7 | 5.0 | $79 |
| 5/20/2009 | Debris Removal, Leaf Removal, Weeding, | 3 | $15.67 | 1.1 | 3.3 | $52 |
| 5/27/2009 | Mowing, Weeding | 2 | $13.00 | 0.3 | 0.5 | $7 |
| 5/27/2009 | Mulching | 3 | $15.67 | 1.0 | 2.9 | $46 |
| 6/2/2009 | Watering | 3 | $15.67 | 2.2 | 6.6 | $103 |
| 6/3/2009 | Mulching | 2 | $17.00 | 1.1 | 2.3 | $38 |
| 6/9/2009 | Debris Removal from Inlet | 2 | $17.00 | 0.2 | 0.5 | $8 |
| 6/11/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $2 |
| 6/15/2009 | Seeding | 1 | $21.00 | 0.1 | 0.1 | $3 |
| 6/17/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.1 | 0.2 | $3 |
| 6/28/2009 | Pruning Plants | 2 | $0.00 | 0.8 | 1.5 | $0 |
| 7/21/2009 | Debris Removal from Inlet | 1 | $13.00 | 0.2 | 0.2 | $2 |
| 7/23/2009 | Dead Plant Removal, Weeding | 2 | $0.00 | 0.8 | 1.5 | $0 |
| 7/27/2009 | Mowing | 2 | $13.00 | 0.2 | 0.3 | $4 |
| 7/28/2009 | Thinning Plants, Weeding | 1 | $21.00 | 3.2 | 3.2 | $66 |
| 7/28/2009 | Debris Removal from Inlet, Pruning Plants | 1 | $13.00 | 0.4 | 0.4 | $5 |
| 8/11/2009 | Inspection: Monthly | 2 | $17.00 | 0.1 | 0.1 | $2 |
| 8/12/2009 | Debris Removal from Inlet, Mowing, Weeding | 2 | $17.00 | 0.3 | 0.6 | $11 |
| 8/26/2009 | Debris Removal from Inlet, Inspection: Post-Rain, Mowing, Temporary Fencing: Installationm, | 4 | $17.00 | 1.4 | 5.5 | $93 |
| 8/27/2009 | Inspection: Post-Rain | 2 | $17.00 | 0.2 | 0.4 | $7 |
| 9/8/2009 | Debris Removal, Inlet Cleaning, Weeding | 10 | $0.00 | 0.5 | 5.0 | $0 |
| 9/10/2009 | Weeding | 2 | $0.00 | 1.0 | 2.0 | $0 |
| 9/10/2009 | Temporary Fencing: Removal | 2 | $13.00 | 0.4 | 0.7 | $10 |
| 9/10/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.3 | 0.6 | $8 |
| 9/15/2009 | Mowing | 2 | $13.00 | 0.3 | 0.6 | $7 |
| 9/21/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 10/5/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 11/2/2009 | Inspection: Monthly | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 11/13/2009 | Leaf Removal | 4 | $17.00 | 1.5 | 5.9 | $100 |
| 11/15/2009 | Pruned plants, Leaf Removal | 1 | $0.00 | 2.0 | 2.0 | $0 |
| 11/16/2009 | Pruned plants, Leaf Removal | 2 | $0.00 | 2.0 | 4.0 | $0 |
| 11/17/2009 | Leaf Removal | 3 | $15.67 | 1.5 | 4.5 | $71 |
| | | | | **CRWD Labor Total:** | **49.8** | **$807** |
| | | | | **Volunteer Labor Total:** | **24.2** | **$0** |
| *Equipment and Materials* | | | | | | |
| 4/1/2009 | Hydrant Meter | | | | | $78 |
| 5/1/2009 | Mulch | | | | | $17 |
| 5/1/2009 | Tools and Supplies | | | | | $3 |
| 6/1/2009 | Tools and Supplies | | | | | $40 |
| | | | | | **Total:** | **$138** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **74** |
| **Total Cost:** | **$945** |

**Table A-42. 2009 Hamline-Midway Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/27/2009 | Replanting/Moving Plants/Trees | 2 | $13.00 | 0.5 | 0.9 | $12 |
| 6/2/2009 | Weeding | 3 | $15.67 | 1.6 | 4.9 | $77 |
| 6/2/2009 | Weeding | 3 | $15.67 | 1.2 | 3.7 | $58 |
| 6/9/2009 | Debris Removal from Inlet, Weeding | 2 | $21.00 | 0.2 | 0.5 | $10 |
| 6/9/2009 | Weeding | 4 | $17.00 | 1.8 | 7.0 | $119 |
| 6/11/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 7/7/2009 | Weeding | 1 | $21.00 | 1.0 | 1.0 | $21 |
| 7/7/2009 | Weeding | 12 | $0.00 | 1.0 | 12.0 | $0 |
| 7/7/2009 | Weeding | 1 | $21.00 | 1.5 | 1.5 | $32 |
| 7/7/2009 | Weeding | 12 | $0.00 | 1.5 | 18.0 | $0 |
| 7/9/2009 | Pruning Plants, Weeding | 1 | $21.00 | 1.3 | 1.3 | $28 |
| 7/9/2009 | Pruning Plants, Weeding | 11 | $0.00 | 1.3 | 14.6 | $0 |
| 7/21/2009 | Debris Removal from Inlet | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 8/11/2009 | Inspection: Monthly | 2 | $17.00 | 0.1 | 0.2 | $3 |
| 8/27/2009 | Inspection: Post-Rain | 2 | $17.00 | 0.2 | 0.3 | $5 |
| 8/27/2009 | Weeding | 3 | $15.67 | 1.0 | 2.9 | $45 |
| 9/21/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $2 |
| 10/5/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $2 |
| 11/2/2009 | Inspection: Monthly | 2 | $13.00 | 0.1 | 0.1 | $1 |
| | | | | **CRWD Labor Total:** | **24.9** | **$418** |
| | | | | **Volunteer Labor Total:** | **44.6** | **$0** |
| *Equipment and Materials* | | | | | | |
| 6/1/2009 | Tools and Supplies | | | | | $40 |
| | | | | | **Total:** | **$40** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **70** |
| **Total Cost:** | **$459** |

**Table A-43. 2009 Pascal Center Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/4/2009 | Pruning Plants, Debris Removal, Debris Removal from Inlet, Leaf Removal | 4 | $17.00 | 1.0 | 4.0 | $68 |
| 5/5/2009 | Inspection: Monthly | 4 | $17.00 | 0.1 | 0.4 | $7 |
| 5/20/2009 | Weeding, Seeding | 3 | $15.67 | 1.8 | 5.3 | $82 |
| 5/22/2009 | Removing Sod | 2 | $13.00 | 1.3 | 2.7 | $35 |
| 5/27/2009 | Weeding, Mowing | 2 | $13.00 | 0.2 | 0.3 | $4 |
| 5/27/2009 | Mulching, Watering, Seeding, Sod Removal | 3 | $15.67 | 1.6 | 4.7 | $73 |
| 6/2/2009 | Watering, Weeding | 3 | $15.67 | 1.0 | 2.9 | $46 |
| 6/2/2009 | Watering | 3 | $15.67 | 0.4 | 1.1 | $16 |
| 6/2/2009 | Watering | 3 | $15.67 | 0.7 | 2.1 | $33 |
| 6/3/2009 | Weeding, Watering | 2 | $17.00 | 0.4 | 0.9 | $15 |
| 6/9/2009 | Debris Removal from Inlet | 2 | $17.00 | 0.1 | 0.3 | $4 |
| 6/10/2009 | Inspection: Post-Rain | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 6/25/2009 | Mowing | 1 | $21.00 | 0.6 | 0.6 | $12 |
| 6/29/2009 | Debris Removal from Inlet, Weeding | 3 | $15.67 | 0.5 | 1.5 | $24 |
| 7/9/2009 | Thinning Plants, Weeding | 9 | $0.00 | 0.5 | 4.5 | $0 |
| 7/9/2009 | Thinning Plants, Weeding | 3 | $15.67 | 0.5 | 1.5 | $24 |
| 7/21/2009 | Debris Removal from Inlet | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 8/4/2009 | Mowing,Weeding, Edging | 3 | $15.67 | 1.1 | 3.3 | $52 |
| 8/11/2009 | Inspection: Monthly | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 8/12/2009 | Mowing | 2 | $17.00 | 0.2 | 0.3 | $6 |
| 8/24/2009 | Mowing, Temporary Fencing: Installation, Weeding | 3 | $18.33 | 1.0 | 3.1 | $57 |
| 8/27/2009 | Inspection: Post-Rain | 2 | $17.00 | 0.1 | 0.2 | $4 |
| 9/1/2009 | Mowing, Weeding | 2 | $13.00 | 0.5 | 0.9 | $12 |
| 9/4/2009 | Inspection: Monthly | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 9/8/2009 | Debris Removal, Inlet Cleaning, Weeding | 18 | $0.00 | 1.0 | 18.0 | $0 |
| 9/10/2009 | Temporary Fencing: Removal | 2 | $13.00 | 0.1 | 0.2 | $3 |
| 9/10/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.1 | 0.3 | $3 |
| 9/15/2009 | Mowing | 2 | $13.00 | 0.3 | 0.5 | $7 |
| 10/5/2009 | Inspection: Monthly | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 11/2/2009 | Inspection: Monthly | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 11/5/2009 | Leaf Removal | 3 | $15.67 | 0.5 | 1.6 | $24 |
| 11/16/2009 | Leaf Removal, Mowing | 4 | $17.00 | 0.6 | 2.5 | $43 |
| | | | | **CRWD Labor Total:** | **41.5** | **$659** |
| | | | | **Volunteer Labor Total:** | **22.5** | **$0** |
| *Equipment and Materials* | | | | | | |
| 4/1/2009 | Hydrant Meter | | | | | $78 |
| 5/1/2009 | Mulch | | | | | $17 |
| 5/1/2009 | Tools and Supplies | | | | | $3 |
| 6/1/2009 | Tools and Supplies | | | | | $40 |
| | | | | | **Total:** | **$138** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **64** |
| **Total Cost:** | **$797** |

**Table A-44. 2009 Pascal North Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/4/2009 | Dead Plant Removal, Debris Removal from Inlet, Debris Removal, Leaf Removal | 4 | $17.00 | 0.7 | 2.6 | $44 |
| 5/5/2009 | Inspection: Monthly | 4 | $17.00 | 0.1 | 0.4 | $7 |
| 5/27/2009 | Weeding, Mowing | 2 | $13.00 | 0.1 | 0.3 | $3 |
| 5/27/2009 | Sod Removal, Mulching | 3 | $15.67 | 0.7 | 2.0 | $31 |
| 6/2/2009 | Weeding, Watering | 3 | $15.67 | 1.0 | 2.9 | $46 |
| 6/3/2009 | Watering | 2 | $17.00 | 0.5 | 1.0 | $16 |
| 6/9/2009 | Debris Removal from Inlet | 2 | $17.00 | 0.1 | 0.2 | $3 |
| 6/10/2009 | Inspection: Post-Rain | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 6/15/2009 | Seeding | 1 | $21.00 | 0.1 | 0.1 | $2 |
| 6/17/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.0 | 0.0 | $1 |
| 6/25/2009 | Mowing | 1 | $21.00 | 0.1 | 0.1 | $2 |
| 6/29/2009 | Debris Removal from Inlet, Mowing, Weeding | 3 | $15.67 | 1.0 | 3.0 | $47 |
| 7/9/2009 | Thinning Plants, Weeding | 3 | $15.67 | 0.5 | 1.5 | $24 |
| 7/9/2009 | Thinning Plants, Weeding | 9 | $0.00 | 0.5 | 4.5 | $0 |
| 7/21/2009 | Debris Removal from Inlet | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 7/28/2009 | Debris Removal from Inlet, Thinning Plants | 1 | $13.00 | 0.3 | 0.3 | $4 |
| 8/4/2009 | Thinning Plants, Mowing, Edging, Weeding | 3 | $15.67 | 0.6 | 1.9 | $29 |
| 8/11/2009 | Inspection: Monthly | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 8/12/2009 | Mowing | 2 | $17.00 | 0.2 | 0.4 | $6 |
| 8/24/2009 | Mowing, Temporary Fencing: Installation, Weeding | 3 | $18.33 | 0.5 | 1.4 | $26 |
| 8/27/2009 | Inspection: Post-Rain | 2 | $17.00 | 0.2 | 0.3 | $6 |
| 9/8/2009 | Debris Removal, Inlet Cleaning, Weeding | 18 | $0.00 | 0.3 | 5.9 | $0 |
| 9/10/2009 | Temporary Fencing: Removal | 2 | $13.00 | 0.1 | 0.3 | $3 |
| 9/10/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 9/21/2009 | Inspection: Monthly | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 10/5/2009 | Inspection: Monthly | 1 | $13.00 | 0.1 | 0.1 | $1 |
| 11/2/2009 | Inspection: Monthly | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 11/5/2009 | Leaf Removal | 3 | $15.67 | 0.5 | 1.6 | $25 |
| | | | | **CRWD Labor Total:** | **20.9** | **$334** |
| | | | | **Volunteer Labor Total:** | **10.4** | **$0** |
| *Equipment and Materials* | | | | | | |
| 4/1/2009 | Hydrant Meter | | | | | $78 |
| 5/1/2009 | Mulch | | | | | $17 |
| 5/1/2009 | Tools and Supplies | | | | | $3 |
| 6/1/2009 | Tools and Supplies | | | | | $40 |
| | | | | | **Total:** | **$138** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **31** |
| **Total Cost:** | **$472** |

Table A-45. 2009 Pascal South Rain Garden operation and maintenance costs.

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/5/2009 | Inspection: Monthly, Weeding | 4 | $17.00 | 0.5 | 2.1 | $36 |
| 5/7/2009 | Debris Removal, Leaf Removal, Inspection: Monthly | 4 | $17.00 | 1.8 | 7.1 | $121 |
| 5/27/2009 | Weeding, Mowing | 2 | $13.00 | 0.7 | 1.3 | $17 |
| 5/27/2009 | Mulching | 3 | $15.67 | 0.2 | 0.7 | $10 |
| 6/9/2009 | Debris Removal from Inlet | 2 | $17.00 | 0.2 | 0.3 | $6 |
| 6/10/2009 | Inspection: Post-Rain | 1 | $13.00 | 0.1 | 0.1 | $2 |
| 6/15/2009 | Seeding | 1 | $21.00 | 0.1 | 0.1 | $3 |
| 6/17/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.1 | 0.1 | $2 |
| 6/25/2009 | Mowing | 1 | $21.00 | 0.1 | 0.1 | $3 |
| 6/29/2009 | Mowing, Weeding, Debris Removal from Inlet | 3 | $15.67 | 1.1 | 3.4 | $53 |
| 7/9/2009 | Pruning Plants, Weeding | 3 | $15.67 | 0.6 | 1.8 | $28 |
| 7/9/2009 | Pruning Plants, Weeding | 9 | $0.00 | 0.6 | 5.4 | $0 |
| 7/21/2009 | Debris Removal from Inlet | 1 | $13.00 | 0.1 | 0.1 | $2 |
| 8/5/2009 | Edging, Weeding | 1 | $13.00 | 2.3 | 2.3 | $30 |
| 8/11/2009 | Inspection: Monthly | 2 | $17.00 | 0.1 | 0.2 | $3 |
| 8/12/2009 | Mowing | 2 | $17.00 | 0.1 | 0.1 | $2 |
| 8/24/2009 | Mowing, Temporary Fencing: Installation, Weeding | 3 | $18.33 | 0.9 | 2.8 | $51 |
| 8/27/2009 | Inspection: Post-Rain | 2 | $17.00 | 0.1 | 0.3 | $4 |
| 9/8/2009 | Debris Removal, Inlet Cleaning, Weeding | 18 | $0.00 | 0.3 | 5.9 | $0 |
| 9/10/2009 | Temporary Fencing: Removal | 2 | $13.00 | 0.2 | 0.4 | $5 |
| 9/10/2009 | Debris Removal from Inlet | 2 | $13.00 | 0.2 | 0.3 | $4 |
| 9/21/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 10/5/2009 | Inspection: Monthly | 1 | $13.00 | 0.2 | 0.2 | $3 |
| 11/2/2009 | Inspection: Monthly | 2 | $13.00 | 0.1 | 0.2 | $3 |
| 11/16/2009 | Leaf Removal | 4 | $17.00 | 0.9 | 3.5 | $59 |
| | | | | **CRWD Labor Total:** | **27.8** | **$448** |
| | | | | **Volunteer Labor Total:** | **11.3** | **$0** |
| *Equipment and Materials* | | | | | | |
| 4/1/2009 | Hydrant Meter | | | | | $78 |
| 5/1/2009 | Mulch | | | | | $17 |
| 5/1/2009 | Tools and Supplies | | | | | $3 |
| 6/1/2009 | Tools and Supplies | | | | | $40 |
| | | | | | **Total:** | **$138** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **39** |
| **Total Cost:** | **$586** |

**Table A-46. 2010 Arlington-McKinley Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/4/2010 | Debris Removal, Mowing | 2 | $21.00 | 0.1 | 0.2 | $4 |
| 5/27/2010 | Debris Removal, Debris Removal from Inlet, Mowing, Weeding | 3 | $15.67 | 0.9 | 2.8 | $44 |
| 6/2/2010 | Seeded | 3 | $15.67 | 0.1 | 0.4 | $6 |
| 6/3/2010 | Mulching | 3 | $15.67 | 0.4 | 1.3 | $20 |
| 6/28/2010 | Debris Removal from Inlet | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 7/22/2010 | Inspection: Post-Rain | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 8/4/2010 | Mowing, Thinning Plants, Weeding | 3 | $15.67 | 0.5 | 1.4 | $23 |
| 8/4/2010 | Mowing, Thinning Plants, Weeding | 2 | $0.00 | 0.5 | 1.0 | $0 |
| 8/12/2010 | Inspection: Post-Rain | 2 | $17.00 | 0.1 | 0.1 | $2 |
| 8/23/2010 | Debris Removal from Inlet, Temporary Fencing: Installation, Weeding | 3 | $18.33 | 0.4 | 1.1 | $21 |
| 9/7/2010 | Debris Removal, Temporary Fencing: Removal | 3 | $18.33 | 0.1 | 0.4 | $7 |
| 9/22/2010 | Inspection: Post-Rain | 4 | $17.00 | 0.3 | 1.0 | $17 |
| 9/23/2010 | Debris Removal from Inlet, Mowing | 2 | $17.00 | 0.2 | 0.3 | $5 |
| 9/30/2010 | Inspection: Monthly | 2 | $13.00 | 0.2 | 0.4 | $5 |
| 10/13/2010 | Debris Removal from Inlet, Leaf Removal, Mowing, Thinning Plants, Weeding | 1 | $13.00 | 0.2 | 0.2 | $2 |
| | | | | **CRWD Labor Total:** | **9.8** | **$158** |
| | | | | **Volunteer Labor Total:** | **1.0** | **$0** |
| *Equipment and Materials* | | | | | | |
| 5/1/2010 | Mulch | | | | | $22 |
| 5/1/2010 | Tools and Supplies | | | | | $4 |
| 6/1/2010 | Tools and Supplies | | | | | $12 |
| 8/1/2010 | Signage | | | | | $595 |
| | | | | | **Total:** | **$633** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **11** |
| **Total Cost:** | **$791** |

Table A-47. 2010 Asbury North Rain Garden operation and maintenance costs.

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/4/2010 | Mowing | 1 | $21.00 | 0.2 | 0.2 | $4 |
| 5/18/2011 | Debris Removal from Inlet, Mowing, Weeding | 5 | $17.80 | 0.4 | 1.8 | $31 |
| 5/19/2010 | Thinning Plants, Weeding | 3 | $15.67 | 0.3 | 0.9 | $14 |
| 5/27/2010 | Debris Removal, Debris Removal from Inlet | 3 | $15.67 | 0.4 | 1.3 | $20 |
| 5/28/2010 | Mulching | 3 | $15.67 | 0.5 | 1.6 | $24 |
| 6/2/2010 | Debris Removal from Inlet, Seeded | 3 | $15.67 | 0.1 | 0.2 | $3 |
| 6/17/2010 | Mow | 2 | $13.00 | 0.1 | 0.2 | $2 |
| 6/28/2010 | Debris Removal from Inlet | 2 | $13.00 | 0.1 | 0.1 | $2 |
| 7/8/2010 | Debris Removal from Inlet, Mowing | 2 | $17.00 | 0.3 | 0.6 | $10 |
| 7/22/2010 | Inspection: Post-Rain | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 8/4/2010 | Thinning Plants, Mowing, Weeding | 3 | $15.67 | 1.3 | 4.0 | $62 |
| 8/4/2010 | Thinning Plants, Mowing, Weeding | 2 | $0.00 | 1.3 | 2.6 | $0 |
| 8/12/2010 | Inspection: Post-Rain | 2 | $17.00 | 0.1 | 0.2 | $3 |
| 8/24/2010 | Debris Removal from Inlet, Mowing, Temporary Fencing: Installation, Weeding | 3 | $18.33 | 1.3 | 4.0 | $73 |
| 9/7/2010 | Temporary Fencing: Removal | 3 | $18.33 | 0.3 | 0.8 | $15 |
| 9/22/2010 | Inspection: Post-Rain | 4 | $17.00 | 0.2 | 0.8 | $14 |
| 9/23/2010 | Debris Removal from Inlet, Mowing | 2 | $17.00 | 0.2 | 0.3 | $6 |
| 9/30/2010 | Debris Removal from Inlet, Leaf Removal, Inspection: Monthly | 2 | $13.00 | 0.5 | 1.0 | $13 |
| 10/13/2010 | Debris Removal from Inlet, Leaf Removal, Mowing, Weeding | 1 | $13.00 | 0.2 | 0.2 | $3 |
| | | | | **CRWD Labor Total:** | **18.2** | **$301** |
| | | | | **Volunteer Labor Total:** | **2.6** | **$0** |
| *Equipment and Materials* | | | | | | |
| 5/1/2010 | Mulch | | | | | $22 |
| 5/1/2010 | Tools and Supplies | | | | | $4 |
| 6/1/2010 | Tools and Supplies | | | | | $12 |
| 8/1/2010 | Signage | | | | | $595 |
| | | | | | **Total:** | **$633** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **21** |
| **Total Cost:** | **$933** |

Table A-49. 2010 Asbury South Rain Garden operation and maintenance costs.

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 5/4/2010 | Debris Removal, Mowing | 2 | $21.00 | 0.5 | 0.9 | $20 |
| 5/18/2010 | Dead Plant Removal, Debris Removal from Inlet, Mowing, Thinning Plants, Weeding | 5 | $14.60 | 1.3 | 6.5 | $95 |
| 5/27/2010 | Mowing | 1 | $21.00 | 0.2 | 0.2 | $4 |
| 5/27/2010 | Mowing | 1 | $13.00 | 0.2 | 0.2 | $2 |
| 5/28/2010 | Mulching | 3 | $15.67 | 1.1 | 3.3 | $52 |
| 6/2/2010 | Debris Removal from Inlet, Seeded | 3 | $15.67 | 0.2 | 0.5 | $8 |
| 6/17/2010 | Mowing | 2 | $13.00 | 0.2 | 0.3 | $4 |
| 6/28/2010 | Debris Removal from Inlet | 2 | $13.00 | 0.1 | 0.1 | $2 |
| 7/8/2010 | Debris Removal from Inlet, Mowing, Weeding | 2 | $17.00 | 0.2 | 0.3 | $5 |
| 7/22/2010 | Inspection: Post-Rain | 2 | $13.00 | 0.1 | 0.1 | $2 |
| 8/12/2010 | Inspection: Post-Rain | 2 | $17.00 | 0.1 | 0.2 | $3 |
| 8/24/2010 | Debris Removal from Inlet, Mowing, Weeding | 2 | $17.00 | 0.8 | 1.7 | $28 |
| 8/24/2010 | Weeding | 2 | $21.00 | 0.3 | 0.7 | $14 |
| 8/24/2010 | Weeding, Temporary Fencing: Installation | 3 | $18.33 | 2.0 | 6.0 | $110 |
| 9/7/2010 | Temporary Fencing: Removal | 3 | $18.33 | 0.3 | 0.8 | $14 |
| 9/22/2010 | Inspection: Post-Rain | 4 | $17.00 | 0.2 | 0.8 | $14 |
| 9/23/2010 | Debris Removal from Inlet, Mowing | 2 | $17.00 | 0.1 | 0.3 | $4 |
| 9/30/2010 | Debris Removal from Inlet, Leaf Removal, Inspection: Monthly | 2 | $13.00 | 0.5 | 1.0 | $13 |
| 10/13/2010 | Debris Removal from Inlet, Leaf Removal, Mowing, Weeding | 1 | $13.00 | 0.4 | 0.4 | $5 |
| | | | | **CRWD Labor Total:** | **24.2** | **$398** |
| | | | | **Volunteer Labor Total:** | **0.0** | **$0** |
| *Equipment and Materials* | | | | | | |
| 5/1/2010 | Mulch | | | | | $22 |
| 5/1/2010 | Tools and Supplies | | | | | $4 |
| 6/1/2010 | Tools and Supplies | | | | | $12 |
| 8/1/2010 | Signage | | | | | $595 |
| | | | | | **Total:** | **$633** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **24** |
| **Total Cost:** | **$1,031** |

Table A-50. 2010 Frankson-McKinley Rain Garden operation and maintenance costs.

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 4/22/2010 | Debris Removal, Weeding | 1 | $0.00 | 0.5 | 0.5 | $0 |
| 4/28/2010 | Dead Plant Removal | 1 | $0.00 | 1.3 | 1.3 | $0 |
| 5/1/2010 | Dead Plant Removal | 1 | $0.00 | 1.3 | 1.3 | $0 |
| 5/19/2010 | Debris Removal from Inlet, Mowing | 3 | $15.67 | 0.2 | 0.5 | $7 |
| 5/27/2010 | Mowing, Weeding | 4 | $17.00 | 0.4 | 1.4 | $24 |
| 6/2/2010 | Debris Removal from Inlet, Seeding | 3 | $15.67 | 0.3 | 0.8 | $13 |
| 6/3/2010 | Mulching, Weeding | 3 | $15.67 | 0.7 | 2.0 | $31 |
| 6/17/2010 | Mowing | 2 | $13.00 | 0.2 | 0.3 | $4 |
| 6/20/2010 | Clipped back plants | 2 | $0.00 | 0.5 | 1.0 | $0 |
| 6/21/2010 | Thinning Plants, Weeding | 4 | $17.00 | 0.7 | 2.9 | $49 |
| 6/24/2010 | Pruning Plants | 2 | $0.00 | 0.8 | 1.5 | $0 |
| 7/8/2010 | Mowing, Weeding | 2 | $17.00 | 0.2 | 0.4 | $7 |
| 7/22/2010 | Inspection: Post-Rain | 2 | $13.00 | 0.1 | 0.2 | $2 |
| 8/12/2010 | Inspection: Post-Rain | 2 | $17.00 | 0.1 | 0.2 | $3 |
| 8/23/2010 | Debris Removal from Inlet, Temporary Fencing: Installation, Mowing, Weeding | 3 | $18.33 | 1.8 | 5.3 | $97 |
| 9/7/2010 | Debris Removal, Temporary Fencing: Removal | 3 | $18.33 | 0.1 | 0.4 | $7 |
| 9/22/2010 | Inspection: Post-Rain | 4 | $17.00 | 0.2 | 0.8 | $14 |
| 9/23/2010 | Debris Removal from Inlet, Mowing | 2 | $17.00 | 0.3 | 0.6 | $10 |
| 9/30/2010 | Debris Removal from Inlet, Leaf Removal, Inspection: Monthly | 2 | $13.00 | 0.5 | 1.0 | $13 |
| 10/5/2010 | Pruning Plants | 1 | $0.00 | 0.5 | 0.5 | $0 |
| 10/13/2010 | Debris Removal from Inlet, Leaf Removal, Mowing | 1 | $13.00 | 0.5 | 0.5 | $6 |
| 10/13/2010 | Pruning Plants | 1 | $0.00 | 1.0 | 1.0 | $0 |
| 10/23/2010 | Pruning Plants | 1 | $0.00 | 0.5 | 0.5 | $0 |
| 10/31/2010 | Pruning Plants | 1 | $0.00 | 0.5 | 0.5 | $0 |
| | | | | **CRWD Labor Total:** | **17.2** | **$287** |
| | | | | **Volunteer Labor Total:** | **8.0** | **$0** |
| *Equipment and Materials* | | | | | | |
| 5/1/2010 | Mulch | | | | | $22 |
| 5/1/2010 | Tools and Supplies | | | | | $4 |
| 6/1/2010 | Tools and Supplies | | | | | $12 |
| 8/1/2010 | Signage | | | | | $595 |
| | | | | | **Total:** | **$633** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **25** |
| **Total Cost:** | **$920** |

**Table A-51. 2010 Hamline-Midway Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 6/23/2010 | Weeded | 2 | $16.50 | 4.0 | 8.0 | $132 |
| 7/6/2010 | Weeded | 2 | $16.50 | 4.0 | 8.0 | $132 |
| 7/22/2010 | Inspection: Post-Rain | 2 | $13.00 | 0.2 | 0.3 | $4 |
| 7/28/2010 | Weeded | 1 | $12.10 | 4.0 | 4.0 | $48 |
| 7/28/2010 | Weeded | 7 | $7.98 | 4.0 | 28.0 | $223 |
| 7/29/2010 | Weeded | 1 | $12.10 | 4.0 | 4.0 | $48 |
| 7/29/2010 | Weeded | 7 | $7.98 | 4.0 | 28.0 | $223 |
| 8/12/2010 | Inspection: Post-Rain | 2 | $17.00 | 0.3 | 0.5 | $9 |
| 8/24/2010 | Herbicide Treatment | 2 | $16.50 | 4.0 | 8.0 | $132 |
| 9/3/2010 | Mulching | 2 | $16.50 | 6.0 | 12.0 | $198 |
| 9/9/2010 | Herbicide Treatment | 1 | $16.50 | 2.0 | 2.0 | $33 |
| 9/30/2010 | Inspection: Monthly | 2 | $13.00 | 0.2 | 0.4 | $5 |
| 10/6/2010 | Tree Maintenance | 1 | $16.50 | 2.0 | 2.0 | $33 |
| | | | | **CRWD Labor Total:** | **1.2** | **$18** |
| | | | | **City of St. Paul Labor Total:** | **104.0** | **$1,204** |
| | | | | **Volunteer Labor Total:** | **0.0** | **$0** |
| *Equipment and Materials* | | | | | | |
| 8/1/2010 | Signage | | | | | $1,190 |
| | | | | | **Total:** | **$1,190** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **105** |
| **Total Cost:** | **$2,411** |

**Table A-52. 2010 Pascal Center Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 4/28/2010 | Debris Removal, Debris Removal from Inlet, Leaf Removal, Mowing, Weeding | 2 | $12.00 | 1.6 | 3.1 | $37 |
| 5/4/2010 | Mowing | 2 | $21.00 | 0.2 | 0.4 | $8 |
| 5/19/2010 | Debris Removal from Inlet, Mowing, Weeding | 3 | $15.67 | 0.3 | 1.0 | $16 |
| 5/27/2010 | Mowing, Weeding | 4 | $17.00 | 0.3 | 1.0 | $17 |
| 5/28/2010 | Mulching | 4 | $17.00 | 0.4 | 1.7 | $29 |
| 6/2/2010 | Debris Removal from Inlet | 3 | $15.67 | 0.2 | 0.5 | $7 |
| 6/17/2010 | Mosing | 2 | $13.00 | 0.2 | 0.3 | $4 |
| 6/28/2010 | Debris Removal from Inlet | 2 | $13.00 | 0.0 | 0.1 | $1 |
| 7/8/2010 | Mowing | 2 | $17.00 | 0.2 | 0.3 | $6 |
| 7/15/2010 | Thinning Plants, Weeding | 1 | $21.00 | 1.0 | 1.0 | $21 |
| 7/15/2010 | Thinning Plants, Weeding | 2 | $13.00 | 0.5 | 0.9 | $12 |
| 7/15/2010 | Thinning Plants, Weeding | 4 | $17.00 | 0.5 | 2.1 | $35 |
| 7/15/2010 | Thinning Plants, Weeding | 2 | $0.00 | 0.5 | 1.0 | $0 |
| 7/22/2010 | Inspection: Post-Rain | 2 | $13.00 | 0.1 | 0.1 | $1 |
| 7/29/2010 | Mowing, Weeding | 2 | $17.00 | 0.7 | 1.4 | $24 |
| 8/4/2010 | Mowing, Weeding | 3 | $15.67 | 0.3 | 0.8 | $13 |
| 8/4/2010 | Mowing, Weeding | 2 | $0.00 | 0.3 | 0.6 | $0 |
| 8/12/2010 | Inspection: Post-Rain | 2 | $17.00 | 0.2 | 0.4 | $7 |
| 8/23/2010 | Mowing, Temporary Fencing: Installation | 2 | $17.00 | 0.7 | 1.4 | $23 |
| 9/7/2010 | Temporary Fencing: Removal | 3 | $18.33 | 0.1 | 0.4 | $7 |
| 9/22/2010 | Inspection: Post-Rain | 4 | $17.00 | 0.2 | 0.8 | $14 |
| 9/23/2010 | Debris Removal from Inlet, Mowing | 2 | $17.00 | 0.2 | 0.4 | $6 |
| 9/30/2010 | Debris Removal from Inlet, Leaf Removal, Inspection: Mothly | 2 | $13.00 | 0.5 | 1.0 | $13 |
| 10/13/2010 | Debris Removal from Inlet, Leaf Removal, Mowing, Weeding | 1 | $13.00 | 0.2 | 0.2 | $3 |
| | | | | **CRWD Labor Total:** | **19.2** | **$304** |
| | | | | **Volunteer Labor Total:** | **1.6** | **$0** |
| *Equipment and Materials* | | | | | | |
| 5/1/2010 | Mulch | | | | | $22 |
| 5/1/2010 | Tools and Supplies | | | | | $4 |
| 6/1/2010 | Tools and Supplies | | | | | $12 |
| 8/1/2010 | Signage | | | | | $595 |
| | | | | | **Total:** | **$633** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **21** |
| **Total Cost:** | **$937** |

**Table A-53. 2010 Pascal North Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 4/28/2010 | Debris Removal, Leaf Removal, Weeding | 3 | $15.67 | 0.42 | 1.3 | $20 |
| 4/28/2010 | Debris Removal, Mowing, Weeding | 3 | $15.67 | 0.55 | 1.7 | $26 |
| 5/4/2010 | Debris Removal, Mowing, Weeding | 2 | $21.00 | 0.08 | 0.2 | $3 |
| 5/28/2010 | Mulching | 4 | $17.00 | 0.43 | 1.7 | $29 |
| 6/17/2010 | Mowing | 2 | $13.00 | 0.08 | 0.2 | $2 |
| 6/28/2010 | Debris Removal from Inlet | 2 | $13.00 | 0.05 | 0.1 | $1 |
| 7/8/2010 | Mowing | 2 | $17.00 | 0.17 | 0.3 | $6 |
| 7/15/2010 | Thinning Plants, Weeding | 1 | $21.00 | 1.33 | 1.3 | $28 |
| 7/15/2010 | Thinning Plants, Weeding | 2 | $0.00 | 0.88 | 1.8 | $0 |
| 7/22/2010 | Inspection: Post-Rain | 2 | $13.00 | 0.05 | 0.1 | $1 |
| 7/29/2010 | Mowing, Weeding | 2 | $17.00 | 0.38 | 0.8 | $13 |
| 8/4/2010 | Mowing, Weeding | 3 | $15.67 | 0.08 | 0.2 | $4 |
| 8/12/2010 | Inspection: Post-Rain | 2 | $17.00 | 0.09 | 0.2 | $3 |
| 8/23/2010 | Mowing, Temporary Fencing: Installation | 3 | $18.33 | 0.25 | 0.8 | $14 |
| 9/7/2010 | Temporary Fencing: Removal | 3 | $18.33 | 0.15 | 0.5 | $8 |
| 9/22/2010 | Inspection: Post-Rain | 4 | $17.00 | 0.2 | 0.8 | $14 |
| 9/23/2010 | Debris Removal from Inlet, Mowing | 2 | $17.00 | 0.22 | 0.4 | $7 |
| 9/30/2010 | Debris Removal from Inlet, Leaf Removal, Inspection: Monthly | 2 | $13.00 | 0.5 | 1.0 | $13 |
| 10/13/2010 | Debris Removal from Inlet, Leaf Removal, Mowing, Weeding | 1 | $13.00 | 0.13 | 0.1 | $2 |
| | | | | **CRWD Labor Total:** | **11.6** | **$194** |
| | | | | **Volunteer Labor Total:** | **1.8** | **$0** |
| *Equipment and Materials* | | | | | | |
| 5/1/2010 | Mulch | | | | | $22 |
| 5/1/2010 | Tools and Supplies | | | | | $4 |
| 6/1/2010 | Tools and Supplies | | | | | $12 |
| | | | | | **Total:** | **$38** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **13** |
| **Total Cost:** | **$232** |

**Table A-54. 2010 Pascal South Rain Garden operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 4/27/2010 | Debris Removal, Dead Plant Removal, Leaf Removal, Weeding | 2 | $17.00 | 1.5 | 3.1 | $52 |
| 4/28/2010 | Mowing, Weeding | 2 | $17.00 | 0.5 | 1.0 | $16 |
| 5/4/2010 | Mowing | 1 | $21.00 | 0.1 | 0.1 | $3 |
| 5/19/2010 | Mowing, Weeding | 2 | $13.00 | 0.3 | 0.5 | $7 |
| 5/28/2010 | Mulching | 4 | $17.00 | 0.8 | 3.2 | $54 |
| 6/2/2010 | Debris Removal from Inlet | 3 | $15.67 | 0.2 | 0.5 | $8 |
| 6/2/2010 | Debris Removal from Inlet, Seeded | 3 | $15.67 | 0.2 | 0.5 | $8 |
| 6/25/2010 | Debris Removal from Inlet, Thinning Plants | 3 | $15.67 | 0.6 | 1.7 | $27 |
| 6/28/2010 | Debris Removal from Inlet | 2 | $13.00 | 0.0 | 0.1 | $1 |
| 7/8/2010 | Mowing | 2 | $17.00 | 0.1 | 0.2 | $3 |
| 7/15/2010 | Thinning Plants, Weeding | 4 | $17.00 | 1.0 | 4.0 | $68 |
| 7/15/2010 | Thinning Plants | 2 | $0.00 | 1.0 | 2.0 | $0 |
| 7/22/2010 | Inspection: Post-Rain | 2 | $13.00 | 0.1 | 0.2 | $2 |
| 7/29/2010 | Debris Removal from Inlet , Mowing, Weeding | 2 | $17.00 | 0.3 | 0.7 | $11 |
| 7/29/2010 | Debris Removal from Inlet, Mowing, Weeding | 3 | $0.00 | 0.3 | 0.9 | $0 |
| 8/4/2010 | Mowing, Thinning Plants, Weeding | 3 | $15.67 | 0.2 | 0.5 | $8 |
| 8/4/2010 | Mowing, Thinning Plants, Weeding | 2 | $0.00 | 0.2 | 0.4 | $0 |
| 8/12/2010 | Inspection: Post-Rain | 2 | $17.00 | 0.1 | 0.2 | $3 |
| 8/23/2010 | Debris Removal from Inlet, Mowing, Temporary Fencing: Installation, Weeding | 2 | $17.00 | 0.5 | 1.0 | $16 |
| 9/7/2010 | Temporary Fencing: Removal | 3 | $18.33 | 0.1 | 0.4 | $7 |
| 9/22/2010 | Inspection: Post-Rain | 1 | $17.00 | 0.2 | 0.2 | $3 |
| 9/23/2010 | Debris Removal from Inlet, Mowing | 2 | $17.00 | 0.2 | 0.3 | $6 |
| 9/30/2010 | Debris Removal from Inlet, Leaf Removal, Inspection: Monthly | 2 | $13.00 | 0.5 | 1.0 | $13 |
| 10/13/2010 | Debris Removal from Inlet, Leaf Removal, Mowing, Weeding | 1 | $13.00 | 0.3 | 0.3 | $4 |
| | | | | **CRWD Labor Total:** | **19.6** | **$321** |
| | | | | **Volunteer Labor Total:** | **3.3** | **$0** |
| *Equipment and Materials* | | | | | | |
| 5/1/2010 | Mulch | | | | | $22 |
| 5/1/2010 | Tools and Supplies | | | | | $4 |
| 6/1/2010 | Tools and Supplies | | | | | $12 |
| | | | | | **Total:** | **$38** |
| *Contract Services* | | | | | | |
| | | | | | **Total:** | **$0** |

**Red Text** signifies that volunteers participated in the maintenance task. Volunteer time was not included in the 'Number of Staff' field and was not included in the cost calculation.

| | |
|---|---|
| **Total Labor Hours:** | **23** |
| **Total Cost:** | **$360** |

**Table A-55. 2009 Underground Infiltration Trenches operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 4/29/2009 | Inspection: CB & Manhole Sediment | 1 | $21.00 | 0.6 | 0.6 | $13 |
| 4/30/2009 | Inspection: CB & Manhole Sediment | 2 | $17.00 | 0.2 | 0.3 | $5 |
| 4/30/2009 | Inspection: CB & Manhole Sediment | 3 | $15.67 | 0.9 | 2.7 | $42 |
| 4/30/2009 | Inspection: CB & Manhole Sediment | 3 | $15.67 | 1.8 | 5.5 | $86 |
| 6/8/2009 | Inspection: Post-Rain | 3 | $15.67 | 0.2 | 0.5 | $7 |
| 6/9/2009 | Inspection: Post-Rain | 2 | $13.00 | 0.4 | 0.8 | $11 |
| 7/27/2009 | Inspection: Post-Rain | 2 | $13.00 | 0.7 | 1.5 | $19 |
| 8/11/2009 | Inspection: Post-Rain | 2 | $17.00 | 0.5 | 1.1 | $18 |
| 10/12/2009 | Inspection: CB & Manhole Sediment | 2 | $13.00 | 0.8 | 1.6 | $20 |
| 10/13/2009 | Inspection: CB & Manhole Sediment | 2 | $13.00 | 1.9 | 3.8 | $50 |
| 10/13/2009 | Inspection: CB & Manhole Sediment | 2 | $13.00 | 1.6 | 3.2 | $41 |
| 10/14/2009 | Inspection: CB & Manhole Sediment | 2 | $13.00 | 0.9 | 1.9 | $24 |
| | | | | **Total:** | **23.3** | **$337** |
| *Equipment and Materials* | | | | | | |
| | | | | | **Total:** | **$0** |

| Date | Activity | # of Units | Hour/Unit[a] | Total Hours | Rate | Cost |
|---|---|---|---|---|---|---|
| *Contract Services* | | | | | | |
| 5/20/09 - 5/26/09 | Vactored 16 Manholes | 16 | 0.5 | 8.0 | $288 | $2,305 |
| 5/20/09 - 5/26/09 | Vactored 30 Catch Basins | 30 | 0.3 | 9.9 | $288 | $2,852 |
| 11/3/09 - 11/4/09 | Vactored 16 Manholes | 16 | 0.5 | 8.0 | $288 | $2,305 |
| 11/3/09 - 11/4/09 | Vactored 30 Catch Basins | 30 | 0.3 | 9.9 | $288 | $2,852 |
| | | | | | **Total:** | **$10,314** |

[a] Time was approximated.

| | |
|---|---|
| **Total Labor Hours:** | **23** |
| **Total Cost:** | **$10,651** |

**Table A-56. 2010 Underground Infiltration Trenches operation and maintenance costs.**

| Date | Activity | # of Staff | Rate | Hours | Total Hours | Cost |
|---|---|---|---|---|---|---|
| *Labor* | | | | | | |
| 3/31/2010 | Inspection: Manhole & Vortech Sediment | 3 | $15.67 | 1.2 | 3.6 | $56 |
| 3/31/2010 | Inspection: CB & Manhole Sediment | 3 | $15.67 | 0.8 | 2.3 | $35 |
| 4/1/2010 | Inspection: CB & Manhole Sediment | 3 | $15.67 | 0.7 | 2.0 | $31 |
| 4/26/2010 | Inspection: CB & Manhole Sediment | 3 | $15.67 | 2.8 | 8.5 | $133 |
| 6/4/2010 | Inspection: Post-Rain | 3 | $15.67 | 1.2 | 3.6 | $56 |
| 6/17/2010 | Inspection: Post-Rain | 2 | $13.00 | 1.2 | 2.4 | $31 |
| 9/17/2010 | Inspection: Post-Rain | 2 | $13.00 | 1.2 | 2.3 | $30 |
| 9/30/2010 | Inspection: Post-Rain | 2 | $21.00 | 1.0 | 2.0 | $42 |
| 10/7/2010 | Inspection: CB & Manhole Sediment | 3 | $15.67 | 3.5 | 10.5 | $165 |
| 10/8/2010 | Inspection: CB & Manhole Sediment | 3 | $15.67 | 2.0 | 6.0 | $94 |
| | | | | **Total:** | **43.2** | **$675** |
| *Equipment and Materials* | | | | | | |
| | | | | | **Total:** | **$0** |

| Date | Activity | # of Units | Hour/Unit[a] | Total Hours | Rate | Cost |
|---|---|---|---|---|---|---|
| *Contract Services* | | | | | | |
| 05/2010 | Vactored 16 Manholes | 16 | 0.5 | 8.0 | $288 | $2,305 |
| 05/2010 | Vactored 30 Catch Basins | 30 | 0.3 | 9.9 | $288 | $2,852 |
| 11/2010 | Vactored 16 Manholes | 16 | 0.5 | 8.0 | $288 | $2,305 |
| 11/2010 | Vactored 30 Catch Basins | 30 | 0.3 | 9.9 | $288 | $2,852 |
| | | | | | **Total:** | **$10,314** |

[a] Time was approximated.

| | |
|---|---|
| **Total Labor Hours:** | **43** |
| **Total Cost:** | **$10,988** |

# Appendix B

## BMP As-Builts

# Appendix B: BMP As-Builts

## Table of Contents

# BMP As-Built:
# Arlington-Hamline Underground Stormwater Facility

Figure B-1. Arlington-Hamline Underground Stormwater Facility As-Builts.

# ARLINGTON PASCAL STORMWATER IMPROVEMENT PROJECT

## Arlington Hamline Underground Storage Post Construction Conditions

### LEGEND

| | EXISTING | PROPOSED |
|---|---|---|
| SILT FENCE | | |
| HEAVY DUTY SILT FENCE | | x |
| TREE LINE | | |
| CONTOUR | ---241--- | |
| STORM SEWER LINE | >> | >> |
| CATCHBASIN | | |
| SANITARY SEWER LINE | > | |
| MANHOLE | | |
| RISER | | |
| WATER MAIN LINE | \| | |
| GAS LINE | GAS | |
| POWER POLE | | |
| LIGHT POLE | | |

DETAIL NUMBER
SHEET CUT ON | SHEET SHOWN ON


| TABLE OF CONTENTS | |
|---|---|
| SHEET NO. | DESCRIPTION |
| 1 | Title Sheet & Location Map |
| 2 | Schedule of Quantities |
| 3 | Grading & Storm Sewer Plan |
| 4 | Erosion Control Plan |
| 5 | Civil Details I |
| 6 | Civil Details II |
| 7 | Civil Details III |

## UTILITIES

THE LOCATION OF UNDERGROUND FACILITES OR STRUCTURES AS SHOWN ON THE PLANS ARE BASED ON AVAILABLE RECORDS AT THE TIME THE PLANS WERE PREPARED AND ARE NOT GUARANTEED TO BE COMPLETE OR CORRECT. CONTRACTOR IS RESPOSIBLE FOR CONTACTING ALL UTILITIES 72 HOURS PRIOR TO CONSTRUCTION TO DETERMINE THE EXACT LOCATION OF ALL FACILITIES AND TO PROVIDE ADEQUATE PROTECTION OF SAID UTIILITIES DURING THE COURSE OF WORK.

## GOPHER STATE ONE CALL

IT IS THE LAW THAT ANYONE EXCAVATING AT ANY SITE MUST NOTIFY GOPHER STATE ONE CALL (GSOC) SO THAT UNDERGROUND ELECTRIC, NATURAL GAS, TELEPHONE OR OTHER UTILITY LINES CAN BE MARKED ON OR NEAR YOUR PROPERTY BEFORE ANY DIGGING BEGINS. A 48-HOUR NOTICE, NOT INCLUDING WEEKENDS, IS REQUIRED. CALLS CAN BE MADE TO GSOC AT 1-800-252-1166 OR (651)454-0002, MONDAY THROUGH FRIDAY (EXCEPT HOLIDAYS) FROM 7 A.M. TO 5 P.M.

| No. | Revision Description | Date | By |
|---|---|---|---|

I hereby certify that this plan or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota

Print Name: Sheila Sahu

Sign Name:

Date 6-21-06 License No. 43897

Date 6-21-06

Drawn By JJS

Checked By SS


Capitol Region Watershed District
1410 Energy Park Drive, Suite 4
St. Paul, MN 55108
Phone: (651) 644-8888

EMMONS & OLIVIER RESOURCES
651 HALE AVENUE NORTH
OAKDALE, MN 55128
PHONE: (651) 770-8448
FAX: (651) 770-2552
WEBSITE: www.eorinc.com


Sheet No. 1 of 7 Sheets

| Mn/DOT Ref. | Spec | Description | Units | Quantity |
|---|---|---|---|---|
| 2021.501 | 1500 | MOBILIZATION | L.S. | 1 |
| 2101.502 | 2905 | CLEARING | TREE | 5 |
| 2104.503 | 2630 | REMOVE CONCRETE WALK | S.F. | 100 |
| 2105.515 | 2315 | UNCLASSIFIED EXCAVATION (EXCAVATION AND HAUL) | C.Y. | 4,730 |
| 2105.535 | 2315 | SALVAGED TOPSOIL (EV) | C.Y. | 269 |
| 2105.607 | 2315 | UNCLASSIFIED EXCAVATION (SALVAGE AND PLACE) | C.Y. | 3,071 |
| 2451.505 | 2315 | AGGREGATE BACKFILL (CV) | C.Y. | 1,975 |
| 2451.509 | 2315 | AGGREGATE BEDDING (CV) | C.Y. | 225 |
| 2503.541 | 2630 | 120", 5" X 1", ALT2, 12GA., CMP PERFORATED PIPE AND FITTINGS | L.F. | 849 |
| 2503.541 | 2630 | 12" HDPE PIPE | L.F. | 25 |
| 2503.541 | 2630 | 24" HDPE PIPE | L.F. | 25 |
| 2503.541 | 2630 | 36" HDPE PIPE | L.F. | 15 |
| 2503.541 | 2630 | 12" CMP ELBOW | EACH | 1 |
| 2506.602 | 2630 | 24" CMP RISERS | EACH | 9 |
| 2506.602 | 2630 | 60" RC MANHOLE | EACH | 1 |
| 2506.602 | 2630 | 60" RC DIVERSION STRUCTURE MANHOLE | EACH | 1 |
| 2506.602 | 2630 | OUTLET STRUCTURE MANHOLE | EACH | 1 |
| 2506.602 | 2630 | CONNECT TO EXISTING STUB | EACH | 2 |
| 2506.602 | 2721 | STORMWATER TREATMENT SYSTEM STRUCTURE | L.S. | 1 |
| 2511.515 | 2315 | GEOTEXTILE FILTER FABRIC, TYPE II | S.Y. | 1,445 |
| 2521.501 | 2630 | 4" CONCRETE WALK | S.F. | 100 |
| 2571.502 | 2905 | TREE REPLACEMENT (2.5") (2 BLUE SPRUCE, 3 RED OAK) | EACH | 5 |
| 2573.502 | 2370 | SILT FENCE, HEAVY DUTY | L.F. | 815 |
| 2573.530 | 2370 | INLET PROTECTION | EACH | 2 |
| 2573.602 | 2370 | TEMPORARY ROCK CONSTRUCTION ENTRANCE | EACH | 1 |
| 2573.603 | 2370 | CONSTRUCTION FENCE | L.F. | 450 |
| 2575.501 | 2920 | SEEDING | ACRE | 0.5 |
| 2575.502 | 2920 | SEED, CUSTOM MIXTURE | LB | 60 |
| 2575.513 | 2920 | MULCH MATERIAL, TYPE 1 | TON | 1 |
| 2575.519 | 2920 | DISK ANCHORING | ACRE | 0.5 |

1

| NO. | REVISION DESCRIPTION | DATE | BY |
|---|---|---|---|
| 1 | ADDENDUM NO. 1 | 7/10/06 | SS |

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Print Name: Sheila Sahu

Sign Name:

Date 6-21-06 License No. 43897

Date 6-21-06

Designed By SS

Drawn By DLD, JJS

Capitol Region Watershed District
1410 Energy Park Drive, Suite 4
St. Paul, MN 55108
Phone: (651) 644-8888

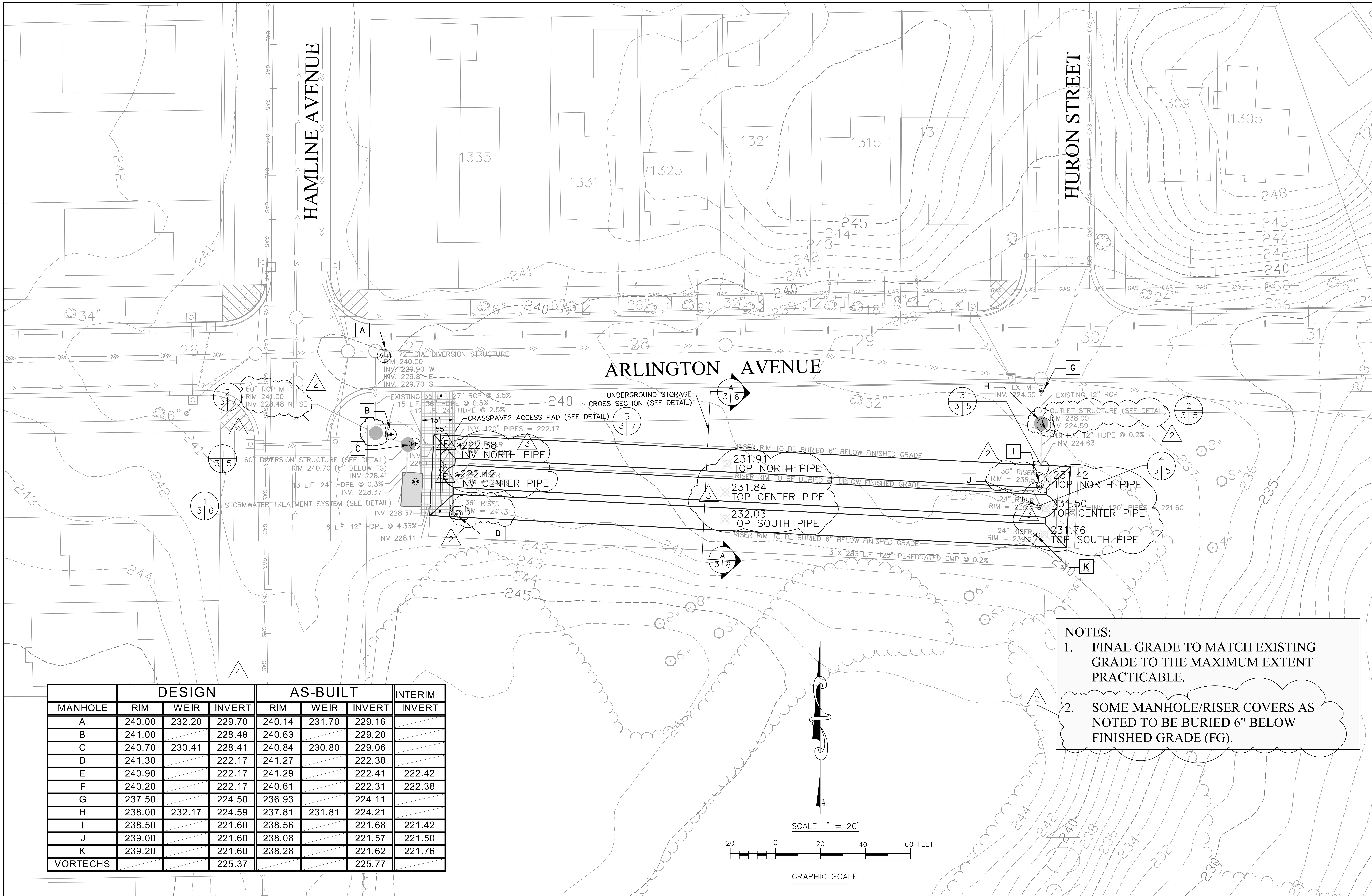
EOR EMMONS & OLIVIER RESOURCES

Arlington Hamline Underground Storage

Schedule Of Quantities

ARLINGTON PASCAL STORMWATER IMPROVEMENT PROJECT

Sheet No. 2 of 7 Sheets




| | DESIGN | | | AS-BUILT | | | INTERIM |
|---|---|---|---|---|---|---|---|
| MANHOLE | RIM | WEIR | INVERT | RIM | WEIR | INVERT | INVERT |
| A | 240.00 | 232.20 | 229.70 | 240.14 | 231.70 | 229.16 | |
| B | 241.00 | | 228.48 | 240.63 | | 229.20 | |
| C | 240.70 | 230.41 | 228.41 | 240.84 | 230.80 | 229.06 | |
| D | 241.30 | | 222.17 | 241.27 | | 222.38 | |
| E | 240.90 | | 222.17 | 241.29 | | 222.41 | 222.42 |
| F | 240.20 | | 222.17 | 240.61 | | 222.31 | 222.38 |
| G | 237.50 | | 224.50 | 236.93 | | 224.11 | |
| H | 238.00 | 232.17 | 224.59 | 237.81 | 231.81 | 224.21 | |
| I | 238.50 | | 221.60 | 238.56 | | 221.68 | 221.42 |
| J | 239.00 | | 221.60 | 238.08 | | 221.57 | 221.50 |
| K | 239.20 | | 221.60 | 238.28 | | 221.62 | 221.76 |
| VORTECHS | | | 225.37 | | | 225.77 | |

NOTES:

1. FINAL GRADE TO MATCH EXISTING GRADE TO THE MAXIMUM EXTENT PRACTICABLE.
2. SOME MANHOLE/RISER COVERS AS NOTED TO BE BURIED 6" BELOW FINISHED GRADE (FG).

| NO. | REVISION DESCRIPTION | DATE | BY |
|---|---|---|---|
| 4 | POST CONSTRUCTION CONDITIONS | 11/10/06 | DVD |
| 3 | POST CONSTRUCTION CONDITIONS | 9/26/06 | DVD |
| 2 | CHANGE ORDER NO. 1 | 8/15/06 | SS |

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Sign Name: Sheila Sahu

Date 6-21-06 License No. 43897

Date 6-21-06

Designed By SS

Drawn By DLD, JJS


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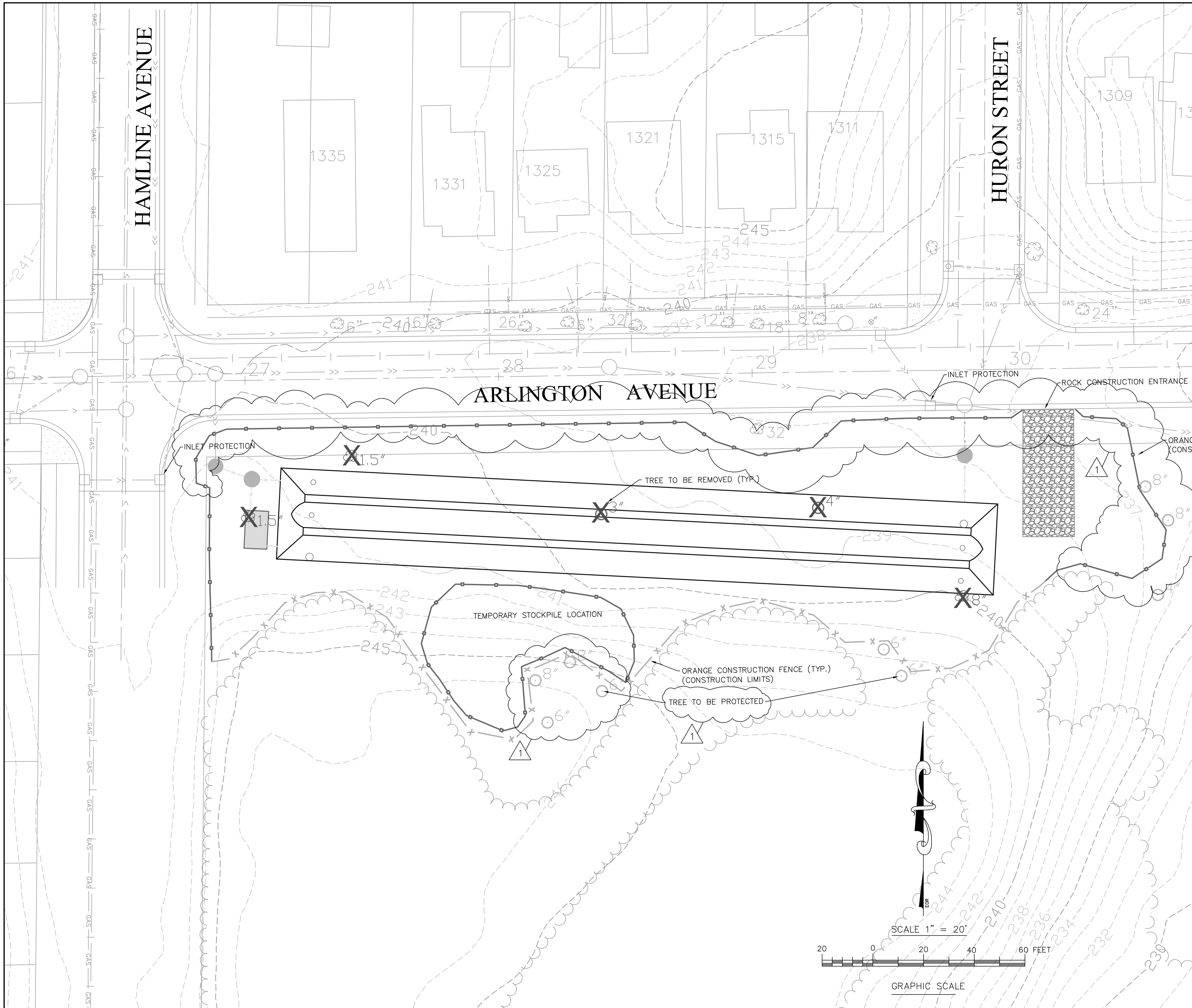
Arlington Hamline Underground Storage

Grading & Storm Sewer Plan

ARLINGTON PASCAL STORMWATER IMPROVEMENT PROJECT

Sheet No. 3 of 7 Sheets




NOTES:

1. AREAS NOT TO BE DISTURBED SHALL BE FENCED OFF PRIOR TO LAND DISTURBING ACTIVITIES.
2. INSTALL SILT FENCE AND CONSTRUCTION FENCE PRIOR TO LAND DISTURBANCE.
3. INSTALL INLET PROTECTION SUCH AS WIMCO® ROAD DRAIN OR APPROVED EQUAL ON STREET INLETS ADJACENT TO PROJECT PRIOR TO LAND DISTURBANCE.
4. INSTALL ROCK CONSTRUCTION ENTRANCE PRIOR TO MOVING VEHICLES OFFSITE FROM DISTURBED AREAS.
5. INSTALL SILT FENCE AROUND ALL SOIL STOCKPILES.
6. PERMANENT SEEDING SHALL BE ACCOMPLISHED USING THE FOLLOWING SEED MIXTURE AT A RATE OF 150 LBS/ACRE:

| Common Name | Bulk Rate (lb/ac) | % of Mix Component |
|---|---|---|
| Bluegrass, Kentucky- Touchdown | 37.5 | 25.0 |
| Bluegrass, Kentucky- Banff | 37.5 | 25.0 |
| Rye-grass, perennial- Edge | 25 | 16.67 |
| Rye-grass, perennial- Cutter | 25 | 16.67 |
| Rye-grass, perennial- Express | 25 | 16.67 |
| **GRAND TOTALS:** | **150** | **100.0** |

OVERSEEDING AS NECESSARY SHALL BE ACCOMPLISHED USING THE ABOVE SEED MIXTURE AT A RATE OF 100 LBS/ACRE.

7. ALL AREAS TO BE SEEDED SHALL BE MULCHED WITH TYPE 1 WEED-FREE CLEAN STRAW, APPLIED IN ACCORDANCE WITH MN/DOT STANDARD SPECIFICATIONS CHAPTER 2575.3F AT THE RATE OF 2 TONS PER ACRE. ALL SEEDED SURFACES SHOULD BE MULCHED AND DISK ANCHORED THE SAME DAY SEED IS APPLIED.
8. NEW TREES TO REPLACE REMOVED TREES AT THE FIVE (5) EXISTING TREE LOCATIONS. 1

| NO. | REVISION DESCRIPTION | DATE | BY |
|---|---|---|---|
| 1 | ADDENDUM NO. 1 | 7/10/06 | SS |

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Sign Name:

Date 6-21-06 License No. 43897

Date 6-21-06

Designed By SS

Drawn By DLD, JJS


Capitol Region Watershed District
1410 Energy Park Drive, Suite 4
St. Paul, MN 55108
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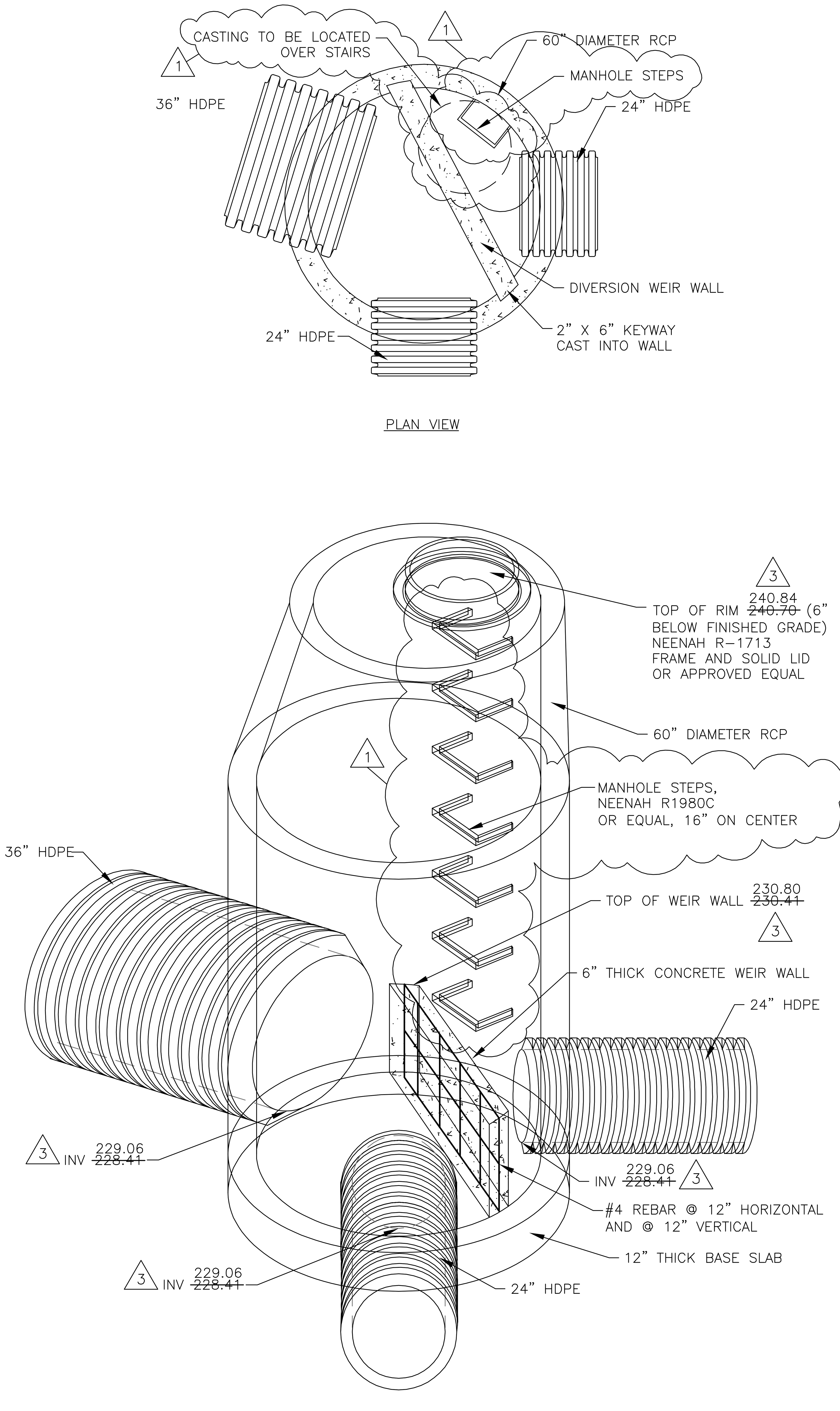
Arlington Hamline Underground Storage

Erosion Control Plan

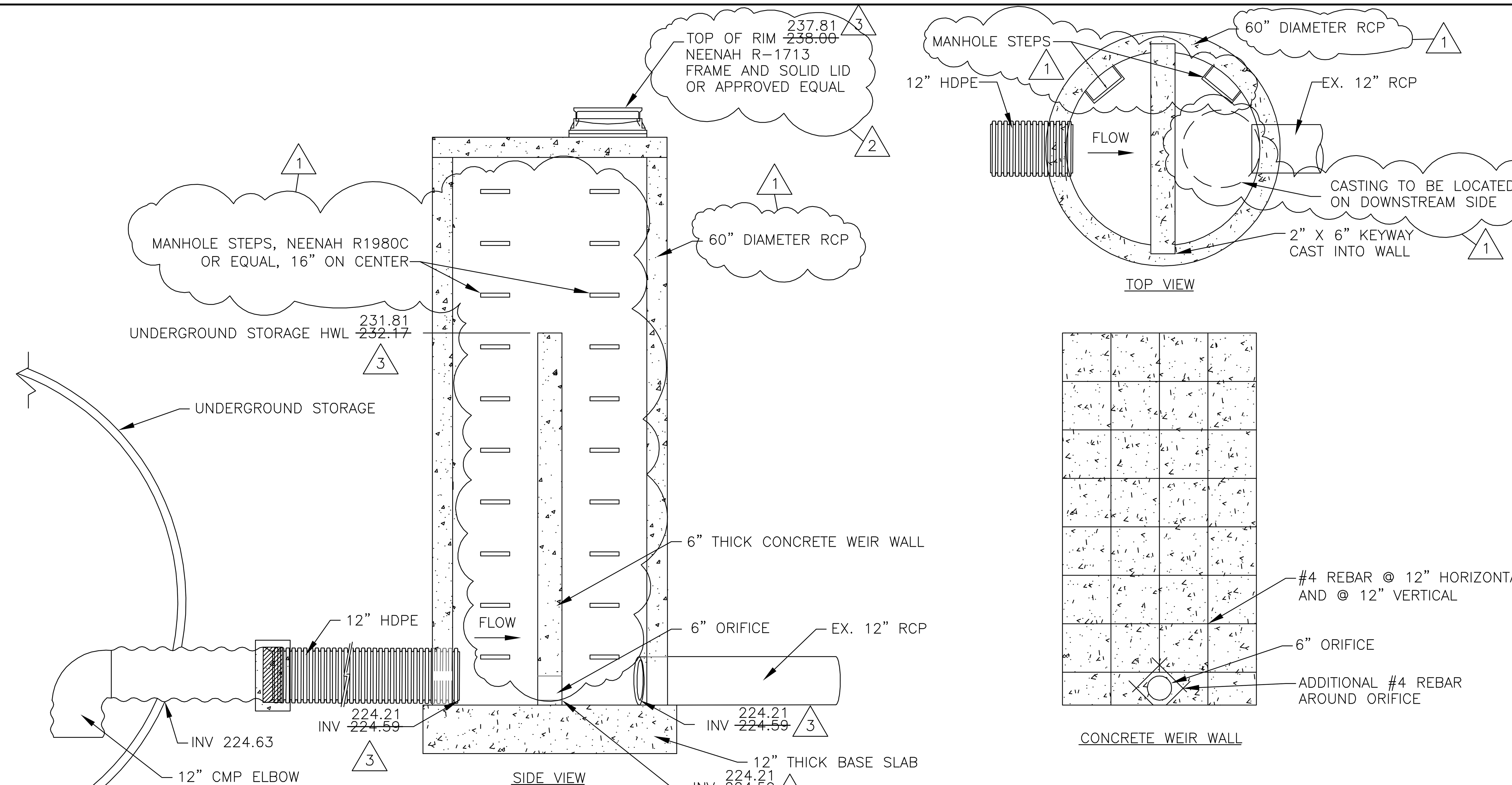
ARLINGTON PASCAL STORMWATER IMPROVEMENT PROJECT

Sheet No. 4 of 7 Sheets



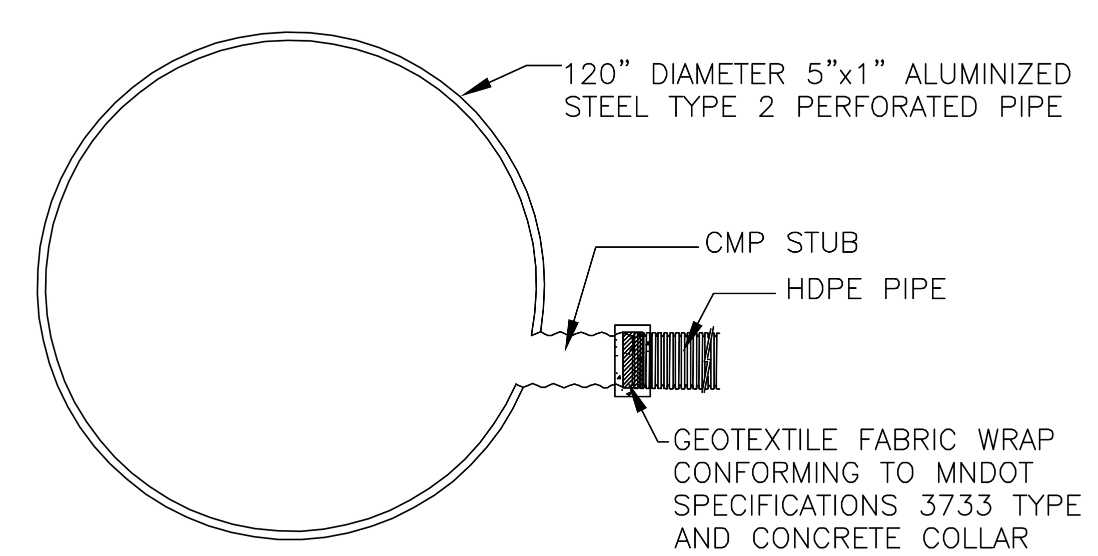

1 | 3 5 DIVERSION STRUCTURE

SCALE: NOT TO SCALE



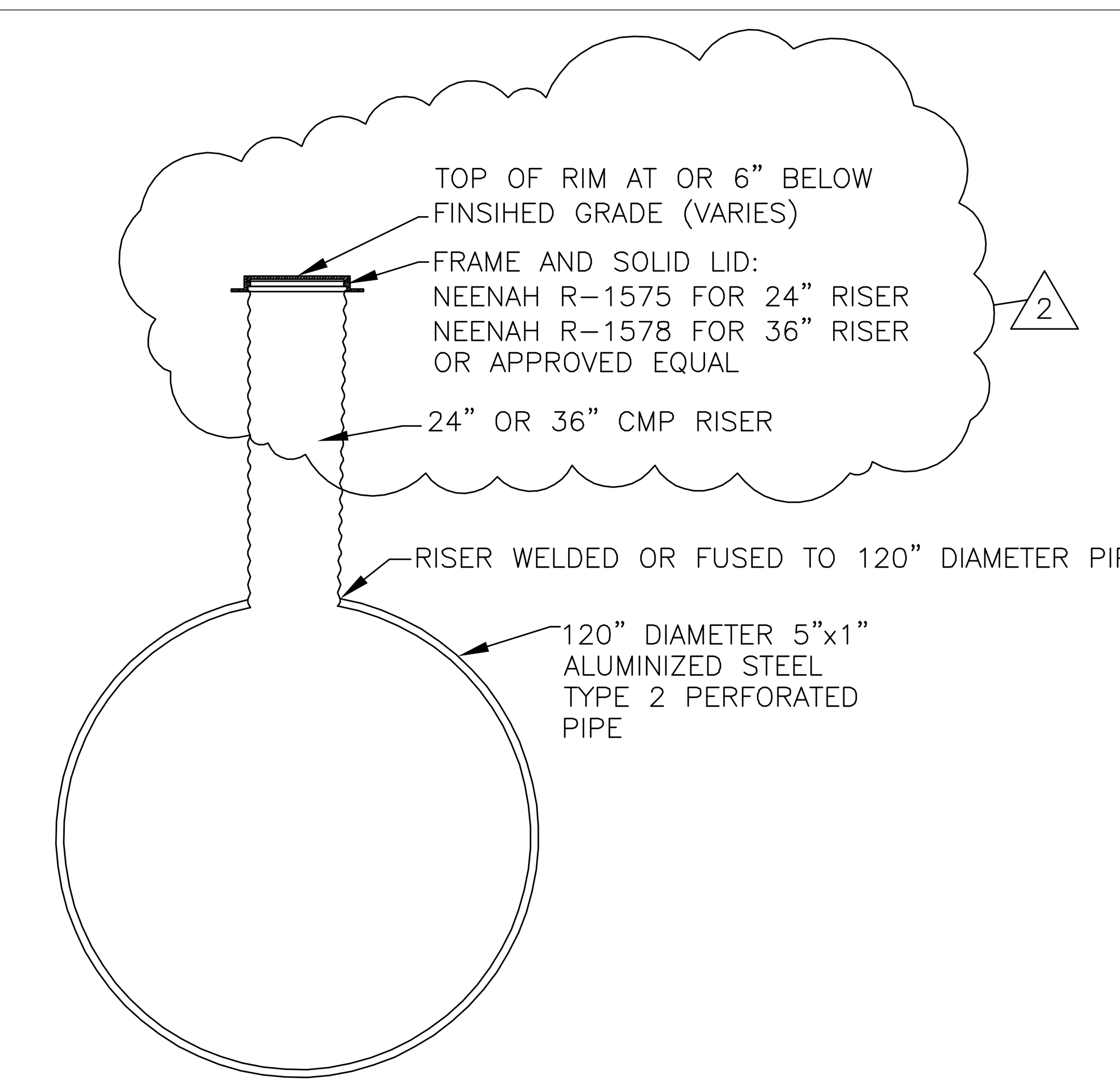

2 | 3 5 OUTLET STRUCTURE

SCALE: NOT TO SCALE




3 | 3 5 TYPICAL CMP-HDPE CONNECTION

SCALE: NOT TO SCALE




4 | 3 5 TYPICAL RISER

SCALE: NOT TO SCALE

| NO. | REVISION DESCRIPTION | DATE | BY |
|---|---|---|---|
| 3 | POST CONSTRUCTION CONDITIONS | 1/09/07 | DVD |
| 2 | CHANGE ORDER NO. 1 | 8/15/06 | SS |
| 1 | ADDENDUM NO. 1 | 7/10/06 | SS |

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Print Name: Sheila Sahu

Sign Name:

Date 6-21-06 License No. 43897

Date 6-21-06
Designed By SS
Drawn By DLD, JJS

Capitol Region Watershed District
1410 Energy Park Drive, Suite 4
St. Paul, MN 55108
Phone: (651) 644-8888

EOR EMMONS & OLIVIER RESOURCES

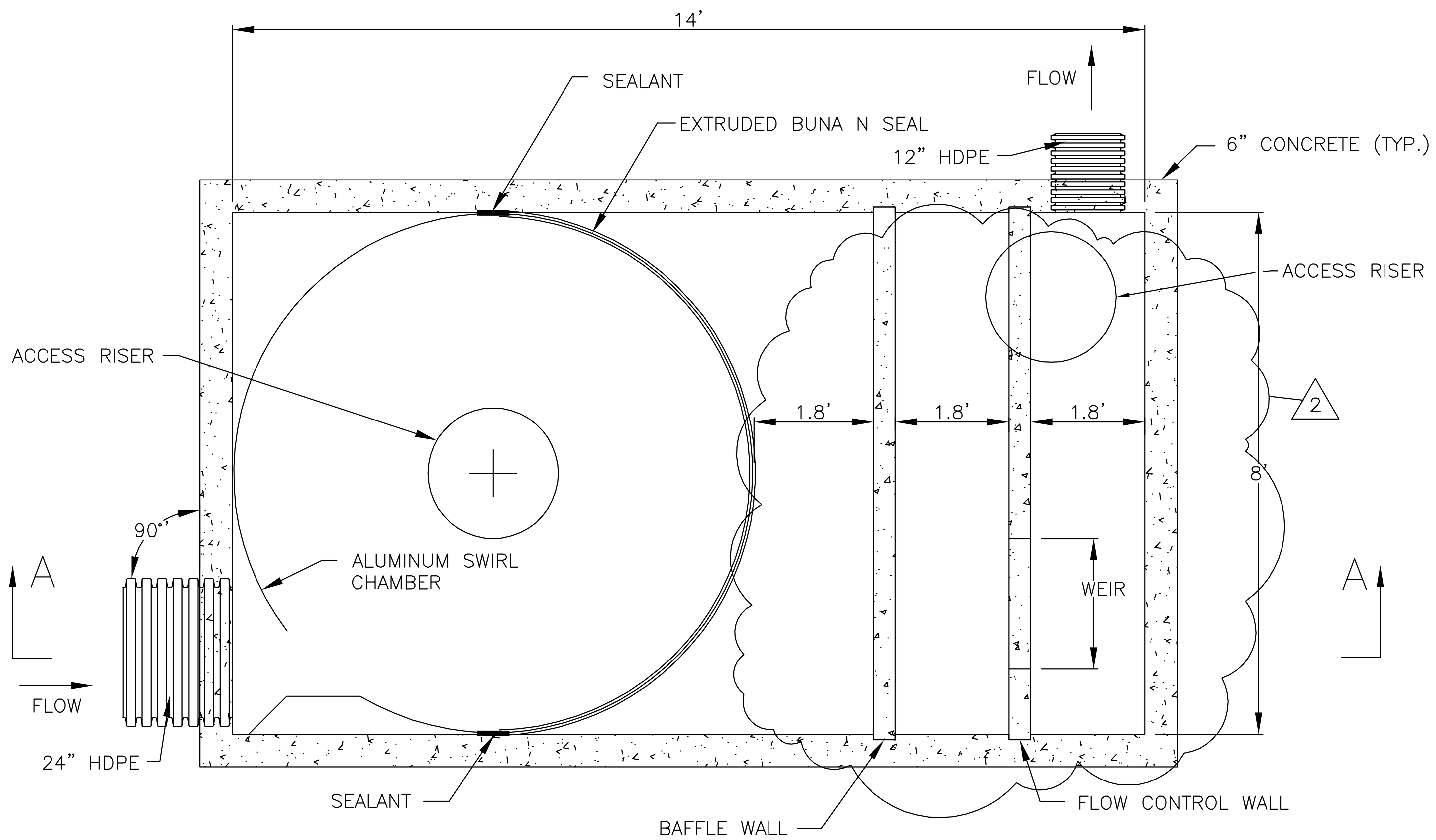
Arlington Hamline Underground Storage

Civil Details I

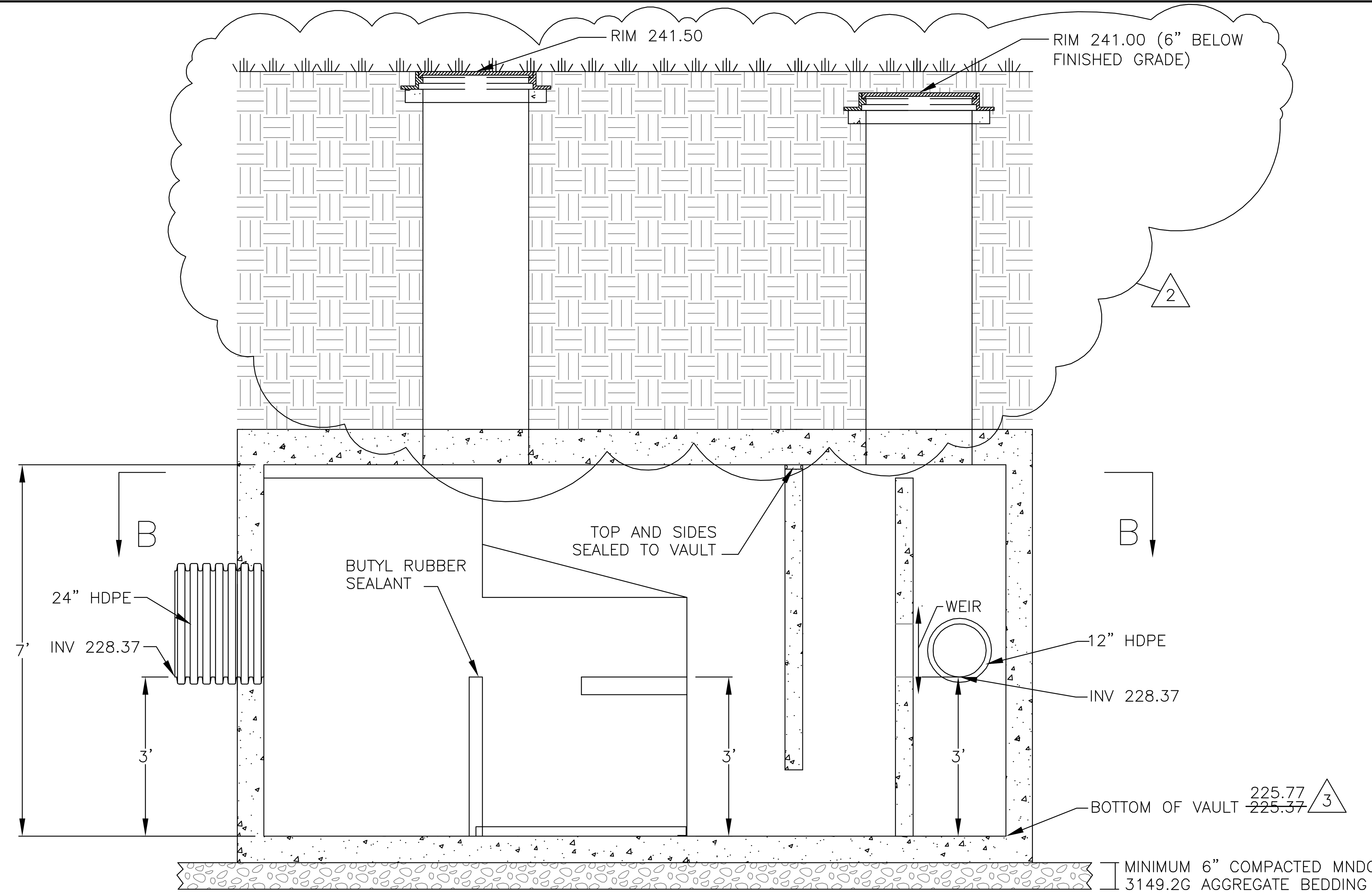
ARLINGTON PASCAL STORMWATER IMPROVEMENT PROJECT

Sheet No. 5 of 7 Sheets

VORTECHS® MODEL 7000



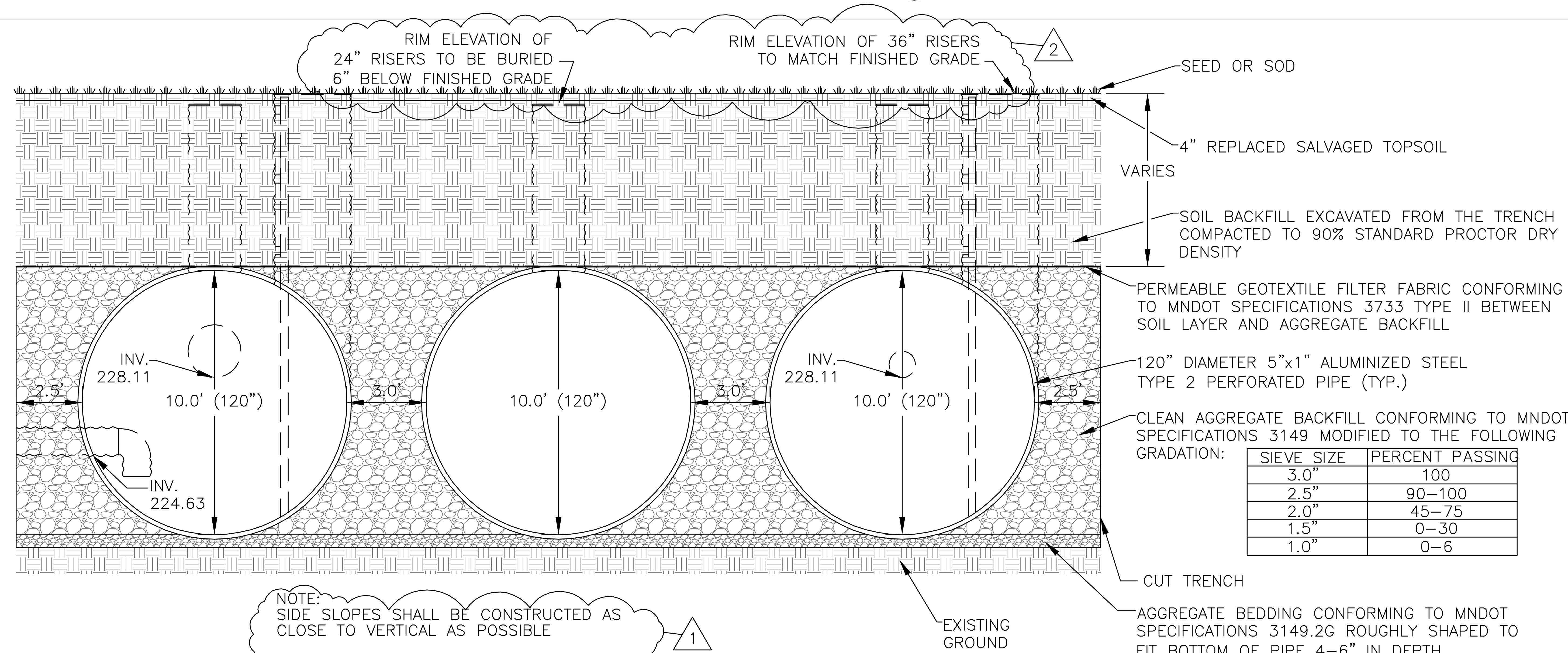

PLAN VIEW B – B




SECTION A – A

1 / 3 6 STORMWATER TREAMENT SYSTEM

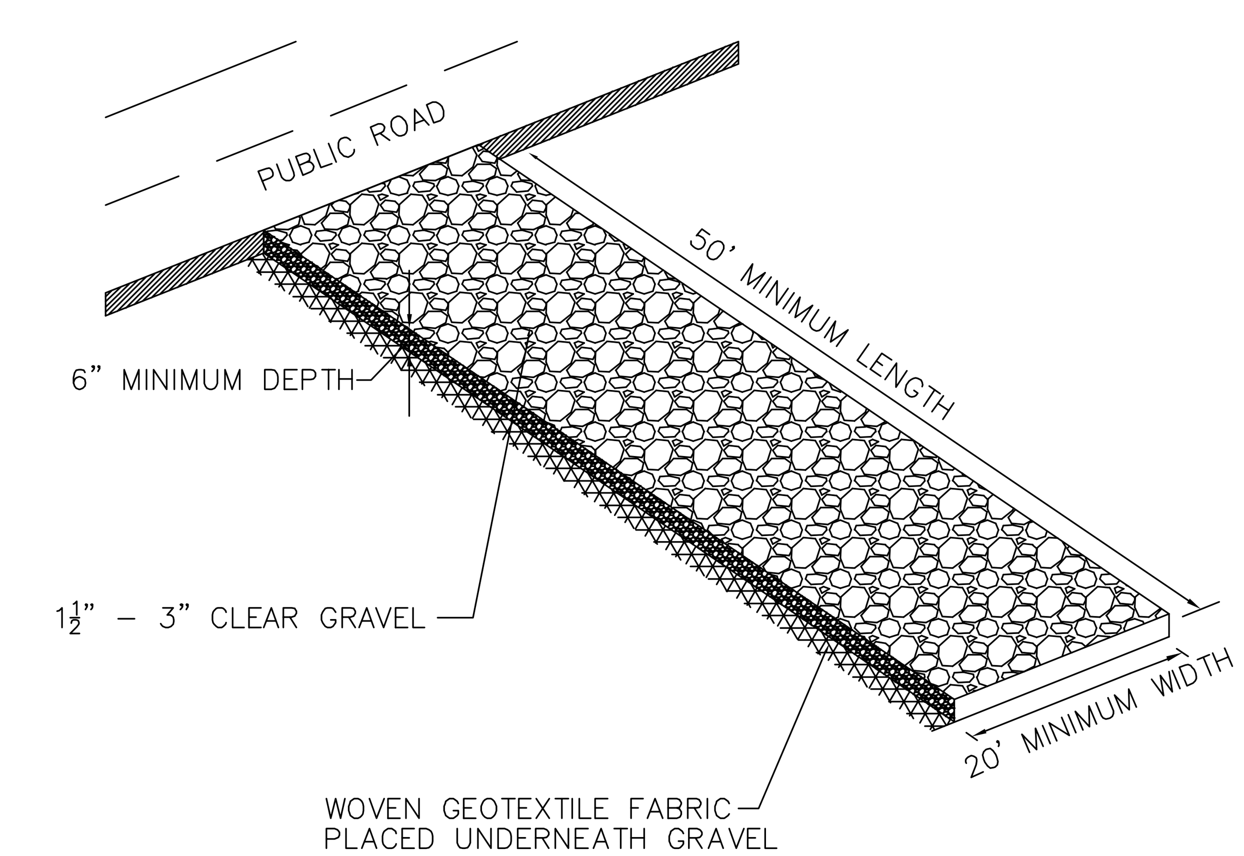
SCALE: NOT TO SCALE




| SIEVE SIZE | PERCENT PASSING |
|---|---|
| 3.0" | 100 |
| 2.5" | 90–100 |
| 2.0" | 45–75 |
| 1.5" | 0–30 |
| 1.0" | 0–6 |

A / 3 6 UNDERGROUND STORAGE CROSS SECTION A–A

SCALE: NOT TO SCALE




2 / 4 6 ROCK CONSTRUCTION ENTRANCE

SCALE: NOT TO SCALE

| NO. | REVISION DESCRIPTION | DATE | BY |
|---|---|---|---|
| 3 | POST CONSTRUCTION CONDITIONS | 1/09/07 | DVD |
| 2 | CHANGE ORDER NO. 1 | 8/15/06 | SS |
| 1 | ADDENDUM NO. 1 | 7/10/06 | SS |

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Print Name: Sheila Sahu

Sign Name:

Date 6-21-06 License No. 43897

Date 6-21-06

Designed By SS

Drawn By DLD, JJS

Capitol Region Watershed District
1410 Energy Park Drive, Suite 4
St. Paul, MN 55108
Phone: (651) 644-8888

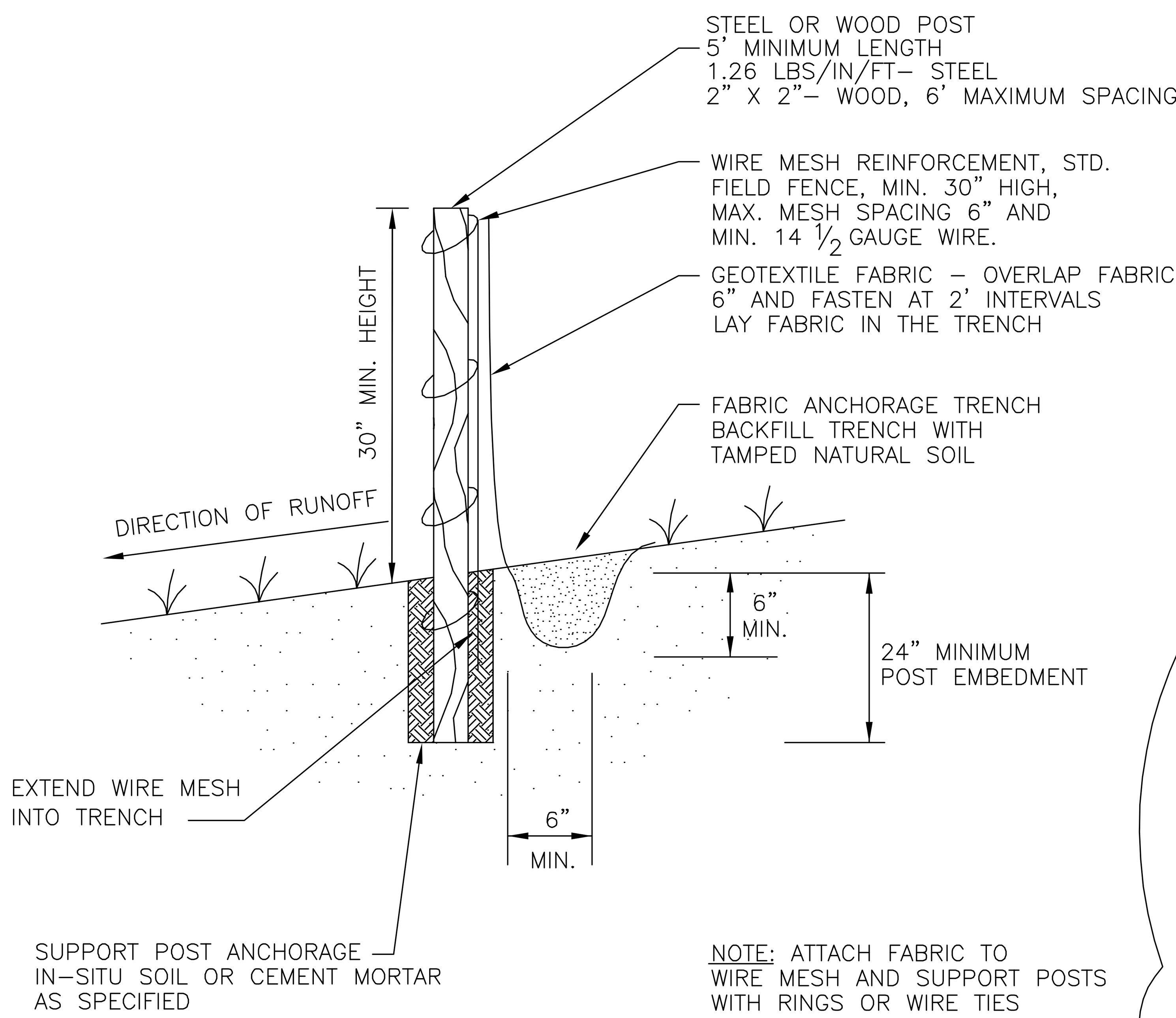
EOR EMMONS & OLIVIER RESOURCES

Arlington Hamline Underground Storage

Civil Details II

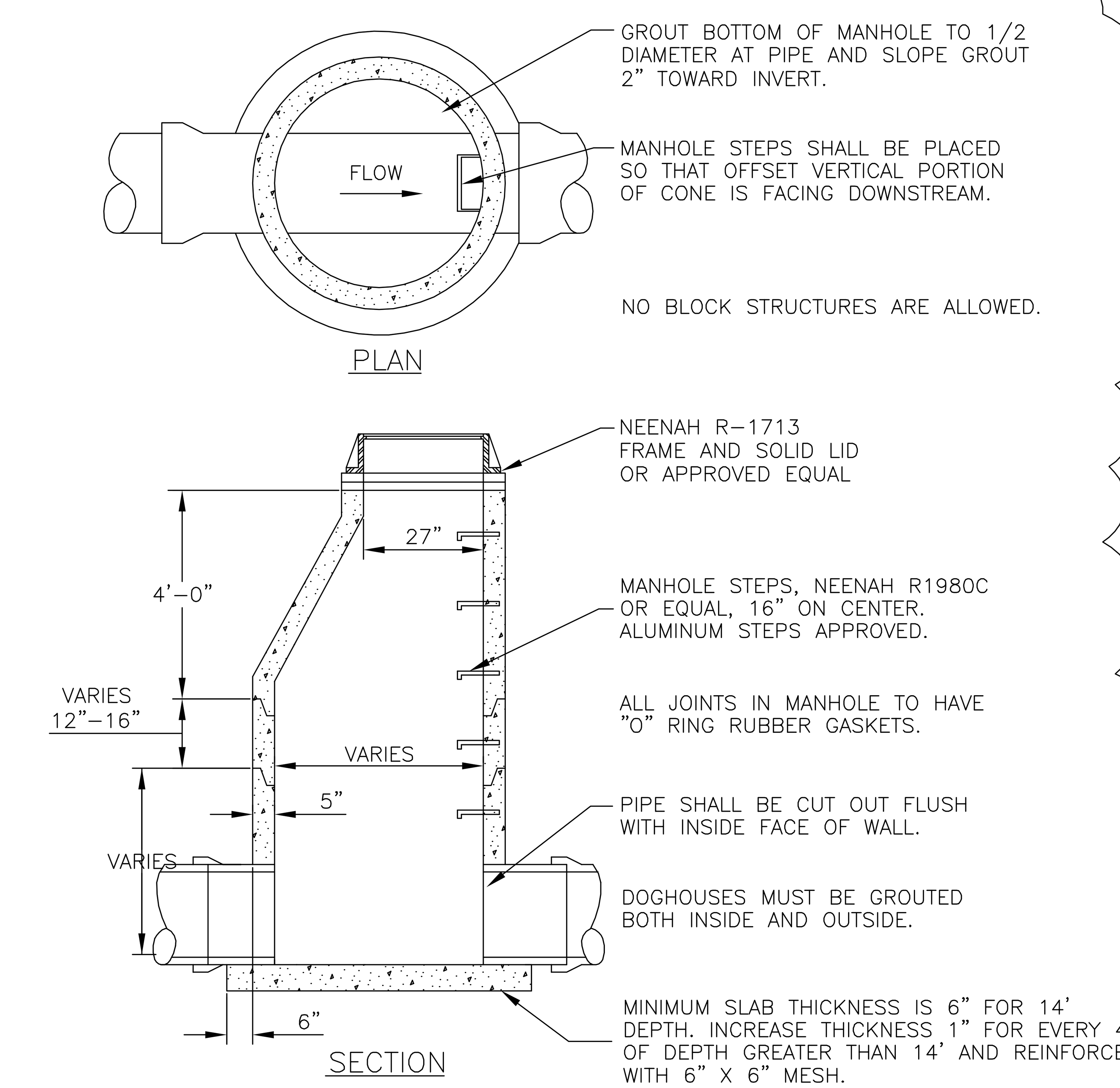
ARLINGTON PASCAL STORMWATER IMPROVEMENT PROJECT

Sheet No. 6 of 7 Sheets



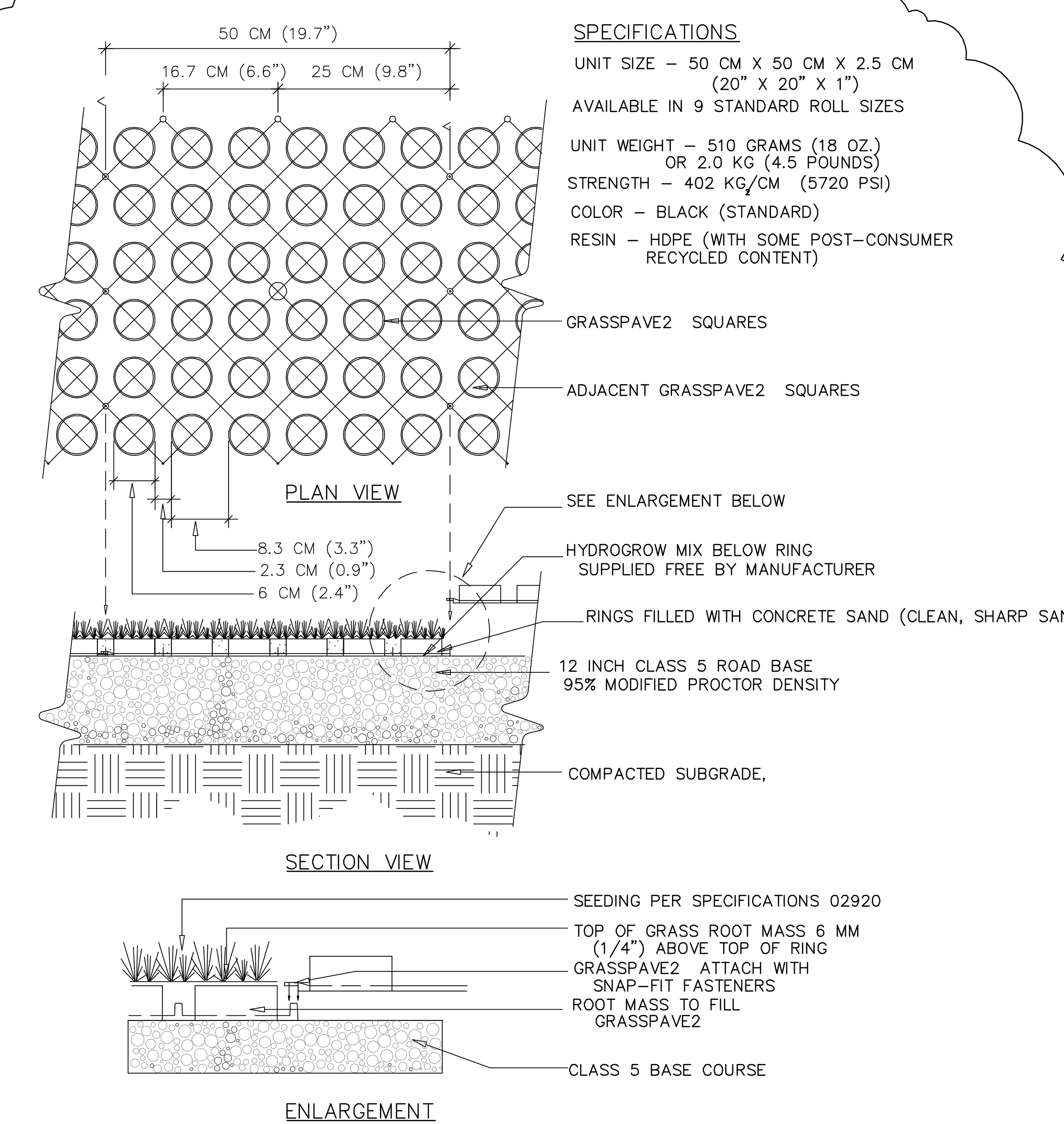

1 | 4 7 ORANGE HEAVY DUTY SILT FENCE

SCALE: NOT TO SCALE




2 | 3 7 STANDARD STORM MANHOLE

SCALE: NOT TO SCALE




INVISIBLE STRUCTURES, INC.
1600 JACKSON STREET, SUITE 310
GOLDEN, COLORADO 80401
800-233-1510 OR 303-233-8383
FAX: 303-233-8282
WWW.INVISIBLESTRUCTURES.COM

3 | 3 7 TYPICAL GRASSPAVE2 DETAIL

SCALE: NOT TO SCALE

| NO. | REVISION DESCRIPTION | DATE | BY |
|---|---|---|---|
| 2 | CHANGE ORDER NO. 1 | 8/15/06 | SS |
| 1 | ADDENDUM NO. 1 | 7/10/06 | SS |

I hereby certify that this plan was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota

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Date 6-21-06 License No. 43897

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Drawn By DLD, JJS

Capitol Region Watershed District
1410 Energy Park Drive, Suite 4
St. Paul, MN 55108
Phone: (651) 644-8888

EOR EMMONS & OLIVIER RESOURCES

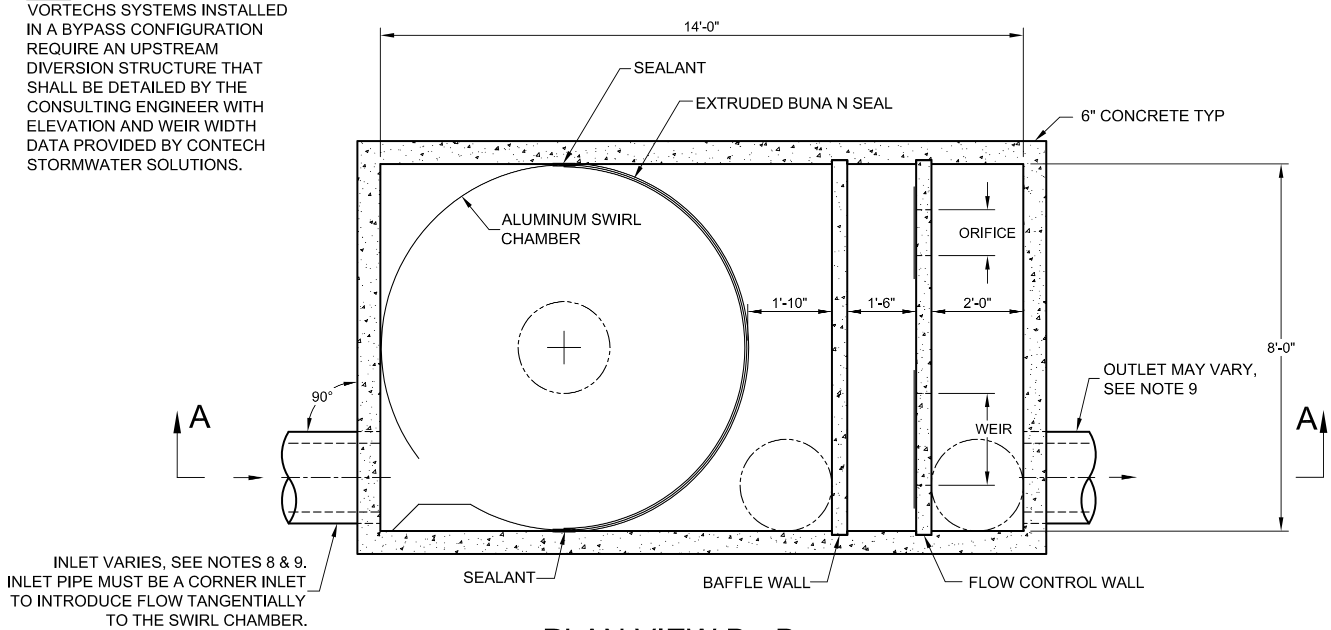
Arlington Hamline Underground Storage

Civil Details III

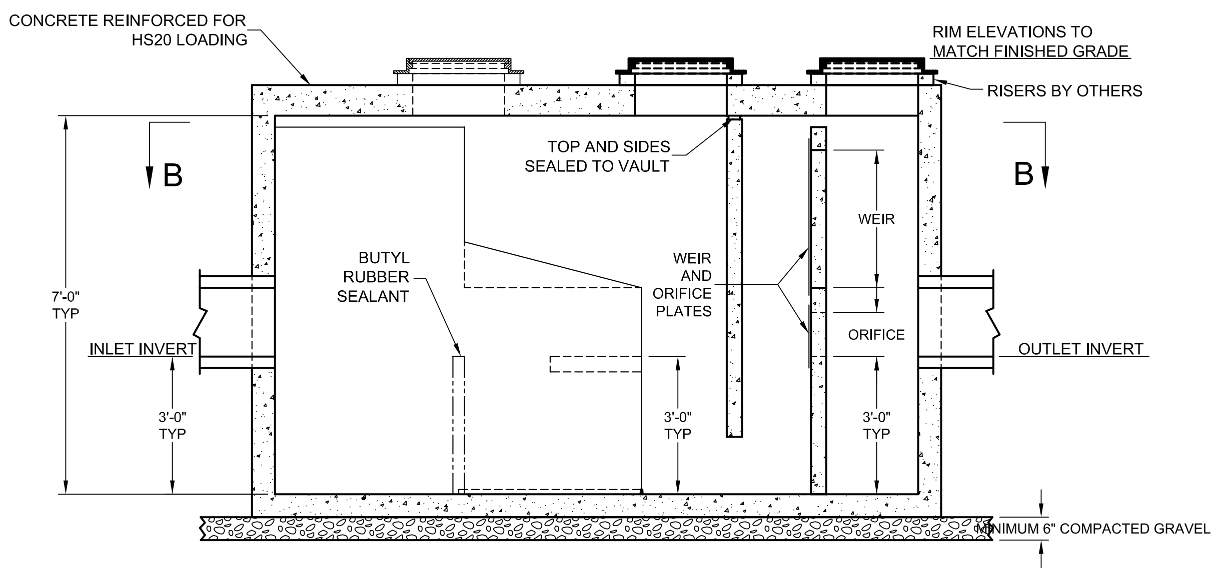
ARLINGTON PASCAL STORMWATER IMPROVEMENT PROJECT

Sheet No. 7 of 7 Sheets

NOTE:
VORTECHS SYSTEMS INSTALLED IN A BYPASS CONFIGURATION REQUIRE AN UPSTREAM DIVERSION STRUCTURE THAT SHALL BE DETAILED BY THE CONSULTING ENGINEER WITH ELEVATION AND WEIR WIDTH DATA PROVIDED BY CONTECH STORMWATER SOLUTIONS.




PLAN VIEW B - B




SECTION A - A

NOTES:
1. STORMWATER TREATMENT SYSTEM (SWTS) SHALL HAVE:
   PEAK TREATMENT CAPACITY: 11 CFS
   SEDIMENT STORAGE: 4 CU YD
   SEDIMENT CHAMBER DIA: 8' MIN
2. SWTS SHALL BE CONTAINED IN ONE RECTANGULAR STRUCTURE
3. SWTS REMOVAL EFFICIENCY SHALL BE DOCUMENTED BASED ON PARTICLE SIZE
4. SWTS SHALL RETAIN FLOATABLES AND TRAPPED SEDIMENT UP TO AND INCLUDING PEAK TREATMENT CAPACITY
5. SWTS INVERTS IN AND OUT ARE TYPICALLY AT THE SAME ELEVATION
6. SWTS SHALL NOT BE COMPROMISED BY EFFECTS OF DOWNSTREAM TAILWATER
7. SWTS SHALL HAVE NO INTERNAL COMPONENTS THAT OBSTRUCT MAINTENANCE ACCESS
8. INLET PIPE MUST BE PERPENDICULAR TO THE STRUCTURE
9. PIPE ORIENTATION MAY VARY; SEE SITE PLAN FOR SIZE AND LOCATION
10. PURCHASER SHALL NOT BE RESPONSIBLE FOR ASSEMBLY OF UNIT
11. MANHOLE FRAMES AND PERFORATED COVERS SUPPLIED WITH SYSTEM, NOT INSTALLED
12. PURCHASER TO PREPARE EXCAVATION AND PROVIDE CRANE FOR OFF-LOADING AND SETTING AT TIME OF DELIVERY
13. VORTECHS SYSTEMS BY CONTECH STORMWATER SOLUTIONS; PORTLAND, OR (800)548-4667; SCARBOROUGH, ME (877) 907-8676; ELKRIDGE, MD (866) 740-3318.

PROPRIETARY INFORMATION - NOT TO BE USED FOR CONSTRUCTION PURPOSES



CONTECH® STORMWATER SOLUTIONS INC.
contechstormwater.com

STANDARD DETAIL
STORMWATER TREATMENT SYSTEM
VORTECHS® MODEL 7000

U.S. PATENT No. 5,759,415

| DATE: 4/5/06 | SCALE: NONE | FILE NAME: STD7k | DRAWN: GMC | CHECKED: NDG |
|---|---|---|---|---|

# BMP As-Built:
# Como Park Regional Pond

Figure B-2. Como Park Regional Pond As-Builts.

## LEGEND

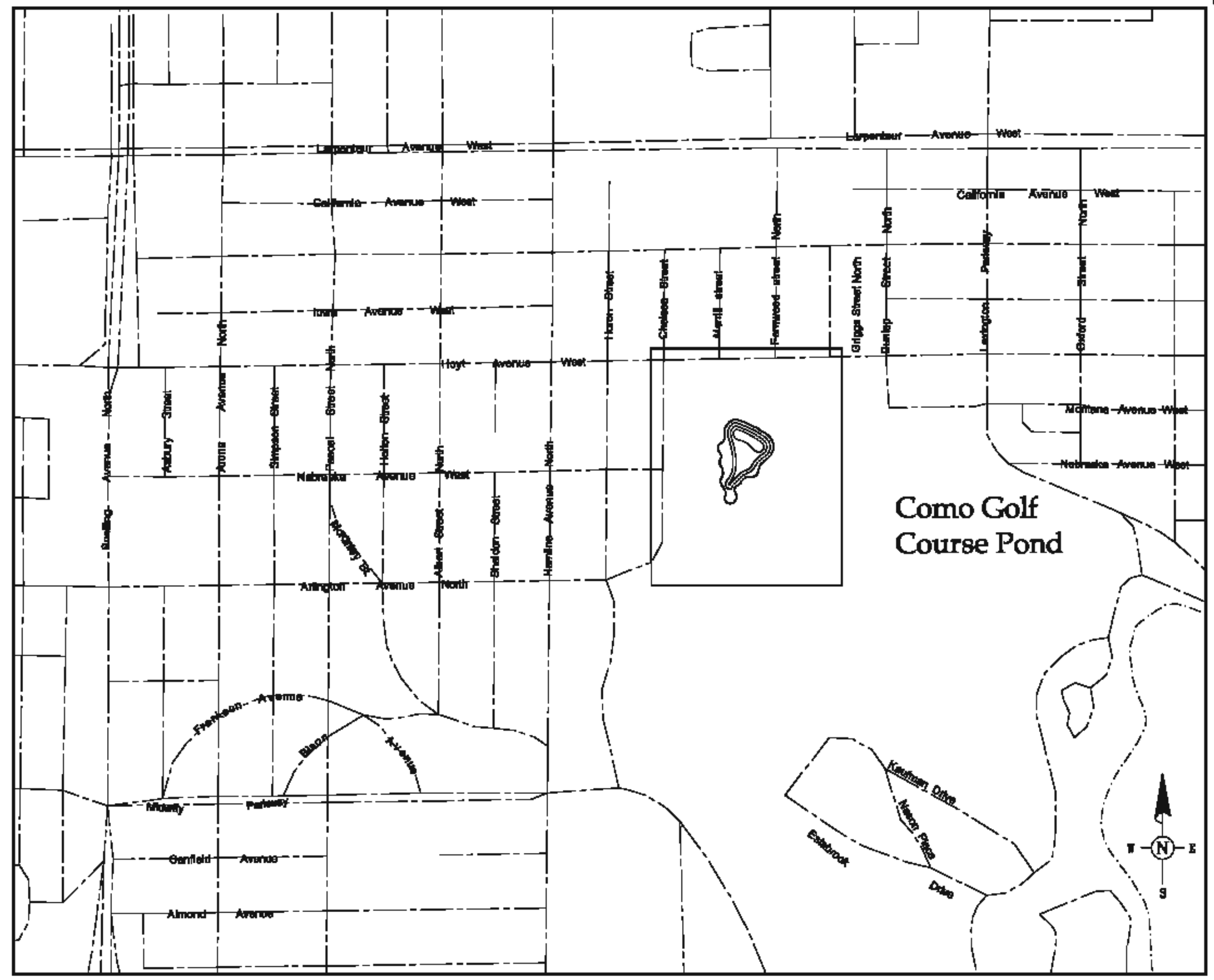
| | EXISTING | REMOVE | PROPOSED |
|---|---|---|---|
| SILT FENCE | | | |
| TREE PROTECTION FENCE | | | |
| CONTOUR | 149 | | 150 |
| SPOT ELEVATION | ×149.25 | | + 150.50 |
| STORM SEWER LINE | | | |
| DRAIN TILE | | | |
| MANHOLE | | | |
| INLET | | | |
| FLARED END SECTION | | | |
| SANITARY SEWER LINE | | | |
| MANHOLE | | | |
| WATER MAIN LINE | | | |
| IRRIGATION LINE | | | |
| IRRIGATION HEAD, FULL CIRCLE | | | |
| IRRIGATION HEAD, PART CIRCLE | | | |
| QUICK COUPLING VALVE | | | |
| BRONZE THREADED GATE VALVE | | | |
| FIRE HYDRANT | | | |
| LOW VOLTAGE IRRIGATION STATION WIRE | | | |
| GAS LINE | | | |
| ELECTRIC LINE | | | |
| ELECRIC BOX | | | |
| POWER POLE | | | |
| CONIFEROUS TREE | | | |
| DECIDUOUS TREE | | | |
| SHRUB | | | |
| CART PATH | | | |
| FAIRWAY | | | |
| CONSTRUCTION LIMITS | | | |
| STAKING POINT | | | 4 |
| FAIRWAY NUMBER | 1 | | |

### BENCHMARK

MAG NAIL: CART PATH X = 559961.26
Y = 170935.58
Z = 936.72

# ARLINGTON PASCAL STORMWATER IMPROVEMENT PROJECT

## Como Golf Course
## Pond Grading And Improvements




### SHEET INDEX

| SHEET NO. | DESCRIPTION |
|---|---|
| 01 | TITLE SHEET & LOCATION MAP |
| 02 | SCHEDULE OF QUANTITIES |
| 03 | SITE DEMOLITON CLEARING & ACCESS PLAN |
| 04 | ROUGH GRADING EROSION CONTROL & STORM SEWER PLAN |
| 05 | FINISH GRADING & DRAINAGE PLAN |
| ⚠ 05A | DESIGN & AS-BUILT GRADING |
| 06 | FAIRWAY LAYOUT PLAN |
| 07 | POND CROSS SECTIONS POND INLET PLAN & PROFILE |
| 08 | POND OUTLET PLAN & PROFILE |
| 09 | ROPE TOW PLAN & PROFILE |
| 10 | IRRIGATION & RECREATIONAL FEATURES PLAN |
| 11 | GRASSING & TREE REPLACEMENT PLAN |
| 12 | CONSTRUCTION DETAILS I |
| 13 | CONSTRUCTION DETAILS II |
| 14 | CONSTRUCTION DETAILS III |

### ⚠ CONTACT INFORMATION:

| | |
|---|---|
| GENERAL CONTRACTOR: | VEIT & CO. |
| NAME | RICK SMITH |
| ADDRESS | 1400 VEIT PLACE |
| ADDRESS | ROGERS, MN 55374 |
| PHONE | (763) 428-2242 |
| IRRIGATION: | PREMIER TURF AND IRRIGATION |
| NAME | JAY SADLER |
| ADDRESS | 1356 9TH AVENUE S. |
| ADDRESS | SOUTH ST. PAUL, MN 55075 |
| PHONE | (952) 480-8857 |
| TREES: | NOBLE LANDSCAPING |
| ADDRESS | 2456 125TH AVE. N.E. |
| ADDRESS | BLAINE, MN 55499 |
| PHONE | (763) 862-7218 |
| ASPHALT PAVING: | FPI PAVING |
| NAME | CHAD NELSON |
| ADDRESS | 3230 RICE STREET |
| ADDRESS | ST. PAUL, MN 55126 |
| PHONE | (651) 484-0385 |

**RECORD DRAWING**
REVISIONS BY IKR DATE 20FEB2008

### UTILITIES

THE LOCATION OF UNDERGROUND FACILITES OR STRUCTURES AS SHOWN ON THE PLANS ARE BASED ON AVAILABLE RECORDS AT THE TIME THE PLANS WERE PREPARED AND ARE NOT GUARANTEED TO BE COMPLETE OR CORRECT. CONTRACTOR IS RESPOSIBLE FOR CONTACTING ALL UTILITIES 72 HOURS PRIOR TO CONSTRUCTION TO DETERMINE THE EXACT LOCATION OF ALL FACILITIES AND TO PROVIDE ADEQUATE PROTECTION OF SAID UTIILITIES DURING THE COURSE OF WORK.

### GOPHER STATE ONE-CALL

IT IS THE LAW THAT ANYONE EXCAVATING AT ANY SITE MUST NOTIFY GOPHER STATE ONE CALL (GSOC) SO THAT UNDERGROUND ELECTRIC, NATURAL GAS, TELEPHONE OR OTHER UTILITY LINES CAN BE MARKED ON OR NEAR YOUR PROPERTY BEFORE ANY DIGGING BEGINS. A 48-HOUR NOTICE, NOT INCLUDING WEEKENDS, IS REQUIRED. CALLS CAN BE MADE TO GSOC AT 1-800-252-1168 OR (651)454-0002, MONDAY THROUGH FRIDAY (EXCEPT HOLIDAYS) FROM 7 A.M. TO 5 P.M.

| No. | Revision Description | Date | By |
|---|---|---|---|
| ⚠ | RECORD DRAWING | 2/20/08 | IR |
| | ADDED SHEET 05A AS-BUILT GRADING | 2/20/08 | IR |

I hereby certify that this plan or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota

Print Name: CECILIO OLIVIER
Sign Name:
Date 02-15-07 License No. 23807

Date 02-15-07
Drawn By JS
Checked By KB


Capitol Region Watershed District
1410 Energy Park Drive, Suite 4
St. Paul, MN 55108
Phone: (651) 644-8888

EMMONS & OLIVIER RESOURCES
651 HALE AVENUE NORTH
OAKDALE, MN 55128
PHONE: (651) 770-8448
FAX: (651) 770-2552
WEBSITE: www.eorinc.com


Sheet No. 01 of 14 Sheets

| | Line No. | MnDOT Ref. | Spec | Base Bid Item | Units | Quantity | |
|---|---|---|---|---|---|---|---|
| | 1 | 2021.501 | 01500 | MOBILIZATION | LS | 1 | |
| | 2 | 2104.521 | 02220 | SALVAGE AND REINSTALL FENCE | LF | 30 | |
| | 3 | 2104.523 | 02700 | CONCRETE APRON REPAIR | SY | 10 | |
| | 4 | 2231.601 | 02700 | ASPHALT PATCH | SY | 15 | |
| | 5 | 2531.501 | 02700 | CURB AND GUTTER DESIGN B-624 | LF | 25 | |
| | 6 | 2101.511 | 02230 | TREE REMOVAL | EACH | 30 | |
| | 7 | 2101.506 | 02230 | CLEAR AND GRUB POND VEGETATION | ACRE | 0.30 | |
| | 8 | 2104.503 | 02220 | REMOVE CART PATH | SF | 965 | |
| | 9 | 2104.601 | 02220 | SALVAGE AND REINSTALL ELECTRICAL BOX | LS | 1 | |
| | 10 | 2104.523 | 02220 | SALVAGE AND REINSTALL ROPE TOW POLES | EACH | 3 | |
| | 11 | 2104.601 | 02220 | SALVAGE AND REINSTALL ROPE TOW FACILITY | LS | 1 | |
| | 12 | 2104.501 | 02220 | REMOVE IRRIGATION SYSTEM | LF | 1730 | |
| 2 | 13 | 2104.501 | 02220 | REMOVE 42" RCP | LF | ~~5~~ | 16 |
| 2 | 14 | 2104.509 | 02220 | REMOVE MANHOLE | EACH | ~~1~~ | 3 |
| | 15 | 2105.501 | 02315 | COMMON EXCAVATION AND GRADING (EV) | CY | 18149 | |
| 1 | 16 | 2105.535 | 02315 | SALVAGED TOPSOIL (EV) | CY | ~~1200~~ | 6300 |
| 2 | 17 | 2575.523 | 02370 | EROSION CONTROL BLANKET CATEGORY 2 | SY | ~~5030~~ | 3300 |
| 2 | 18 | 2575.523 | 02370 | EROSION CONTROL BLANKET CATEGORY 3 | SY | ~~4900~~ | 2450 |
| | 19 | 2575.513 | 02370 | STRAW MULCH | ACRE | 3 | |
| | 20 | 2573.502 | 02370 | SILT FENCE TYPE HEAVY DUTY | LF | 1730 | |
| | 21 | 2511.515 | 02380 | GEOTEXTILE FILTER TYPE 3 | S Y | 8 | |
| | 22 | 2506.502 | 02630 | 96 IN MH DIVERSION STRUCTURE | EACH | 1 | |
| | 23 | 2504.602 | 02630 | 42 IN SLUICE GATE, INSTALLED | EACH | 1 | |
| | 24 | 2506.502 | 02630 | 66 IN MANHOLE | EACH | 1 | |
| | 25 | 2506.502 | 02630 | 84 IN MANHOLE | EACH | 1 | |
| | 26 | 2501.602 | 02630 | 48 IN MANHOLE | EACH | 2 | |
| 2 | 27 | 2503.511 | 02630 | 48 IN RCP CLASS 3 TRENCH INSTALL | LF | ~~5~~ | 8 |
| | 28 | 2503.511 | 02630 | 54 IN RCP CLASS 3 TRENCH INSTALL | LF | 76 | |
| | 29 | 2503.573 | 02630 | 42 IN RCP CLASS 3 45 DEGREE BEND | EACH | 1 | |
| 2 | 30 | 2503.511 | 02630 | 42 IN RCP CLASS 3 TRENCH INSTALL | LF | ~~210~~ | 212 |
| 2 | 31 | 2503.511 | 02630 | 30 IN RCP CLASS 3 TRENCH INSTALL | LF | ~~264~~ | 279 |
| | 32 | 2503.511 | 02630 | 24 IN RCP CLASS 3 TRENCH INSTALL | LF | 239 | |
| | 33 | 2501.573 | 02630 | 54 IN FLARED END SECTION | EACH | 1 | |
| | 34 | 2503.571 | 02630 | 8 IN PVC DRAIN PIPE | LF | 24 | |
| | 35 | 2504.602 | 02630 | 10 IN GATE VALVE AND BOX | EACH | 1 | |

| | Line No. | MnDOT Ref. | Spec | Base Bid Item | Units | Quantity | |
|---|---|---|---|---|---|---|---|
| | 36 | 2502.541 | 02620 | 4 IN PERFORATED DRAIN TILE, INSTALLED | LF | 235 | |
| | 37 | 2502.521 | 02620 | 4 IN NON-PERFORATED DUAL WALL DRAIN TILE, INSTALLED | LF | 310 | |
| | 38 | 2506.602 | 02620 | 24 IN HANCOR DRAIN INLET/CATCH BASIN WITH SUMP, INSTALLED | EACH | 3 | |
| | 39 | 2506.602 | 02620 | 18 IN NDS CATCH BASIN WITH GRATE, INSTALLED | EACH | 1 | |
| 2 | 40 | 2572.501 | 02230 | TEMPORARY PROTECTION FENCE | LF | ~~690~~ | 1300 |
| | 41 | 2511.505 | 02380 | HAND PLACED RIPRAP CLASS 2 | CY | 8 | |
| | 42 | 2575.604 | 02920 | GEOGRID FOR MUSKRAT CONTROL | SY | 2500 | |
| | 43 | 2571.502 | 02900 | 2 IN BB AMERICAN LINDEN WITH MULCH | EACH | 10 | |
| | 44 | 2571.502 | 02900 | 2 IN BB HACKBERRY WITH MULCH | EACH | 3 | |
| | 45 | 2571.501 | 02900 | 6 FT BB NORWAY (RED) PINE WITH MULCH | EACH | 6 | |
| | 46 | 2571.502 | 02900 | 2 IN BB NORTHERN PIN OAK WITH MULCH | EACH | 4 | |
| | 47 | 2571.502 | 02900 | 2 IN BB 'FIREDANCE' RED MAPLE WITH MULCH | EACH | 3 | |
| | 48 | 2571.502 | 02900 | 2 IN BB SUGAR MAPLE WITH MULCH | EACH | 7 | |
| | 49 | 2571.501 | 02900 | 6 FT BB WHITE PINE WITH MULCH | EACH | 6 | |
| | 50 | 2451.607 | 02318 | BUNKER SAND | CY | 60 | |
| | 51 | 2451.607 | 02318 | TEE MIX | CY | 87 | |
| 2 | 52 | 2575.505 | 02920 | FAIRWAY SODDING | SY | ~~6600~~ | 8791 |
| 2 | 53 | 2575.505 | 02920 | ROUGH SODDING | SY | ~~5950~~ | 11,422 |
| 1 | 54 | 2521.511 | 02705 | CART PATH 2" BITUM SURFACE 4" AGGREGATE 8' WIDTH | SF | 4125 | |
| | 55 | 2504.601 | 02810 | INSTALL IRRIGATION SYSTEM | LS | 1 | |

**BID ALTERNATES**

| | Line No. | MnDOT Ref. | Spec | Base Bid Item | Units | Quantity | |
|---|---|---|---|---|---|---|---|
| 2 | ALT 1 | | | DEDUCT TO EXCLUDE SAND FROM RIGHT FAIRWAY BUNKER ON HOLE 11 | LS | ~~1~~ | NOT SELECTED |
| 2 | ALT 2 | | | DEDUCT TO EXCLUDE SAND FROM RIGHT FAIRWAY BUNKER ON HOLE 3 | LS | ~~1~~ | NOT SELECTED |
| 2 | ALT 3 | | | DEDUCT TO EXCLUDE 275 LF 8' WIDE BITUMINOUS ASPHALT PAVING NEAR HOLE 3 TEE | LS | ~~1~~ | NOT SELECTED |
| 2 | ALT 4 | | | DEDUCT TO EXCLUDE 65 LF OF 8' WIDE BITUMINOUS ASPHALT PAVING FROM HOLE 3 FAIRWAY TO HOLE 3 GREEN | LS | ~~1~~ | NOT SELECTED |
| 2 | ALT 5 | | 02921 | ADD TO INCLUDE DISKING AND SEEDING 15,725 SF OF SECONDARY ROUGH ON SE SIDE OF HOLE 3 FAIRWAY | LS | ~~1~~ | NOT SELECTED |
| 2 | ALT 6 | | 02921 | ADD/DEDUCT TO SEED 22,600 SF NATIVE AREA WITH ROUGH SEED MIX IN LIEU OF PLACING ROUGH SOD NORTH OF POND | LS | 1 | SELECTED |
| 2 | ALT 7 | | | DEDUCT TO EXCLUDE GEOGRID FOR MUSKRAT CONTROL FROM ALONG PROPOSED POND BANK | LS | ~~1~~ | NOT SELECTED |

RECORD DRAWING
REVISIONS BY IKR DATE 20FEB2008

| NO. | REVISION DESCRIPTION | DATE | BY |
|---|---|---|---|
| 1 | ADDENDUM #1 | | |
| 2 | RECORD DRAWING | 2/20/08 | IKR |

Date 02-15-07
Designed By KB
Drawn By JS

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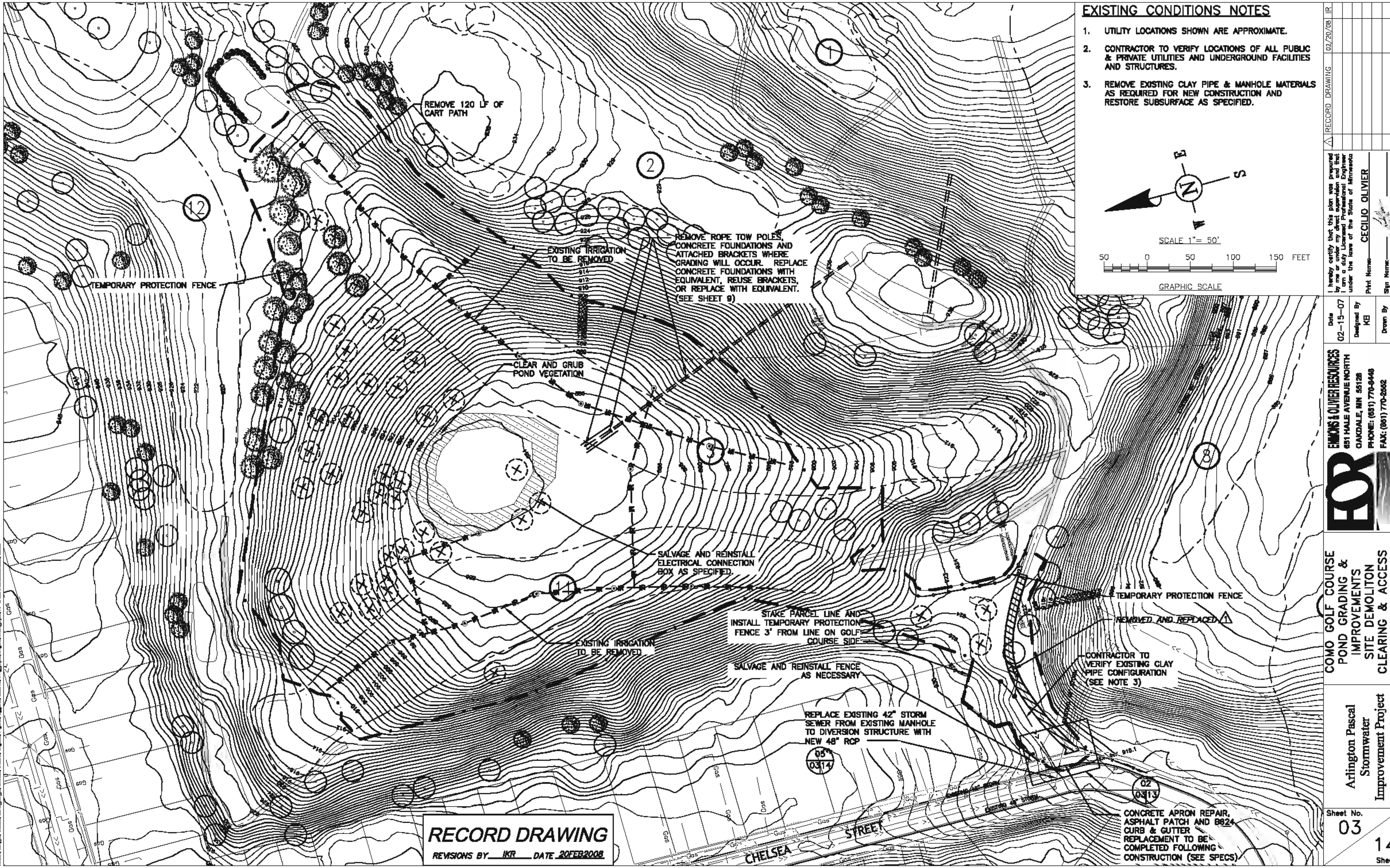
Print Name: CECILIO OLIVIER
Sign Name:
Date 02-15-07 License No. 23807

EOR
EMMONS & OLIVIER RESOURCES
651 HALE AVENUE NORTH
OAKDALE, MN 55128
PHONE: (651) 770-8448
FAX: (651) 770-2552
WEBSITE: www.eorinc.com

COMO GOLF COURSE POND GRADING AND IMPROVEMENTS SCHEDULE OF QUANTITIES

Arlington Pascal Stormwater Improvement Project

Sheet No. 02 of 14 Sheets


EXISTING CONDITIONS NOTES
1. UTILITY LOCATIONS SHOWN ARE APPROXIMATE.
2. CONTRACTOR TO VERIFY LOCATIONS OF ALL PUBLIC & PRIVATE UTILITIES AND UNDERGROUND FACILITIES AND STRUCTURES.
3. REMOVE EXISTING CLAY PIPE & MANHOLE MATERIALS AS REQUIRED FOR NEW CONSTRUCTION AND RESTORE SUBSURFACE AS SPECIFIED.
SCALE 1"= 50'
50 0 50 100 150 FEET
GRAPHIC SCALE
REMOVE 120 LF OF CART PATH
TEMPORARY PROTECTION FENCE
EXISTING IRRIGATION TO BE REMOVED
REMOVE ROPE TOW POLES, CONCRETE FOUNDATIONS AND ATTACHED BRACKETS WHERE GRADING WILL OCCUR. REPLACE CONCRETE FOUNDATIONS WITH EQUIVALENT, REUSE BRACKETS, OR REPLACE WITH EQUIVALENT. (SEE SHEET 9)
CLEAR AND GRUB POND VEGETATION
SALVAGE AND REINSTALL ELECTRICAL CONNECTION BOX AS SPECIFIED.
STAKE PARCEL LINE AND INSTALL TEMPORARY PROTECTION FENCE 3' FROM LINE ON GOLF COURSE SIDE
EXISTING IRRIGATION TO BE REMOVED
SALVAGE AND REINSTALL FENCE AS NECESSARY
TEMPORARY PROTECTION FENCE
REMOVED AND REPLACED 1
CONTRACTOR TO VERIFY EXISTING CLAY PIPE CONFIGURATION (SEE NOTE 3)
REPLACE EXISTING 42" STORM SEWER FROM EXISTING MANHOLE TO DIVERSION STRUCTURE WITH NEW 48" RCP
05 0314
02 0313
CONCRETE APRON REPAIR, ASPHALT PATCH AND B624 CURB & GUTTER REPLACEMENT TO BE COMPLETED FOLLOWING CONSTRUCTION (SEE SPECS)
CHELSEA STREET
RECORD DRAWING
REVISIONS BY IKR DATE 20FEB2008
1 RECORD DRAWING 02/20/08 IR
NO. REVISION DESCRIPTION DATE BY
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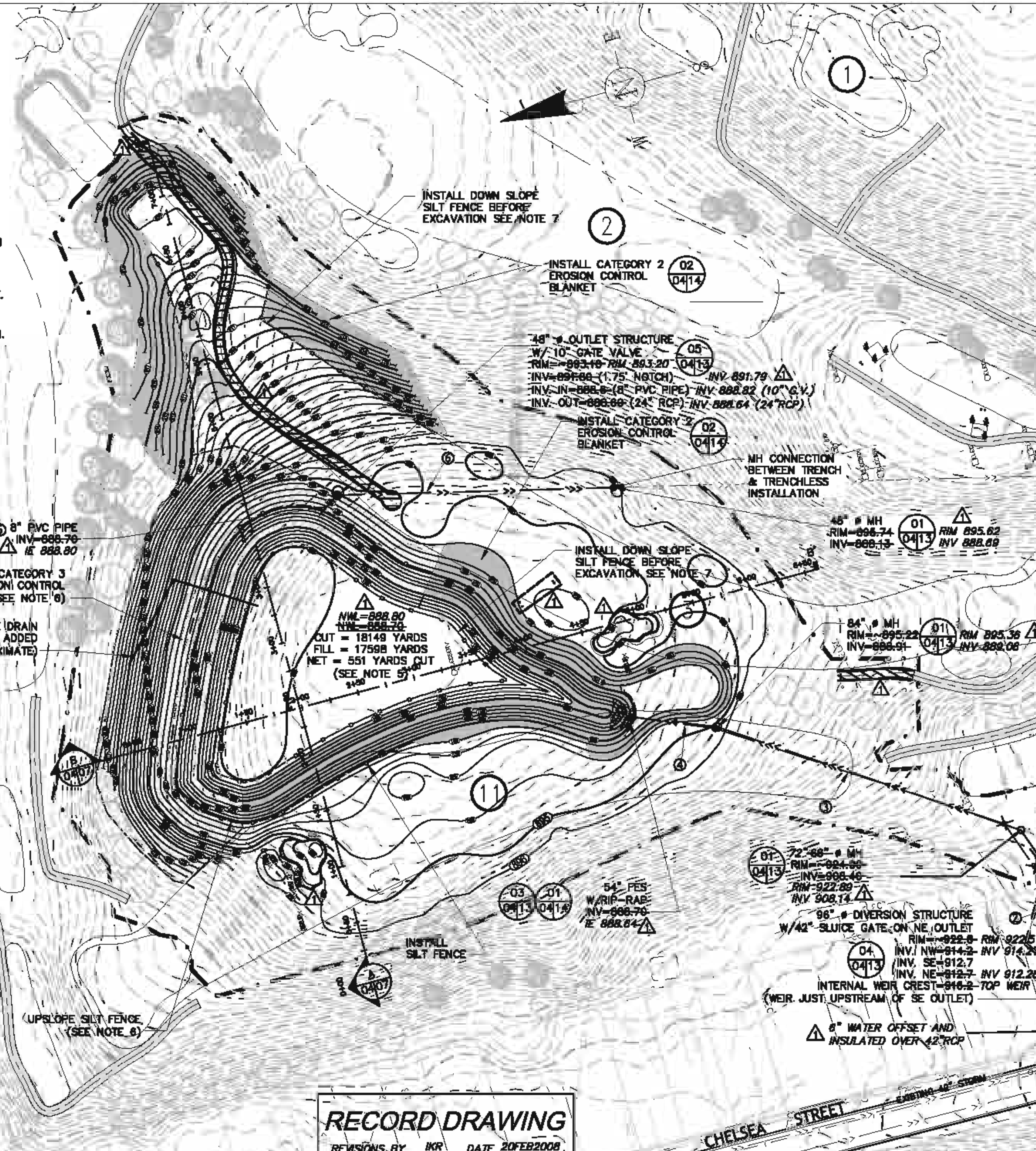
EMMONS & OLIVIER RESOURCES
651 HALE AVENUE NORTH
OAKDALE, MN 55128
PHONE: (651) 770-8448
FAX: (651) 770-2552
WEBSITE: www.eorinc.com
COMO GOLF COURSE POND GRADING & IMPROVEMENTS SITE DEMOLITON CLEARING & ACCESS PLAN
Arlington Pascal Stormwater Improvement Project
Sheet No. 03 of 14 Sheets

## GRADING & EROSION CONTROL NOTES:

1. STREET SWEEPING ON CHELSEA STREET SHALL BE PERFORMED DAILY DURING HAUL OPERATIONS OR AS DIRECTED BY THE ENGINEER (INCIDENTAL)
2. PLACE STRAW MULCH ON ALL DISTURBED AREAS NOT COVERED BY EROSION CONTROL BLANKET
3. REMOVE ANY LOCAL DEPRESSIONS NEAR CART PATH & GRADE TO PROVIDE POSITIVE SLOPE & DRAINAGE TOWARD RIDGE
4. EXCESS MATERIAL SHALL BE BLENDED INTO NORTH POND EMBANKMENT
5. FINAL GRADES OF AREAS EXCAVATED FOR PIPE INSTALLATION SHALL BE THE THE SAME AS EXISTING GRADES
6. EROSION BLANKET, STRAW MULCH, AND UPSLOPE SILT FENCE SHALL BE INSTALLED WITHIN 24HRS OF FINAL GRADE.
7. SILT FENCE AT THE POND BOTTOM AND THE BOTTOM OF HOLE 3 TEE GRADING TO BE INSTALLED BEFORE EXCAVATION.




## PIPE DATA

1. ED 13 L.F. 42" RCP 45' BEND @ ~~1.93%~~ 2.05%
2. ~~210~~ L.F. 42" RCP, CL III @ ~~1.93%~~ 199 LF @ 2.05%
3. ~~264~~ L.F. 30" RCP, CL III @ ~~7.41%~~ 277 LF @ 6.89%
4. ~~76~~ L.F. 54" RCP, CL III @ ~~0.14%~~ 79.2 LF @ 0.53%
5. 23 L.F. 8" PVC, LOW FLOW PIPE (FLAT)
6. 239 L.F. 24" RCP, TRENCH INSTALLED
7. 10 LF OF 48" RCP, CONNECT TO NEW STRUCTURE

**STORM SEWER NOTES:**

- INSTALL MANHOLES SUCH THAT LIDS ARE FLUSH WITH GROUND SURFACE
- FASTEN MANHOLE LIDS TO MANHOLE FRAMES AS SPECIFIED
- INSTALL FES SUCH THAT SLOPING WINGWALLS COINCIDE WITH EMBANKMENT SLOPE

SCALE 1"= 50'

50 0 50 100 150 FEET

GRAPHIC SCALE

**RECORD DRAWING**

REVISIONS BY IKR DATE 20FEB2008

| NO | REVISION DESCRIPTION | DATE | BY |
|---|---|---|---|
| 1 | RECORD DRAWING | 02/20/08 | IR |

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Print Name: CECILIO OLIVER

Sign Name:

Date 02-15-07 License No. 23807

Date 02-15-07

Designed By KB

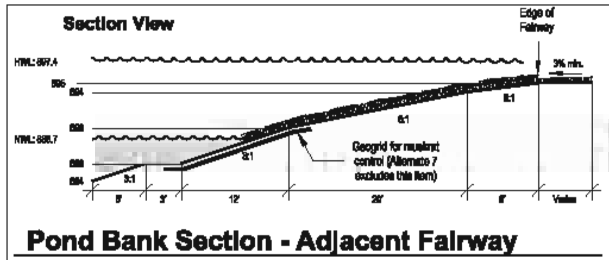
Drawn By JS


EMMONS & OLIVIER RESOURCES
651 HALE AVENUE NORTH
OAKDALE, MN 55128
PHONE: (651) 770-8448
FAX: (651) 770-2552
WEBSITE: www.eorinc.com

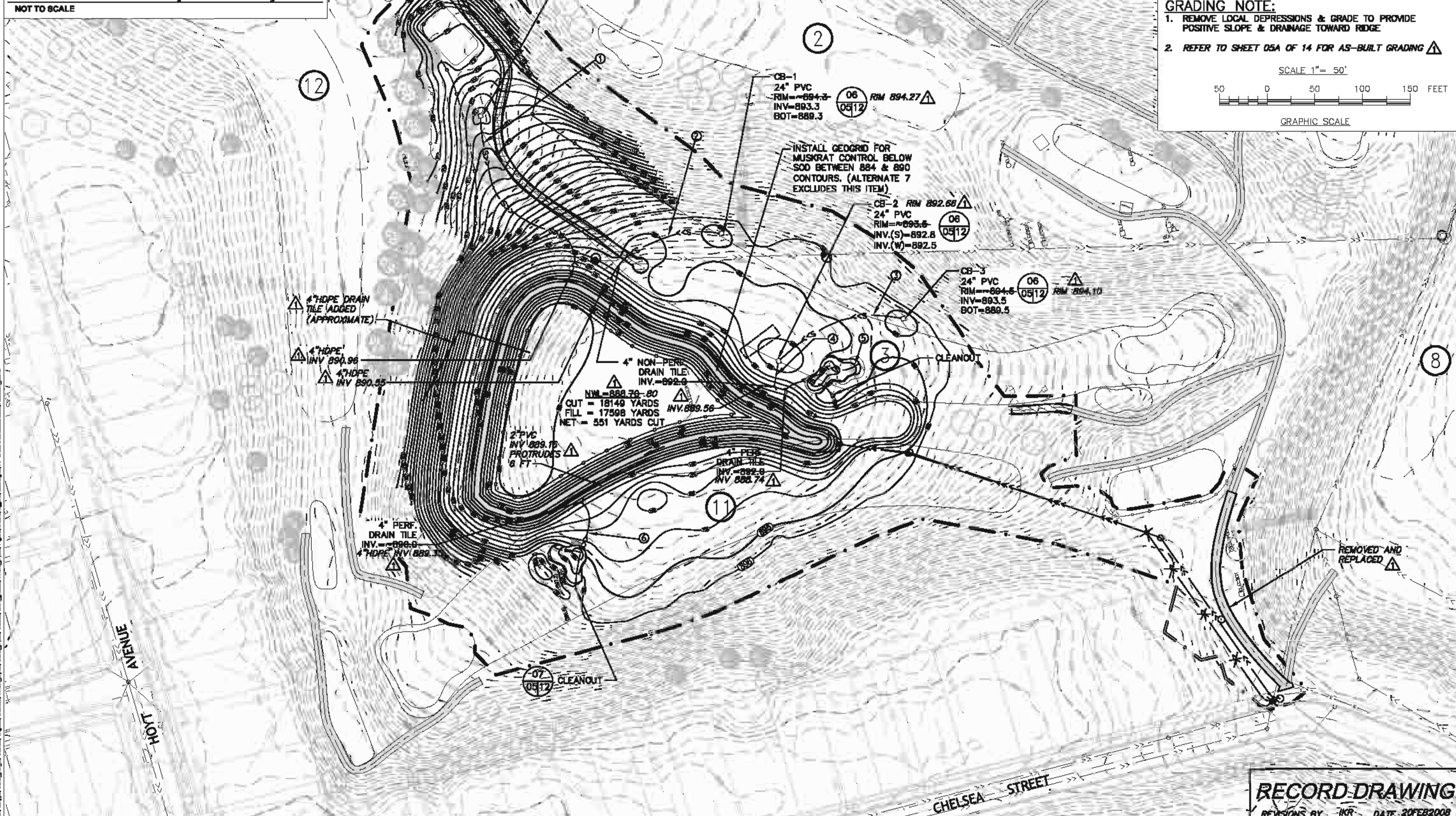

COMO GOLF COURSE POND GRADING & IMPROVEMENTS ROUGH GRADING EROSION CONTROL & STORM SEWER PLAN

Arlington Pascal Stormwater Improvement Project

Sheet No. 04 of 14 Sheets




**Pond Bank Section - Adjacent Fairway**
NOT TO SCALE




## PIPE DATA

| | | |
|---|---|---|
| 1 | 200 L.F. OF 4" NON-PERFORATED DRAIN TILE | 04 / 05\|12 |
| 2 | 130 L.F. OF 4" NON-PERFORATED DRAIN TILE | 05\|12 |
| 3 | 150 L.F. OF 4" NON-PERFORATED DRAIN TILE | 04 / 05\|12 |
| 4 | 30 L.F. OF 4" NON-PERFORATED DRAIN TILE | 05\|12 |
| 5 | 110 L.F. OF 4" PERFORATED DRAIN TILE | 03 / 05\|12 |
| 6 | 125 L.F. OF 4" PERFORATED DRAIN TILE | 05\|12 |

## GRADING NOTE:

1. REMOVE LOCAL DEPRESSIONS & GRADE TO PROVIDE POSITIVE SLOPE & DRAINAGE TOWARD RIDGE
2. *REFER TO SHEET 05A OF 14 FOR AS-BUILT GRADING*

SCALE 1"= 50'
50 0 50 100 150 FEET
GRAPHIC SCALE

**RECORD DRAWING**
REVISIONS BY IKR DATE 20FEB2008

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651 HALE AVENUE NORTH
OAKDALE, MN 55128
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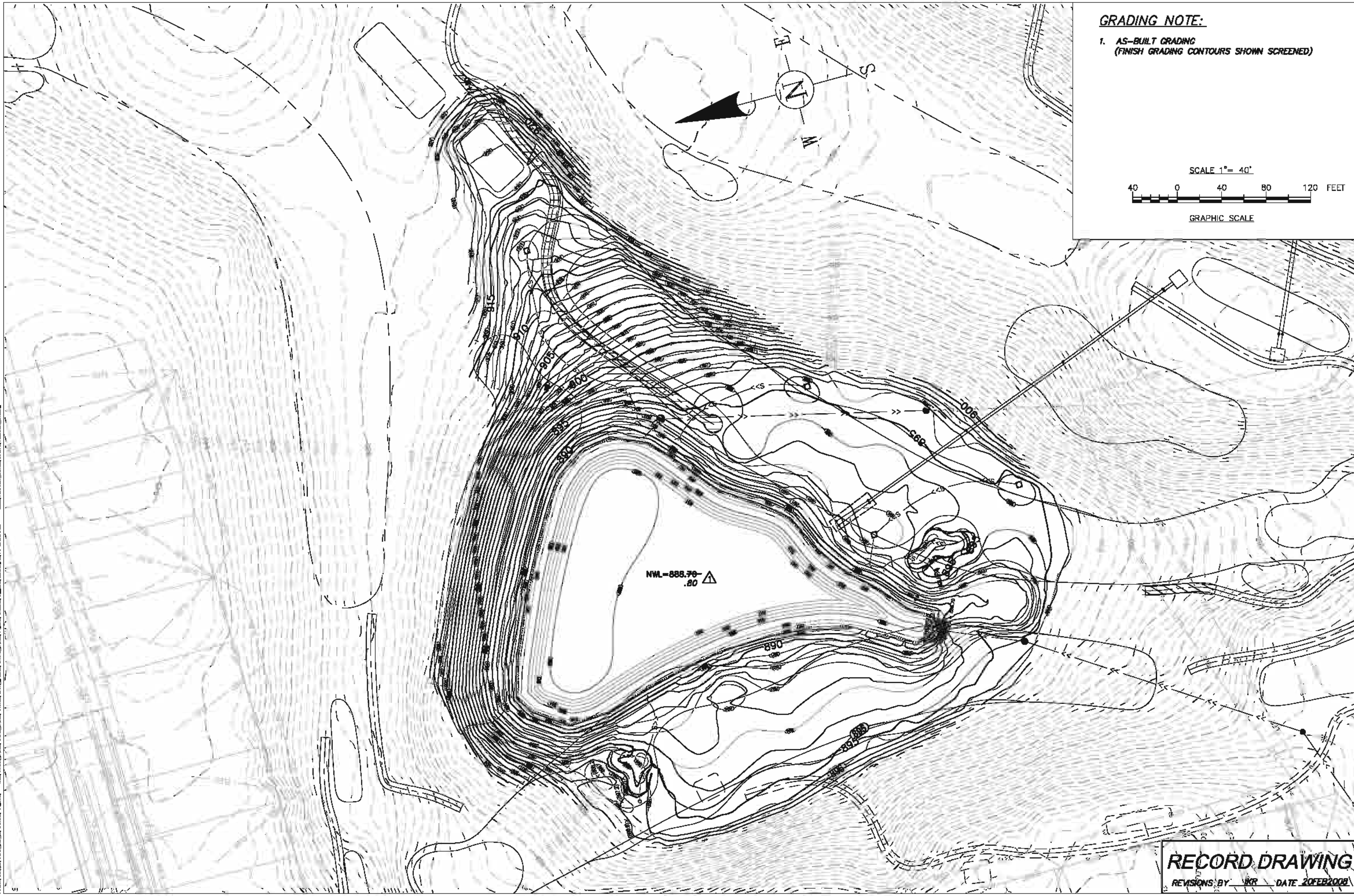
COMO GOLF COURSE POND GRADING & IMPROVEMENTS FINISH GRADING & DRAINAGE PLAN

**Arlington Pascal Stormwater Improvement Project**

Sheet No 05 of 14 Sheets




## GRADING NOTE:

1. AS-BUILT GRADING (FINISH GRADING CONTOURS SHOWN SCREENED)

SCALE 1" = 40'

40 0 40 80 120 FEET

GRAPHIC SCALE

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OAKDALE, MN 55128
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COMO GOLF COURSE DESIGN & AS-BUILT GRADING

Arlington Pascal Stormwater Improvement Project

Sheet No. 05A of 14 Sheets


## STAKING POINT TABLE

| Staking Point No. | Description | Northing | Easting |
|---|---|---|---|
| 0 | Benchmark – | – | – |
| 1 | Hole 3 – Back Tee | 171,553.72 | 560,369.67 |
| 2 | Hole 3 – Center of Back Tee | 171,538.07 | 560,338.91 |
| 3 | Hole 3 – Center of New Forward Tee | 171,480.49 | 560,242.14 |
| 4 | Hole 3 – 1st Dogleg Point | 171,212.18 | 559,840.28 |
| 5 | Hole 3 – Center of Right Fairway Bunker | 171,195.11 | 559,797 81 |
| 6 | Hole 3 – Center of Existing Green | 170,836.53 | 559,735.46 |
| 7 | Hole 11 – Center of Back Tee | 170,817.69 | 559,596.80 |
| 8 | Hole 11 – 1st Dogleg Point | 171,443.74 | 559,667.31 |
| 9 | Hole 11 – Center of Right Fairway Bunker | 171,500.42 | 559,673 31 |
| 10 | Hole 11 – Center of Existing Green | 171,867.84 | 559,811.28 |

SCALE 1"= 50'

50 0 50 100 150 FEET

GRAPHIC SCALE

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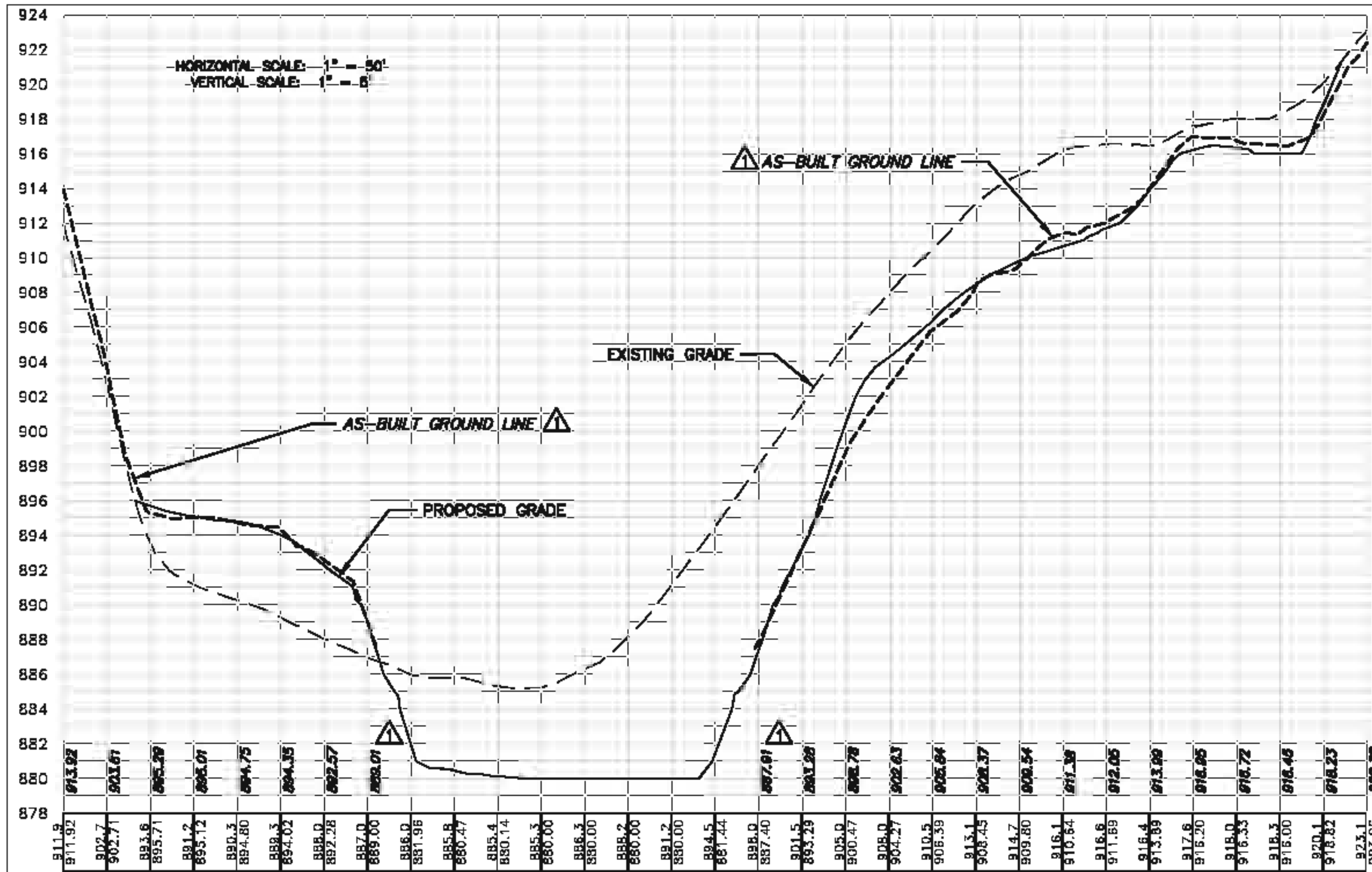
EOR

EMMONS & OLIVIER RESOURCES
651 HALE AVENUE NORTH
OAKDALE, MN 55128
PHONE: (651) 770-8448
FAX: (651) 770-2552
WEBSITE: www.eorinc.com

COMO GOLF COURSE POND GRADING & IMPROVEMENTS FAIRWAY LAYOUT PLAN

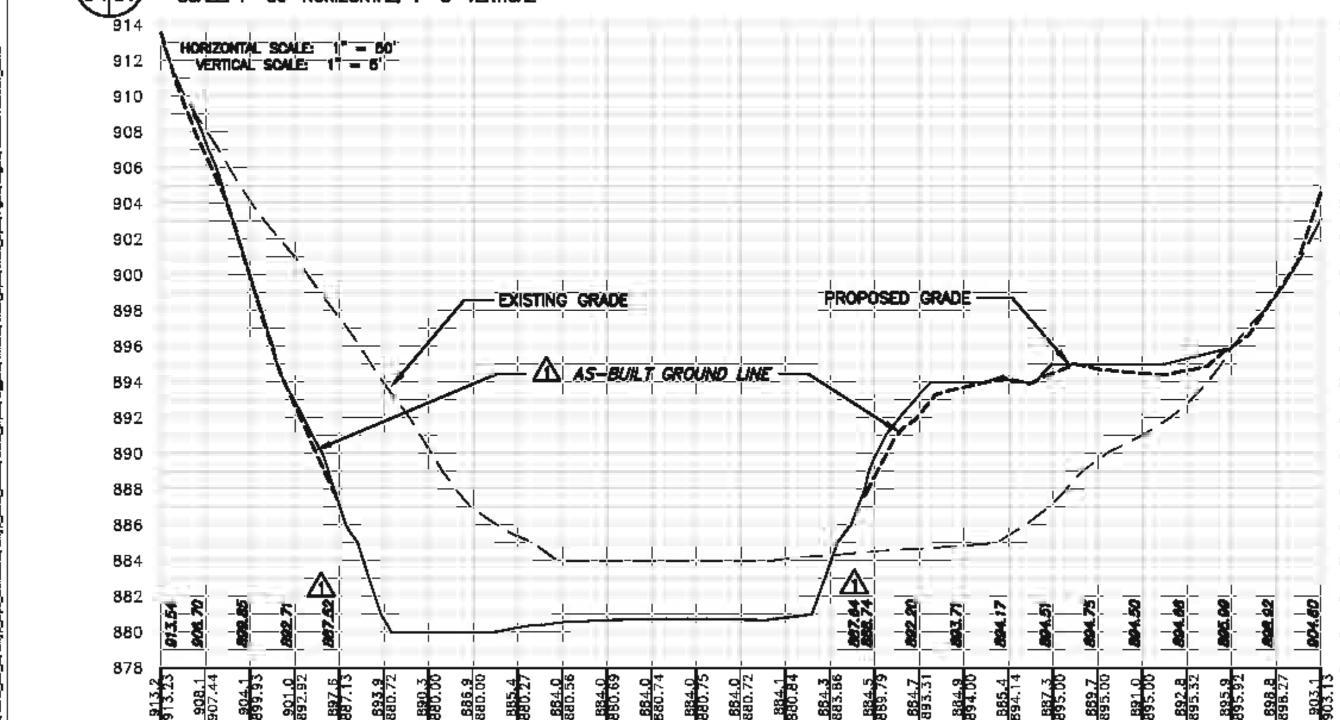
Arlington Pascal Stormwater Improvement Project

Sheet No. 06 of 14 Sheets



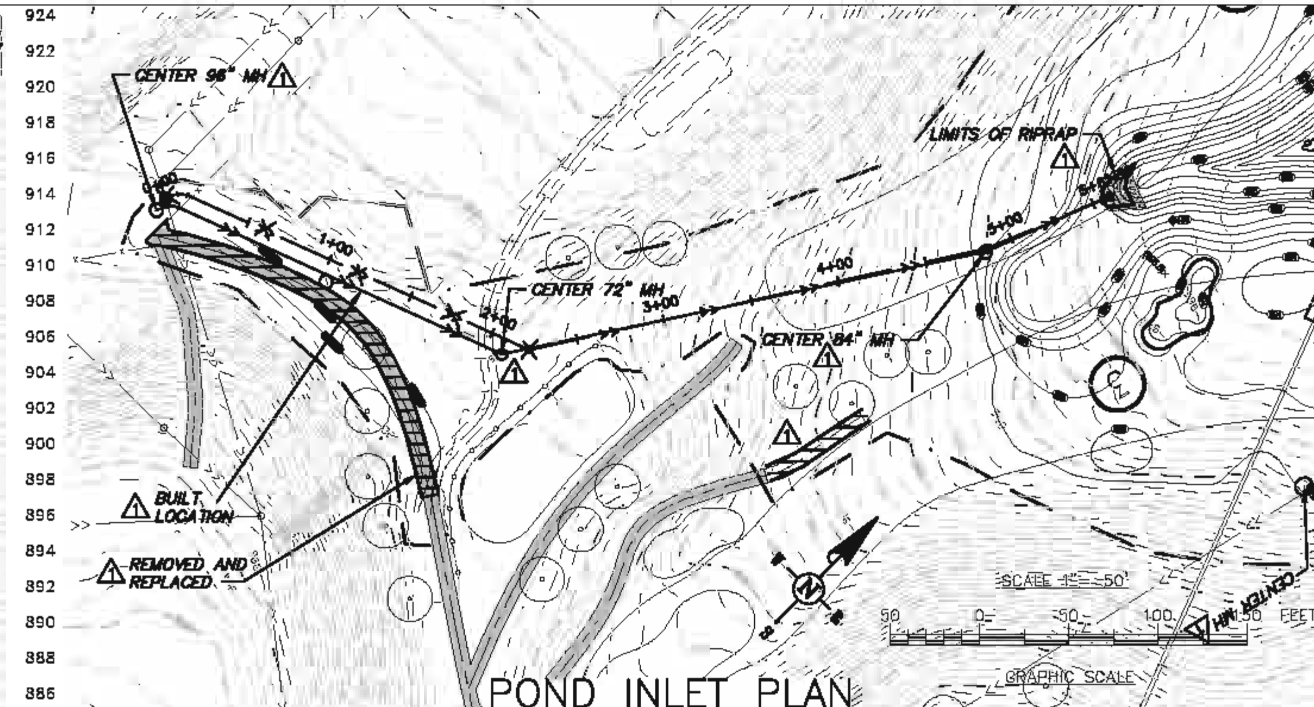

CROSS SECTION A–A'

SCALE: 1"=50' HORIZONTAL, 1"=5' VERTICAL

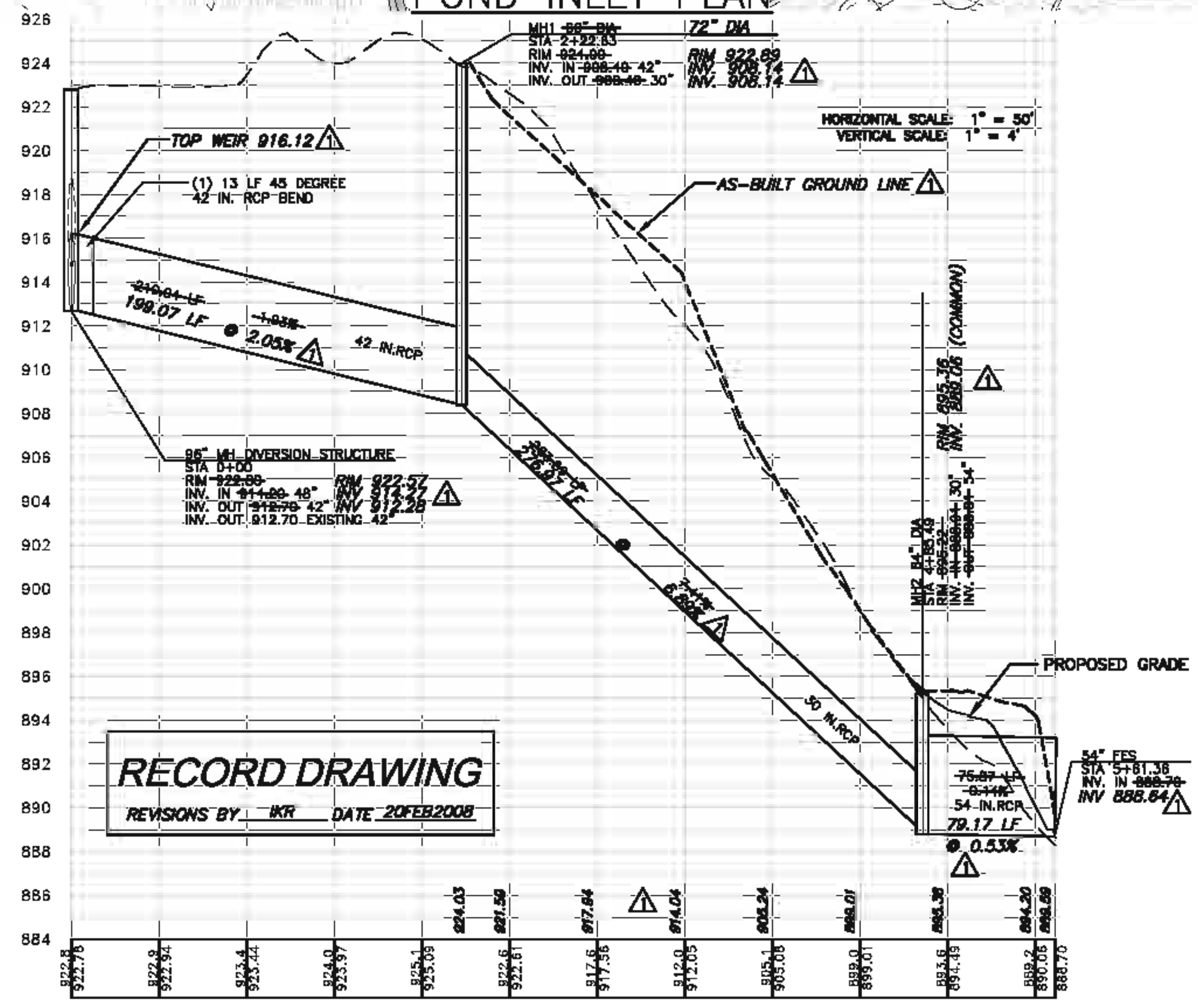



CROSS SECTION B–B'

SCALE: 1"=50' HORIZONTAL, 1"=5' VERTICAL




POND INLET PLAN




POND INLET PROFILE

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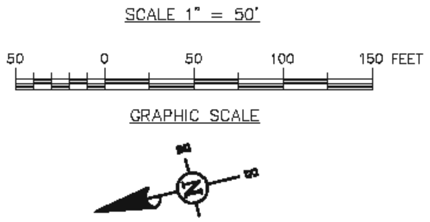
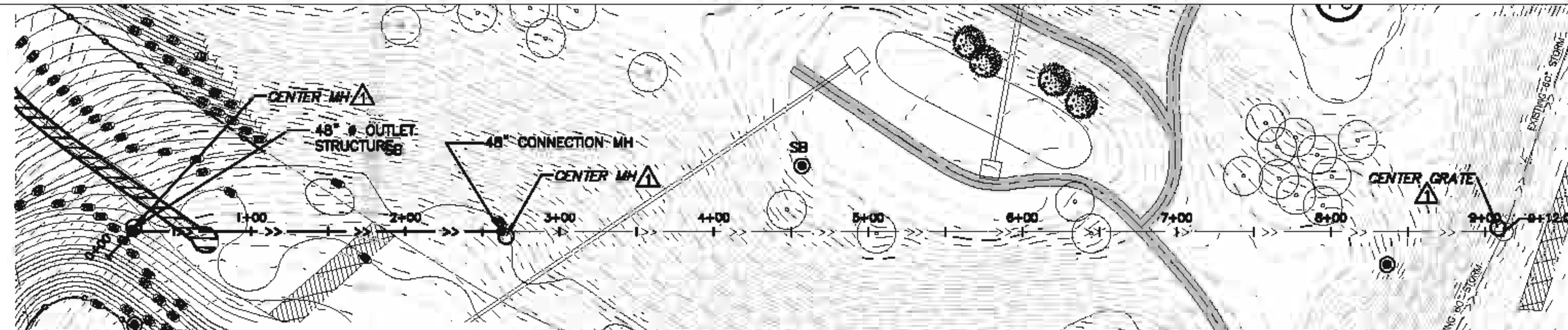
COMO GOLF COURSE POND GRADING & IMPROVEMENTS POND CROSS SECTIONS POND INLET PLAN & PROFILE

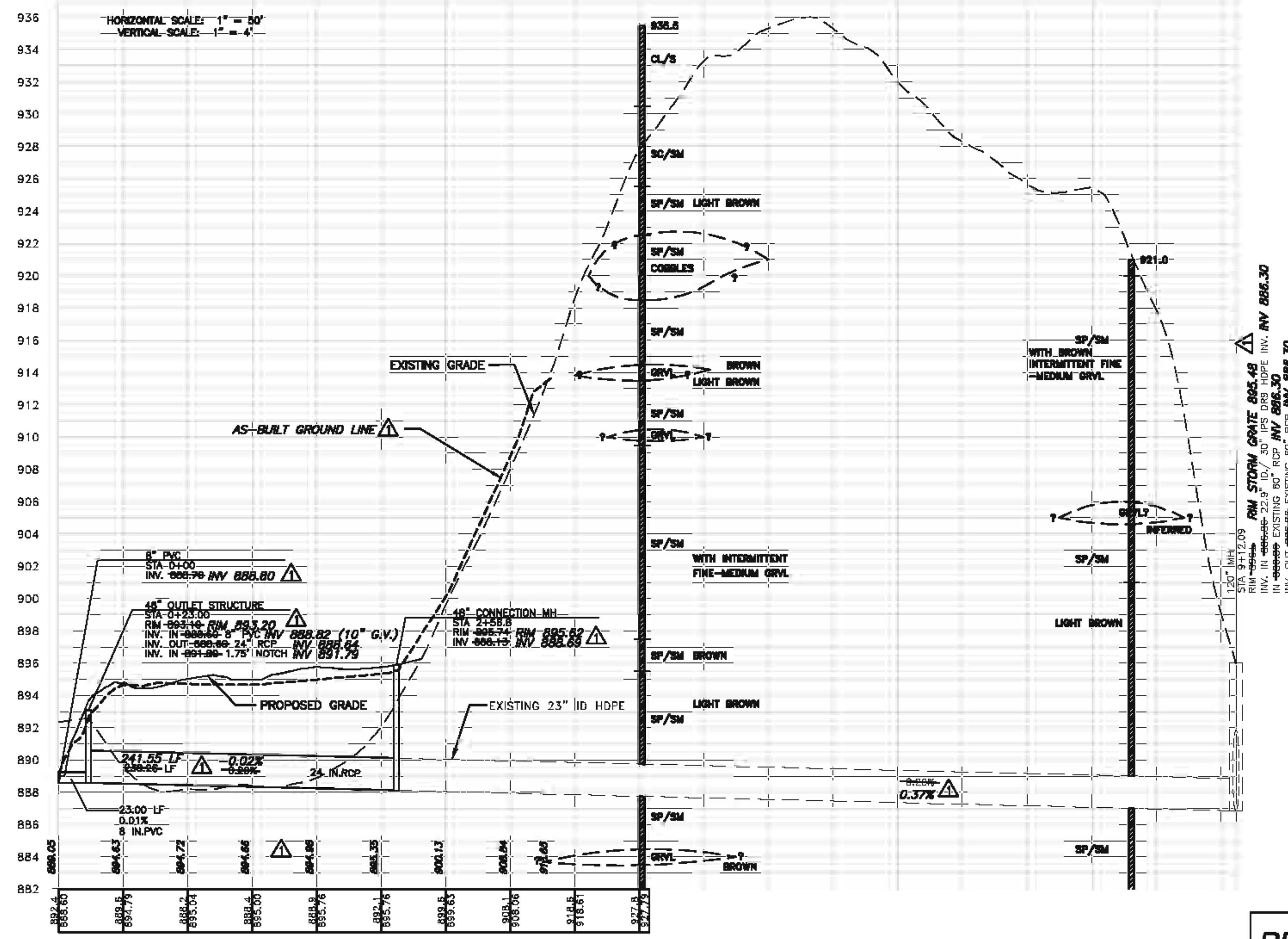
Arlington Pascal Stormwater Improvement Project

Sheet No. 07 of 14 Sheets




POND OUTLET PLAN




POND OUTLET PROFILE

**RECORD DRAWING**

REVISIONS BY IKR DATE 20FEB2008

| NO. | REVISION DESCRIPTION | DATE | BY |
|---|---|---|---|
| | RECORD DRAWING | 2/20/08 | IR |

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Print Name: CECILIO OLIVIER

Sign Name:

Date 02-15-07 License No. 23807

Date 02-15-07

Designed By KB

Drawn By JS

EMMONS & OLIVIER RESOURCES
651 HALE AVENUE NORTH
OAKDALE, MN 55128
PHONE: (651) 770-8448
FAX: (651) 770-2552
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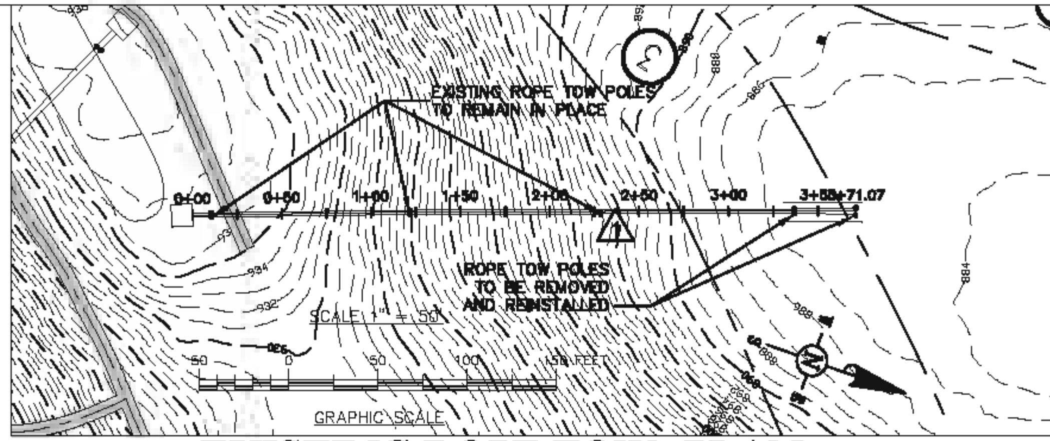
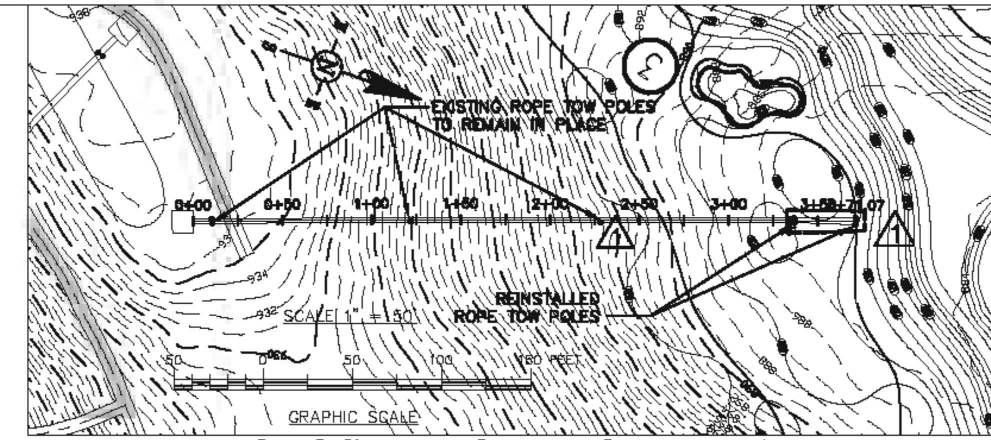
COMO GOLF COURSE POND GRADING & IMPROVEMENTS POND OUTLET PLAN & PROFILE

Arlington Pascal Stormwater Improvement Project

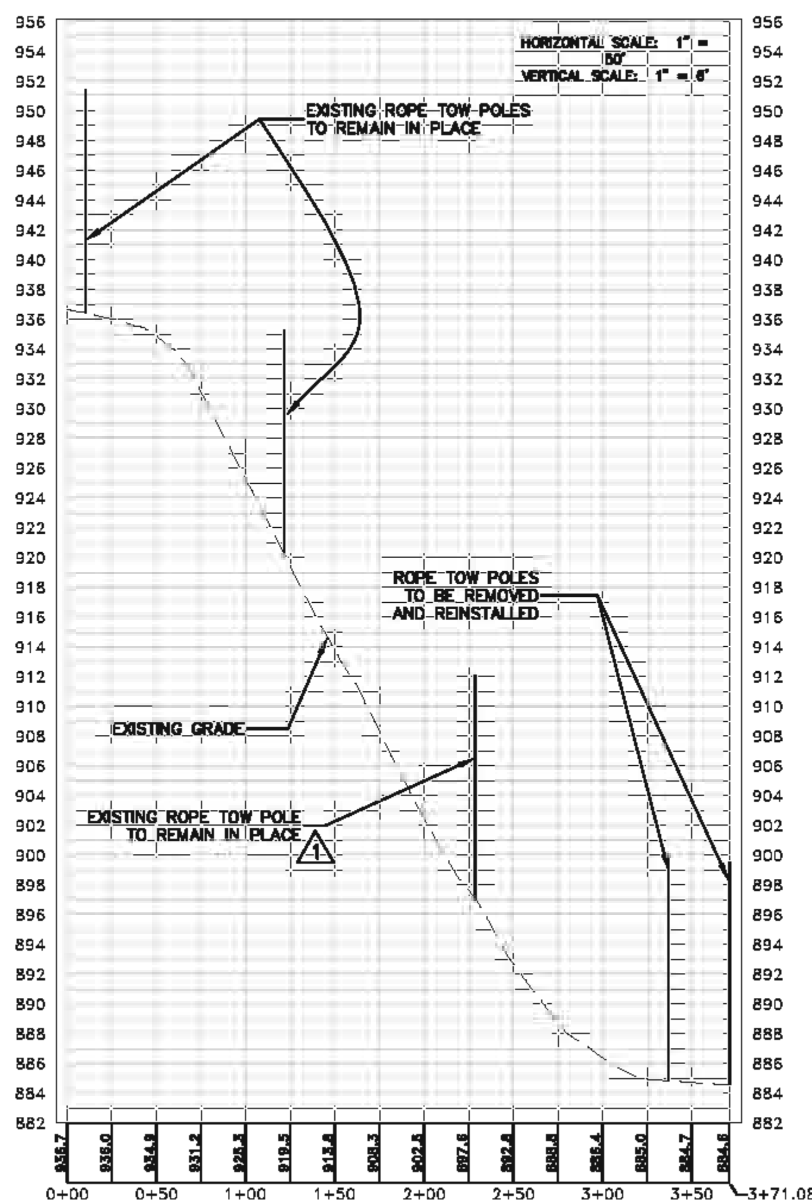
Sheet No. 08 of 14 Sheets




# EXISTING ROPE TOW -PLAN




# PROPOSED ROPE TOW -PLAN

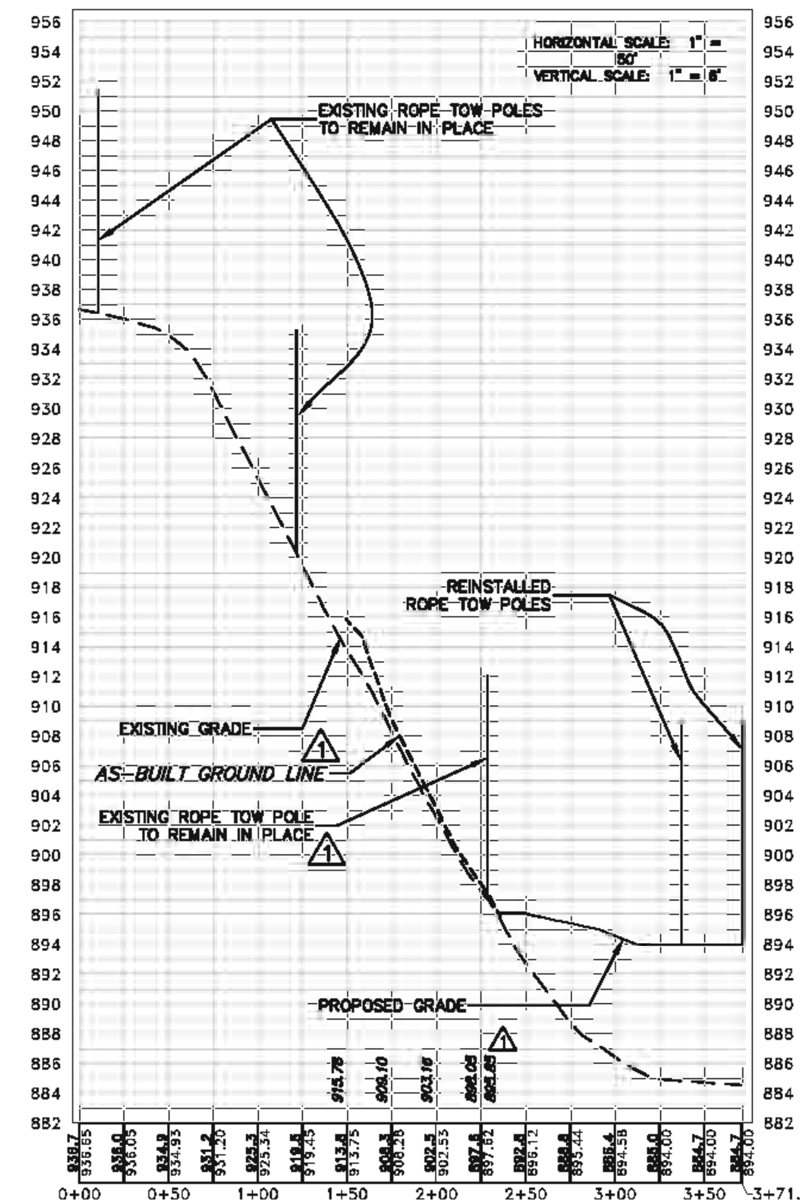



# EXISTING ROPE TOW -PROFILE

**NOTES:**

1. HORIZONTAL LOCATIONS OF EXISTING ROPE TOW POLES DETERMINED BY SURVEY.
2. CONFIGURATION OF EXISTING ROPE TOW POLE CONCRETE FOUNDATION TO BE VERIFIED BY CONTRACTOR; POLES SHALL BE REINSTALLED USING NEW CONCRETE FOUNDATION OF EQUIVALENT SIZE AND SHAPE. METAL BRACKETS CURRENTLY USED TO ATTACH POLES SHALL BE REMOVED AND BE REUSED, OR REPLACED WITH EQUIVALENT.
3. PROPOSED LOCATIONS OF ROPE TOW POLES ARE SUBJECT TO FIELD VERIFICATION BY ENGINEER TO ENSURE PROPER FUNCTION OF ROPE TOW SYSTEM.

RECORD DRAWING
REVISIONS BY IKR DATE 20FEB2008




# PROPOSED ROPE TOW -PROFILE

| NO. | REVISION DESCRIPTION | DATE | BY |
| --- | --- | --- | --- |
| 1 | RECORD DRAWING | 2/20/08 | IR |

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OAKDALE, MN 55128
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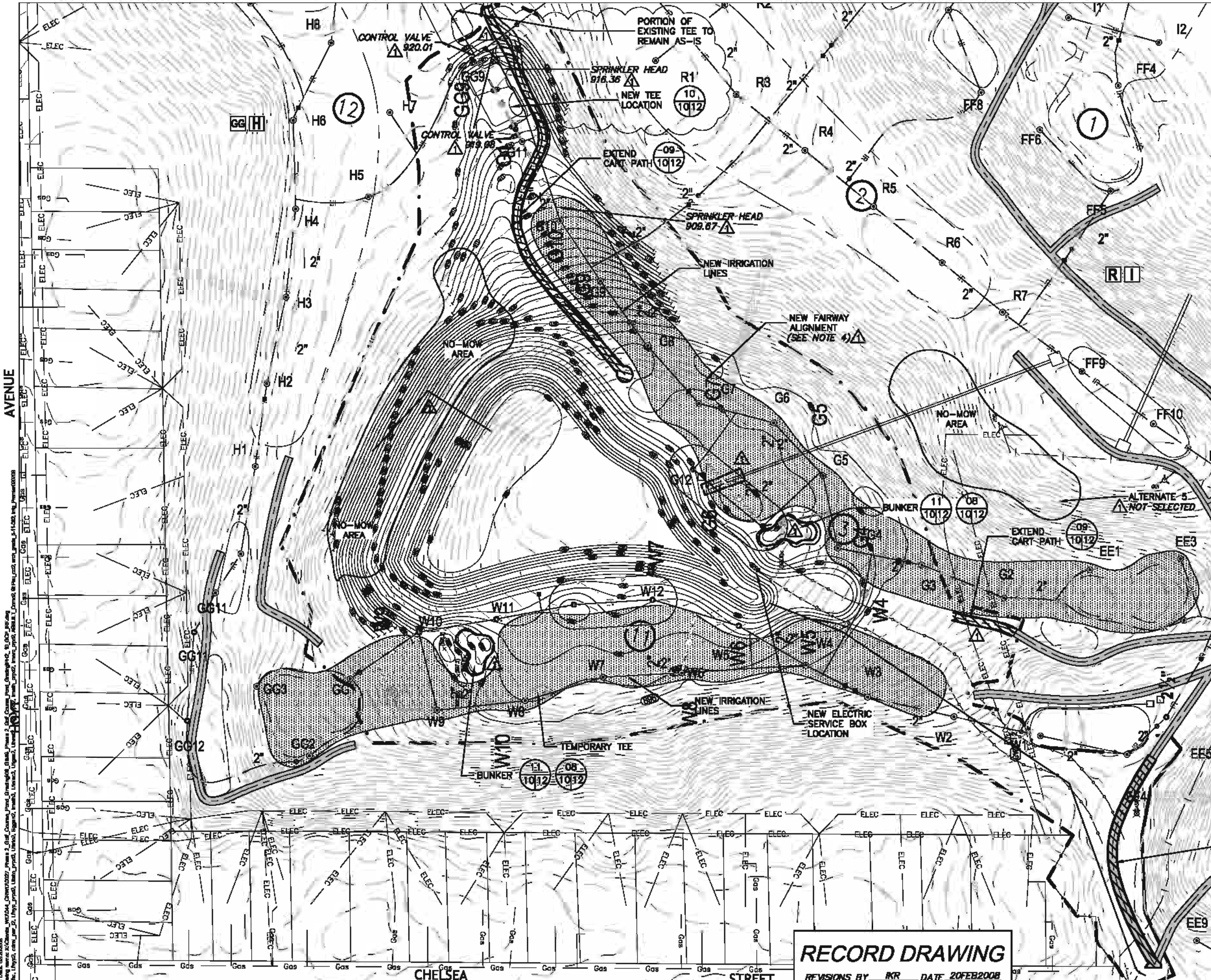
COMO GOLF COURSE POND GRADING & IMPROVEMENTS ROPE TOW PLAN & PROFILE

Arlington Pascal Stormwater Improvement Project

Sheet No. 09 of 14 Sheets




## IRRIGATION & RECREATIONAL FEATURES:

1. EXISTING IRRIGATION LINES TO BE VERIFIED BY CONTRACTOR PRIOR TO CONSTRUCTION.
2. LETTERS ENCASED IN BOXES INDICATE SATELLITE CONTROL BOX LABELS
3. TEMPORARY TEES AND TEMPORARY CART PATH TO BE CONSTRUCTED BY OTHERS.
4. *ASBUILT LOCATION OF FAIRWAYS' EDGE NOT DETERMINED.*
5. *IRRIGATION PLAN / SPRINKLER LAYOUT PROVIDED BY PREMIER TURF AND IRRIGATION.*

SCALE 1"= 50'

50 0 50 100 150 FEET

GRAPHIC SCALE

RECORD DRAWING

REVISIONS BY IKR DATE 20FEB2008

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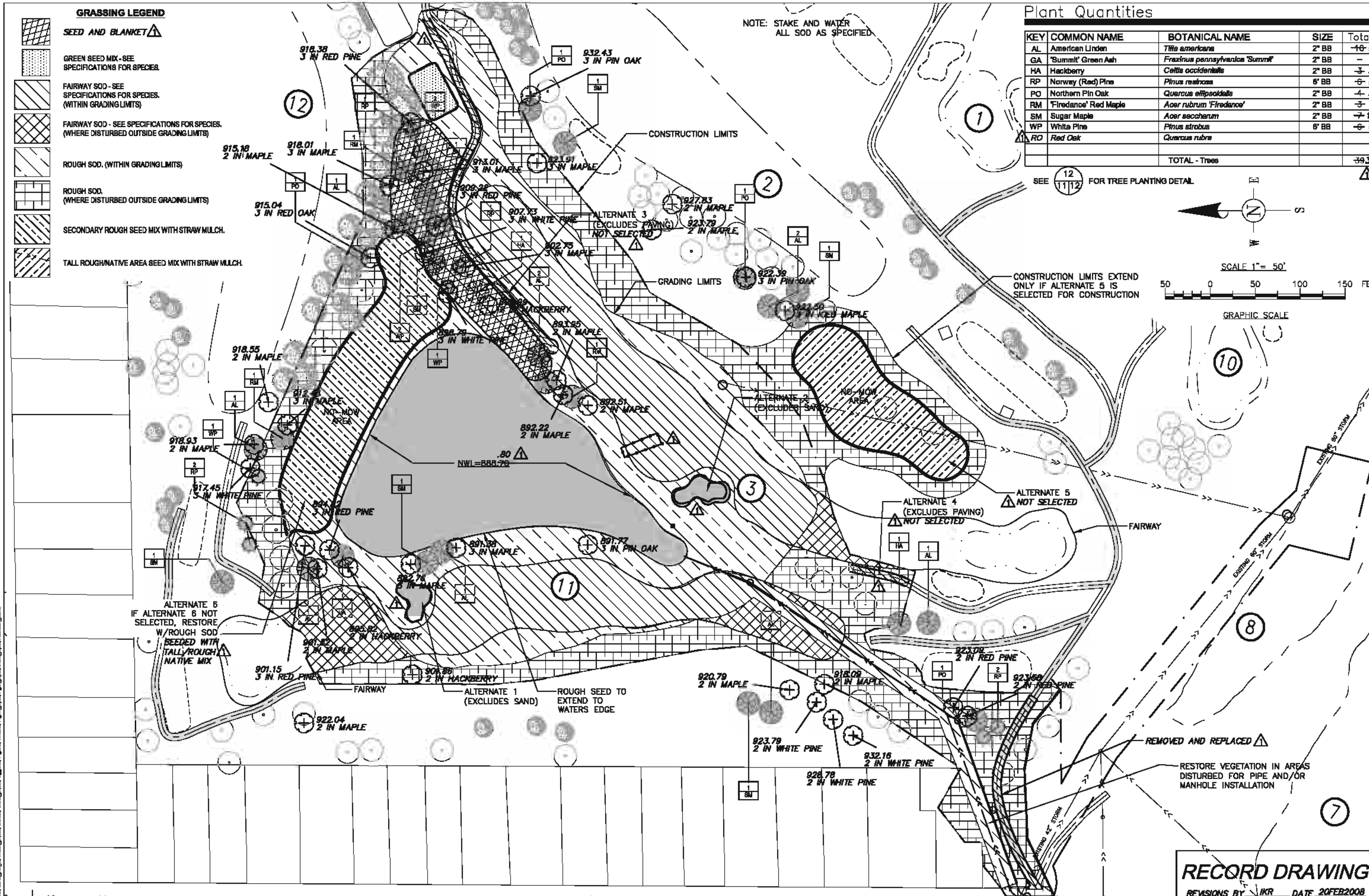
COMO GOLF COURSE POND GRADING & IMPROVEMENTS IRRIGATION & RECREATIONAL FEATURES PLAN

Arlington Pascal Stormwater Improvement Project

Sheet No. 10 of 14 Sheets




## Plant Quantities

| KEY | COMMON NAME | BOTANICAL NAME | SIZE | Total |
|---|---|---|---|---|
| AL | American Linden | *Tilia americana* | 2" BB | ~~10~~ 0 |
| GA | 'Summit' Green Ash | *Fraxinus pennsylvanica 'Summit'* | 2" BB | – |
| HA | Hackberry | *Celtis occidentalis* | 2" BB | ~~3~~ 3 |
| RP | Norway (Red) Pine | *Pinus resinosa* | 6' BB | ~~6~~ 6 |
| PO | Northern Pin Oak | *Quercus ellipsoidalis* | 2" BB | ~~4~~ 3 |
| RM | 'Firedance' Red Maple | *Acer rubrum 'Firedance'* | 2" BB | ~~3~~ 7 |
| SM | Sugar Maple | *Acer saccharum* | 2" BB | ~~7~~ 13 |
| WP | White Pine | *Pinus strobus* | 6' BB | ~~6~~ 6 |
| *RO* | *Red Oak* | *Quercus rubra* | | 1 |
| | | | | |
| | | TOTAL - Trees | | ~~39~~ 39 |

SEE 12 / 11 12 FOR TREE PLANTING DETAIL

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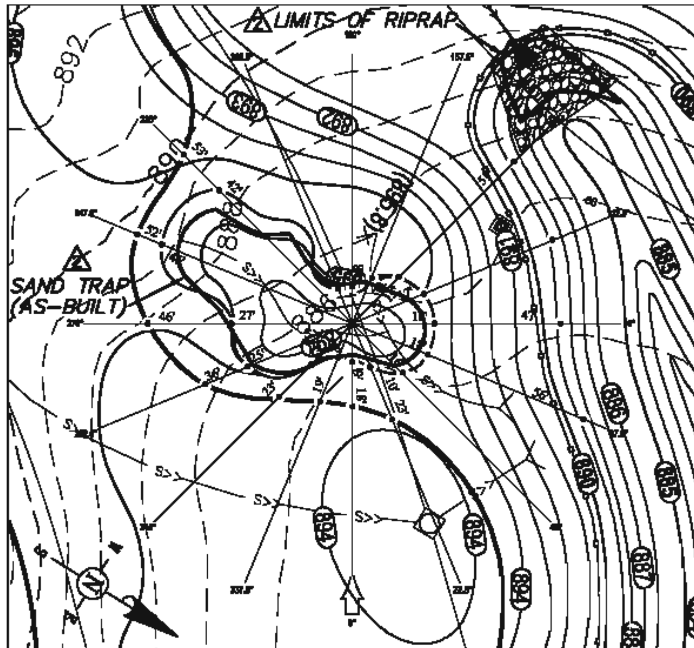
# COMO GOLF COURSE POND GRADING & IMPROVEMENTS GRASSING & TREE REPLACEMENT PLAN

Arlington Pascal Stormwater Improvement Project

RECORD DRAWING
REVISIONS BY IKR DATE 20FEB2008

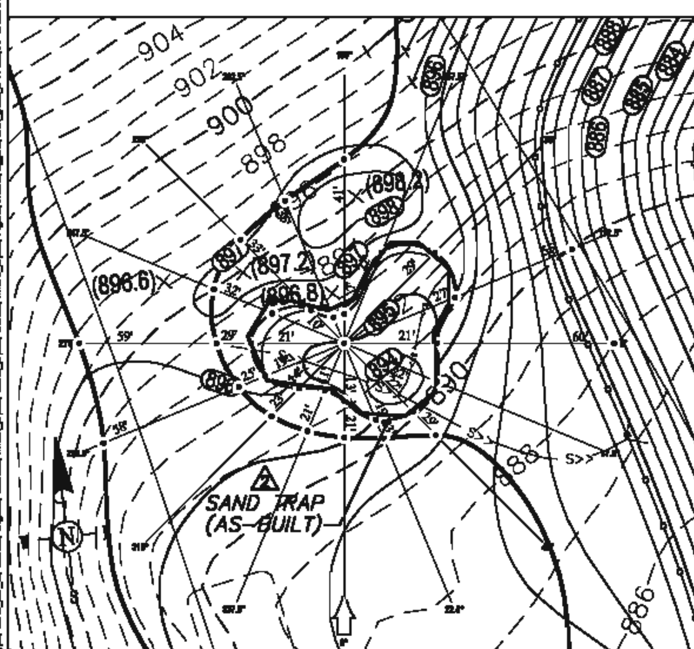
Sheet No. 11 of 14 Sheets




**Hole No. 3**
**Fairway Bunker - Right Side**
**225 Yards from Blue Tee**
**1,425 Sq. Ft., 27 Cu. Yds.**

3

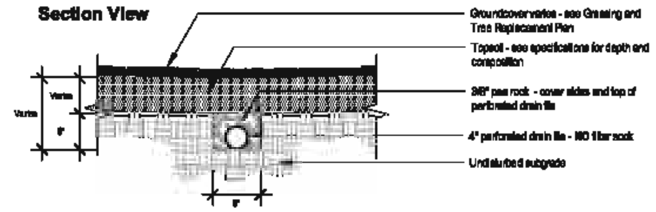
01 / 06|12 BUNKER DESIGN DETAIL – HOLE 3
SCALE: 1" = 20'



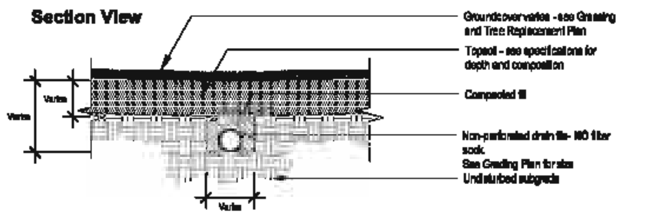

**Hole No. 11**
**Fairway Bunker - Right Side**
**225 Yards from Blue Tee**
**1,075 Sq. Ft., 20 Cu. Yds.**

11

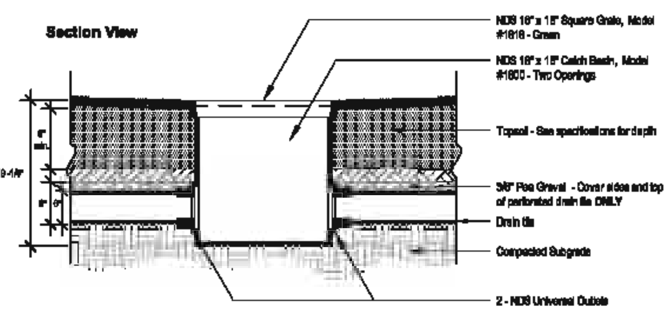
02 / 06|12 BUNKER DESIGN DETAIL – HOLE 11
SCALE: 1" = 20'




03 / 05|12 TYPICAL NON–PERFERATED DRAIN TILE
SCALE: NOT TO SCALE




04 / 05|12 TYPICAL NON–PERFERATED DRAIN TILE
SCALE: NOT TO SCALE




05 / 05|12 TYPICAL 18 IN. CATCH BASIN DETAIL
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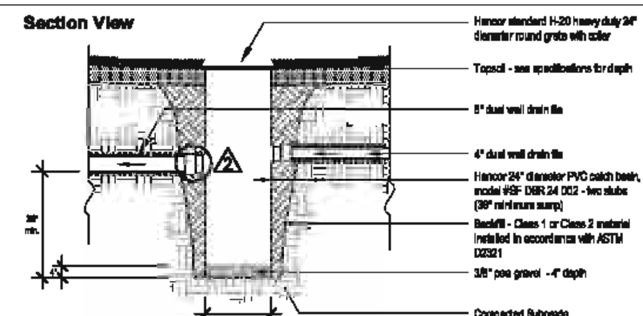


06 / 05|12 TYPICAL 24 IN. CATCH BASIN DETAIL
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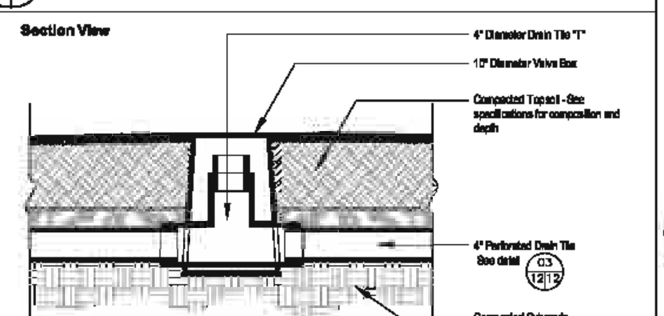
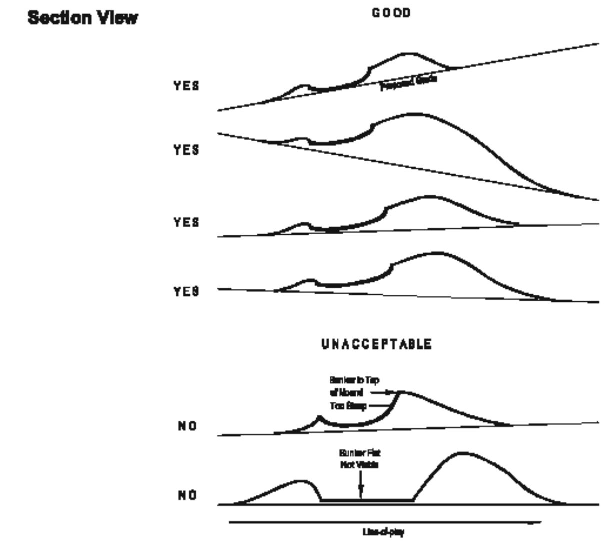
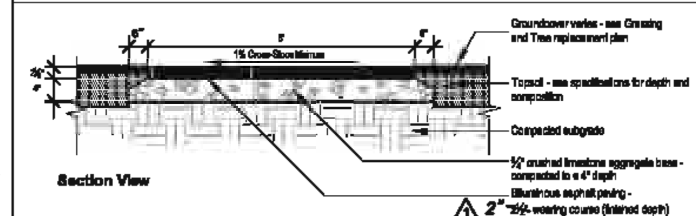


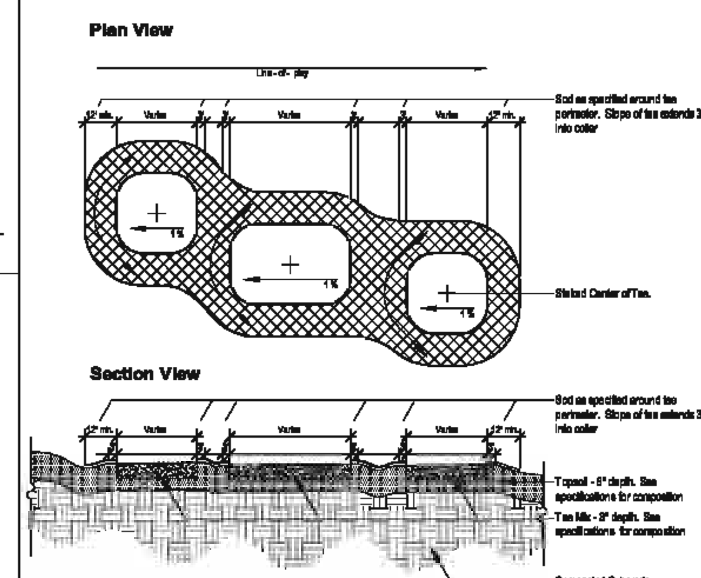

07 / 05|12 TYPICAL CLEANOUT
SCALE: NOT TO SCALE



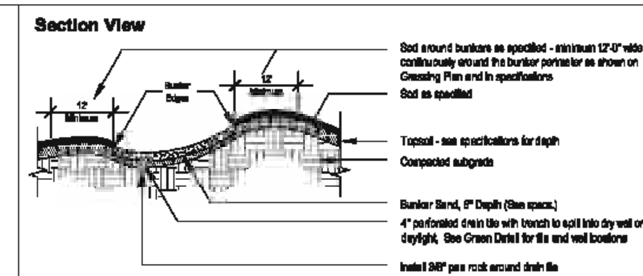

08 / 05|12 TYPICAL BUNKER SECTION
SCALE: NOT TO SCALE




09 / 10|12 TYPICAL BITUMINOUS PATH DETAIL
SCALE: NOT TO SCALE




10 / 10|12 TYPICAL TEE LAYOUT
SCALE: NOT TO SCALE




11 / 10|12 TYPICAL BUNKER CONSTRUCTION DETAIL
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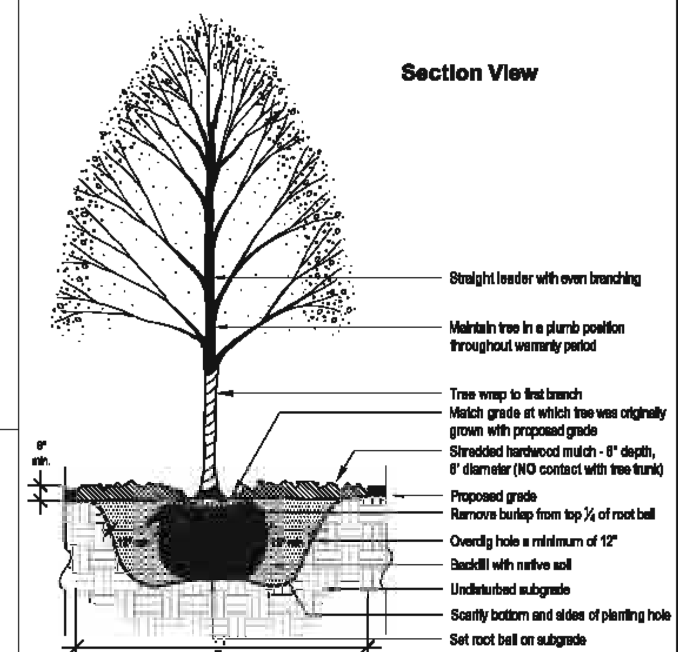


12 / 11|12 TREE PLANTING DETAIL
SCALE: NOT TO SCALE

**RECORD DRAWING**
REVISIONS BY IKR DATE 20FEB2008



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| 1 | ADDENDUM #1 | 2/20/08 | IR |
| 2 | RECORD DRAWING | 2/20/08 | IR |

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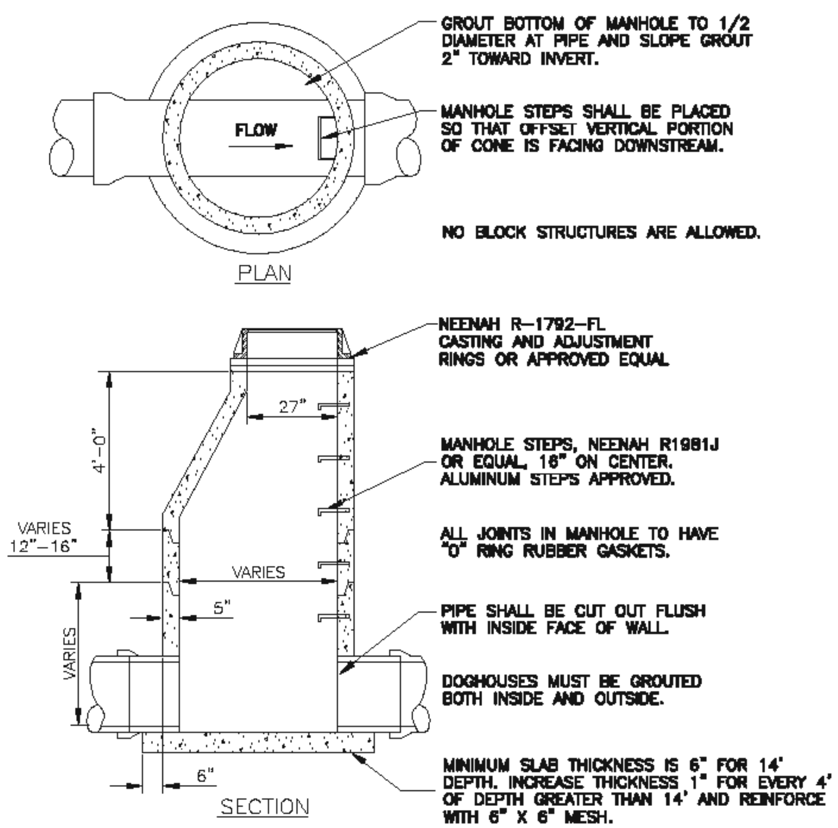
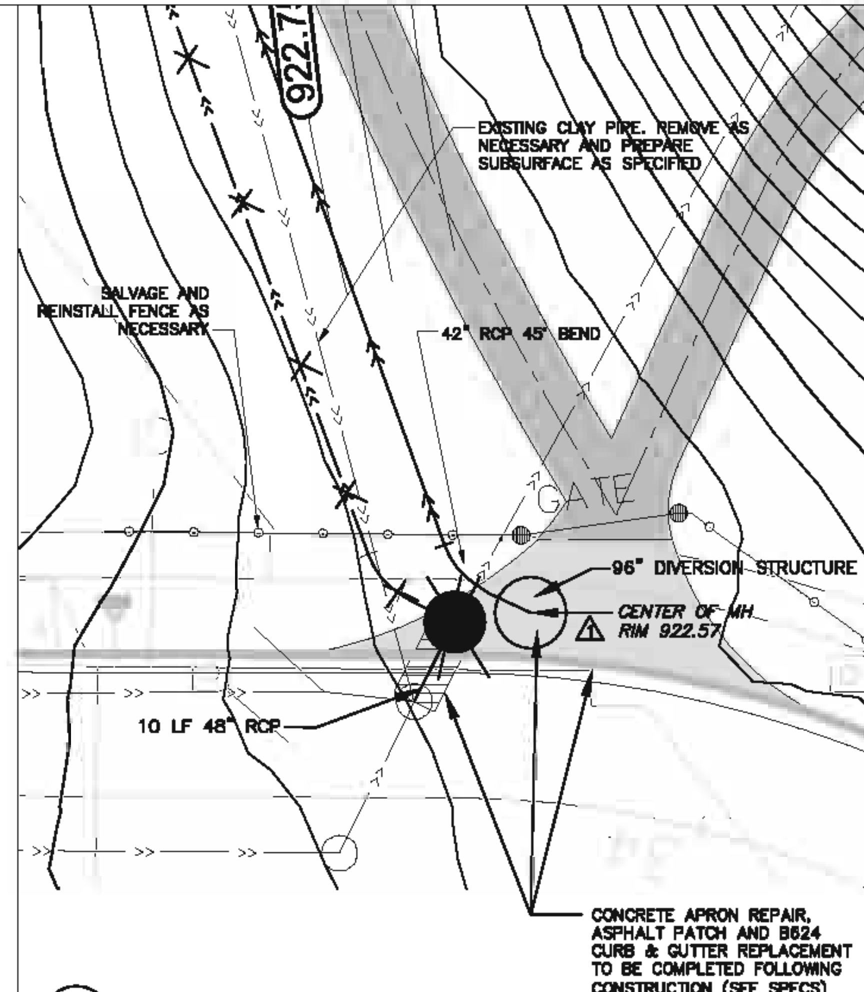
COMO GOLF COURSE
POND GRADING & IMPROVEMENTS
CONSTRUCTION DETAILS

Arlington Pascal Stormwater Improvement Project

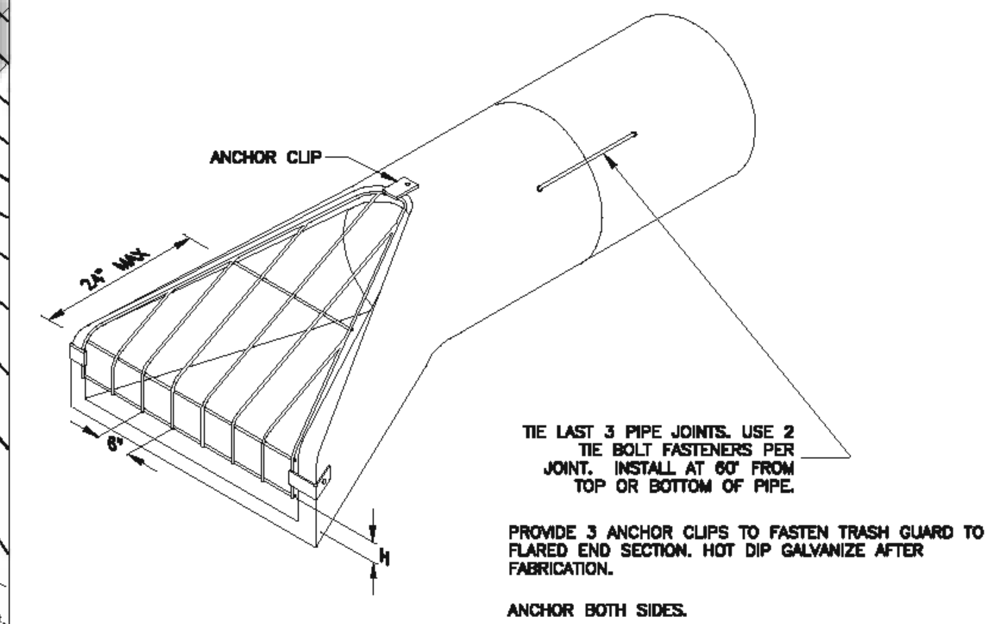
Sheet No. 12 of 14 Sheets




01 | 04 13 **STANDARD STORM MANHOLE**
SCALE: NOT TO SCALE




02 | 03 13 **PLAN VIEW**
SCALE: 1:10'

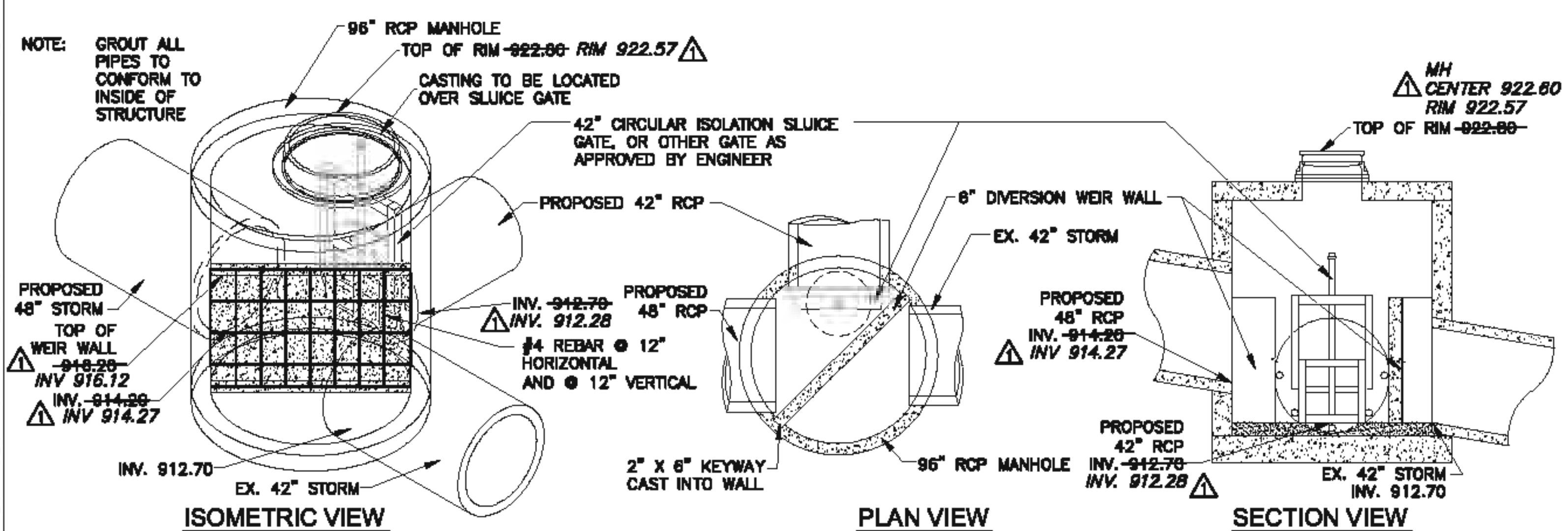



TRASH GUARD SIZING

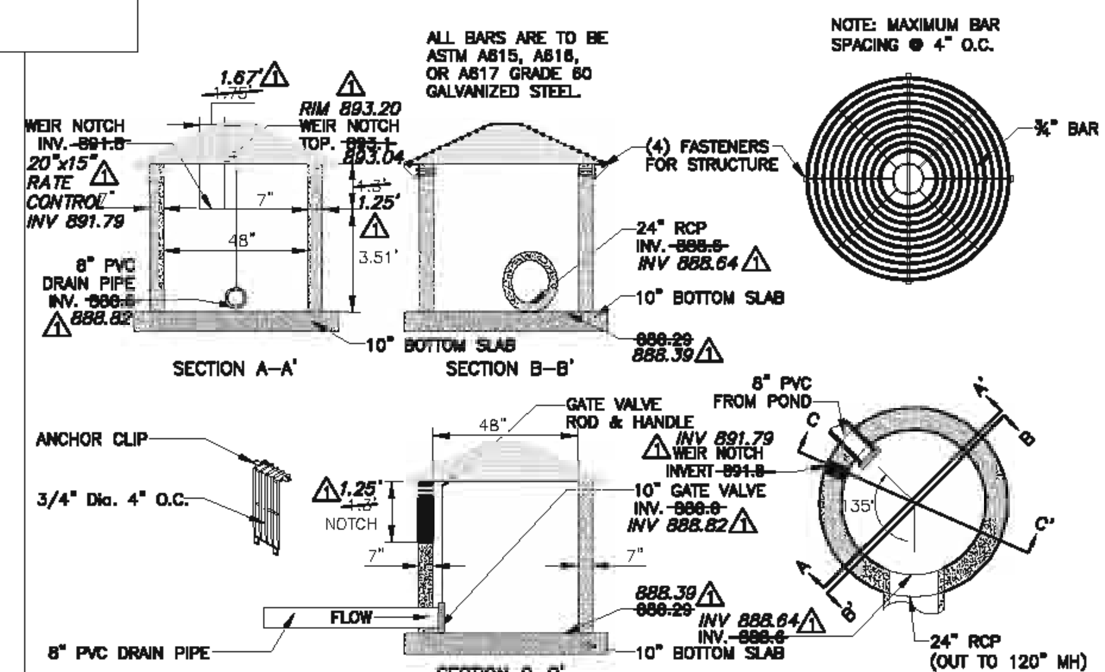
| PIPE SIZE | BARS | "H" | BOLTS |
|---|---|---|---|
| 12"-18" | 3/4"ø | 4" | 5/8" |
| 21"-42" | 1"ø | 6" | 3/4" |
| 48"-72" | 1 1/4"ø | 12" | 1" |

03 | 04 13 **FLARED END SECTION**
SCALE: NOT TO SCALE

**RECORD DRAWING**
REVISIONS BY IKR DATE 20FEB2008




04 | 04 13 **96 IN. DIVERSION STRUCTURE**
SCALE: NOT TO SCALE




05 | 04 13 **48 IN. OUTLET STRUCTURE**
SCALE: NOT TO SCALE

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| 1 | RECORD DRAWING | 2/20/08 | IR |

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651 HALE AVENUE NORTH
OAKDALE, MN 55128
PHONE: (651) 770-8448
FAX: (651) 770-2552
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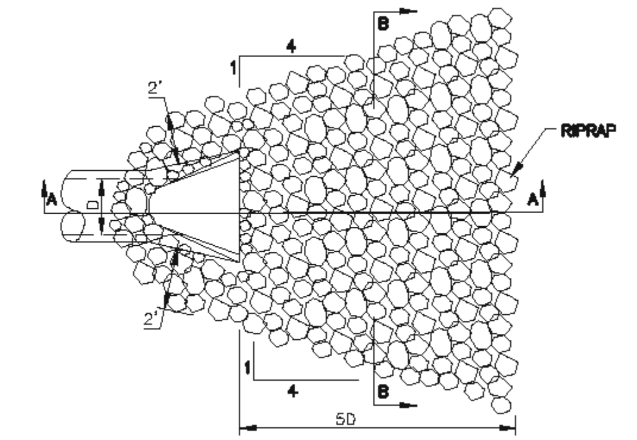
COMO GOLF COURSE POND GRADING & IMPROVEMENTS
CONSTRUCTION DETAILS II

Arlington Pascal Stormwater Improvement Project

Sheet No. 13 of 14 Sheets

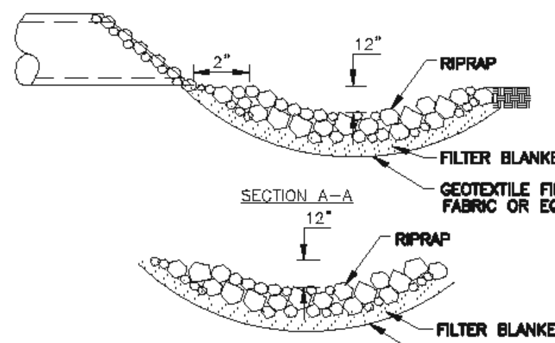



**RIPRAP REQUIREMENTS**

| | | |
|---|---|---|
| 12" TO 24" | 8 to 12 CY | CL.2 |
| 27" TO 33" | 14 to 20 CY | CL.3 |
| 36" TO 48" | 23 to 38 CY | CL.3 |
| 54" AND UP | 62 CY and up | CL.4 |

(ONE CUBIC YARD IS APPROXIMATELY 2,800 LBS.)

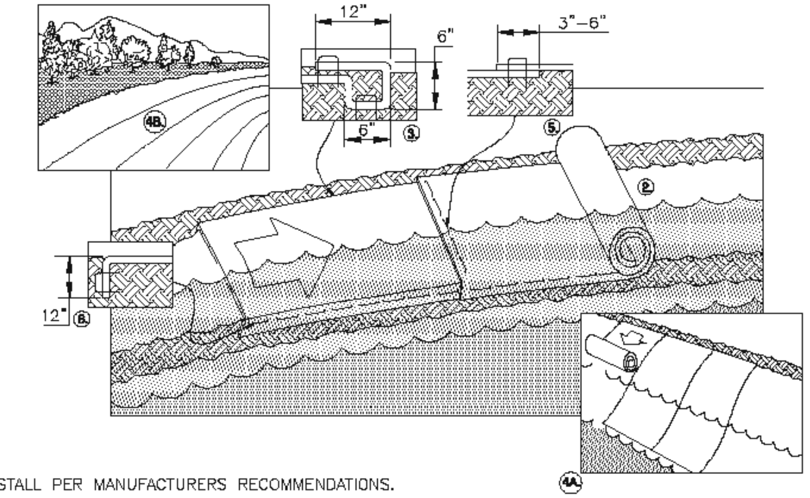
**NOTE**
FILTER BLANKET REQUIRED UNDER RIP RAP OR 2 LAYERS OF 500X MIRAFI




01
04|14

## RIP RAP INSTALLATION AT OUTLETS

SCALE: NOT TO SCALE




1. INSTALL PER MANUFACTURERS RECOMMENDATIONS.
2. PREPARE SOIL BEFORE INSTALLING BLANKETS, INCLUDING ANY NECESSARY APPLICATION OF SEED AND MULCH.
3. BEGIN AT THE TOP OF THE SHORELINE BY ANCHORING THE BLANKET IN A 6" DEEP X 6" WIDE TRENCH WITH APPROXIMATELY 12" (30cm) OF BLANKET EXTENDED BEYOND THE UP-SLOPE PORTION OF THE TRENCH. ANCHOR THE BLANKET WITH A ROW OF STAPLES/STAKES APPROXIMATELY 12" APART IN THE BOTTOM OF THE TRENCH. BACKFILL AND COMPACT THE TRENCH AFTER STAPLING. APPLY SEED TO COMPACTED SOIL AND FOLD REMAINING 12" PORTION OF BLANKET BACK OVER SEED AND COMPACTED SOIL. SECURE BLANKET OVER COMPACTED SOIL WITH A ROW OF STAPLES/STAKES SPACED APPROXIMATELY 12" APART ACROSS THE WIDTH OF THE BLANKET.
4. ROLL BLANKETS EITHER (A.) DOWN THE SHORELINE FOR LONG BANKS, (TOP TO BOTTOM) OR (B.) HORIZONTALLY ACROSS THE SHORELINE SLOPE. BLANKETS WILL UNROLL WITH APPROPRIATE SIDE AGAINST THE SOIL SURFACE. ALL BLANKETS MUST BE SECURELY FASTENED TO SOIL SURFACE BY PLACING STAPLES/STAKES IN APPROPRIATE LOCATIONS AS SHOWN IN THE STAPLE PATTERN GUIDE. WHEN USING OPTIONAL DOT SYSTEM , STAPLES/STAKES SHOULD BE PLACED THROUGH EACH OF THE COLORED DOTS CORRESPONDING TO THE APPROPRIATE STAPLE PATTERN.
5. THE EDGES OF ALL HORIZONTAL AND VERTICAL BLANKET SEAMS MUST BE STAPLED WITH APPROXIMATELY 3–6" OVERLAP. TO ENSURE PROPER SEAM ALIGNMENT BETWEEN ADJACENT BLANKETS, PLACE THE EDGE OF THE OVERLAPPING BLANKET (BLANKET BEING INSTALLED ON TOP) EVEN WITH THE COLORED SEAM STITCH ON THE PREVIOUSLY INSTALLED BLANKET. SECURE ALL OVERLAPS WITH STAPLES SPACED 12" APART.

NOTE: * SEAM OVERLAP SHOULD BE SHINGLED ACCORDING TO DIRECTION OF WATER FLOW.

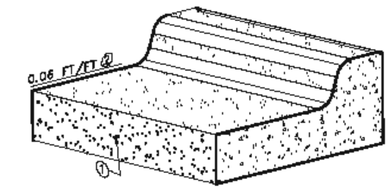
6. THE EDGE OF THE BLANKET AT OR BELOW NORMAL WATER LEVEL MUST BE ANCHORED BY PLACING THE BLANKET IN A 12" DEEP X 6" WIDE ANCHOR TRENCH. ANCHOR THE BLANKET WITH A ROW OF STAPLES/STAKES SPACED APPROXIMATELY 12" APART IN THE TRENCH. BACKFILL AND COMPACT THE TRENCH AFTER STAPLING (STONE OR SOIL MAY BE USED AS BACKFILL.)

NOTE. * IN LOOSE SOIL CONDITIONS, THE USE OF STAPLE OR STAKE LENGTHS GREATER THAN 6" MAY BE NECESSARY TO PROPERLY ANCHOR THE BLANKETS.

02
04|14

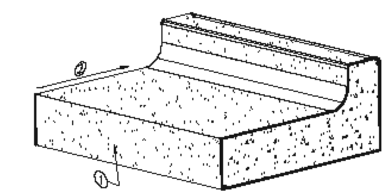
## EROSION BLANKET SLOPE INSTALLATION

SCALE: NOT TO SCALE




DESIGN B

REVERSE SLOPE GUTTER SECTION
(FORMS MAY BE TILTED)




DESIGN V

NOTES:
1. LONGITUDNAL JOINT WHEN ADJACENT TO RIGID PAVEMENT OR BASE
2. SLOPE 0.06 FT/FT NORMAL, UNLESS OTEHRWISE SPECIFIED, GUTTER SLOPE IS PERMITTED, THE FORM MAY BE TILTED

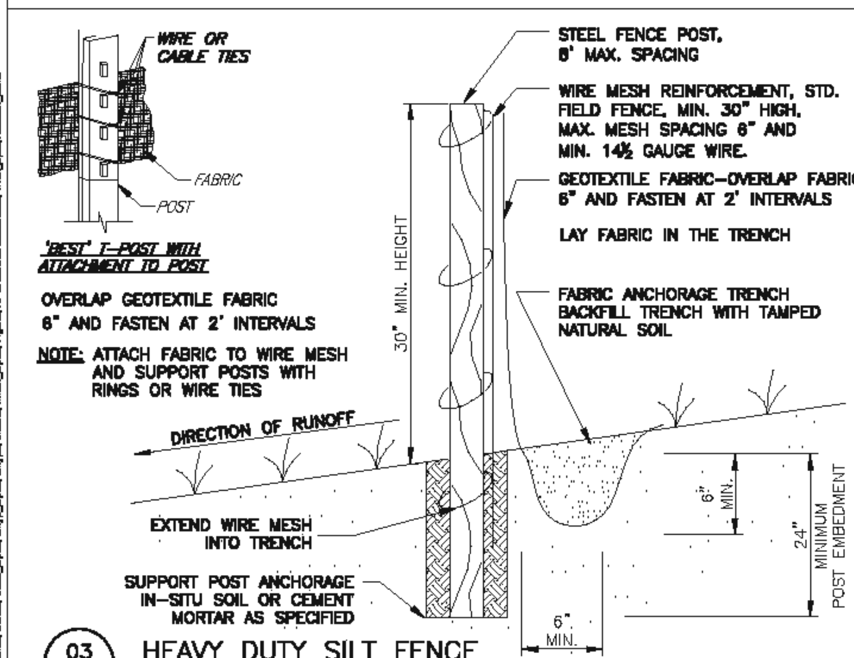
| DESIGN B | | |
|---|---|---|
| [illegible] | A | B |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |

| DESIGN V | | |
|---|---|---|
| [illegible] | A | B |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |

05
03|14

## CONCRETE CURB & GUTTER (DESIGN B AND V)

SCALE: NOT TO SCALE




OVERLAP GEOTEXTILE FABRIC 6" AND FASTEN AT 2' INTERVALS

NOTE: ATTACH FABRIC TO WIRE MESH AND SUPPORT POSTS WITH RINGS OR WIRE TIES

03
04|14

## HEAVY DUTY SILT FENCE

SCALE: NOT TO SCALE

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COMO GOLF COURSE POND GRADING & IMPROVEMENTS CONSTRUCTION DETAILS III

Arlington Pascal Stormwater Improvement Project

Sheet No. 14 of 14 Sheets

**RECORD DRAWING**
REVISIONS BY IKR DATE 20FEB2008

# BMP As-Built:
# Underground Infiltration Trenches

Capitol Region Watershed District

# ARLINGTON/PASCAL RSVP INFILTRATION TRENCHES

## ST. PAUL, MINNESOTA

AS BUILT

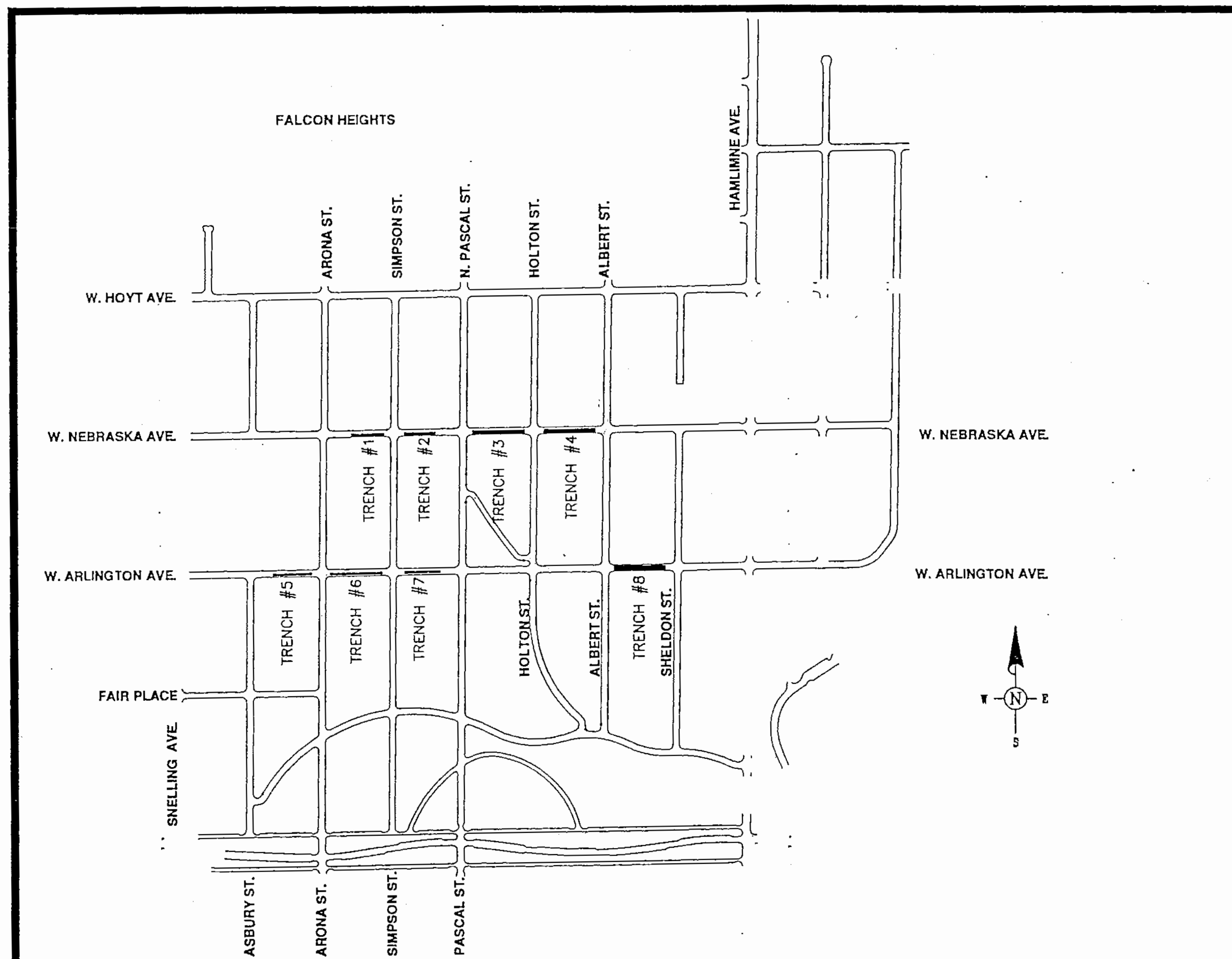
PROJECT CONTACTS


*OWNER*

*CAPITOL REGION WATERSHED DISTRICT*
*BOB FOSSUM*
*1410 ENERGY PARK DR, STE 4*
*ST PAUL, MN 55108*
*PH: (651) 644-8888*

*PROJECT MANAGER*

*JOEL PETERSON*
*EMMONS & OLIVIER RESOURCES, INC.*
*651 HALE AVENUE NORTH*
*OAKDALE, MINNESOTA 55128*
*PH: (651) 770-8448*

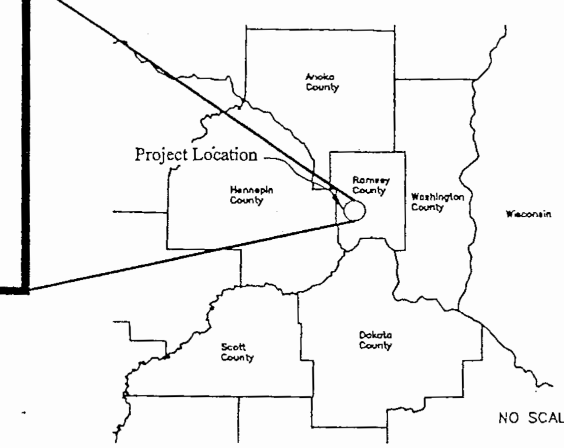




SITE MAP

NOT TO SCALE

SHEET INDEX

| SHEET | TITLE |
|---|---|
| 01 | TITLE SHEET AND LOCATION MAP |
| 02 | TRENCH 1 AND 2 PLAN |
| 03 | TRENCH 3 AND 4 PLAN |
| 04 | TRENCH 5 AND 6 PLAN |
| 05 | TRENCH 7 AND 8 PLAN |
| 06 | TYPICAL TRENCH SECTIONS – NEBRASKA |
| 07 | TYPICAL TRENCH SECTIONS – ARLINGTON |
| 08 | MANHOLE CONNECTION DETAIL |
| 09 | PVC END CAP DETAIL |




LOCATION MAP

UTILITIES

THE LOCATION OF UNDERGROUND FACILITES OR STRUCTURES AS SHOWN ON THE PLANS ARE BASED ON AVAILABLE RECORDS AT THE TIME THE PLANS WERE PREPARED AND ARE NOT GUARANTEED TO BE COMPLETE OR CORRECT. CONTRACTOR IS RESPOSIBLE FOR CONTACTING ALL UTILITIES 72 HOURS PRIOR TO CONSTRUCTION TO DETERMINE THE EXACT LOCATION OF ALL FACILITIES AND TO PROVIDE ADEQUATE PROTECTION OF SAID UTILITIES DURING THE COURSE OF WORK.

GOPHER STATE ONE-CALL

IT IS THE LAW THAT ANYONE EXCAVATING AT ANY SITE MUST NOTIFY GOPHER STATE ONE CALL (GSOC) SO THAT UNDERGROUND ELECTRIC, NATURAL GAS, TELEPHONE OR OTHER UTILITY LINES CAN BE MARKED ON OR NEAR YOUR PROPERTY BEFORE ANY DIGGING BEGINS. A 48-HOUR NOTICE, NOT INCLUDING WEEKENDS, IS REQUIRED. CALLS CAN BE MADE TO GSOC AT 1-800-252-1166 OR (651)454-0002, MONDAY THROUGH FRIDAY (EXCEPT HOLIDAYS) FROM 7 A.M. TO 5 P.M.

| NO. | REVISION DESCRIPTION | DATE | BY |
|---|---|---|---|

I hereby certify that this plan was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota

Print Name: JOEL R PETERSON

Sign Name:

Date XX-XX-05 License No. 44595

Date 30 Mar 06

Designed By JRP

Drawn By JRP

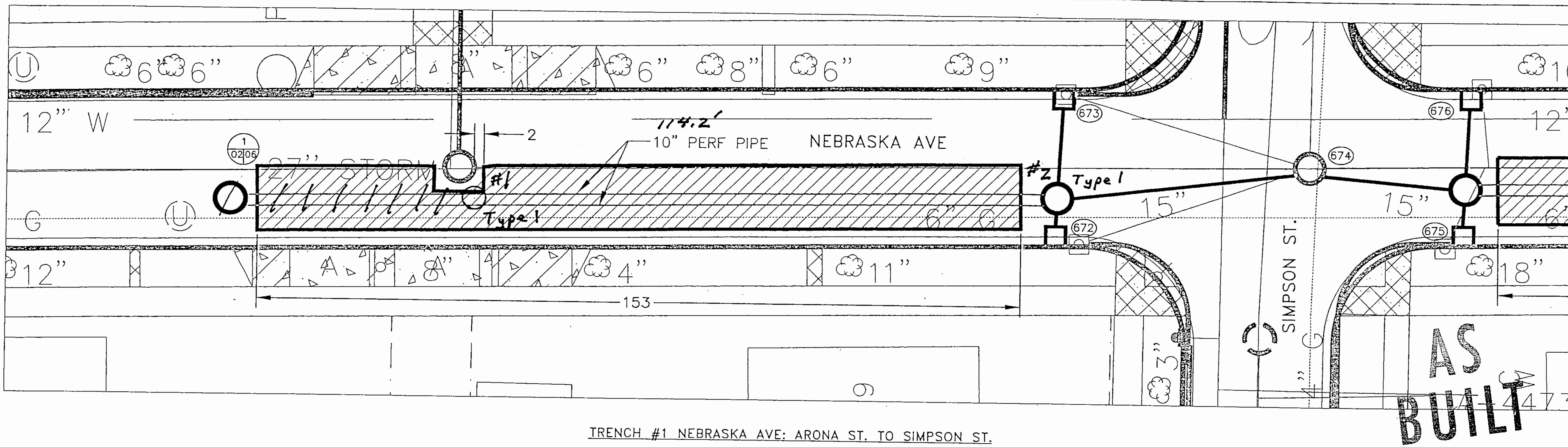

EOR

EMMONS & OLIVIER RESOURCES
651 HALE AVENUE NORTH
OAKDALE, MN 55128
PHONE: (651) 770-8448
FAX: (651) 770-2552
WEBSITE: www.eorinc.com

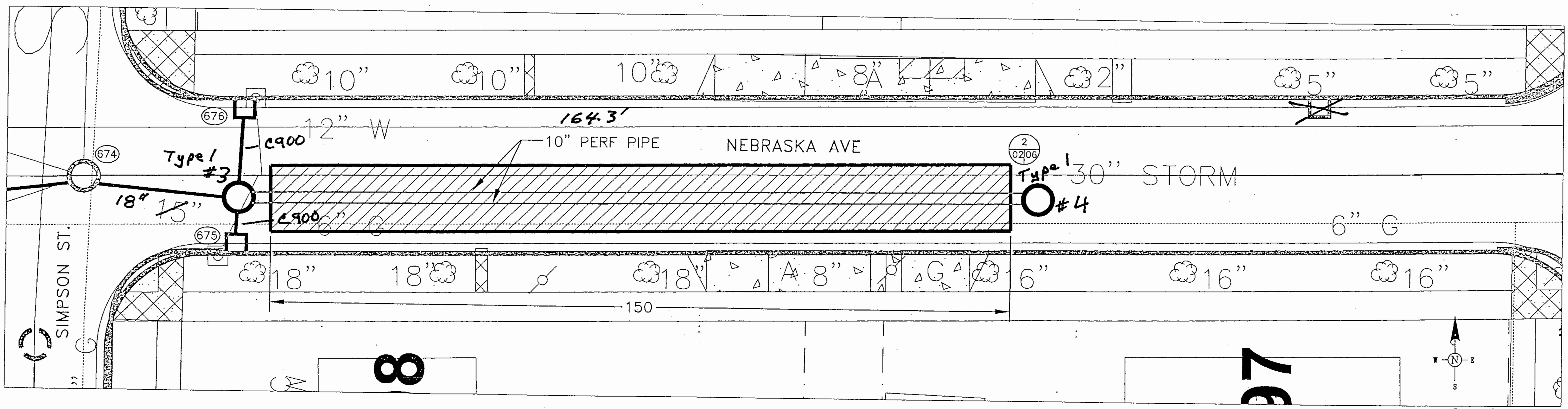

CAPITOL REGION WATERSHED DISTRICT
ARLINGTON/PASCAL RSVP INFILTRATION TRENCHES
ST. PAUL, MINNESOTA

TITLE SHEET AND LOCATION MAP

Sheet No: 01 of 09 Sheets




TRENCH #1 NEBRASKA AVE: ARONA ST. TO SIMPSON ST.




TRENCH #2 NEBRASKA AVE: SIMPSON ST. TO PASCAL ST. NORTH

SCALE 1" = 10'

10' 0 10' 20' 30 FEET

GRAPHIC SCALE

| No. | Revision Description | Date | By |
|---|---|---|---|

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TRENCH 1 AND 2
PLAN

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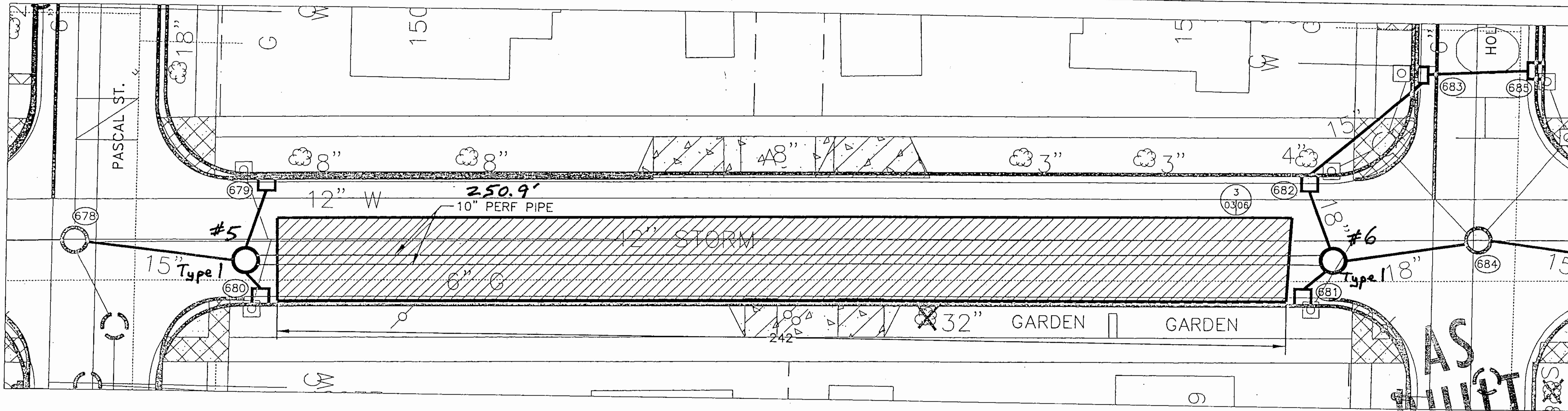
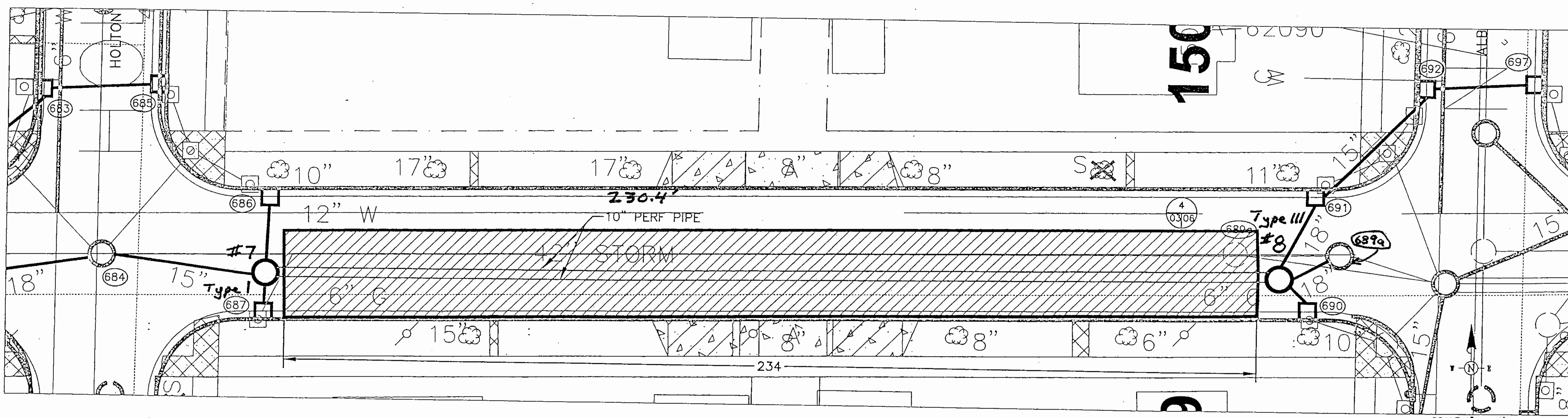
Sheet No. 02 of 09 Sheets




TRENCH #3 NEBRASKA AVE: PASCAL ST. TO HOLTON ST.




TRENCH #4 NEBRASKA AVE: HOLTON ST. TO ALBERT ST.

SCALE 1" = 1'

12' 0 12' 24' 36 FEET

GRAPHIC SCALE

| No. | Revision Description | Date | By |
|---|---|---|---|

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TRENCH 3 AND 4
PLAN

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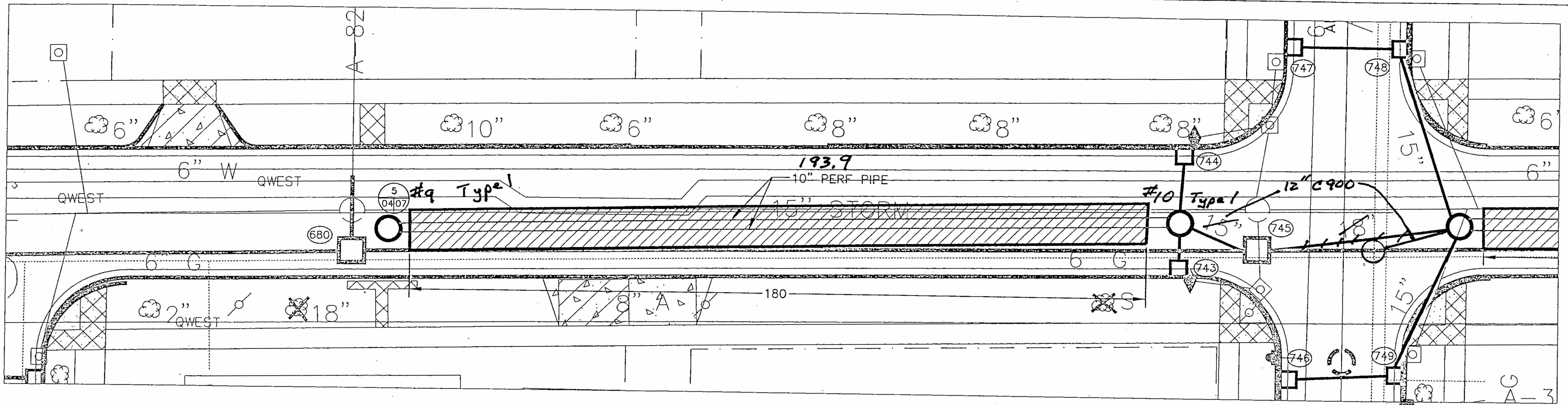
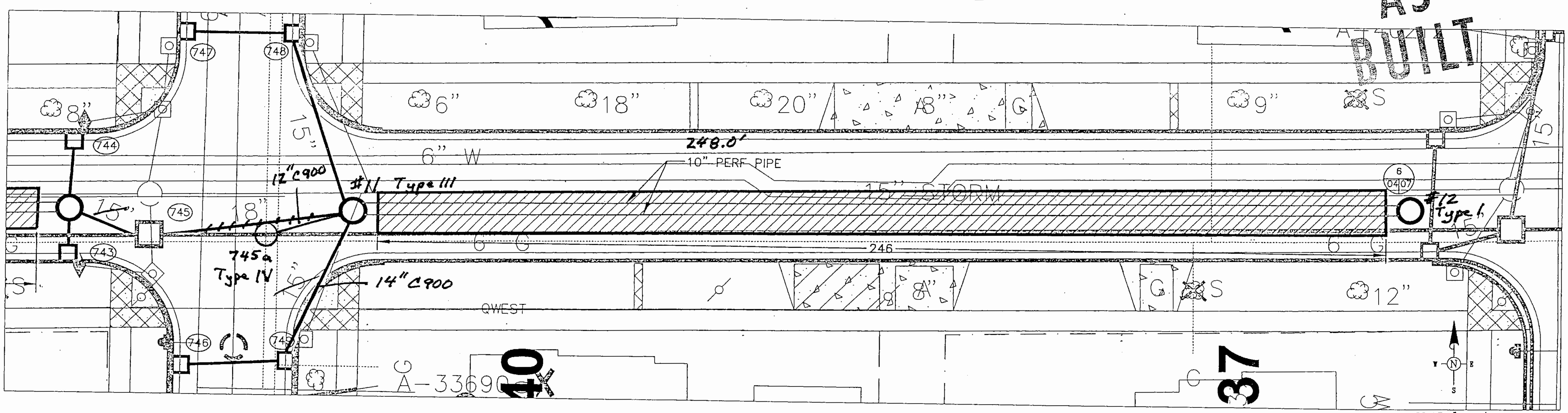
Sheet No. 03 of 09 Sheets




TRENCH #5 ARLINGTON AVE: ASBURY ST. TO ARONA ST.




TRENCH #6 ARLINGTON AVE: ARONA ST. TO SIMPSON ST.

SCALE 1" = 1'

12' 0 12' 24' 36 FEET

GRAPHIC SCALE

| No. | Revision Description | Date | By |
|---|---|---|---|
| | | | |

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TRENCH 5 AND 6
PLAN

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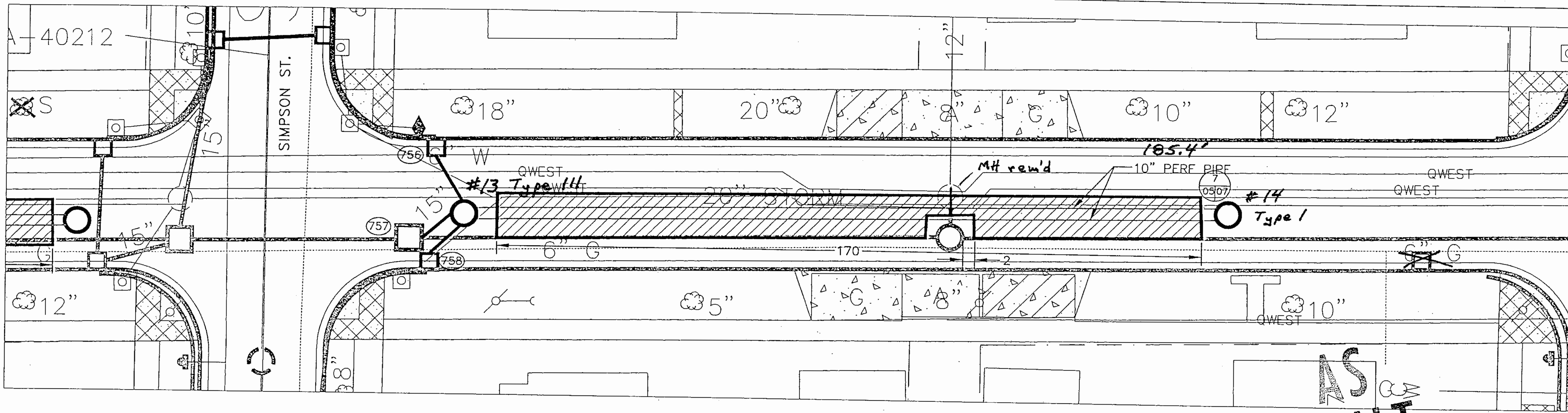
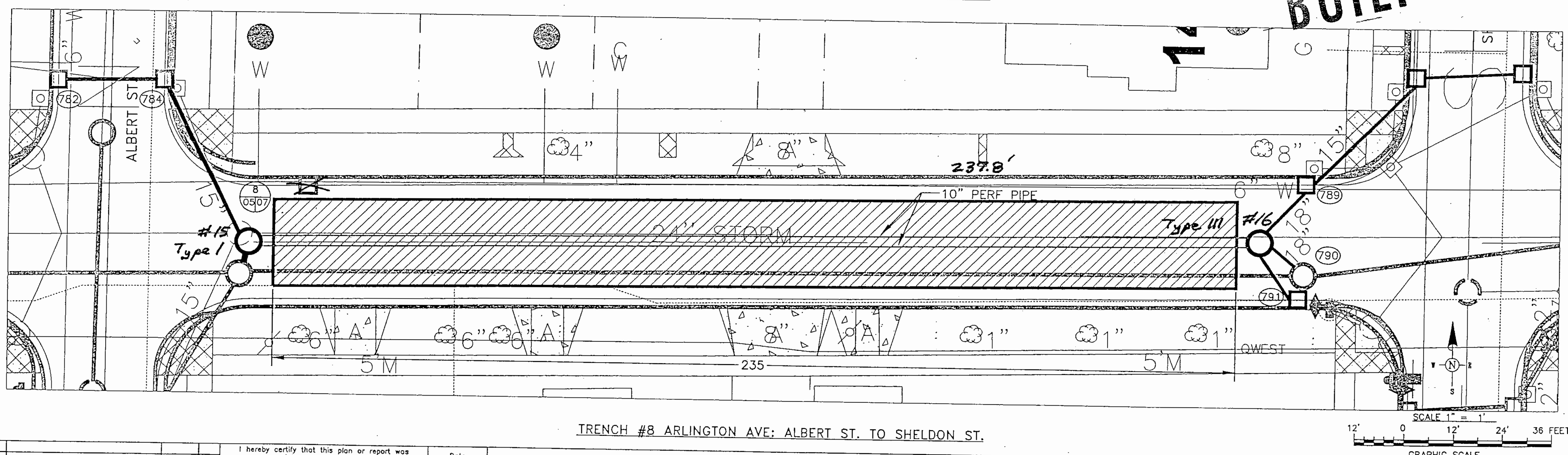



TRENCH #7 ARLINGTON AVE: SIMPSON ST. TO PASCAL ST.




TRENCH #8 ARLINGTON AVE: ALBERT ST. TO SHELDON ST.

| No. | Revision Description | Date | By |
|---|---|---|---|

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TRENCH 7 AND 8
PLAN

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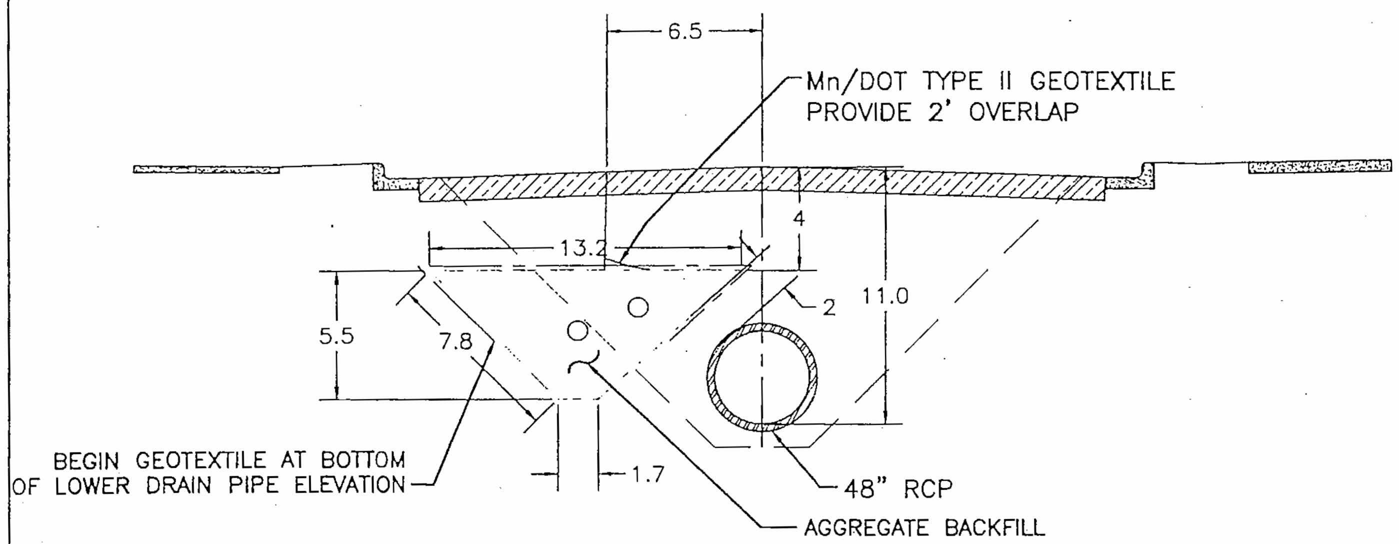
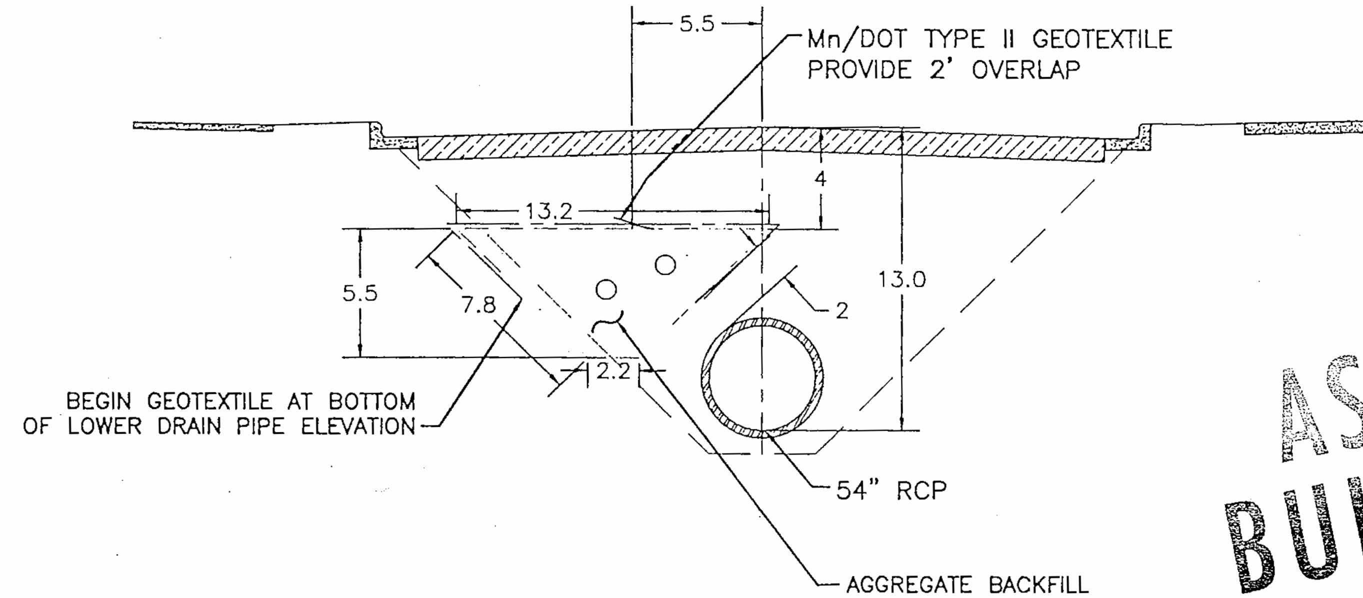
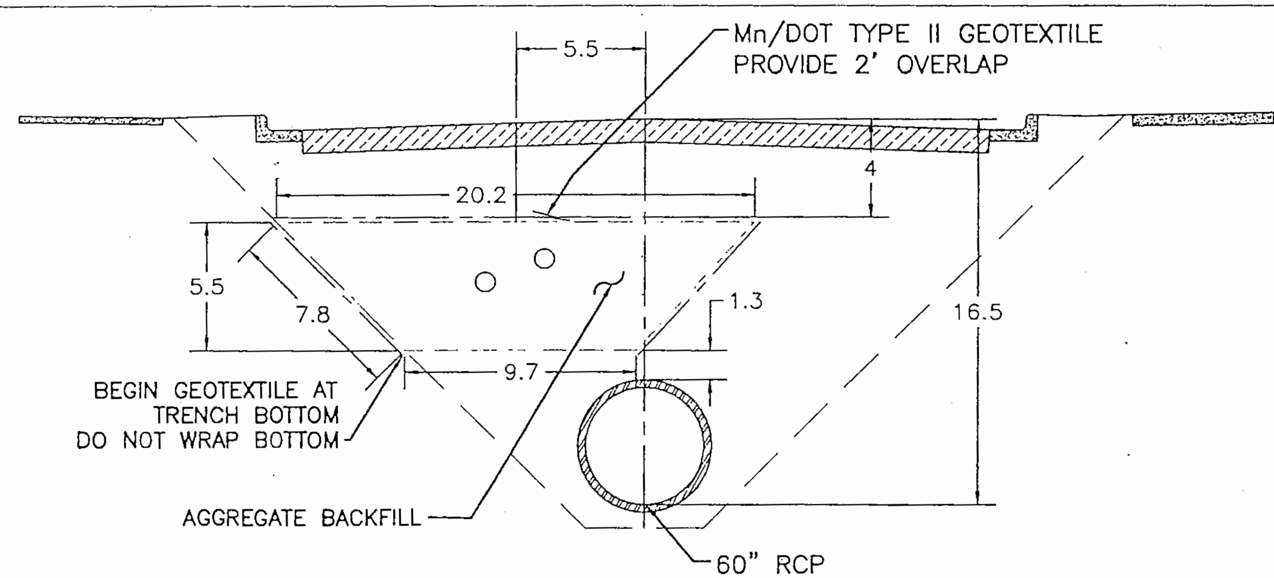



1 / 02|06 NEBRASKA – ARONA TO SIMPSON
SCALE: NOT TO SCALE

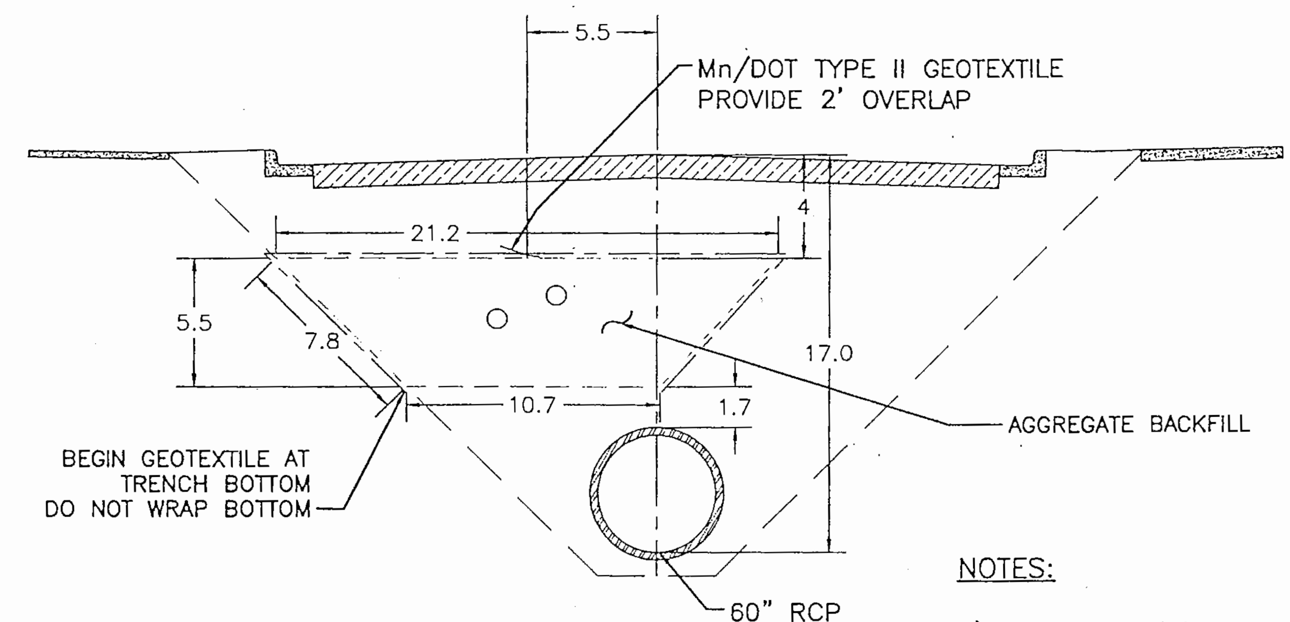



AS BUILT

2 / 02|06 NEBRASKA – SIMPSON TO PASCAL
SCALE: NOT TO SCALE




3 / 03|06 NEBRASKA – PASCAL TO HOLTON
SCALE: NOT TO SCALE




NOTES:

1) ALL MATERIAL SPECIFICATIONS SHALL CONFORM TO ORIGINAL BIDDING DOCUMENTS

4 / 03|06 NEBRASKA – HOLTON TO ALBERT
SCALE: NOT TO SCALE

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|---|---|---|---|

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TYPICAL TRENCH
SECTIONS – NEBRASKA

NEBRASKA AVE

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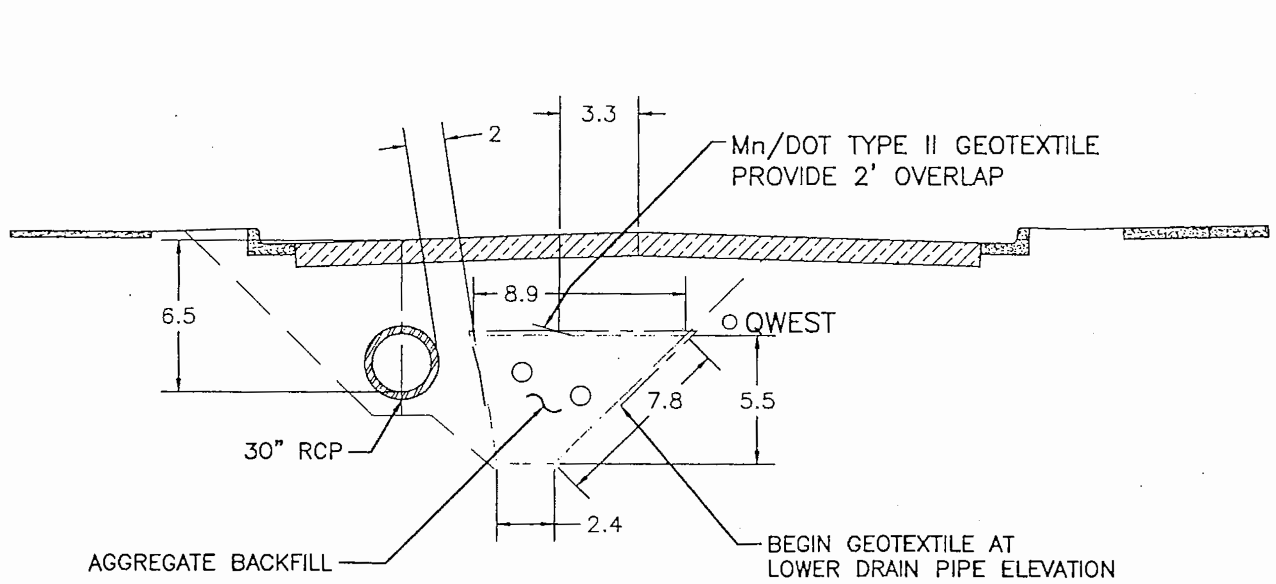
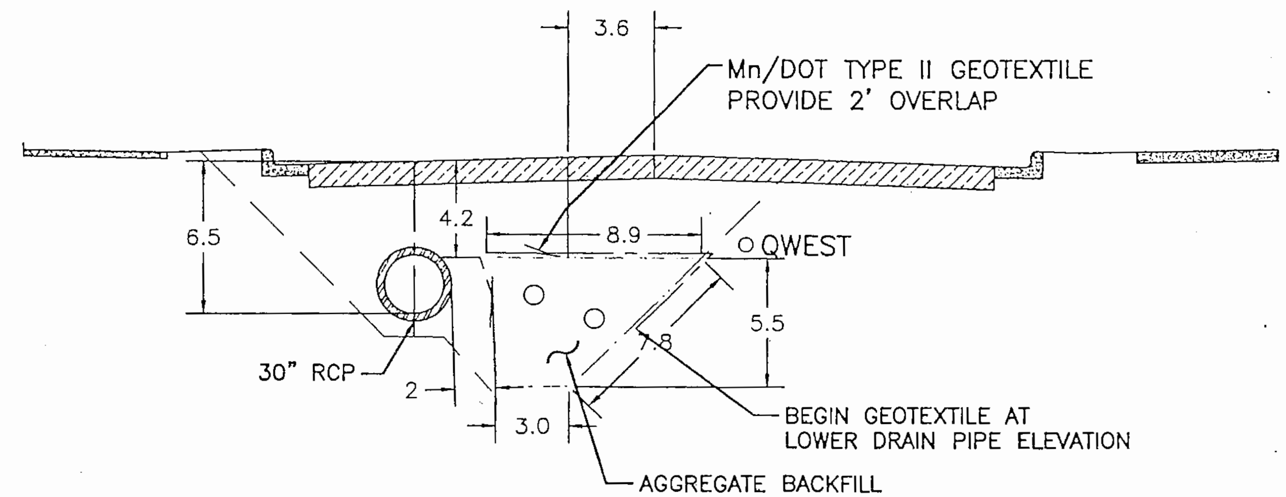
Sheet No. 06 of 09 Sheets

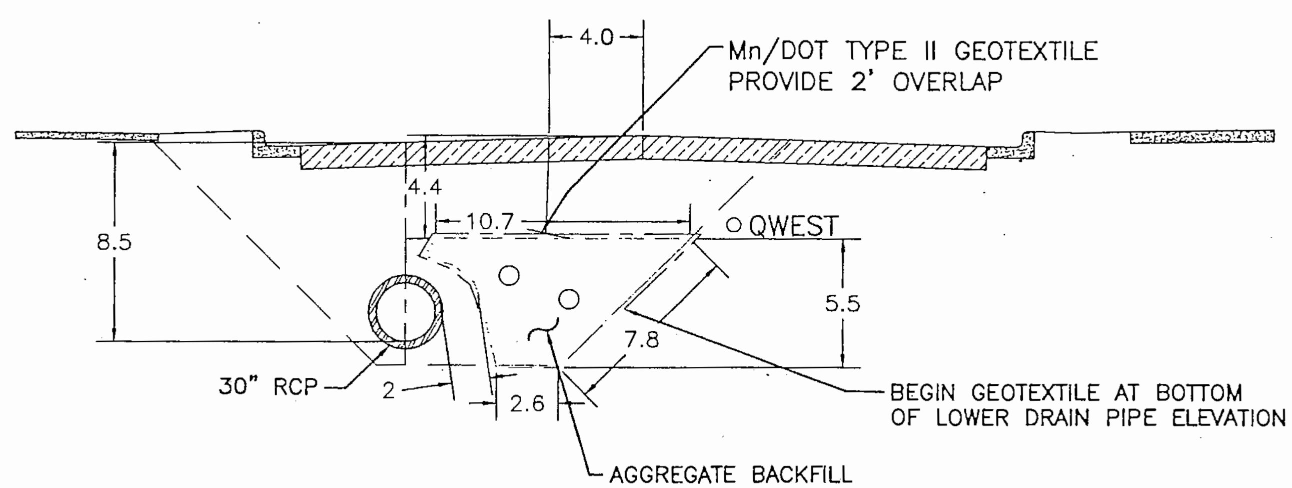



5 04|07 ARLINGTON – ASBURY TO ARONA
SCALE: NOT TO SCALE

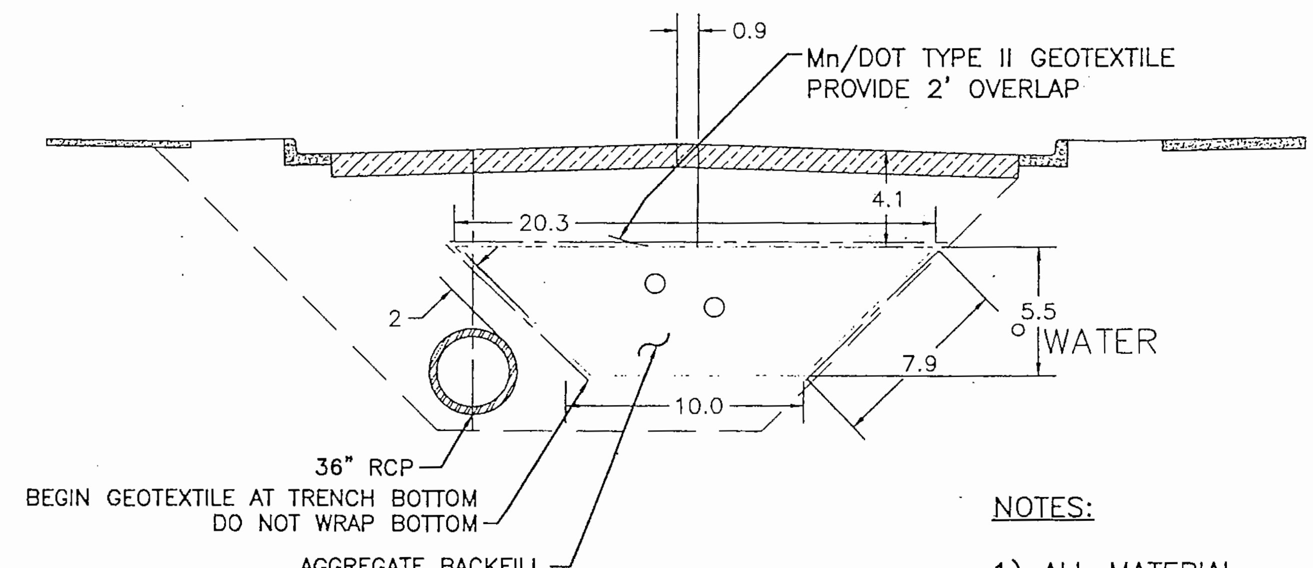



6 04|07 ARLINGTON – ARONA TO SIMPSON
SCALE: NOT TO SCALE

AS BUILT




7 05|07 ARLINGTON – SIMPSON TO PASCAL
SCALE: NOT TO SCALE




8 05|07 ARLINGTON – ALBERT TO SHELDON
SCALE: NOT TO SCALE

NOTES:

1) ALL MATERIAL SPECIFICATIONS SHALL CONFORM TO ORIGINAL BIDDING DOCUMENTS

| No. | Revision Description | Date | By |
|---|---|---|---|
| | | | |

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Sign Name:

Date X-X-X License No. 44595

Date 30 MAR 06

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Checked By JRP

TYPICAL TRENCH SECTIONS – ARLINGTON

ARLINGTON AVE


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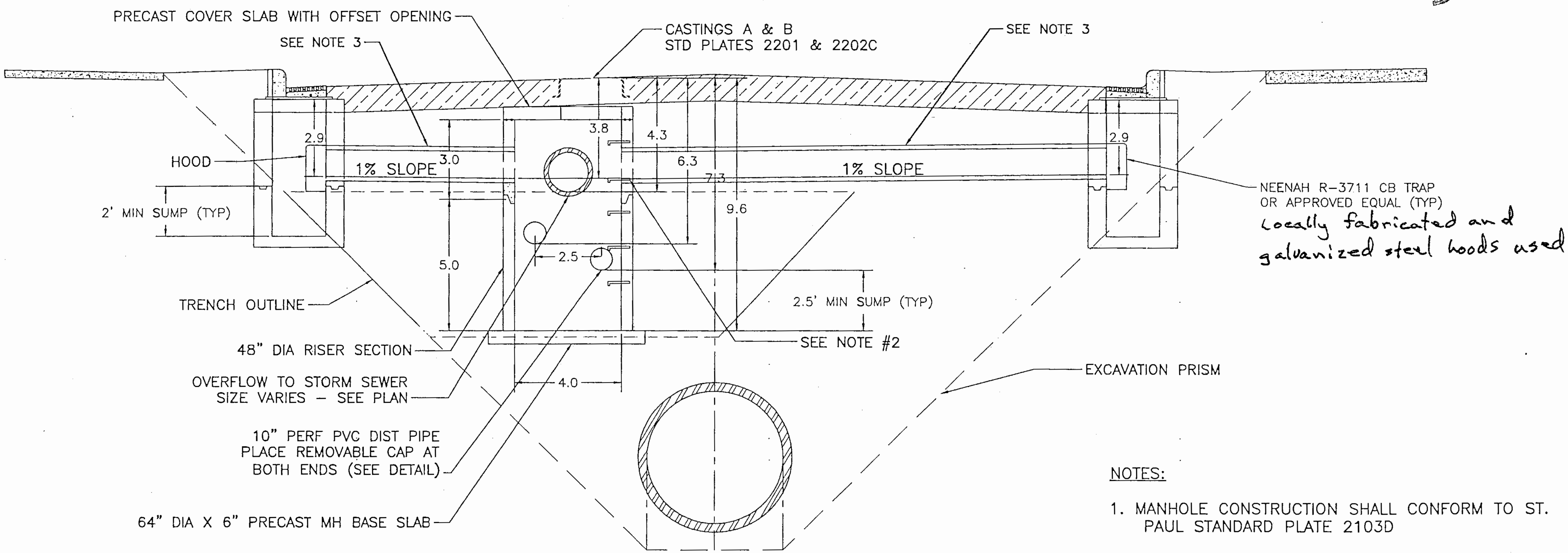
Sheet No. 07 of 09 Sheets

AS BUILT




## CONNECTION DETAIL

NOTES:

1. MANHOLE CONSTRUCTION SHALL CONFORM TO ST. PAUL STANDARD PLATE 2103D
2. PLACE MANHOLE TO AVOID CONFLICT BETWEEN STEPS AND PIPES
3. ALL CB LEADS ARE 12" UNLESS SPECIFIED ON PLANS
4. MATERIAL SPECIFICATIONS SHALL CONFORM TO ORIGINAL BIDDING DOCUMENTS

| No. | Revision Description | Date | By |
|---|---|---|---|

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Sign Name:

Date X-X-X License No. 44595

Date 30 MAR 06

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Checked By JRP

MANHOLE CONNECTION DETAIL

MODIFIED TYPE III MANHOLE


EMMONS & OLIVIER RESOURCES
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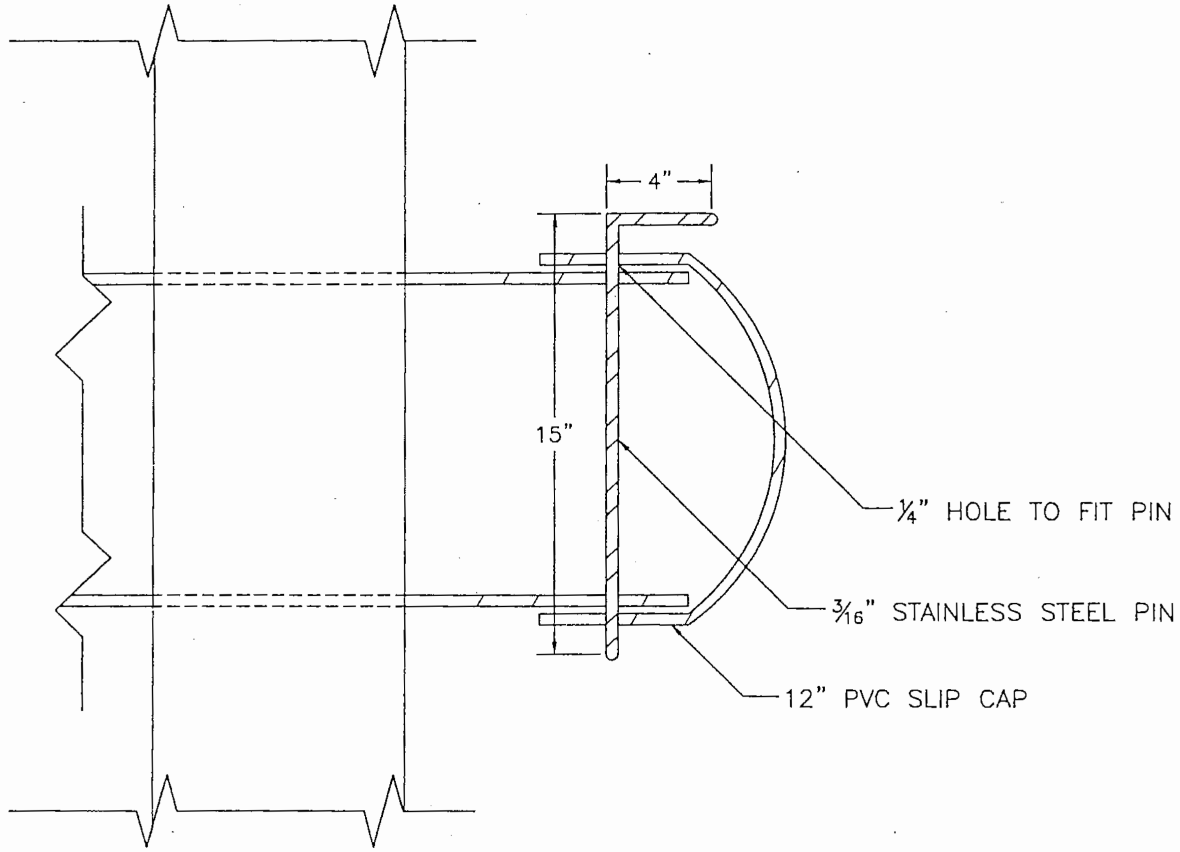
Sheet No. 08 of 09 Sheets




AS BUILT

| No. | Revision Description | Date | By |
|---|---|---|---|
| | | | |

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Sign Name:

Date X-X-X License No. 44595

Date 30 MAR 06

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PVC END CAP DETAIL


EMMONS & OLIVIER RESOURCES
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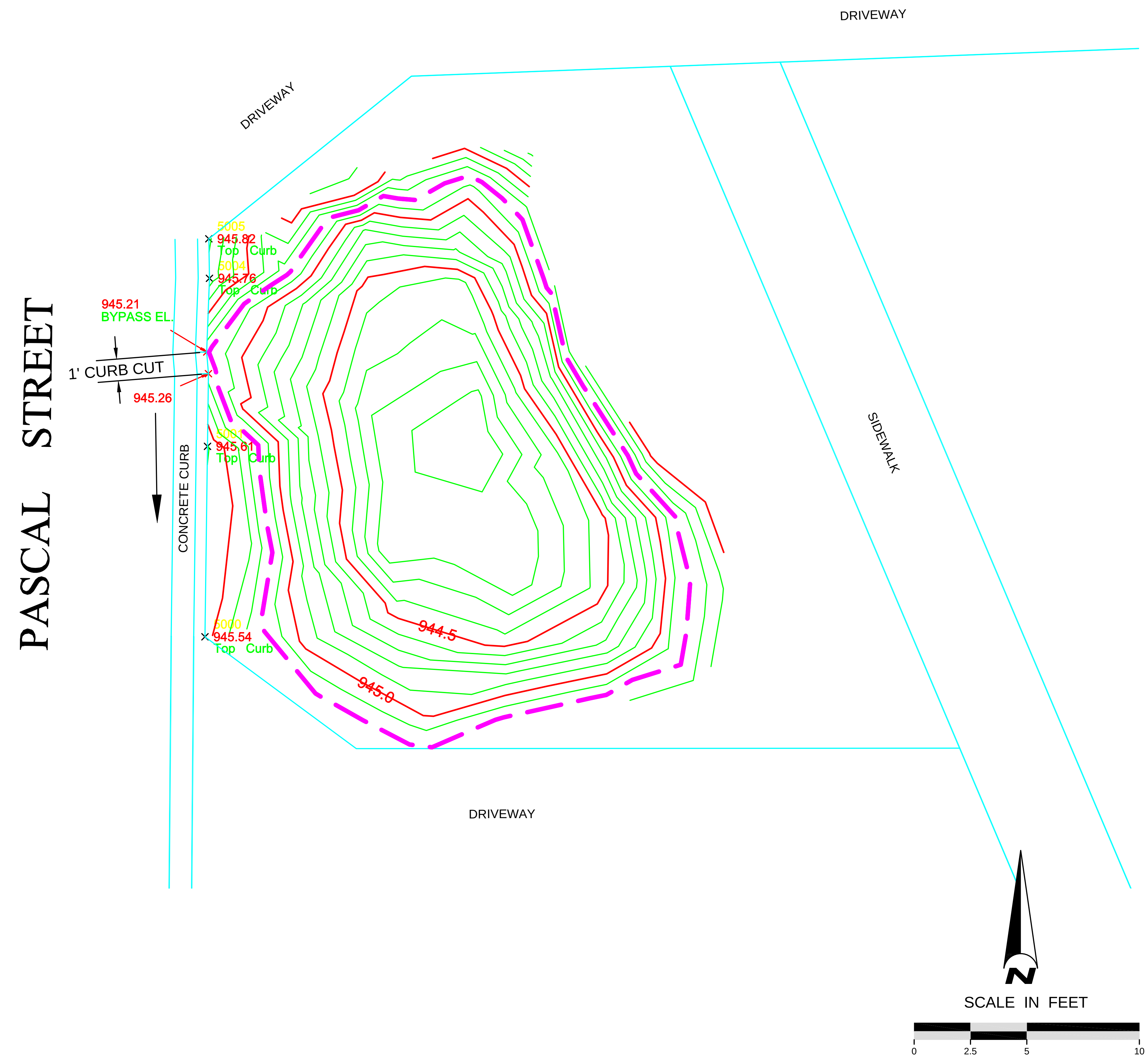
Sheet No. 09 of 09 Sheets

# Rain Garden Topographical Surveys

Figure B-4. Rain Gardens Topographic Surveys (October 2008).

# RG-1




| RAINGARDEN 1 | | | |
|---|---|---|---|
| BYPASS EL. = 945.21 = 0.00 DEPTH | | | |
| Water Depth | Depth Below Inlet | Area Sq. Ft. | Accum. Volume Cu. Ft. |
| 1.1 | 0.0 | 357.1 | 211 |
| 1.0 | 0.1 | 323.7 | 174 |
| 0.9 | 0.2 | 292.6 | 143 |
| 0.8 | 0.3 | 267.2 | 115 |
| 0.7 | 0.4 | 229.8 | 90 |
| 0.6 | 0.5 | 201.8 | 69 |
| 0.5 | 0.6 | 174.9 | 50 |
| 0.4 | 0.7 | 148.2 | 34 |
| 0.3 | 0.8 | 120.1 | 20 |
| 0.2 | 0.9 | 83.2 | 10 |
| 0.1 | 1.0 | 52.1 | 3 |
| 0.0 | 1.1 | 11.6 | |

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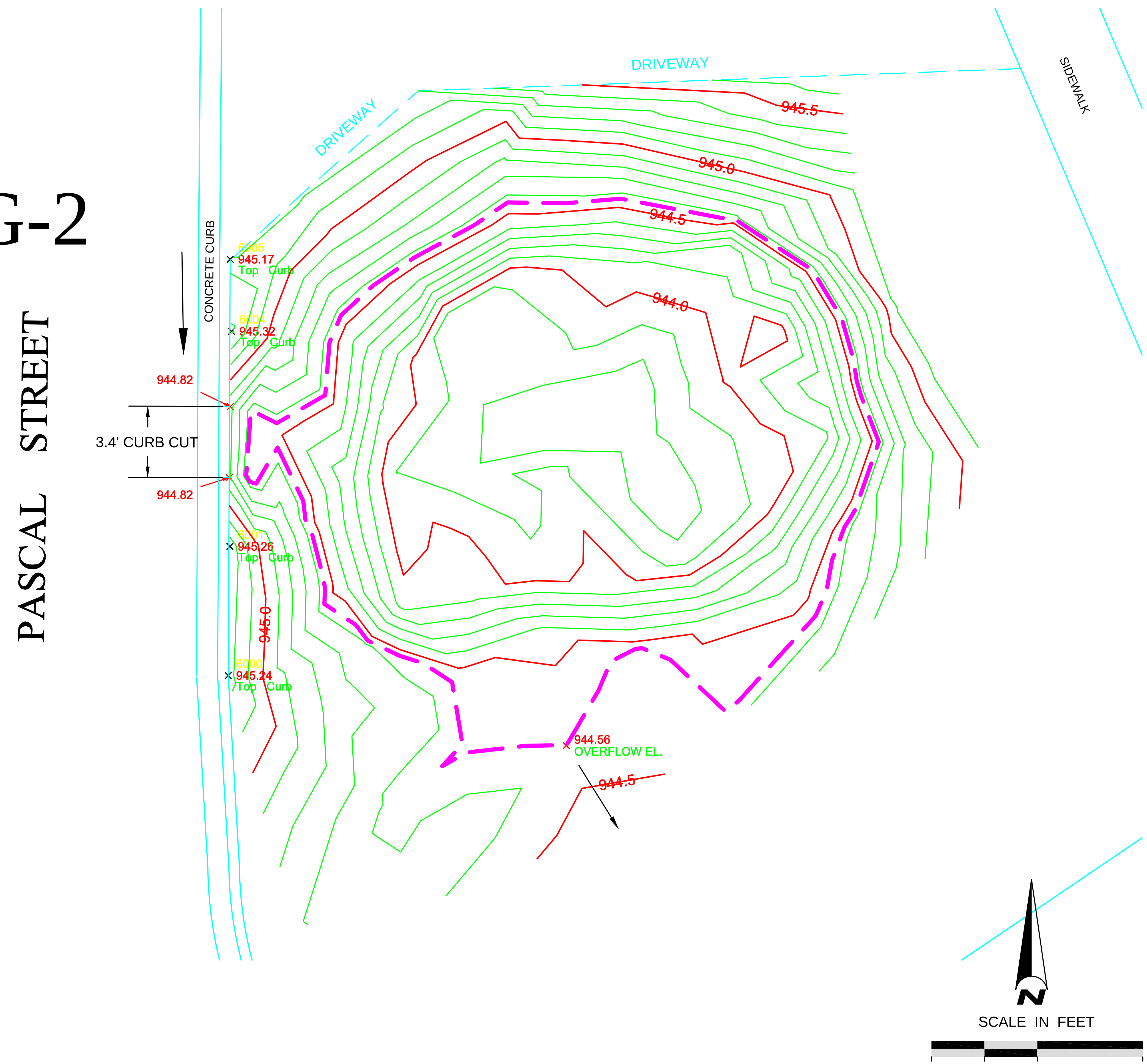
# RG-2




| RAINGARDEN 2 | | | |
|---|---|---|---|
| | BYPASS EL. = 944.82<br>OVERFLOW = 944.56 = 0.00 DEPTH | | |
| Water Depth | Depth Below Inlet | Area Sq. Ft. | Accum. Volume Cu. Ft. |
| 0.8 | 0.0 | 534 | 227 |
| 0.7 | 0.1 | 461.8 | 197 |
| 0.6 | 0.2 | 409.0 | 153 |
| 0.5 | 0.3 | 366.8 | 114 |
| 0.4 | 0.4 | 325.7 | 80 |
| 0.3 | 0.5 | 281.7 | 49 |
| 0.2 | 0.6 | 209.4 | 25 |
| 0.1 | 0.7 | 124.6 | 8 |
| 0.0 | 0.8 | 38.6 | |

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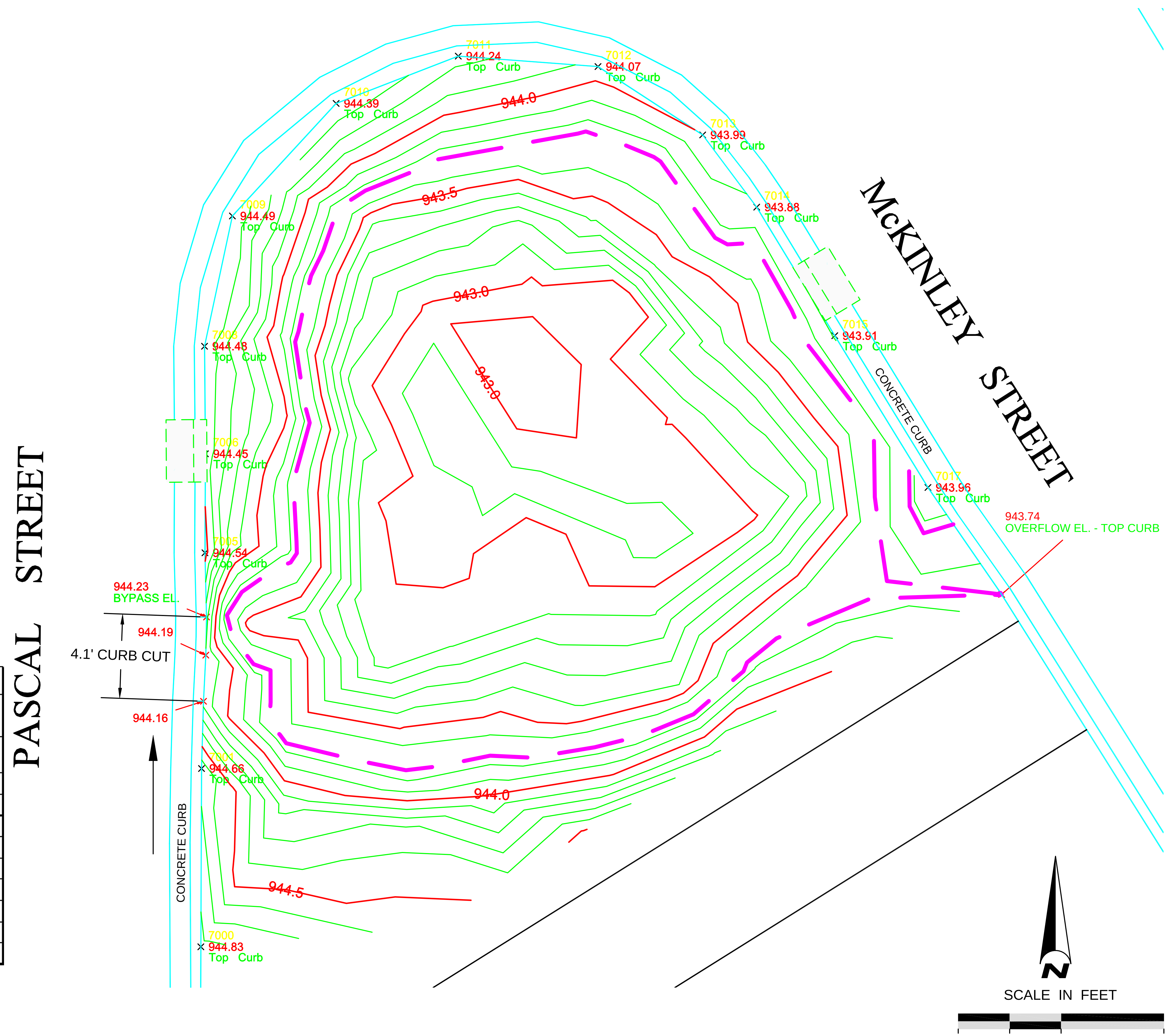
# RG-3




| RAINGARDEN 3 | | | |
|---|---|---|---|
| BYPASS EL. = 944.23<br>OVERFLOW = 943.74 = 0.00 DEPTH | | | |
| Water Depth | Depth Below Inlet | Area Sq. Ft. | Accum. Volume Cu. Ft. |
| 0.8 | 0.0 | 708 | 346 |
| 0.7 | 0.1 | 604.6 | 254 |
| 0.6 | 0.2 | 537.9 | 197 |
| 0.5 | 0.3 | 471.6 | 146 |
| 0.4 | 0.4 | 411.3 | 102 |
| 0.3 | 0.5 | 351.1 | 64 |
| 0.2 | 0.6 | 284.4 | 32 |
| 0.1 | 0.7 | 161.8 | 10 |
| 0.0 | 0.8 | 38.2 | |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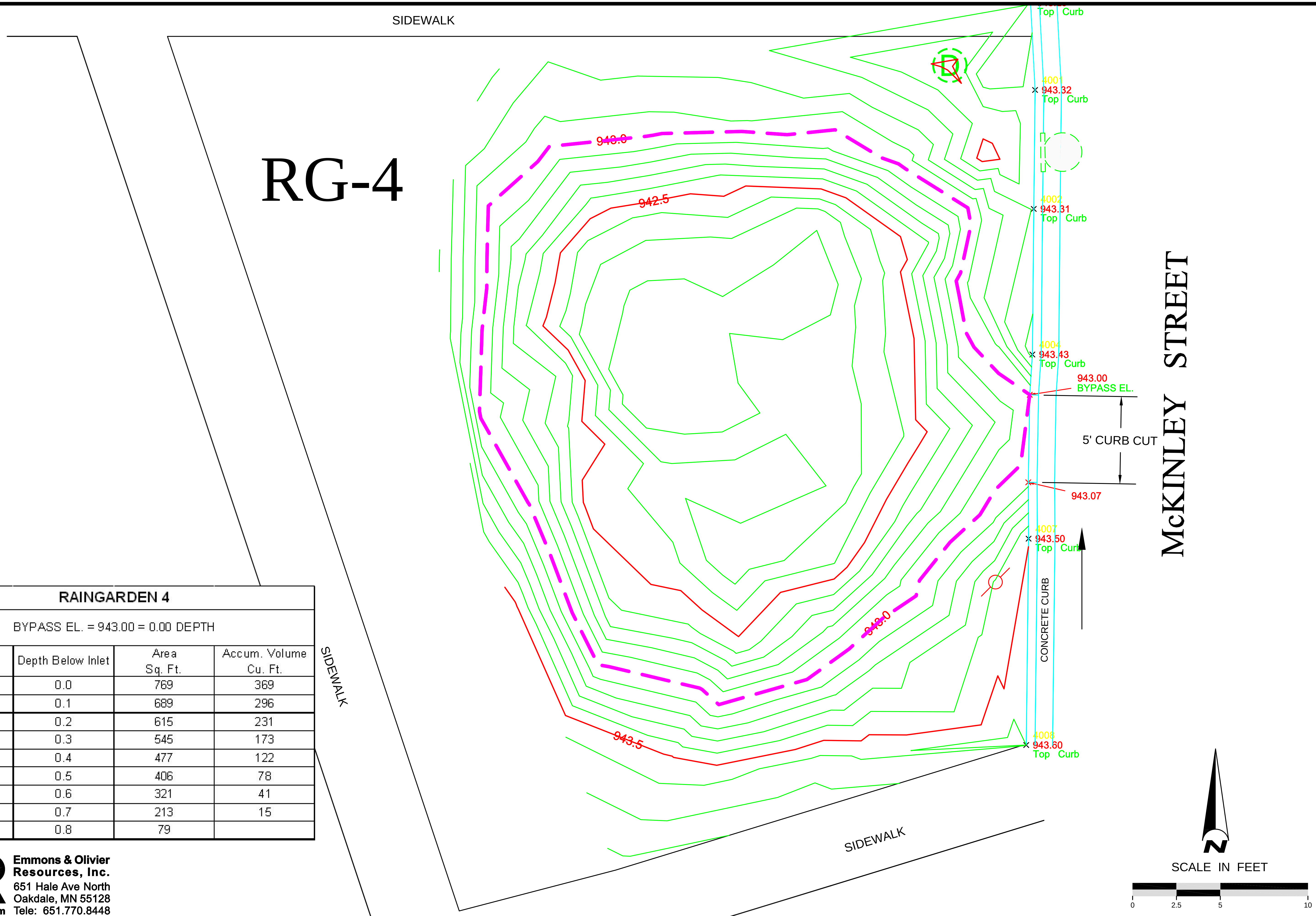


| RAINGARDEN 4 | | | |
|---|---|---|---|
| BYPASS EL. = 943.00 = 0.00 DEPTH | | | |
| Water Depth | Depth Below Inlet | Area Sq. Ft. | Accum. Volume Cu. Ft. |
| 0.8 | 0.0 | 769 | 369 |
| 0.7 | 0.1 | 689 | 296 |
| 0.6 | 0.2 | 615 | 231 |
| 0.5 | 0.3 | 545 | 173 |
| 0.4 | 0.4 | 477 | 122 |
| 0.3 | 0.5 | 406 | 78 |
| 0.2 | 0.6 | 321 | 41 |
| 0.1 | 0.7 | 213 | 15 |
| 0.0 | 0.8 | 79 | |


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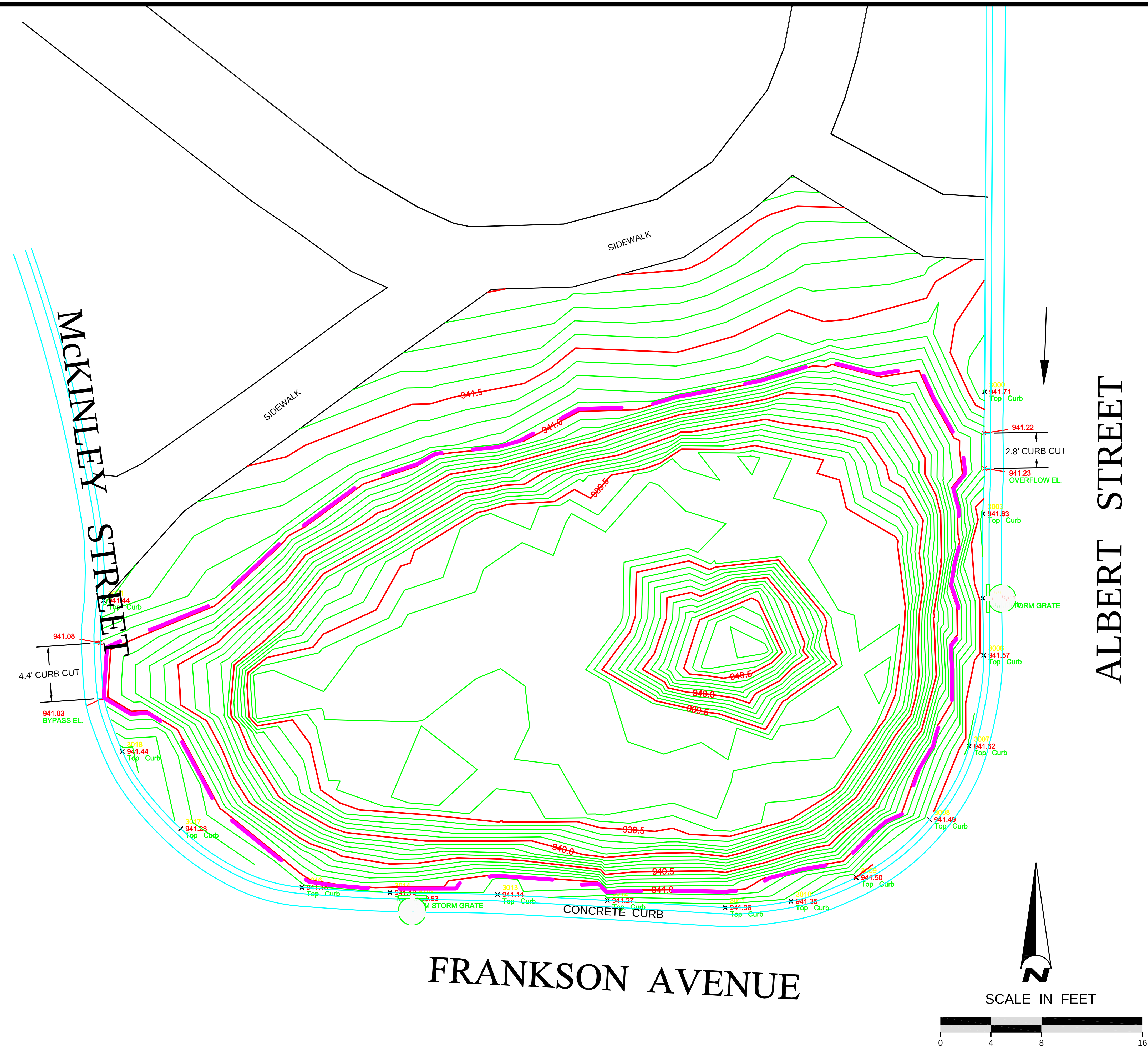
# RG-5




| RAINGARDEN 5 | | | |
|---|---|---|---|
| BYPASS EL. = 941.03 = 0.00 DEPTH<br>OVERFLOW = 941.23 | | | |
| Water Depth | Depth Below Inlet | Area Sq. Ft. | Accum. Volume Cu. Ft. |
| 1.7 | 0.0 | 2076 | 2491 |
| 1.6 | 0.1 | 1971 | 2228 |
| 1.5 | 0.2 | 1897 | 2035 |
| 1.4 | 0.3 | 1822 | 1849 |
| 1.3 | 0.4 | 1753 | 1670 |
| 1.2 | 0.5 | 1685 | 1499 |
| 1.1 | 0.6 | 1619 | 1333 |
| 1.0 | 0.7 | 1553 | 1175 |
| 0.9 | 0.8 | 1486 | 1023 |
| 0.8 | 0.9 | 1421 | 877 |
| 0.7 | 1.0 | 1356 | 739 |
| 0.6 | 1.1 | 1290 | 606 |
| 0.5 | 1.2 | 1222 | 481 |
| 0.4 | 1.3 | 1148 | 362 |
| 0.3 | 1.4 | 1069 | 251 |
| 0.2 | 1.5 | 980 | 149 |
| 0.1 | 1.6 | 796 | 60 |
| 0.0 | 1.7 | 406 | |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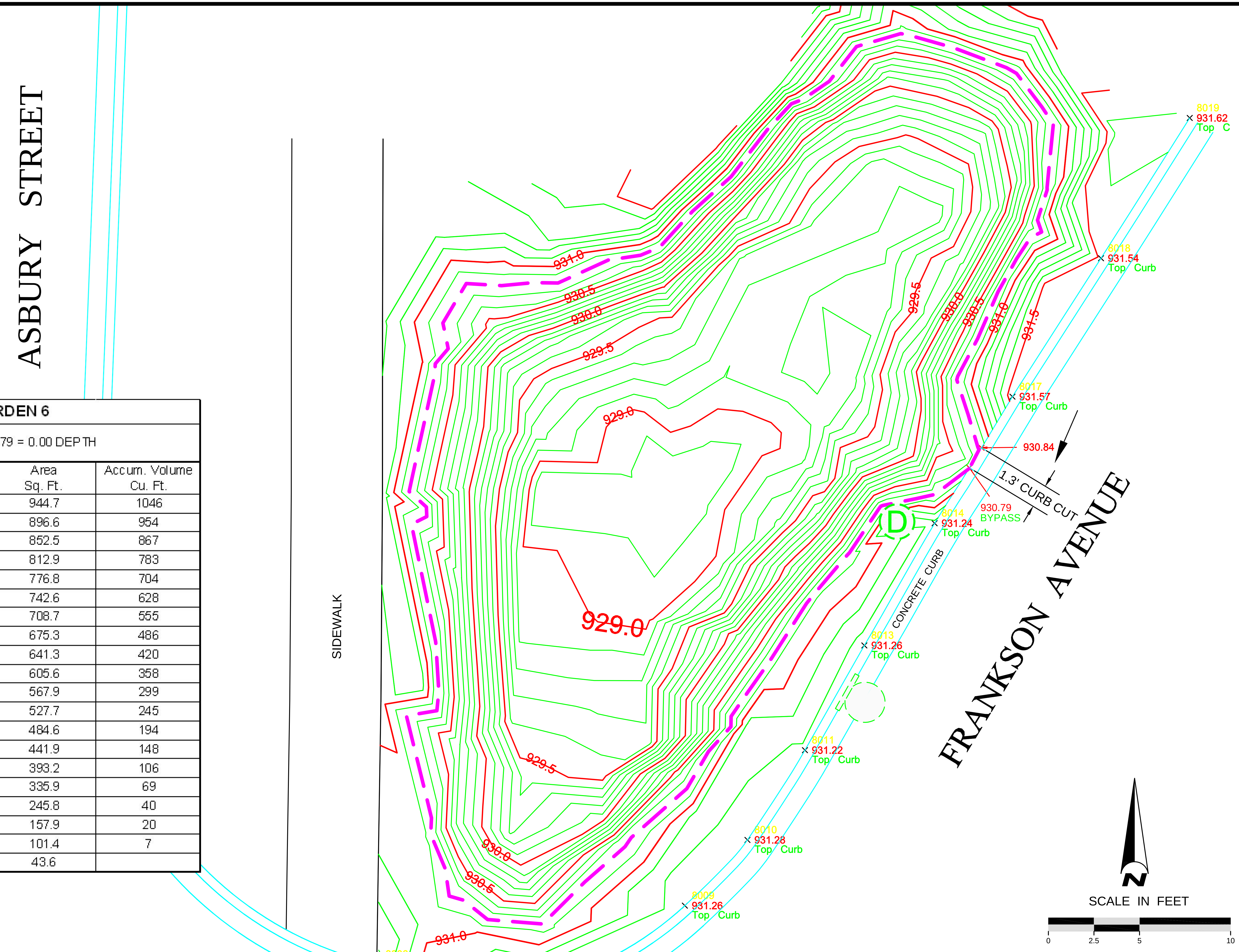
# RG-6




| RAINGARDEN 6 | | | |
|---|---|---|---|
| BYPASS EL. = 930.79 = 0.00 DEPTH | | | |
| Water Depth | Depth Below Inlet | Area Sq. Ft. | Accum. Volume Cu. Ft. |
| 1.9 | 0.0 | 944.7 | 1046 |
| 1.8 | 0.1 | 896.6 | 954 |
| 1.7 | 0.2 | 852.5 | 867 |
| 1.6 | 0.3 | 812.9 | 783 |
| 1.5 | 0.4 | 776.8 | 704 |
| 1.4 | 0.5 | 742.6 | 628 |
| 1.3 | 0.6 | 708.7 | 555 |
| 1.2 | 0.7 | 675.3 | 486 |
| 1.1 | 0.8 | 641.3 | 420 |
| 1.0 | 0.9 | 605.6 | 358 |
| 0.9 | 1.0 | 567.9 | 299 |
| 0.8 | 1.1 | 527.7 | 245 |
| 0.7 | 1.2 | 484.6 | 194 |
| 0.6 | 1.3 | 441.9 | 148 |
| 0.5 | 1.4 | 393.2 | 106 |
| 0.4 | 1.5 | 335.9 | 69 |
| 0.3 | 1.6 | 245.8 | 40 |
| 0.2 | 1.7 | 157.9 | 20 |
| 0.1 | 1.8 | 101.4 | 7 |
| 0.0 | 1.9 | 43.6 | |

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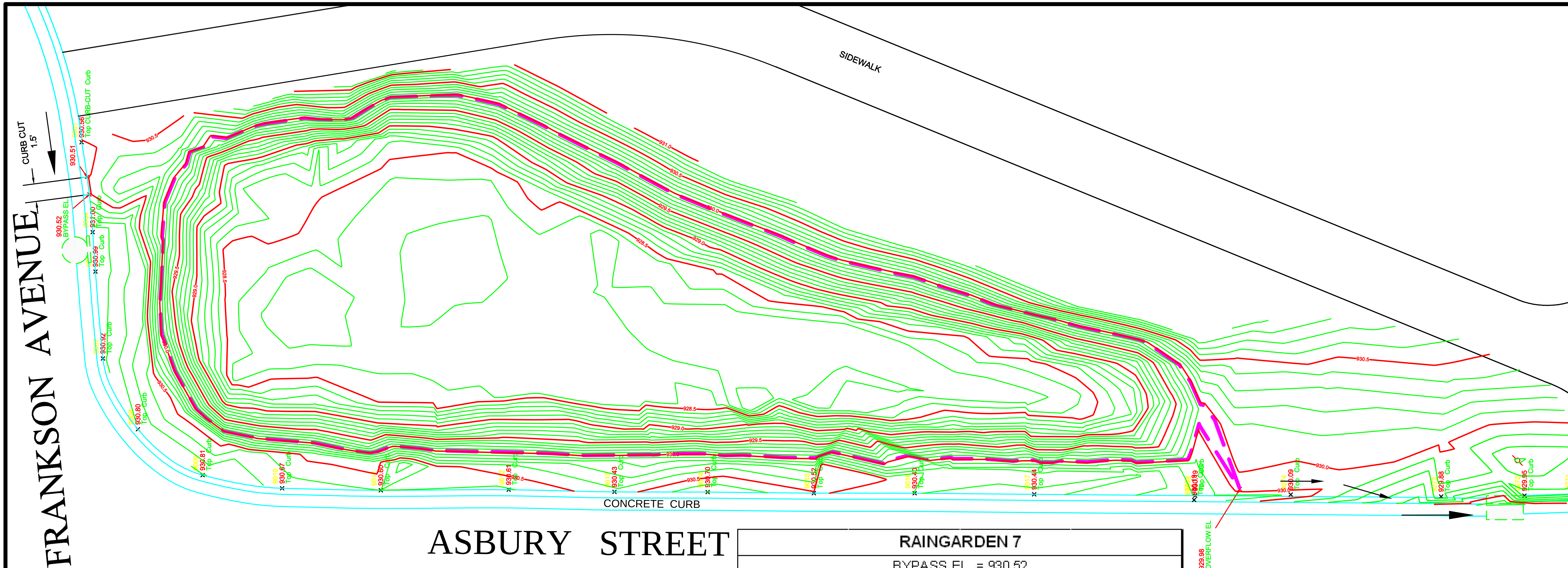


**RAINGARDEN 7**

BYPASS EL. = 930.52
OVERFLOW EL. = 929.98 = 0.00 DEPTH

| Water Depth | Depth Below Inlet | Area Sq. Ft. | Accum. Volume Cu. Ft. |
|---|---|---|---|
| 1.8 | 0.0 | 1713.0 | 2112 |
| 1.7 | 0.1 | 1667.8 | 1977 |
| 1.6 | 0.2 | 1618.9 | 1812 |
| 1.5 | 0.3 | 1570.7 | 1653 |
| 1.4 | 0.4 | 1522.6 | 1498 |
| 1.3 | 0.5 | 1473.7 | 1348 |
| 1.2 | 0.6 | 1424.6 | 1203 |
| 1.1 | 0.7 | 1375.4 | 1063 |
| 1.0 | 0.8 | 1326.2 | 928 |
| 0.9 | 0.9 | 1276.5 | 798 |
| 0.8 | 1.0 | 1225.1 | 673 |
| 0.7 | 1.1 | 1170.0 | 553 |
| 0.6 | 1.2 | 1110.8 | 439 |
| 0.5 | 1.3 | 1043.6 | 332 |
| 0.4 | 1.4 | 964.2 | 231 |
| 0.3 | 1.5 | 858.3 | 140 |
| 0.2 | 1.6 | 687.3 | 63 |
| 0.1 | 1.7 | 276.4 | 15 |
| 0.0 | 1.8 | 15.0 | |

SCALE IN FEET

0 4 8 16

EOR
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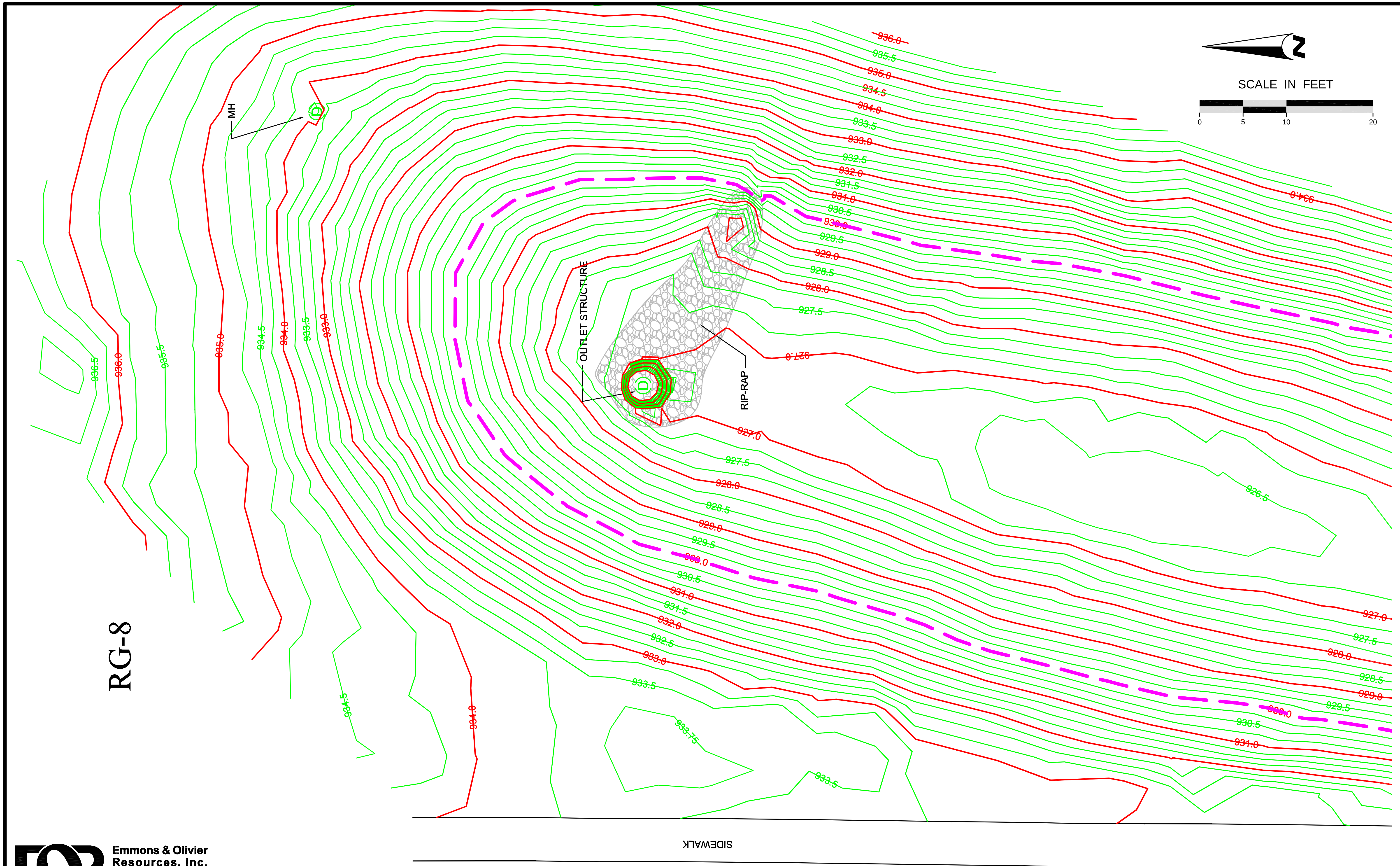
Oakdale, MN 55128
Tele: 651.770.8448
www.eorinc.com




# RG-8

HAMLINE AVENUE

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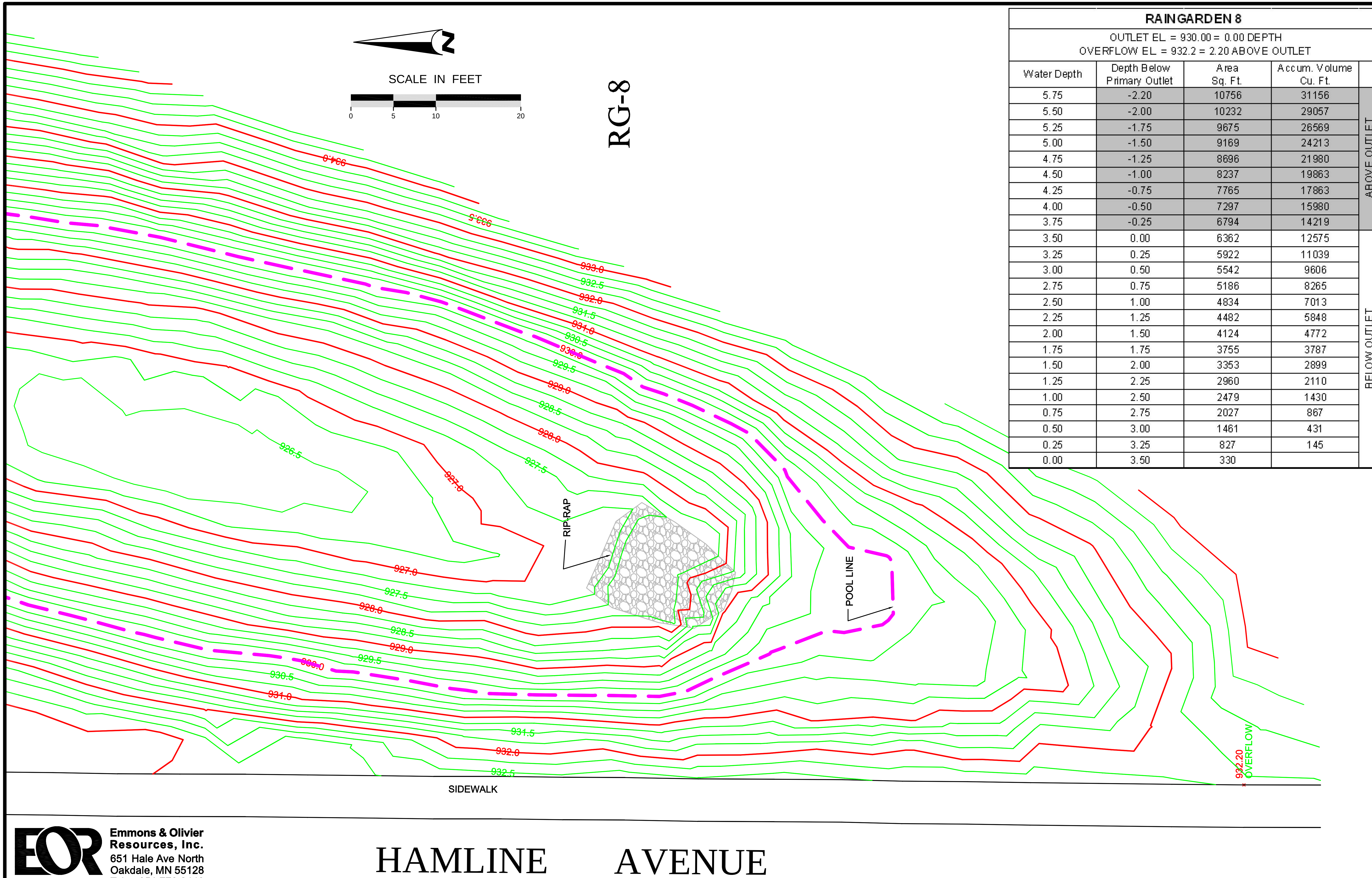
Oakdale, MN 55128
Tele: 651.770.8448




## RAINGARDEN 8

OUTLET EL = 930.00 = 0.00 DEPTH
OVERFLOW EL = 932.2 = 2.20 ABOVE OUTLET

| Water Depth | Depth Below Primary Outlet | Area Sq. Ft. | Accum. Volume Cu. Ft. | |
|---|---|---|---|---|
| 5.75 | -2.20 | 10756 | 31156 | ABOVE OUTLET |
| 5.50 | -2.00 | 10232 | 29057 | |
| 5.25 | -1.75 | 9675 | 26569 | |
| 5.00 | -1.50 | 9169 | 24213 | |
| 4.75 | -1.25 | 8696 | 21980 | |
| 4.50 | -1.00 | 8237 | 19863 | |
| 4.25 | -0.75 | 7765 | 17863 | |
| 4.00 | -0.50 | 7297 | 15980 | |
| 3.75 | -0.25 | 6794 | 14219 | |
| 3.50 | 0.00 | 6362 | 12575 | BELOW OUTLET |
| 3.25 | 0.25 | 5922 | 11039 | |
| 3.00 | 0.50 | 5542 | 9606 | |
| 2.75 | 0.75 | 5186 | 8265 | |
| 2.50 | 1.00 | 4834 | 7013 | |
| 2.25 | 1.25 | 4482 | 5848 | |
| 2.00 | 1.50 | 4124 | 4772 | |
| 1.75 | 1.75 | 3755 | 3787 | |
| 1.50 | 2.00 | 3353 | 2899 | |
| 1.25 | 2.25 | 2960 | 2110 | |
| 1.00 | 2.50 | 2479 | 1430 | |
| 0.75 | 2.75 | 2027 | 867 | |
| 0.50 | 3.00 | 1461 | 431 | |
| 0.25 | 3.25 | 827 | 145 | |
| 0.00 | 3.50 | 330 | | |

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Oakdale, MN 55128
Tele: 651.770.8448
www.eorinc.com

# Appendix C

# Technical Memorandum: Arlington Pascal P8 Model Calibration Report

Prepared by Emmons & Olivier Resource, Inc.
For the Capitol Regional Watershed District

# Technical Memorandum: Arlington Pascal P8 Model Calibration Report

April 20, 2011

| | | | |
|---|---|---|---|
| **Date \|** | 4/20/2011 | | |
| **To \|** | Melissa Baker | **Contact info \|** | Melissa@capitolregionwd.org |
| **cc \|** | Bob Fossum, | **Contact info \|** | bob@capitolregionwd.org |
| | Nancy-Jeanne LeFevre | | nlefevre@eorinc.com |
| **From \|** | Tom Miller, | **Contact info \|** | tmiller@eorinc.com |
| | Pat Conrad, | | pconrad@eorinc.com |
| | Dan Fabian | | dfabian@eorinc.com |
| **Regarding \|** | Arlington Pascal P8 Calibration Report | | |

This technical memorandum is a summary of the flow, TSS and TP calibration of the Como 7 P8 model (Task 4 of the project - Arlington Pascal BMP Model Update 2011). This memorandum details all parameter changes that were made in the model and many relevant figures and tables but does not include all the data that went into this analysis. A CD will be provided which will contain the spreadsheets, notes, input data and models used throughout calibration as well as previous reports. Appendix A contains figures showing the output from the calibrated model.

### 1. Calibration Data Assessment

A large amount of calibration data was available for this project. In general, there were four years of data (2007-2010) and 15 monitoring sites with varying levels of information (Table 1). To ensure that the data used in this project was of adequate quality for calibration, it was extensively reviewed in collaboration with District staff to define anomalous and/or erroneous monitoring data. Appendix B contains the technical memorandum which summarizes the data assessment process.

Table 1. Calibration Points

| Monitoring Site | Type |
|---|---|
| RG1: McKinley Pascal North | Crest Gage - Level |
| RG2: McKinley Pascal Middle | Crest Gage - Level |
| RG3: McKinley Pascal South | Crest Gage - Level |
| RG4: Arlington McKinley | Crest Gage - Level |
| RG5: Frankson McKinley | Crest Gage - Level |
| RG6: Asbury Frankson North | Crest Gage - Level |
| RG7: Asbury Frankson South | Crest Gage - Level |
| RG8: Hamline Midway | Crest Gage - Level |
| Trench 4 | Level, Flow and Water quality |
| Trench 5 | Level, Flow and Water quality |
| Como Golf Course Inlet | Level, Flow and Water quality |
| Gottfried's Pit | Loading Tables |
| Como Golf Course Outlet | Level, Flow and Water quality |

| | |
|---|---|
| AHUG Inlet | Level, Flow and Water quality |

**P8 Calibration Summary**

Modeled runoff volumes were calibrated to monitored data at eight raingardens, Arlington-Hamline Underground BMP (AHUG) inlet, Gottfrieds Pit (GP), Como Golf Pond (CGP) Inlet and Como Golf Pond outlet. Watershed and infiltration parameters were modified (Table 2) to match recorded inflows and high water elevations with particular attention to maintaining the model as an accurate annual prediction model while still being reasonable on a shorter event time frame.

The model was updated to reflect a more consistent landuse throughout the trench, raingarden, and AHUG areas. Although landuses are similar between drainage areas, the monitoring indicates that hydrological differences do occur. These differences are likely due to the individual connectivity of impervious surfaces within each drainage area. Table 2 shows the monitored runoff depth for the monitoring period by year. The depth was calculated at each site by dividing the volume of runoff monitored and dividing by the area draining to the monitoring location. For the AHUG drainage area the drainage areas of the trenches were removed from the area calculation because the trenches have proven nearly 100% removal of runoff volume every year except 2010, where removals varied between 68% and 92% efficient.

Table 2. Monitored annual runoff depths to four monitoring stations within Como7 (in)

| Year | AHUG | GCP | Trench 4 | Trench 5 |
|---|---|---|---|---|
| 2007 | 4.2 | | 7.0 | 9.9 |
| 2008 | 3.0 | 4.8 | 9.9 | 17.4 |
| 2009 | 2.9 | 4.7 | *0.8* | *1.3* |
| 2010 | 5.2 | 10.0 | 9.5 | *3.5* |

The monitored data shows that the runoff depth over the drainage area of the GCP is significantly higher than it is in the AHUG drainage area and the monitored runoff depths to the trenches are highly variable. Because of the uncertainty associated with these monitored trench volumes the runoff parameters of the trench drainage areas have been modified to match the AHUG drainage area and then calibrated levels within the trench by modifying the infiltration rates in P8. There is also some speculation that the monitored volumes at the GCP may be overestimated due to inadvertently including a portion of the flows from Gottfried's Pit. Future monitoring of Gottfried's Pit will help clarify this flow and aid in hydrograph separation.

In addition to the volume and loading calibration the model was enhanced to improve the generality of overall watershed characteristics. This was done primarily by globally modifying the TSS and TP loading factors and maintaining a standard curve number (CN) of 61 throughout the Como 7 watershed. In previous calibrations, watersheds were individually calibrated utilizing pollutant loading factors in each watershed. After many iterations and calibration runs in monitored watersheds it became apparent that the current CRWD particle file is under producing both TSS and TP loads in the Como 7 subwatershed. Further investigation into the creation of the CRWD particle file shows that it was not created using monitoring data within this subwatershed. Increasing the water quality parameter TSS scale factor from 1.0 to 2.0 in the P8 model provides a good starting calibration and essentially doubles the amount of sediment in watershed runoff. This modification produces the desired effect of increasing average watershed TSS runoff concentrations from ~75 ppm to 150 ppm, much more closely matching those concentrations regularly monitored at the AHUG inlet and the Como Golf Pond Inlet. Previous model calibrations used watershed-specific pollutant scale factors to increase the base particle file to match monitored concentrations. Table 3 summarizes all parameter changes made to the model.

Table 3. Calibration Parameter Summary*

| | Location | ID | Parameter | Initial Value | Calibrated Value |
|---|---|---|---|---|---|
| Watershed | Como 7 | All trench and RG watersheds | Directly Connected Impervious fraction | Varies | 0.15 |
| | Como 7 | All trench and RG watersheds | Indirectly Connected Impervious fraction | Varies | 0.17 |
| | All | All | Depressional Storage | 0.01”-0.25” | 0.02” |
| | Golf Course Pond | COMO7_GolfPond | Area | 142.24 | 123.41 |
| | Como 7 | All Como 7 watersheds | CN | 72 | 61 |
| | Golf Course Pond | COMO7_GolfPond – Direct | New Watershed Area | NA | 18.83 |
| | Golf Course Pond | COMO7_AHUG Central | Particle Scale Factor | 2.4 | 1.22 |
| | Golf Course Pond | COMO7_AHUG_West | Particle Scale Factor | NA | 1.22 |
| | Como 7 | All Como 7 watersheds | Impervious Runoff Coefficient | 0.8-1.0 | 1.0 |
| WQ parameters | All | All | TSS Scale Factor | 1.0 | 2.0 |
| | All | All | TP Scale Factor | 1.0 | 1.3 |
| Device | Trench 4 | Trench 4 | Infiltration Rate | 0.4”/hr | 1”/hr |
| | Trench 5 | Trench 5 | Infiltration Rate | 0.6”/hr | 0.45”/hr |
| | Trenches 1-3 and 6-8 | Trench 1, Trench 2, Trench 3, Trench 6, Trench 7, Trench 8 | Infiltration Rate | 1”/hr | 0.75”/hr |
| | Gottfrieds Pit | Gottfried | Infiltration Rates | Max 1”/hr | Max 6”/hr |
| | Gottfried’s Pit | Gottfried | Pumping Rates | 7 CFS | 3.26 CFS |
| | Golf Course Pond | COMO7_GOLFPOND | Infiltration Rate | 0.06-0.5”/hr | 0.02”/hr |
| | Golf Course Pond | COMO7_GOLFPOND | Particle Removal Factor | 3.0 | 2.5 |
| | AHUG | COMO7_AHUG | Infiltration Rate | 1”/hr | Varies with Depth |
| | AHUG | COMO7_AHUG | Device Type | Dry Pond | General Device |
| | Raingardens | RG2_McPascM, RG3_McPascS, RG_4Arlington McKinley | Infiltration Rate | 5”/hr | 4”/hr |
| | Frankson-McKinley | RG5_FrnksMc | Infiltration Rate | 7”/hr | 9”/hr |
| | Asbury Frankson North | RG6_AsbFrnksN | Infiltration Rate | 6”/hr | 8”/hr |
| | Asbury Frankson South | RG6_AsbFrnksS | Infiltration Rate | 12”/hr | 14”/hr |

*See individual report sections and Appendix A for discussion of calibration changes and calibration figures.

## 2a. Rain Gauge and Temperature Data Processing

15-minute rain gauge data was received from the CRWD from the St. Paul Campus for the years 2007-2010. P8 requires rainfall data to be in hourly timesteps. To convert this data to an hourly data while preserving total volumes, HEC-DSS software was used. The 15-minute monitoring data was manually input into HEC-DSS and the mathematics function was used to convert to hourly timesteps. This converted rainfall data was exported to Excel and the P8 utility was used to create the precipitation interface file for use in the model.

The 2007-2008 15-minute rainfall data was complete. The 2009 and 2010 data contained missing values in the 15 minute data. 2009 contained a total of 24 missing days and 2010 contained 5 missing days. Most gaps span a few hours or occur outside of the monitoring season, these gaps were filled in with zero values. The following significant gaps occurred within the monitoring season: 10/14/2009-10/25/2009, 10/28/2010. The daily recorded rainfall at the University precipitation station 218450 was used to fill in these missing gaps. The daily recorded rainfall was distributed based on an hourly SCS type II distribution as used in HydroCAD. Annual precipitation varies considerably over the calibration period. (Table 4)

Table 4. Annual Rainfall Data

| Year | Precipitation Year Total (in) | Precipitation 4/15-11/4* (in) |
|---|---|---|
| 2007 | 25.0 | 23.9 |
| 2008 | 21.7 | 16.5 |
| 2009 | 22.3 | 17.5 |
| 2010 | 36.3 | 30.5 |
| **TOTAL** | **105.3** | **88.4** |

*4/15-11/4 represents the average BMP monitoring period

Temperature data is used in the P8 model in a degree-day snowmelt routine. The climatology data retrieved from the gauge at University site 218350 was used. The daily high and low values recorded at the station were averaged to create a daily average temperature for input to the model.

## 2b. Raingarden Level Calibration

Crest gauge data was available at 8 raingardens throughout Como 7 for 2008-2010. A crest gauge measures the maximum water elevation reached within each raingarden since the last time it was checked. This is not a direct measurement of total inflow because infiltration is occurring during the storm and multiple storms and peaks could have occurred between observations, it only records the peak elevation reached during the period. In spite of the drawbacks of crest gauges, they provide important data for the raingarden calibration. Calibration was accomplished by adjusting raingarden infiltration rates in the model until recorded peak elevations were matched. (Appendix A Raingarden Figures) Although the calibration figures show large variability in the modeled vs. monitored data, it is important to note that the majority of the monitoring data is recording crest below 6” of depth and that spatial variability and short-term distribution of rainfall events producing these low crests are not all captured by the rainfall data used in the model.

### 2c. Depressional Storage Calibration

Rainfall and monitoring at the AHUG inlet were used to estimate the amount of impervious depressional storage within the watershed. This parameter can have a great effect on small storms and annual volumes. Additionally, these graphs were used to identify deviation between rainfall and monitored runoff. These deviations are important to understanding specific watersheds that the model may have trouble simulating. This information was used throughout the calibration process.

A continuous hydrograph was constructed for the entire period of record. Daily precipitation values and small storms were analyzed to determine the break point at which rainfall results in runoff. The break point in runoff generation varied between 0.01” and 0.03”, with precipitation events of greater than 0.03” always producing runoff at AHUG Inlet. The depressional storage in all watersheds was set to 0.02”.

### 2d. Evapotranspiration from Raingardens

The role evapotranspiration (ET) plays in removing stormwater volume from the raingardens was evaluated. Research conducted in the Madison, WI area reports that monthly ET rates for prairie vegetated raingardens in sandy soils vary significantly throughout the year. Growing season averages range from 0.8-1.2 inches in March and October to 2.8–4.1 inches in July. The research further reports that the annual stormwater uptake that can be attributed to ET ranges from 6-19% of the total volume lost within a prairie vegetated raingarden in sandy soils. A comparison of the physical characteristics of the study raingardens and watersheds with the raingardens and watersheds within the Arlington Pascal project suggests that ET values on the low end of these ranges would be appropriate.

Source:
*Selbig, W.R., Balster, Nicholas, 2010, Evaluation of turf-grass and prairie-vegetated rain gardens in a clay and sand soil: Madison, Wisconsin, water years 2004–08: U.S. Geological Survey, Scientific Investigations Report 2010–5077, 75 p.*

### 2e. Arlington-Hamline Underground Storage Infiltration Rate

Previously the AHUG infiltration rate was set in the model as the design value of 0.5”/hr. This rate was used uniformly throughout the device. This value has proven to be highly conservative with measured rates of up to 37.1”/hr observed with automatic level data. (Appendix A figures) The device was converted from a dry pond to a general device in P8 to account for varying infiltration rates in the practice.

Using continuously monitored level data, the infiltration rate within the practice was directly calculated. It became obvious that the infiltration rate is dependent on hydraulic head within the practice. Only three monitored events eclipsed 2 feet of depth in the practice and infiltration rates during these events were used to define the infiltration rates in the practice. (Table 5)

Because the measured data only went up to 3 feet of head, infiltration rates at depths greater than this were extrapolated in the model based on a linear relationship.

Table 5. Measured AHUG infiltration rates

| Depth (ft) | Infiltration Rate (in/hr) | |
|---|---|---|
| 0 | 0 | Measured |
| 1 | 14.2 | |
| 2 | 28.5 | |
| 3 | 42.7 | |

**2f. Trench volume update**

Modeled storage in trenches 4 and 5 were reviewed and found to be consistent with design plans.

**2g. Volume Calibration (See Appendix for Figures Used in Calibration)**

Volumes were calibrated at AHUG Inlet, Gottfried's Pit, GCP Inlet, GCP Level and GCP Outlet. The models were calibrated based on annual volume during the monitored period and hourly P8 output was compared to monitored data to ensure adequate annual distribution of loading volume. (Table 6)

Trenches 4 and 5 were calibrated to level data within the trenches. This was done because after much analysis, it was apparent that there is a discrepancy between the trench load monitoring and the model. Levels within the trenches calibrate well and the outlets were checked to ensure that outflow only occurs when monitoring indicated that it should. Discrepancies between modeled and monitored elevation occur at high flows because the model does not account for infiltration rates increasing with depth.

Annual volumes were also calibrated at the inlet to AHUG. Annual volumes were calibrated for each of the monitoring years (2007-2010) using the 10-minute monitored flow data and storm distribution was verified using 2010 only. (Appendix Figures)

Gottfried's pit was calibrated to annual volumes reported in the loading tables. As the Gottfried's pit is a portion of the GCP inlet monitored flow, these two sites were calibrated simultaneously to ensure consistency. Additionally, cumulative volume graphs were plotted to ensure storm distribution. Infiltration rates in the upper portion of Gottfrieds Pit were modified to match recorded flows and pumping rates were modified to match the average monitored pumping rate for 2008-2010.

The watersheds were calibrated by reducing the pervious curve number in the watershed from 72 to 61. Additionally, an 18.8 acre portion of direct drainage area was separated from the rest of the GCP drainage area because it is downstream of the monitoring location. The GCP level and outflow data were calibrated simultaneously so that the calibration of one would not compromise the accuracy of the other. Infiltration was measured by examining the level data within the basin. The infiltration rate appears to vary significantly but for the majority of the monitoring period a rate of 0.02 in/hr is a reasonable estimate.

**3. P8 Pollutant Calibration (See Appendix for Figures Used in Calibration)**

Pollutant calibration was undertaken by first comparing annual loads of TSS and then TP and adjusting the pollutant scale factor for particle loads so that annual monitored loads matched.

Pollutant loads to Gottfried's Pit, GCP inlet and AHUG were calibrated simultaneously to ensure consistency. Because of the lack of additional data in Gottfried's Pit and good overall match, no changes were made to the Como 8 subwatershed. By changing the scale factor for particle loads in the particle file from 1.0 to 2.0 for TSS and from 1.0 to 1.3 all watershed loading parameters were matched.

To match the monitored outflow of pollutants from Como Golf Pond the pollutant removal factor was decrease from 3.0 to 2.5 in the device.

Table 6. Volume and Pollutant Loading Calibration Summary

| | | | Volume | | Load | | | |
|---|---|---|---|---|---|---|---|---|
| Site | Year | Monitoring Period | Monitored Volume (ac-ft) | Modeled Volume (ac-ft) | Monitored TSS Load (lb) | Modeled TSS Load (lb) | Monitored TP Load (lb) | Modeled TP Load (lb) |
| AHUG Inlet | 2007 | 4/30 to 10/18 | 13 | 13 | 7,342 | 4,758 | 14 | 13 |
| | 2008 | 4/10 - 11/7 | 9 | 9 | 4,716 | 3,099 | 13 | 9 |
| | 2009 | 4/4 - 11/3 | 9 | 9 | 3,334 | 4,198 | 11 | 11 |
| | 2010 | 4/14 - 10/27 | 16 | 19 | 9,567 | 12,652 | 21 | 26 |
| Golf Course Pond Inlet | 2008 | 5/2 - 11/13 | 50 | 47 | 16,260 | 14,881 | 47 | 42 |
| | 2009 | 4/26 - 11/4 | 48 | 55 | 20,170 | 18,235 | 58 | 50 |
| | 2010 | 4/13 - 10/27 | 102 | 108 | 50,282 | 53,492 | 107 | 116 |
| Gottfried's Pit | 2008 | 5/2 - 11/13 | 73 | 72 | 7,532 | 3,878 | 58 | 31 |
| | 2009 | 4/26 - 11/4 | 103 | 102 | 8,337 | 8,246 | 67 | 48 |
| | 2010 | 4/13 - 10/27 | 161 | 179 | 14,708 | 18,476 | 106 | 90 |
| Golf Course Pond Outlet | 2008 | 5/10 - 11/14 | 97 | 99 | 4,542 | 2,354 | 56 | 47 |
| | 2009 | 4/26 - 11/2 | 160 | 159 | 9,463 | 6,240 | 77 | 75 |
| | 2010 | 4/24 - 11/4 | 313 | 284 | 20,420 | 24,416 | 162 | 156 |
| Trench 4 East | 2007 | 7/26 - 10/19 | 3 | 3 | 786 | 968 | 2 | 3 |
| | 2008 | 4/10 - 11/10 | 4 | 4 | 1,077 | 1,138 | 4 | 3 |
| | 2009 | 4/19 - 11/3 | *0.3* | *3* | *136* | *1,116* | *0.4* | *3* |
| | 2010 | 5/4 - 10/27 | 4 | 6 | 1,458 | 2,232 | 3 | 6 |
| Trench 5 East | 2007 | 7/26 - 10/24 | 1 | 0.3 | 269 | 149 | 0.6 | 0.3 |
| | 2008 | 4/10 - 11/8 | 2 | 0.3 | 415 | 112 | 1.3 | 0.3 |
| | 2009 | 4/29 - 11/3 | 0.1 | 0.3 | 49 | 172 | 0.1 | 0.4 |
| | 2010 | 5/7 - 9/23 | 0.4 | 0.6 | 146 | 565 | 0.2 | 0.9 |

**4. Annual model summary**

The calibrated P8 Model was run for 2007-2010 and an average precipitation year (1995 water year) and the results are summarized in Tables 7, 8, 9, 10 and 11. Tables 7-9 summarize the model results for the rain gardens and trenches. Table 7 reports the volume loading to each practice and the removal provided by the practice in cubic feet and the removal efficiency expressed as a percentage of the loading. Tables 8 and 9 report the total suspended solids and total phosphorus loading to each practice, removal provided by each practice (in pounds) and the removal efficiency.

Table 10 reports the performance of the Arlington Hamline Underground Storage and Como Golf Course Pond. The table reports the loading to each practice, the reduction provided by each practice and the load coming out of each practice for volume in cubic feet and TP and TSS in pounds. Table 11 summarizes the overall performance of all practices in the study area.

**5. Recommendations and Observations**

The following recommendations and observations were noted during this analysis.

1. AHUG is currently being underutilized. The exceptionally high infiltration rates recorded in the practice show that it can treat more water than it is currently receiving. The feasibility of redirecting additional drainage or altering the upstream diversion should be evaluated.
2. Level monitoring should be reinstated at AHUG to quantify infiltration rates at higher elevations within the practice.
3. Gottfried's pit was calibrated by significantly increasing infiltration rates in the upper elevations of the pond with a maximum of 6"/hr infiltration defined in the device. Although this provides a good input (calibration) for the GCP, it is not likely an accurate description of Gottfried's pit operation itself. Although Gottfried's pit is realistically described under low-moderate flows, without monitoring data within Gottfried's Pit it is impossible to further characterize the volume losses that occur during high flows. Recommend installing a level logger in the basin.
4. Gottfried's Pit loading values for 2009 appear to be skewed high do to use of high average concentration to calculate load.
5. Trench monitoring protocol should be explored to identify any shortcoming. Specifically, the monitored runoff depths to the trenches are inconsistent with the precipitation record and monitoring results. Possible explanations could be inlet clogging, inlet bypassing, or inaccurate measurements under low flows or during quick-return flows. Simplifying the monitoring of the trenches to include a single level logger in the trench may be a good option for future monitoring.
6. Calibration of the Golf Course Pond level and outlet is complicated due to the unknown effect of irrigation within the golf course.

Table 7. Raingarden and Trench Volumes

| Rain garden / Trench | 2007 In (ft³) | 2007 Removed (ft³) | 2007 % Removed | 2008 In (ft³) | 2008 Removed (ft³) | 2008 % Removed | 2009 In (ft³) | 2009 Removed (ft³) | 2009 % Removed | 2010 In (ft³) | 2010 Removed (ft³) | 2010 % Removed | 07-10 Average In (ft³) | 07-10 Average Removed (ft³) | 07-10 Average % Removed | Average Annual In (ft³) | Average Annual Removed (ft³) | Average Annual % Removed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RG1: McKinley Pascal North | 6,490 | 6,403 | 99% | 5,706 | 5,706 | 100% | 5,881 | 5,881 | 100% | 15,246 | 13,286 | 87% | 8,331 | 7,819 | 94% | 7,013 | 7,013 | 100% |
| RG2: McKinley Pascal Middle | 1,917 | 1,917 | 100% | 1,612 | 1,612 | 100% | 1,655 | 1,655 | 100% | 6,229 | 4,051 | 65% | 2,853 | 2,309 | 81% | 1,960 | 1,960 | 100% |
| RG3: McKinley Pascal South | 5,053 | 5,053 | 100% | 4,443 | 4,443 | 100% | 4,617 | 4,617 | 100% | 11,979 | 10,542 | 88% | 6,523 | 6,164 | 94% | 5,489 | 5,489 | 100% |
| RG4: Arlington McKinley | 5,184 | 5,184 | 100% | 4,574 | 4,574 | 100% | 4,748 | 4,748 | 100% | 12,240 | 10,759 | 88% | 6,686 | 6,316 | 94% | 5,619 | 5,619 | 100% |
| RG5: Frankson McKinley | 39,727 | 39,727 | 100% | 34,935 | 34,935 | 100% | 36,198 | 36,198 | 100% | 93,698 | 81,631 | 87% | 51,139 | 48,123 | 94% | 42,994 | 42,994 | 100% |
| RG6: Asbury Frankson North | 5,663 | 5,663 | 100% | 4,966 | 4,966 | 100% | 5,140 | 5,140 | 100% | 13,329 | 12,894 | 97% | 7,275 | 7,166 | 99% | 6,098 | 6,098 | 100% |
| RG7: Asbury Frankson South | 15,246 | 15,246 | 100% | 13,416 | 13,416 | 100% | 13,896 | 13,896 | 100% | 35,981 | 34,717 | 96% | 19,635 | 19,319 | 98% | 16,509 | 16,509 | 100% |
| RG8: Hamline Midway | 177,855 | 177,855 | 100% | 155,466 | 155,466 | 100% | 158,384 | 158,384 | 100% | 380,279 | 333,365 | 88% | 217,996 | 206,267 | 95% | 191,969 | 191,969 | 100% |
| **Rain garden Subtotal** | **257,135** | **257,048** | **100%** | **225,118** | **225,118** | **100%** | **230,520** | **230,520** | **100%** | **568,981** | **501,245** | **88%** | **320,438** | **303,483** | **95%** | **277,651** | **277,651** | **100%** |
| Trench 1 | 10,411 | 10,411 | 100% | 9,148 | 9,148 | 100% | 9,496 | 9,496 | 100% | 24,524 | 21,911 | 89% | 13,395 | 12,741 | 95% | 11,238 | 11,238 | 100% |
| Trench 2 | 11,805 | 11,805 | 100% | 10,367 | 10,367 | 100% | 10,759 | 10,759 | 100% | 27,835 | 25,570 | 92% | 15,192 | 14,625 | 96% | 12,763 | 12,763 | 100% |
| Trench 3 | 45,433 | 45,433 | 100% | 39,945 | 39,945 | 100% | 41,382 | 41,382 | 100% | 107,114 | 95,048 | 89% | 58,468 | 55,452 | 95% | 49,179 | 49,179 | 100% |
| Trench 4 | 74,705 | 74,705 | 100% | 65,732 | 65,732 | 100% | 68,084 | 68,084 | 100% | 176,200 | 141,657 | 80% | 96,180 | 87,545 | 91% | 80,891 | 80,891 | 100% |
| Trench 5 | 18,077 | 18,077 | 100% | 15,899 | 15,899 | 100% | 16,466 | 16,466 | 100% | 42,645 | 32,539 | 76% | 23,272 | 20,745 | 89% | 19,558 | 19,558 | 100% |
| Trench 6 | 36,721 | 36,460 | 99% | 32,322 | 32,322 | 100% | 33,454 | 33,454 | 100% | 86,641 | 61,942 | 71% | 47,284 | 41,044 | 87% | 39,770 | 39,770 | 100% |
| Trench 7 | 23,000 | 23,000 | 100% | 20,255 | 20,255 | 100% | 20,952 | 20,952 | 100% | 54,276 | 43,473 | 80% | 29,621 | 26,920 | 91% | 24,916 | 24,916 | 100% |
| Trench 8 | 100,014 | 97,357 | 97% | 87,948 | 87,948 | 100% | 91,128 | 91,128 | 100% | 235,834 | 160,214 | 68% | 128,731 | 109,161 | 85% | 108,247 | 108,247 | 100% |
| **Trench Subtotal** | **320,166** | **317,247** | **99%** | **281,615** | **281,615** | **100%** | **291,721** | **291,721** | **100%** | **755,069** | **582,354** | **77%** | **412,143** | **368,234** | **89%** | **346,563** | **346,563** | **100%** |
| **Rain garden and Trench Total** | **577,301** | **574,295** | **99%** | **506,733** | **506,733** | **100%** | **522,241** | **522,241** | **100%** | **1,324,050** | **1,083,599** | **82%** | **732,581** | **671,717** | **92%** | **624,215** | **624,215** | **100%** |

*Average Annual results are derived from using the 1995 water year (Oct, 1994-Sept, 1995)

Table 8. Raingarden and Trench TSS Loads

| | 2007 | | | 2008 | | | 2009 | | | 2010 | | | 07-10 Average | | | Average Annual | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rain garden / Trench** | **In (lb)** | **Removed (lb)** | **% Removed** | **In (lb)** | **Removed (lb)** | **% Removed** | **In (lb)** | **Removed (lb)** | **% Removed** | **In (lb)** | **Removed (lb)** | **% Removed** | **In (lb)** | **Removed (lb)** | **% Removed** | **In (lb)** | **Removed (lb)** | **% Removed** |
| RG1: McKinley Pascal North | 68 | 67 | 98% | 59 | 59 | 100% | 68 | 68 | 100% | 375 | 322 | 86% | 142 | 129 | 91% | 67 | 67 | 100% |
| RG2: McKinley Pascal Middle | 20 | 20 | 100% | 16 | 16 | 100% | 19 | 19 | 100% | 158 | 110 | 69% | 54 | 41 | 77% | 19 | 19 | 100% |
| RG3: McKinley Pascal South | 53 | 53 | 100% | 46 | 46 | 100% | 54 | 54 | 100% | 294 | 261 | 89% | 112 | 104 | 93% | 52 | 52 | 100% |
| RG4: Arlington McKinley | 55 | 55 | 100% | 47 | 47 | 100% | 55 | 55 | 100% | 301 | 269 | 89% | 114 | 106 | 93% | 54 | 54 | 100% |
| RG5: Frankson McKinley | 417 | 417 | 100% | 359 | 359 | 100% | 420 | 420 | 100% | 2,300 | 1,974 | 86% | 874 | 793 | 91% | 410 | 410 | 100% |
| RG6: Asbury Frankson North | 59 | 59 | 100% | 51 | 51 | 100% | 60 | 60 | 100% | 327 | 318 | 97% | 124 | 122 | 98% | 58 | 58 | 100% |
| RG7: Asbury Frankson South | 160 | 160 | 100% | 138 | 138 | 100% | 161 | 161 | 100% | 883 | 852 | 96% | 336 | 328 | 98% | 158 | 158 | 100% |
| RG8: Hamline Midway | 1,579 | 1,579 | 100% | 1,379 | 1,379 | 100% | 1,517 | 1,517 | 100% | 7,927 | 6,806 | 86% | 3,100 | 2,820 | 91% | 1,538 | 1,538 | 100% |
| **Rain garden Subtotal** | **2,412** | **2,410** | 100% | **2,096** | **2,096** | 100% | **2,354** | **2,354** | 100% | **12,564** | **10,913** | 87% | **4,856** | **4,443** | 91% | **2,357** | **2,357** | 100% |
| Trench 1 | 109 | 109 | 100% | 94 | 94 | 100% | 110 | 110 | 100% | 602 | 546 | 91% | 229 | 215 | 94% | 107 | 107 | 100% |
| Trench 2 | 124 | 124 | 100% | 107 | 107 | 100% | 125 | 125 | 100% | 684 | 637 | 93% | 260 | 248 | 96% | 122 | 122 | 100% |
| Trench 3 | 477 | 477 | 100% | 411 | 411 | 100% | 480 | 480 | 100% | 2,630 | 2,364 | 90% | 999 | 933 | 93% | 469 | 469 | 100% |
| Trench 4 | 785 | 785 | 100% | 676 | 676 | 100% | 790 | 790 | 100% | 4,326 | 3,613 | 84% | 1,644 | 1,466 | 89% | 772 | 772 | 100% |
| Trench 5 | 190 | 190 | 100% | 164 | 164 | 100% | 191 | 191 | 100% | 1,047 | 880 | 84% | 398 | 356 | 90% | 187 | 187 | 100% |
| Trench 6 | 386 | 383 | 99% | 332 | 332 | 100% | 388 | 388 | 100% | 2,127 | 1,682 | 79% | 808 | 697 | 86% | 380 | 380 | 100% |
| Trench 7 | 242 | 242 | 100% | 208 | 208 | 100% | 243 | 243 | 100% | 1,332 | 1,127 | 85% | 506 | 455 | 90% | 238 | 238 | 100% |
| Trench 8 | 1,050 | 1,025 | 98% | 905 | 905 | 100% | 1,057 | 1,057 | 100% | 5,790 | 4,425 | 76% | 2,200 | 1,853 | 84% | 1,033 | 1,033 | 100% |
| **Trench Subtotal** | **3,362** | **3,334** | 99% | **2,896** | **2,896** | 100% | **3,385** | **3,385** | 100% | **18,537** | **15,274** | 82% | **7,045** | **6,222** | 88% | **3,308** | **3,308** | 100% |
| **Rain garden and Trench Total** | **5,773** | **5,745** | **100%** | **4,992** | **4,992** | **100%** | **5,739** | **5,739** | **100%** | **31,101** | **26,187** | **84%** | **11,901** | **10,666** | **90%** | **5,665** | **5,665** | **100%** |

*Average Annual results are derived from using the 1995 water year (Oct, 1994-Sept, 1995)

Table 9. Raingarden and Trench TP Loads

| | 2007 | | | 2008 | | | 2009 | | | 2010 | | | 07-10 Average | | | Average Annual | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rain garden / Trench | In (lb) | Removed (lb) | % Removed | In (lb) | Removed (lb) | % Removed | In (lb) | Removed (lb) | % Removed | In (lb) | Removed (lb) | % Removed | In (lb) | Removed (lb) | % Removed | In (lb) | Removed (lb) | % Removed |
| RG1: McKinley Pascal North | 0.2 | 0.2 | 98% | 0.1 | 0.1 | 100% | 0.1 | 0.1 | 100% | 0.6 | 0.5 | 83% | 0.3 | 0.2 | 90% | 0.2 | 0.2 | 100% |
| RG2: McKinley Pascal Middle | 0.05 | 0.05 | 100% | 0.04 | 0.04 | 100% | 0.04 | 0.04 | 100% | 0.3 | 0.2 | 60% | 0.1 | 0.1 | 73% | 0.05 | 0.05 | 100% |
| RG3: McKinley Pascal South | 0.1 | 0.1 | 100% | 0.1 | 0.1 | 100% | 0.1 | 0.1 | 100% | 0.5 | 0.4 | 85% | 0.2 | 0.2 | 91% | 0.1 | 0.1 | 100% |
| RG4: Arlington McKinley | 0.1 | 0.1 | 100% | 0.1 | 0.1 | 100% | 0.1 | 0.1 | 100% | 0.5 | 0.4 | 85% | 0.2 | 0.2 | 92% | 0.1 | 0.1 | 100% |
| RG5: Frankson McKinley | 0.9 | 0.9 | 100% | 0.8 | 0.8 | 100% | 0.9 | 0.9 | 100% | 3.6 | 2.9 | 83% | 1.6 | 1.4 | 90% | 1.0 | 1.0 | 100% |
| RG6: Asbury Frankson North | 0.1 | 0.1 | 100% | 0.1 | 0.1 | 100% | 0.1 | 0.1 | 100% | 0.5 | 0.5 | 96% | 0.2 | 0.2 | 98% | 0.1 | 0.1 | 100% |
| RG7: Asbury Frankson South | 0.4 | 0.4 | 100% | 0.3 | 0.3 | 100% | 0.3 | 0.3 | 100% | 1.4 | 1.3 | 95% | 0.6 | 0.6 | 97% | 0.4 | 0.4 | 100% |
| RG8: Hamline Midway | 3.9 | 3.9 | 100% | 3.4 | 3.4 | 100% | 3.6 | 3.6 | 100% | 13.1 | 10.9 | 83% | 6.0 | 5.5 | 91% | 4.1 | 4.1 | 100% |
| **Rain garden Subtotal** | **5.8** | **5.8** | 100% | **5.1** | **5.1** | 100% | **5.4** | **5.4** | 100% | **20.3** | **17.1** | 84% | **9.1** | **8.3** | 91% | **6.0** | **6.0** | 100% |
| Trench 1 | 0.2 | 0.2 | 100% | 0.2 | 0.2 | 100% | 0.2 | 0.2 | 100% | 0.9 | 0.8 | 87% | 0.4 | 0.4 | 93% | 0.3 | 0.3 | 100% |
| Trench 2 | 0.3 | 0.3 | 100% | 0.2 | 0.2 | 100% | 0.3 | 0.3 | 100% | 1.1 | 1.0 | 90% | 0.5 | 0.4 | 94% | 0.3 | 0.3 | 100% |
| Trench 3 | 1.1 | 1.1 | 100% | 0.9 | 0.9 | 100% | 1.0 | 1.0 | 100% | 4.1 | 3.5 | 86% | 1.8 | 1.6 | 92% | 1.1 | 1.1 | 100% |
| Trench 4 | 1.8 | 1.8 | 100% | 1.5 | 1.5 | 100% | 1.7 | 1.7 | 100% | 6.7 | 5.2 | 78% | 2.9 | 2.6 | 87% | 1.8 | 1.8 | 100% |
| Trench 5 | 0.4 | 0.4 | 100% | 0.4 | 0.4 | 100% | 0.4 | 0.4 | 100% | 1.6 | 1.2 | 76% | 0.7 | 0.6 | 86% | 0.4 | 0.4 | 100% |
| Trench 6 | 0.9 | 0.9 | 99% | 0.8 | 0.8 | 100% | 0.8 | 0.8 | 100% | 3.3 | 2.3 | 70% | 1.4 | 1.2 | 83% | 0.9 | 0.9 | 100% |
| Trench 7 | 0.5 | 0.5 | 100% | 0.5 | 0.5 | 100% | 0.5 | 0.5 | 100% | 2.1 | 1.6 | 78% | 0.9 | 0.8 | 87% | 0.6 | 0.6 | 100% |
| Trench 8 | 2.4 | 2.3 | 97% | 2.1 | 2.1 | 100% | 2.3 | 2.3 | 100% | 9.0 | 6.0 | 66% | 3.9 | 3.2 | 80% | 2.5 | 2.5 | 100% |
| **Trench Subtotal** | **7.6** | **7.5** | 99% | **6.6** | **6.6** | 100% | **7.3** | **7.3** | 100% | **28.8** | **21.6** | 75% | **12.6** | **10.8** | 86% | **7.9** | **7.9** | 100% |
| **Rain garden and Trench Total** | **13.4** | **13.3** | **99%** | **11.7** | **11.7** | **100%** | **12.7** | **12.7** | **100%** | **49.0** | **38.7** | **79%** | **21.7** | **19.1** | **88%** | **13.9** | **13.9** | **100%** |
| *Average Annual results are derived from using the 1995 water year (Oct, 1994-Sept, 1995) | | | | | | | | | | | | | | | | | | |

Table 10. AHUG and Golf Course Pond Summary

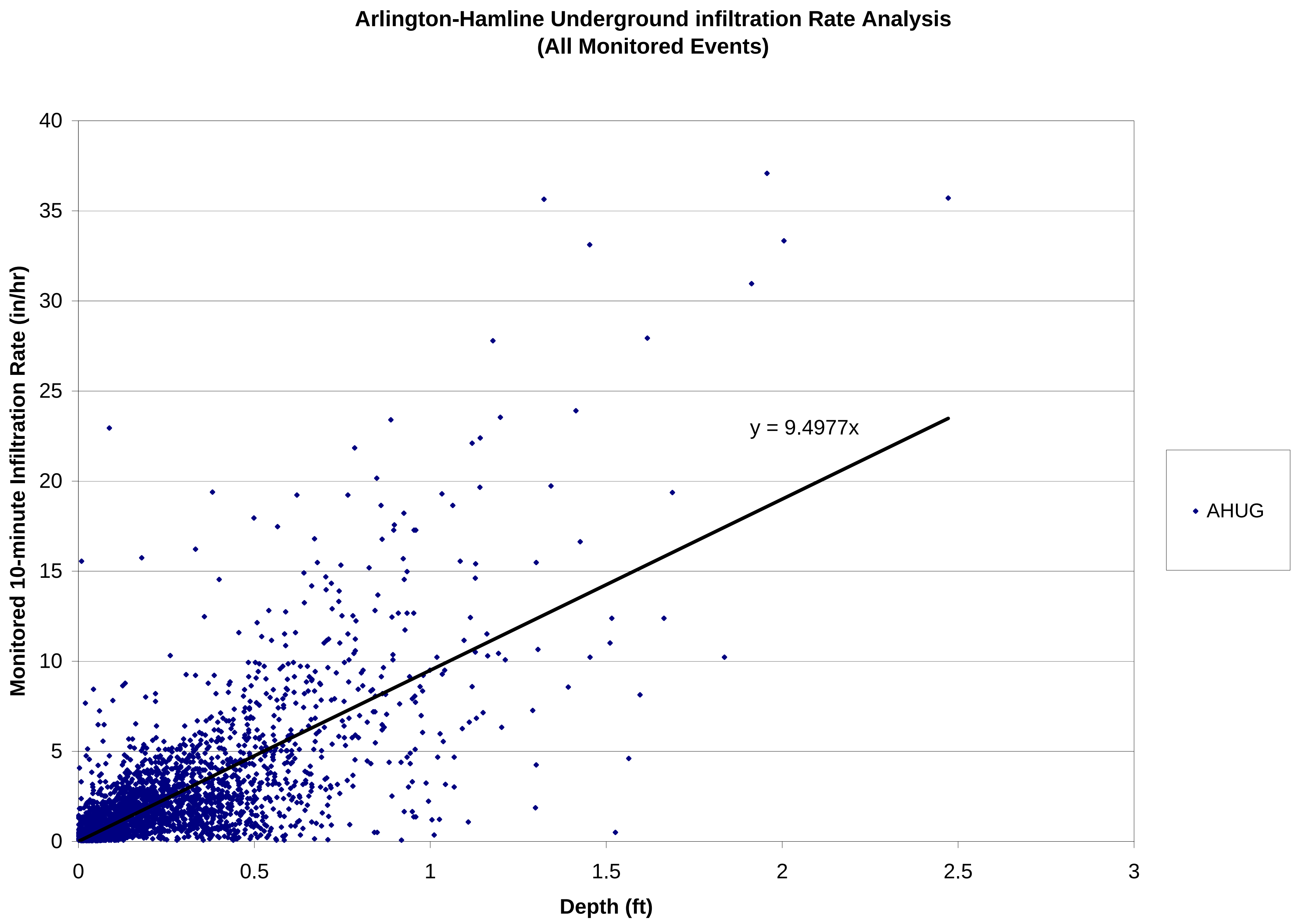
| Site | Year | Volume ($ft^3$) In | Volume Out | Volume Removed | Volume % Removal | TSS Load (lb) In | TSS Out | TSS Removed | TSS % Removal | TP Load (lb) In | TP Out | TP Removed | TP % Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AHUG Inlet | 2007 | 526,248 | 0.0 | 526,248 | 100% | 6,608 | 0.0 | 6,608 | 100% | 15.0 | 0.0 | 15.0 | 100% |
| | 2008 | 458,600 | 0.0 | 458,600 | 100% | 5,669 | 0.0 | 5,669 | 100% | 13.0 | 0.0 | 13.0 | 100% |
| | 2009 | 475,675 | 0.0 | 475,675 | 100% | 6,625 | 0.0 | 6,625 | 100% | 14.2 | 0.0 | 14.2 | 100% |
| | 2010 | 1,245,032 | 0.0 | 1,245,032 | 100% | 33,851 | 0.0 | 33,851 | 100% | 54.9 | 0.0 | 54.9 | 100% |
| | Average of 2007-2010 | 676,389 | 0.0 | 676,389 | 100% | 13,188 | 0.0 | 13,188 | 100% | 24.2 | 0.0 | 24.2 | 100% |
| | Average Year 1994-1995 | 566,149 | 0.0 | 566,149 | 100% | 6,470 | 0.0 | 6,470 | 100% | 15.4 | 0.0 | 15.4 | 100% |
| Golf Course Pond | 2008 | 7,711,819 | 6,992,905 | 718,914 | 9% | 28,581 | 5,079 | 23,502 | 82% | 108.6 | 76.4 | 32.3 | 29.7% |
| | 2009 | 7,598,694 | 6,851,204 | 747,490 | 10% | 29,845 | 6,221 | 23,624 | 79% | 109.8 | 76.8 | 33.0 | 30.0% |
| | 2010 | 16,327,464 | 15,589,471 | 737,994 | 5% | 124,242 | 38,513 | 85,729 | 69% | 302.2 | 212.5 | 89.7 | 29.7% |
| | Average of 2008-2010 | 10,545,992 | 9,811,193 | 734,799 | 7% | 60,889 | 16,604 | 44,285 | 73% | 173.5 | 121.9 | 51.7 | 29.8% |
| | Average Year 1994-1995 | 9,690,663 | 8,814,322 | 876,340 | 9% | 32,782 | 6,609 | 26,173 | 80% | 133.5 | 96.1 | 37.4 | 28.0% |

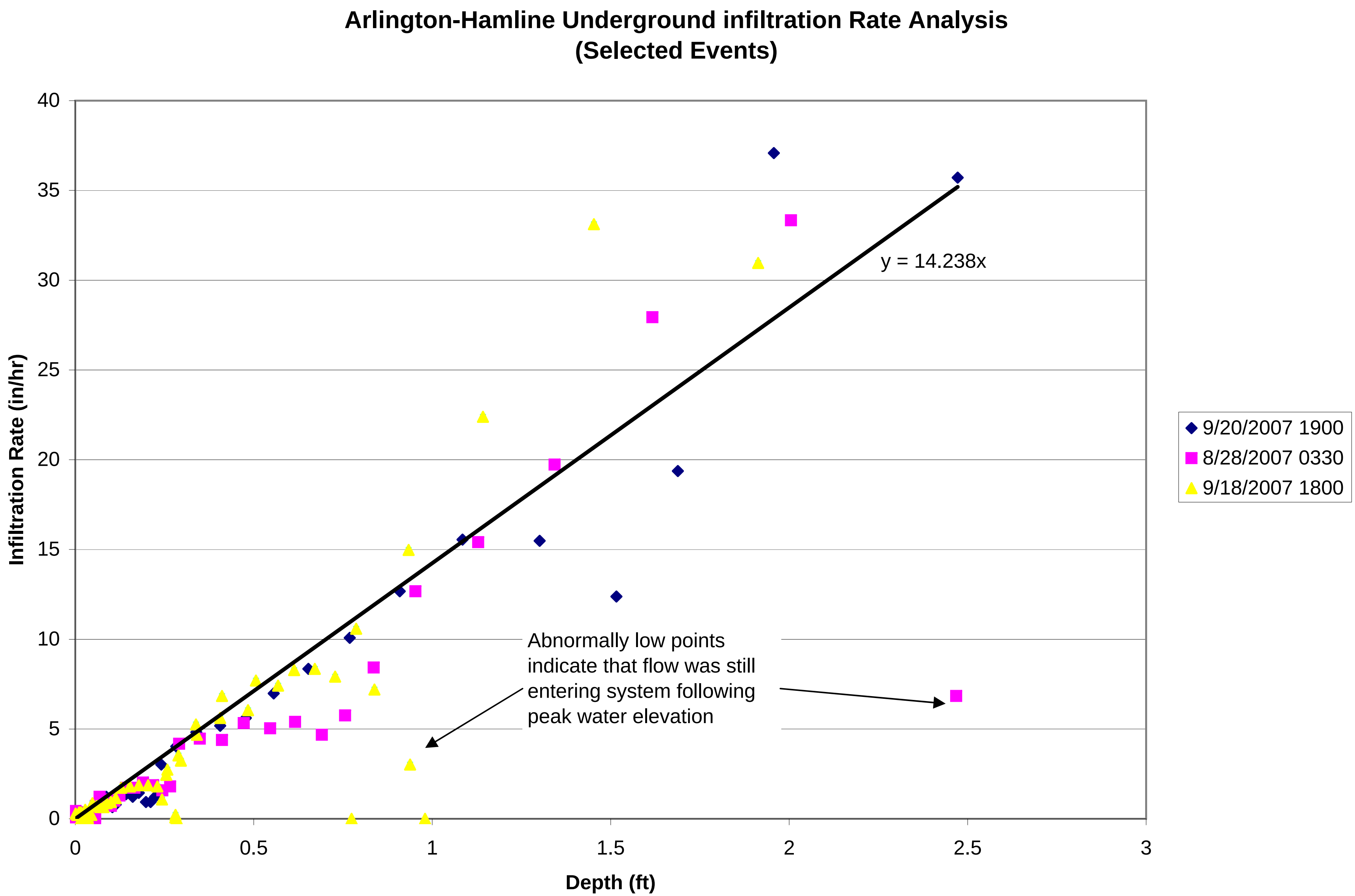
Table 11. P8 Model Results – Study Area Summary

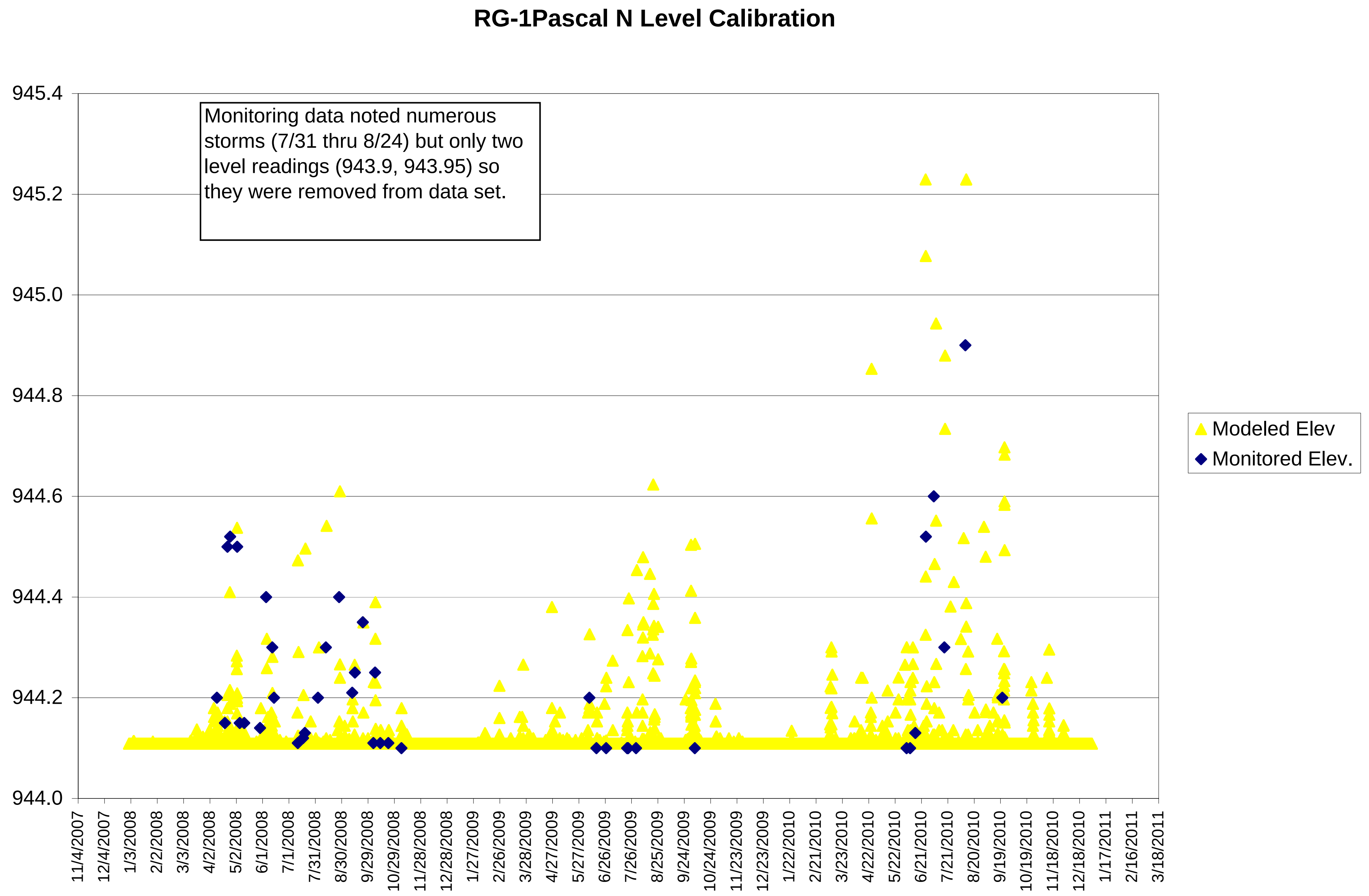
| | Flow Removal | | | | | | Total Suspended Solids Removal | | | | | | Total Phosphorus Removal | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2007 | 2008 | 2009 | 2010 | ’07-’10 Average | 1994-1995 | 2007 | 2008 | 2009 | 2010 | ’07-’10 Average | 1994-1995 | 2007 | 2008 | 2009 | 2010 | ’07-’10 Average | 1994-1995 |
| | ($ft^3$) | ($ft^3$) | ($ft^3$) | ($ft^3$) | ($ft^3$) | ($ft^3$) | (lbs) | (lbs) | (lbs) | (lbs) | (lbs) | (lbs) | (lbs) | (lbs) | (lbs) | (lbs) | (lbs) | (lbs) |
| **Rain Gardens** | 257,048 | 225,118 | 230,520 | 501,245 | 303,483 | 277,651 | 2,410 | 2,096 | 2,354 | 10,913 | 4,443 | 2,357 | 6 | 5 | 5 | 17 | 8 | 6 |
| **Trenches** | 317,247 | 281,615 | 291,721 | 582,354 | 368,234 | 346,563 | 3,334 | 2,896 | 3,385 | 15,274 | 6,222 | 3,308 | 8 | 7 | 7 | 22 | 11 | 8 |
| **Arlington Hamline Underground Storage** | 526,248 | 458,600 | 475,675 | 1,245,032 | 676,389 | 566,149 | 6,608 | 5,669 | 6,625 | 33,851 | 13,188 | 6,470 | 15 | 13 | 14 | 55 | 24 | 15 |
| **Como Golf Course Pond** | | 718,914 | 747,490 | 737,994 | 734,799 | 876,340 | | 23,502 | 23,624 | 85,729 | 44,285 | 26,173 | | 32 | 33 | 90 | 52 | 37 |
| **Total** | **1,100,543** | **1,684,247** | **1,745,406** | **3,066,624** | **2,082,905** | **2,066,704** | **12,352** | **34,164** | **35,989** | **145,767** | **68,139** | **38,307** | **28** | **57** | **60** | **183** | **95** | **67** |

*Average Annual results are derived from using the 1995 water year (Oct, 1994-Sept, 1995)

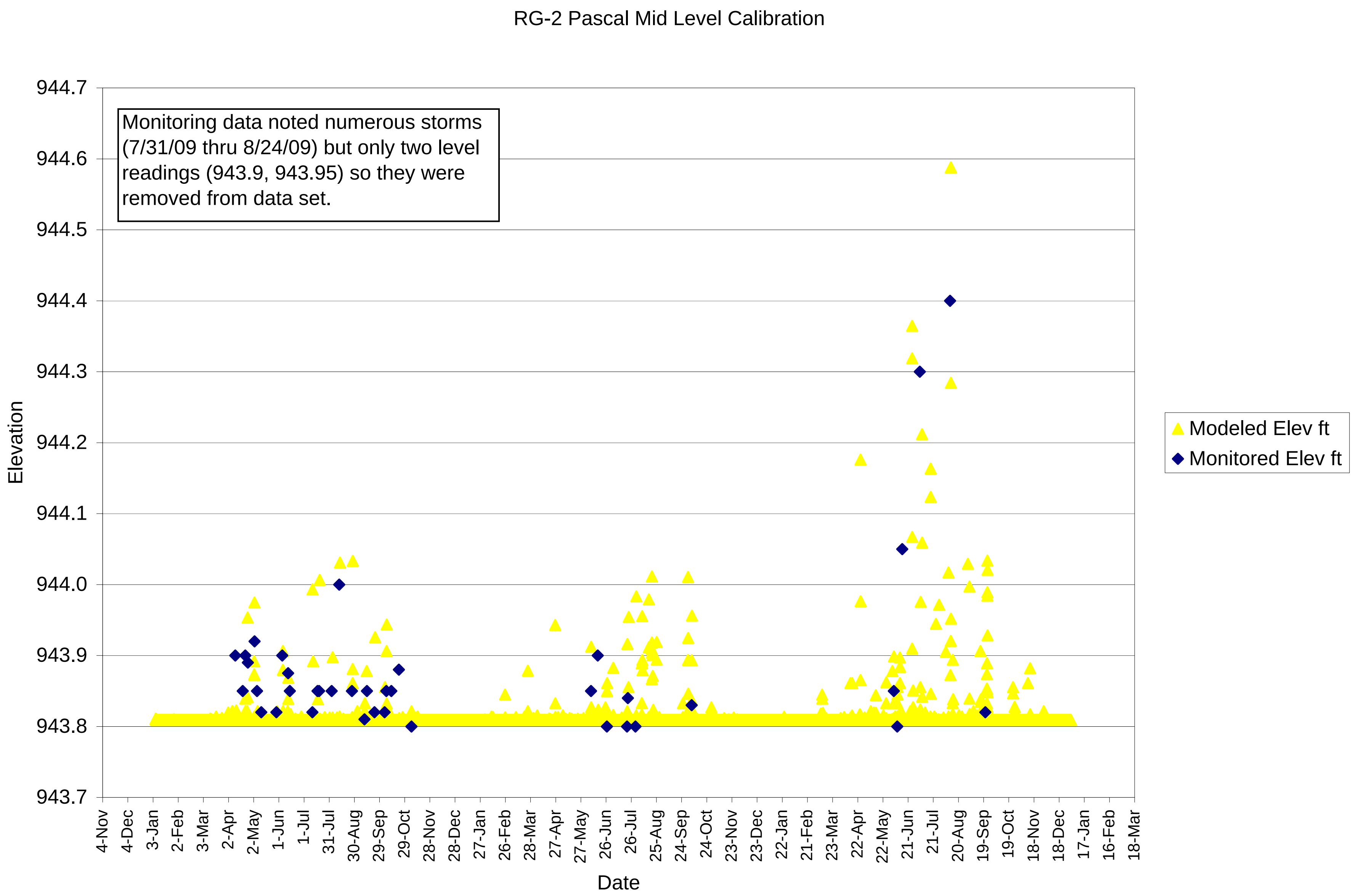
# APPENDIX A

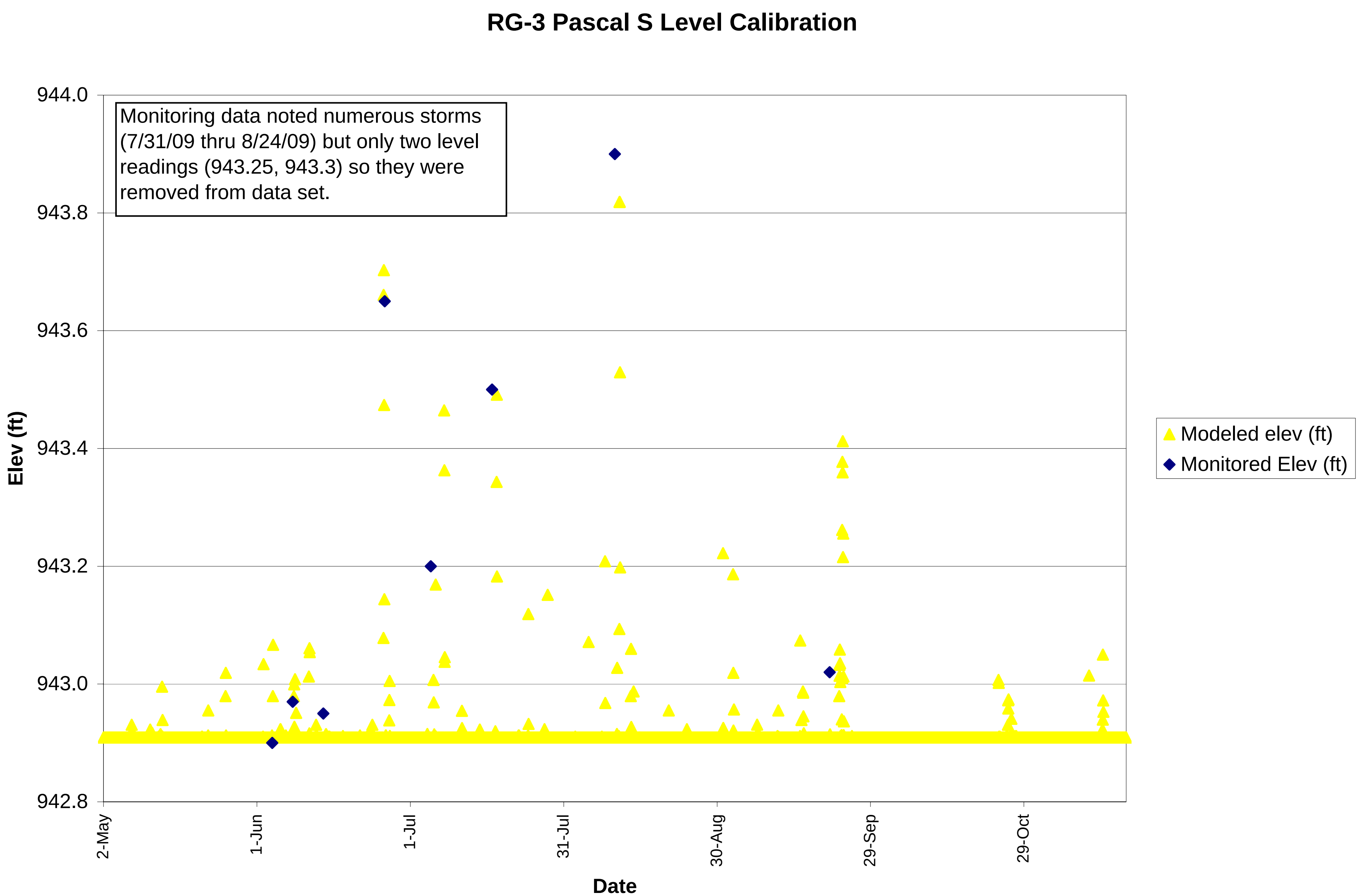

Arlington-Hamline Underground infiltration Rate Analysis
(All Monitored Events)
Monitored 10-minute Infiltration Rate (in/hr)
Depth (ft)
y = 9.4977x
AHUG
0
5
10
15
20
25
30
35
40
0
0.5
1
1.5
2
2.5
3

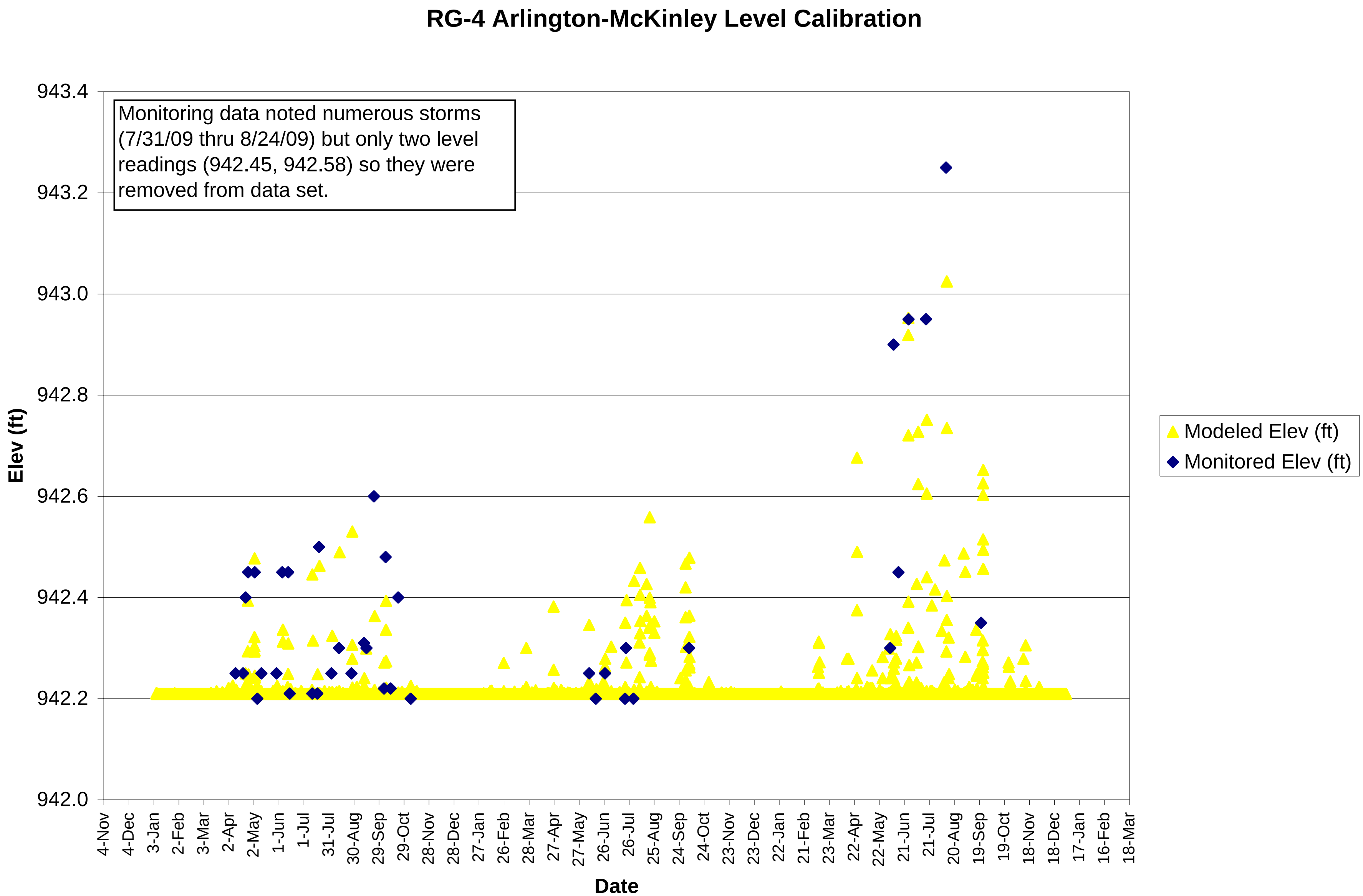

Arlington-Hamline Underground infiltration Rate Analysis
(Selected Events)
Infiltration Rate (in/hr)
Depth (ft)
0
5
10
15
20
25
30
35
40
0
0.5
1
1.5
2
2.5
3
y = 14.238x
Abnormally low points indicate that flow was still entering system following peak water elevation
9/20/2007 1900
8/28/2007 0330
9/18/2007 1800



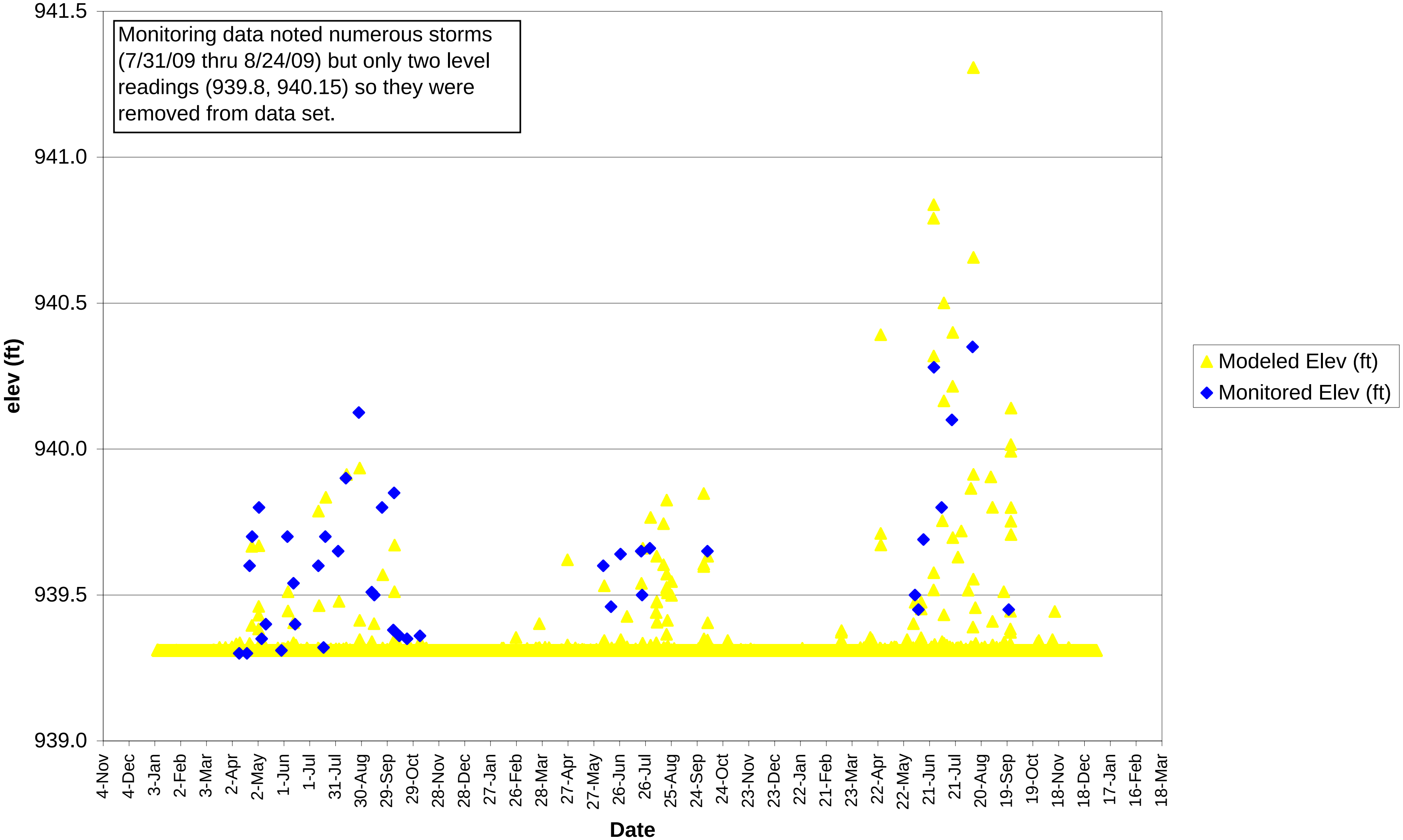
RG-1Pascal N Level Calibration
Monitoring data noted numerous storms (7/31 thru 8/24) but only two level readings (943.9, 943.95) so they were removed from data set.
945.4
945.2
945.0
944.8
944.6
944.4
944.2
944.0
11/4/2007
12/4/2007
1/3/2008
2/2/2008
3/3/2008
4/2/2008
5/2/2008
6/1/2008
7/1/2008
7/31/2008
8/30/2008
9/29/2008
10/29/2008
11/28/2008
12/28/2008
1/27/2009
2/26/2009
3/28/2009
4/27/2009
5/27/2009
6/26/2009
7/26/2009
8/25/2009
9/24/2009
10/24/2009
11/23/2009
12/23/2009
1/22/2010
2/21/2010
3/23/2010
4/22/2010
5/22/2010
6/21/2010
7/21/2010
8/20/2010
9/19/2010
10/19/2010
11/18/2010
12/18/2010
1/17/2011
2/16/2011
3/18/2011
Modeled Elev
Monitored Elev.

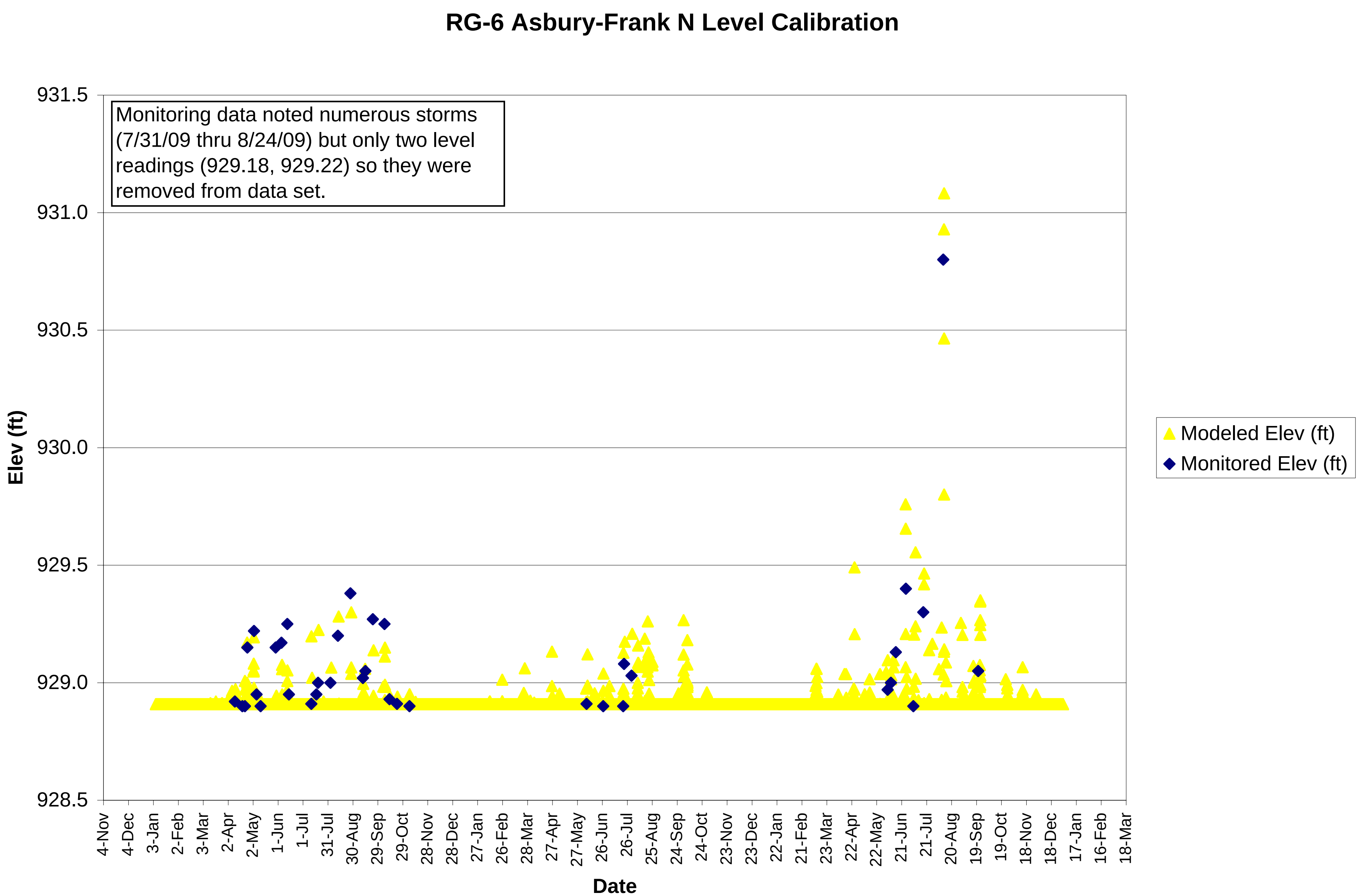

RG-2 Pascal Mid Level Calibration
Monitoring data noted numerous storms (7/31/09 thru 8/24/09) but only two level readings (943.9, 943.95) so they were removed from data set.
Elevation
944.7
944.6
944.5
944.4
944.3
944.2
944.1
944.0
943.9
943.8
943.7
Date
4-Nov
4-Dec
3-Jan
2-Feb
3-Mar
2-Apr
2-May
1-Jun
1-Jul
31-Jul
30-Aug
29-Sep
29-Oct
28-Nov
28-Dec
27-Jan
26-Feb
28-Mar
27-Apr
27-May
26-Jun
26-Jul
25-Aug
24-Sep
24-Oct
23-Nov
23-Dec
22-Jan
21-Feb
23-Mar
22-Apr
22-May
21-Jun
21-Jul
20-Aug
19-Sep
19-Oct
18-Nov
18-Dec
17-Jan
16-Feb
18-Mar
Modeled Elev ft
Monitored Elev ft

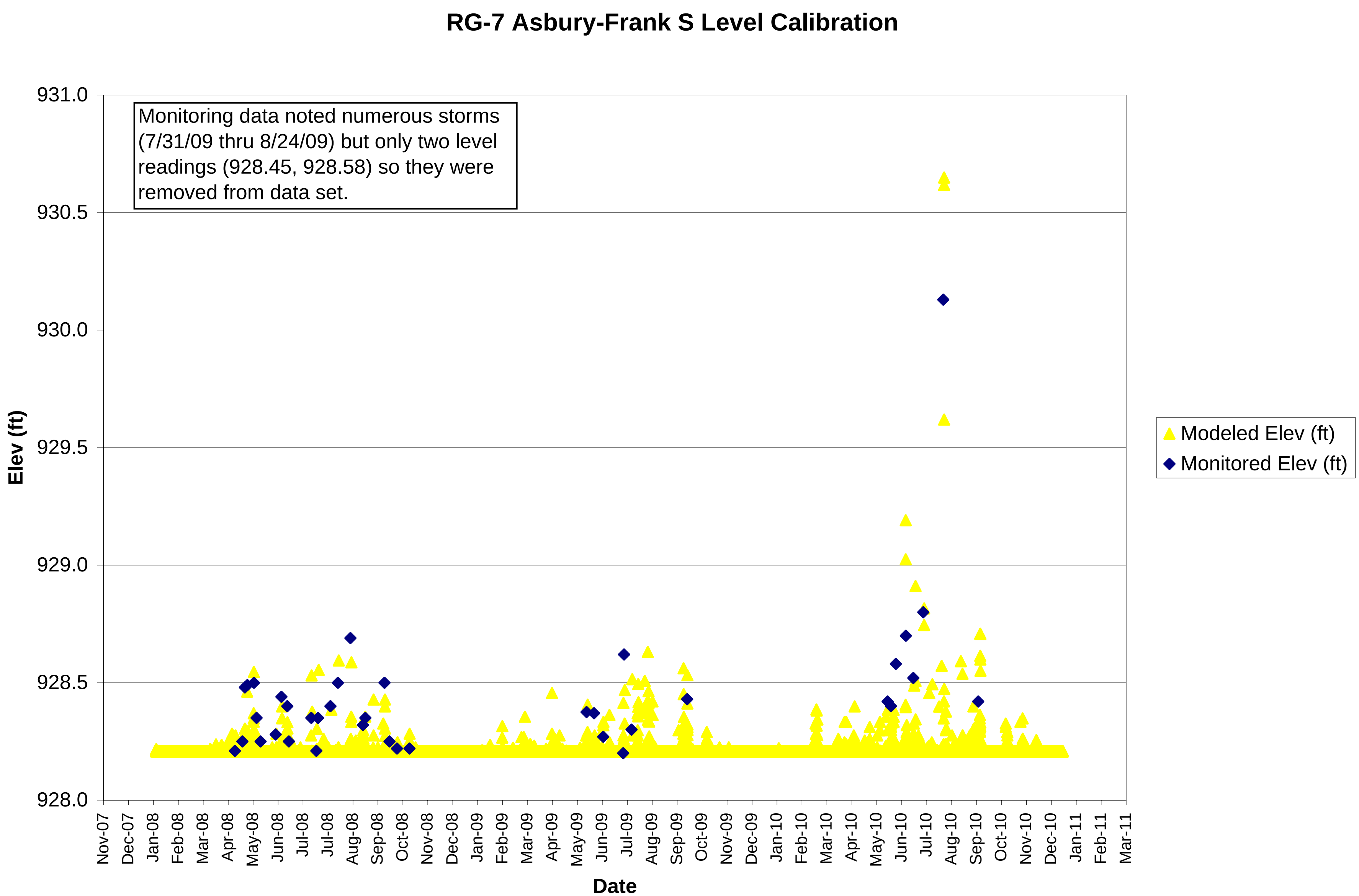

RG-3 Pascal S Level Calibration
Monitoring data noted numerous storms (7/31/09 thru 8/24/09) but only two level readings (943.25, 943.3) so they were removed from data set.
944.0
943.8
943.6
943.4
943.2
943.0
942.8
Elev (ft)
2-May
1-Jun
1-Jul
31-Jul
30-Aug
29-Sep
29-Oct
Date
Modeled elev (ft)
Monitored Elev (ft)


RG-4 Arlington-McKinley Level Calibration
Monitoring data noted numerous storms (7/31/09 thru 8/24/09) but only two level readings (942.45, 942.58) so they were removed from data set.
943.4
943.2
943.0
942.8
942.6
942.4
942.2
942.0
Elev (ft)
4-Nov
4-Dec
3-Jan
2-Feb
3-Mar
2-Apr
2-May
1-Jun
1-Jul
31-Jul
30-Aug
29-Sep
29-Oct
28-Nov
28-Dec
27-Jan
26-Feb
28-Mar
27-Apr
27-May
26-Jun
26-Jul
25-Aug
24-Sep
24-Oct
23-Nov
23-Dec
22-Jan
21-Feb
23-Mar
22-Apr
22-May
21-Jun
21-Jul
20-Aug
19-Sep
19-Oct
18-Nov
18-Dec
17-Jan
16-Feb
18-Mar
Date
Modeled Elev (ft)
Monitored Elev (ft)

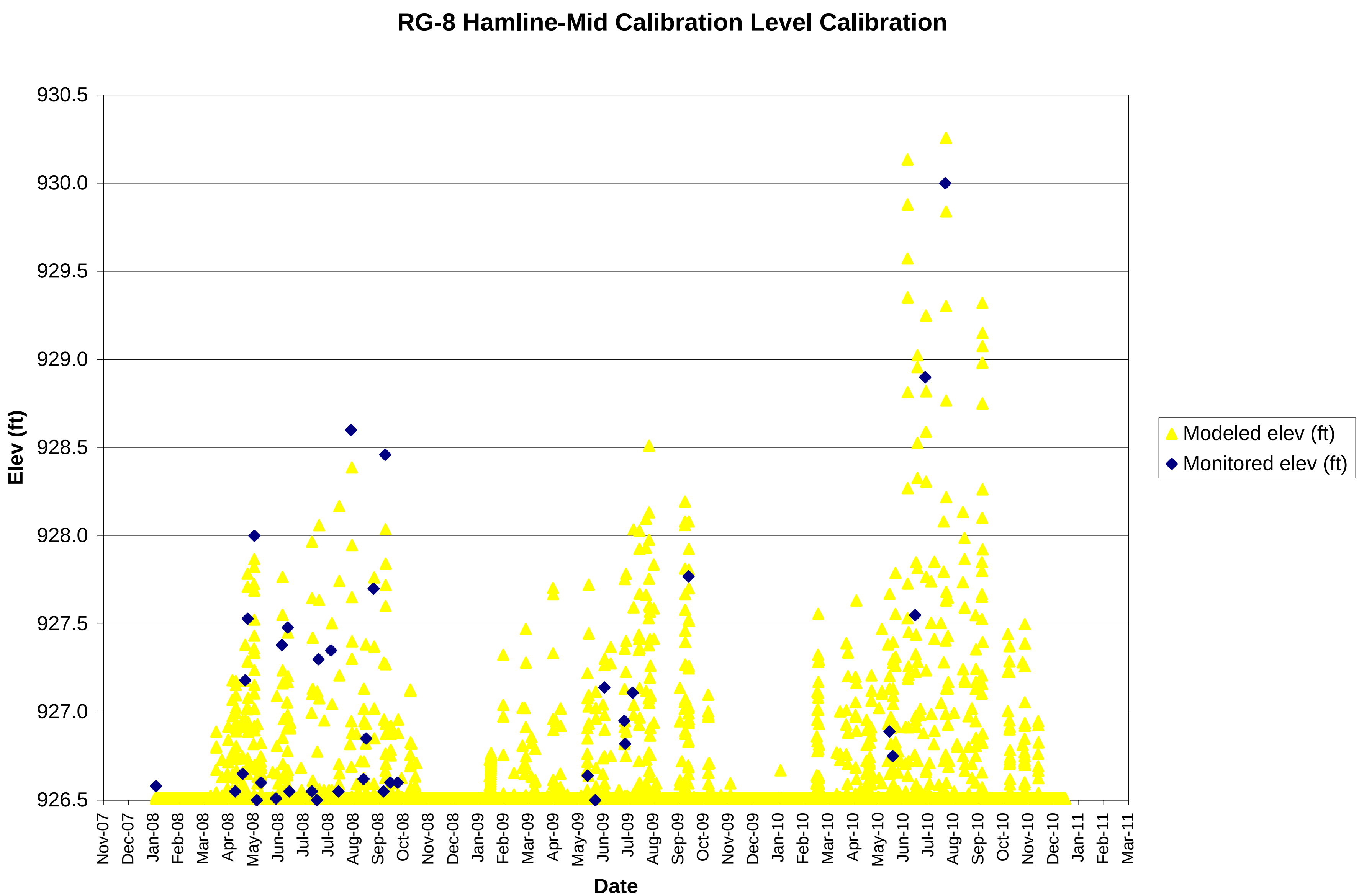
## RG-5 Frankson McK Level Calibration

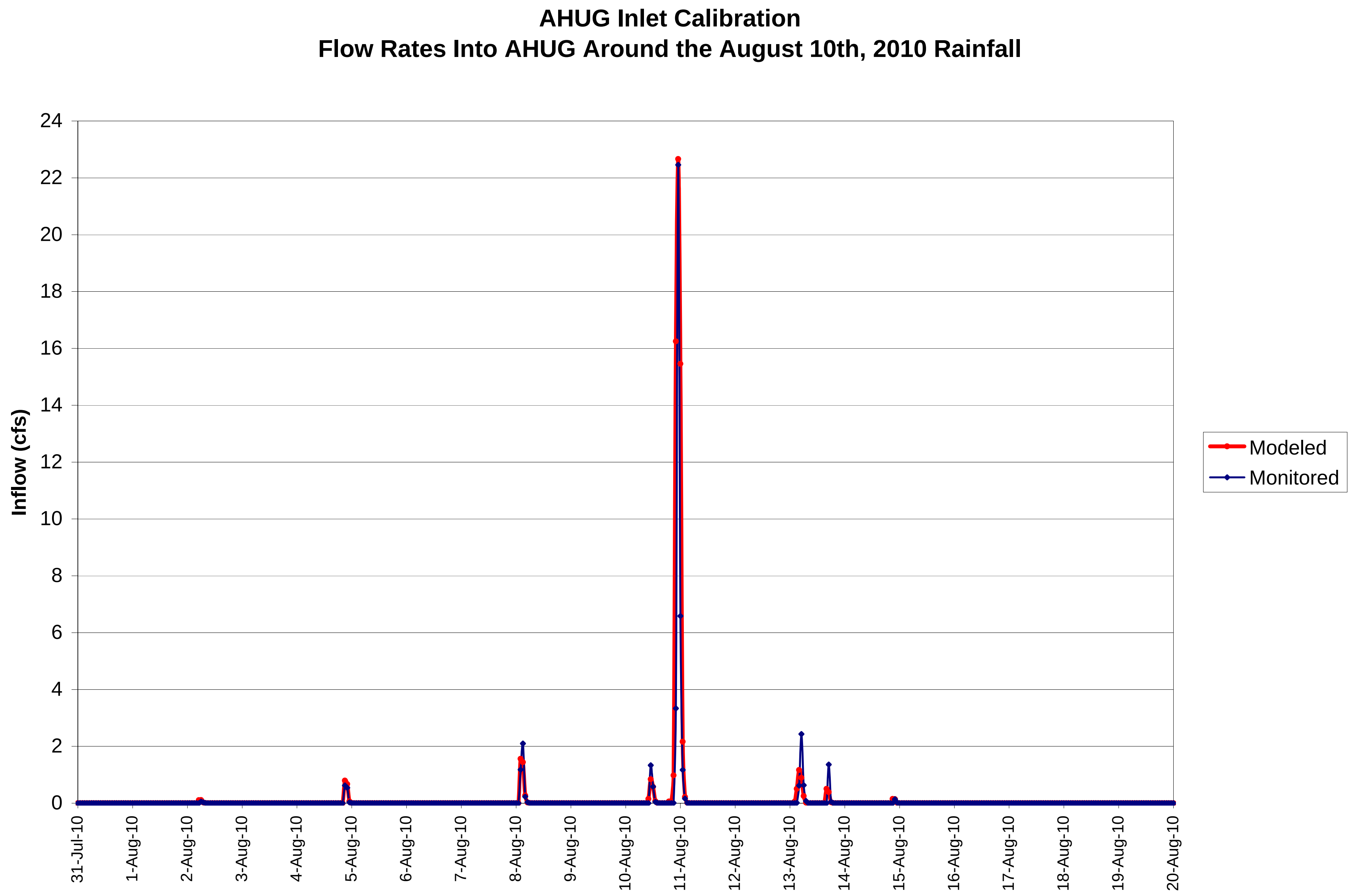


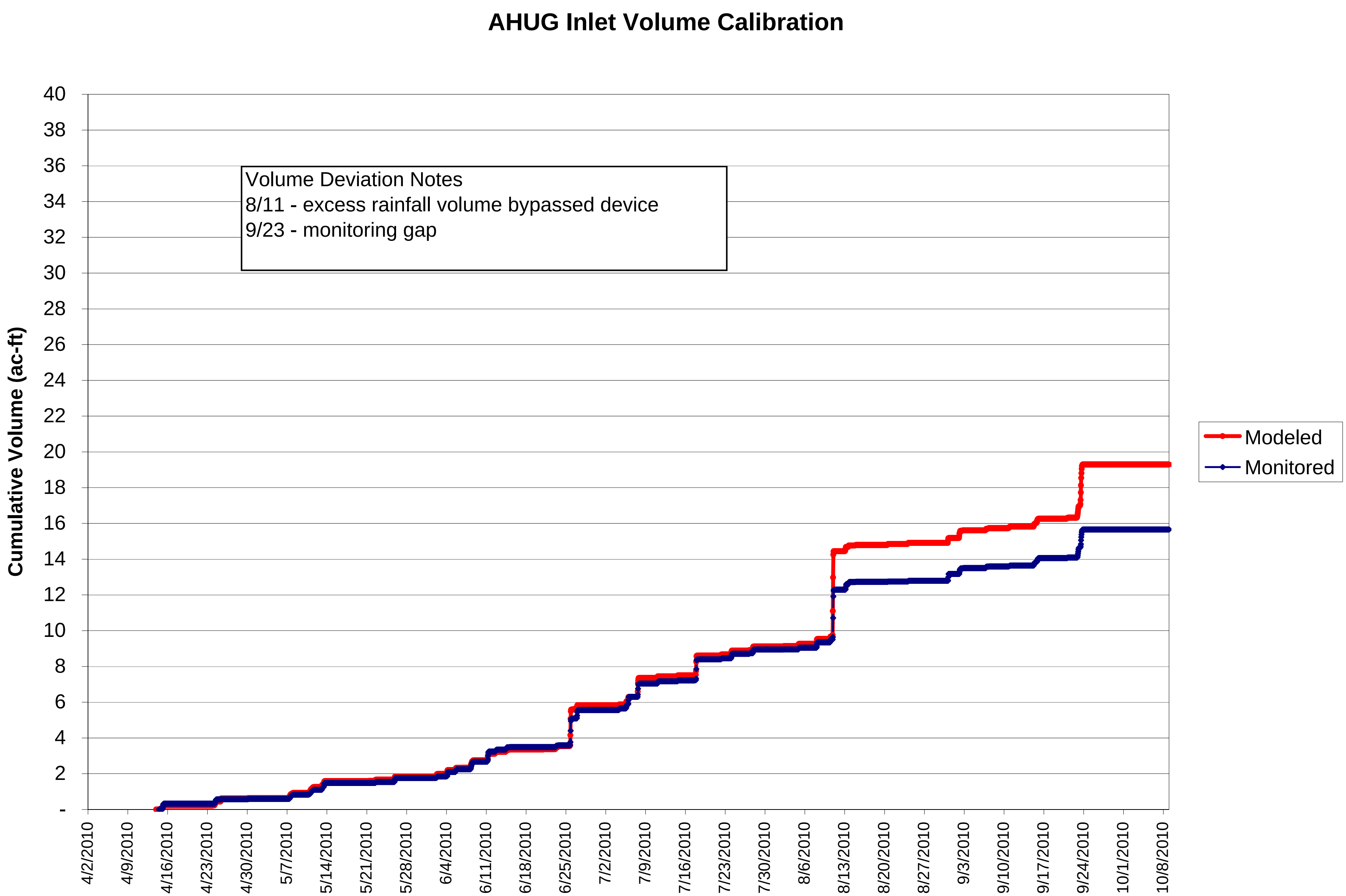

RG-6 Asbury-Frank N Level Calibration
Monitoring data noted numerous storms (7/31/09 thru 8/24/09) but only two level readings (929.18, 929.22) so they were removed from data set.
931.5
931.0
930.5
930.0
929.5
929.0
928.5
Elev (ft)
4-Nov
4-Dec
3-Jan
2-Feb
3-Mar
2-Apr
2-May
1-Jun
1-Jul
31-Jul
30-Aug
29-Sep
29-Oct
28-Nov
28-Dec
27-Jan
26-Feb
28-Mar
27-Apr
27-May
26-Jun
26-Jul
25-Aug
24-Sep
24-Oct
23-Nov
23-Dec
22-Jan
21-Feb
23-Mar
22-Apr
22-May
21-Jun
21-Jul
20-Aug
19-Sep
19-Oct
18-Nov
18-Dec
17-Jan
16-Feb
18-Mar
Date
Modeled Elev (ft)
Monitored Elev (ft)



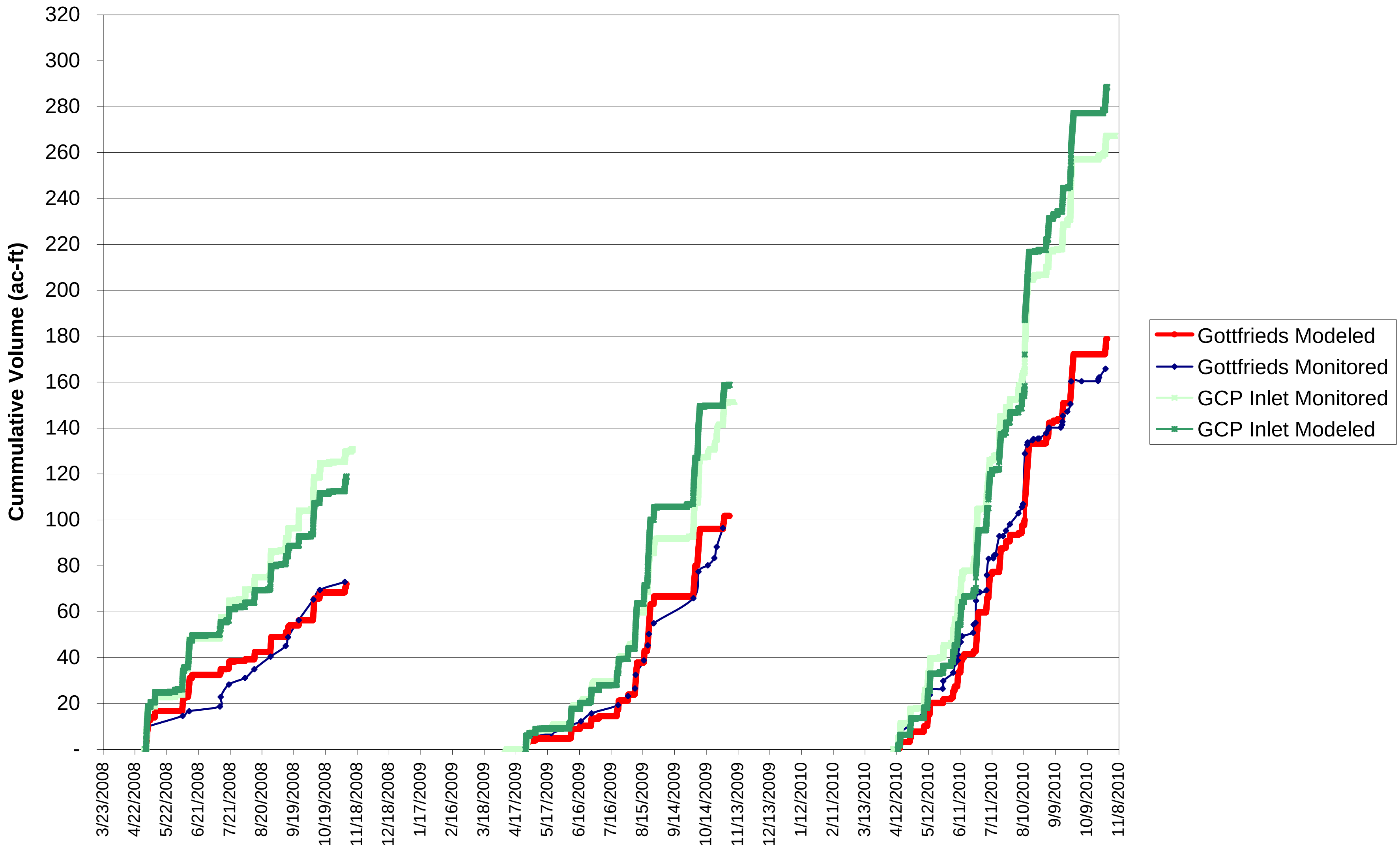
RG-7 Asbury-Frank S Level Calibration
Monitoring data noted numerous storms (7/31/09 thru 8/24/09) but only two level readings (928.45, 928.58) so they were removed from data set.
Elev (ft)
931.0
930.5
930.0
929.5
929.0
928.5
928.0
Nov-07
Dec-07
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
Jan-10
Feb-10
Mar-10
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Date
Modeled Elev (ft)
Monitored Elev (ft)


RG-8 Hamline-Mid Calibration Level Calibration
Elev (ft)
930.5
930.0
929.5
929.0
928.5
928.0
927.5
927.0
926.5
Date
Nov-07
Dec-07
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
Jan-10
Feb-10
Mar-10
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Modeled elev (ft)
Monitored elev (ft)

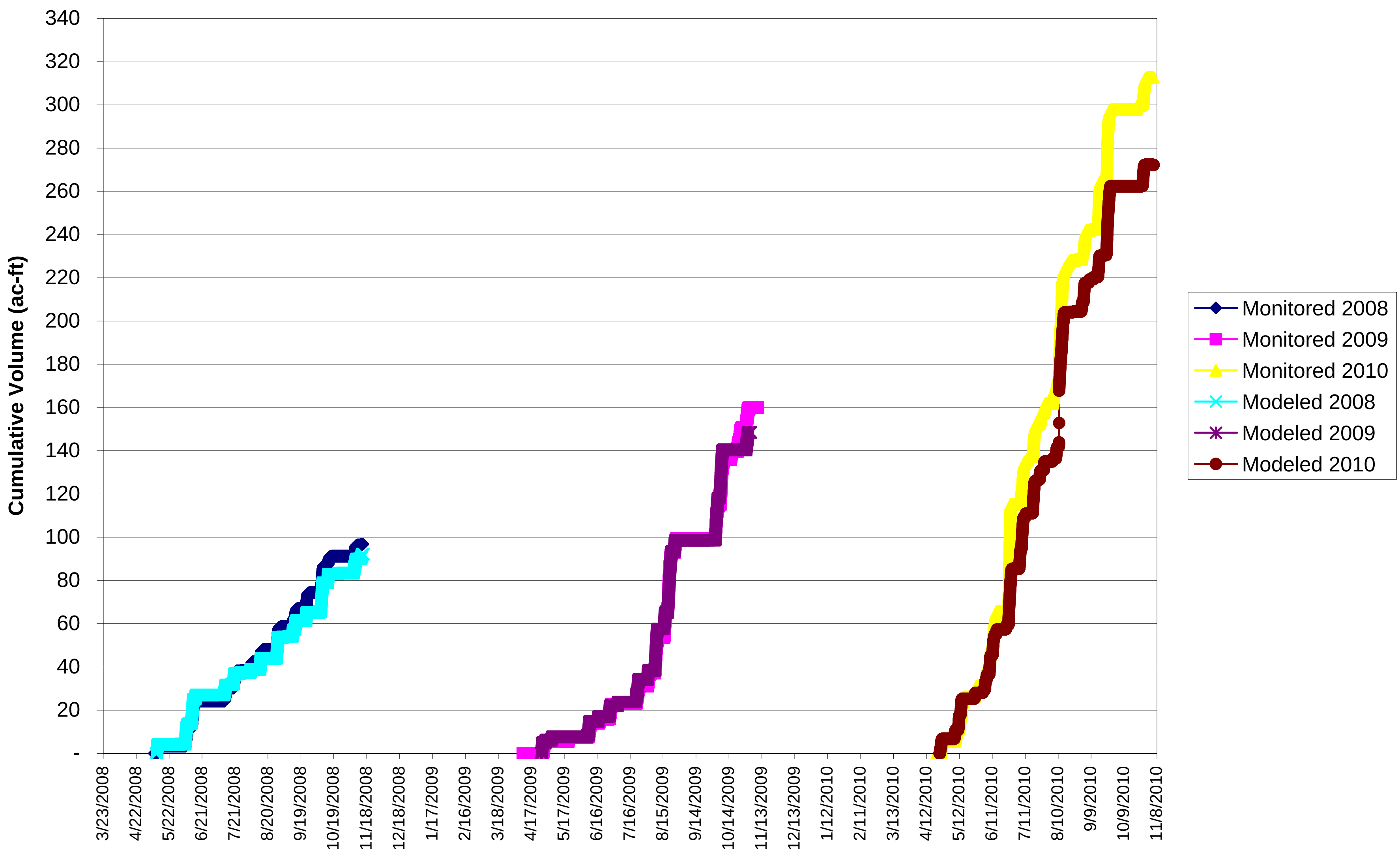

AHUG Inlet Calibration
Flow Rates Into AHUG Around the August 10th, 2010 Rainfall
Inflow (cfs)
0
2
4
6
8
10
12
14
16
18
20
22
24
31-Jul-10
1-Aug-10
2-Aug-10
3-Aug-10
4-Aug-10
5-Aug-10
6-Aug-10
7-Aug-10
8-Aug-10
9-Aug-10
10-Aug-10
11-Aug-10
12-Aug-10
13-Aug-10
14-Aug-10
15-Aug-10
16-Aug-10
17-Aug-10
18-Aug-10
19-Aug-10
20-Aug-10
Modeled
Monitored

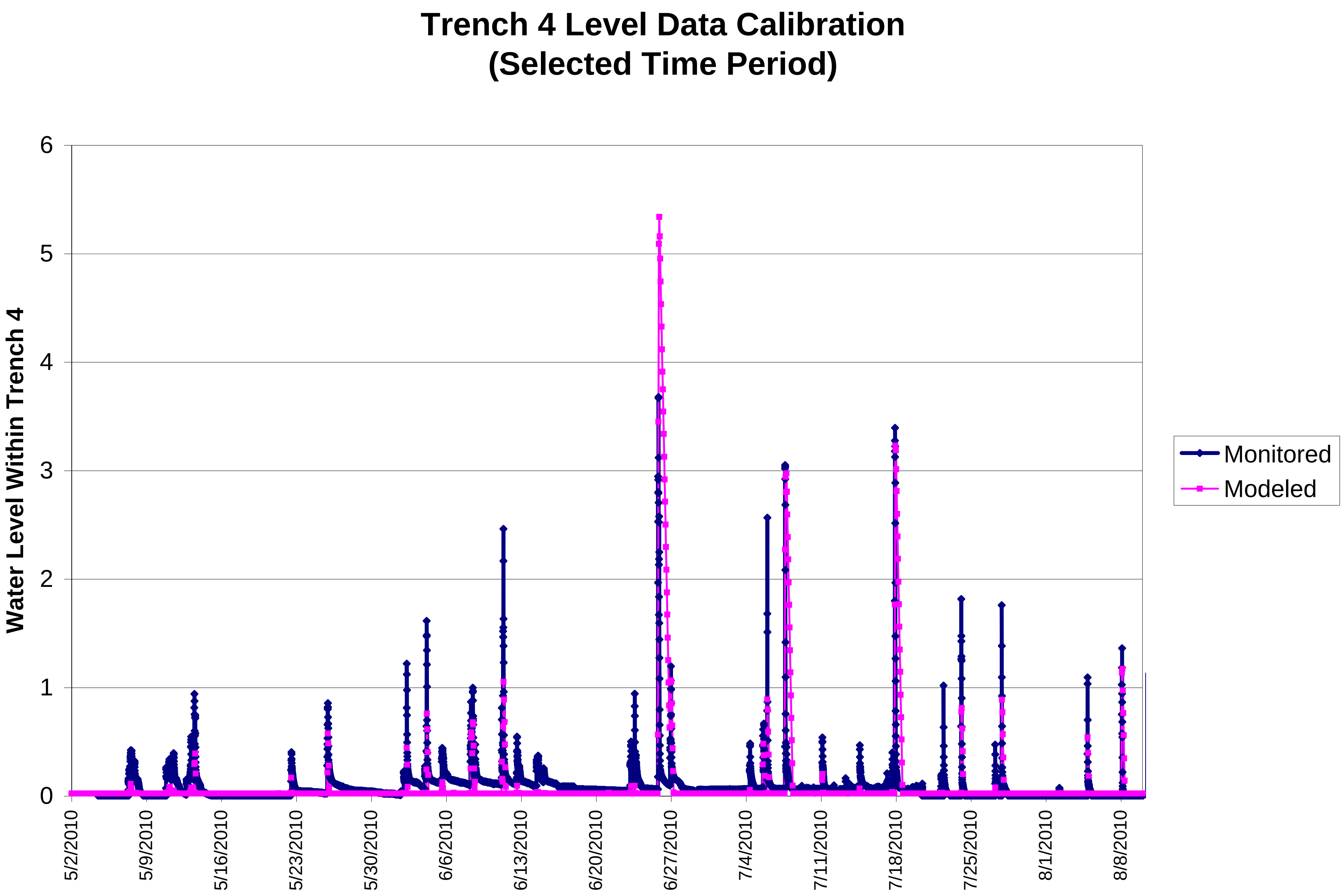

AHUG Inlet Volume Calibration
Volume Deviation Notes
8/11 - excess rainfall volume bypassed device
9/23 - monitoring gap
Cumulative Volume (ac-ft)
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
-
4/2/2010
4/9/2010
4/16/2010
4/23/2010
4/30/2010
5/7/2010
5/14/2010
5/21/2010
5/28/2010
6/4/2010
6/11/2010
6/18/2010
6/25/2010
7/2/2010
7/9/2010
7/16/2010
7/23/2010
7/30/2010
8/6/2010
8/13/2010
8/20/2010
8/27/2010
9/3/2010
9/10/2010
9/17/2010
9/24/2010
10/1/2010
10/8/2010
Modeled
Monitored

## Golf Course Pond Inlet and Gottfrieds Pit Cummulative Volume Calibration

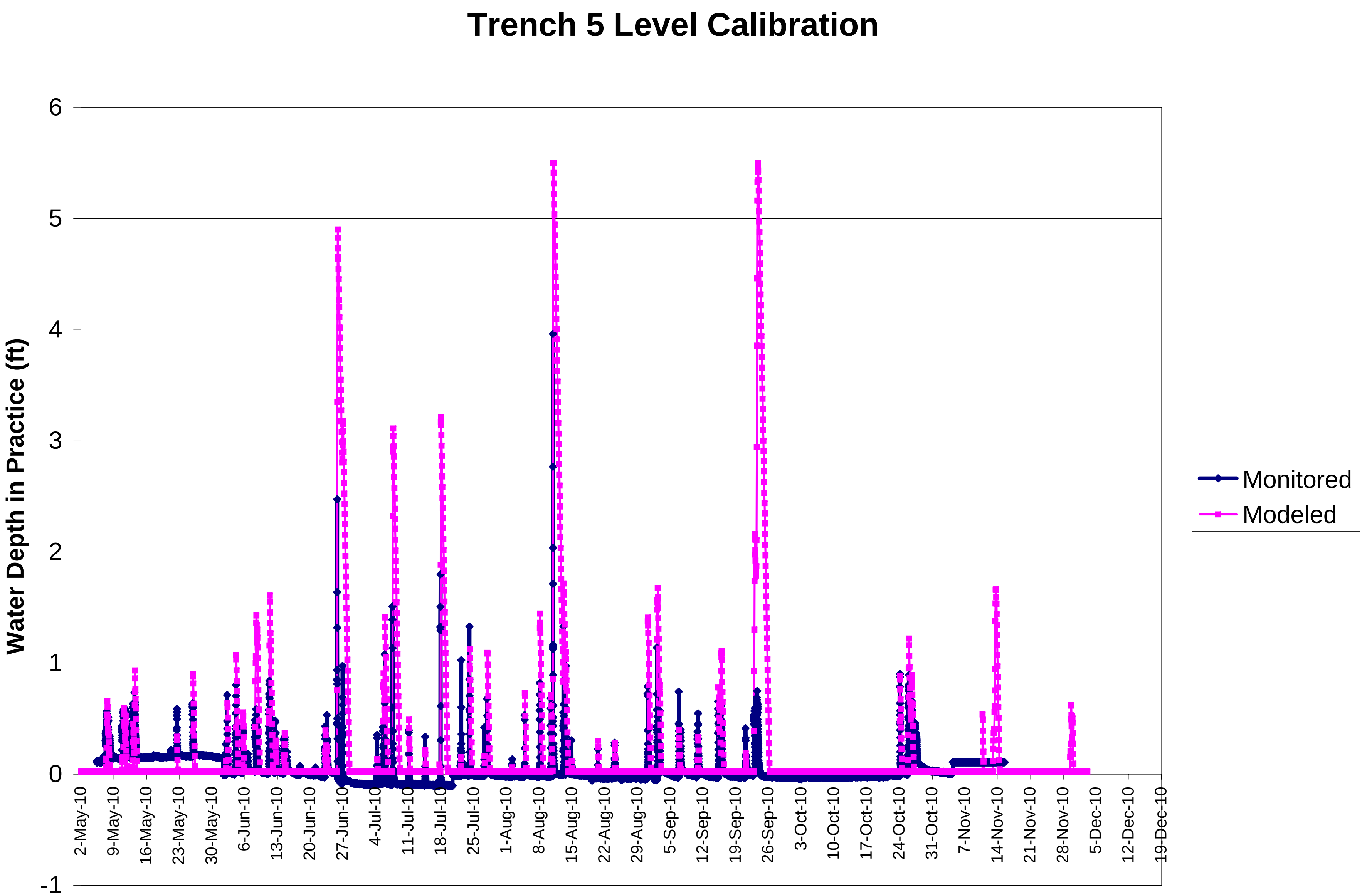


## Golf Course Pond Outlet Cummulative Volume Calibration



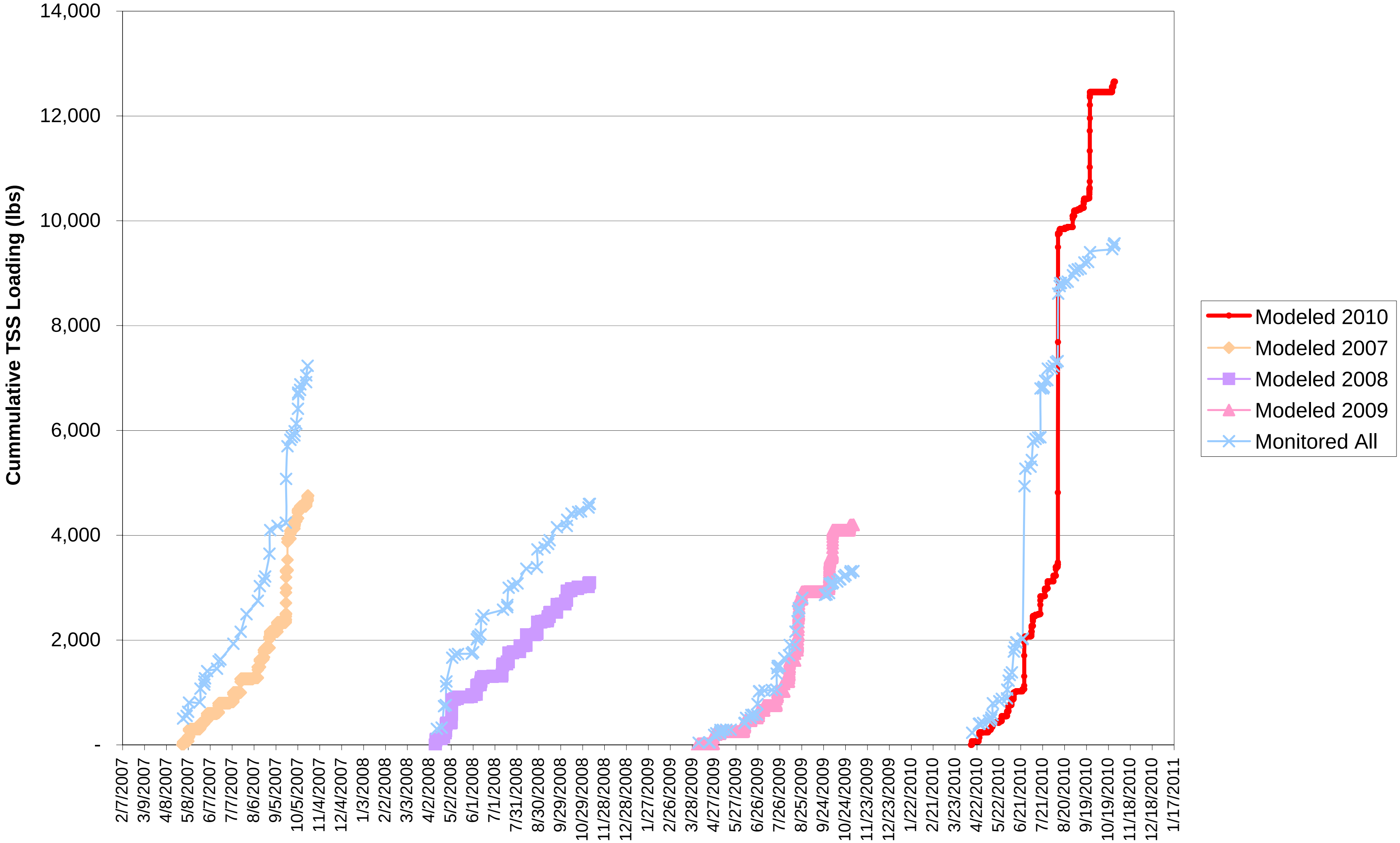


Trench 4 Level Data Calibration
(Selected Time Period)
Water Level Within Trench 4
6
5
4
3
2
1
0
5/2/2010
5/9/2010
5/16/2010
5/23/2010
5/30/2010
6/6/2010
6/13/2010
6/20/2010
6/27/2010
7/4/2010
7/11/2010
7/18/2010
7/25/2010
8/1/2010
8/8/2010
Monitored
Modeled



Trench 5 Level Calibration
Water Depth in Practice (ft)
6
5
4
3
2
1
0
-1
2-May-10
9-May-10
16-May-10
23-May-10
30-May-10
6-Jun-10
13-Jun-10
20-Jun-10
27-Jun-10
4-Jul-10
11-Jul-10
18-Jul-10
25-Jul-10
1-Aug-10
8-Aug-10
15-Aug-10
22-Aug-10
29-Aug-10
5-Sep-10
12-Sep-10
19-Sep-10
26-Sep-10
3-Oct-10
10-Oct-10
17-Oct-10
24-Oct-10
31-Oct-10
7-Nov-10
14-Nov-10
21-Nov-10
28-Nov-10
5-Dec-10
12-Dec-10
19-Dec-10
Monitored
Modeled

## AHUG Inlet TSS Cummulative Loading Calibration



# Appendix D

## Technical Memorandum: Sump Monitoring Study

Prepared by Wenck Associates, Inc.
For the Capitol Regional Watershed District

# Technical Memorandum: Sump Monitoring Study

March 21, 2011

# I. Background

This memorandum summarizes a study conducted by Wenck Associates that aimed to assist the Capitol Region Watershed District (CRWD) in understanding the performance of sumps for removing total phosphorus (TP) and total suspended solids (TSS) from stormwater. Sumps are often utilized in stormwater management practices as pretreatment units to capture sediment and debris in stormwater runoff. Several stormwater best management practices (BMPs) in CRWD utilize sumped catch basins as stormwater pretreatment units for runoff to remove sediment. Also, sumped catch basins are used on BMP projects where gross pollutant removal does not achieve 90% total suspended solids (TSS) removal. Although relatively inexpensive to construct, sump catch basins require intensive maintenance to ensure continued effectiveness. The purpose of this study is to evaluate the effectiveness of sumps as BMP pretreatment units for removing TP and TSS in stormwater runoff.

For this study, a literature review of sump performance data was conducted; sediment samples from five sumps in St. Paul were collected; and samples were analyzed at Pace Laboratories for density, total phosphorus, and particle size distribution.

# II. Literature Review

A literature search was completed to determine if others have conducted similar studies on sumps. The Oregon Department of Environmental Quality (2005) reported perhaps the most important observation regarding sumps: they are not designed to remove TSS or soluble pollutants. Design engineers and stormwater managers may forget that fact and often try to make sumps something they are not. We must remember that there are other practices more suitable to removing the small particles (TSS) in stormwater runoff.

Most recently, the University of Minnesota (Howard, 2010) conducted an extensive laboratory study on sumps. The work was conducted in a laboratory with simulated stormwater runoff rather than with actual field data. Removal efficiency under low flow conditions as well as sediment washout rate under high flow conditions was measured. The sumps removed suspended sediment at low flows, but washout was substantial at high flows. A porous baffle, named St. Anthony Falls Laboratory (SAFL) Baffle, was designed and tested as a possible retrofit to the standard sump. Results indicate that, with the correct baffle configuration, the washout of sediments accumulated in the sump can be nearly eliminated for flows up to approximately the 10-year design storm runoff, and removal efficiency can be increased by 10 to 15%.

A University of Washington researcher (Engstrom, 2004) conducted a comprehensive field study of stormwater runoff. The author analyzed the particle size distribution of 35 stormwater runoff samples. She found that most suspended solids in stormwater were less than 250 microns and 64% of all suspended particles were less than 62 microns. The particle size distributions reported in the study show that 80% of suspended solids were less than 120 microns. (The 120-micron threshold will be discussed further in the “Conclusions” section of this memo.) The author concluded that TSS washoff and removal were directly tied to antecedent moisture conditions and precipitation intensity and duration.

For their Stormceptor wet vault, Rinker Materials (Rinker, 2004) prepared a literature review of available data on stormwater runoff particle size distributions. Rinker noted that the Municipal Research & Services Center of Washington, Nationwide Urban Runoff Program (NURP), and Environmental Protection Agency (EPA) report 60-100% of particles in stormwater runoff are less than 100 microns. Another study reported that 80% of particles are less than 25 microns. Conversely, there are also studies that indicate stormwater particle size distributions are coarse. However, these are mainly associated with highway surfaces.

A memorandum to CRWD dated February 22, 2007 provided a summary of sump pollutant removal studies. Much of the literature reviewed stressed the importance of maintenance to sustain the pollutant removal provided by sumps. To that end, an annual cleaning or maintenance program is necessary. Intuitively, sump maintenance immediately following snowmelt in the spring and leaf off in the fall is ideal. However, a study that specifically evaluated the optimal time of year to conduct maintenance was not located. A complete list of the references used for this literature review is listed at the end of this memo.

# III. Methods

A total of five sumps were selected for sampling. Each sump was located near recent City of St. Paul Public Works projects with infiltration trenches (Figure 1). On February 9 and 11, 2011, Wenck and CRWD staff collected accumulated sediment using a Ponar dredge or shovel and placed it in a bucket. From the bucket, two samples from four sumps and one sample from one sump were submitted for laboratory analysis. A sufficient amount of sediment for two samples was not collected in the fifth sump. Samples to be analyzed for density and total phosphorus were collected in a 4 ounce glass jar. Particle size distribution samples were collected in half-liter plastic bottles.

The samples were delivered to Pace Laboratories in Minneapolis for analysis. Each sample was analyzed for density [according to American Society for Testing and Materials (ASTM) D5057], total phosphorus (according to EPA 365.4), and particle size distribution (according to ASTM D422). A description of each sump location is listed below. A City of St. Paul typical detail for the catch basin, manhole and trench plumbing is shown in Figure 2.

A field note summary for each sump is provided below. Note that the depth of accumulated sediment and amount of organic matter and trash in each sump was also estimated.

*Sump 1:*

- Location: at the intersection of Syndicate Street and Jefferson Avenue.
- Structure number 429 as labeled in the City of St. Paul Griggs/Jefferson Residential Street Vitality Project (RSVP) plans dated 6/8/07.
- Two catch basins were investigated, but little to no sediment accumulation was observed in either. There was mostly leaf accumulation in the catch basins with little to no trash.
- The two catch basins drain to the infiltration trench sump manhole. Wenck collected one sample from the sump manhole using the Ponar dredge. There was only enough sediment for one of two samples. By observation, the sample was mostly organic but had coarse-grained sediment.

*Sump 2:*

- Location: at the east end of the infiltration trench on Englewood Avenue between Albert Street and Hamline Avenue.
- Structure number not labeled in the City of St. Paul Hubbard/Griggs RSVP plans dated 3/27/07.
- CRWD staff collected two samples from the infiltration trench sump manhole using a shovel. There was a large accumulation of sediment in the sump, which should be removed.
- The samples were primarily coarse grained material with no organics.
- During sample collection, a large, green sand truck driving on a trail near the sampling site was observed. (The owner of the sand truck could not be identified.) Spreading of sand is a possible source for the large sediment accumulation in the sump.

*Sump 3:*

- Location: at the west end of the infiltration trench on Englewood Avenue between Albert Street and Hamline Avenue (on the opposite end of Sump2).
- Structure number not labeled in the City of St. Paul Hubbard/Griggs RSVP plans dated 3/27/07.
- Two samples were collected from the infiltration trench sump manhole using the Ponar dredge.
- The samples were primarily organic with a large accumulation of trash. The coarse sediment was separated from the organics and trash.

*Sump 4:*

- Location: at the north end of the infiltration trench on Griggs Street between James Avenue and Palace Avenue.
- Structure number 492 as labeled in the City of St. Paul Griggs/Jefferson RSVP plans dated 6/8/07.
- Two samples were collected from the infiltration trench manhole using the Ponar dredge.
- The samples felt like drained mud; there was little to no leaves or trash. The sediment appeared finer than at other sites.

*Sump 5:*

- Location: at the south end of the infiltration trench on Griggs Street between James Avenue and Palace Avenue (on the opposite end of Sump4).
- Structure number 523 as labeled in the City of St. Paul Griggs/Jefferson RSVP plans dated 6/8/07.
- CRWD collected two samples from the infiltration trench sump manhole using a shovel.
- The samples were coarse, and there was little to no leaves or trash.

# IV. Results

Pace analyzed the nine samples. The density and total phosphorus results are summarized in Table 1. As noted above, Sump 3 contained mostly organic material, and Sump4 contained very fine, mud-like material. As such, Pace was not able to obtain accurate results due to the organic and water content entrained in each of the samples. Lab staff reported that there would have been nothing left to analyze had the lab burned the organic material before conducting the grain size analysis and that the results are not accurate due to the "vast amounts of organic material."

**Table 1. Sump sediment lab results from Pace Analytical.**

| SUMP SITE | Density (g/mL) | TP (mg/kg) |
|---|---|---|
| Sump 1 | 1.54 | 291 |
| Sump 2, S1 | 1.59 | 368 |
| Sump 2, S2 | 1.58 | 416 |
| Sump 3, S1 | 1.04 | 2,050 |
| Sump 3, S2 | 1.12 | 3,460 |
| Sump 4, S1 | 1.07 | 1,670 |
| Sump 4, S2 | 1.18 | 1,570 |
| Sump 5, S1 | 1.89 | 395 |
| Sump 5, S2 | 1.86 | 451 |
| Average | 1.43 | 1,186 |
| **Average of Sump 1, Sump 2, and Sump 5** | 1.69 | 384 |

Because of the inaccuracy for Sump3 and Sump4, two different averages were calculated: one for all sample results and one for those sample results from Sump1, Sump2, and Sump5. (The shaded boxes in Table 1 indicate the sample results from Sump3 and Sump4.) It is possible that watershed conditions are the cause of the high amount of organic matter in Sump3 and Sump4 (i.e. grass clippings and leaves).

The average density of the collected sediment is 1.69 g/mL while the average total phosphorus content of sediment is 384 mg/kg. The University of Washington stormwater study (Engstrom 2004) measured a concentration of 273 mg/kg total phosphorus in collected sediment. (Engstrom did not report a density value.) These concentrations are greater than lab results from a previous Wenck study for the City of Andover that found a total phosphorus concentration of 215 mg/kg of sediment obtained from street sweeping. As part of the City of Andover's Non-degradation Study, Wenck collected this data to quantify the amount of TSS and total phosphorus removed by street sweeping. The difference in concentration between Andover and CRWD may be due to Anoka Sand Plain soils in Andover versus slightly more silty soils in St. Paul; greater percent impervious/urbanization in St.Paul; and/or winter de-icing methods.

Pace also determined the particle size distribution of the collected sediment samples. Evaluating the particle size distribution of a sample allows one to understand what portion of sediment is being captured – large, medium, or small sized particles. The particle size distribution results for the nine samples are shown in Figure 3. The NURP particle size distribution for urban stormwater runoff is also plotted for comparison purposes. The horizontal axis indicates the grain size of a particle while the vertical axis indicates the percent of all particles smaller than that particular size.

Similar to the density and total phosphorus measurements, the particle size distribution analysis was not accurate for samples from Sump3 and Sump4. The results of the four samples from Sump3 and Sump4 indicate that 95% of the material in the samples is finer (smaller in diameter) than 7 microns. Given the high amount of total phosphorus found in these samples, it is likely that this material is partially degraded organic matter rather than mineral-based sediment.

# V. Conclusions

The particle size distributions for the five samples not from Sump3 and Sump4 generally indicate that the tested sumps are 90-100% efficient at retaining particles 5,000 microns (um) and larger. The P8 computer model defines TSS as particles 120 um and smaller. Figure 3 shows that approximately 8 to 15% (with an average of 11%) of the collected material would be classified as TSS. This compares favorably with lab results Wenck obtained for the City of Andover that found approximately 15% of sediment collected by street sweeping was smaller than 120 um.

The data demonstrates that sumps are effective at removing coarse sand and gravel from stormwater runoff. However, comparison of the NURP and University of Washington particle size distributions in Figure 3 to the data found through this study demonstrates that sumps are not effective in trapping fine particles.

The density, total phosphorus, and particle size distribution data obtained from this study is useful to CRWD for future water quality analyses. Consider an example using the Vortechs unit upstream of the Arlington-Hamline Underground system:

- CRWD staff calculates a volume of 10 cubic feet per year of accumulated sediment using the sediment depth and structure diameter.

- Using an average density of 1.69 g/mL, the weight of accumulated sediment is 1,052 pounds.
    - $10 \text{ cubic feet} * \frac{28.3 \text{ L}}{1 \text{ cubic foot}} * \frac{1{,}000 \text{ mL}}{1 \text{ L}} * \frac{1.69 \text{ g}}{\text{mL}} * \frac{2.2 \text{ lb}}{1{,}000 \text{ g}} = 1{,}052 \text{ lb/yr}$

- Using the particle size distributions, approximately 11% of the 1,052 lb/yr would be classified as TSS (116 lb/yr). (The remaining 936 lb/yr of sediment would be considered settleable load rather than suspended.)

- Using the total phosphorus concentration, approximately 0.044 lb of total phosphorus is trapped per year.
    - $116 \text{ lb} * \frac{1 \text{ kg}}{2.2 \text{ lb}} * \frac{384 \text{ mg TP}}{\text{kg}} * \frac{1 \text{ g}}{1{,}000 \text{ mg}} * \frac{2.2 \text{ lb}}{1{,}000 \text{ g}} = 0.044 \text{ lb/yr TP}$

# VI. References


Engstrom, Amy. “Characterizing Water Quality of Urban Stormwater Runoff: Interactions of Heavy Metals and Solids in Seattle Residential Catchments.” University of Washington. 2004.

Howard, Adam. “Use of Standard Sumps for Suspended Sediment Removal from Stormwater.” University of Minnesota. June 2010.

Oregon Department of Environmental Quality. “Portland Harbor Catch Basins.” May 2005.

Rinker Materials. “Particle Size Distribution in Stormwater Runoff.” June 2004.

Sansalone, John and Robert Rooney. “Assessing the Environmental Benefits of Selected Source Control and Maintenance Practices for MS4 Permits.” University of Florida. June 2007.

Townsend, Timothy, Yong-Chul Jang, Paul Thurdekoos, Matthew Booth, Pradeep Jain, and Thabet Tolaymat. “Characterization of Street Sweepings, Stormwater Sediments, and Catch basin Sediments in Florida for Disposal and Reuse.” Florida Center for Solid and Hazardous Waste Management. December 31, 2002.


CAPITOL REGION WATERSHED DISTRICT

Sump Locations

Wenck

Engineers - Scientists
Business Professionals
www.wenck.com

1800 Pioneer Creek Center
Maple Plain, MN 55359-0429
1-800-472-2232

FEB 2011

Figure 1

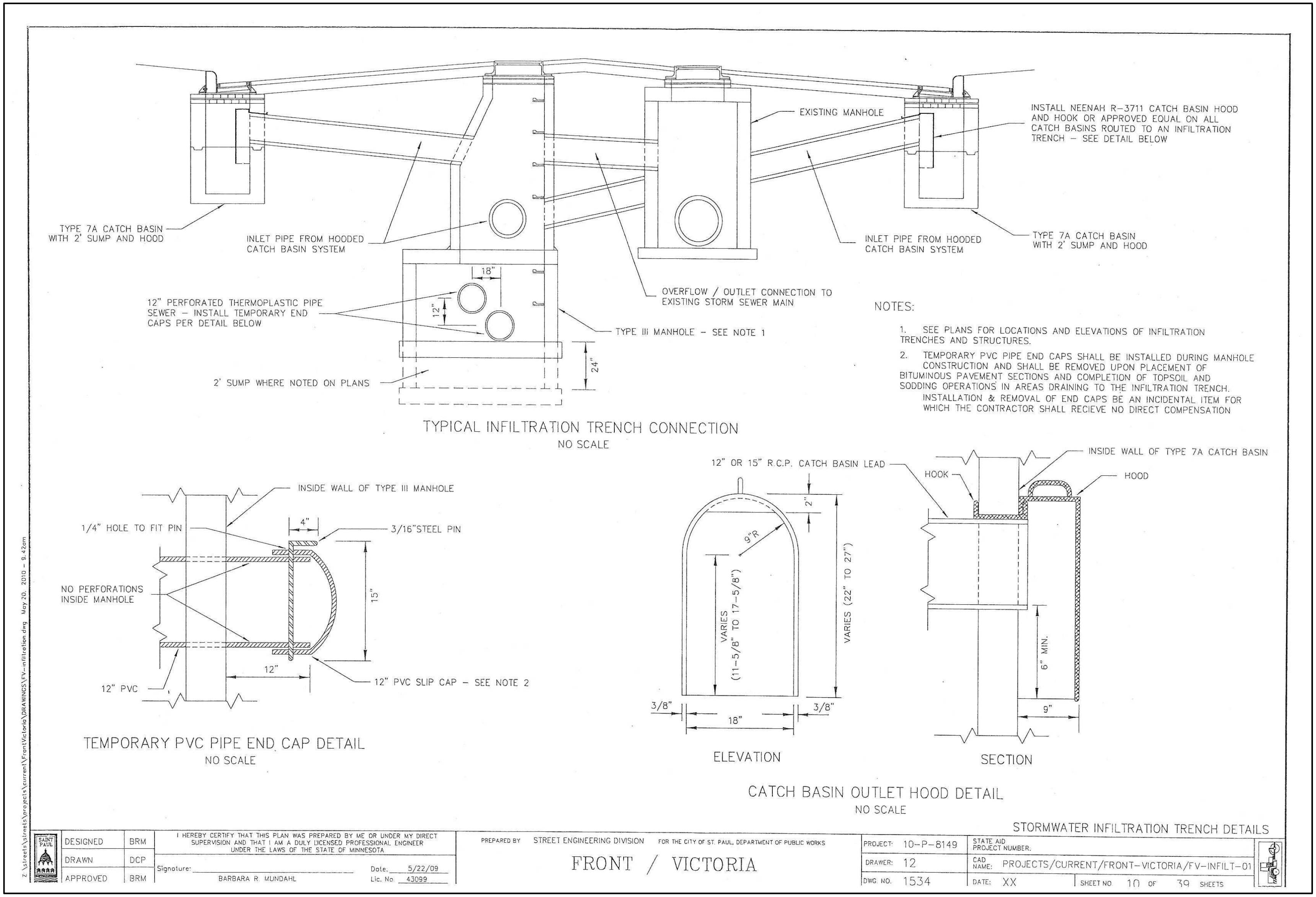



**Figure 2. Typical detail for St. Paul infiltration trench.**

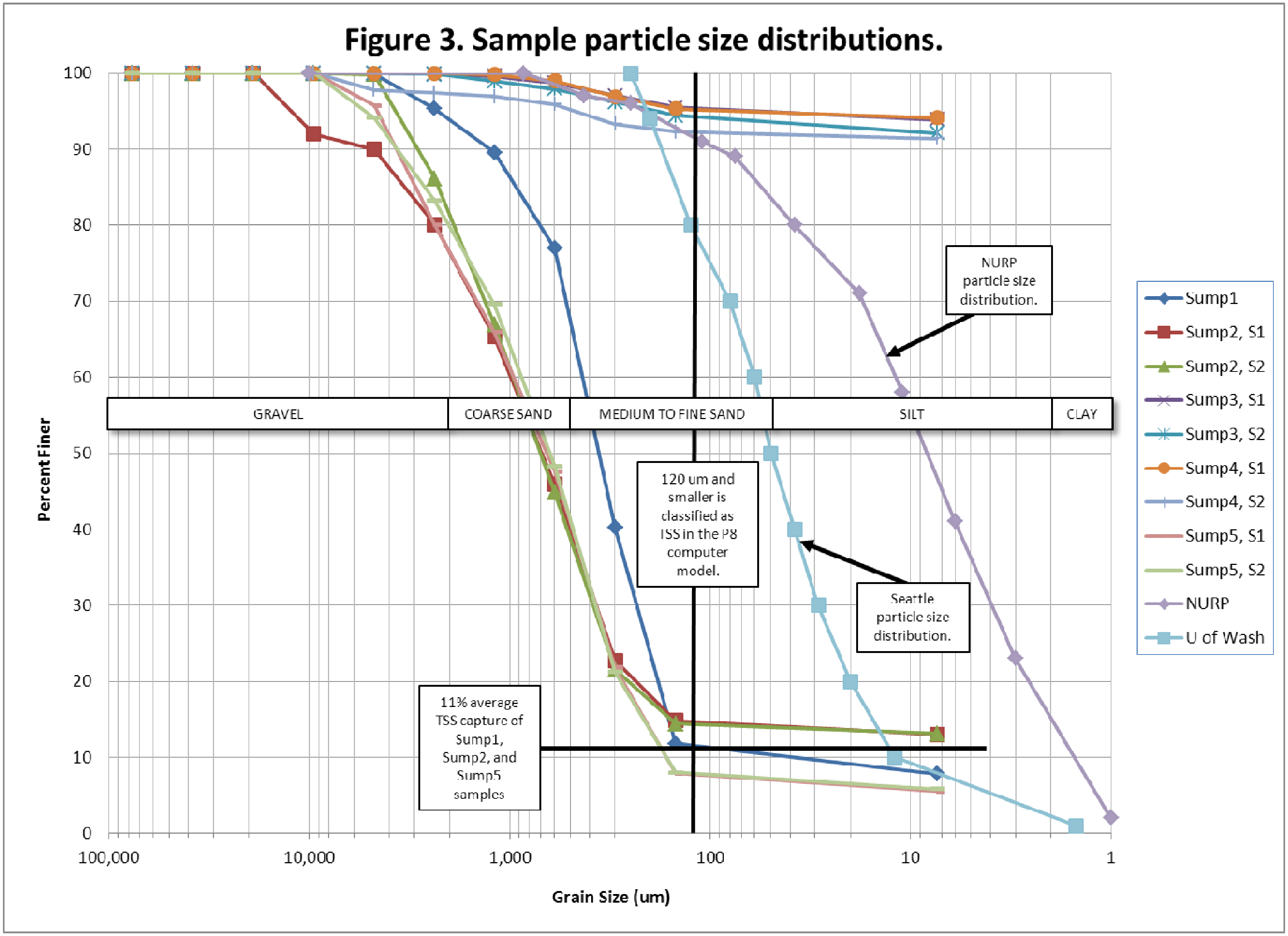


Figure 3. Sample particle size distributions.
Percent Finer
Grain Size (um)
100
90
80
70
60
50
40
30
20
10
0
100,000
10,000
1,000
100
10
1
GRAVEL
COARSE SAND
MEDIUM TO FINE SAND
SILT
CLAY
NURP particle size distribution.
120 um and smaller is classified as TSS in the P8 computer model.
Seattle particle size distribution.
11% average TSS capture of Sump1, Sump2, and Sump5 samples
Sump1
Sump2, S1
Sump2, S2
Sump3, S1
Sump3, S2
Sump4, S1
Sump4, S2
Sump5, S1
Sump5, S2
NURP
U of Wash

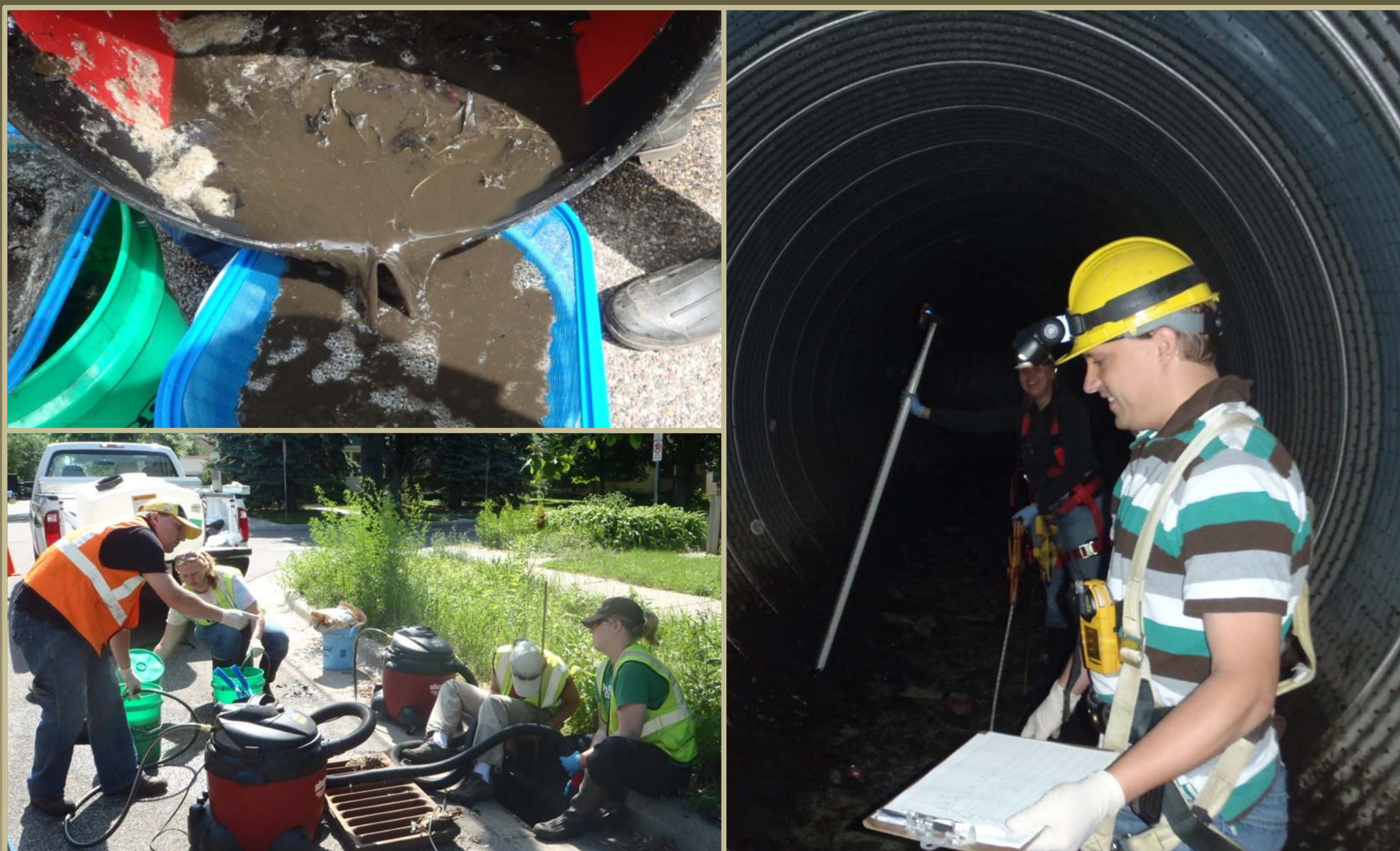
# Appendix E

# Arlington Pascal Project: Gross Solids Accumulation Study

# Arlington Pascal Project: Gross Solids Accumulation Study

March 9, 2012

# Capitol Region Watershed District



## Arlington Pascal Project:
## Gross Solids Accumulation Study

March 9, 2012

# Arlington Pascal Project:
# Gross Solids Accumulation Study

**Prepared by:**

Capitol Region Watershed District
1410 Energy Park Drive, Suite 4
St. Paul, MN 55108
651.644.8888
www.capitolregionwd.org

**March 9, 2012**

# Table of Contents

**Appendices**

# Acronyms and Abbreviations

| | |
|---|---|
| ac | Acre |
| ASTM | American Society for Testing and Materials |
| BMP | Best management practice |
| cf | Cubic feet |
| CRWD | Capitol Region Watershed District |
| EPA | Environmental Protection Agency |
| ft | Foot |
| in | Inch |
| kg | Kilogram |
| L | Liter |
| lb | Pound |
| m | Meter |
| mg | Milligram |
| mL | Milliliter |
| NWS | National Weather Service |
| s | Second |
| TP | Total phosphorus |
| TSS | Total suspended solids |
| µm | Micrometer |
| USCS | Unified Soils Classification System |

# Glossary of Terms

**Benthic** – refers to anything associated with or occurring on the bottom of a body of water. The animals and plants that live on or in the bottom of a body of water are known as benthos.

**Best management practice (BMP)** – activities or behaviors that prevent or reduce the impacts of stormwater runoff. Stormwater BMPs are structural and non-structural practices intended to manage the quantity and/or quality of stormwater runoff.

**Bulk density –** the measure of the mass of soil per unit volume, commonly expressed in lbs/cf. Bulk density is dependent upon the mineral composition of the soil and its degree of compaction.

**Catch basin –** a chamber, typically constructed at the curb line of a street, which captures and conveys stormwater runoff to a storm sewer or sub-drain. A sediment sump, designed to retain gravel and detritus below the point of overflow, may be incorporated at the base of a catch basin.

**Confined Space** – any area that has limited openings for entry and exit that would make escape difficult in an emergency, has a lack of ventilation, contains known and potential hazards, and is not intended nor designated for continuous human occupancy.

**Decant –** to draw off (a liquid) without disturbing the sediment or the lower liquid layer.

**Discharge –** rate of flow, in a pipe or stream; commonly expressed as a volume per unit time, i.e. cubic feet per second (cfs).

**Drainage area (watershed) –** the total area contributing runoff to a single point/area. A watershed boundary is typically delineated by topography or other landscape features.

**Drainage basin (sub-watershed) –** a geographic and hydrologic sub-unit of a watershed.

**Gross solids –** all litter, organic debris, and coarse sediments (greater than 75 µm) that are transported in urban stormwater runoff. Litter includes all human derived trash (e.g. paper, plastic, Styrofoam, metal). Organic debris consists of detritus from leaves, branches, twigs, and grass clippings. Coarse sediments include inorganic materials greater than 75 µm, including soil particles, pavement breakdown, and building materials.

**Impervious surfaces –** a hard surface that prevents the entry of water into the soil which results in direct stormwater runoff during a precipitation or melting event. Common types of impervious surfaces include roads, sidewalks, driveways, parking lots, or rooftops covered by asphalt, concrete, roofing materials, or compacted earthen materials.

**Manhole –** an underground structure or chamber connected to a storm sewer that is capped with a manhole cover. The structure can be sumped to act as a pretreatment device to remove gross solids and other pollutants from stormwater.

**Pipe gallery** – a series of interconnected underground pipes.

**Pollutant load –** the total mass of a pollutant, often expressed in lbs or kg.

**Pretreatment unit** – a device incorporated into the design of a stormwater BMP intended to capture and pretreat stormwater runoff (e.g. sumped catch basins). Pretreatment units help maintain the performance and prolong the life expectancy of a BMP by capturing debris that would otherwise flow directly into a BMP.

**Stormwater –** water that is not infiltrated (runoff) into the soil during a precipitation or snowmelt event.

**Sump** – a design element, incorporated at the base of a catch basin or manhole, used to retain gravel and detritus below the point of overflow.

**Total phosphorus (TP) –** a measure of both inorganic and organic forms of phosphorus within the water column, where it can be present as both dissolved and particulate matter. Commonly reported in mg/L. Phosphorus is the most limiting nutrient to plant growth in fresh water. In excess, total phosphorus can cause algal growth and eutrophication in surface waters.

**Total solids** – includes the total amount of total suspended solids removed by a stormwater best management practice as well as the amount of gross solids removed by the best management practice itself and/or gross solids removed by pretreatment devices connected to the best management practice. Typically expressed in lbs.

**Total suspended solids (TSS) –** all particles (< 63 µm in size), both organic and inorganic, suspended in and carried by the water. Commonly reported in mg/L. High levels of TSS in surface waters can be detrimental to aquatic species by reducing dissolved oxygen levels and burying benthic communities.

# Executive Summary

In 2005, the Capitol Region Watershed District (CRWD) and partners began construction of eighteen stormwater best management practices (BMPs) as part of the Arlington Pascal Stormwater Improvement Project. The BMPs constructed included: eight rain gardens; eight underground infiltration trenches; an underground, stormwater storage and infiltration facility (Arlington-Hamline Facility); and a regional stormwater pond (Como Park Regional Pond). These BMPs were constructed to treat and infiltrate stormwater runoff, ultimately reducing pollutant loading to Como Lake; an impaired water body.

The majority of the Arlington Pascal Project BMPs became operational in 2007. The performance of the BMPs, with regards to volume and pollutant load reduction through infiltration, is largely understood due to an extensive monitoring network and dataset. However, accumulation of gross solids within the pretreatment units connected to the BMPs and/or within the BMPs themselves is less understood. The term gross solids, refers to all litter, organic debris, and coarse sediments (greater than 75 μm) which are transported in urban stormwater runoff.

In CRWD's report *Stormwater BMP Performance Assessment and Cost-Benefit Analysis* (CRWD, 2010), it was recommended that further research and monitoring be conducted to better quantify the annual rate of gross solids accumulation and to characterize the content of the material being deposited. It was also recommended that the amount of total phosphorous (TP) adhering to the gross solids load be quantified. A greater understanding of the gross solids load would provide more accurate pollutant load reductions. In turn, a more precise BMP performance evaluation and cost-benefit analysis could be conducted.

This report details the sample and data collection methods used to determine the annual gross solids and associated TP loads for all Arlington Pascal Project BMPs and pretreatment units, as well as an analysis of lab results obtained through sampling.

Data collection methods were developed to determine annual gross solids and TP load accumulations, from 2007 to 2010, for all BMPs. Samples were collected from thirty sumped catch basins and from fifteen locations within the pipe gallery of the Arlington-Hamline Facility in June 2011. All samples were analyzed for bulk density, TP, and particle size.

The lab results from those samples in addition to data collected for the pretreatment units and the BMPs were used to determine annual gross solids loads and annual TP loads in gross solids from 2007 to 2010. Annual loads were calculated for the infiltration trenches and the Arlington-Hamline Facility. In addition, the annual loads for the infiltration trenches were used to extrapolate annual gross solids loads and TP loads in gross solids for the Como Park Regional Pond and all eight rain gardens.

Although annual loads captured by the individual BMPs varied, the cumulative amount of gross solids and associated TP loads captured by the pretreatment units for the BMPs and/or by the BMP themselves was substantial. During the years when all BMPs were operational (2008 through 2010), on average approximately 207,000 lbs of gross solids and 93 lbs of TP in gross solids were removed each year. This is a considerable amount that is in addition to the total suspended solids and TP loads already being removed by the BMPs through stormwater infiltration. See CRWD's *BMP Performance and Cost-Benefit Analysis: Arlington Pascal Project 2007-2010* for the thorough analysis (CRWD, 2012).

On average, the Arlington-Hamline Facility (pretreatment unit and pipe gallery combined) captured approximately 25,600 lbs of gross solids and 20 lbs of TP annually. Overall, the pretreatment unit to the Arlington-Hamline Facility accumulated more annual gross solids and TP loads than those which accumulated within the pipe gallery. Although the pipe gallery is much larger in scale than the pretreatment unit, stormwater runoff is generally first treated by the pretreatment unit before flowing into the pipe gallery.

Initial assumptions of gross solids depositions in the pipe gallery of the Arlington-Hamline Facility (i.e. composition of material changed across the gradient of the pipes from west to east and from north to south), prior to this study, were proven correct. The bulk density of the fifteen samples collected from within the pipe gallery decreased from west to east while TP concentrations inversely increased along the same gradient. The particle size analysis conducted also verified the composition change of the material; clay/silt content generally increased from west to east. The average bulk density of the fifteen samples collected within the pipe gallery was 1.43 g/mL; the average TP concentration was 1,115 mg/kg.

Lab results from the samples collected from each of the thirty catch basins showed high variability in TP concentrations of gross solids across all samples, however, this extent of variability was not observed for bulk density lab results.

Samples collected from June 24-28, 2011 (14 samples total) had significantly higher TP concentrations (average 556 mg/kg) than those samples collected from June 13-14, 2011 (15 samples total which averaged 258 mg/kg). During that timeframe, approximately four inches of precipitation fell. One sample was collected from one catch basin on June 1, 2011. This particular sample had the highest TP concentration of any other sample collected (1,980 mg/kg). The average TP concentration of all samples collected, except for the TP concentration of the sample collected on June 1, 2011 which was excluded due to being an extreme outlier, was 402 mg/kg.

Although the bulk density of sample material collected from individual catch basins did not vary significantly from each other, there were some apparent trends dependent on the infiltration trench and its corresponding catch basin(s) and the numbered series the catch basin was categorized as (Series 1, 2, or 3). The bulk densities of samples collected from catch basins discharging to Trench 1 were substantially higher than the bulk density of all other catch basins. Also, bulk density values for those catch basins discharging to Trenches 5 through 8 were generally higher than bulk density values for catch basins discharging to Trenches 2 through 4. The median bulk density also slightly increased as the catch basin series number increased. The average bulk density of all catch basins was 1.28 g/mL.

From 2007 to 2010, overall, more annual gross solids and TP loads were captured by sumped catch basin than sumped manholes. Sumped manholes have larger storage volumes than sumped catch basins; however, the manholes serve as the last form of pretreatment for stormwater before flowing into the infiltration trenches. Less material, which is most likely finer in composition, would be expected to deposit in the sumped manholes. Annual gross solids and TP loads varied significantly from 2007 to 2010, however, on average approximately 23,000 lbs of gross solids and 9 lbs of TP was captured each year by sumped catch basins and manholes discharging to the infiltration trenches.

Annual pollutant yields (gross solids and TP) were calculated for all infiltration trenches and incorporated the amount of impervious surfaces coverage over the entire drainage area for all infiltration trenches and the annual loads (gross solids and TP) for all trenches. The yields calculated and annual loads extrapolated for other BMPs (Como Park Regional Pond and all rain gardens) were slightly more conservative than those calculated using the entire subwatershed area for all infiltration trenches. The Como Park Regional Pond became operational in 2008. From 2008 to 2010, average annual gross solids and TP load accumulations were approximately 144,800 lbs and 58 lbs, respectively. From 2007 to 2010, average annual load accumulations for all eight rain gardens were 9,600 lbs of gross solids and 4 lbs of TP.

Gross solids loading was initially assumed to be dependent on annual precipitation. It was hypothesized that annual gross solids loads and TP loads in gross solids would increase as the amount of annual amount of precipitation increased. However, after analysis it was apparent that annual loading was independent of annual precipitation. For example, gross solids loads and TP loads in gross solids captured by the trenches from 2007 to 2010 were found to be highest in 2009 during a below average precipitation year. Whereas in 2010, during a higher than normal precipitation year, annual loads captured were the lowest of the four year. Contributing drainage area size and percent coverage by impervious surfaces seems to have a greater impact on annual loading than annual precipitation. Future work should include investigation on identifying those variables (e.g. climatic factors, seasonality, subwatershed characteristics, etc.) which affect gross solids loading to the BMPs.

# 1. Background


**Figure 1: Como 7 Subwatershed project area.**

The Capitol Region Watershed District (CRWD) constructed eighteen stormwater best management practices (BMPs) for the Arlington Pascal Stormwater Improvement Project; a multi-jurisdictional project centrally located within the Como 7 Subwatershed in St. Paul, Minnesota (Figure 1). The project ultimately aimed to achieve pollutant load reductions (particularly total phosphorous (TP)) to Como Lake while addressing intercommunity flooding issues and storm sewer improvements.

Construction of the BMPs commenced in 2005 and concluded in 2007. The BMPs constructed included: eight rain gardens, eight infiltration trenches, a large underground stormwater storage and infiltration facility (the Arlington-Hamline Underground Storage Facility/the Arlington-Hamline Facility), and a regional stormwater pond (the Como Park Regional Pond) (Figure 2). All BMPs were operational by late December 2007. The BMPs form a treatment train and collectively have a combined drainage area of 190 acres and a combined storage capacity of approximately 444,000 cubic feet (cf).

Since the BMPs have been operational, water quality and quantity monitoring as well as routine inspections and maintenance have been conducted in order to determine and track BMP performance and ensure proper function. The effectiveness of the BMPs at volume reduction and pollutant removal efficiency, with regards to TP and total suspended solids (TSS) load reductions, have also been modeled.

The BMP performance data, combined with actual construction, inspection, and maintenance costs, have allowed CRWD to complete a cost-benefit analysis in which volume reduction and pollutant removal costs for all BMPs were calculated. This analysis resulted in a cost per cubic foot of volume reduction and a cost per pound of pollutant removed (TP and total solids) for each BMP. ‘Total solids’ refers to the annual TSS load removed through infiltration of stormwater runoff and settlement of suspended particles and the annual gross solids load captured by any pretreatment device(s) and/or accumulating within the BMP. These results are presented in a bi-annual report published by CRWD (CRWD, 2012).

It was recommended in that report that additional monitoring efforts be conducted to better quantify the types and amounts of material captured by pretreatment units to the BMPs and by the BMPs themselves. This material is referred to as gross solids. Gross solids include all litter, organic debris, and coarse sediments (greater than 75 μm) that are transported in urban stormwater runoff.

The Arlington-Hamline Facility and all underground infiltration trenches have pretreatment units which provide initial treatment of stormwater runoff flowing to the BMPs. Gross solids are captured by and accumulate within the pretreatment units, which are installed to prevent clogging and to ensure the performance of the BMPs. In addition, gross solids also accumulate within the BMP themselves.

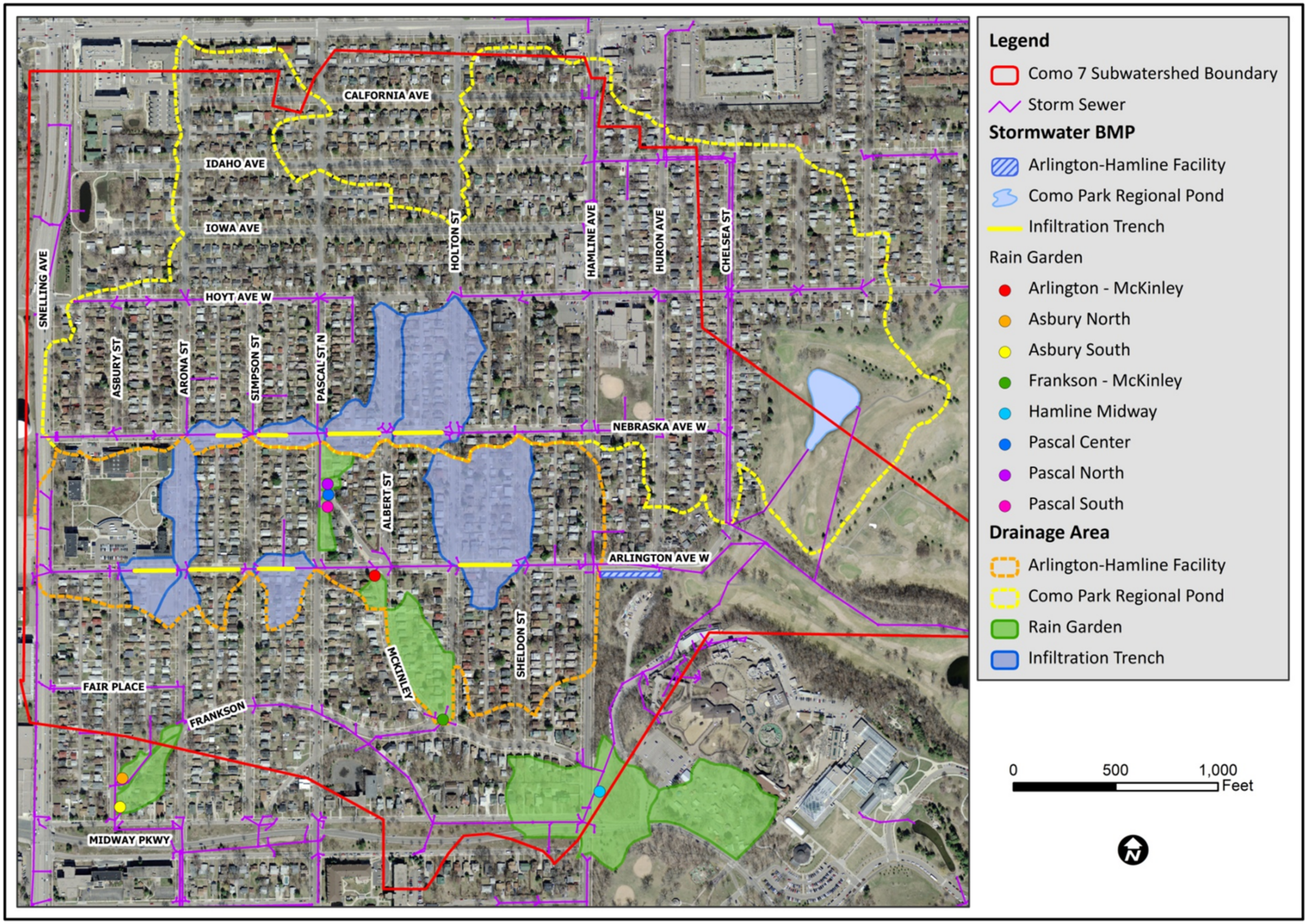



**Figure 2: Arlington Pascal Project BMPs and corresponding drainage areas.**

## 1.1. The Arlington-Hamline Facility

The Arlington-Hamline Facility is a large underground stormwater retention and infiltration system that has a watershed area of 50 acres; impervious surfaces cover 22 acres (44%) of that watershed area. Primarily, the facility only receives flow resulting from stormwater runoff and has a storage capacity of approximately 86,000 cubic feet. The facility consists of 861-feet of ten-foot diameter, perforated, corrugated metal pipes which store and infiltrate stormwater (pipe gallery) (Figure 3). A diversion weir in the inlet directs stormwater runoff to the pretreatment unit in instances of low flow. During higher flows, stormwater runoff flows directly into the pipe gallery. Note: In instances of high flows, some amount of runoff is still diverted to the pretreatment unit.

The pretreatment unit for the Arlington-Hamline Facility consists of a large Contech Vortech® model 7000 pretreatment device (Figure 4). The Vortech® is a hydrodynamic separator which is designed to effectively treat low flows by removing sediment, oil, and debris before discharging into the pipe gallery of the Arlington-Hamline Facility. A series of flow controls (i.e. large swirl chamber, baffle, and flow control walls) reduce turbulent velocities, decreasing the probability of re-suspension of debris and sediment, and increase the residence time for treatment of stormwater runoff in the device. The pretreatment unit installed for the Arlington-Hamline Facility was has a storage area of 80 square feet ($ft^2$).

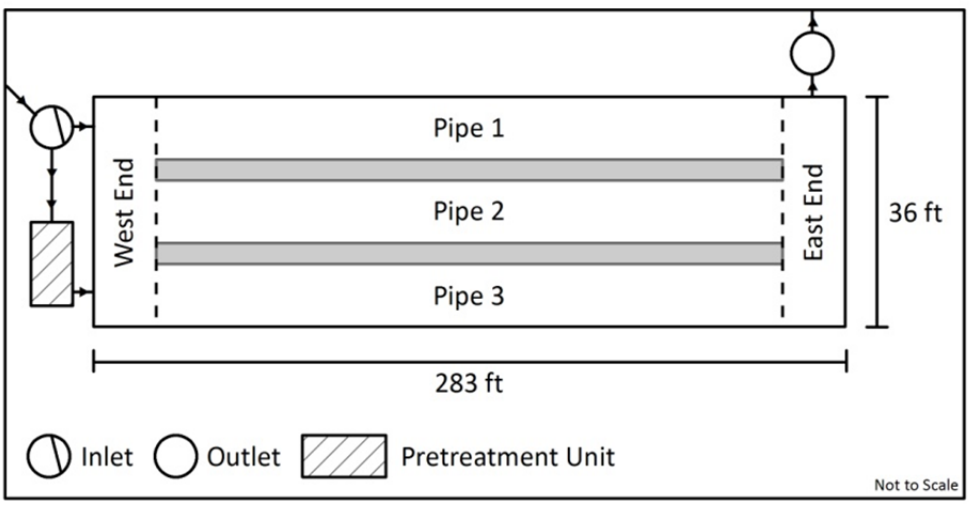



**Figure 3: Diagram of the Arlington-Hamline Facility.**

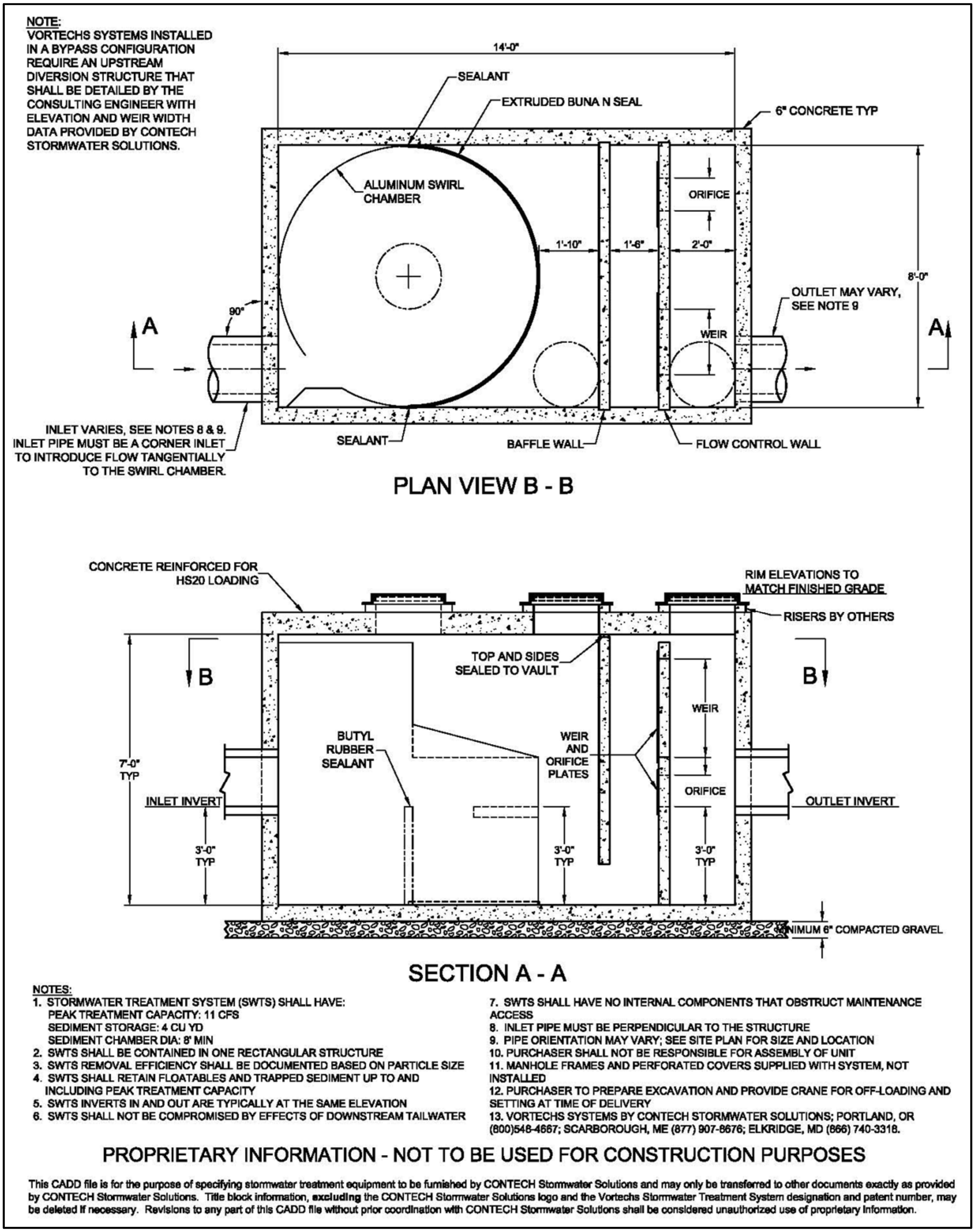



**Figure 4: A standard detail of a Vortech® model 7000 pretreatment unit (Contech, 2006).**

## 1.2. Underground Infiltration Trenches

Eight underground infiltration trenches were constructed beneath the roadbed; four beneath Arlington Avenue and four beneath Nebraska Avenue. Collectively, the trenches have a combined drainage area of approximately 23 acres; of which 39% is covered by impervious surfaces. Each trench is comprised of two ten-inch perforated pipes (with an approximate one foot offset in elevation) that run parallel to each other in an aggregate backfill. The trenches total 3,220 feet in length and have a combined storage volume of approximately 37,000 cubic feet. The cross section of the connection detail of an infiltration trench is illustrated in Figure 5.

Sixteen sumped manholes and thirty sumped catch basins pretreat stormwater runoff before flowing into the infiltration trenches. Sumped catch basins drain to one/both ends of an infiltration trench and have standard dimensions of two by three feet. Sump depth of the individual catch basins varies; however, all catch basins have a minimum two-foot (ft) sump. The minimum storage volume of a sumped catch basin is 12 cubic feet. All catch basins are also equipped with a steel hood, positioned over the outlet of each catch basin, to more effectively retain floatables and larger debris within the catch basin.

Stormwater runoff discharging from the sumped catch basins next flows into sumped manholes before flowing into the actual infiltration trench. The manholes are located on both ends of each infiltration trench. The diameter of the manholes varies, from four to six feet. The manholes have a minimum sump depth of two and one-half feet. Figure 6 illustrates the flow configuration of the eight infiltration trenches.

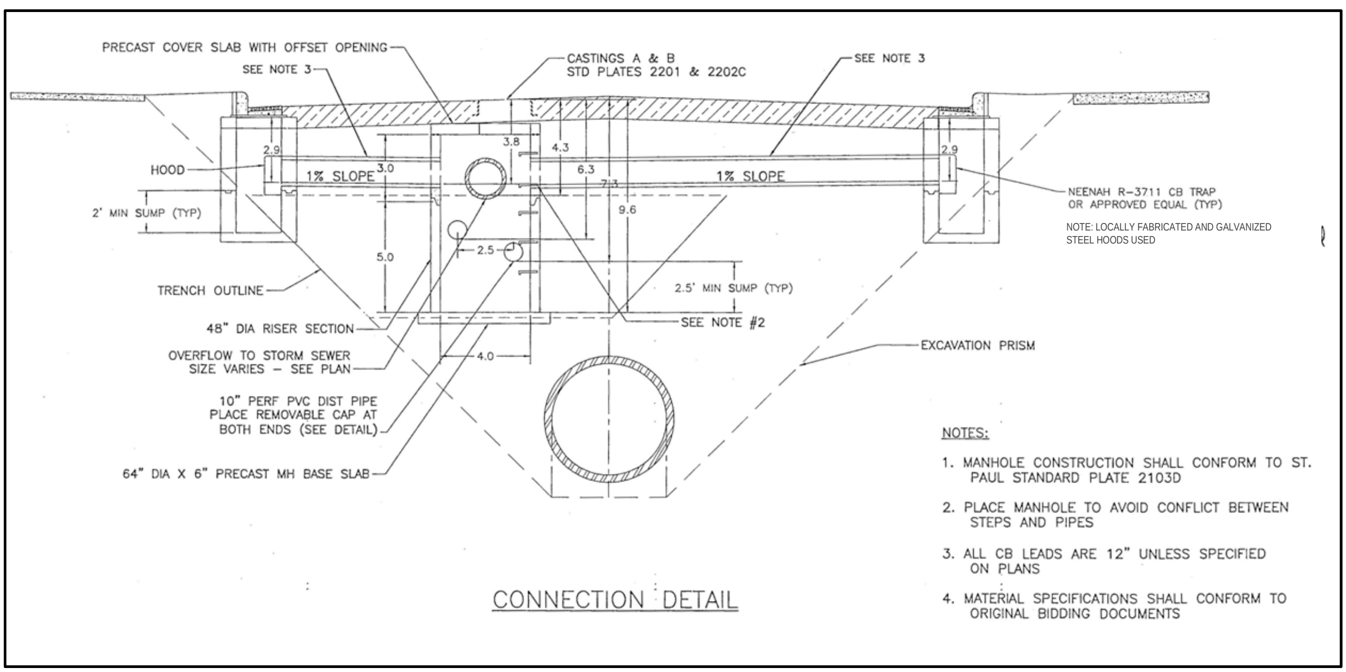



**Figure 5: General Detail of a cross section of an infiltration trench.**

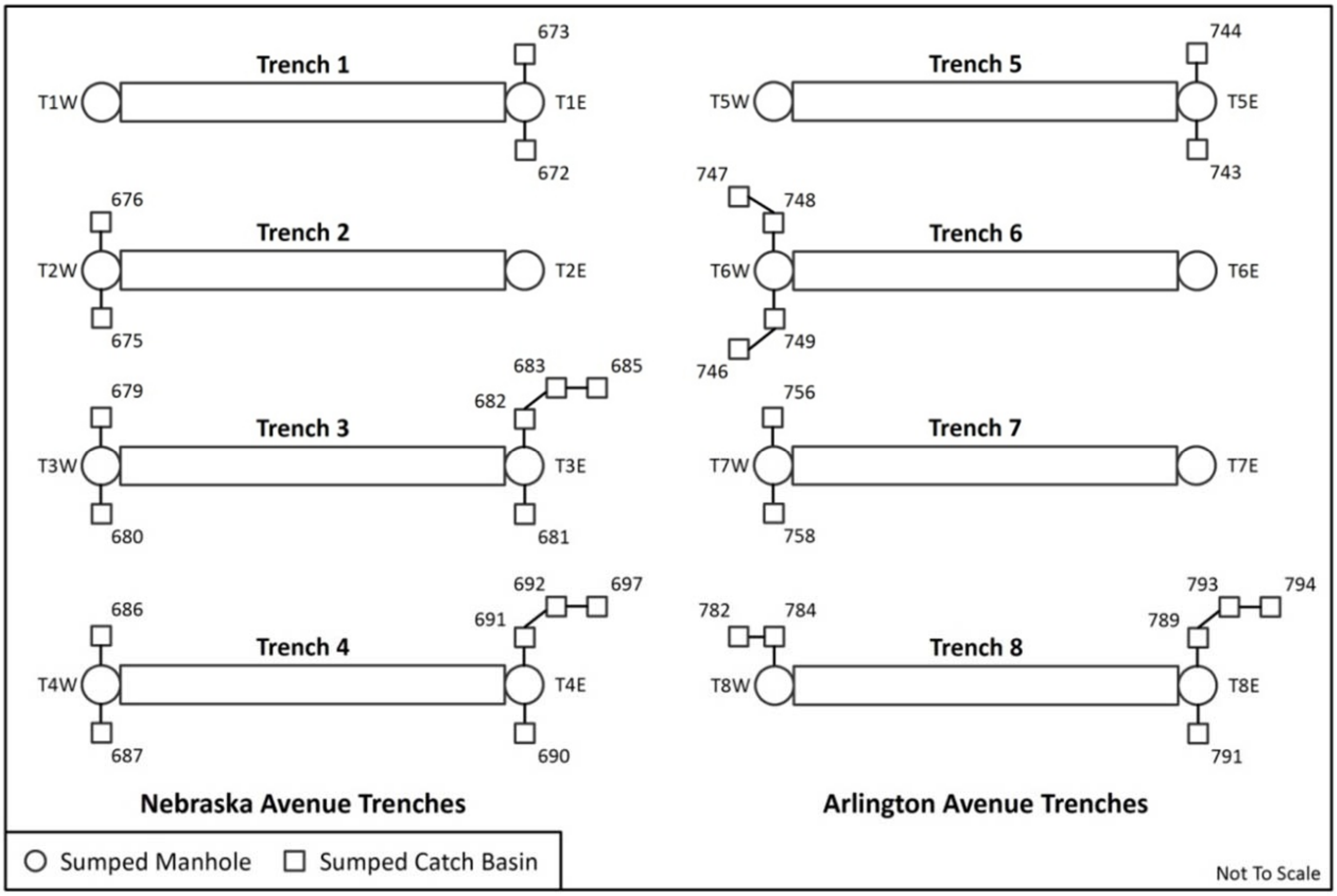



**Figure 6: Flow Configuration of the Infiltration Trenches.**

## 1.3. Como Park Regional Pond

The Como Park Regional Pond is a regional stormwater pond that was constructed on the Como Golf Course in St. Paul, MN. The pond has a direct drainage area of 128 acres, of which 39% is covered by impervious surfaces. The pond also receives runoff from the City of Roseville (540 acres) via discharges from Gottfried's Pit, a stormwater basin which has an automatic pumping system. The storage volume of the pond is approximately 302,000 cubic feet.

There are no pretreatment devices for the pond. However, overflow, if any, from the four infiltration trenches on Nebraska Avenue ultimately discharge to the pond.

## 1.4. Rain Gardens

Eight rain gardens of varying size were constructed, most within street right-of-ways. All but one rain garden receive stormwater runoff from curb-cut inlets; the other has two storm sewer inlets. The rain gardens have a combined storage volume of 19,000 cubic feet and 16 acre drainage area. Impervious surfaces cover 23% of the drainage area. There is no pretreatment of stormwater runoff before flowing into the rain gardens.

# 2. Study Goals

In CRWD's report, *Stormwater BMP Performance and Cost-Benefit Analysis*, it was identified that the accumulation of gross solids within pretreatment units was substantial and that there was value in incorporating those gross solids load reductions into total solids load reductions (CRWD, 2010). It was recommended that additional research and monitoring efforts should be expanded to more accurately characterize and quantify the type and amount of gross solids accumulating within these pretreatment devices. It was also recommended that TP loads in those gross solids be quantified.

In late 2010, a consultant was hired by CRWD to conduct the *Sump Monitoring Study* to sample material accumulating within sumped catch basins and manholes, determine the average bulk density and total phosphorous concentration of the material sampled, and develop a methodology from which to use those results to determine gross solids loads and TP loads in gross solids (CRWD, 2011). Due to the timing of the project, sampling of material within the pretreatment units draining to the infiltration trenches owned by CRWD was not completed because the debris in the pretreatment units had been recently removed (in accordance with CRWD's routine maintenance schedule).

Samples were collected from sumped catch basins and manholes which drained to infiltration trenches owned by the City of St. Paul which had similar drainage areas and land uses as those owned by CRWD. After completion of the project and review of the results, it was determined that supplementary sampling, over a greater number of sample sites, was necessary to have greater confidence in the data being used to calculate the gross solids and TP loads.

This study expanded upon the methodologies detailed in the *Sump Monitoring Study* and was designed to:

1) Determine the annual gross solids loads and TP loads in gross solids captured by and accumulating within all pretreatment devices and BMPs from 2007 to 2010. This would be accomplished through:

    a. Collection of samples from pretreatment devices (i.e. sumped catch basins) owned and maintained by CRWD.
    b. Collection of samples from within the Arlington-Hamline Facility Pipe Gallery.
    c. Refinement of methodologies used for determining the volume of gross solids accumulating within the Arlington-Hamline Facility pipe gallery.
    d. Refinement of extrapolation methods used to determine the gross solids loads which accumulated within the Como Park Regional Pond and the rain gardens.

2) Analyze data for trends which may help further guide future monitoring and sampling efforts.

Annual gross solids and associated TP loading data determined for this study were used in the *Stormwater BMP Performance and Cost-Benefit Analysis: Arlington Pascal Project 2007-2010* (CRWD, 2012).

# 3. Climatological Summary

Over the four year period (2007 to 2010) that the Arlington Pascal Project BMPs have been in operation, weather conditions and precipitation trends varied significantly. The precipitation totals over the four year monitoring period reflected both very dry and very wet conditions.

The 2007 annual precipitation total was closest to the National Weather Service (NWS) 30-year normal value of 29.4 inches with the mean temperature being two and one-half degrees higher than normal (Table 1). In 2008, approximately eight inches of precipitation less than the 30 year normal value were recorded; showing the greatest departure from normal during the 2007 to 2010 monitoring record. Similarly, 2009 recorded six fewer inches of precipitation than normal. By far, 2010 was the wettest year in the BMP monitoring record, yielding seven more inches of rain than normal with a mean temperature nearly three degrees hotter. The significant rainfall amounts in 2010 represented a 24% increase in annual precipitation in comparison to the NWS 30-year normal amount.

**Table 1: Annual precipitation total and mean temperatures compared to the NWS 30-year normal.**

| Year | Annual Precipitation (in) | Mean Temperature (°F) | Departure from Normal |
|---|---|---|---|
| 2007 | 29.72 | 47.8 | 0.3" higher, 2.5° higher |
| 2008 | 21.67 | 44.7 | 7.7" lower, 0.6° lower |
| 2009 | 23.24 | 45.4 | 6.2" lower, 0.1° higher |
| 2010 | 36.32 | 48.2 | 6.9" higher, 2.9° higher |
| NWS 30-Year Normal | 29.41 | 45.3 | |

# 4. Study Methods

This section presents a brief summary of the sample and data collection methods and data calculations and analysis methods used in this study. A comprehensive description of those methodologies may be found in Appendix A.

Sample and data collection methodologies for the Arlington-Hamline Facility and the pretreatment units (sumped catch basins) discharging to the underground infiltration trenches varied significantly due to the differences in characteristics of each. However, all samples were collected in June 2011 and were analyzed for the same constituents, using the same methods. Samples were submitted to PACE Analytical Laboratories in Minneapolis, Minnesota for analysis. The parameters analyzed include:

- Bulk Density – Using American Society for Testing and Materials (ASTM) D5057.
- Total Phosphorous – Using Environmental Protection Agency (EPA) 365.4.
- Particle Size Distribution – Using ASTM D422.

## 4.1. Arlington-Hamline Facility: Pipe Gallery

The pipe gallery of the Arlington-Hamline Facility consists of three parallel 283-ft corrugated, metal, perforated pipes that are all ten feet in diameter (Figure 7). The three pipes are denoted:

- Pipe 1. The northern pipe.
- Pipe 2. The center pipe.
- Pipe 3. The southern pipe.

Additionally, two perpendicular 36-ft long pipes, identical in diameter and type as the three parallel pipes, are connected at both ends (East End and West End) of the pipe gallery. Gross solids have the potential to enter into the pipe gallery at two locations on the west end of the facility; an inlet on the north and an inlet on the south.

General observations of gross solids deposits accumulations and composition drove sample and data collection methods in order to use the most direct and time efficient sampling techniques. Gross solids which accumulate within the pipe gallery vary significantly in width, depth, and extent in each pipe. This is largely due to the entry point and gradient of the pipe gallery.

Based on previous inspections of debris and sediment accumulation in the pipe, it was observed that in general, very minimal to no gross solids are deposited in the western end of the pipe gallery near the inlets to the pipe gallery. In addition, the majority of gross solids deposits were observed to generally to have accumulated within the middle to the eastern end of the pipe gallery. It was also observed that the composition of gross solids changes on a west-to-east gradient. Material in the western portion of the pipe gallery appeared to have a greater mineral content than that in the eastern portion. Largely, the material accumulating in the eastern portion of the pipe gallery consists of organic matter.

### 4.1.1. Data and Sample Collection Methods

A variety of equipment (e.g. survey equipment, measurement apparatuses, coring device, etc.) were used to collect data and samples. Survey equipment was used to more accurately measure the width and true elevation of depth of the gross solids deposits, along a longitudinal gradient, in each pipe. Also, the pipe gallery of the Arlington-Hamline Facility is considered a confined space. In addition to the equipment and materials used in sample and data collection, additional equipment was also used for entry into a confined space. The equipment and methods used for entry into a confined space were conducted in accordance with the requirements and procedures outlined in CRWD's *Safety Manual* (CRWD, 2008).

Prior to surveying each pipe (Pipe 1, 2, 3, or East End), a benchmark was established which allowed for future replication of the survey. Once the benchmark elevation was determined, survey stations were established every ten feet in Pipes 1, 2, and 3 starting at the eastern edge of the West End Pipe and ending at the center of the East End Pipe. The West End Pipe was excluded from the survey due to very minimal to no gross solids present in the pipe.

Survey stations in the East End Pipe were also established, in half-foot to one-foot increments, with one station also established at the midpoint between the distance between Pipes 1 and 2 and another station between Pipes 2 and 3. Survey stations in the East End Pipe began at the northern edge of the East End Pipe and ended at the southern edge. A longitudinal profile of each pipe (Pipe 1, 2, 3, and East End) was surveyed and depth and elevation measurements of the gross solids deposit were taken at the center of the pipe, at each survey station.

Fifteen samples were collected from within the pipe gallery at equidistant sampling locations, in each pipe (Pipe 1, 2, and 3). Sampling points were established every 55-feet in each pipe (Pipe 1, 2, and 3), resulting in five sampling points per pipe (Sampling Point 1, 2, 3, 4, and 5). At each sample point, the gross solids coring device (Figure 8) was used to extract individual samples across the entire cross-section of the gross solids deposit; length and if necessary, width wise (Figure 9). Figures 10, 11, and 12 portray data and sample collection efforts.

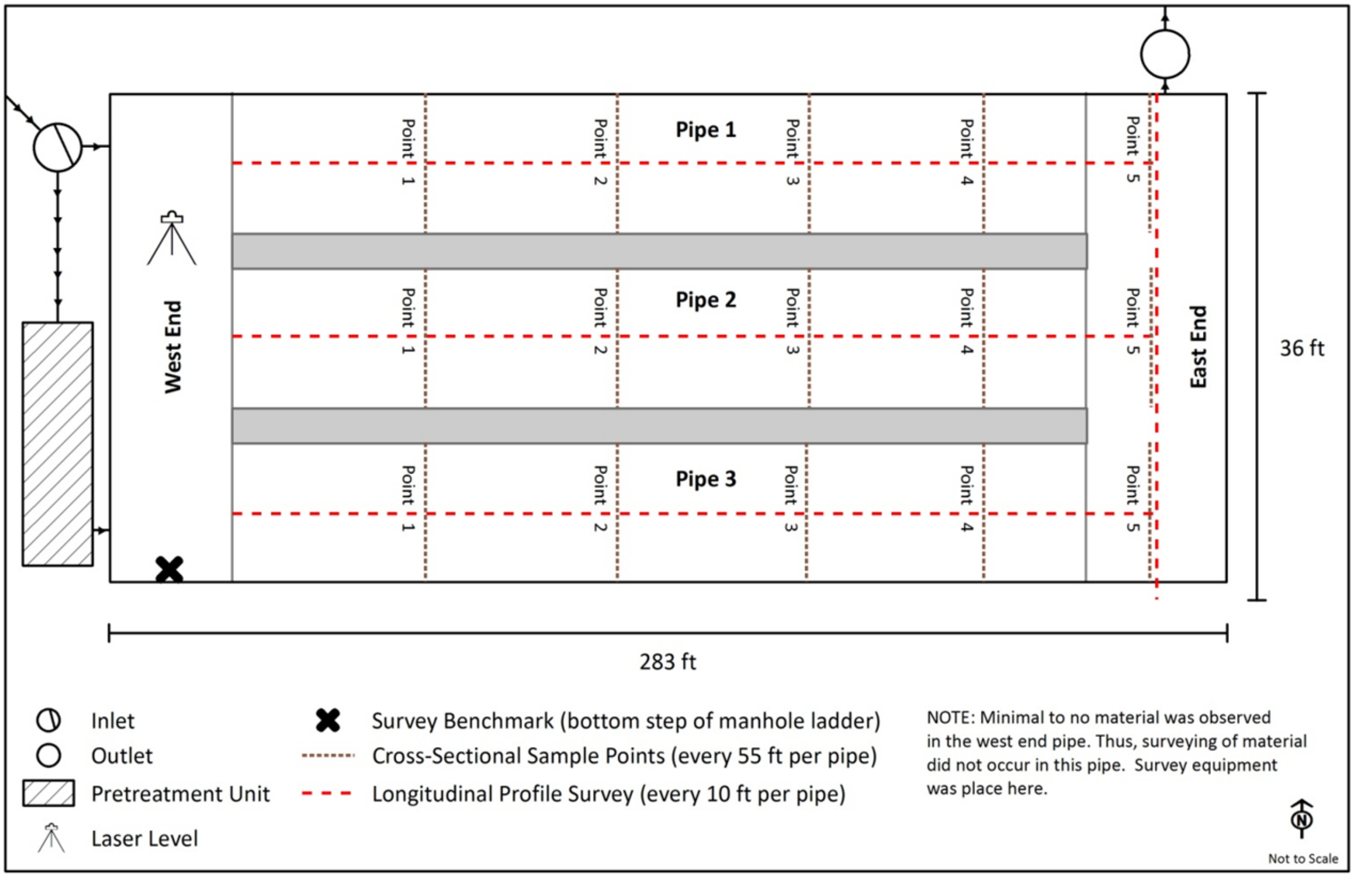



**Figure 7: A diagram of the Arlington-Hamline Facility pipe gallery, pretreatment unit, and the inlets to the pipe gallery. Longitudinal survey stations and sampling points in each pipe are denoted.**

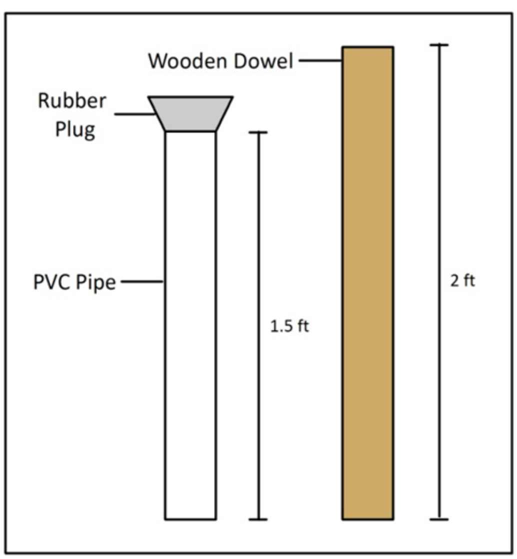



**Figure 8: Diagram of the gross solids coring device.**

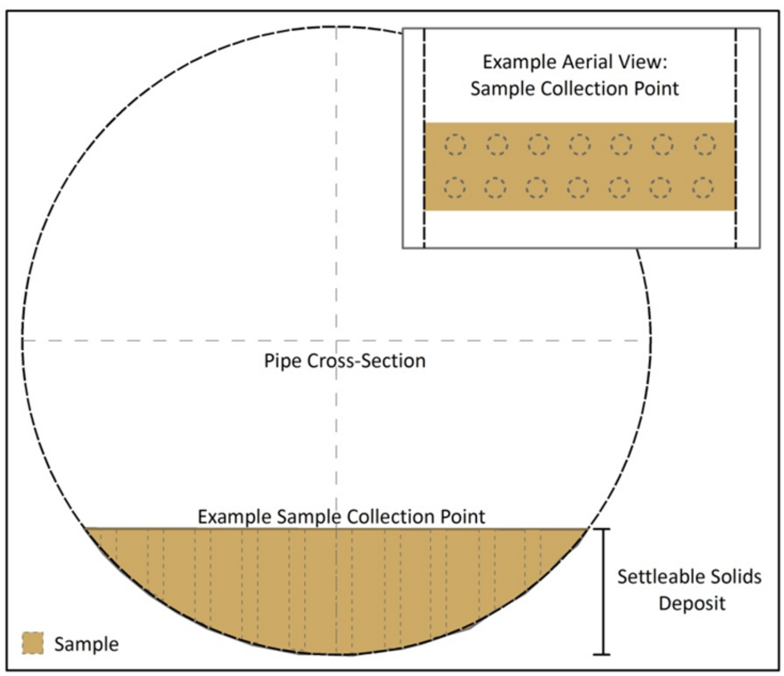



**Figure 9: Aerial and cross-sectional view of an example sample point.**

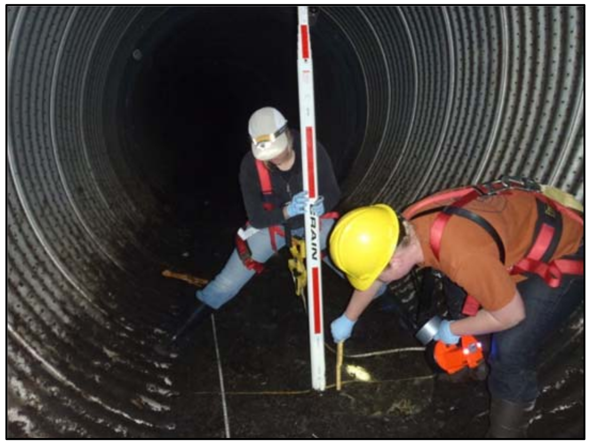


**Figure 10: Longitudinal survey of pipe 2. Length measurement of the gross solids deposit (LEFT). Measurement of gross solids deposit elevation and depth (RIGHT).**

**Figure 11: Gross solids sample collection. Extracting sample from the deposit (LEFT). Removal Of the sample from the coring device, into a bucket (RIGHT).**

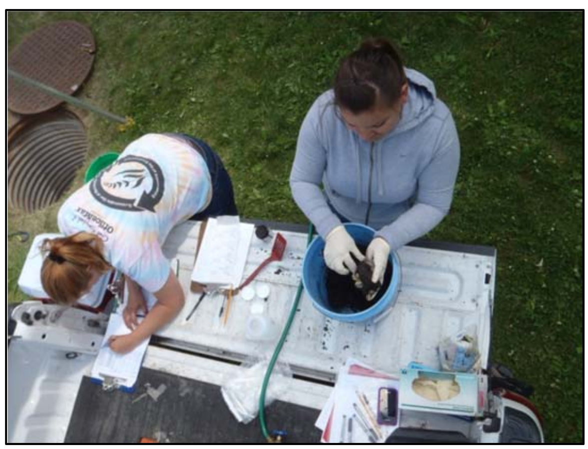


**Figure 12: Gross solids sample, before compositing, taken from a sampling point within the pipe gallery (LEFT). Sample preparation (RIGHT).**

### 4.1.2. Data Calculations: Gross Solids Load

The volume of gross solids which accumulated in the pipe gallery was calculated for each survey station, in each pipe (Pipe 1, 2, 3, and East End), using a cylindrical pipe equation and the depth of the gross solids deposit at each survey station. A gross solids load for each survey station was then calculated using the volume of gross solids at each survey station and bulk density lab results for samples collected at the sampling points in the pipe gallery. The gross solids loads for all survey stations in each pipe (Pipe, 1, 2, 3, and East End) were summed to produce gross solids loads per pipe. The gross solids load for the entire pipe gallery was then determined by summing the gross solids loads in all pipes (Pipe 1, 2, 3, and East End).

### 4.1.3. Data Calculations: Total Phosphorous Load in Gross Solids

TP loads in gross solids captured within the pipe gallery were also calculated using the gross solids loads at each survey station (in Pipe 1, 2, 3, and the East End Pipe) and the TP concentrations from samples collected within the pipe gallery. This produced a TP load for each survey station, in each pipe. The TP loads in gross solids for all survey station in a specific pipe (Pipe 1, 2, 3, and East End) were summed to produce a TP load per pipe. All TP loads, for all survey stations, were then summed to produce a TP load in gross solids captured by the entire pipe gallery.

### 4.1.4. Data Calculations: Annual Gross Solids Load and Annual Total Phosphorous Load in Gross Solids

Gross solids loads and TP loads in gross solids which accumulated within the pipe gallery are representative of four years (2007 to 2010) of accumulation because no discharge has been monitored at the outlet of the pipe gallery and no gross solids have ever been removed. In order for the loading data to be incorporated into BMP performance results, annual loads must be determined.

Annual gross solids loads and annual TP loads in gross solids which accumulated in the pipe gallery were determined by multiplying the gross solids or TP load by the percentage of annual precipitation per year, from the 2007 to 2010 total precipitation amounts (Table 2). This method was determined to be a representative estimation of annual accumulation based on the assumption that sediment transport and TP loading is proportional to precipitation amounts and associated runoff volumes.

**Table 2. The annual percentages of precipitation based on the four-year total from 2007 through 2010.**

| Monitoring Year | Annual Precipitation (in) | Total 4-Year Precipitation Amount (%) |
|---|---|---|
| 2007 | 25.0 | 24% |
| 2008 | 21.7 | 21% |
| 2009 | 22.3 | 21% |
| 2010 | 36.3 | 34% |
| **Total:** | **105.3** | **100%** |

## 4.2. Arlington-Hamline Facility: Pretreatment Unit

### *4.2.1. Data Calculations: Gross Solids Load*

The Arlington-Hamline Facility has a pretreatment unit which also accumulated gross solids. This unit is maintained regularly; debris and sediment are removed bi-annually (spring and fall). Prior to debris removal, depth measurements of the accumulated gross solids were taken. The volume of gross solids which accumulated bi-annually in the pretreatment unit was calculated using the record of depth measurements, from 2007 to 2010. The bi-annual volumes for each year (2007 through 2010) were summed to produce the annual volume of gross solids which was captured by the pretreatment unit.

It was not possible to extract samples of the gross solids which had accumulated within the pretreatment unit due several factors. Those include: the proximity of access point (the access point to the pretreatment unit is located over the swirl chamber; sample collection from the chamber between the flow control walls would be more ideal), size of the pretreatment unit (the distance, 15-18 feet, between the access point and the solids deposit was too great to extract a sample with the equipment available), and amount of standing water inside the unit (it was not possible to decant the large volume of water present with the equipment available, as well as, extract samples due to the depth of water and the equipment available). The sampling results from the Arlington-Hamline Facility pipe gallery were utilized to calculate the annual load of gross solids removed by the pretreatment unit.

The average bulk density found for the entire pipe gallery (1.43 g/mL), along with the annual volumes of gross solids captured by the pretreatment unit were used to calculate the annual gross solids loads captured by the pretreatment unit from 2007 through 2010.

### *4.2.2. Data Calculations: Total Phosphorous Load in Gross Solids*

The annual TP loads in gross solids loads captured by the pretreatment unit, from 2007 to 2010, were calculated using the annual gross solids loads captured by the pretreatment unit and TP concentrations from the Arlington-Hamline Facility pipe gallery. Specifically, the TP concentrations from samples taken at Sample Point 1 in all three pipes (Pipe 1, 2, and 3) were averaged to determine the mean TP concentration (568 mg/kg). This average TP concentration was assumed to be representative of the material in the pretreatment unit because the sample points reside closest to the outlet of the pretreatment unit. Additionally, the composition of the material at these three sample locations generally consisted of larger, coarser particles (e.g. sands, gravels) which are generally captured by the pretreatment unit.

The same values for average bulk density and TP concentration were used to calculate annual gross solids and TP loads for all years, from 2007 to 2010. This was done in order to determine annual loadings using the data that was available. It is recognized that gross solids load accumulations and composition of material varies from year-to-year. These annual loadings will most likely be refined as additional future sampling is conducted.

## 4.3. Arlington-Hamline Facility

### *4.3.1. Annual Gross Solids and TP Loads*

Annual gross solids and TP loads calculated for both components of the Arlington-Hamline Facility (pipe gallery and pretreatment unit), from 2007 through 2010, were summed to produce annual gross solids and TP loads captured by the entire Arlington-Hamline Facility.

## 4.4. Infiltration Trenches

Thirty sumped catch basins and sixteen sumped manholes pretreat stormwater runoff before flowing into the eight infiltration trenches beneath Arlington and Nebraska Avenues. Each catch basin and manhole has an ID unique to each structure. Figure 6 illustrates each unit and ID. The accumulated material is removed from all units twice a year (spring and fall). Prior to removal, inspections of the pretreatment units were performed. Inspections included depth measurements of the debris and sediment which was captured by each catch basin.

For this study, only the sumped catch basins were sampled; sumped manholes were not sampled. It was observed in previous inspections, that in general, the overall depth of debris and sediment which had accumulated within the catch basins was greater than that which had accumulated in the manholes; making sample collection less difficult. The overall sumped area of the catch basins was also smaller than that of the sumped manholes, also making sample collection less difficult.

Several challenges were met while developing the sampling protocol. After additional research on sediment sampling equipment and in review of performance of the sampling equipment used in the *Sump Monitoring Study* (CRWD, 2011), traditional sediment sampling equipment (i.e. core samplers, sludge samplers, augers, ponar dredges, etc.) were not used to collect samples in this study due to the saturation, composition, and lack of compaction of the material in the catch basins. The material was too saturated and not compacted enough to remain intact; all or portions of the sample would be lost out of the bottom of the augers/samplers.

A method for extracting a representative sample of all material in the catch basin also had to be developed. It was observed that stratification and extent of material in the catch basins varied; there were slight variations in depth of material within a catch basin and varying layers of sand, silt, and organic matter were stratified without uniformity. Thus, sample collection needed to capture the entire column of material in the catch basin. The ponar dredge would only collect a sample from the top portion of the material and not from the entire column of debris.

In addition to the accumulation of gross solids, large volumes of stagnant stormwater remained in the sumped portion of each catch basin. A method had to be developed to decant the standing stormwater from the sump of the catch basin without disturbing the material. Decanting the stormwater was necessary for sample collection.

### *4.4.1. Sample Collection Methods: Sumped Catch Basins*

Before a sample could be collected from a catch basin, the stormwater was first decanted using two wet/dry vacuums. A sump screen was placed into the catch basin and held underwater on top of the gross solids deposit (Figure 13). This screen allowed for the water in the catch basin to be decanted without disturbing or re-suspending the material in the catch basin. Each vacuum was equipped with a pump which allowed for the water to be pumped from the catch basin and into buckets which were emptied into a sumped manhole that drained to an infiltration trench. This enabled the vacuums to run continuously until all water was decanted from the catch basin

A pipe, placed in the center of the catch basin, was used to 'cut out' a cylinder of gross solids to be sampled. It was assumed to contain a representative sample of gross solids because it included material from the entire column; from the bottom of the catch basin to the top of the deposit. A third wet/dry vacuum, used only for sample removal purposes, was used to extract all sample material from inside of the pipe. Following removal, clean water was used to rinse the vacuum hose and vacuum to ensure that any debris particles trapped in the hose corrugation or vacuum top were included in the sample material.

The debris and water in the vacuum was then strained using a two-step process to remove excess water from the sample material. The contents of the vacuum were poured through a standard pool skimmer net, to capture the larger material, and again through a dip net bag to remove the finer material (clays, silts, and sands). The strained material (captured by the pool skimmer and the dip net) were combined and mixed to create a representative sample.

Figures 14 through 16 illustrate sample collection efforts for a sumped catch basin.

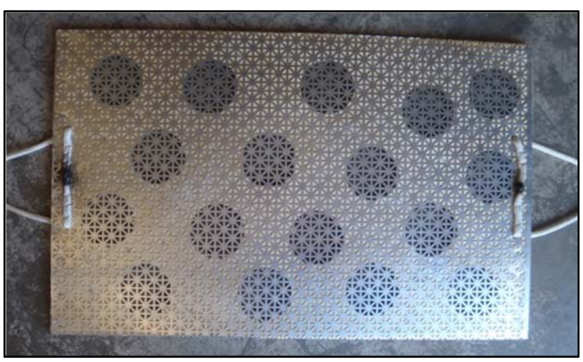


**Figure 13: Fabricated sump screen; a 2-foot by 3-foot perforated, plywood board covered by a metal screen.**

**Figure 14: Placement of the sump screen in to the catch basin (LEFT). Submerging the sump screen (CENTER). Decanting water from a catch basin (RIGHT).**

**Figure 15: Placement of the stove pipe in a catch basin (LEFT). Sample material collected from a catch basin being strained through the first screen (CENTER) and through the second screen (RIGHT).**

**Figure 16: Mixing of the sample material (LEFT). Placement of the samples material in to the sample container (RIGHT).**

### 4.4.2. Data Calculations: Gross Solids Loads Captured by Catch Basins and Manholes

Gross solids depth measurements taken during the bi-annual inspections (inspections prior to debris removal), from 2007 to 2010, were used to calculate the bi-annual volume of gross solids which accumulated within each sumped catch basin and manhole. The two volume calculations, for each unit for each year from 2007 to 2010, were summed to produce the annual volume of gross solids captured by each pretreatment unit.

The average bulk density (1.28 g/mL or 79.91 lbs/cf) of all samples collected from the catch basins and the annual volumes of gross solids captured by each pretreatment unit was used to determine the annual load of gross solids captured by each unit, from 2007 to 2010. The annual gross solids loads captured by pretreatment units (catch basins and manholes) draining to a particular infiltration trench (Trench 1 through 8), were summed to determine the annual gross solids load removed by each infiltration trench. The annual gross solids loads captured by all pretreatment units (catch basins and manholes), from 2007 to 2010, were all summed to produce annual gross solids loads captured by all infiltration trenches.

### 4.4.3. Data Calculations: Total Phosphorous Loads in Gross Solids Captured by Catch Basins and Manholes

Annual TP loads in gross solids captured by each pretreatment unit (catch basin and manhole), from 2007 to 2010, were determined by using the annual gross solids loads captured by each unit and an average TP concentration (402 mg/kg) of samples collected from all catch basins. Note: The TP concentration of the sample collected from catch basin 690 was excluded from the average TP concentration calculation of all catch basins due to being an extreme outlier.

Annual TP loads in gross solids captured by pretreatment units draining to a particular infiltration trench (Trench 1 through 8) were summed to produce annual TP loads in gross solids captured by each infiltration trench from 2007 to 2010. Additionally, annual TP loads in gross solids captured by all units were summed to determine annual TP loads in gross solids captured by all infiltration trenches from 2007 to 2010.

## 4.5. Como Park Regional Pond and Rain Gardens

The annual gross solids loads and annual TP loads in gross solids cumulatively removed by all sumped catch basins and manholes connected to the infiltration trenches were used to extrapolate annual gross solids loads and associated TP loads accumulating within the Como Park Regional Pond and all eight rain gardens.

The drainage areas to the pond and the rain gardens have fairly similar land uses and impervious surfaces coverage characteristics as the drainage area to the infiltration trenches. Due to the similarities in characteristics, it was assumed that the drainage areas of the rain gardens and the pond would yield similar pollutant loads as those to the infiltration trenches.

### 4.5.1. Data Calculations: Gross Solids Loads

The annual gross solids yield for the infiltration trenches was calculated by dividing the annual gross solids loads captured by all pretreatment units (all sumped catch basins and manholes), from 2007 to 2010, by the portion of the total drainage area to all infiltration trenches covered by impervious surfaces (Table 3). Annual gross solids loads captured by the Como Park Regional Pond and by each rain garden, from 2007 to 2010, were calculated by multiplying the annual gross solids yield for the infiltration trenches by the portion of drainage area to each BMP (pond and each rain garden) covered by impervious surfaces. Table 4 lists the total drainage area and percentage covered by impervious surfaces for each BMP.

**Table 3: The gross solids loading yields for the infiltration trenches from 2007 to 2010.**

| | | Gross Solids | |
|---|---|---|---|
| Year | Acres Impervious | Load (lbs) | Yield (lbs/ac) |
| 2007 | 8.93 | 14,536 | 1,628 |
| 2008 | 8.93 | 26,080 | 2,920 |
| 2009 | 8.93 | 32,200 | 3,606 |
| 2010 | 8.93 | 19,448 | 2,178 |

**Table 4: Como Park Regional Pond and individual rain garden drainage areas and impervious surfaces coverage.**

| BMP | Drainage Area (acres) | Impervious Surfaces (acres) | % Impervious Surfaces |
|---|---|---|---|
| Como Park Regional Pond | 128.00 | 49.92 | 39% |
| Arlington-McKinley Rain Garden | 0.37 | 0.15 | 41% |
| Asbury North Rain Garden | 0.40 | 0.17 | 43% |
| Asbury South Rain Garden | 1.08 | 0.33 | 31% |
| Frankson-McKinley Rain Garden | 2.81 | 0.94 | 33% |
| Hamline Midway Rain Garden | 10.47 | 1.86 | 18% |
| Pascal Center Rain Garden | 0.13 | 0.06 | 46% |
| Pascal North Rain Garden | 0.46 | 0.13 | 28% |
| Pascal South Rain Garden | 0.36 | 0.09 | 24% |

### 4.5.2. Data Calculations: Total Phosphorous Loads in Gross Solids

Annual TP loads in gross solids which accumulated in the Como Park Regional Pond and each rain garden, from 2007 to 2010, were extrapolated by multiplying the annual TP yield for the infiltration trenches by the portion of drainage area (for the pond and each rain garden) covered by impervious surfaces. Table 5 lists the annual infiltration trench TP yields.

**Table 5: The TP loading yields for the infiltration trenches drainage area covered by impervious surfaces.**

| | | Total Phosphorous | |
|---|---|---|---|
| **Year** | **Acres Impervious** | Load (lbs) | Yield (lbs/ac) |
| 2007 | 8.93 | 5.84 | 0.65 |
| 2008 | 8.93 | 10.48 | 1.17 |
| 2009 | 8.93 | 12.94 | 1.45 |
| 2010 | 8.93 | 7.82 | 0.88 |

# 5. Arlington-Hamline Facility: Analysis and Discussion

Results and analysis on gross solids and TP loads for the Arlington-Hamline Facility are discussed in this section. There are three main divisions in this section, in which, the gross solids and TP loads for each element of the Arlington-Hamline Facility (pipe gallery and pretreatment unit) and the annual load results for the entire BMP are discussed.

Additional data and information used to determine gross solids and TP loads for the Arlington-Hamline Facility may be found in Appendix B. This information includes pipe gallery lab results and survey station data including deposit elevations, volumes, and loads. Data for the pretreatment unit is also available.

## 5.1. Arlington-Hamline Facility: Pipe Gallery

### *5.1.1. Gross Solids Volume Calculation*

At every sample point in Pipes 1, 2, and 3 (fifteen points in total) depth measurements were taken across the entire cross-section of the gross solids deposit. The cross-sectional area of the gross solids deposit was calculated for each sample point using both an integral calculation, which took into consideration the varying depths of the deposit, as well as calculated using a cylindrical pipe equation, which assumed a uniform surface, for a one-foot section of pipe at each sample point.

A regression analysis was completed on the debris areas calculated using both methods (Figure 17). The regression analysis resulted in an $R^2$ of 0.94; which indicates that overall there was very little statistical difference between the gross solids deposit areas calculated using the integral calculation and those calculated using the pipe equation method. Because there was little statistical difference, the cylindrical pipe equation was used to calculate gross solids volumes. The cylindrical pipe equation required less data and resulted in a simpler and more time efficient method for volume calculations rather than the integral calculation.

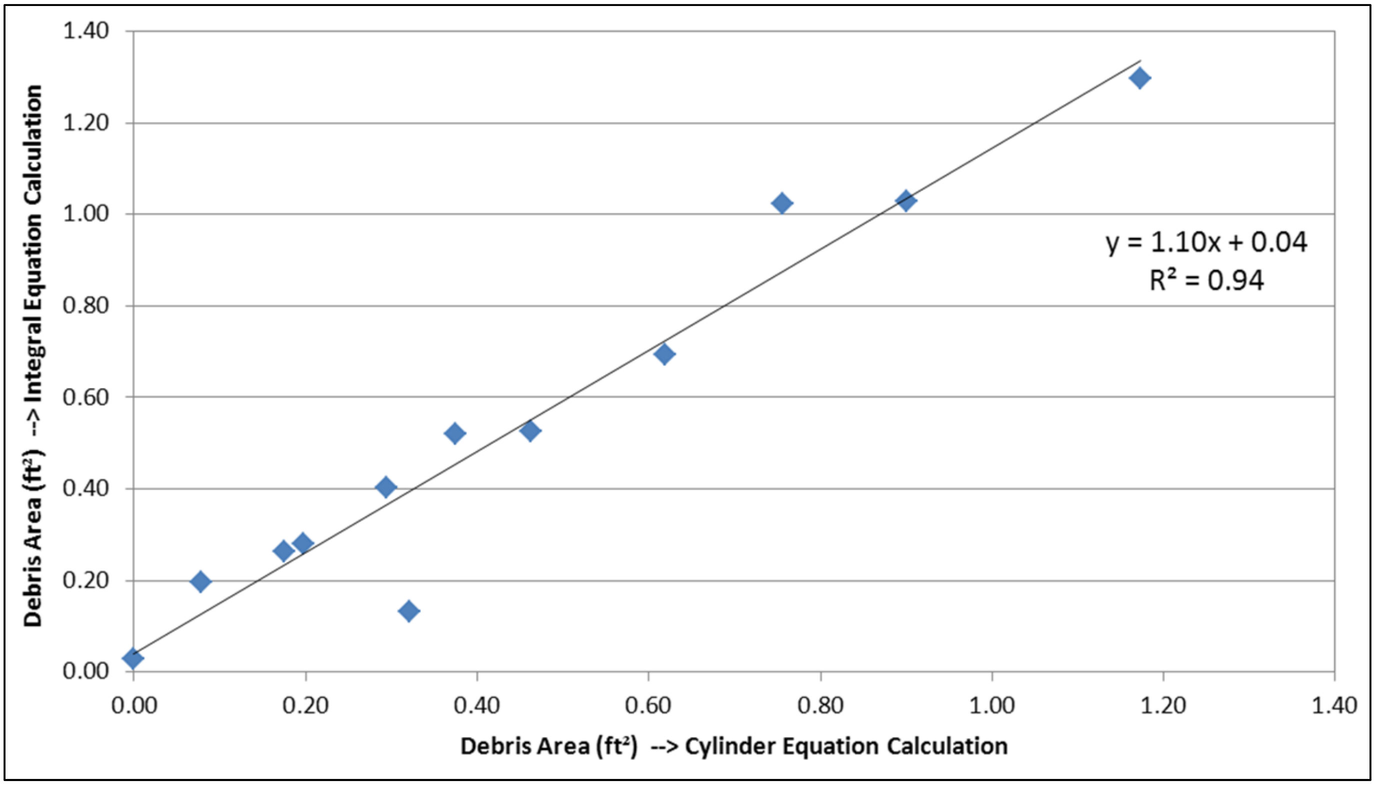



**Figure 17: Regression analysis of gross solids deposit areas, at the fifteen sampling points (for a one-foot section), calculated using an integral method versus a pipe (Cylinder) equation.**

### *5.1.2. Gross Solids Load*

The calculated volumes of gross solids, gross solids loads, and TP loads in gross solids by individual pipe (Pipe 1, 2, 3, and East End) are listed in Table 6. Cumulatively, the pipe gallery accumulated approximately 393 cf (32,745 lbs) of gross solids from 2007 to 2010; an equivalent to approximately 16 tons of debris. No debris has been removed or transported out of the pipe gallery. Therefore, these loads are representative of four years of accumulation.

**Table 6: Gross solids volumes, gross solids loads, and TP loads in gross solids captured by the Arlington-Hamline Facility pipe gallery.**

| | Gross Solids Volume (cf) | Gross Solids Load (lbs) | TP Load (lbs) |
|---|---|---|---|
| Pipe 1 | 125.77 | 11,142 | 11.32 |
| Pipe 2 | 150.86 | 11,914 | 15.16 |
| Pipe 3 | 89.46 | 7,538 | 9.83 |
| East End Pipe | 26.68 | 2,151 | 4.40 |
| **TOTAL:** | **392.77** | **32,745** | **40.71** |

Pipe 2, the center pipe, accumulated the greatest volume and load of gross solids in comparison to Pipes 1 or 3; approximately 151 cf or 11,914 lbs. In contrast, Pipe 3 (the south pipe) accumulated the least volume and load of gross solids (37% less gross solids load than Pipe 2). The East End Pipe also accumulated a substantial amount of gross solids, considering its short pipe length (approximately eight times shorter than the length of the other pipes) with a total of approximately 27 cf or 2,150 lbs.

While conducting the survey, the variability of gross solids deposits, in the pipes, were visually apparent; a greater volume of gross solids was observed in Pipe 2 than in Pipe 1 or 3. It was hypothesized that this occurred due to the central position of Pipe 2 and its proximity to the two pipe gallery inlets (i.e. the inlet to the pipe gallery from the overflow weir and the inlet from the pretreatment unit).

Pipes 1 and 3 are in direct line with the pipe gallery inlets (Figure 3). During a storm event with higher stormwater flows, turbulent velocities may cause stormwater runoff to bypass the pretreatment unit (or flow quickly through it) and flow directly into Pipes 1 and 3. This may potentially cause re-suspension of gross solids in the water column and scour and sediment transport within Pipes 1 and 3. Whereas Pipe 2 may allow for non-turbulent stormwater runoff to come to a standstill, thus allowing for particles to settle out of the water column.

The lower load of gross solids in Pipe 3 than in Pipes 1 and 2, may also partially attributable to the amount of sediment and debris in the stormwater runoff discharging from the pretreatment unit and into Pipe 3. There are lower amounts of debris and sediment in stormwater runoff discharging from the pretreatment unit, because it's being treated, than from the stormwater runoff which bypasses the pretreatment unit and discharges directly into the pipe gallery.

Also, the East End Pipe is essentially at the base of the pipe gallery due to the gradual downward gradient of the pipe gallery. Gross solids are transported to the East End Pipe and deposited.

In proportion to pipe length, the East End Pipe contained the greatest load of gross solids per foot of pipe in comparison to Pipes 1, 2, and 3. The East End Pipe contained 60 lbs of gross solids per foot of pipe. In contrast, Pipe 3 contained less than half that amount, accumulating 26 lbs of gross solids per foot of pipe. Pipes 1 and 2 were somewhat similar, accumulating 39 lbs and 42 lbs of gross solids per foot of pipe.

### *5.1.3. Bulk Density Results*

Bulk density values from the fifteen samples collected in the pipe gallery revealed variations in bulk densities by pipe and by the longitudinal distance within the pipe gallery. Bulk densities generally decreased with longitudinal distance, from west to east, in each pipe (Pipe 1, 2, and 3) (Table 7). Figure 18 illustrates the decrease in bulk densities over the longitudinal distance of all three pipes.

Gross solids deposits transition from high mineral content to high organic content, from west to east in the pipe gallery. It can be inferred that the deposition of gross solids in the pipe gallery occurs similarly to those processes which form alluvial fans; where heavier particles drop out at the apex of the feature and the lighter smaller particles are deposited at the toe.

**Table 7: Bulk density and TP concentration lab results for material collected from sample points within the pipe gallery of the Arlington-Hamline Facility.**

| Date Collected | Pipe | Sample Point | Dry-Weight % Moisture | Bulk Density (g/mL) | TP (mg/kg) |
|---|---|---|---|---|---|
| 6/9/2011 | 1 | 1 | 9.7 | 1.90 | 270 |
| 6/9/2011 | 1 | 2 | 33.3 | 1.62 | 679 |
| 6/9/2011 | 1 | 3 | 62.7 | 1.28 | 1,240 |
| 6/9/2011 | 1 | 4 | 59.9 | 1.27 | 1,400 |
| 6/9/2011 | 1 | 5 | 57.9 | 1.34 | 1,250 |
| 6/9/2011 | 2 | 1 | 49.9 | 1.38 | 1,010 |
| 6/9/2011 | 2 | 2 | 68.1 | 1.23 | 1,510 |
| 6/9/2011 | 2 | 3 | 67.7 | 1.27 | 1,520 |
| 6/9/2011 | 2 | 4 | 65.1 | 1.30 | 1,510 |
| 6/9/2011 | 2 | 5 | 63.8 | 1.27 | 1,440 |
| 6/9/2011 | 3 | 1 | 12.6 | 2.18 | 425 |
| 6/9/2011 | 3 | 2 | 31.8 | 1.50 | 653 |
| 6/9/2011 | 3 | 3 | 58.4 | 1.32 | 1,320 |
| 6/9/2011 | 3 | 4 | 57.0 | 1.34 | 1,310 |
| 6/9/2011 | 3 | 5 | 58.6 | 1.25 | 1,180 |

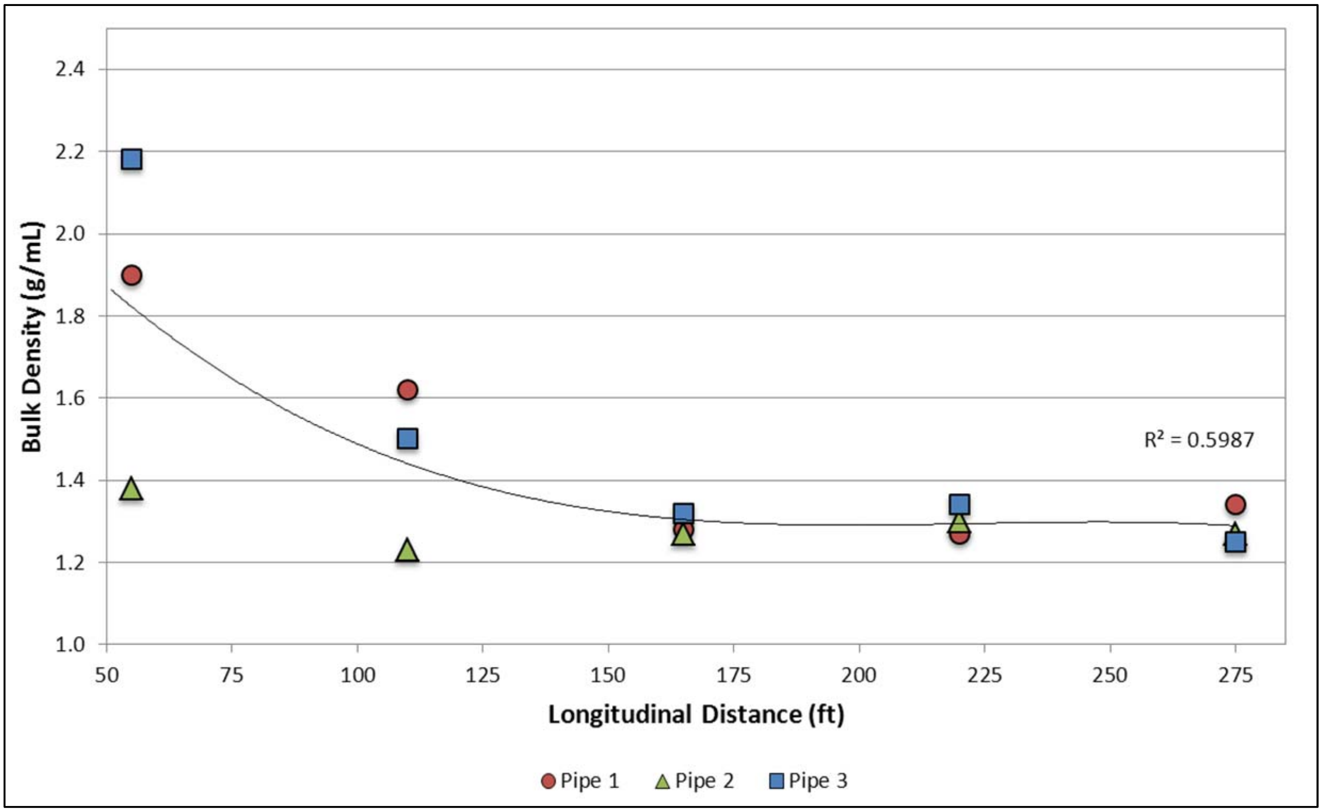



**Figure 18: The distribution of bulk densities, for material collected from sampling points in Pipes 1, 2, and 3 across the west-east longitudinal gradient of the pipe gallery.**

### *5.1.4. Particle Size Distribution Analysis*

Particle size distribution is a measurement designed to determine the distribution of particle sizes present in a soil material. The relative amount of particles present are determined and sorted according to size. Figures 19 and 20 illustrate the composition of samples collected at sampling points within the pipe gallery. The classifications used included clay/silt, fine sand, medium sand, coarse sand, and gravel. Sampling points, in each pipe, progress incrementally from west to east in each pipe. Sample Point 1 is furthest west and Sample Point 5 is furthest east.

Overall, samples collected from Pipe 2 contained larger portions of clay/silt than those samples in Pipes 1 and 3. Samples collected in Pipe 1 were largely composed of fine sand and medium sand, of which, the content slightly decreased from west to east. In Pipe 3, samples in the western end of the pipe gallery (sample points 1, 2, and 3) were largely composed of fine sand and medium sand and in the eastern end of the system (sample points 4 and 5) were largely composed of clay/silt. Clay/silt content in all samples generally increased from west to east (sample points 1 to 5). It is interesting that in both Pipes 1 and 3, fine sand content peaked at sample point 2. In Pipe 2, clay/silt content peaked at sample point 2.

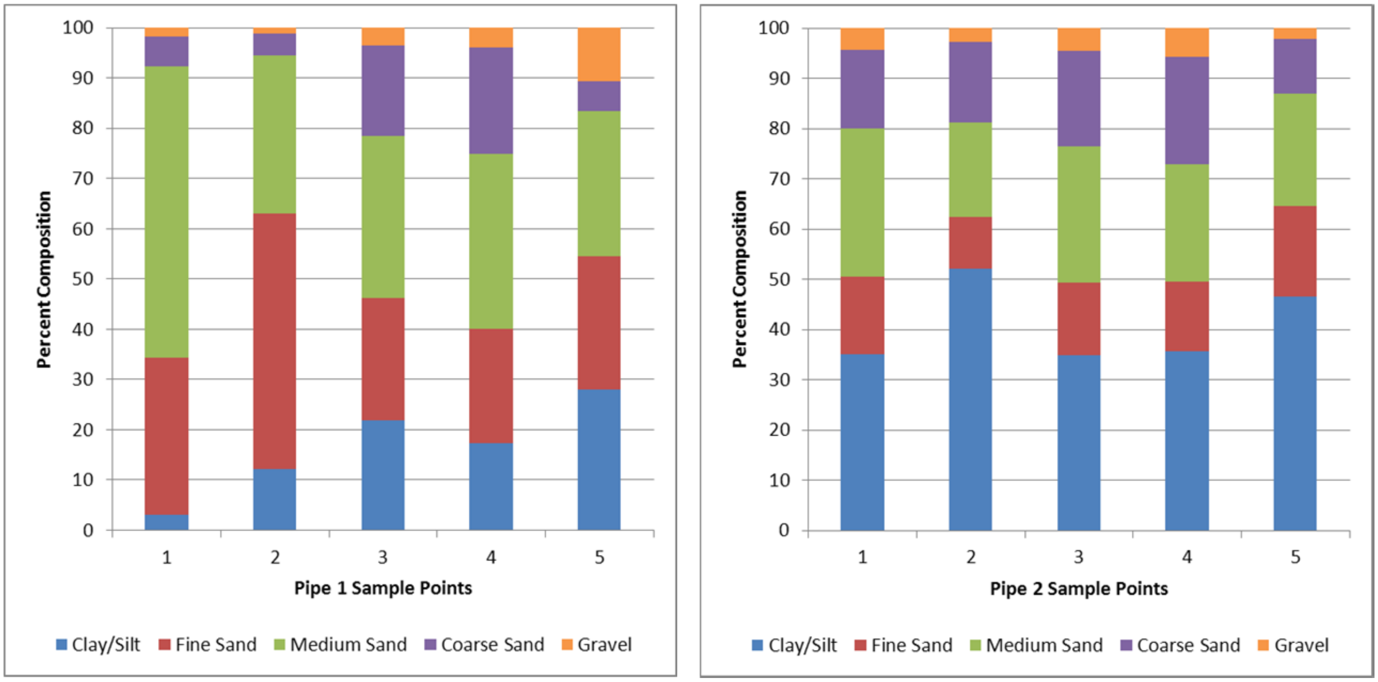



**Figure 19: Composition of samples collected in Pipe 1 (LEFT) and Pipe 2 (RIGHT). Illustrates the percentage of each sample classified as Clay/Silt, Fine Sand, Medium Sand, Coarse Sand, and Gravel.**

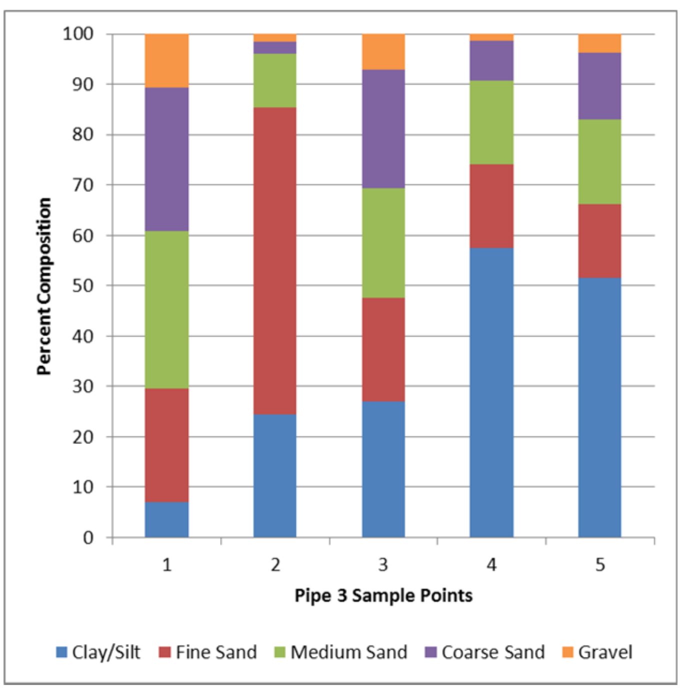



**Figure 20: Composition of samples collected in Pipe 3. Illustrates the percentage of each sample classified as Clay/Silt, Fine Sand, Medium Sand, Coarse Sand, and Gravel.**

### 5.1.5. Total Phosphorous Load

Cumulatively from 2007 to 2010, the TP load in gross solids which accumulated within the pipe gallery of the Arlington-Hamline Facility was approximately 41 lbs (Table 8). Over a four-year period, this is a substantial amount of TP which was prevented from discharging into Como Lake.

TP load accumulations in the pipe gallery were commensurate with the trend of gross solids accumulation in the pipes. The greatest TP load accumulated in Pipe 2 (~15 lbs). Pipe 1 accumulated approximately 11 lbs TP and Pipe 3 accumulated the least amount (~10 lbs). The East End Pipe accumulated approximately 4 lbs of TP. However, in relation to the shorter pipe length of the East End Pipe than of Pipes 1, 2, and 3, the East End Pipe accumulated the largest amount of TP per foot of pipe; 0.12 lbs per foot of pipe. In comparison, Pipe 2 accumulated the largest TP load which results in 0.05 lbs of TP per foot of pipe.

Like bulk density, TP concentrations at sample points varied by pipe and by the longitudinal distance (west to east) in Pipes 1, 2, and 3. However, unlike bulk densities which decreased as longitudinal distance increased, TP concentrations increased with longitudinal distance in each pipe (Table 7). Figure 21 illustrates the increase in TP concentrations over the longitudinal distance of all three pipes.

A soil with a lower bulk density (i.e. high organic content) will have a high TP concentration. In contrast, a soil with high bulk density (i.e. high mineral content) will tend to have lower TP concentration even though phosphorus binds to mineral particles in the environment. The TP results confirm the process in which gross solids accumulate within the pipe gallery and transition from higher mineral content to higher organic content.

Figure 21 illustrates the wide range of TP concentrations in the pipe gallery. The overall TP average of all fifteen samples was 1,115 mg/kg. TP concentrations were at their lowest at sample point 1 in each pipe, the sample point furthest to the west. This was due to sample material having more mineral than organic content. Pipe 2 had considerable higher TP concentrations than Pipes 1 and 2; on average the TP concentration of gross solids in Pipe 2 was 1,398 mg/kg. Average TP concentrations of gross solids in Pipes 1 and 3 were similar; 968 mg/kg and 978 mg/kg, respectively.

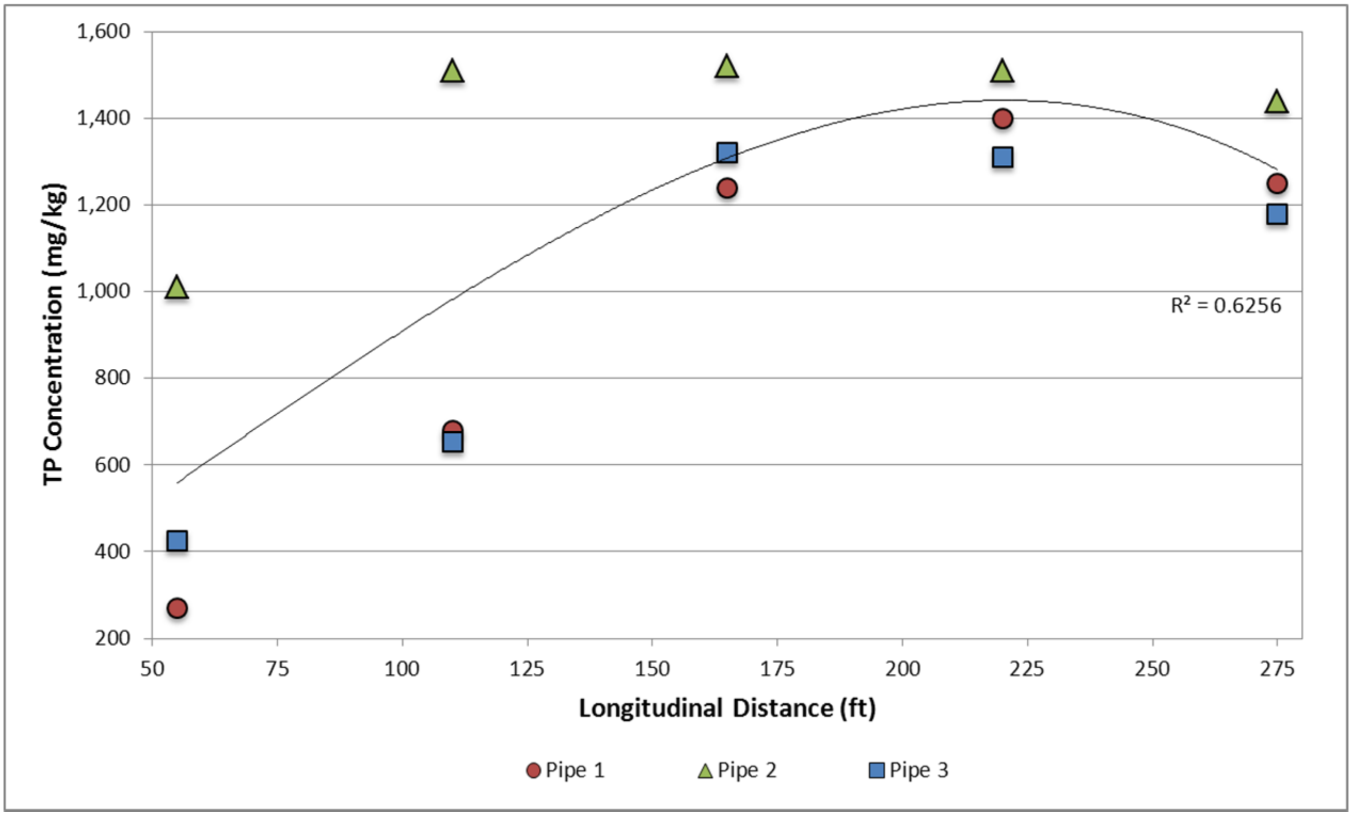


**Figure 21: The distribution of TP concentrations of sample material collected at sampling points in Pipes 1, 2, and 3 across the west-east longitudinal gradient of the pipe gallery.**

### *5.1.6. Annual Gross Solids and TP Load Accumulations*

To determine annual gross solids and TP loads for the pipe gallery, the cumulative total loads for gross solids and TP were multiplied by the percentage of annual precipitation per year, from the 2007 to 2010 total precipitation amount (Table 8).

**Table 8: Annual precipitation percentages, of the 2007 to 2010 precipitation total, used to determine annual gross solids and TP loads in gross solids which accumulated in the Arlington-Hamline Facility pipe gallery from 2007 to 2010.**

| | Annual Rainfall (in) | Percentage of 4-Year Rainfall Total (%) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | TP Load (lbs) |
|---|---|---|---|---|---|
| 2007 | 25.0 | 24% | 94.26 | 7,859 | 9.77 |
| 2008 | 21.7 | 21% | 82.48 | 6,876 | 8.55 |
| 2009 | 22.3 | 21% | 82.48 | 6,876 | 8.55 |
| 2010 | 36.3 | 34% | 133.54 | 11,133 | 13.84 |
| **TOTAL:** | **105.3** | **100%** | **392.77** | **32,745** | **40.71** |

Due to a higher than average precipitation year, the largest loads of gross solids and TP were estimated to have accumulated in the pipe gallery in 2010. Thirty-four percent of the total gross solids and TP loads were deposited in the pipe gallery in 2010. In comparison, smaller loads of gross solids and TP (21%) were deposited in the pipe gallery in 2008 and 2009. Annual precipitation in 2007 was considered average; therefore, annual gross solids and TP loads in 2007 are median values in comparison to the other years of accumulation.

## 5.2. Arlington-Hamline Facility: Pretreatment Unit

### *5.2.1. Gross Solids and Total Phosphorous Loads*

Annual gross solids and TP loads for the pretreatment unit were determined using sediment depth measurements taken twice annually, from 2007 to 2010, in the pretreatment unit. The debris depth measurements may be found in Appendix B-4. The average bulk density of samples collected in the pipe gallery (1.43 g/mL) and the mean TP concentration for samples collected at sample Point 1 in Pipes 1, 2, and 3 (568 mg/kg) were also used.

Table 9 lists the results for annual gross solids and TP loads captured by the pretreatment unit. From 2007 to 2010, on average, annual gross solids and TP loads captured by the pretreatment unit were approximately 14,400 lbs of gross solids and 10 lbs of TP annually.

**Table 9: Annual gross solids loads and TP loads in gross solids captured by the pretreatment unit from 2007 to 2010.**

| | Gross Solids Volume (cf) | Gross Solids Load (lbs) | TP Load (lbs) |
|---|---|---|---|
| 2007 | 189.60 | 16,880 | 9.59 |
| 2008 | 234.40 | 20,869 | 11.85 |
| 2009 | 270.40 | 24,074 | 13.67 |
| 2010 | 88.00 | 7,835 | 4.45 |
| **TOTAL:** | **782.40** | **69,658** | **39.57** |

Accumulation of gross solids loads and TP loads over the four-year period were variable and did not correspond with annual precipitation trends. 2010 had the lowest accumulation of gross solids and TP loads of all four monitoring years (2007 to 2010) even though there was above average precipitation. In contrast, 2009 had the highest accumulation of gross solids and TP loads and the least amount of precipitation occurred this year.

It may be inferred that the amount of gross solids and TP loads captured by the pretreatment unit increased during low precipitation years (2008 and 2009) due to less stormwater runoff flushing through the unit. It is probable that there were less stormwater runoff or smaller, low flow precipitation events with less turbulent velocities flowing into the pretreatment unit. The less turbulent velocities allow more debris and sediment to settle out of the water column and in the pretreatment unit before flowing into the pipe gallery.

Conversely, increased amounts of precipitation and subsequent stormwater runoff may have more frequent occurrences of turbulent velocities; causing shorter residence times for stormwater runoff in the pretreatment unit and re-suspension of debris and sediment into the water column.

## 5.3. Arlington-Hamline Facility: Total Annual Gross Solids and TP Loads

Annual gross solids and TP loads for both the pipe gallery and the pretreatment unit were summed to produce total annual gross solids and TP loads captured by the entire Arlington-Hamline Facility. Those results are presented in Table 10.

**Table 10: 2007 to 2010 annual gross solids and TP loads in gross solids captured by the Arlington-Hamline Facility.**

| | 2007 | 2008 | 2009 | 2010 | Total |
|---|---|---|---|---|---|
| Gross Solids Load: Pretreatment Unit (lbs) | 16,880 | 20,869 | 24,074 | 7,835 | 69,658 |
| Gross Solids Load: Pipe Gallery (lbs) | 7,859 | 6,876 | 6,876 | 11,133 | 32,744 |
| **Arlington-Hamline Facility TOTAL:** | **24,739** | **27,745** | **30,950** | **18,968** | **102,402** |
| | | | | | |
| TP Load: Pretreatment Unit (lbs) | 9.59 | 11.85 | 13.67 | 4.45 | 39.56 |
| TP Load: Pipe Gallery (lbs) | 9.77 | 8.55 | 8.55 | 13.84 | 40.71 |
| **Arlington-Hamline Facility TOTAL:** | **19.36** | **20.40** | **22.22** | **18.29** | **80.27** |

Cumulatively from 2007 to 2010, the Arlington-Hamline Facility captured approximately 102,000 lbs of gross solids; equivalent to nearly 50 tons. Approximately 80 lbs of TP was captured from 2007 to 2010. Although annual load results were variable, on average, approximately 25,600 lbs of gross solids and 20 lbs of TP were captured annually.

From 2007 to 2009, the pretreatment unit captured more gross solids annually than the amount which had accumulated within the pipe gallery. Collectively, the pretreatment unit accumulated more than two times the load of gross solids which accumulated in the pipe gallery. This is not surprising since the pretreatment unit receives stormwater runoff before (in most instances) it is discharged into the pipe gallery. There are instances of high flows where stormwater runoff both flows into the pretreatment unit and also bypasses the pretreatment unit and flows directly into the pipe gallery. The pretreatment unit is also regularly maintained; debris and sediment are removed from the unit two times each year. Removing this material maintains the functionality of the pretreatment unit (less occurrence for re-suspension of particles, maintains the debris storage capacity) and ultimately increases the longevity of the Arlington-Hamline Facility itself.

Less gross solids were captured by the pretreatment unit in 2010 than the amount which accumulated within the pipe gallery. In 2010, there was significantly more precipitation than from 2007 to 2009. This increase in precipitation may have caused higher flows of stormwater runoff which would have bypassed the pretreatment unit and/or decreased the residence time for stormwater runoff in the pretreatment unit. Also, the higher flows may have resulted in more turbulent velocities; re-suspending sediment and debris in the water column, as it flows through the pretreatment unit, and thus discharging into the pipe gallery.

Although there was a large difference between the annual load of gross solids which accumulated within the pretreatment unit and the load within the pipe gallery; the cumulative TP load captured by each from 2007 to 2010 was fairly comparable. Cumulatively, from 2007 to 2010, the pretreatment unit and the pipe gallery captured almost the same amount. Gross solids in the pipe gallery were more organic in nature and generally had significantly higher TP concentrations than the material which was captured by the pretreatment unit. The higher TP concentrations of gross solids in the pipe gallery offset the large difference of the gross solids loads between the pipe gallery and the pretreatment unit.

# 6. Infiltration Trenches: Analysis and Discussion

Results and analysis on gross solids and TP loads for all eight infiltration trenches are discussed in this section. In this section, there are three main divisions, in which, the gross solids and TP loads for each pretreatment component of the infiltration trenches (catch basins and manholes) and then annual loading results for all infiltration trenches are discussed.

Additional data and information used to determine gross solids and TP loads for the infiltration trenches may be found in Appendix C. This information includes bi-annual debris depths and corresponding debris volumes in each catch basin and manhole, bi-annual gross solids and TP loads for each catch basin and manhole, and lab results for samples taken from catch basins.

## 6.1. Infiltration Trenches: Sumped Catch Basins

### *6.1.1. Sample Collection Dates/Lab Results*

Sample collection occurred over several days in June 2011. Samples collection from most of the catch basins discharging to Trenches 2 through 4 (13 catch basins) occurred June 13-14, 2011. One catch basin discharging to Trench 4 (catch basin number 690) was sampled on June 1, 2011. Samples were collected from all catch basins discharging to Trenches 5 through 8 (14 catch basins) June 24-28, 2011. Of the two catch basins discharging to Trench 1, one catch basin (number 672) was sampled on June 14, 2011 and one (number 673) was sampled on June 24, 2011. Please refer to Figure 6 for catch basin ID numbers.

During the time frame between sampling events (June 13-14$^{th}$ and June 24-28$^{th}$), approximately four inches of precipitation fell. The majority of that precipitation fell during four storm events; June 14$^{th}$ (after sampling occurred, 0.98 inches of rain fell), June 15$^{th}$ (0.64 inches), June 21$^{st}$ (1.47 inches), and June 22$^{nd}$ (0.43 inches). The stormwater runoff from this precipitation generated new deposits of gross solids in the catch basins. These additional deposits were visually apparent in catch basins sampled during the second round of sampling and apparent in the bulk density, TP, and particle size lab results as well.

There are obvious differences in TP concentrations from samples collected prior to the storm events and those samples collected after the storm event (Figure 22). Those catch basins sampled from June 24-28$^{th}$ express a significantly higher average TP concentration (561.6 mg/kg) than those sampled June 13-14$^{th}$ (230.7 mg/kg); nearly two and a half times greater than the average TP concentration for those sampled June 13-14$^{th}$. The TP concentration of sample material collected from catch basin 690 (on June 1$^{st}$), was the highest of all samples collected from all catch basins. This concentration was excluded from the overall average TP concentration calculation of all catch basins due to being an extreme outlier.

Bulk densities for those catch basins sampled prior and after storm events did not illustrate the same trend. Bulk densities for those samples collected before and after the storm events were similar.

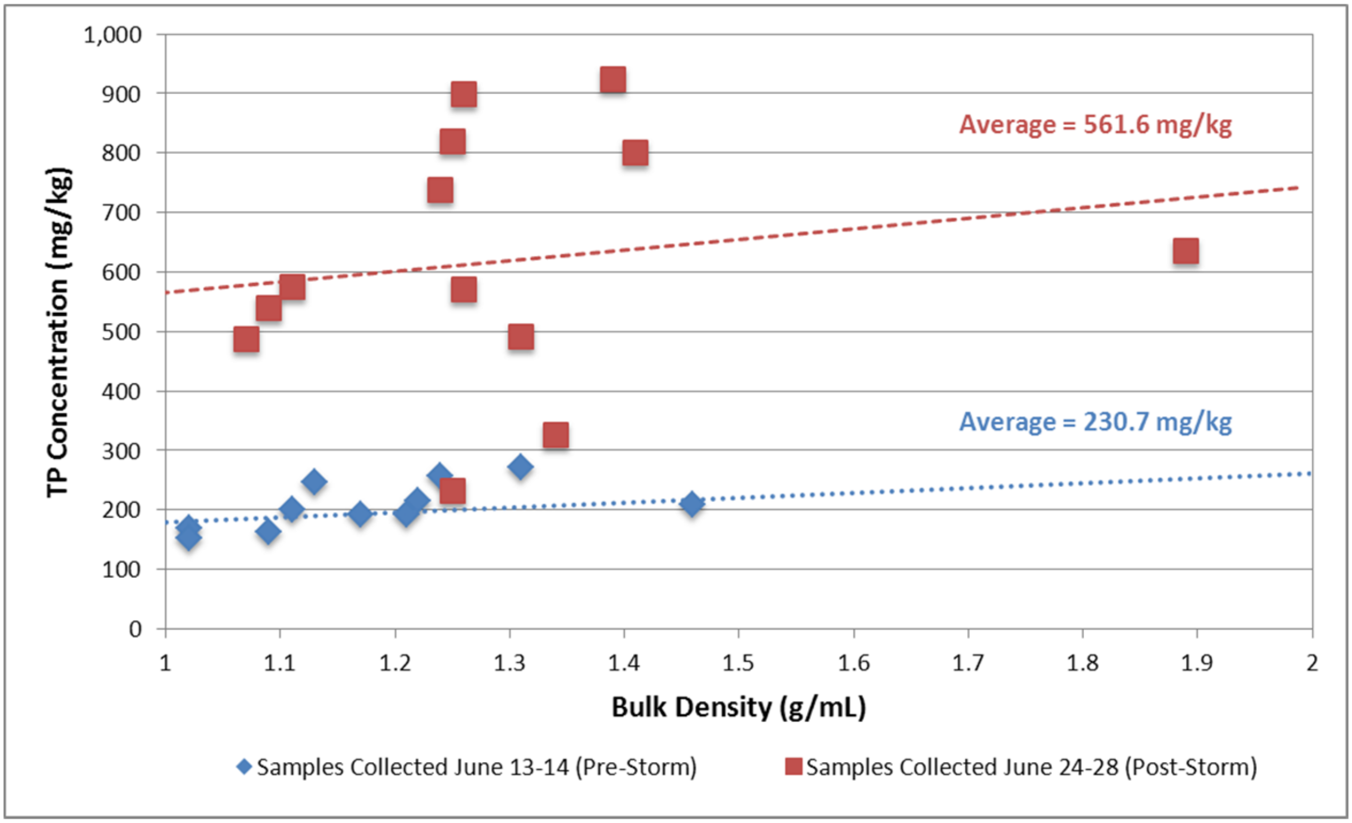



**Figure 22: Bulk density and TP concentration lab results for samples collected from the catch basins on June 13-14th (before storm events) and June 24-28th (after storm events).**

### *6.1.2. Gross Solids Volume Calculation*

Bi-annual depth measurements taken during inspections of the catch basins from 2007 to 2010, prior to debris removal, were used to determine the total annual volume of gross solids in each catch basin. Table 11 lists the volume of gross solids captured by sump catch basins discharging to Trenches 1 through 8. The volume is listed by infiltration trench, not individual catch basin. The annual volume of gross solids captured by individual catch basin may be found in Appendix C.

The least volume of gross solids was captured by catch basins in 2007; approximately 113 cf. 2007 gross solids volumes are only representative of one-half of a year, because the infiltration trenches did not become operational until late June 2007. The largest volume of gross solids was captured in 2009. The exact same volumes of gross solids were captured by catch basins in 2008 and 2010. Individual accumulations by infiltration trench differ in 2008 and 2010; however, the annual total of gross solids for all catch basins was the same. It is unknown as to why the volume of gross solids in 2008 and 2010 were identical. The data was quality checked to ensure there were no erroneous data.

**Table 11: Annual gross solids volume captured by sumped catch basins discharging to the infiltration trenches (1 through 8) from 2007 to 2010.**

| | Gross Solids Volume (cf) | | | |
|---|---|---|---|---|
| **Trench Number** | 2007 | 2008 | 2009 | 2010 |
| 1 | 3.48 | 10.20 | 20.10 | 15.54 |
| 2 | 4.74 | 11.52 | 18.30 | 11.16 |
| 3 | 27.00 | 35.40 | 65.82 | 38.82 |
| 4 | 25.86 | 63.42 | 55.74 | 40.44 |
| 5 | 15.84 | 10.02 | 18.84 | 11.10 |
| 6 | 12.06 | 23.28 | 41.46 | 29.40 |
| 7 | 0.00 | 9.30 | 21.90 | 13.62 |
| 8 | 23.64 | 43.50 | 66.72 | 46.56 |
| **TOTAL:** | **112.62** | **206.64** | **308.88** | **206.64** |

### *6.1.3. Gross Solids Load*

Annual gross solids loads captured by catch basins discharging to infiltration trenches from 2007 to 2010 are listed in Table 12. Although annual results were variable, on average approximately 16,700 lbs of gross solids were captured each year. This average annual accumulation results in approximately 560 lbs of gross solids per catch basin.

The trend for gross solids load accumulations in the catch basins is independent of amount of precipitation. Generally, the greater amount of precipitation, the greater amount of stormwater runoff and larger amount of pollutant loads are generated. Overall, the largest gross solids load was captured by catch basins in 2009 (approximately 24,700 lbs). This is significant considering that 2009 was a below average precipitation year. In 2010 when precipitation was well above average, approximately 16,500 lbs of gross solids were captured by all catch basins. This amount was exactly the same as in 2008 during a below average precipitation year.

Average annual gross solids loading yields for those catch basins discharging to trenches on Nebraska Avenue (Trenches 1 through 4) were generally higher than those discharging to trenches on Arlington Avenue (Trenches 5 through 8) (Table 14). Those catch basins discharging to infiltration trenches whose drainage areas have a higher percentage of coverage by impervious surfaces, overall, generally have higher gross solids loading yields than those trenches which have drainage areas covered by a lower percentage of impervious surfaces. For example, Trench 4 had the second lowest coverage by impervious surfaces (Table 13) and on average accumulated approximately 3,705 lbs of gross solids annually (Table 12); resulting in a gross solids loading yield of 700 lbs/acre (Table 14). Trench 2 has the highest coverage by impervious surfaces and on average accumulated approximately 914 lbs annually; resulting in a gross solids loading yield of 1,087 lbs/acre.

Overall, it is apparent that the greater the drainage area size, the greater the gross solids load which is captured by the catch basins. Also, those catch basins whose drainage areas have greater coverage by impervious surfaces, generally yield larger loads of gross solids than those drainage areas with lower impervious surfaces coverage. In addition, drainage area size and coverage by impervious surfaces seem to have a greater impact on annual gross solids loads than the annual amount of precipitation.

**Table 12: Annual gross solids loads captured by sumped catch basins discharging to the infiltration trenches from 2007 to 2010.**

| | Gross Solids Load (lbs) | | | |
|---|---|---|---|---|
| **Trench Number** | 2007 | 2008 | 2009 | 2010 |
| 1 | 278 | 815 | 1,606 | 1,242 |
| 2 | 379 | 921 | 1,462 | 892 |
| 3 | 2,158 | 2,829 | 5,260 | 3,102 |
| 4 | 2,066 | 5,068 | 4,454 | 3,232 |
| 5 | 1,266 | 801 | 1,506 | 887 |
| 6 | 964 | 1,860 | 3,313 | 2,349 |
| 7 | 0 | 743 | 1,750 | 1,088 |
| 8 | 1,889 | 3,476 | 5,332 | 3,721 |
| **TOTAL:** | **8,999** | **16,513** | **24,683** | **16,513** |

**Table 13: Infiltration trench drainage areas and coverage by impervious surfaces.**

| Trench Number | Drainage Area (acres) | Percent Impervious |
|---|---|---|
| 1 | 0.74 | 47% |
| 2 | 0.84 | 49% |
| 3 | 3.21 | 36% |
| 4 | 5.29 | 37% |
| 5 | 1.28 | 40% |
| 6 | 2.60 | 40% |
| 7 | 1.63 | 44% |
| 8 | 7.08 | 39% |
| **TOTAL:** | **22.67** | **39%** |

**Table 14: Annual gross solids loading yields for sumped catch basins.**

| Trench Number | Gross Solids Loading Yield (lbs/ac) | | | | |
|---|---|---|---|---|---|
| | 2007 | 2008 | 2009 | 2010 | Average |
| 1 | 376 | 1,101 | 2,171 | 1,678 | 1,331 |
| 2 | 451 | 1,096 | 1,741 | 1,062 | 1,087 |
| 3 | 672 | 881 | 1,639 | 966 | 1,040 |
| 4 | 391 | 958 | 842 | 611 | 700 |
| 5 | 989 | 626 | 1,176 | 693 | 871 |
| 6 | 371 | 716 | 1,274 | 904 | 816 |
| 7 | 0 | 456 | 1,074 | 668 | 549 |
| 8 | 267 | 491 | 753 | 526 | 509 |
| **TOTAL:** | **397** | **728** | **1,089** | **728** | **736** |

### *6.1.4. Bulk Density Lab Results*

Bulk density lab results for samples collected from the catch basins are listed in Table 15. In general, there were no substantial variations in bulk density. The average bulk density of all samples collected was 1.28 g/mL. Several boxplots were created in order to identify any trends in bulk density.

The second quartile (median of the data set), for bulk densities, for Trenches 2 through 8 were all within 1.0 g/mL to 1.6 g/mL (Figure 23). The median bulk density for Trench 1 was significantly higher than the other infiltration trenches. Trench 1 has the smallest drainage area of all other infiltration trenches; however, the portion of that drainage area covered by impervious surfaces is the second highest of any other trench (47%). The samples collected from catch basins discharging to Trench 1 are comprised of a large proportion of medium sand and coarse sand, though not substantially more than the other catch basins (Figure 26).

Several of the catch basins are connected in a series (1, 2, or 3), in which, each catch basin captures stormwater runoff and conveys it through a maximum of three catch basins before discharging into an infiltration trench. Catch basins delineated as a Series 1 are those that first receive stormwater runoff before conveying that runoff into either an infiltration trench or a Series 2 catch basin. Series 2 catch basins receive and convey runoff into either an infiltration trench or a Series 3 catch basin. Series 3 catch basins are those catch basins last in the series and discharge into an infiltration trench. Figure 24 illustrates catch basins categorized as a series 1, 2, and 3. There are 21 catch basins categorized as a series 1, six categorized as series 2, and three categorized as series 3.

Boxplots of bulk densities, by catch basin series number, were created in order to identify any trends which may be apparent (Figure 25). Bulk densities for those catch basins which were categorized as Series 1, varied more than those bulk density values for catch basins categorized as a Series 2 or 3. The second quartile (median of each data set), slightly increased as the series number increased.

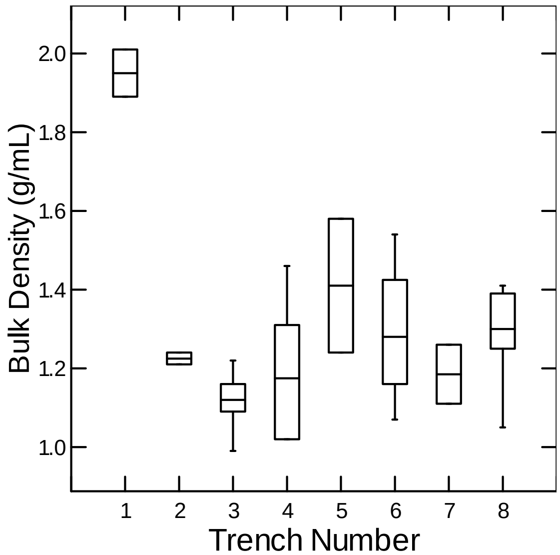



**Figure 23: Bulk density boxplots for samples collected from all catch basins. The bulk density of sample material collected from the catch basins were plotted according to the corresponding infiltration trench the catch basin discharges into.**

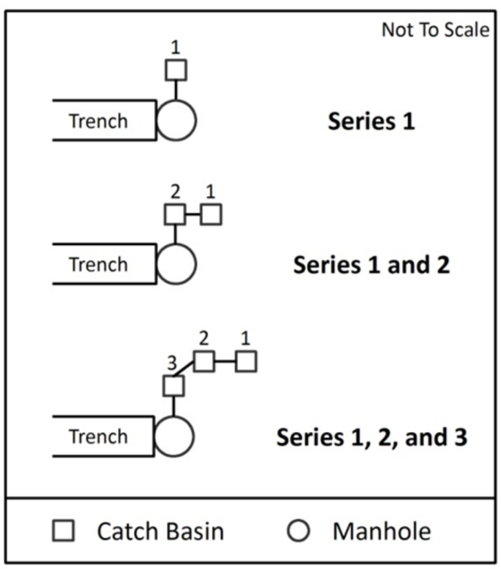



**Figure 24: Illustrations of catch basins categorized as either a Series 1, 2, or 3.**

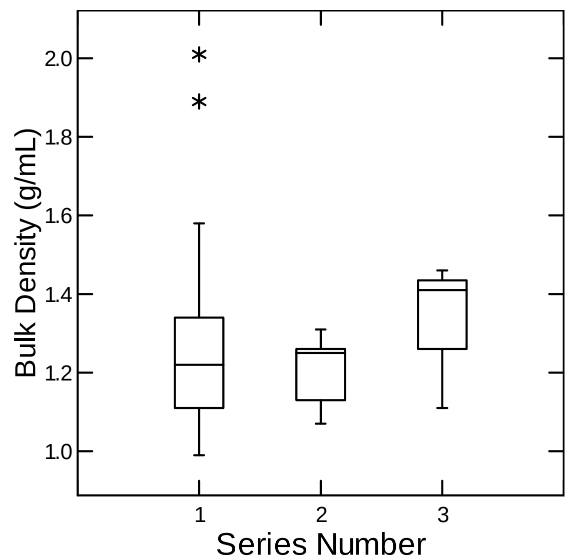



**Figure 25: Bulk density boxplots for samples collected from all catch basins. Bulk densities were plotted according to the corresponding series number of the catch basin (i.e. one, two, or three).**

**Table 15: Bulk density and TP concentration lab results for samples collected from all catch basins.**

| Trench Number | Trench End | Catch Basin Number | Sample ID | Date Collected | Dry-Weight % Moisture | Bulk Density (g/mL) | TP (mg/kg) |
|---|---|---|---|---|---|---|---|
| 1 | East | 672 | T1E-672 | 6/14/2011 | 18.8 | 2.01 | 223 |
| 1 | East | 673 | T1E-673 | 6/24/2011 | 27.8 | 1.89 | 636 |
| 2 | West | 675 | T2W-675 | 6/14/2011 | 66.8 | 1.21 | 192 |
| 2 | West | 676 | T2W-676 | 6/14/2011 | 59.5 | 1.24 | 258 |
| 3 | West | 679 | T3W-679 | 6/14/2011 | 81.7 | 0.99 | 92 |
| 3 | West | 680 | T3W-680 | 6/14/2011 | 83.7 | 1.16 | 645 |
| 3 | East | 681 | T3E-681 | 6/14/2011 | 67.3 | 1.22 | 215 |
| 3 | East | 682 | T3E-682 | 6/14/2011 | 83.5 | 1.11 | 200 |
| 3 | East | 683 | T3E-683 | 6/14/2011 | 54.7 | 1.13 | 246 |
| 3 | East | 685 | T3E-685 | 6/14/2011 | 79.8 | 1.09 | 163 |
| 4 | West | 686 | T4W-686 | 6/13/2011 | 84.0 | 1.02 | 169 |
| 4 | West | 687 | T4W-687 | 6/13/2011 | 87.1 | 1.02 | 153 |
| 4 | East | 690 | T4E-690 | 6/1/2011 | 82.5 | 1.18 | 1,980[a] |
| 4 | East | 691 | T4E-691 | 6/13/2011 | 52.2 | 1.46 | 210 |
| 4 | East | 692 | T4E-692 | 6/13/2011 | 54.3 | 1.31 | 271 |
| 4 | East | 697 | T4E-697 | 6/13/2011 | 74.0 | 1.17 | 193 |
| 5 | East | 743 | T5E-743 | 6/24/2011 | 48.4 | 1.58 | 208 |
| 5 | East | 744 | T5E-744 | 6/24/2011 | 73.7 | 1.24 | 737 |
| 6 | West | 746 | T6W-746 | 6/24/2011 | 78.8 | 1.31 | 492 |
| 6 | West | 747 | T6W-747 | 6/27/2011 | 21.9 | 1.54 | 178 |
| 6 | West | 748 | T6W-748 | 6/27/2011 | 70.4 | 1.25 | 820 |
| 6 | West | 749 | T6W-749 | 6/27/2011 | 81.4 | 1.07 | 488 |
| 7 | West | 756 | T7W-756 | 6/27/2011 | 69.0 | 1.11 | 575 |
| 7 | West | 758 | T7W-758 | 6/27/2011 | 67.9 | 1.26 | 570 |
| 8 | West | 782 | T8W-782 | 6/28/2011 | 64.5 | 1.34 | 327 |
| 8 | West | 784 | T8W-784 | 6/28/2011 | 75.3 | 1.26 | 899 |
| 8 | East | 789 | T8E-789 | 6/28/2011 | 83.2 | 1.41 | 800 |
| 8 | East | 791 | T8E-791 | 6/28/2011 | 75.5 | 1.39 | 923 |
| 8 | East | 793 | T8E-793 | 6/28/2011 | 23.6 | 1.25 | 232 |
| 8 | East | 794 | T8E-794 | 6/28/2011 | 63.0 | 1.09 | 539 |
| | | | | | **AVERAGE:** | **1.28** | **402** |

[a]This value was excluded from the average calculation due to being an extreme outlier.

### 6.1.5. Particle Size Distribution Analysis

Figures 26 and 27 illustrate the composition of samples collected from catch basins. The classifications used included clay/silt, fine sand, medium sand, coarse sand, and gravel. Composition lab results for catch basin 686, which discharges to Trench 4, did not equal 100%. This is most likely a reporting error with one or more of the portions of grain size (clay/silt, fine sand, etc.). Please refer to Figure 6 for catch basin ID numbers.

All samples collected from the catch basins were largely comprised of medium sand, coarse sand, and gravel. Overall, samples collected during the first round of sampling (prior to storm events) were comprised of larger proportions of gravel than samples collected during the second round of sampling. Those samples collected during the second round of sampling were generally comprised of higher proportions of medium and coarse sand.

Clay/silt and fine sand comprised the lowest proportion of the solids composition overall of all samples collected. Those catch basins draining to Trenches 1 through 4 generally have slightly higher proportions of clay/silt and fine sand than those catch basins draining to Trenches 5 through 8.

There were no apparent trends in changes in composition for those catch basins in a sequence (i.e. Series 1 and 2 or Series 1, 2, and 3). It would be expected that coarser material would settle out in catch basins categorized as a Series 1 or 2. This was observed in some instances. For example, catch basin 782 flows to catch basin 784 before discharging into the west end of Trench 8. There was a noticeable decrease in the proportion of coarse sand and an increase in the proportion of fine sand from catch basin 782 to catch basin 784. However, the opposite was also observed; the proportion of coarser material increased as the series number increased. Catch basin 746 flows to catch basin 749 before flowing in the west end of Trench 6. There was a substantial increase in the portion of gravel from catch basin 746 to 749.

For the systems with a series of three catch basins, the percent composition of coarser material generally peaked in those catch basins categorized as a Series 2. For example, catch basin 794 flows to catch basin 793 which flows to catch basin 789 before discharging into the east end of Trench 8. The proportion of coarse sand peaks in catch basin 793.

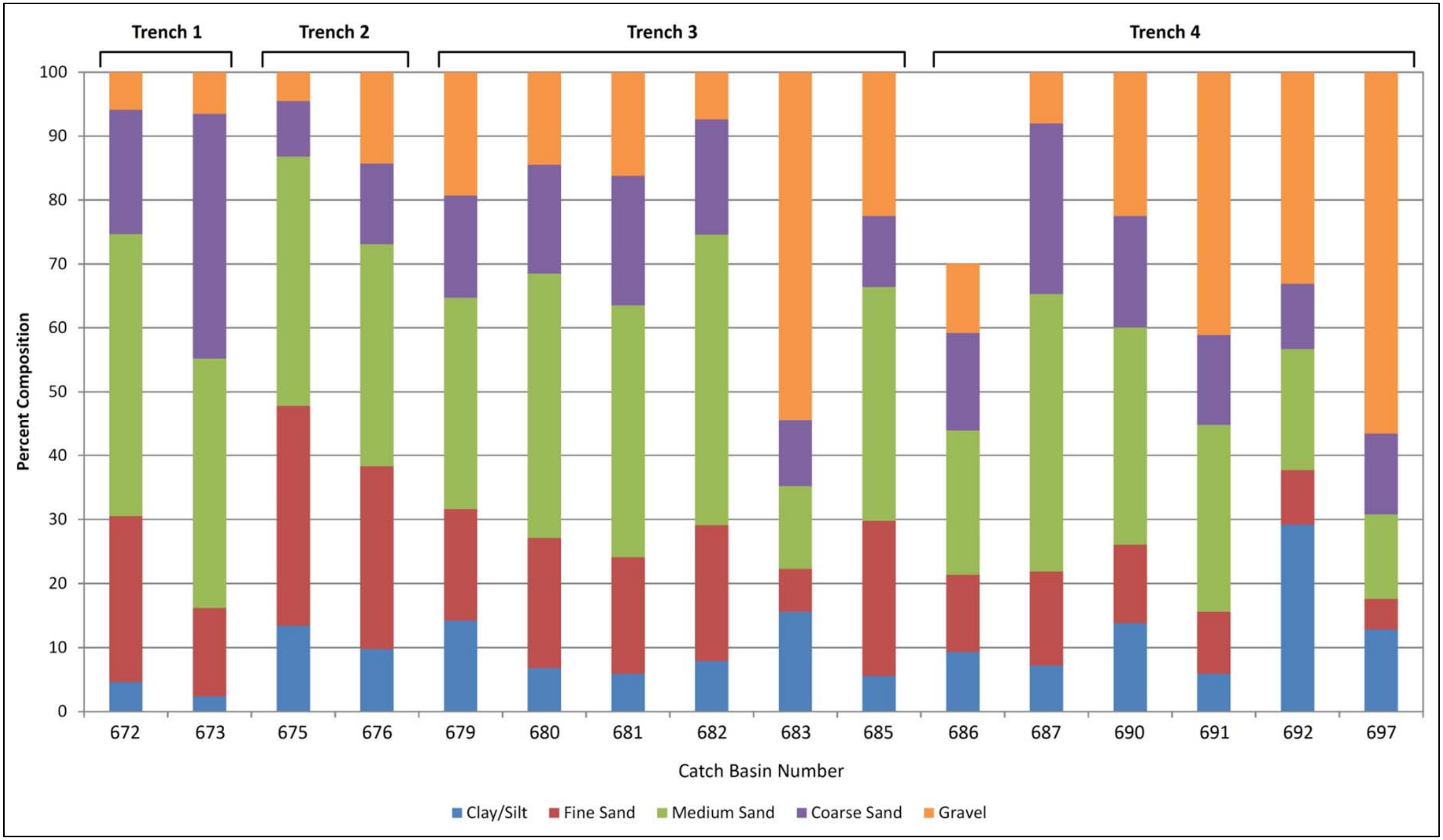



**Figure 26: Composition of samples collected from all catch basins discharging into Trenches 1 through 4. Depicts the percentage of each sample classified as Clay/Silt, Fine Sand, Medium Sand, Coarse Sand, and Gravel.**

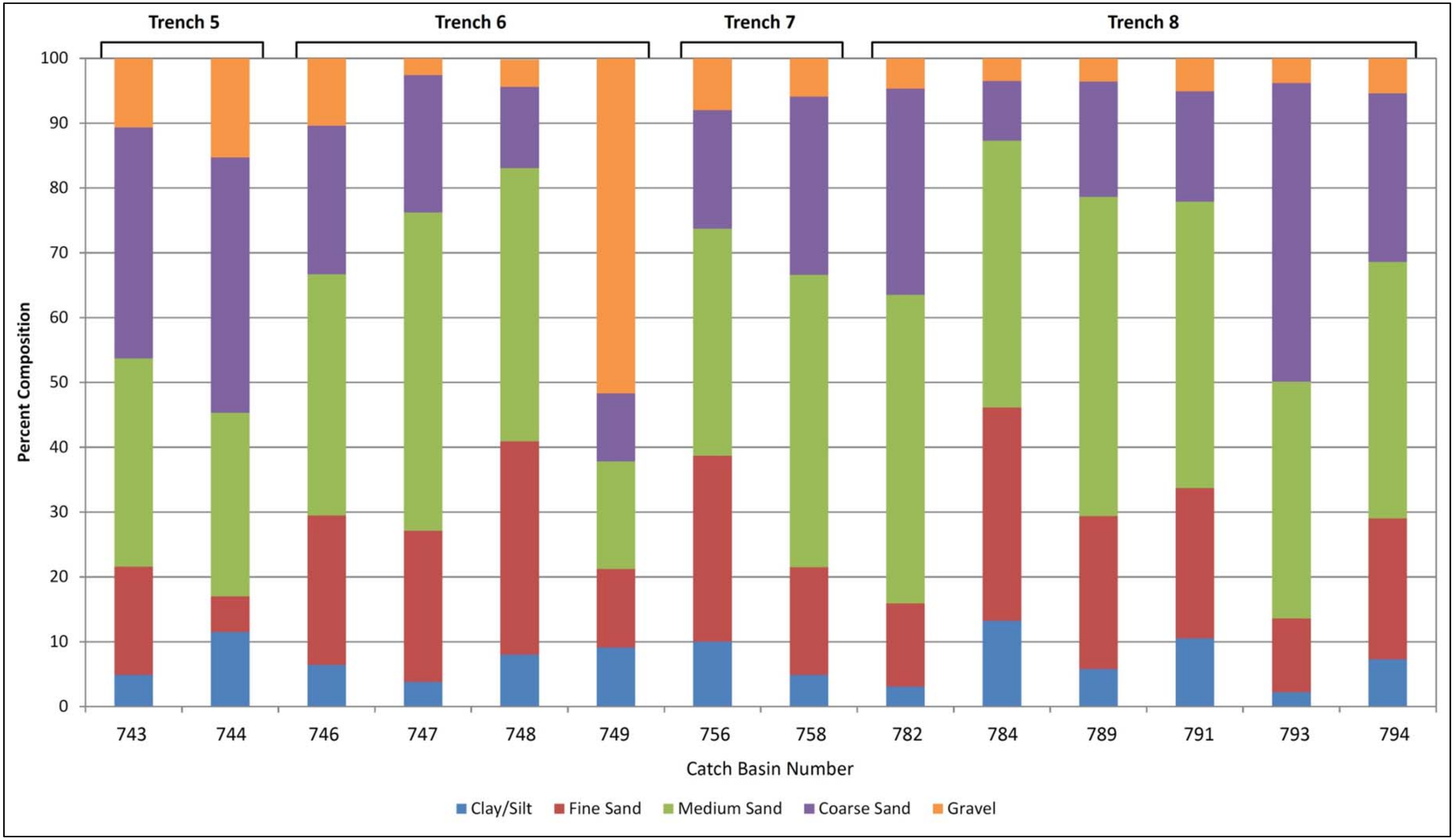



**Figure 27: Composition of samples collected from all catch basins discharging into Trenches 5 through 8. Depicts the percentage of each sample classified as Clay/Silt, Fine Sand, Medium Sand, Coarse Sand, and Gravel.**

### *6.1.6. Total Phosphorous Load*

The 2007 to 2010 annual TP loads associated with the gross solids load captured by catch basins discharging to infiltration trenches are listed in Table 16. Although annual loads were variable, on average, approximately 7 lbs of TP was captured annually by all catch basins. This equates to approximately 0.22 lbs of TP per catch basin per year.

Similar trends in TP loads in gross solids captured by catch basins are similar to gross solids accumulation trends in the catch basins. The greatest annual load of TP was removed by catch basins in 2009. The least amount was removed in 2007 and is only representative of one-half of a year of accumulations. The trenches did not become operational until June 2007. The majority of the annual TP loads removed by the catch basins was attributable to the TP load removed by those trenches which have the largest drainage area; Trenches 3, 4, and 5. Catch basins discharging to these three trenches accounted for approximately 61% to 69% of the annual TP loads captured by all catch basins.

Annual TP loading yields for those catch basins discharging to infiltration trenches on Nebraska Avenue (Trenches 1 through 4), overall, were generally higher than the TP loading yields for those discharging to infiltration trenches on Arlington Avenue (Trenches 5 through 8) (Table 17). This is consistent with results observed for annual gross solids loading yields. The total drainage area to the trenches on Arlington Avenue (12.59 ac) is slightly higher than the total drainage area those on Nebraska Avenue (10.08 ac). However, the average percentages of those total drainage areas, covered by impervious surfaces is slightly higher for the trenches on Nebraska Avenue (42%) than those on Arlington Avenue (41%).

**Table 16: Annual TP loads in gross solids captured by sumped catch basins from 2007 to 2010.**

| | **Total Phosphorous Load (lbs)** | | | |
|---|---|---|---|---|
| **Trench Number** | 2007 | 2008 | 2009 | 2010 |
| 1 | 0.11 | 0.33 | 0.65 | 0.50 |
| 2 | 0.15 | 0.37 | 0.59 | 0.36 |
| 3 | 0.87 | 1.14 | 2.11 | 1.25 |
| 4 | 0.83 | 2.04 | 1.79 | 1.30 |
| 5 | 0.51 | 0.32 | 0.61 | 0.36 |
| 6 | 0.39 | 0.75 | 1.33 | 0.94 |
| 7 | 0.00 | 0.30 | 0.70 | 0.44 |
| 8 | 0.76 | 1.40 | 2.14 | 1.50 |
| **TOTAL:** | **3.62** | **6.64** | **9.92** | **6.64** |

**Table 17: Annual TP load loading yields for sumped catch basins from 2007 to 2010.**

| Trench Number | TP Loading Yield (lbs/ac) | | | | |
|---|---|---|---|---|---|
| | 2007 | 2008 | 2009 | 2010 | Average |
| 1 | 0.15 | 0.44 | 0.87 | 0.67 | 0.54 |
| 2 | 0.18 | 0.44 | 0.70 | 0.43 | 0.44 |
| 3 | 0.27 | 0.35 | 0.66 | 0.39 | 0.42 |
| 4 | 0.16 | 0.39 | 0.34 | 0.25 | 0.28 |
| 5 | 0.40 | 0.25 | 0.47 | 0.28 | 0.35 |
| 6 | 0.15 | 0.29 | 0.51 | 0.36 | 0.33 |
| 7 | 0.00 | 0.18 | 0.43 | 0.27 | 0.22 |
| 8 | 0.11 | 0.20 | 0.30 | 0.21 | 0.20 |
| **TOTAL:** | **0.16** | **0.29** | **0.44** | **0.29** | **0.30** |

### *6.1.7. Total Phosphorous Concentration Lab Results*

Overall, there were fairly significant variations in TP concentrations of samples collected from the catch basins. The average TP concentrations of samples collected was 402 mg/kg (Table 15). Note: The TP concentration for material collected from catch basin 690 was excluded from the average calculation due to being an extreme outlier. The highest TP concentration was 1,980 mg/kg (catch basin 690) and the lowest value was 92 mg/kg (catch basin 679). The substantially higher TP concentration for catch basin 690 is most likely due to a variety and combination of climatic or subwatershed factors which corresponded with the sampling date for catch basin 690 (6/1/2011) than the other catch basins (6/13-6/14/2011, 6/24/2011, and 6/27-6/28/11). See Section 6.1.1 for additional discussion.

Several boxplots were created in order to identify any trends in TP concentrations. Figure 28 illustrates TP concentration boxplots, in which, TP concentrations were plotted according to the infiltration trench that the catch basin discharges into. Catch basins discharging to Trenches 5 through 8 have higher median TP concentrations than those catch basins discharging to Trenches 1 through 4. Overall, the spread of TP concentrations for catch basins discharging to Trenches 5 through 8 is larger than those concentrations for catch basins draining to Trenches 1 through 4. While there were two far outlier TP concentrations for catch basins flowing to Trenches 3 and 4, the overall spread of data and median concentrations for those catch basins flowing to Trenches 2 through 4 is significantly lower and more comparable than the TP concentrations of the other catch basins.

Boxplots of TP concentrations of the catch basins were also plotted according to each catch basin's series number (i.e. Series 1, 2, or 3) (Figure 29). The median TP concentration for those catch basins categorized as a Series 2 was higher than those categorized as either a Series 1 or Series 3. The median TP concentrations and overall spread of data for those catch basins categorized as a Series 1 and Series 3 were fairly comparable.

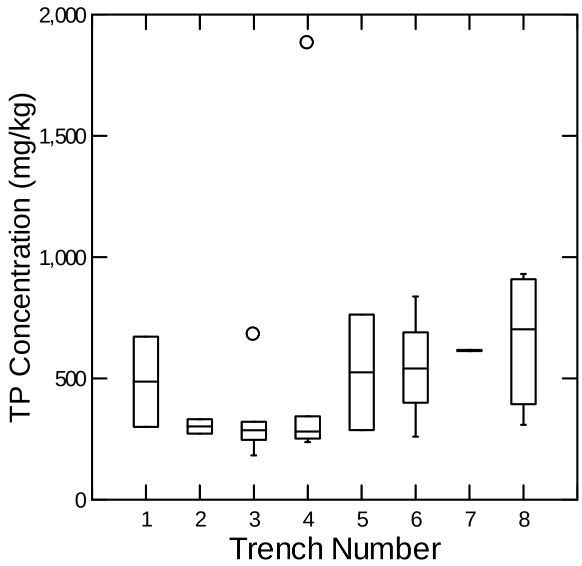



**Figure 28: TP boxplots for samples collected from all catch basins. TP concentrations were plotted according to the corresponding infiltration trench (1 through 8) the catch basin discharges into.**

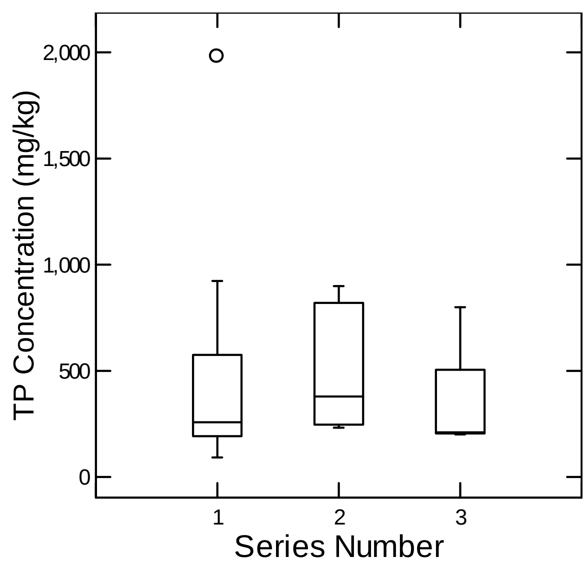



**Figure 29: TP boxplots for samples collected from all catch basins. TP concentrations were plotted according to the corresponding catch basin series number (i.e. one, two, and three).**

## 6.2. Infiltration Trenches: Sumped Manholes

All sixteen sumped manholes function as the last form of pretreatment for stormwater runoff before flowing into the infiltration trenches. Catch basins do not discharge to both ends of all trenches; however, debris and sediment still accumulate in the sumped manholes which do not have catch basins draining directly to them.

### *6.2.1. Gross Solids Volume*

As with gross solids load accumulations in the catch basins in 2007, gross solids accumulation in the manholes in 2007 is representative of a half-year. In addition, not all manholes were fully operative. Due to various reasons, the ends of the infiltration trenches located in the manholes on the east ends of Trench 2, 6, and 7 and those located in manholes on the west ends of Trench 1 and 5 were covered with PVC caps until the summer of 2008. Note: These manholes have no catch basins discharging into them. The PVC caps minimized the amounts of stormwater runoff and debris and sediment that flowed to or deposited into those manholes. 2009 and 2010 gross solids volumes are representative of an entire year of operation in which all manholes and infiltration trenches were unobstructed.

Table 18 lists the annual gross solids volume by infiltration trench, from 2007 to 2010, which accumulated in sumped manholes. Although not all manholes have catch basins discharging into them and annual volumes of gross solids vary, from 2007 to 2010 on average approximately 80 cf of gross solids accumulated in the manholes annually.

**Table 18. Annual volumes of gross solids captured by sumped manholes discharging to the infiltration trenches (1 through 8) from 2007 to 2010.**

| | Gross Solids Volume (cf) | | | |
|---|---|---|---|---|
| **Trench Number** | 2007 | 2008 | 2009 | 2010 |
| 1 | 15.08 | 4.90 | 19.47 | 3.78 |
| 2 | 5.41 | 12.44 | 2.01 | 14.71 |
| 3 | 7.92 | 22.24 | 25.51 | 7.17 |
| 4 | 7.57 | 24.28 | 14.95 | 0.25 |
| 5 | 4.02 | 2.76 | 1.76 | 0.38 |
| 6 | 14.15 | 18.40 | 18.56 | 2.59 |
| 7 | 1.64 | 7.26 | 3.47 | 3.34 |
| 8 | 13.49 | 27.45 | 8.34 | 4.51 |
| **TOTAL:** | **69.28** | **119.73** | **94.07** | **36.73** |

### *6.2.2. Gross Solids Load*

From 2007 through 2010, on average the sumped manholes captured approximately 6,400 lbs of gross solids annually; approximately 400 lbs per manhole per year. Actual annual gross solids loads vary significantly. Table 19 lists the annual gross solids loads captured by manholes, from 2007 to 2010, by the infiltration trench the manhole discharges into.

The largest annual load of gross solids was captured by manholes in 2008. The smallest annual gross solids load was captured in 2010. 2010 had an above average annual precipitation amount and the 2010 annual gross solids load was well below the load accumulations in previous years when annual precipitation was lower than 2010. The annual gross solids loads were not representative of the amount of annual precipitation.

In 2007 and 2009, gross solids loading yields for manholes discharging to Trench 1 and in 2008 and 2010 gross solids loading yields for manholes discharging to Trench 2 were by far the largest of any other infiltration trench in those years (Table 20). Trench 1 and 2 have the smallest two drainage areas of all other trenches; however, the drainage areas to these trenches have the largest percent coverages by impervious surfaces. Overall, the manholes discharging to Trench 1, 2, 3, and 4 generally had higher average annual gross solids loading yields than those manholes discharging to Trench 5, 6, 7, and 8.

**Table 19: 2007 to 2010 annual gross solids load accumulations in sumped manholes discharging to the infiltration trenches.**

| Trench Number | Gross Solids Load (lbs) 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| 1 | 1,205 | 392 | 1,556 | 302 |
| 2 | 432 | 994 | 161 | 1,175 |
| 3 | 633 | 1,777 | 2,039 | 573 |
| 4 | 605 | 1,940 | 1,195 | 20 |
| 5 | 321 | 221 | 141 | 30 |
| 6 | 1,131 | 1,470 | 1,483 | 207 |
| 7 | 131 | 580 | 277 | 267 |
| 8 | 1,078 | 2,194 | 666 | 360 |
| **TOTAL:** | **5,536** | **9,568** | **7,517** | **2,935** |

**Table 20: 2007 to 2010 annual gross solids loading yields for sumped manholes discharging to the infiltration trenches.**

| Trench Number | Gross Solids Loading Yield (lbs/ac) | | | | |
|---|---|---|---|---|---|
| | 2007 | 2008 | 2009 | 2010 | Average |
| 1 | 1,628 | 529 | 2,102 | 408 | 1,167 |
| 2 | 515 | 1,183 | 191 | 1,399 | 822 |
| 3 | 197 | 554 | 635 | 178 | 391 |
| 4 | 114 | 367 | 226 | 4 | 178 |
| 5 | 251 | 172 | 110 | 24 | 139 |
| 6 | 435 | 566 | 570 | 80 | 413 |
| 7 | 80 | 356 | 170 | 164 | 193 |
| 8 | 152 | 310 | 94 | 51 | 152 |
| **TOTAL:** | **244** | **422** | **332** | **129** | **282** |

### *6.2.3. Total Phosphorous Load*

Table 21 lists the annual TP loads captured by manholes according to the infiltration trench that the manholes discharge in to. On average, approximately 3 lbs of TP each year was captured through gross solids accumulations in sumped manholes.

Similar to trends in annual gross solids loads captured by manholes, the largest annual TP load was captured by manholes in 2008 and the smallest annual TP load in 2010. The similarity in trends is expected since TP load accumulations are directly related to the amount of gross solids load accumulations. Also, like gross solids loads, annual TP load accumulations by infiltration trench, varied significantly from year-to-year with no apparent trends.

Annual TP loading yields for the manholes also varied significantly from year-to-year and by infiltration trench (Table 22). Overall, the average annual TP loading yields for Trenches 1, 2, 3, and 4 were generally higher than those for Trenches 5, 6, 7, and 8.

**Table 21: 2007 to 2010 annual TP loads in gross solids captured by sumped manholes.**

| Trench Number | Total Phorphorous Load (lbs) 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| 1 | 0.48 | 0.16 | 0.63 | 0.12 |
| 2 | 0.17 | 0.40 | 0.06 | 0.47 |
| 3 | 0.25 | 0.71 | 0.82 | 0.23 |
| 4 | 0.24 | 0.78 | 0.48 | 0.01 |
| 5 | 0.13 | 0.09 | 0.06 | 0.01 |
| 6 | 0.45 | 0.59 | 0.60 | 0.08 |
| 7 | 0.05 | 0.23 | 0.11 | 0.11 |
| 8 | 0.43 | 0.88 | 0.27 | 0.14 |
| **TOTAL:** | **2.23** | **3.85** | **3.02** | **1.18** |

**Table 22: 2007 to 2010 annual TP loading yields for sumped manholes.**

| Trench Number | TP Loading Yield (lbs/ac) 2007 | 2008 | 2009 | 2010 | Average |
|---|---|---|---|---|---|
| 1 | 0.65 | 0.21 | 0.85 | 0.16 | 0.47 |
| 2 | 0.21 | 0.48 | 0.08 | 0.56 | 0.33 |
| 3 | 0.08 | 0.22 | 0.26 | 0.07 | 0.16 |
| 4 | 0.05 | 0.15 | 0.09 | 0.00 | 0.07 |
| 5 | 0.10 | 0.07 | 0.04 | 0.01 | 0.06 |
| 6 | 0.17 | 0.23 | 0.23 | 0.03 | 0.17 |
| 7 | 0.03 | 0.14 | 0.07 | 0.07 | 0.08 |
| 8 | 0.06 | 0.12 | 0.04 | 0.02 | 0.06 |
| **TOTAL:** | **0.10** | **0.17** | **0.13** | **0.17** | **0.11** |

## 6.3. Infiltration Trenches: Total Annual Gross Solids and TP Loads

Gross solids and TP loads captured by both sumped catch basins and sumped manholes were combined according to the infiltration trench they discharge in to, to produce annual load removals for both gross solids and TP per infiltration trench. The sum totals of gross solids and TP loads for all infiltration trenches were then combined to produce collective annual load removals for all pretreatment units (all 30 catch basins and all 16 manholes), for all infiltration trenches. Table 23 lists those collective annual gross solids and TP loads, for all infiltration trenches, from 2007 to 2010.

Collectively from 2007 to 2010, all sumped catch basins and manholes discharging to infiltration trenches captured approximately 92,100 lbs of gross solids and 37 lbs of TP. Although annual load accumulations varied, on average, approximately 23,100 lbs of gross solids and 9 lbs of TP were captured each year. The largest annual gross solids and TP loads captured by all pretreatment units (catch basins and manholes) occurred in 2009 and the smallest annual loads in 2007. As stated in the previous gross solids and TP loading discussions for the trench pretreatment units, annual precipitation is not the driving factor in gross solids and TP loading. Other factors such as variations in watershed characteristics amongst the individual drainage areas are having a greater impact on pollutant loading.

The year-to-year variations in gross solids and TP load accumulations for the manholes are offset by the overall loads captured by the catch basins. Overall, the catch basins accumulated larger loads of gross solids and TP. The manholes function as the last form of pretreatment for stormwater runoff before it flows into the infiltration trenches. Therefore, less load accumulations would be expected to be observed in the manholes than in the catch basins.

**Table 23: 2007 to 2010 annual gross solids and TP loads in gross solids captured by both sumped catch basins and manholes discharging to infiltration trenches 1 through 8.**

| | Gross Solids Load (lbs) | | | | Total Phosphrous Load (lbs) | | | |
|---|---|---|---|---|---|---|---|---|
| Trench Number | 2007 | 2008 | 2009 | 2010 | 2007 | 2008 | 2009 | 2010 |
| 1 | 1,483 | 1,207 | 3,162 | 1,544 | 0.60 | 0.49 | 1.27 | 0.62 |
| 2 | 811 | 1,915 | 1,623 | 2,067 | 0.33 | 0.77 | 0.65 | 0.83 |
| 3 | 2,790 | 4,606 | 7,298 | 3,675 | 1.12 | 1.85 | 2.93 | 1.48 |
| 4 | 2,671 | 7,008 | 5,649 | 3,252 | 1.07 | 2.82 | 2.27 | 1.31 |
| 5 | 1,587 | 1,021 | 1,646 | 917 | 0.64 | 0.41 | 0.66 | 0.37 |
| 6 | 2,094 | 3,331 | 4,796 | 2,556 | 0.84 | 1.34 | 1.93 | 1.03 |
| 7 | 131 | 1,323 | 2,027 | 1,355 | 0.05 | 0.53 | 0.81 | 0.54 |
| 8 | 2,967 | 5,670 | 5,998 | 4,081 | 1.19 | 2.28 | 2.41 | 1.64 |
| **TOTAL:** | **14,536** | **26,080** | **32,200** | **19,448** | **5.84** | **10.48** | **12.94** | **7.82** |

## 6.4. Como Park Regional Pond and Rain Gardens

Annual gross solids and TP loading yields (lbs/acre) were calculated for the infiltration trenches by using the annual gross solids and TP loads captured by the pretreatment units discharging to the infiltration trenches and also the portion of the infiltration trenches drainage areas covered by impervious surfaces. These annual yields were used to extrapolate annual gross solids and TP loads for the Como Park Regional Pond and eight rain gardens (Arlington-McKinley, Asbury North, Asbury South, Frankson-McKinley, Hamline-Midway, Pascal Center, Pascal North, and Pascal South Rain Gardens).

### 6.4.1. Como Park Regional Pond: Gross Solids and Total Phosphorous Loads

The Como Park Regional Pond was still under construction in 2007. Therefore, gross solids and TP loading data for the pond for that year is not available. Table 24 lists the estimated annual gross solids and TP loads captured by the pond from 2008 to 2010.

From 2008 through 2010, the Como Park Regional Pond has accumulated a collective total of approximately 434,500 lbs of gross solids and 175 lbs of TP; on average 144,800 lbs of gross solids and 58 lbs of TP per year. The greatest annual gross solids and TP loads accumulated in 2009 and the smallest loads in 2010. It would have been expected that the largest annual loads would have been observed in 2010, when annual precipitation totals were well above average. This greater amount of precipitation would have generated more stormwater runoff, carrying more pollutants loads to the pond. Contrastingly, 2009 was a dry year. The greatest gross solids and TP loads were deposited in the pond that year.

**Table 24: 2008 to 2010 annual gross solids and TP loads in gross solids captured by the Como Park Regional Pond.**

| Year | Gross Solids Load (lbs) | TP Load (lbs) |
|---|---|---|
| 2008 | 145,791 | 58.58 |
| 2009 | 180,003 | 72.34 |
| 2010 | 108,717 | 43.71 |

### 6.4.2. Rain Gardens: Gross Solids Load

Annual gross solids loads captured by the rain gardens from 2007 to 2010 are listed in Table 25. Cumulatively from 2007 until 2010, the rain gardens captured approximately 38,500 lbs of gross solids. On average, 9,600 lbs were captured each year.

The Hamline-Midway and Frankson-McKinley Rain Gardens captured the largest amount of gross solids loads each year. Combined, the two rain gardens account for 75% of the annual gross solids load captured by all rain gardens from 2007 to 2010. The Hamline-Midway and Frankson-McKinley Rain Gardens have the two largest drainage areas of all eight rain gardens. The Pascal Center Rain Garden has the smallest drainage area and captured the smallest load of gross solids. This rain garden comprises nearly 2% of the annual gross solids load of all rain gardens from 2007 to 2010.

Although the Pascal Center Rain Garden captured substantially less annual gross solids loads than the Hamline-Midway Rain Gardens, the gross solids yield for the Pascal Center Rain Garden is on average actually more than two times that of the Hamline-Midway Rain Garden (Table 26). Overall, the Pascal Center Rain Garden's drainage area is smaller than that of the Hamline-Midway Rain Garden. However, the drainage area to the Pascal Center Rain Garden is covered by a higher portion of impervious surfaces (46% versus 18% impervious surfaces coverage for that drainage area to the Hamline-Midway Rain Garden).

**Table 25: Annual gross solids loads captured by the rain gardens from 2007 to 2010.**

| Rain Garden | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| Arlington-McKinley | 247 | 447 | 552 | 333 |
| Asbury North | 276 | 499 | 617 | 372 |
| Asbury South | 539 | 975 | 1,204 | 727 |
| Frankson-McKinley | 1,511 | 2,734 | 3,375 | 2,038 |
| Hamline-Midway | 3,009 | 5,444 | 6,721 | 4,059 |
| Pascal Center | 97 | 175 | 216 | 131 |
| Pascal North | 205 | 371 | 458 | 277 |
| Pascal South | 142 | 257 | 317 | 192 |
| **TOTAL:** | **6,026** | **10,902** | **13,461** | **8,130** |

**Table 26: Annual gross solids loading yields for the rain gardens.**

| | Gross Solids Loading Yield (lbs/acre) | | | | |
|---|---|---|---|---|---|
| **Rain Garden** | **2007** | **2008** | **2009** | **2010** | **Average** |
| Arlington-McKinley | 668 | 1,208 | 1,491 | 901 | 1,067 |
| Asbury North | 690 | 1,249 | 1,541 | 931 | 1,103 |
| Asbury South | 499 | 903 | 1,115 | 674 | 798 |
| Frankson-McKinley | 538 | 973 | 1,201 | 725 | 859 |
| Hamline-Midway | 287 | 520 | 642 | 388 | 459 |
| Pascal Center | 745 | 1,348 | 1,664 | 1,005 | 1,191 |
| Pascal North | 446 | 806 | 996 | 601 | 712 |
| Pascal South | 395 | 714 | 881 | 532 | 631 |
| **TOTAL:** | **375** | **678** | **837** | **506** | **599** |

### *6.4.3. Rain Gardens: Total Phosphorous Load*

Annual TP loads in gross solids captured by the rain gardens from 2007 to 2010 are listed in Table 27. On average, approximately 4 lbs of TP was captured by all rain gardens annually, from 2007 through 2010. Because the TP loads captured by the rain gardens is dependent upon gross solids loading, trends in TP loading mimics those trends observed in gross solids loading.

The largest TP load was captured by rain gardens in 2009 and the smallest TP load was captured in 2007. The Hamline-Midway and Frankson-McKinley Rain Gardens captured the largest portion of annual TP loads from 2007 to 2010. These two rain gardens accounted for approximately 75% of annual TP loads for all rain gardens from 2007 to 2010.

**Table 27: Annual TP loads in gross solids captured by the rain gardens from 2007 to 2010.**

| Rain Garden | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| Arlington-McKinley | 0.10 | 0.18 | 0.22 | 0.13 |
| Asbury North | 0.11 | 0.20 | 0.25 | 0.15 |
| Asbury South | 0.22 | 0.39 | 0.48 | 0.29 |
| Frankson-McKinley | 0.61 | 1.10 | 1.36 | 0.82 |
| Hamline-Midway | 1.22 | 2.19 | 2.70 | 1.63 |
| Pascal Center | 0.04 | 0.07 | 0.09 | 0.05 |
| Pascal North | 0.08 | 0.15 | 0.18 | 0.11 |
| Pascal South | 0.06 | 0.10 | 0.13 | 0.08 |
| **TOTAL:** | **2.44** | **4.38** | **5.41** | **3.27** |

**Table 28: Annual TP loading yields for the rain gardens.**

| | TP Loading Yield (lbs/acre) | | | | |
|---|---|---|---|---|---|
| **Rain Garden** | **2007** | **2008** | **2009** | **2010** | **Average** |
| Arlington-McKinley | 0.27 | 0.49 | 0.60 | 0.36 | 0.43 |
| Asbury North | 0.28 | 0.50 | 0.62 | 0.37 | 0.44 |
| Asbury South | 0.20 | 0.36 | 0.45 | 0.27 | 0.32 |
| Frankson-McKinley | 0.22 | 0.39 | 0.48 | 0.29 | 0.35 |
| Hamline-Midway | 0.12 | 0.21 | 0.26 | 0.16 | 0.18 |
| Pascal Center | 0.30 | 0.54 | 0.67 | 0.40 | 0.48 |
| Pascal North | 0.18 | 0.32 | 0.40 | 0.24 | 0.29 |
| Pascal South | 0.16 | 0.29 | 0.35 | 0.21 | 0.25 |
| **TOTAL:** | **0.15** | **0.27** | **0.34** | **0.20** | **0.24** |

# 7. Conclusions

Although annual loads captured by the individual BMPs varied, the cumulative amount of gross solids and associated TP loads captured by the pretreatment units for the BMPs and/or by the BMP themselves was substantial. During the years when all BMPs were operational (2008 through 2010), on average approximately 207,000 lbs of gross solids and 93 lbs of TP in gross solids were removed each year. This is a considerable amount that is in addition to the total suspended solids and TP loads already being removed by the BMPs through stormwater infiltration. See CRWD's *BMP Performance and Cost-Benefit Analysis: Arlington Pascal Project 2007-2010* for the thorough analysis (CRWD, 2012). The collective annual loads of gross solids and TP loads in gross solids captured by all Arlington Pascal Project BMPs are summarized in Appendix D.

## 7.1. Arlington-Hamline Facility

Initial assumptions of gross solids depositions in the pipe gallery (i.e. composition of material changed across the gradient of the pipes from west to east and from north to south), prior to this study, were proven correct. The bulk density of samples collected within the pipe gallery decreased from west to east while TP concentrations inversely increased along the same gradient. The particle size analysis conducted also verified the composition change of the material; clay/silt content generally increased from west to east. The average bulk density of the fifteen samples collected within the pipe gallery was 1.43 g/mL; the average TP concentration was 1,115 mg/kg.

Larger amounts of gross solids and TP loads accumulated within Pipe 2 of the pipe gallery than in Pipes 1 and 3. However, on a per foot of pipe basis the East End Pipe (primarily due to the gradient of the pipe gallery) had the largest accumulation of gross solids and TP loads; 60 lbs of gross solids and 0.12 lbs of TP per foot of pipe. Overall, the pretreatment unit to the Arlington-Hamline Facility accumulated higher annual loads of gross solids and TP than the annual loads which accumulated within the pipe gallery. Although the pipe gallery is much larger in scale than the pretreatment unit, stormwater runoff is generally first treated by the pretreatment unit before flowing into the pipe gallery. On average, the Arlington-Hamline Facility (pretreatment unit and pipe gallery combined) captured approximately 25,600 lbs of gross solids and 20 lbs of TP annually.

## 7.2. Underground Infiltration Trenches

Lab results from the samples collected from the thirty catch basins showed high variability in TP concentrations of gross solids across all samples, however, this extent of variability was not observed for bulk density lab results.

Samples collected from June 24-28, 2011 (14 samples total) had significantly higher TP concentrations (average 556 mg/kg) than those samples collected from June 13-14, 2011 (15 samples total which averaged 258 mg/kg). During that timeframe, approximately four inches of precipitation fell. One sample was collected from one catch basin on June 1, 2011. This particular sample had the highest TP concentration of any other sample collected (1,980 mg/kg). The average TP concentration of all samples collected, except for the TP concentration of the sample collected on June 1, 2011 which was excluded due to being an extreme outlier, was 402 mg/kg.

Although the bulk density of sample material collected from individual catch basins did not vary significantly from each other, there were some apparent trends dependent on the infiltration trench and its corresponding catch basin(s) and the numbered series the catch basin was categorized as (Series 1, 2, or 3).

The bulk densities of samples collected from catch basins discharging to Trench 1 were substantially higher than the bulk density of all other catch basins. Also, bulk density values for those catch basins discharging to Trenches 5 through 8 were generally higher than bulk density values for catch basins discharging to Trenches 2 through 4. The median bulk density also slightly increased as the catch basin series number increased. The average bulk density of all catch basins was 1.28 g/mL.

From 2007 to 2010, overall, greater annual gross solids and TP loads were captured by sumped catch basin than sumped manholes. Sumped manholes have larger storage volumes than sumped catch basins; however, the manholes serve as the last form of pretreatment for stormwater before flowing into the infiltration trenches. Less material, which is most likely finer in composition, would be expected to deposit in the sumped manholes. Annual gross solids and TP loads varied significantly from 2007 to 2010, however, on average approximately 23,000 lbs of gross solids and 9 lbs of TP was captured by sumped catch basins and manholes each year.

It was apparent that annual gross solids and associated TP loads captured by pretreatment units discharging to the infiltration trenches was not dependent on precipitation. From 2007 to 2010, 2010 had significantly more total annual precipitation than any other year. However, generally the lowest annual loads were captured in 2010. Annual load accumulations were more dependent on drainage area size (the larger the drainage area, the greater the load accumulations) than annual precipitation. In addition, coverage by impervious surfaces also affected annual load accumulations. Generally, the higher the percentage of impervious surfaces coverage within the drainage area, the greater the annual load accumulations.

## 7.3. Como Park Regional Pond and Rain Gardens

Annual pollutant yields (gross solids and TP) were calculated for all pretreatment units discharging to all infiltration trenches. This yield incorporated the amount of impervious surfaces coverage over the entire drainage area for all infiltration trenches and the annual loads for all trenches. The impervious surfaces coverage was used instead of the entire drainage area to all infiltration trenches because, based on surrounding land uses (which was primarily residential), it was probable that the majority of stormwater runoff was being generated by those impervious surfaces areas (driveways, roofs, streets, and sidewalks).

The yields calculated and annual loads extrapolated for other BMPs (Como Park Regional Pond and all rain gardens) were slightly more conservative than those calculated using the entire subwatershed area for all infiltration trenches.

The Como Park Regional Pond became operational in 2008. From 2008 to 2010, average annual gross solids and TP load accumulations were approximately 144,800 lbs and 58 lbs, respectively. From 2007 to 2010, average annual load accumulations for all eight rain gardens were 9,600 lbs of gross solids and 4 lbs of TP.

## 7.4. Lessons Learned and Recommendations

### *7.4.1. Arlington-Hamline Facility*

Data collection within the pipe gallery of the Arlington-Hamline Facility was time intensive. The scale of the pipe gallery itself is large. The lengths of the pipes (Pipe 1, 2, and 3) made equipment set-up and surveying time consuming. Also, collecting cross-sectional depth measurements of the gross solids deposits at the sample points was time consuming. Although both were time intensive, they were a one-time incidence necessary for future replication of the project and also to determine if the cylindrical pipe equation used to calculate gross solids volumes had the same level of accuracy of integral calculations. The pipe equation, which was as accurate as the integral calculations, required less depth measurement data and was ultimately a faster calculation method.

In addition, because the pipe gallery is considered a confined space, protocols for ensuring a safe work environment had to be followed. Because the pipe gallery is enclosed with decomposition of large amounts of material occurring, unsafe conditions were often encountered (e.g. unsafe oxygen levels) and the system had to be evacuated. Manhole lids at both ends of the system as well as manholes at the inlets were removed to encourage circulation of fresh air into the pipe gallery.

Annual load calculations for the pipe gallery were based off the assumption that the annual loads were dependent upon precipitation. This was the most logical assumption as no material had been removed or transported from the pipe gallery. As was observed with the annual loading results from the Arlington-Hamline Facility pretreatment unit and the infiltration trenches, this assumption is most likely not accurate. Annual loads appear to be more contingent on other variables such as individual subwatershed characteristics (i.e. percentage of impervious surfaces coverage, land cover, etc.). Future data collection efforts should include a review of other variables which might affect annual load accumulations.

Furthermore, future sample collection efforts should also incorporate sample collection from the pretreatment unit to the Arlington-Hamline Facility. Material accumulating within this unit likely differs in composition from that which was assumed.

### *7.4.2. Underground Infiltration Trenches*

Sample collection completed for the thirty sumped catch basins discharging to the eight underground infiltration trenches was time consuming and labor intensive. It took approximately one hour to sample a single catch basin. Significant amounts of time were spent decanting stagnant stormwater from the catch basins. For future sampling efforts, a faster method for decanting stormwater runoff from the catch basin or sampling equipment which would allow sample extraction without decanting stormwater that would still keep the sample material intact (e.g. LacCore freeze core) should be explored.

Future sampling efforts should also further focus on identifying those variables (i.e. climatic, seasonality, subwatershed characteristics, etc.) which drive variability in bulk density and TP concentrations of samples collected and ultimately annual load accumulations in individual pretreatment units (catch basins and manholes). Additional sampling efforts should also attempt to include sample collection from the sumped manholes. It is probable that the material accumulating within the manholes is composed of finer material (silt/clay) than what accumulates in the catch basins. Therefore, this could potentially result in a material with lower bulk density and higher TP concentrations than the material in the catch basins.

In addition, more continuity in conducting bi-annual inspections (in which debris depths of the catch basins and manholes are measured) should be completed. Consistency in measurement of debris depths in each pretreatment unit, every year, is necessary to accurately calculate annual loads.

# 8. References

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# APPENDIX A:
# Project Methods

# A. Study Methods

This section presents a comprehensive description of sample collection, data collection, and data calculation and analysis methodologies used in this study. A brief synopsis of these methodologies may be found in Section 4.

Sample and data collection methodologies for the Arlington-Hamline Facility and the pretreatment units (sumped catch basins) discharging to the underground infiltration trenches varied significantly due to the differences in characteristics of each and will be thoroughly detailed below. Although sampling methods differed, all samples collected were analyzed for the same parameters, using the same methods. Samples were submitted to PACE Analytical Laboratories in Minneapolis, Minnesota for analysis. The parameters analyzed include:

- Bulk Density – Using American Society for Testing and Materials (ASTM) D5057.
- Total Phosphorous – Using Environmental Protection Agency (EPA) 365.4.
- Particle Size Distribution – Using ASTM D422.

Sample collection occurred in June 2011.

## A.1. Arlington-Hamline Facility: Pipe Gallery

The pipe gallery of the Arlington-Hamline Facility consists of three parallel 283-ft corrugated, metal, perforated pipes that are all ten-feet in diameter. The three pipes are denoted:

- Pipe 1. The northern pipe.
- Pipe 2. The center pipe.
- Pipe 3. The southern pipe.

Additionally, two perpendicular 36-ft long header pipes, identical in diameter and type as the three parallel pipes, are connected at both ends (East End and West End) of the pipe gallery (Figure 7). Debris and sediment have the potential to enter into the pipe gallery at two locations on the west end of the pipe gallery; an inlet on the north and an inlet on the south.

As previously stated, during instances of low flows, stormwater runoff is diverted into the pretreatment unit by way of a concrete weir. After pretreatment, the runoff is discharged through the outlet on the southwest end of the pipe gallery. During high flows, stormwater runoff overtopping the diversion weir, does not receive any pretreatment, and flows directly into the pipe gallery through an inlet on the northwest end. Note that during those high flows, a portion of stormwater runoff is still diverted to the pretreatment unit.

General observations drove sample and data collection methods in order to use the most direct and time efficient sampling techniques. Gross solids which accumulate within the pipe gallery vary significantly in width, depth, and extent in each pipe. This is largely due to the entry point and overall gradient of the pipe gallery. Based on observations noted in previous inspections of debris and sediment accumulation in the pipe, it was noted that in general, very minimal to no gross solids were deposited in the western end (West End Pipe) of the facility near the inlets to the pipe gallery. In addition, the majority of gross solids were observed to have generally accumulated within the middle to the eastern end of the pipe gallery. The composition of gross solids also appeared to change on a west-to-east gradient. Material in the western portion of the pipe gallery appeared to have a greater mineral content than that in the eastern portion. Largely, the material accumulating in the eastern portion of the pipe gallery consists of organic matter.

### *A.1.1. Data and Sample Collection Methods*

The pipe gallery of the Arlington-Hamline Facility is considered a confined space. In addition to the equipment and materials used in sample and data collection (listed below), additional equipment was used for entry into a confined space. The equipment and methods used for entry into a confined space were conducted in accordance with the requirements and procedures outlined in CRWD's *Safety Manual* (CRWD, 2008).

The following equipment was utilized to complete sampling and data collection within the pipe gallery of the Arlington-Hamline Facility:

- Buckets
- Gross solids coring device (Figure A-3)
- Measuring tapes
- Metal spoons
- Rotating laser level
- Ruler
- Sample containers
- Stadia Rod with a laser receiver

Survey equipment was used to more accurately measure the width and true elevation of depth of the gross solids deposits, along a longitudinal gradient, in each pipe. Prior to surveying each pipe (Pipe 1, 2, 3, or East End), a benchmark was established which allowed for future replication of the survey. The benchmark selected was the bottom step of a manhole ladder, located at an access point at the southwest end of the pipe gallery (Figure A-1).

Once the benchmark elevation was determined, survey stations were established every ten feet in Pipes 1, 2, and 3 starting at the eastern edge of the West End Pipe and ending at the center of the East End Pipe. The West End Pipe was excluded from the survey due to very minimal to no gross solids present in the pipe. Survey stations in the East End Pipe were also established, in half-foot to one-foot increments, with one station also established at the midpoint between the distance between Pipes 1 and 2 and another station between Pipes 2 and 3. Survey stations in the East End Pipe began at the northern edge of the East End Pipe and ended at the southern edge. A longitudinal profile of each pipe (Pipe 1, 2, 3, or East End) was surveyed and depth and elevation measurements of the gross solids deposit were taken at the center of the pipe, at each survey station.

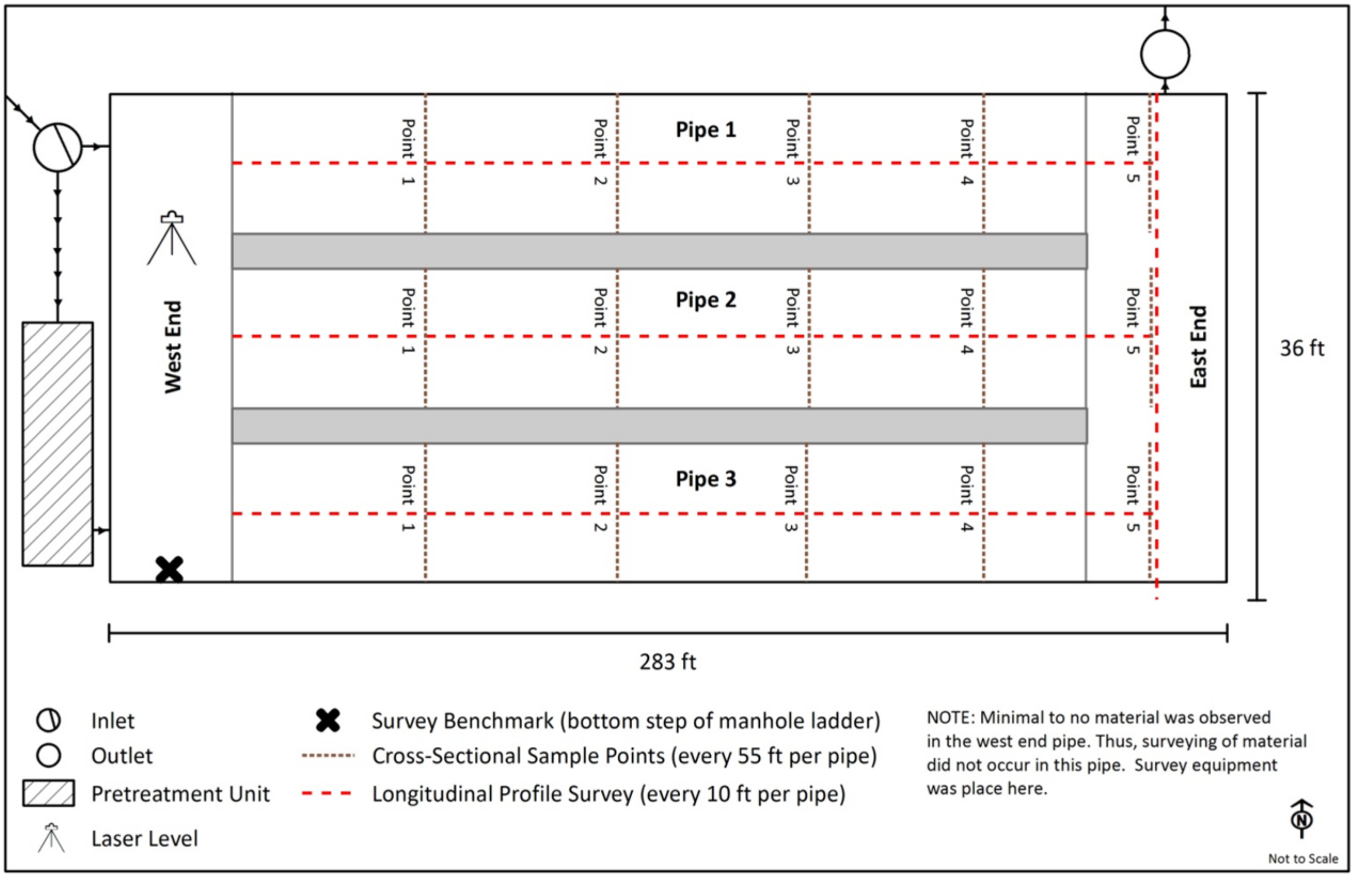


**Figure A-1: A diagram of the Arlington-Hamline Facility pipe gallery, pretreatment unit, and the inlets to the pipe gallery. Longitudinal survey stations and sampling points in each pipe are denoted.**

Fifteen samples were collected from within the pipe gallery at equidistant sampling locations, in each pipe (Pipe 1, 2, and 3). This level of sampling was deemed adequate in order to accurately characterize changes in the gross solids deposits, composition of the debris, and TP concentrations of the gross solids through the pipes. Sampling points were established every 55-feet in each pipe (Pipe 1, 2, and 3), resulting in five sampling points per pipe (Sample Point 1, 2, 3, 4, and 5). At each sample point, the gross solids coring device (Figure A-3) was used to extract individual samples across the entire cross-section of the gross solids deposit; length and if necessary, width wise (Figure A-2).

The gross solids coring device was inserted into the deposit and then capped with the rubber plug. The coring device was removed from the deposit and held over a bucket which was marked with the pipe number and sample point (e.g. Pipe 1 to Point 1). The plug was removed and a wooden dowel was used to push the sample from the device and into the bucket. The samples collected into the bucket for a sample point, were composited together using metal spoons. The sample containers were then filled with the composited material. Figures A-4, A-5, and A-6 portray data and sample collection efforts.

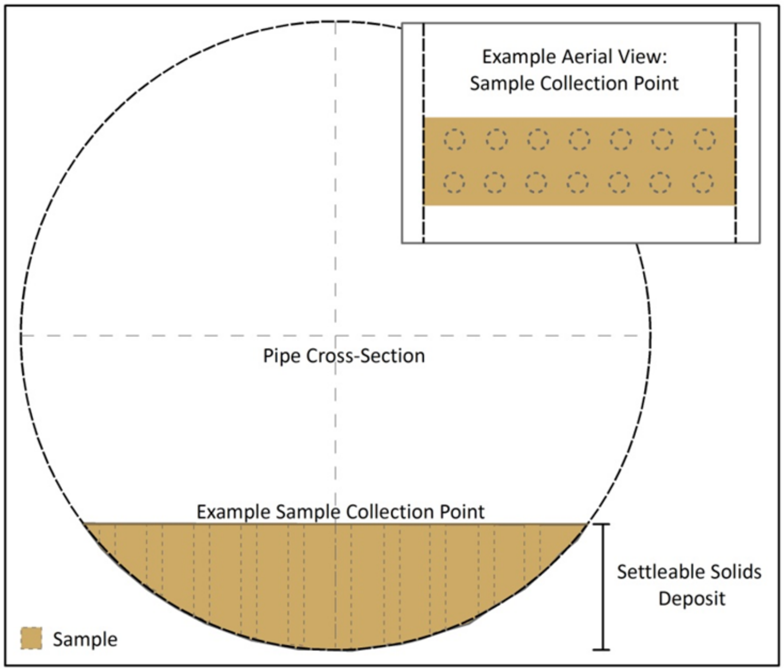


**Figure A-2: Aerial and cross-sectional view of an example sample point.**

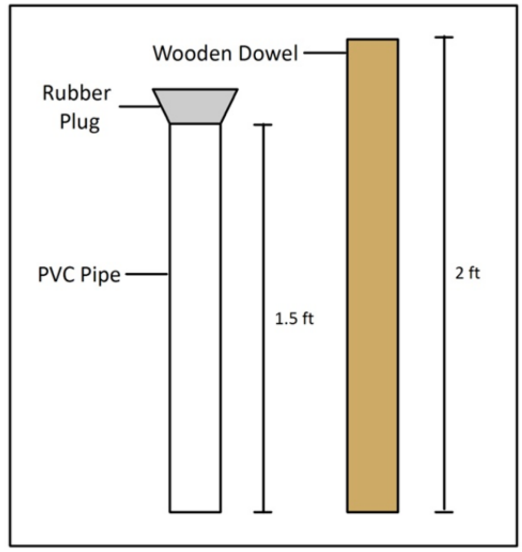


**Figure A-3: Diagram of the gross solids coring device.**

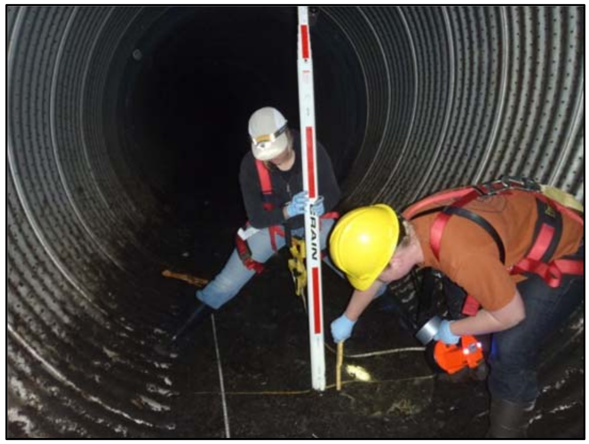

**Figure A-4: Longitudinal survey of pipe 2. Length measurement of the gross solids deposit (LEFT). Measurement of gross solids deposit elevation and depth (RIGHT).**

**Figure A-5: Gross solids sample collection. Extracting sample from the deposit (LEFT). Removal Of the sample from the coring device, into a bucket (RIGHT).**

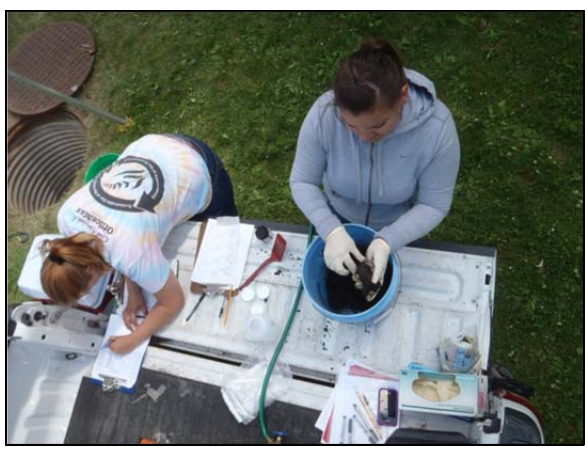

**Figure A-6: Gross solids sample, before compositing, taken from a sampling point within the pipe gallery (LEFT). Sample preparation (RIGHT).**

### *A.1.2. Data Calculations: Gross Solids Load*

Several calculations were necessary to calculate the gross solids load, expressed in pounds (lbs), which accumulated within the pipe gallery. The volume of gross solids which accumulated in the pipe gallery was calculated for each survey station in each pipe (Pipe 1, 2, 3, and East End). The following equation was used to calculate gross solids volume:

Gross Solids Volume per Survey Station (cf) =

$$(L * [R^2 \cos^{-1}((R - h) / R) - (R - h) \sqrt{2Rh - h^2}])$$

Where L=length (10 ft), R=radius (5 ft), h=height of debris (ft)

**(Equation 1)**

Bulk density lab results for the samples collected at the sample points in the pipe gallery and the volumes of gross solids at each survey station were used to calculate the gross solids load for each survey station.

Because there were only five sample points in each pipe (Pipe 1, 2, and 3), the bulk densities from the sample points were applied to the volume of gross solids in the preceding survey stations. For example, the bulk density at Point 1 represented the material in the previous survey stations (those stations between 0 ft and 60 ft), in each respective pipe (Pipe 1, 2, or 3). The bulk density at Point 2 represented 70 ft through 130 ft. The bulk density at Point 3 represented 140 ft through 190 ft and so forth. The bulk densities at Point 5 were used to calculate the gross solids load for the East End Pipe. The following equation was applied to the survey stations to calculate the gross solids load:

Gross Solids Load per Survey Station (lbs) =

((Gross Solids Volume per Survey Station (cf)) * (28.3 L / 1 cf) * (1,000 mL / 1 L) *
(Bulk Density per Survey Station (g/mL)) * (2.2 lbs / 1,000 g))

**(Equation 2)**

The gross solids loads for all survey stations in each pipe, were summed to produce a gross solids load per pipe (Pipe 1, 2, 3, and East End). The gross solids load for the entire pipe gallery was determined by summing the gross solids loads in all pipes (Pipe 1, 2, 3, and the East End).

### *A.1.3. Data Calculations: Total Phosphorous Load in Gross Solids*

The TP load (lbs) in gross solids captured in the pipe gallery was also calculated. TP concentrations of the samples collected were applied to the gross solids load in the preceding survey stations to determine the TP load in gross solids at each survey station in all pipes (Pipe 1, 2, 3, and East End). The following equation was applied to the survey station gross solids load to calculate TP load:

TP Load per Survey Station (lbs) =

((Gross Solids Load per Survey Station (lbs) ) * (TP Concentration per Survey Station (mg/kg)) / (1,000,000 mg/kg)

**(Equation 3)**

The TP loads in gross solids for all survey stations in a specific pipe (Pipe 1, 2, 3, and East End) were summed to produce a TP load per pipe. TP loads, for all survey stations, were then summed to produce a TP load in gross solids captured by the entire pipe gallery.

### *A.1.4. Data Calculations: Annual Gross Solids Loads and Annual Total Phosphorous Loads in Gross Solids*

Gross solids loads and TP loads in gross solids which accumulated within the pipe gallery are representative of four years (2007 to 2010) of accumulation because no discharge has been monitored at the outlet of the pipe gallery and no gross solids have ever been removed. In order for the loading data to be incorporated into BMP performance results, annual loads must be determined.

Annual gross solids loads and annual TP loads in gross solids which accumulated in the pipe gallery were determined by multiplying the gross solids or TP load by the percentage of annual precipitation per year, from the 2007 to 2010 total precipitation amounts (Table A-1). This method was determined to be a representative estimation of annual accumulation based on the assumption that sediment transport and TP loading is proportional to precipitation amounts and associated runoff volumes.

**Table A-1. The annual percentages of precipitation based on the four-year (2007 to 2010) total.**

| Monitoring Year | Annual Precipitation (in) | Total 4-Year Precipitation Amount (%) |
|---|---|---|
| 2007 | 25.0 | 24% |
| 2008 | 21.7 | 21% |
| 2009 | 22.3 | 21% |
| 2010 | 36.3 | 34% |
| **Total:** | **105.3** | **100%** |

## A.2. Arlington-Hamline Facility: Pretreatment Unit

It was not possible to extract samples of the gross solids which had accumulated within the pretreatment unit due several factors. Those include: the proximity of access point (the access point to the pretreatment unit is located over the swirl chamber; sample collection from the chamber between the flow control walls would be more ideal), size of the pretreatment unit (the distance, 15-18 feet, between the access point and the solids deposit was too great to extract a sample with the equipment available), and amount of standing water inside the unit (it was not possible to decant the large volume of water present with the equipment available, as well as, extract samples due to the depth of water and the equipment available). The bulk density and TP concentration sampling results from the Arlington-Hamline Facility pipe gallery were utilized to calculate the annual load of gross solids removed by the pretreatment unit.

### *A.2.1. Data Calculations: Gross Solids Load*

The Arlington-Hamline Facility pretreatment unit accumulates gross solids and is maintained regularly; debris and sediment are removed bi-annually (spring and fall). Prior to debris removal, depth measurements of the accumulated gross solids were taken. The volume of gross solids which accumulated bi-annually in the pretreatment unit was calculated using the record of depth measurements, from 2007 to 2010. The volume of gross solids captured by the pretreatment unit was calculated using the following equation:

Pretreatment Unit Annual Gross Solids Volume (cf) =

(*Length* of Pretreatment Unit (ft)) * (*Width* of Pretreatment Unit (ft)) * (*Depth* of Gross Solids (ft))

**(Equation 4)**

The bi-annual volumes for each year (2007 through 2010) were summed to produce the annual volume of gross solids which was captured by the pretreatment unit.

The average bulk density found for the entire pipe gallery (1.43 g/mL), along with the annual volumes of gross solids captured by the pretreatment unit were used to calculate the annual gross solids loads captured by the pretreatment unit from 2007 through 2010. The following equation was used to calculate the annual gross solids load:

Pretreatment Unit Annual Gross Solids Load (lbs) =

(Gross Solids Volume (cf)) * (28.3 L / 1 cf) * (1,000 mL / 1 L) *
(Average Bulk Density (g/mL) from Arlington-Hamline Facility Pipe Gallery) * (2.2 lbs / 1,000 g)

**(Equation 5)**

### *A.2.2. Data Calculations: Total Phosphorous Load in Gross Solids*

The annual TP loads in gross solids loads captured by the pretreatment unit, from 2007 to 2010, were calculated using the annual gross solids loads captured by the pretreatment unit and TP concentrations from the Arlington-Hamline Facility pipe gallery. Specifically, the TP concentrations from samples taken at sample Point 1 in all three pipes (Pipe 1, 2, and 3) were averaged to determine an average TP concentration (568 mg/kg). This average TP concentration was assumed to be representative of the material in the pretreatment unit because the sample points reside closest to the outlet of the pretreatment unit. Additionally, the composition of the material at these three sample locations generally consisted of larger, coarser particles (e.g. sands, gravels) which are generally captured by the pretreatment unit. The following equation was used to determine annual TP loads:

Pretreatment Unit Annual TP Load (lbs) =

((Pretreatment Unit Annual Gross Solids Load (lbs))*
(Average TP (mg/kg) from Arlington-Hamline Facility Pipe Gallery Sampling Points 1) / (1,000,000 mg/kg)

**(Equation 6)**

The same values for average bulk density and TP concentration were used to calculate annual gross solids and TP loads for all years, from 2007 to 2010. This was done in order to determine annual loadings using the data that was available. It is recognized that gross solids load accumulations and composition of material varies from year-to-year. These annual loadings will most likely be refined as additional future sampling is conducted.

## A.3. Arlington-Hamline Facility

### *A.3.1. Annual Gross Solids and TP Loads*

Annual gross solids and TP loads calculated for both components of the Arlington-Hamline Facility (pipe gallery and pretreatment unit), from 2007 through 2010, were summed to produce annual gross solids and TP loads captured by the entire Arlington-Hamline Facility.

## A.4. Infiltration Trenches

Thirty sumped catch basins and sixteen sumped manholes pretreat stormwater runoff before flowing into the eight infiltration trenches beneath Arlington and Nebraska Avenues. Each catch basin and manhole has an ID unique to each structure. Figure 6, in the main body of the report, illustrates each unit and ID. The accumulated material is removed from all units twice a year (spring and fall). Prior to removal, inspections of the pretreatment units were performed. Inspections included depth measurements of the debris and sediment which was captured by each catch basin.

For this study, only the sumped catch basins were sampled; sumped manholes were not sampled. It was observed in previous inspections, that in general, the overall depth of debris and sediment which had accumulated within the catch basins was greater than that which had accumulated in the manholes; making sample collection less difficult. The overall sumped area of the catch basins was also smaller than that of the sumped manholes, also making sample collection less difficult.

Several challenges were met while developing the sampling protocol. After additional research on sediment sampling equipment and in review of performance of the sampling equipment used in the *Sump Monitoring Study* (CRWD, 2011), traditional sediment sampling equipment (i.e. core samplers, sludge samplers, augers, ponar dredges, etc.) were not used to collect samples in this study due to the saturation, composition, and lack of compaction of the material in the catch basins. The material was too saturated and not compacted enough to remain intact; all or portions of the sample would be lost out of the bottom of the augers/samplers.

A method for extracting a representative sample of all material in the catch basin also had to be developed. It was observed that stratification and extent of material in the catch basins varied; there were slight variations in depth of material within a catch basin and varying layers of sand, silt, and organic matter were stratified without uniformity. Thus, sample collection needed to capture the entire column of material in the catch basin. The ponar dredge would only collect a sample from the top portion of the material and not from the entire column of debris.

In addition to the accumulation of gross solids, large volumes of stagnant stormwater remained in the sumped portion of each catch basin. A method had to be developed to decant the standing stormwater from the sump of the catch basin without disturbing the material. Decanting the stormwater was necessary for sample collection.

### *A.4.1. Sample Collection Methods: Sumped Catch Basins*

A variety of equipment was used to decant water and collect samples from the catch basins (see below).

<u>Equipment Used to Decant Water:</u>

- Buckets
- Generators
- Sump screen (Figure A-7)
- Wet/dry vacuums with pump

<u>Equipment Used for Sample Collection:</u>

- Buckets
- Dip net bags with one-mm screen
- Generator
- Mesh pool skimmers
- Metal rod
- Metal spoons
- Ruler (in increments of tenths of feet)
- Sample containers
- Ten-inch diameter, three-foot tall, metal stove pipe
- Water tank, fitted with a gate valve and garden hose (filled with tap water)
- Wet/dry vacuum with pump (filters removed)

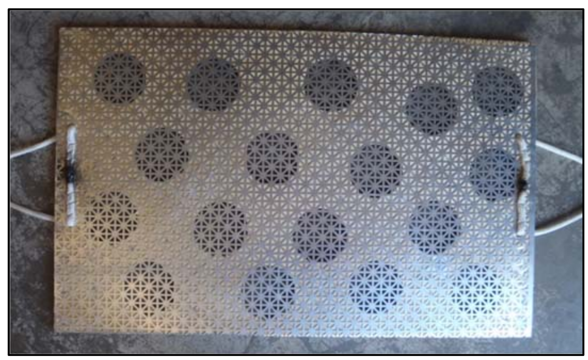

**Figure A-7: Fabricated sump screen; a 2 foot by 3 foot perforated, plywood board covered by a metal screen.**

The catch basins sampled were all located on the curb line of Arlington and Nebraska Avenues. Before any sampling took place, safety equipment and procedures for working in roadways were implemented in accordance with the *CRWD Safety Manual* (CRWD, 2008).

To begin sampling at a catch basin, the catch basin inlet grate and hood were first removed using manhole hooks. Next, the standing stormwater was decanted. Since the gross solids material was completely saturated with the water, separation of the water and material was necessary. The sump screen was placed into the catch basin and pushed underwater, with a small amount of pressure, and held in place at the top of the gross solids deposit using the metal rod. This screen allowed for the water in the catch basin to be decanted without disturbing or re-suspending the material in the catch basin.

The water was then decanted out of the catch basin using two wet/dry vacuums, each of which was powered by a generator. Each vacuum was equipped with a pump which allowed for the water to be pumped from the catch basin and into buckets which were emptied into a sumped manhole that drained to an infiltration trench. This enabled the vacuums to run continuously until all water was decanted from the catch basin. A hose was attached to each vacuum and discharged the pumped water into buckets that were emptied into a sumped manhole which drained to an infiltration trench.

Once the water was decanted from the catch basin, the sump screen and metal rod were removed. A pipe, placed in the center of the catch basin, was used to 'cut out' a cylinder of gross solids to be sampled. It was assumed to contain a representative sample of gross solids because it included material from the entire debris column; from the bottom of the catch basin to the top of the deposit. A third wet/dry vacuum, used only for sample removal purposes, was used to extract all sample material from inside of the pipe. The filters inside the vacuum were removed (so as not to block material) and the pump feature of the vacuum was disabled. Following removal, clean water was used to rinse the vacuum hose and vacuum to ensure that any debris particles trapped in the hose corrugation or vacuum top were included in the sample material.

The debris and water in the vacuum was then strained using a two-step process to remove excess water from the sample material. The contents of the vacuum were poured through a standard pool skimmer net, to capture the larger material, and again through a dip net bag to remove the finer material (clays, silts, and sands). The strained material (captured by the pool skimmer and the dip net) were combined and mixed to create a representative sample. Samples were extracted from this material and put into sample containers.

Excess material was placed back into the catch basin. The vacuum, pool skimmers, dip net bags, buckets, and metal spoons were all rinsed with water from the water tank. The catch basin hood and inlet grate were replaced using the manhole hooks.

Figures A-8 through A-10 illustrate sample collection efforts.

**Figure A-8: Placement of the sump screen in to the catch basin (LEFT). Submerging the sump screen (CENTER). Decanting water from a catch basin (RIGHT).**

**Figure A-9: Placement of the stove pipe in a catch basin (LEFT). Sample material collected from a catch basin being strained through the first screen (CENTER) and through the second screen (RIGHT).**

**Figure A-10: Mixing of the sample material (LEFT). Placement of the samples material in to the sample container (RIGHT).**

### A.4.2. Data Calculations: Gross Solids Load Captured by Catch Basins and Manholes

Gross solids depth measurements taken during the bi-annual inspections (inspections prior to debris removal), from 2007 to 2010, were used to calculate the bi-annual volume of gross solids which accumulated within each sumped catch basin and manhole. The two volume calculations, for each unit for each year from 2007 to 2010, were summed to produce the annual volume of gross solids captured by each pretreatment unit. The following equation was used to calculate volume of gross solids captured by catch basins:

Catch Basin Gross Solids Volume (cf) =

(*Length* (ft)) * (*Width* (ft)) * (*Depth* of Gross Solids (ft))

**(Equation 7)**

The following equation was used to calculate the volume of gross solids captured by manholes:

Manhole Gross Solids Volume (cf) =

(π) * (manhole radius (ft))² * (*Depth* of Gross Solids (ft))

**(Equation 8)**

The average bulk density (1.28 g/mL or 79.91 lbs/ $ft^3$) of all samples collected from the catch basins and the annual volumes of gross solids captured by each pretreatment unit were used to determine the annual load of gross solids captured by each unit, from 2007 to 2010. Annual gross solids loads were calculated using the following equation:

Annual Gross Solids Load (per Catch Basin or Manhole) (lbs) =

(Gross Solids Volume (cf) * Average Bulk Density (lb/cf))

**(Equation 9)**

The annual gross solids loads captured by pretreatment units (catch basins and manholes) draining to a particular infiltration trench (Trench 1 through 8), were summed to determine the annual gross solids load removed by each infiltration trench. The annual gross solids loads captured by all pretreatment units (catch basins and manholes), from 2007 to 2010, were all summed to produce annual gross solids loads captured by all infiltration trenches.

### A.4.3. Data Calculations: Total Phosphorous Loads in Gross Solids captured by Catch Basins and Manholes

Annual TP loads in gross solids captured by each pretreatment unit (catch basin and manhole), from 2007 to 2010, were determined by using the annual gross solids loads captured by each unit and an average TP concentration (402 mg/kg) of samples collected from all catch basins. (Note: The TP concentration of the sample collected from catch basin 690 was excluded from the average TP concentration calculation of all catch basins due to being an extreme outlier.). The following equation was used to calculate the TP loads in gross solids captured by the catch basins and manholes:

$$\text{TP Load (per Catch Basin or Manhole) (lbs)} =$$

$$\text{((Gross Solids Load per unit (lbs))* (Average TP Concentration (mg/kg)) / (1,000,000 mg/kg)}$$

**(Equation 10)**

Annual TP loads in gross solids captured by pretreatment units draining to a particular infiltration trench (Trench 1 through 8) were summed to produce annual TP loads in gross solids captured by each infiltration trench from 2007 to 2010. Additionally, annual TP loads in gross solids captured by all units were summed to determine annual TP loads in gross solids captured by all infiltration trenches from 2007 to 2010.

## A.5. Como Park Regional Pond and Rain Gardens

The annual gross solids loads and annual TP loads in gross solids cumulatively removed by all sumped catch basins and manholes connected to the infiltration trenches were used to extrapolate annual gross solids loads and associated TP loads accumulating within the Como Park Regional Pond and all eight rain gardens.

The drainage areas to the pond and the rain gardens have fairly similar land uses and impervious surfaces coverage characteristics as the drainage area to the infiltration trenches. Due to the similarities in characteristics, it was assumed that the drainage areas of the rain gardens and the pond would yield similar pollutant loads as those to the infiltration trenches.

### *A.5.1. Data Calculations: Gross Solids Loads*

The annual gross solids yield for the infiltration trenches was calculated by dividing the annual gross solids loads captured by all pretreatment units (all sumped catch basins and manholes), from 2007 to 2010, by the portion of the total drainage area to all infiltration trenches covered by impervious surfaces (Table A-2). Annual gross solids loads captured by the Como Park Regional Pond and by each rain garden were calculated by multiplying the annual gross solids yield for the infiltration trenches by the portion of drainage area to each BMP (pond and each rain garden) covered by impervious surfaces. Table A-3 lists the total drainage area and percentage covered by impervious surfaces for each BMP.

**Table A-2: The gross solids loading yield for the infiltration trenches from 2007 to 2010.**

| Year | Acres Impervious | Gross Solids Load (lbs) | Gross Solids Yield (lbs/ac) |
|---|---|---|---|
| 2007 | 8.93 | 14,536 | 1,628 |
| 2008 | 8.93 | 26,080 | 2,920 |
| 2009 | 8.93 | 32,200 | 3,606 |
| 2010 | 8.93 | 19,448 | 2,178 |

**Table A-3: Como Park Regional Pond and individual rain garden drainage areas and impervious surfaces coverage.**

| BMP | Drainage Area (acres) | Impervious Surfaces (acres) | % Impervious Surfaces |
|---|---|---|---|
| Como Park Regional Pond | 128.00 | 49.92 | 39% |
| Arlington-McKinley Rain Garden | 0.37 | 0.15 | 41% |
| Asbury North Rain Garden | 0.40 | 0.17 | 43% |
| Asbury South Rain Garden | 1.08 | 0.33 | 31% |
| Frankson-McKinley Rain Garden | 2.81 | 0.94 | 33% |
| Hamline Midway Rain Garden | 10.47 | 1.86 | 18% |
| Pascal Center Rain Garden | 0.13 | 0.06 | 46% |
| Pascal North Rain Garden | 0.46 | 0.13 | 28% |
| Pascal South Rain Garden | 0.36 | 0.09 | 24% |

### *A.5.2. Data Calculations: Total Phosphorous Loads in Gross Solids*

Annual TP loads in gross solids which accumulated in the Como Park Regional Pond and each rain garden, from 2007 to 2010, were extrapolated by multiplying the annual TP yield for the infiltration trenches by the portion of drainage area (for the pond and each rain garden) covered by impervious surfaces. Table A-4 lists the annual infiltration trench TP yields.

**Table A-4: The TP loading yield for the infiltration trenches drainage area covered by impervious surfaces.**

| Year | Acres Impervious | Total Phosphorous Load (lbs) | Total Phosphorous Yield (lbs/ac) |
|---|---|---|---|
| 2007 | 8.93 | 5.84 | 0.65 |
| 2008 | 8.93 | 10.48 | 1.17 |
| 2009 | 8.93 | 12.94 | 1.45 |
| 2010 | 8.93 | 7.82 | 0.88 |

# APPENDIX B:
# Arlington-Hamline Facility Data

Appendix B-1: Arlington-Hamline Facility pipe gallery survey station data.

| Survey Station Id[a] | Pipe 1 | | | | Pipe 2 | | | | Pipe 3 | | | | East End Pipe | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Elevation | | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Elevation | | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Elevation | | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Elevation | | Gross Solids Depth (ft) | Gross Solids Volume (cf) |
| | Deposit Top (ft) | Pipe Bottom (ft) | | | Deposit Top (ft) | Pipe Bottom (ft) | | | Deposit Top (ft) | Pipe Bottom (ft) | | | Deposit Top (ft) | Pipe Bottom (ft) | | |
| 1 | 98.17 | 98.17 | 0.00 | 0.00 | 98.29 | 98.30 | 0.01 | 0.04 | 98.14 | 98.14 | 0.00 | 0.00 | 97.77 | 97.72 | 0.05 | 0.02 |
| 2 | 98.17 | 98.34 | 0.17 | 2.94 | 98.34 | 98.41 | 0.07 | 0.78 | 98.27 | 98.30 | 0.03 | 0.22 | 97.75 | 97.57 | 0.18 | 0.32 |
| 3 | 98.44 | 98.64 | 0.20 | 3.75 | 98.36 | 98.41 | 0.05 | 0.47 | 98.23 | 98.31 | 0.08 | 0.95 | 97.70 | 97.37 | 0.33 | 0.79 |
| 4 | 98.44 | 98.59 | 0.15 | 2.44 | 98.33 | 98.35 | 0.02 | 0.12 | 98.22 | 98.24 | 0.02 | 0.12 | 97.79 | 97.30 | 0.49 | 1.42 |
| 5 | 98.45 | 98.62 | 0.17 | 2.94 | 98.32 | 98.34 | 0.02 | 0.12 | 98.26 | 98.27 | 0.01 | 0.04 | 97.77 | 97.29 | 0.48 | 1.38 |
| 6 | 98.30 | 98.38 | 0.08 | 0.48 | 98.28 | 98.28 | 0.00 | 0.00 | 98.22 | 98.25 | 0.03 | 0.11 | 97.80 | 97.50 | 0.30 | 0.55 |
| 7 | 98.38 | 98.56 | 0.18 | 1.60 | 98.26 | 98.33 | 0.07 | 0.39 | 98.24 | 98.24 | 0.00 | 0.00 | 97.80 | 97.30 | 0.50 | 6.24 |
| 8 | 98.42 | 98.56 | 0.14 | 2.20 | 98.28 | 98.42 | 0.14 | 2.20 | 98.19 | 98.19 | 0.00 | 0.00 | 97.73 | 97.50 | 0.23 | 1.96 |
| 9 | 98.19 | 98.26 | 0.07 | 0.78 | 98.17 | 98.37 | 0.20 | 3.75 | 98.11 | 98.13 | 0.02 | 0.12 | 97.70 | 97.52 | 0.18 | 0.64 |
| 10 | 98.07 | 98.11 | 0.04 | 0.34 | 98.20 | 98.39 | 0.19 | 3.47 | 98.06 | 98.07 | 0.01 | 0.04 | 97.76 | 97.61 | 0.15 | 0.73 |
| 11 | 98.08 | 98.31 | 0.23 | 4.62 | 98.16 | 98.22 | 0.06 | 0.62 | 98.01 | 98.03 | 0.02 | 0.12 | 97.83 | 97.60 | 0.23 | 2.17 |
| 12 | 98.06 | 98.30 | 0.24 | 4.92 | 98.14 | 98.46 | 0.32 | 7.56 | 97.82 | 97.83 | 0.01 | 0.04 | 97.76 | 97.26 | 0.50 | 6.24 |
| 13 | 97.98 | 98.15 | 0.17 | 2.94 | 98.06 | 98.49 | 0.43 | 11.73 | 97.86 | 97.98 | 0.12 | 1.75 | 97.60 | 97.47 | 0.13 | 0.84 |
| 14 | 98.00 | 98.24 | 0.24 | 4.92 | 98.07 | 98.62 | 0.55 | 16.91 | 97.88 | 98.02 | 0.14 | 2.20 | 97.72 | 97.57 | 0.15 | 0.12 |
| 15 | 97.96 | 98.12 | 0.16 | 2.69 | 97.96 | 98.38 | 0.42 | 11.33 | 97.94 | 98.16 | 0.22 | 4.32 | 97.78 | 97.55 | 0.23 | 0.83 |
| 16 | 98.00 | 98.20 | 0.20 | 3.75 | 98.09 | 98.37 | 0.28 | 6.19 | 97.92 | 98.14 | 0.22 | 4.32 | 97.83 | 97.53 | 0.30 | 1.85 |
| 17 | 97.98 | 98.09 | 0.11 | 1.53 | 98.07 | 98.15 | 0.08 | 0.95 | 97.85 | 98.03 | 0.18 | 3.20 | 97.69 | 97.57 | 0.12 | 0.56 |
| 18 | 97.93 | 98.14 | 0.21 | 2.02 | 98.10 | 98.24 | 0.14 | 1.10 | 97.90 | 98.25 | 0.35 | 4.32 | | | | |
| 19 | 97.95 | 98.15 | 0.20 | 1.87 | 98.08 | 98.31 | 0.23 | 2.31 | 97.89 | 98.17 | 0.28 | 3.10 | | | | |
| 20 | 97.92 | 98.06 | 0.14 | 2.20 | 98.03 | 98.16 | 0.13 | 1.97 | 97.91 | 98.26 | 0.35 | 8.64 | | | | |
| 21 | 97.99 | 98.38 | 0.39 | 10.15 | 97.99 | 98.21 | 0.22 | 4.32 | 97.84 | 98.01 | 0.17 | 2.94 | | | | |
| 22 | 97.94 | 98.17 | 0.23 | 4.62 | 97.97 | 98.25 | 0.28 | 6.19 | 97.80 | 97.93 | 0.13 | 1.97 | | | | |
| 23 | 97.92 | 98.22 | 0.30 | 6.87 | 97.95 | 98.37 | 0.42 | 11.33 | 97.86 | 98.08 | 0.22 | 4.32 | | | | |
| 24 | 97.92 | 98.14 | 0.22 | 4.32 | 97.96 | 98.19 | 0.23 | 4.62 | 97.91 | 98.23 | 0.32 | 7.56 | | | | |
| 25 | 97.88 | 98.24 | 0.36 | 9.01 | 97.94 | 98.26 | 0.32 | 7.56 | 97.80 | 97.93 | 0.13 | 1.97 | | | | |
| 26 | 97.97 | 98.39 | 0.42 | 11.33 | 97.91 | 98.12 | 0.21 | 4.03 | 97.85 | 98.27 | 0.42 | 11.33 | | | | |
| 27 | 97.94 | 98.22 | 0.28 | 6.19 | 97.91 | 98.33 | 0.42 | 11.33 | 97.88 | 98.16 | 0.28 | 6.19 | | | | |
| 28 | 97.90 | 98.19 | 0.29 | 6.53 | 97.95 | 98.38 | 0.43 | 11.73 | 97.82 | 98.22 | 0.40 | 10.54 | | | | |
| 29 | 97.89 | 98.26 | 0.37 | 9.38 | 97.95 | 98.47 | 0.52 | 15.56 | 97.85 | 98.15 | 0.30 | 6.87 | | | | |
| 30 | 97.97 | 98.52 | 0.55 | 8.46 | 97.85 | 98.07 | 0.22 | 2.16 | 97.74 | 97.96 | 0.22 | 2.16 | | | | |
| | | | TOTAL: | 125.77 | | | TOTAL: | 150.86 | | | TOTAL: | 89.46 | | | TOTAL: | 26.68 |

[a] Survey stations were established every ten feet in Pipes 1, 2, and 3. Survey stations in the East End Pipe were established approximately every 0.5-1 foot, with one measurement taken at the midpoint of each of the cavities between Pipes 1 and 2 and Pipes 2 and 3.

**Appendix B-2: Arlington-Hamline Facility pipe gallery survey station gross solids and TP loads. Gross solids and TP loads were derived using gross solids volumes and bulk density and TP concentrations analyzed from samples collected at fifteen sampling points within the pipe gallery.**

| | Pipe 1 | | | | | Pipe 2 | | | | | Pipe 3 | | | | | East End Pipe | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Survey Station Id[a] | Gross Solids Volume (cf) | Bulk Density (g/mL) | Gross Solids Load (lbs) | TP Concentration (mg/kg) | TP Load (lbs) | Gross Solids Volume (cf) | Bulk Density (g/mL) | Gross Solids Load (lbs) | TP Concentration (mg/kg) | TP Load (lbs) | Gross Solids Volume (cf) | Bulk Density (g/mL) | Gross Solids Load (lbs) | TP Concentration (mg/kg) | TP Load (lbs) | Gross Solids Volume (cf) | Bulk Density (g/mL) | Gross Solids Load (lbs) | TP Concentration (mg/kg) | TP Load (lbs) |
| 1 | 0.00 | 1.90 | 0 | 270 | 0.00 | 0.04 | 1.38 | 4 | 1,010 | 0.88 | 0.00 | 2.18 | 0 | 425 | 1.38 | 0.02 | 1.34 | 2 | 1,250 | 0.68 |
| 2 | 2.94 | 1.90 | 348 | 270 | 0.09 | 0.78 | 1.38 | 67 | 1,010 | 0.00 | 0.22 | 2.18 | 30 | 425 | 1.43 | 0.32 | 1.34 | 27 | 1,250 | 1.15 |
| 3 | 3.75 | 1.90 | 443 | 270 | 0.12 | 0.47 | 1.38 | 40 | 1,010 | 0.00 | 0.95 | 2.18 | 129 | 425 | 1.77 | 0.79 | 1.34 | 66 | 1,250 | 0.63 |
| 4 | 2.44 | 1.90 | 288 | 270 | 0.08 | 0.12 | 1.38 | 10 | 1,010 | 0.00 | 0.12 | 2.18 | 16 | 425 | 0.25 | 1.42 | 1.34 | 119 | 1,250 | 0.20 |
| 5 | 2.94 | 1.90 | 348 | 270 | 0.09 | 0.12 | 1.38 | 10 | 1,010 | 0.07 | 0.04 | 2.18 | 6 | 425 | 0.00 | 1.38 | 1.34 | 115 | 1,250 | 0.00 |
| 6 | 0.48 | 1.90 | 56 | 270 | 0.02 | 0.00 | 1.38 | 0 | 1,010 | 0.04 | 0.11 | 2.18 | 15 | 425 | 0.00 | 0.55 | 1.34 | 46 | 1,250 | 0.00 |
| 7 | 1.60 | 1.90 | 189 | 270 | 0.05 | 0.39 | 1.38 | 33 | 1,010 | 0.01 | 0.00 | 2.18 | 0 | 425 | 0.00 | 6.24 | 1.34 | 521 | 1,250 | 0.00 |
| 8 | 2.20 | 1.90 | 260 | 270 | 0.07 | 2.20 | 1.38 | 189 | 1,010 | 0.01 | 0.00 | 2.18 | 0 | 425 | 0.01 | 1.96 | 1.27 | 155 | 1,440 | 0.03 |
| 9 | 0.78 | 1.62 | 79 | 679 | 0.05 | 3.75 | 1.23 | 287 | 1,510 | 0.00 | 0.12 | 1.50 | 11 | 653 | 0.05 | 0.64 | 1.27 | 51 | 1,440 | 0.08 |
| 10 | 0.34 | 1.62 | 34 | 679 | 0.02 | 3.47 | 1.23 | 266 | 1,510 | 0.03 | 0.04 | 1.50 | 4 | 653 | 0.01 | 0.73 | 1.27 | 58 | 1,440 | 0.15 |
| 11 | 4.62 | 1.62 | 466 | 679 | 0.32 | 0.62 | 1.23 | 47 | 1,510 | 0.19 | 0.12 | 1.50 | 11 | 653 | 0.00 | 2.17 | 1.27 | 172 | 1,440 | 0.14 |
| 12 | 4.92 | 1.62 | 496 | 679 | 0.34 | 7.56 | 1.23 | 579 | 1,510 | 0.43 | 0.04 | 1.50 | 4 | 653 | 0.01 | 6.24 | 1.27 | 493 | 1,440 | 0.06 |
| 13 | 2.94 | 1.62 | 297 | 679 | 0.20 | 11.73 | 1.23 | 899 | 1,510 | 0.40 | 1.75 | 1.50 | 163 | 653 | 0.00 | 0.84 | 1.25 | 65 | 1,180 | 0.65 |
| 14 | 4.92 | 1.62 | 496 | 679 | 0.34 | 16.91 | 1.23 | 1,295 | 1,510 | 0.07 | 2.20 | 1.50 | 205 | 653 | 0.00 | 0.12 | 1.25 | 9 | 1,180 | 0.22 |
| 15 | 2.69 | 1.62 | 271 | 679 | 0.18 | 11.33 | 1.23 | 868 | 1,510 | 0.87 | 4.32 | 1.50 | 404 | 653 | 0.01 | 0.83 | 1.25 | 65 | 1,180 | 0.07 |
| 16 | 3.75 | 1.28 | 299 | 1,240 | 0.37 | 6.19 | 1.27 | 490 | 1,520 | 1.36 | 4.32 | 1.32 | 355 | 1,320 | 0.00 | 1.85 | 1.25 | 144 | 1,180 | 0.08 |
| 17 | 1.53 | 1.28 | 122 | 1,240 | 0.15 | 0.95 | 1.27 | 75 | 1,520 | 1.96 | 3.20 | 1.32 | 263 | 1,320 | 0.01 | 0.56 | 1.25 | 43 | 1,180 | 0.25 |
| 18 | 2.02 | 1.28 | 161 | 1,240 | 0.20 | 1.10 | 1.27 | 87 | 1,520 | 1.31 | 4.32 | 1.32 | 355 | 1,320 | 0.00 | | | | | |
| 19 | 1.87 | 1.28 | 149 | 1,240 | 0.19 | 2.31 | 1.27 | 183 | 1,520 | 0.74 | 3.10 | 1.32 | 255 | 1,320 | 0.11 | | | | | |
| 20 | 2.20 | 1.28 | 175 | 1,240 | 0.22 | 1.97 | 1.27 | 156 | 1,520 | 0.11 | 8.64 | 1.32 | 710 | 1,320 | 0.13 | | | | | |
| 21 | 10.15 | 1.28 | 809 | 1,240 | 1.00 | 4.32 | 1.27 | 342 | 1,520 | 0.13 | 2.94 | 1.32 | 242 | 1,320 | 0.26 | | | | | |
| 22 | 4.62 | 1.28 | 368 | 1,240 | 0.46 | 6.19 | 1.27 | 490 | 1,520 | 0.28 | 1.97 | 1.32 | 162 | 1,320 | 0.47 | | | | | |
| 23 | 6.87 | 1.27 | 543 | 1,400 | 0.76 | 11.33 | 1.30 | 917 | 1,510 | 0.24 | 4.32 | 1.34 | 361 | 1,310 | 0.35 | | | | | |
| 24 | 4.32 | 1.27 | 342 | 1,400 | 0.48 | 4.62 | 1.30 | 374 | 1,510 | 0.52 | 7.56 | 1.34 | 631 | 1,310 | 0.47 | | | | | |
| 25 | 9.01 | 1.27 | 712 | 1,400 | 1.00 | 7.56 | 1.30 | 612 | 1,510 | 0.74 | 1.97 | 1.34 | 164 | 1,310 | 0.34 | | | | | |
| 26 | 11.33 | 1.27 | 896 | 1,400 | 1.25 | 4.03 | 1.30 | 326 | 1,510 | 1.38 | 11.33 | 1.34 | 945 | 1,310 | 0.94 | | | | | |
| 27 | 6.19 | 1.27 | 490 | 1,400 | 0.69 | 11.33 | 1.30 | 917 | 1,510 | 0.56 | 6.19 | 1.34 | 517 | 1,310 | 0.32 | | | | | |
| 28 | 6.53 | 1.27 | 516 | 1,400 | 0.72 | 11.73 | 1.30 | 950 | 1,510 | 0.92 | 10.54 | 1.34 | 879 | 1,310 | 0.21 | | | | | |
| 29 | 9.38 | 1.34 | 783 | 1,250 | 0.98 | 15.56 | 1.27 | 1,230 | 1,440 | 0.49 | 6.87 | 1.25 | 534 | 1,180 | 0.47 | | | | | |
| 30 | 8.46 | 1.34 | 705 | 1,250 | 0.88 | 2.16 | 1.27 | 171 | 1,440 | 1.38 | 2.16 | 1.25 | 168 | 1,180 | 0.83 | | | | | |
| **TOTALS:** | **125.77** | | **11,142** | | **11.32** | **150.86** | | **11,914** | | **15.16** | **89.46** | | **7,538** | | **9.83** | **26.68** | | **2,151** | | **4.40** |

**Appendix B-3: Arlington-Hamline Facility pipe gallery particle size analysis lab results.**

| | | | | Composition | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date Collected | Pipe | Sample Point | Moisture (%) | Clay/Silt (%) | Fine Sand (%) | Medium Sand (%) | Coarse Sand (%) | Gravel (%) | TOTAL | Soil Classification[a] |
| 6/9/2011 | 1 | 1 | 11.5 | 3.0 | 31.4 | 57.9 | 5.9 | 1.8 | 100 | (SP) Poorly Graded Sand |
| 6/9/2011 | 1 | 2 | 48.6 | 12.2 | 50.9 | 31.3 | 4.4 | 1.2 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 1 | 3 | 144.9 | 21.9 | 24.3 | 32.3 | 17.9 | 3.6 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 1 | 4 | 154.2 | 17.4 | 22.6 | 34.8 | 21.3 | 3.9 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 1 | 5 | 141.6 | 27.9 | 26.7 | 28.9 | 5.8 | 10.7 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 2 | 1 | 80.4 | 35.2 | 15.3 | 29.6 | 15.6 | 4.3 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 2 | 2 | 64.4 | 52.1 | 10.4 | 18.8 | 16.0 | 2.7 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 2 | 3 | 59.9 | 34.9 | 14.4 | 27.1 | 19.0 | 4.6 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 2 | 4 | 104.2 | 35.7 | 13.9 | 23.3 | 21.4 | 5.7 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 2 | 5 | 51.7 | 46.6 | 18.0 | 22.4 | 10.9 | 2.1 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 3 | 1 | 15.7 | 7.1 | 22.4 | 31.3 | 28.6 | 10.6 | 100 | (SW-SM/SW-SC) Well Graded Sand with Silt to Well Graded Sand with Clay |
| 6/9/2011 | 3 | 2 | 36.9 | 24.4 | 61.0 | 10.6 | 2.4 | 1.6 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 3 | 3 | 137.5 | 27.1 | 20.5 | 21.7 | 23.6 | 7.1 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 3 | 4 | 42.7 | 57.4 | 16.8 | 16.6 | 7.8 | 1.4 | 100 | (OL/OH) Sandy Organic Soil |
| 6/9/2011 | 3 | 5 | 123.7 | 51.6 | 14.6 | 16.8 | 13.3 | 3.7 | 100 | (OL/OH) Sandy Organic Soil |

[a] Unified Soils Classification System (USCS) was used. See classification letters below.

| First/Second Letter | Second Letter |
|---|---|
| O: Organic | L: Low Plasticity |
| S: Sand | H: High Plasticity |
| W: Well Graded | |
| M: Silt | |
| C: Clay | |

**Appendix B-4: Arlington-Hamline Facility pretreatment unit gross solids depths taken during bi-annual inspections from 2007 to 2010. Corresponding gross solids volumes and gross solids and TP loads are also listed.**

| Year | Season | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Bulk Density (g/mL) | Gross Solids Load (lbs) | TP Concentration (mg/kg) | TP Load (lbs) |
|---|---|---|---|---|---|---|---|
| 2007 | Spring | 0.60 | 48.00 | 1.43 | 4,274 | 568 | 2.43 |
| 2007 | Fall | 1.77 | 141.60 | 1.43 | 12,607 | 568 | 7.16 |
| 2008 | Spring | 1.64 | 131.20 | 1.43 | 11,681 | 568 | 6.63 |
| 2008 | Fall | 1.29 | 103.20 | 1.43 | 9,188 | 568 | 5.22 |
| 2009 | Spring | 1.85 | 148.00 | 1.43 | 13,177 | 568 | 7.48 |
| 2009 | Fall | 1.53 | 122.40 | 1.43 | 10,897 | 568 | 6.19 |
| 2010 | Spring | 0.62 | 49.60 | 1.43 | 4,416 | 568 | 2.51 |
| 2010 | Fall | 0.48 | 38.40 | 1.43 | 3,419 | 568 | 1.94 |

# APPENDIX C:
# Infiltration Trench Data

**Appendix C-1: Gross solids depths in sumped catch basins discharging to the infiltration trenches from 2007 to 2010. Measurements taken during bi-annual inspections of the catch basins. Corresponding gross solids volumes are also listed.**

| | | | Fall 2007 | | Spring 2008 | | Fall 2008 | | Spring 2009 | | Fall 2009 | | Spring 2010 | | Fall 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trench Number | Trench End | Catch Basin Number | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solds Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) |
| 1 | East | 672 | 0.31 | 1.86 | 0.07 | 0.42 | 0.74 | 4.44 | 0.85 | 5.10 | 0.48 | 2.88 | 0.52 | 3.12 | 0.30 | 1.80 |
| 1 | East | 673 | 0.27 | 1.62 | 0.07 | 0.42 | 0.82 | 4.92 | 1.46 | 8.76 | 0.56 | 3.36 | 1.50 | 9.00 | 0.27 | 1.62 |
| 2 | West | 675 | 0.00 | 0.00 | 0.12 | 0.72 | 0.84 | 5.04 | 1.19 | 7.14 | 0.47 | 2.82 | 0.55 | 3.30 | 0.34 | 2.04 |
| 2 | West | 676 | 0.79 | 4.74 | 0.08 | 0.48 | 0.88 | 5.28 | 0.92 | 5.52 | 0.47 | 2.82 | 0.68 | 4.08 | 0.29 | 1.74 |
| 3 | West | 679 | 1.12 | 6.72 | 0.13 | 0.78 | 1.14 | 6.84 | 1.55 | 9.30 | 0.66 | 3.96 | 0.94 | 5.64 | 0.03 | 0.18 |
| 3 | West | 680 | 0.41 | 2.46 | 0.17 | 1.02 | 0.66 | 3.96 | 1.29 | 7.74 | 0.31 | 1.86 | 1.11 | 6.66 | 0.09 | 0.54 |
| 3 | East | 681 | 0.49 | 2.94 | 0.06 | 0.36 | 0.75 | 4.50 | 1.22 | 7.32 | 0.46 | 2.76 | 0.65 | 3.90 | 0.24 | 1.44 |
| 3 | East | 682 | 0.88 | 5.28 | 0.21 | 1.26 | 0.66 | 3.96 | 0.85 | 5.10 | 0.39 | 2.34 | 0.71 | 4.26 | 0.07 | 0.42 |
| 3 | East | 683 | 0.82 | 4.92 | 0.21 | 1.26 | 0.78 | 4.68 | 0.79 | 4.74 | 0.83 | 4.98 | 0.95 | 5.70 | 0.41 | 2.46 |
| 3 | East | 685 | 0.78 | 4.68 | 0.27 | 1.62 | 0.86 | 5.16 | 0.75 | 4.50 | 1.87 | 11.22 | 0.96 | 5.76 | 0.31 | 1.86 |
| 4 | West | 686 | 0.73 | 4.38 | 0.17 | 1.02 | 0.91 | 5.46 | 1.60 | 9.60 | 0.49 | 2.94 | 0.79 | 4.74 | 0.31 | 1.86 |
| 4 | West | 687 | 0.82 | 4.92 | 0.08 | 0.48 | 0.95 | 5.70 | 1.25 | 7.50 | 0.28 | 1.68 | 1.05 | 6.30 | 0.18 | 1.08 |
| 4 | East | 690 | 1.16 | 6.96 | 1.64 | 9.84 | 0.35 | 2.10 | 1.21 | 7.26 | 0.16 | 0.96 | 0.37 | 2.22 | 0.31 | 1.86 |
| 4 | East | 691 | 0.36 | 2.16 | 1.37 | 8.22 | 0.01 | 0.06 | 0.34 | 2.04 | 0.09 | 0.54 | 0.82 | 4.92 | 0.27 | 1.62 |
| 4 | East | 692 | 1.24 | 7.44 | 7.83 | 10.98 | 0.60 | 3.60 | 1.13 | 6.78 | 0.72 | 4.32 | 0.95 | 5.70 | 0.37 | 2.22 |
| 4 | East | 697 | 0.00 | 0.00 | 1.87 | 11.22 | 0.79 | 4.74 | 1.35 | 8.10 | 0.67 | 4.02 | 0.79 | 4.74 | 0.53 | 3.18 |
| 5 | East | 743 | 1.92 | 11.52 | 0.09 | 0.54 | 0.79 | 4.74 | 1.12 | 6.72 | 0.11 | 0.66 | 0.81 | 4.86 | 0.10 | 0.60 |
| 5 | East | 744 | 0.72 | 4.32 | 0.04 | 0.24 | 0.75 | 4.50 | 1.56 | 9.36 | 0.35 | 2.10 | 0.76 | 4.56 | 0.18 | 1.08 |
| 6 | West | 746 | 0.52 | 3.12 | 0.08 | 0.48 | 1.10 | 6.60 | 1.79 | 10.74 | 0.46 | 2.76 | 1.23 | 7.38 | 0.15 | 0.90 |
| 6 | West | 747 | 0.33 | 1.98 | 0.43 | 2.58 | 0.90 | 5.40 | 1.06 | 6.36 | 0.47 | 2.82 | 1.03 | 6.18 | 0.33 | 1.98 |
| 6 | West | 748 | 0.63 | 3.78 | 0.23 | 1.38 | 0.50 | 3.00 | 0.86 | 5.16 | 0.62 | 3.72 | 0.79 | 4.74 | 0.10 | 0.60 |
| 6 | West | 749 | 0.53 | 3.18 | 0.00 | 0.00 | 0.64 | 3.84 | 1.24 | 7.44 | 0.41 | 2.46 | 1.27 | 7.62 | 0.00 | 0.00 |
| 7 | West | 756 | 0.00 | 0.00 | 0.22 | 1.32 | 0.85 | 5.10 | 1.57 | 9.42 | 0.56 | 3.36 | 1.06 | 6.36 | 0.16 | 0.96 |
| 7 | West | 758 | 0.00 | 0.00 | 0.08 | 0.48 | 0.40 | 2.40 | 1.08 | 6.48 | 0.44 | 2.64 | 0.98 | 5.88 | 0.07 | 0.42 |
| 8 | West | 782 | 0.86 | 5.16 | 0.07 | 0.42 | 0.91 | 5.46 | 0.95 | 5.70 | 0.92 | 5.52 | 0.66 | 3.96 | 0.03 | 0.18 |
| 8 | West | 784 | 1.01 | 6.06 | 0.23 | 1.38 | 0.85 | 5.10 | 0.97 | 5.82 | 0.85 | 5.10 | 0.85 | 5.10 | 0.02 | 0.12 |
| 8 | East | 789 | 0.00 | 0.00 | 0.57 | 3.42 | 0.73 | 4.38 | 0.98 | 5.88 | 0.38 | 2.28 | 1.12 | 6.72 | 0.27 | 1.62 |
| 8 | East | 791 | 1.22 | 7.32 | 0.16 | 0.96 | 0.49 | 2.94 | 1.04 | 6.24 | 0.26 | 1.56 | 1.20 | 7.20 | 0.35 | 2.10 |
| 8 | East | 793 | 0.85 | 5.10 | 0.90 | 5.40 | 0.94 | 5.64 | 1.23 | 7.38 | 0.59 | 3.54 | 289.00 | 5.34 | 0.33 | 1.98 |
| 8 | East | 794 | 0.00 | 0.00 | 0.19 | 1.14 | 1.21 | 7.26 | 1.85 | 11.10 | 1.10 | 6.60 | 1.33 | 7.98 | 0.71 | 4.26 |
| | | **TOTAL:** | | **112.62** | | **69.84** | | **136.80** | | **210.30** | | **98.58** | | **163.92** | | **42.72** |

**Appendix C-2: Gross solids loads for catch basins discharging to the infiltration trenches from 2007 to 2010. Loads were calculated using gross solids volumes and an average bulk density of all samples collected from the catch basins.**

| | | | Fall 2007 | | Spring 2008 | | Fall 2008 | | Spring 2009 | | Fall 2009 | | Spring 2010 | | Fall 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trench Number** | **Trench End** | **Catch Basin Number** | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) |
| 1 | East | 672 | 1.86 | 149 | 0.42 | 34 | 4.44 | 355 | 5.10 | 408 | 2.88 | 230 | 3.12 | 249 | 1.80 | 144 |
| 1 | East | 673 | 1.62 | 129 | 0.42 | 34 | 4.92 | 393 | 8.76 | 700 | 3.36 | 268 | 9.00 | 719 | 1.62 | 129 |
| 2 | West | 675 | 0.00 | 0 | 0.72 | 58 | 5.04 | 403 | 7.14 | 571 | 2.82 | 225 | 3.30 | 264 | 2.04 | 163 |
| 2 | West | 676 | 4.74 | 379 | 0.48 | 38 | 5.28 | 422 | 5.52 | 441 | 2.82 | 225 | 4.08 | 326 | 1.74 | 139 |
| 3 | West | 679 | 6.72 | 537 | 0.78 | 62 | 6.84 | 547 | 9.30 | 743 | 3.96 | 316 | 5.64 | 451 | 0.18 | 14 |
| 3 | West | 680 | 2.46 | 197 | 1.02 | 82 | 3.96 | 316 | 7.74 | 619 | 1.86 | 149 | 6.66 | 532 | 0.54 | 43 |
| 3 | East | 681 | 2.94 | 235 | 0.36 | 29 | 4.50 | 360 | 7.32 | 585 | 2.76 | 221 | 3.90 | 312 | 1.44 | 115 |
| 3 | East | 682 | 5.28 | 422 | 1.26 | 101 | 3.96 | 316 | 5.10 | 408 | 2.34 | 187 | 4.26 | 340 | 0.42 | 34 |
| 3 | East | 683 | 4.92 | 393 | 1.26 | 101 | 4.68 | 374 | 4.74 | 379 | 4.98 | 398 | 5.70 | 455 | 2.46 | 197 |
| 3 | East | 685 | 4.68 | 374 | 1.62 | 129 | 5.16 | 412 | 4.50 | 360 | 11.22 | 897 | 5.76 | 460 | 1.86 | 149 |
| 4 | West | 686 | 4.38 | 350 | 1.02 | 82 | 5.46 | 436 | 9.60 | 767 | 2.94 | 235 | 4.74 | 379 | 1.86 | 149 |
| 4 | West | 687 | 4.92 | 393 | 0.48 | 38 | 5.70 | 455 | 7.50 | 599 | 1.68 | 134 | 6.30 | 503 | 1.08 | 86 |
| 4 | East | 690 | 6.96 | 556 | 9.84 | 786 | 2.10 | 168 | 7.26 | 580 | 0.96 | 77 | 2.22 | 177 | 1.86 | 149 |
| 4 | East | 691 | 2.16 | 173 | 8.22 | 657 | 0.06 | 5 | 2.04 | 163 | 0.54 | 43 | 4.92 | 393 | 1.62 | 129 |
| 4 | East | 692 | 7.44 | 595 | 10.98 | 877 | 3.60 | 288 | 6.78 | 542 | 4.32 | 345 | 5.70 | 455 | 2.22 | 177 |
| 4 | East | 697 | 0.00 | 0 | 11.22 | 897 | 4.74 | 379 | 8.10 | 647 | 4.02 | 321 | 4.74 | 379 | 3.18 | 254 |
| 5 | East | 743 | 11.52 | 921 | 0.54 | 43 | 4.74 | 379 | 6.72 | 537 | 0.66 | 53 | 4.86 | 388 | 0.60 | 48 |
| 5 | East | 744 | 4.32 | 345 | 0.24 | 19 | 4.50 | 360 | 9.36 | 748 | 2.10 | 168 | 4.56 | 364 | 1.08 | 86 |
| 6 | West | 746 | 3.12 | 249 | 0.48 | 38 | 6.60 | 527 | 10.74 | 858 | 2.76 | 221 | 7.38 | 590 | 0.90 | 72 |
| 6 | West | 747 | 1.98 | 158 | 2.58 | 206 | 5.40 | 432 | 6.36 | 508 | 2.82 | 225 | 6.18 | 494 | 1.98 | 158 |
| 6 | West | 748 | 3.78 | 302 | 1.38 | 110 | 3.00 | 240 | 5.16 | 412 | 3.72 | 297 | 4.74 | 379 | 0.60 | 48 |
| 6 | West | 749 | 3.18 | 254 | 0.00 | 0 | 3.84 | 307 | 7.44 | 595 | 2.46 | 197 | 7.62 | 609 | 0.00 | 0 |
| 7 | West | 756 | 0.00 | 0 | 1.32 | 105 | 5.10 | 408 | 9.42 | 753 | 3.36 | 268 | 6.36 | 508 | 0.96 | 77 |
| 7 | West | 758 | 0.00 | 0 | 0.48 | 38 | 2.40 | 192 | 6.48 | 518 | 2.64 | 211 | 5.88 | 470 | 0.42 | 34 |
| 8 | West | 782 | 5.16 | 412 | 0.42 | 34 | 5.46 | 436 | 5.70 | 455 | 5.52 | 441 | 3.96 | 316 | 0.18 | 14 |
| 8 | West | 784 | 6.06 | 484 | 1.38 | 110 | 5.10 | 408 | 5.82 | 465 | 5.10 | 408 | 5.10 | 408 | 0.12 | 10 |
| 8 | East | 789 | 0.00 | 0 | 3.42 | 273 | 4.38 | 350 | 5.88 | 470 | 2.28 | 182 | 6.72 | 537 | 1.62 | 129 |
| 8 | East | 791 | 7.32 | 585 | 0.96 | 77 | 2.94 | 235 | 6.24 | 499 | 1.56 | 125 | 7.20 | 575 | 2.10 | 168 |
| 8 | East | 793 | 5.10 | 408 | 5.40 | 432 | 5.64 | 451 | 7.38 | 590 | 3.54 | 283 | 5.34 | 427 | 1.98 | 158 |
| 8 | East | 794 | 0.00 | 0 | 1.14 | 91 | 7.26 | 580 | 11.10 | 887 | 6.60 | 527 | 7.98 | 638 | 4.26 | 340 |
| | | **TOTAL:** | | **8,999** | | **5,581** | | **10,932** | | **16,805** | | **7,878** | | **13,099** | | **3,414** |

Note: An average bulk density value of 1.28 g/mL (or 79.91 lbs/cf) was used to calculate the gross solids loads for all data points.

Appendix C-3: Particle size analysis lab results for samples collected from the catch basins.

| Date Collected | Trench Number | Trench End | Catch Basin Number | Moisture (%) | Composition: Clay/Silt (%) | Fine Sand (%) | Medium Sand (%) | Coarse Sand (%) | Gravel (%) | TOTAL | Soil Classification[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/14/2011 | 1 | East | 672 | 82.2 | 4.6 | 25.9 | 44.2 | 19.4 | 5.9 | 100 | (OL/OH) Sandy Organic Soil |
| 6/24/2011 | 1 | East | 673 | 31.6 | 2.4 | 13.8 | 39.0 | 38.3 | 6.5 | 100 | (SW) Well graded sand |
| 6/14/2011 | 2 | West | 675 | 126.8 | 13.4 | 34.4 | 39.0 | 8.7 | 4.5 | 100 | (OL/OH) Sandy Organic Soil |
| 6/14/2011 | 2 | West | 676 | 187.8 | 9.8 | 28.5 | 34.8 | 12.6 | 14.3 | 100 | (OL/OH) Sandy Organic Soil |
| 6/14/2011 | 3 | East | 681 | 199.1 | 14.2 | 17.4 | 33.1 | 16.0 | 19.3 | 100 | (OL/OH) Sandy Organic Soil |
| 6/14/2011 | 3 | East | 682 | 224.9 | 6.8 | 20.3 | 41.4 | 17.0 | 14.5 | 100 | (OL/OH) Sandy Organic Soil |
| 6/14/2011 | 3 | East | 683 | 300.6 | 5.9 | 18.2 | 39.4 | 20.3 | 16.2 | 100 | (OL/OH) Organic Soil |
| 6/14/2011 | 3 | East | 685 | 318.6 | 7.9 | 21.2 | 45.5 | 18.0 | 7.4 | 100 | (OL/OH) Sandy Organic Soil |
| 6/14/2011 | 3 | West | 679 | 400.7 | 15.6 | 6.7 | 12.9 | 10.3 | 54.5 | 100 | (OL/OH) Organic Soil |
| 6/14/2011 | 3 | West | 680 | 500.2 | 5.6 | 24.2 | 36.6 | 11.1 | 22.5 | 100 | (OL/OH) Organic Soil |
| 6/1/2011 | 4 | East | 690 | 457.2 | 9.3 | 12.1 | 22.5 | 15.3 | 10.9 | 70 | (OL/OH) Sandy Organic Soil |
| 6/13/2011 | 4 | East | 691 | 93.2 | 7.2 | 14.7 | 43.4 | 26.7 | 8.0 | 100 | (OL/OH) Sandy Organic Soil |
| 6/13/2011 | 4 | East | 692 | 235.2 | 13.8 | 12.3 | 34.0 | 17.4 | 22.5 | 100 | (OL/OH) Sandy Organic Soil |
| 6/13/2011 | 4 | East | 697 | 339.7 | 5.9 | 9.7 | 29.2 | 14.1 | 41.1 | 100 | (OL/OH) Organic Soil |
| 6/13/2011 | 4 | West | 686 | 272.2 | 29.2 | 8.5 | 19.0 | 10.2 | 33.1 | 100 | (OL/OH) Organic Soil |
| 6/13/2011 | 4 | West | 687 | 572.6 | 12.8 | 4.8 | 13.2 | 12.6 | 56.6 | 100 | (OL/OH) Organic Soil |
| 6/24/2011 | 5 | East | 743 | 28.3 | 4.9 | 16.7 | 32.1 | 35.6 | 10.7 | 100 | (SW) Well graded sand |
| 6/24/2011 | 5 | East | 744 | 88.2 | 11.5 | 5.5 | 28.3 | 39.4 | 15.3 | 100 | (OL/OH) Sandy Organic Sand |
| 6/24/2011 | 6 | West | 746 | 58.6 | 6.4 | 23.1 | 37.2 | 22.9 | 10.4 | 100 | (OL/OH) Sandy Organic Sand |
| 6/27/2011 | 6 | West | 747 | 46.6 | 3.8 | 23.3 | 49.1 | 21.2 | 2.6 | 100 | (OL/OH) Sandy Organic Sand |
| 6/27/2011 | 6 | West | 748 | 96.0 | 8.0 | 32.9 | 42.2 | 12.5 | 4.2 | 100 | (OL/OH) Sandy Organic Sand |
| 6/27/2011 | 6 | West | 749 | 264.1 | 9.1 | 12.1 | 16.6 | 10.5 | 51.7 | 100 | (OL/OH) Organic Soil |
| 6/27/2011 | 7 | West | 756 | 91.5 | 10.0 | 28.7 | 35.0 | 18.3 | 8.0 | 100 | (OL/OH) Sandy Organic Sand |
| 6/27/2011 | 7 | West | 758 | 51.1 | 4.9 | 16.6 | 45.1 | 27.5 | 5.9 | 100 | (SW) Well graded sand |
| 6/28/2011 | 8 | East | 789 | 43.9 | 3.1 | 12.8 | 47.6 | 31.8 | 4.7 | 100 | (SW) Well graded sand |
| 6/28/2011 | 8 | East | 791 | 91.5 | 13.2 | 32.9 | 41.2 | 9.2 | 3.5 | 100 | (OL/OH) Sandy Organic Sand |
| 6/28/2011 | 8 | East | 793 | 102.9 | 5.8 | 23.6 | 49.2 | 17.8 | 3.6 | 100 | (OL/OH) Sandy Organic Sand |
| 6/28/2011 | 8 | East | 794 | 167.0 | 10.5 | 23.2 | 44.2 | 17.0 | 5.1 | 100 | (OL/OH) Sandy Organic Sand |
| 6/28/2011 | 8 | West | 782 | 47.6 | 2.2 | 11.4 | 36.5 | 46.1 | 3.8 | 100 | (SW) Well graded sand |
| 6/28/2011 | 8 | West | 784 | 73.4 | 7.3 | 21.7 | 39.6 | 26.0 | 5.4 | 100 | (OL/OH) Sandy Organic Sand |

[a] Unified Soils Classification System (USCS) was used. See classification letters below.

| First/Second Letter | Second Letter |
|---|---|
| O: Organic | L: Low Plasticity |
| S: Sand | H: High Plasticity |
| W: Well Graded | |
| M: Silt | |
| C: Clay | |

**Appendix C-4: TP loads in gross solids loads captured by the thirty catch basins discharging to the infiltration trenches from 2007 to 2010. Loads were calculated using gross solids volumes and an average TP concentration of samples collected from all catch basins.**

| | | | Fall 2007 | | Spring 2008 | | Fall 2008 | | Spring 2009 | | Fall 2009 | | Spring 2010 | | Fall 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trench Number | Trench End | Catch Basin Number | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) |
| 1 | East | 672 | 149 | 0.06 | 34 | 0.01 | 355 | 0.14 | 408 | 0.16 | 230 | 0.09 | 249 | 0.10 | 144 | 0.06 |
| 1 | East | 673 | 129 | 0.05 | 34 | 0.01 | 393 | 0.16 | 700 | 0.28 | 268 | 0.11 | 719 | 0.29 | 129 | 0.05 |
| 2 | West | 675 | 0 | 0.00 | 58 | 0.02 | 403 | 0.16 | 571 | 0.23 | 225 | 0.09 | 264 | 0.11 | 163 | 0.07 |
| 2 | West | 676 | 379 | 0.15 | 38 | 0.02 | 422 | 0.17 | 441 | 0.18 | 225 | 0.09 | 326 | 0.13 | 139 | 0.06 |
| 3 | West | 679 | 537 | 0.22 | 62 | 0.03 | 547 | 0.22 | 743 | 0.30 | 316 | 0.13 | 451 | 0.18 | 14 | 0.01 |
| 3 | West | 680 | 197 | 0.08 | 82 | 0.03 | 316 | 0.13 | 619 | 0.25 | 149 | 0.06 | 532 | 0.21 | 43 | 0.02 |
| 3 | East | 681 | 235 | 0.09 | 29 | 0.01 | 360 | 0.14 | 585 | 0.24 | 221 | 0.09 | 312 | 0.13 | 115 | 0.05 |
| 3 | East | 682 | 422 | 0.17 | 101 | 0.04 | 316 | 0.13 | 408 | 0.16 | 187 | 0.08 | 340 | 0.14 | 34 | 0.01 |
| 3 | East | 683 | 393 | 0.16 | 101 | 0.04 | 374 | 0.15 | 379 | 0.15 | 398 | 0.16 | 455 | 0.18 | 197 | 0.08 |
| 3 | East | 685 | 374 | 0.15 | 129 | 0.05 | 412 | 0.17 | 360 | 0.14 | 897 | 0.36 | 460 | 0.19 | 149 | 0.06 |
| 4 | West | 686 | 350 | 0.14 | 82 | 0.03 | 436 | 0.18 | 767 | 0.31 | 235 | 0.09 | 379 | 0.15 | 149 | 0.06 |
| 4 | West | 687 | 393 | 0.16 | 38 | 0.02 | 455 | 0.18 | 599 | 0.24 | 134 | 0.05 | 503 | 0.20 | 86 | 0.03 |
| 4 | East | 690 | 556 | 0.22 | 786 | 0.32 | 168 | 0.07 | 580 | 0.23 | 77 | 0.03 | 177 | 0.07 | 149 | 0.06 |
| 4 | East | 691 | 173 | 0.07 | 657 | 0.26 | 5 | 0.00 | 163 | 0.07 | 43 | 0.02 | 393 | 0.16 | 129 | 0.05 |
| 4 | East | 692 | 595 | 0.24 | 877 | 0.35 | 288 | 0.12 | 542 | 0.22 | 345 | 0.14 | 455 | 0.18 | 177 | 0.07 |
| 4 | East | 697 | 0 | 0.00 | 897 | 0.36 | 379 | 0.15 | 647 | 0.26 | 321 | 0.13 | 379 | 0.15 | 254 | 0.10 |
| 5 | East | 743 | 921 | 0.37 | 43 | 0.02 | 379 | 0.15 | 537 | 0.22 | 53 | 0.02 | 388 | 0.16 | 48 | 0.02 |
| 5 | East | 744 | 345 | 0.14 | 19 | 0.01 | 360 | 0.14 | 748 | 0.30 | 168 | 0.07 | 364 | 0.15 | 86 | 0.03 |
| 6 | West | 746 | 249 | 0.10 | 38 | 0.02 | 527 | 0.21 | 858 | 0.35 | 221 | 0.09 | 590 | 0.24 | 72 | 0.03 |
| 6 | West | 747 | 158 | 0.06 | 206 | 0.08 | 432 | 0.17 | 508 | 0.20 | 225 | 0.09 | 494 | 0.20 | 158 | 0.06 |
| 6 | West | 748 | 302 | 0.12 | 110 | 0.04 | 240 | 0.10 | 412 | 0.17 | 297 | 0.12 | 379 | 0.15 | 48 | 0.02 |
| 6 | West | 749 | 254 | 0.10 | 0 | 0.00 | 307 | 0.12 | 595 | 0.24 | 197 | 0.08 | 609 | 0.24 | 0 | 0.00 |
| 7 | West | 756 | 0 | 0.00 | 105 | 0.04 | 408 | 0.16 | 753 | 0.30 | 268 | 0.11 | 508 | 0.20 | 77 | 0.03 |
| 7 | West | 758 | 0 | 0.00 | 38 | 0.02 | 192 | 0.08 | 518 | 0.21 | 211 | 0.08 | 470 | 0.19 | 34 | 0.01 |
| 8 | West | 782 | 412 | 0.17 | 34 | 0.01 | 436 | 0.18 | 455 | 0.18 | 441 | 0.18 | 316 | 0.13 | 14 | 0.01 |
| 8 | West | 784 | 484 | 0.19 | 110 | 0.04 | 408 | 0.16 | 465 | 0.19 | 408 | 0.16 | 408 | 0.16 | 10 | 0.00 |
| 8 | East | 789 | 0 | 0.00 | 273 | 0.11 | 350 | 0.14 | 470 | 0.19 | 182 | 0.07 | 537 | 0.22 | 129 | 0.05 |
| 8 | East | 791 | 585 | 0.24 | 77 | 0.03 | 235 | 0.09 | 499 | 0.20 | 125 | 0.05 | 575 | 0.23 | 168 | 0.07 |
| 8 | East | 793 | 408 | 0.16 | 432 | 0.17 | 451 | 0.18 | 590 | 0.24 | 283 | 0.11 | 427 | 0.17 | 158 | 0.06 |
| 8 | East | 794 | 0 | 0.00 | 91 | 0.04 | 580 | 0.23 | 887 | 0.36 | 527 | 0.21 | 638 | 0.26 | 340 | 0.14 |
| | | **TOTAL:** | **8,999** | **3.62** | **5,581** | **2.24** | **10,932** | **4.39** | **16,805** | **6.76** | **7,878** | **3.17** | **13,099** | **5.27** | **3,414** | **1.37** |

Note: An average TP concentration of 402 mg/kg was used to calculate the TP loads for all data points.

Appendix C-5: Gross solids depths in sumped manholes discharging to the infiltration trenches from 2007 to 2010. Measurements taken during bi-annual inspections of the manholes. Corresponding gross solids volumes are also listed.

| | | Fall 2007 | | Spring 2008 | | Fall 2008 | | Spring 2009 | | Fall 2009 | | Spring 2010 | | Fall 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trench Number** | **Manhole** | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) | Gross Solids Depth (ft) | Gross Solids Volume (cf) |
| 1 | East | 0.61 | 7.67 | 0.30 | 3.77 | 0.05 | 0.63 | 0.41 | 5.15 | 0.06 | 0.75 | 0.05 | 0.63 | 0.00 | 0.00 |
| 1 | West | 0.59 | 7.41 | 0.00 | 0.00 | 0.04 | 0.50 | 0.00 | 0.00 | 1.08 | 13.57 | 0.17 | 2.14 | 0.08 | 1.01 |
| 2 | East | 0.01 | 0.13 | 0.00 | 0.00 | 0.41 | 5.15 | 0.00 | 0.00 | 0.14 | 1.76 | 0.88 | 11.06 | 0.21 | 2.64 |
| 2 | West | 0.42 | 5.28 | 0.58 | 7.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.25 | 0.08 | 1.01 | 0.00 | 0.00 |
| 3 | East | 0.63 | 7.92 | 0.46 | 5.78 | 0.23 | 2.89 | 0.89 | 11.18 | 0.02 | 0.25 | 0.24 | 3.02 | 0.00 | 0.00 |
| 3 | West | 0.00 | 0.00 | 0.51 | 6.41 | 0.57 | 7.16 | 0.05 | 0.63 | 1.07 | 13.45 | 0.33 | 4.15 | 0.00 | 0.00 |
| 4 | East | 0.01 | 0.28 | 0.26 | 7.35 | 0.27 | 7.63 | 0.04 | 1.13 | 0.12 | 3.39 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | West | 0.58 | 7.29 | 0.47 | 5.91 | 0.27 | 3.39 | 0.29 | 3.64 | 0.54 | 6.79 | 0.02 | 0.25 | 0.00 | 0.00 |
| 5 | East | 0.13 | 1.63 | 0.00 | 0.00 | 0.18 | 2.26 | 0.01 | 0.13 | 0.03 | 0.38 | 0.00 | 0.00 | 0.03 | 0.38 |
| 5 | West | 0.19 | 2.39 | 0.00 | 0.00 | 0.04 | 0.50 | 0.04 | 0.50 | 0.06 | 0.75 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6 | East | 0.97 | 12.19 | 0.00 | 0.00 | 0.48 | 6.03 | 0.46 | 5.78 | 0.72 | 9.05 | 0.19 | 2.39 | 0.00 | 0.00 |
| 6 | West | 0.10 | 1.96 | 0.15 | 2.95 | 0.48 | 9.42 | 0.18 | 3.53 | 0.01 | 0.20 | 0.01 | 0.20 | 0.00 | 0.00 |
| 7 | East | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7 | West | 0.08 | 1.64 | 0.37 | 7.26 | 0.00 | 0.00 | 0.12 | 2.36 | 0.05 | 0.98 | 0.17 | 3.34 | 0.00 | 0.00 |
| 8 | East | 0.61 | 11.98 | 0.68 | 13.35 | 0.52 | 10.21 | 0.36 | 7.07 | 0.02 | 0.39 | 0.18 | 3.53 | 0.05 | 0.98 |
| 8 | West | 0.12 | 1.51 | 0.20 | 2.51 | 0.11 | 1.38 | 0.04 | 0.50 | 0.03 | 0.38 | 0.00 | 0.00 | 0.00 | 0.00 |
| | **TOTAL:** | | **69.28** | | **62.58** | | **57.15** | | **41.60** | | **52.47** | | **31.72** | | **5.01** |

**Appendix C-6: Gross solids loads for the sumped manholes discharging to the infiltration trenches from 2007 to 2010. Loads were calculated using gross solids volumes and an average bulk density of all samples collected from the catch basins.**

| | | Fall 2007 | | Spring 2008 | | Fall 2008 | | Spring 2009 | | Fall 2009 | | Spring 2010 | | Fall 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trench Number** | **Manhole** | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) | Gross Solids Volume (cf) | Gross Solids Load (lbs) |
| 1 | East | 7.67 | 613 | 3.77 | 301 | 0.63 | 50 | 5.15 | 412 | 0.75 | 60 | 0.63 | 50 | 0.00 | 0 |
| 1 | West | 7.41 | 592 | 0.00 | 0 | 0.50 | 40 | 0.00 | 0 | 13.57 | 1,084 | 2.14 | 171 | 1.01 | 81 |
| 2 | East | 0.13 | 10 | 0.00 | 0 | 5.15 | 412 | 0.00 | 0 | 1.76 | 141 | 11.06 | 884 | 2.64 | 211 |
| 2 | West | 5.28 | 422 | 7.29 | 583 | 0.00 | 0 | 0.00 | 0 | 0.25 | 20 | 1.01 | 81 | 0.00 | 0 |
| 3 | East | 7.92 | 633 | 5.78 | 462 | 2.89 | 231 | 11.18 | 893 | 0.25 | 20 | 3.02 | 241 | 0.00 | 0 |
| 3 | West | 0.00 | 0 | 6.41 | 512 | 7.16 | 572 | 0.63 | 50 | 13.45 | 1,075 | 4.15 | 332 | 0.00 | 0 |
| 4 | East | 0.28 | 22 | 7.35 | 587 | 7.63 | 610 | 1.13 | 90 | 3.39 | 271 | 0.00 | 0 | 0.00 | 0 |
| 4 | West | 7.29 | 583 | 5.91 | 472 | 3.39 | 271 | 3.64 | 291 | 6.79 | 543 | 0.25 | 20 | 0.00 | 0 |
| 5 | East | 1.63 | 130 | 0.00 | 0 | 2.26 | 181 | 0.13 | 10 | 0.38 | 30 | 0.00 | 0 | 0.38 | 30 |
| 5 | West | 2.39 | 191 | 0.00 | 0 | 0.50 | 40 | 0.50 | 40 | 0.75 | 60 | 0.00 | 0 | 0.00 | 0 |
| 6 | East | 12.19 | 974 | 0.00 | 0 | 6.03 | 482 | 5.78 | 462 | 9.05 | 723 | 2.39 | 191 | 0.00 | 0 |
| 6 | West | 1.96 | 157 | 2.95 | 236 | 9.42 | 753 | 3.53 | 282 | 0.20 | 16 | 0.20 | 16 | 0.00 | 0 |
| 7 | East | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.13 | 10 | 0.00 | 0 | 0.00 | 0 |
| 7 | West | 1.64 | 131 | 7.26 | 580 | 0.00 | 0 | 2.36 | 189 | 0.98 | 78 | 3.34 | 267 | 0.00 | 0 |
| 8 | East | 11.98 | 957 | 13.35 | 1,067 | 10.21 | 816 | 7.07 | 565 | 0.39 | 31 | 3.53 | 282 | 0.98 | 78 |
| 8 | West | 1.51 | 121 | 2.51 | 201 | 1.38 | 110 | 0.50 | 40 | 0.38 | 30 | 0.00 | 0 | 0.00 | 0 |
| TOTAL: | | | **5,536** | | **5,001** | | **4,567** | | **3,324** | | **4,193** | | **2,535** | | **400** |

Note: An average bulk density value of 1.28 g/mL (or 79.91 lbs/cf) was used to calculate the gross solids loads for all data points.

**Appendix C-7: TP loads in the gross solids loads captured by the manholes discharging to the infiltration trenches from 2007 to 2010. TP loads were calculated using gross solids volumes and an average TP concentration of all samples collected from the catch basins.**

| | | Fall 2007 | | Spring 2008 | | Fall 2008 | | Spring 2009 | | Fall 2009 | | Spring 2010 | | Fall 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trench Number** | **Manhole** | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) | Gross Solids Load (lbs) | TP Load (lbs) |
| 1 | East | 613 | 0.25 | 301 | 0.12 | 50 | 0.02 | 412 | 0.17 | 60 | 0.02 | 50 | 0.02 | 0 | 0.00 |
| 1 | West | 592 | 0.24 | 0 | 0.00 | 40 | 0.02 | 0 | 0.00 | 1084 | 0.44 | 171 | 0.07 | 81 | 0.03 |
| 2 | East | 10 | 0.00 | 0 | 0.00 | 412 | 0.17 | 0 | 0.00 | 141 | 0.06 | 884 | 0.36 | 211 | 0.08 |
| 2 | West | 422 | 0.17 | 583 | 0.23 | 0 | 0.00 | 0 | 0.00 | 20 | 0.01 | 81 | 0.03 | 0 | 0.00 |
| 3 | East | 633 | 0.25 | 462 | 0.19 | 231 | 0.09 | 893 | 0.36 | 20 | 0.01 | 241 | 0.10 | 0 | 0.00 |
| 3 | West | 0 | 0.00 | 512 | 0.21 | 572 | 0.23 | 50 | 0.02 | 1075 | 0.43 | 332 | 0.13 | 0 | 0.00 |
| 4 | East | 22 | 0.01 | 587 | 0.24 | 610 | 0.25 | 90 | 0.04 | 271 | 0.11 | 0 | 0.00 | 0 | 0.00 |
| 4 | West | 583 | 0.23 | 472 | 0.19 | 271 | 0.11 | 291 | 0.12 | 543 | 0.22 | 20 | 0.01 | 0 | 0.00 |
| 5 | East | 130 | 0.05 | 0 | 0.00 | 181 | 0.07 | 10 | 0.00 | 30 | 0.01 | 0 | 0.00 | 30 | 0.01 |
| 5 | West | 191 | 0.08 | 0 | 0.00 | 40 | 0.02 | 40 | 0.02 | 60 | 0.02 | 0 | 0.00 | 0 | 0.00 |
| 6 | East | 974 | 0.39 | 0 | 0.00 | 482 | 0.19 | 462 | 0.19 | 723 | 0.29 | 191 | 0.08 | 0 | 0.00 |
| 6 | West | 157 | 0.06 | 236 | 0.09 | 753 | 0.30 | 282 | 0.11 | 16 | 0.01 | 16 | 0.01 | 0 | 0.00 |
| 7 | East | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 10 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| 7 | West | 131 | 0.05 | 580 | 0.23 | 0 | 0.00 | 189 | 0.08 | 78 | 0.03 | 267 | 0.11 | 0 | 0.00 |
| 8 | East | 957 | 0.38 | 1067 | 0.43 | 816 | 0.33 | 565 | 0.23 | 31 | 0.01 | 282 | 0.11 | 78 | 0.03 |
| 8 | West | 121 | 0.05 | 201 | 0.08 | 110 | 0.04 | 40 | 0.02 | 30 | 0.01 | 0 | 0.00 | 0 | 0.00 |
| | TOTAL: | **5536** | **2.23** | **5,001** | **2.01** | **4,567** | **1.84** | **3,324** | **1.34** | **4,193** | **1.69** | **2,535** | **1.02** | **400** | **0.16** |

Note: A TP value of 402 mg/kg was used to calculate the TP loads for all data points.

**Appendix C-8: Annual gross solids load and TP loads in gross solids captured by pretreatment units discharging to a specific infiltration trench (1 through 8).**

| Trench Number | Pretreatment Unit Type | Gross Solids Load (lbs) | | | | Total Phosphorous Load (lbs) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2007 | 2008 | 2009 | 2010 | 2007 | 2008 | 2009 | 2010 |
| 1 | Catch Basins | 278 | 815 | 1,606 | 1,242 | 0.11 | 0.33 | 0.65 | 0.50 |
| | Manholes | 1,205 | 392 | 1,556 | 302 | 0.48 | 0.16 | 0.63 | 0.12 |
| 2 | Catch Basins | 379 | 921 | 1,462 | 892 | 0.15 | 0.37 | 0.59 | 0.36 |
| | Manholes | 432 | 994 | 161 | 1,175 | 0.17 | 0.40 | 0.06 | 0.47 |
| 3 | Catch Basins | 2,158 | 2,829 | 5,260 | 3,102 | 0.87 | 1.14 | 2.11 | 1.25 |
| | Manholes | 633 | 1,777 | 2,039 | 573 | 0.25 | 0.71 | 0.82 | 0.23 |
| 4 | Catch Basins | 2,066 | 5,068 | 4,454 | 3,232 | 0.83 | 2.04 | 1.79 | 1.30 |
| | Manholes | 605 | 1,940 | 1,195 | 20 | 0.24 | 0.78 | 0.48 | 0.01 |
| 5 | Catch Basins | 1,266 | 801 | 1,506 | 887 | 0.51 | 0.32 | 0.61 | 0.36 |
| | Manholes | 321 | 221 | 141 | 30 | 0.13 | 0.09 | 0.06 | 0.01 |
| 6 | Catch Basins | 964 | 1,860 | 3,313 | 2,349 | 0.39 | 0.75 | 1.33 | 0.94 |
| | Manholes | 1,131 | 1,470 | 1,483 | 207 | 0.45 | 0.59 | 0.60 | 0.08 |
| 7 | Catch Basins | 0 | 743 | 1,750 | 1,088 | 0.00 | 0.30 | 0.70 | 0.44 |
| | Manholes | 131 | 580 | 277 | 267 | 0.05 | 0.23 | 0.11 | 0.11 |
| 8 | Catch Basins | 1,889 | 3,476 | 5,332 | 3,721 | 0.76 | 1.40 | 2.14 | 1.50 |
| | Manholes | 1,078 | 2,194 | 666 | 360 | 0.43 | 0.88 | 0.27 | 0.14 |
| | **TOTAL:** | **14,536** | **26,080** | **32,200** | **19,448** | **5.84** | **10.48** | **12.94** | **7.82** |

# APPENDIX D:
# Arlington Pascal Project Pollutant Loading Data

**Appendix D-1: Gross solids loads and TP loads in gross solids captured by all Arlington Pascal Project BMPs from 2007 to 2010.**

| | Gross Solids Load (lbs) | | | | Total Phosphorous Load (lbs) | | | |
|---|---|---|---|---|---|---|---|---|
| **BMP** | 2007 | 2008 | 2009 | 2010 | 2007 | 2008 | 2009 | 2010 |
| Arlington-Hamline Facility | 24,739 | 27,745 | 30,950 | 18,968 | 19.36 | 20.40 | 22.22 | 18.29 |
| Como Park Regional Pond | | 145,791 | 180,003 | 108,717 | | 58.58 | 72.34 | 43.71 |
| Rain Gardens | 6,026 | 10,902 | 13,461 | 8,130 | 2.44 | 4.38 | 5.41 | 3.27 |
| Underground Infiltration Trenches | 14,415 | 26,080 | 32,200 | 19,448 | 5.84 | 10.48 | 12.94 | 7.82 |
| **PROJECT TOTAL:** | **45,180** | **210,518** | **256,614** | **155,263** | **27.64** | **93.84** | **112.91** | **73.09** |