BEST MANAGEMENT PRACTICES FOR HIGHWAY CONSTRUCTION SITE SEDIMENTATION BASINS

by

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BEST MANAGEMENT PRACTICES FOR CONSTRUCTION SITE SEDIMENTATION BASINS

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University of Pittsburgh, 2007

The objective of this PhD research is to develop a set of stormwater Best Management Practices (BMPs) with respect to design, operation and maintenance of sedimentation basins (SBs). Stormwater BMPs may be defined as any program, technology, process, citing criteria, operating method, or device, which controls, prevents, or reduces pollution from stormwater runoff. Sedimentation basins at construction sites are currently designed for runoff capture rather than for particle removal. Well designed SBs that capture particles effectively are essential for capturing sediments and particulate contaminants (iron, aluminum, manganese and phosphate). An integrated methodology for designing basins incorporating runoff capture, required level of particle removal and effective sediment containment is not available. Through this research an integrated method for designing SBs by applying rainfall probability plots to determine basin settling volume, Revised Universal Soil Loss Equation (RUSLE) to identify sediment zone volume and overflow rate to identify particle removal in the basin was developed. Further a set of design curves were generated to understand the change in basin performance and cost with change in basin design parameters. In addition the capacity of sedimentation basins to neutralize naturally occurring mildly acidic seeps (pH 5-6) was identified. Best management practices of frequent sediment dredging and maintaining drainage time within five days were suggested for the control of algae growth and mosquito breeding in the basin respectively. The feasibility of adding polymer to enhance sedimentation in the basin during high flow conditions was

demonstrated. The suggested integrated design method and the best management practices address runoff capture, particle removal, pollutant peak attenuation, acidic seep drainage, algae growth and mosquito breeding in the basins. The outcome of this research is a methodology for designing SBs that can protect water quality and control particulate contaminants (iron, manganese, phosphate and aluminum) released from construction activities. The new design methodology offers engineers more input choices leading to a number of basin performance and installation cost outputs.

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1.0 INTRODUCTION

Stormwater Best Management Practices (BMPs) are generally classified as (i) source control BMPs and treatment control BMPs or as (ii) structural BMPs and non-structural BMPs. “Source control” BMPs are operational practices that prevent pollution by reducing potential pollutants at the source. “Treatment control” BMPs are methods of treatment to remove pollutants from stormwater. Structural BMPs are mostly treatment BMPs and operate by trapping and detaining runoff so that stormwater constituents settle out or are filtered and trapped by the underlying soil or media. Nonstructural BMPs are typically "source control" measures, designed to reduce the level of contaminants and their concentrations in stormwater runoff (USDOT, 2006; California Stormwater Quality Association, 2003)

The focus of this research is to develop BMPs specific to sedimentation basins (SBs), which are considered a structural erosion and runoff control BMP by Federal Highway Administration (FHWA). A review of literature reveals that SBs are currently designed for water storage considerations rather than water quality considerations i.e., they are designed to capture the quantity of runoff rather than the suspended sediments in the runoff. The existing design criteria for SBs requires that a 1,000 cu ft sediment storage zone per disturbed acre within the watershed and a drainage zone of 5,000 cubic feet for each acre tributary (the land area that drains to one of the smaller streams that flow to the main channel of a watershed) to the basin be provided (PADEP 2000). The procedure for designing SBs to capture runoff resulting from a design storm is clearly documented in the literature, but there appears to be no rational and comprehensive method for the design of SBs addressing runoff capture, particle removal based on particle size distribution, sediment containment in the basin and sediment dredging frequency. When construction sites are situated in pristine environments with high quality streams or protected wetlands, then stringent limits may be applied to the runoff from the site. Hence, there appears to be a need for developing a systematic method for designing SBs, integrating the various aspects of basin design namely: settling volume, sediment volume, overflow rate, basin area, frequency of sediment removal and drainage time.

The objective of this PhD research was to develop a set of best management practices for SBs which include suggesting a rational and integrated method for designing SBs. The new design methodology would apply rainfall probability plots to determine basin settling volume, RUSLE to identify sediment zone volume and sediment dredging frequency, overflow rate to determine basin area and extent of particle removal. The design methodology would also use a constant design overflow rate along the depth of the basin to attenuate peaks in particulate contaminant concentration in the effluent during high flow conditions. Other water quality issues such as naturally occurring mildly acidic seeps, algae growth and mosquito breeding observed during field visits would be analyzed and best management practices would be suggested to control these issues.

This research yields a new methodology for designing SBs for runoff capture, particle removal and attenuation of peaks in suspended solid concentration during high flow events. It has introduced a method to arrive at sediment storage volume, settling zone volume and sediment dredging frequency that are specific to a construction site and hence reduce sediment re-suspension in the basin. It helps to better understand the science and engineering of sedimentation basins to yield improved removal of particulate contaminants including iron, aluminum, manganese and phosphate from stormwater runoff, and results in the protection of surface waters from sediment pollution. It offers more choices in terms of extent of particle removal, runoff capture and construction costs. If stringent effluent concentration limits are applied to SBs in the future, then an integrated design methodology can help in designing and constructing sedimentation basins to achieve those limits. It can also provide solutions to secondary water quality issues such as algae growth, mosquito breeding and naturally occurring mildly acidic drainages. This research presents a set of BMPs that take into consideration all elements of SB design and represent a significant advance to the current design and performance of SBs.

1.1 SCOPE OF RESEARCH

The scope of this research pertains to the development of a set of BMPs with respect to sedimentation basin design, operation and maintenance as detailed below:

1. A comprehensive method was suggested for the design of SBs that will satisfy both runoff capture requirements and particle removal requirements by integrating the following design aspects:
    a. Calculation of settling volume of SB based on the percentage of the storms required to be captured in a given duration using rainfall probability plots.
    b. Identifying the minimum particle size that is to be removed in the basin and setting the design overflow rate of the basin equal to the Stokes' settling velocity of the smallest particle to be removed in the basin. Adjusting the basin outflow

rate and area to yield the design overflow rate. Applying a constant overflow rate along the depth of the basin to achieve constant particle removal, even during high flow conditions and hence attenuate peaks in particulate pollutant concentration during heavy rainfall events.

   c. Applying RUSLE to calculate sediment load and the sediment volume that needs to be provided to control re-suspension of settled solids and identifying sediment dredging frequency for the given sediment volume.

2. In addition, best management practices of decreasing drainage time (by varying pond dimensions) to control mosquito growth, and increasing sediment dredging frequency to control algae growth, were suggested to improve SB performance while maintaining particle removal efficiency.

3. The impact of mildly acidic naturally occurring seeps on the water quality of the basin was analyzed through computer modeling and laboratory sample analysis. The results were used to identify whether sedimentation basins enhance or attenuate the changes in water chemistry due the presence of acidic seeps.

4. BMPs were suggested to issues related to SB design based on design criteria followed in conventional water treatment sedimentation tank design. The issues addressed were (a) placement of baffles, (b) positioning of inlet and outlet, (c) shape of the SB and (d) the type of basin inflow and outflow structure.

1.2 PROJECT BACKGROUND

The Pennsylvania Department of Transportation (PENNDOT) is constructing the US Route 220/I-99/SR 6220 that is part of a larger effort to extend I-99 up to I-80 at Bellefonte, PA. Several SBs have been constructed onsite to collect the runoff from the site and remove suspended particles from them by retention. In order to evaluate their particle removal capacity, four basins were selected for monitoring. Between September 2004 and August 2005, ten sampling trips were conducted, during which water samples were collected from the basin inlets and outlets. The SB samples were analyzed for total suspended solids (TSS), total iron, magnesium, manganese, aluminum, calcium, sulfate and phosphate. The data showed peaks in concentrations of TSS and particulate contaminants including iron, aluminum, manganese, and phosphate that closely correlated to localized rainfall peaks. For certain samples, the concentration of TSS in the outlet was higher than the TSS concentration at the basin inlet, suggesting a possibility of sediment re-suspension. It was also found that TSS removal was significant only when the inlet TSS concentration is greater than 100mg/L. Further, during some of the sampling trips, effluent TSS concentration in the four basins was found to be higher than the daily maximum and daily average TSS limits for industrial Stormwater runoff (PADEP 2005). In general SBs managed high flows during wet weather events, but were not effective in capturing particulates. Evaluation of SB performance showed that, in order to reduce particulate contaminants present in soil sediments from being released into the environment, a methodology of design for SBs focusing on particle removal needs to be developed.

2.0 LITERATURE REVIEW

2.1 EROSION AND SEDIMENTATION CONTROL BMPS

Pennsylvania Department of Environmental Protection (PADEP) requires the implementation and maintenance of erosion and sediment control BMPs to minimize the potential for accelerated erosion and sedimentation, including for those activities (non-agricultural) which disturb less than 5,000 square feet (4,64.5 square meters). A written Erosion and Sedimentation Control Plan is required for earth disturbance activities that affect 5,000 square feet of land or more (Commonwealth of Pennsylvania, 2006). A review of literature was carried out in order to understand the BMPs prevalent for erosion, sedimentation and runoff control at construction sites. BMPs for erosion and sediment control for highway construction sites are measures designed to reduce the amount of sediment leaving a construction site and to prevent them from entering nearby surface waters (Johnson et al., 2003). Some of the BMPs associated with land disturbance and construction activities are sediment basins, sediment traps, silt fences, vegetative filter strips, straw bale barriers, rock filters and erosion control blankets (Pack et al., 2004). Several categories of runoff and erosion control BMPs are stated in the literature. Table 1 shows some general categories of runoff treatment BMPs. Table 2 lists common erosion and runoff control BMPs.

Table 1. General categories of storm water runoff treatment BMPs[a]

Major Categories	Treatment BMPs
Basins	1. Wet retention basin 2. Dry detention basin 3. Extended detention basin
Vegetative Filters	1. Grass swales (wet/dry) 2. Filter strip / buffer
Constructed Wetlands	1. Constructed wetland
Filters	1. Sand Filter 2. Perimeter filter
Technology Options and Others	1. Inlet filters 2. Multi chambered treatment train

[a]Table adapted from "Considerations in the Design of Treatment BMPs to Improve Water Quality", USEPA document 600/R-03/103, September 2002.

Table 2. Common erosion & sediment control BMPs[a]

BMP & Purpose
Velocity dissipation device - Physical device placed at the outlet of a pipe or channel to prevent scour of the soil caused by high velocity flows
Hydraulic mulch - A mixture of shredded wood fiber or a hydraulic matrix, and a stabilizing emulsion which temporarily protects exposed soil from erosion by raindrop impact or wind
Soil binder – Soil binders are materials applied to the soil surface to temporarily prevent water induced erosion of exposed soils on construction sites
Straw mulch - A uniform layer of straw incorporated into the soil with a studded roller or anchored with a tackifier stabilizing emulsion. Straw mulch protects the soil surface from the impact of rain drops, preventing soil particles from becoming dislodged
Geo-textiles and mats - Mattings of natural materials are used to cover the soil surface to reduce erosion from rainfall impact, hold soil in place, and absorb and hold moisture near the soil surface

Table 2. (Continued)

Wood mulching – Consist of applying a mixture of shredded wood mulch, bark or compost to disturbed soils. Its primary function is to reduce erosion by protecting bare soil from rainfall impact, increasing infiltration, and reducing runoff.
Earth dike and drainage swale - Temporary berm or ridge of compacted soil used to divert runoff to a desired location. A drainage swale is a shaped and sloped depression in the soil surface used to convey runoff to a desired location. They are used to divert off site runoff around the construction site, divert runoff from stabilized areas and disturbed areas, and direct runoff into sediment basins or traps.
Silt fence - A silt fence is made of a filter fabric that has been entrencher, attaché to supporting poles, and sometimes backed by a plastic fence or wire mesh for support. It detains sediment laden water promoting sedimentation behind the silt fence
Sedimentation trap - A sediment trap is a containment area where sediment-laden runoff is temporarily detained under quiescent conditions, allowing sediment to settle out or before the runoff is discharged. Sediment traps are formed by excavating or constructing an earthen embankment across a waterway or low drainage area.
Sedimentation basin - A sediment basin is a temporary basin formed by excavation or by constructing an embankment so that sediment-laden runoff is temporarily detained under quiescent conditions, allowing sediment to settle out before the runoff is discharged.
Check dam - A check dam is a small barrier constructed of rock, gravel bags, sandbags, fiber rolls, or reusable products, placed across a constructed swale or drainage ditch. Check dams reduce the effective slope of the channel, thereby reducing the velocity of flowing water, allowing sediment to settle and reducing erosion.
Gravel bag berm – A gravel bag berm is a series of gravel-filled bags placed on a level contour to intercept sheet flows. Gravel bags pond sheet flow runoff, allowing sediment to settle out, and release runoff slowly as sheet flows, preventing erosion.
Sand bag barrier - A sandbag barrier is a series of sand-filled bags placed on a level contour to intercept sheet flows. Sandbag barriers pond sheet flow runoff, allowing sediment to settle out
Straw bale barrier – A straw bale barrier is a series of straw bales placed on a level contour to intercept sheet flows. Straw bale barriers pond sheet flow runoff, allowing sediment to settle out

[a]Table adapted from California Storm Water Association Construction Storm Water BMP handbook, 2004

A number of papers discuss BMPs for runoff control (Pack et al., 2004; Stevens et al., 2004; Persson et al, 2003; Starzec et al., 2005). Vegetated buffer strips and swales in the roadside environment have been found to be useful in reducing pollutant concentrations and increasing the infiltration of annual storm water (Barrett, M. E., 2004; Pack et al., 2004). Swales in good condition have been shown to be capable of removing up to 70% TSS, 30% phosphorous, 25 % nitrogen and 50-90 % of various trace metals (Pack et al., 2004). In these vegetated controls a minimum vegetation cover of 70% was required for concentration reduction. It has also been suggested that for pollutant removal the optimum cross-section geometry for highway medians is V-shape or parabolic rather than trapezoidal geometry as normally illustrated in guidance manuals (Barrett, M. E., 2004). Han et al., have reported that in the case of vegetated filter strips, condition of vegetation and length of the strip are the major factors affecting the performance of the strip (Han et al., 2005).

The structural BMPs discussed in literature include silt fences, SBs and constructed treatment wetlands (Stevens et al., 2004; Persson et al., 2003; Rohrer et al., 2004; Schuster et al., 2004; Rapp et al., 2004; Carleton et al., 2000). Silt fences are among the most common structural BMPs implemented for sediment control at construction sites. Investigation reveals that silt fences remove particles by allowing them to settle in a pool of water held behind the silt fence and not by filtering (Pack et al., 2004). Stevens et al., in their study on the performance of silt fences, state that silt fences have marginal trapping efficiency of only about 50%. They recommend that for the prevention of undercutting of silt fences, on-contour installation and proper trenching in at the toe are essential. They also stress on the necessity for further work on structural modification of silt fences (Stevens et al., 2004).

Another structural BMP for runoff control is the surface flow wetland. In a study of hydraulic conditions that affect the performance of surface flow wetlands, it has been suggested that for comparing different design solutions with each other, hydraulic efficiency factor (defined as the time of peak outflow concentration divided by the nominal residence time) may be used (Persson et al., 2003). Carleton et al., (2000) conducted an investigation of pollutant removal performance of constructed wetlands. They conclude that a dry detention basin could be converted into a storm water wetland by the simple addition of an outlet weir. In their study, a constructed urban marsh was established in a former dry detention basin. The site retrofit included re-grading and removal of existing cattail stands, followed by establishment of a 1.5-foot weir at the basin outlet, and the planting of over 3,000 plugs of native emergent plants within the facility. The outlet weir was designed to detain additional vertical (extended detention) storage above the permanent pool. They suggest that this approach would provide a low-cost retrofit to improve water quality at older detention facilities.

2.2 WATER QUALITY ISSUES OF SEDIMENTATION BASINS

A review of literature to identify the impacts of highway construction on the environment reveals several studies that discuss either negative impacts or negligible impacts on water quality and habitat. A study of water quality impacts due to highway construction on water-supply lakes indicates increase in turbidity, total suspended solids and manganese concentration (Tan et al., 1978). Biogeochemical analyses of the impact of the Richard B. Russell Scenic Highway on Dukes Creek, White County, Georgia, has shown that geochemical characteristics of the watershed have a greater influence on Dukes Creek than the highway (Nixon R. A., 1978). A study of the impact of highway construction on a north Florida watershed has shown that highway construction resulted in an increase in turbidity, suspended solids, total P and dissolved Si in downstream waters, whereas dissolved P and N were not increased (Burton et al, 1976). A study on the trace metal leachability from highway construction solid wastes (HCSW) indicates low risk of surface and ground water contamination (Olajire et al., 2005). The impacts of acidic rock drainages (ARD) resulting from construction activities on water quality have been discussed in the literature by Daniels and Orndorff, (2003). The acidity resulting from these drainages are found to range from <10 to >100 mg CaCO3 equiv / 1000 mg material. Acidic (pH 3.0; Fe >45 mg/L) runoff from the site was found to heavily damage a receiving stream, partially because it dissolved the galvanized steel water control structures in storm water detention basins leading to direct discharge of runoff and sulfidic sediment. Kalin (2004) in his study advocates the use of phosphate as a likely inhibitor of mineral weathering which leads to acidic runoff.

Studies on the impacts of highway construction on aquatic habitats has showed that contaminants from highway runoff can reduce the decomposition of plant detritus in streams affecting the food cycle of stream invertebrates. Shredders (crayfish, sowbugs) are a class of invertebrates that consume decomposed plant matter in stream pools breaking them down into smaller particles or fecal pellets consumable by other stream fauna. A study showed that contaminants from highway runoff tend to reduce the quality of detritus, reducing leaf processing by shredders due to direct toxicity from the contaminants, thus affecting the food cycle and stream community (Furrow et al, 200). Another study showed that leaf processing in a riffle below the highway was slower than the reference riffle, and shredders were reduced in number. Further removal of streamside vegetation during highway construction caused increased stream temperatures and reduced the amount of natural leaf accumulations, thereby reducing shredder habitat (Stout et al., 1989). Assessment of the impacts of motorway runoff on a basin, stream and wetland showed that highway runoff has long term impacts on wetland and wetland habitat (Sriyaraj and Shutes, 2001). Another environmental issue associated with construction site SBs is the possibility of mosquito breeding and constructed wetlands have been viewed as "mosquito-friendly habitats" (Knight et al., 2003). Studies show that typical mosquito cycle ranges from 7 to 18 days (National Center for Infectious Diseases, 2004; Westchester County Department of Health, 2006; Cornell University Center for the Environment, 2002, The American Mosquito Control Association, 2006; University of Florida, 1995). Retention of water in the sedimentation basins for seven days or longer can lead to mosquito growth in them causing sedimentation basins to turn into mosquito friendly habitats.

2.3 SEDIMENTATION BASINS

Sedimentation Basins are structural BMPs that are widely used for erosion and sedimentation control. In addition to sediment removal, they also serve as runoff infiltration trenches and as structures to capture the first flush of rainfall in the event of a highway spill. A study of 200 detention basins was conducted in Sweden to evaluate their performance for the treatment of highway runoff (Starzec et al., 2005). This study revealed that many basins do not function optimally in terms of their pollution retention capacity. They also found that the observed sediment thickness in the detention basins was lower than expected indicating turbulent conditions and sediment loss. Their studies showed that metal removal was affected significantly by basin size and not by basin shape. Statistically significant differences in metal content in sediment with regard to basins size were found; sediment in small basins (surface area

$<100m^2$) showed significantly higher metal content than in large basins (area$>1,000m^2$) whereas differences between small and medium-size ($100\ m^2 < \text{area} < 1,000\ m^2$), and medium size and large basins were found to be insignificant. Basin geometry/shape did not show any significant impact on the metal accumulation rate since no differences in the metal content between circular and elongated basin shapes could be statistically validated. Starzec et al., have concluded that there is still significant potential for the development of the design and technical function of the basins, such as improving the design elements and elements for enhancing hydraulic efficiency (Starzec et al., 2005). In another study, of three detention basins in southern Sweden, it was found that concentrations of total-N, Cd, Cu, Pb and Zn were higher in the basin effluents, than what would be expected based on background water concentration. The study suggests that the possible explanation for the high contaminant concentration could be that the basins were not correctly dimensioned or that sediment sludge was mobilized. This study stresses the need for further improvement in detention basin design (Lundberg et al, 1999).

2.4 CURRENT SEDIMENTATION BASIN DESIGN PRACTICES

The existing design criteria for construction site SBs for Pennsylvania requires that a 1,000 cu ft sediment storage zone per disturbed acre within the watershed and a drainage zone of 5,000 cubic feet for each acre tributary (the land area that drains to one of the smaller streams that flow to the main channel of a watershed) to the basin be provided (PADEP, 2000). According to EPA, 3,600 cubic ft of storage per acre drained should be provided for SBs that serve an area with 10 or more disturbed acres at one time (Stormwater Management for Construction Activities Manual, 1997). PADEP design criteria also suggests a drainage time of 4 to 7 days for SBs

(PADEP, 2000). The site specific design for SBs at the I-99 construction site shows that the SBs have been designed according to existing PADEP design criteria cited above. Consequently, overflow rate or particle removal was not considered in the basin design. There appears to be no holistic procedure for arriving at SB volume, sediment storage zone volume, sediment dredging frequency and basin drainage time. Pennsylvania BMPs for SBs suggest that 75 to 90 % of total annual rainfall should be captured while managing runoff for water quality. In addition, the use of RUSLE for selecting alternative BMP configurations for erosion and sedimentation control has been suggested (Pennsylvania Association of Conservation Districts (PACD), 1998). However from review of literature and existing design criteria for SB design, it appears that an integrated and rational method for designing SBs for particle capture, runoff control and identification of appropriate sediment dredging frequency is necessary. As several factors affect the performance of sedimentation basins, it would be more appropriate to design sedimentation basins case by case according to the nature of the construction site and drainage basin.

2.5 CONCLUSIONS FROM LITERAURE REVIEW

The following conclusions can be drawn from literature review:

1. In the past, BMPs for controlling construction site runoff concentrated primarily on reducing the quantity of runoff rather than the quality of runoff. There is a current focus in research and practice to use the erosion and runoff control structures for both quality and quantity control of the runoff.
2. Although vegetated BMPs such as vegetated swales and shoulders are developing to be promising low cost alternatives, SBs still play a major role in stormwater runoff treatment

and control. In addition to removing suspended solids and providing for runoff infiltration, they also protect the downstream water quality and ecosystem from the negative impacts of construction site erosion.

3. Several case studies on the performance of SBs show that SBs are useful in removing suspended solids, however their efficiency is less than or equal to 50% and any attempt to increase their efficiency rapidly increases installation and maintenance cost involved. Studies have also showed sludge mobilization in SBs leading to an increase in particulate contaminants in the outlet.
4. In order to improve the performance of SBs it is necessary to investigate the basis of their current design and the extent to which the current design is efficient. A systematic method for the design of SB needs to be developed based on rainfall data, sediment yield and overflow rate.

Based on the literature search, the following erosion and runoff control Best Management Practices have been suggested for highway construction sites to PENNDOT as a deliverable of the project:

1. Erosion and runoff control structures should be designed for capturing runoff as well as for improving the quality of runoff.
2. Vegetated swales and buffers can be used as low cost alternatives for reducing and treating storm water runoff.
3. Silt fences should be installed properly on contours and maintained regularly for good performance.

4. Sedimentation basins are effective erosion and sedimentation control BMP provided they are designed by integrating rainfall runoff capture, particle removal and sediment dredging frequency.

3.0 PRELIMINARY STUDIES

3.1 SEDIMENTATION BASIN SELECTION

Four SBs at the "I-99 construction site" were chosen for monitoring during the period of August 2004 to August 2005. The basins chosen were SB-11, SB-14, SB-103 and SB-111. Topographical maps of sedimentation basins are shown in appendix D. The location of I-99 site on PA map is shown in Figure 1 and the positioning of the SB11 basin along the highway construction area is shown as an example in Figure 2. These basins were chosen in particular for the following reasons:

1. SB-11 – Receives runoff from a drainage basin involved in hydrologic monitoring and modeling to predict the quantity of runoff from the construction site.
2. SB-14 – Has highly turbid discharge.
3. SB-103 – Receives acid mine drainage type constituents from seeps along the banks of the basin.
4. SB-111 – Has a highly disturbed drainage area due to constructional activity.

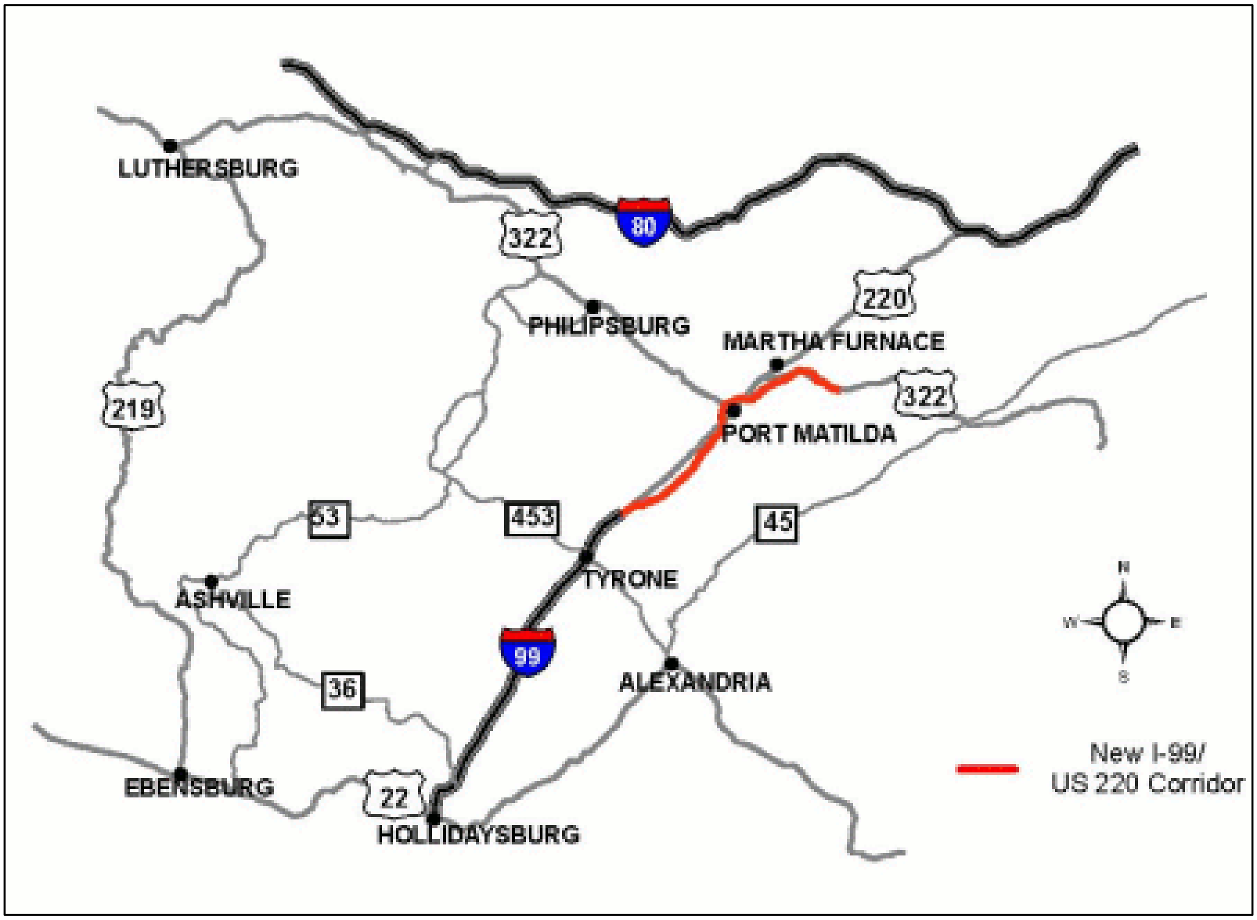

Figure 1. Location of I-99 corridor on PA map

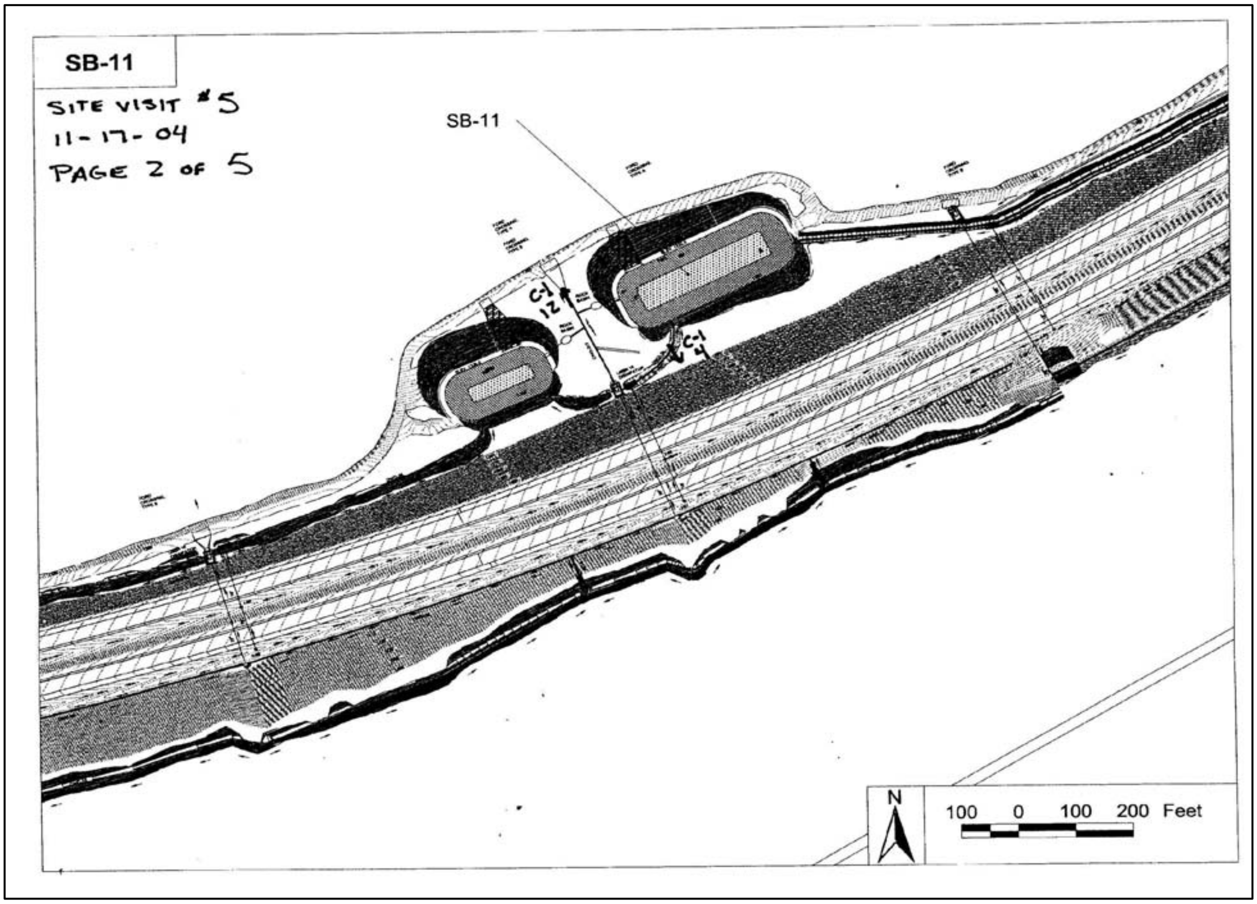

Figure 2. Position of SB10 and SB11 down stream of the construction site

3.2 SAMPLING PROTOCOL

Ten sets of samples from SB inlets and outlets (SB11, SB14, SB103, and SB111) were collected on the following dates: September 22, 2004; October 5, 2004; October 20, 2004; November 3, 2004; November 17, 2004, December 1, 2004; April 21, 2005, May 4, 2005; June 23, 2005 and July 26, 2005 by Uni-Tec Consulting Engineers Inc and were sent to the University of Pittsburgh, Department of Civil and Environmental Engineering Lab. Chain of custody forms, field sampling data forms, photo logs and photo location maps were also sent along with each set of samples (see appendix G). The chain of custody form lists the sample details such as the basin number and whether the sample is from the basin inlet or outlet. The field sampling data form gives the pH and color of the sample at the time of sampling. It also includes additional comments such as the presence of seeps, absence of flow in the inlet or outlet or any other noticeable aspects of the SBs. The photo log explains each photograph taken and the photo location maps show the location at which the photographs were taken. Due to the absence of flow into the inlet of the basin at the time of sampling, samples from the inlets were not obtained during certain field visits. Samples from the outlet were available during every visit.

3.3 LABORATORY SAMPLE ANALYSIS

The SB influent and effluent samples were analyzed for the following parameters in the lab:

1. pH
2. True color (color of filtered samples)
3. Apparent color (color of unfiltered samples)
4. Turbidity (filtered and unfiltered)
5. Total suspended solids
6. Volatile suspended solids
7. Iron (total and dissolved)
8. Magnesium (total and dissolved)
9. Manganese (total and dissolved)
10. Aluminum (total and dissolved)

11. Calcium (total and dissolved)
12. Sulfate (total and dissolved)
13. Phosphate (total and dissolved)

The following additional tests were performed on samples obtained from the last three sampling trips:

1. Ammonia
2. COD
3. Alkalinity
4. TOC
5. Na (total & dissolved)

The data obtained through analysis is tabulated in Appendix A. All analysis was performed in accordance with Standard Methods for the Examination of Water and Wastewater (APHA, 2005) EPA methods (EPA, 2005) or Hach methods (Hach, 2002). Total concentrations of metals were measured by digesting the unfiltered water samples using microwave digestion. The procedure for microwave digestion was adapted from EPA method 3015 (USEPA, 1994). Forty mL of water sample was mixed with 8 mL nitric acid and 2 mL hydrochloric acid and digested in a CEM-MARS brand microwave digester. During digestion the temperature was ramped to 170^{o} C in the first 15 min and then held at 170^{o} C for 15 min. Dissolved concentrations were measured by filtering the samples through 0.45 micron filter and digesting the filtrate. A plot of the concentrations of the various components analyzed for, are shown below in Figure 3 through Figure 18 for each sampling trip.

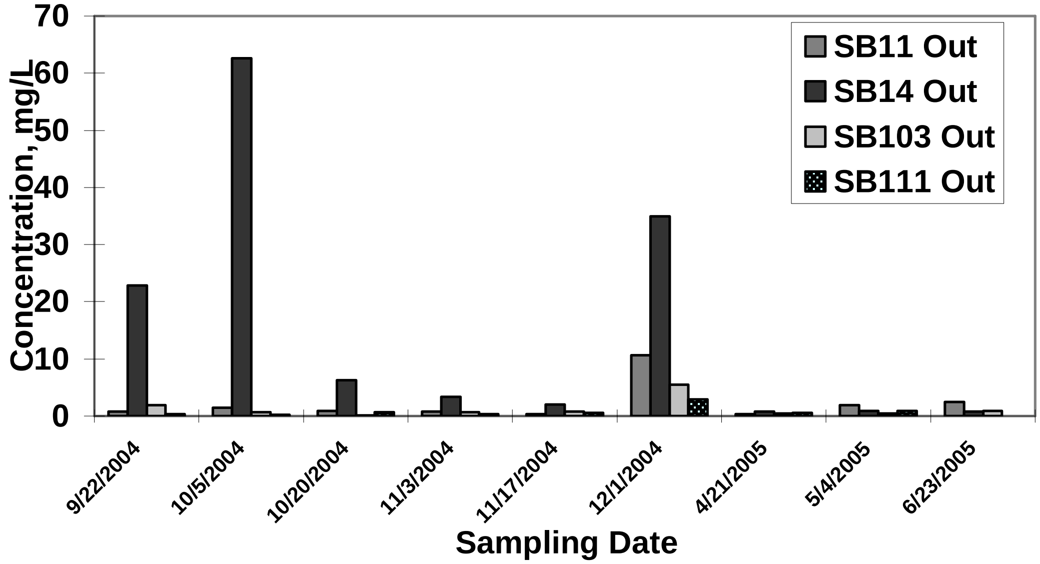

Figure 3. Total iron concentration in the pond outlets for each sampling trip

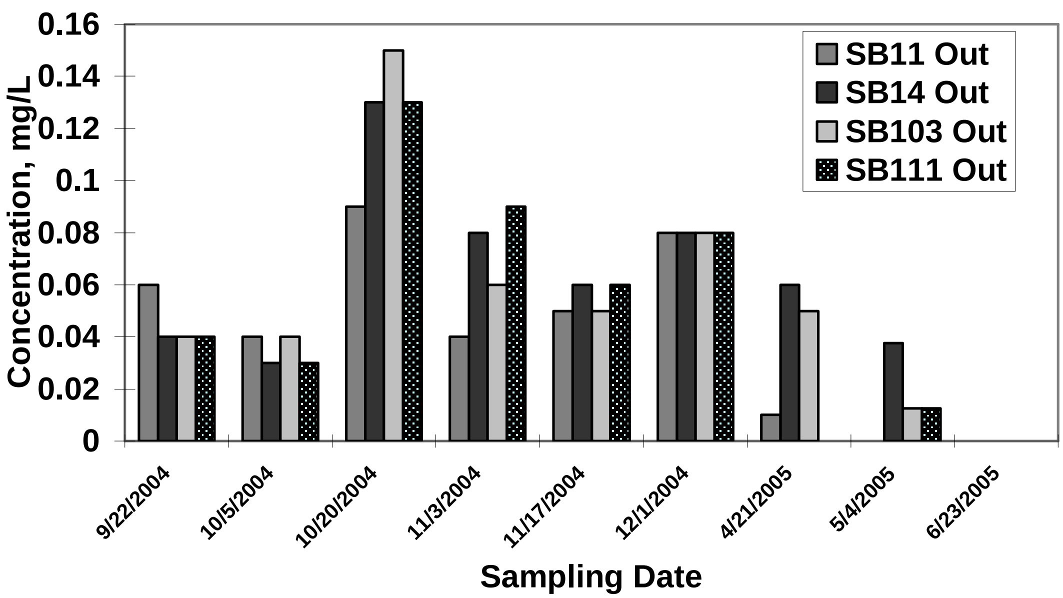

Figure 4. Dissolved iron concentration in the pond outlets for each sampling trip

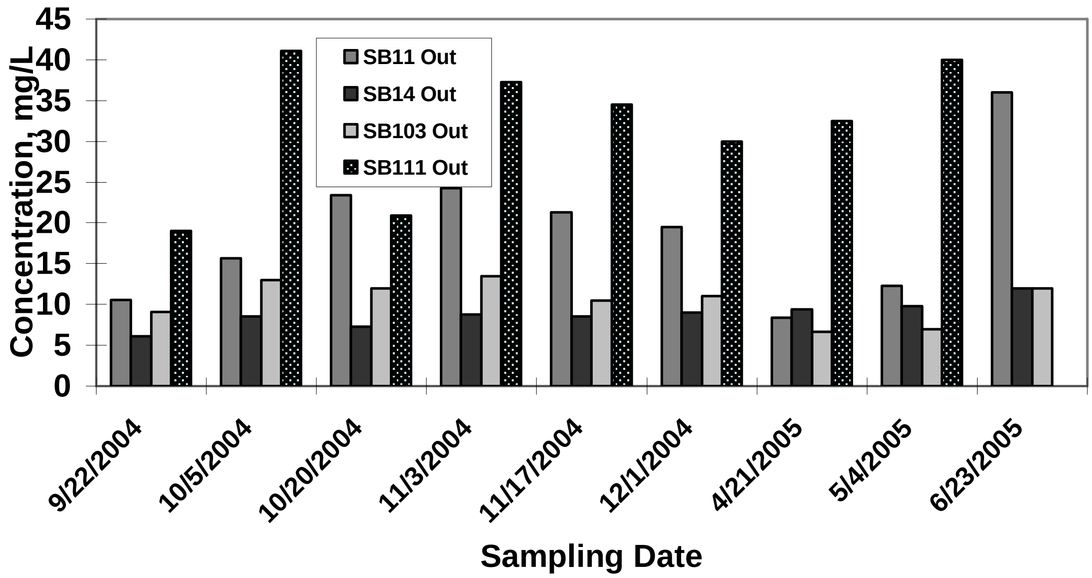

Figure 5. Total magnesium concentration in the pond outlets for each sampling trip

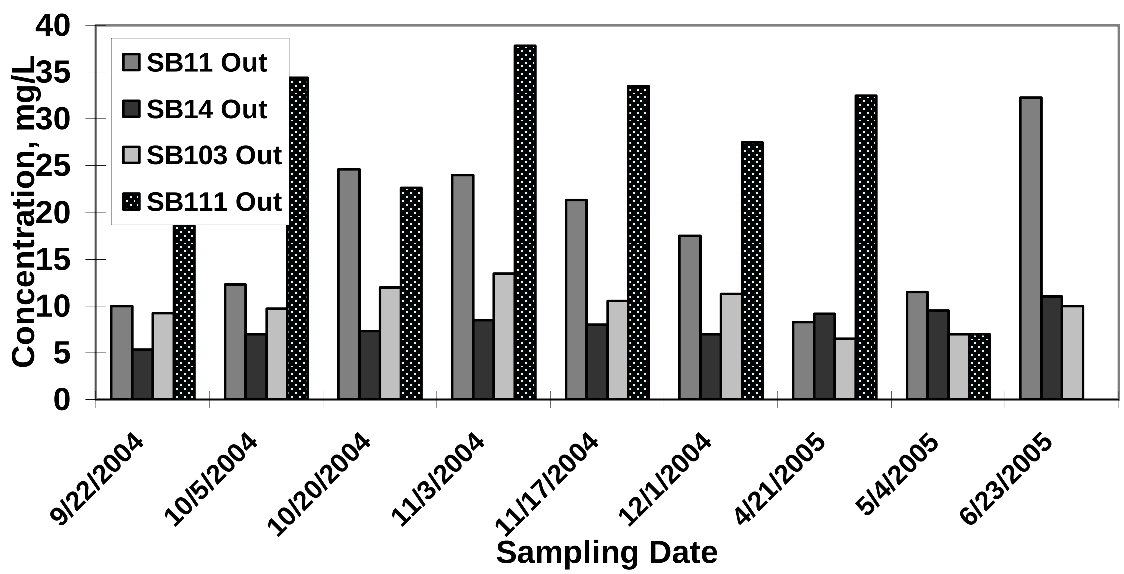

Figure 6. Dissolved magnesium concentration in the pond outlets for each sampling trip

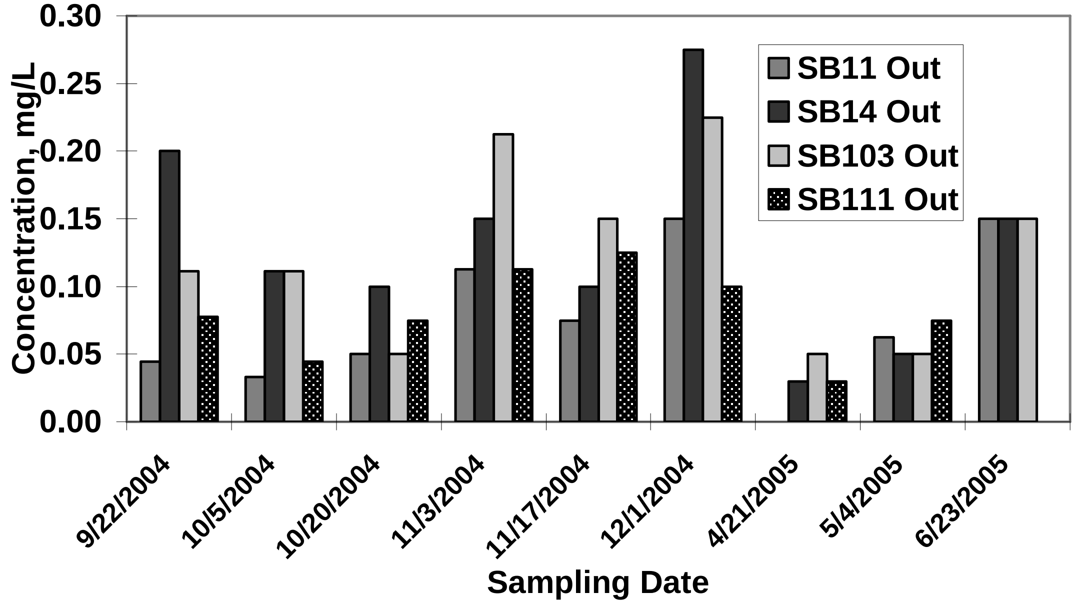

Figure 7. Total manganese concentration in the pond outlets for each sampling trip

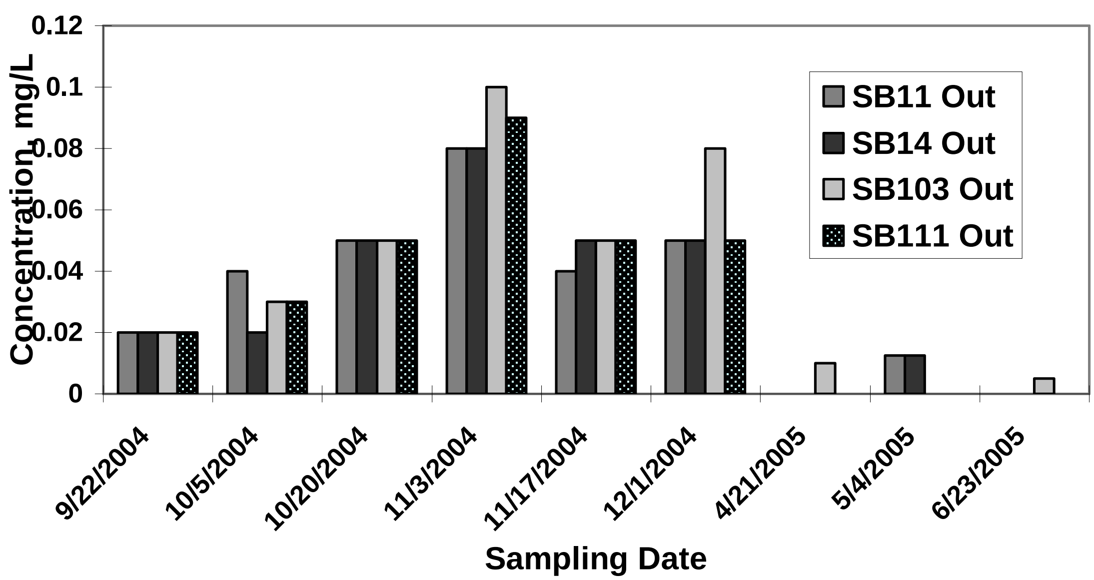

Figure 8. Dissolved manganese concentration in the pond outlets for each sampling trip

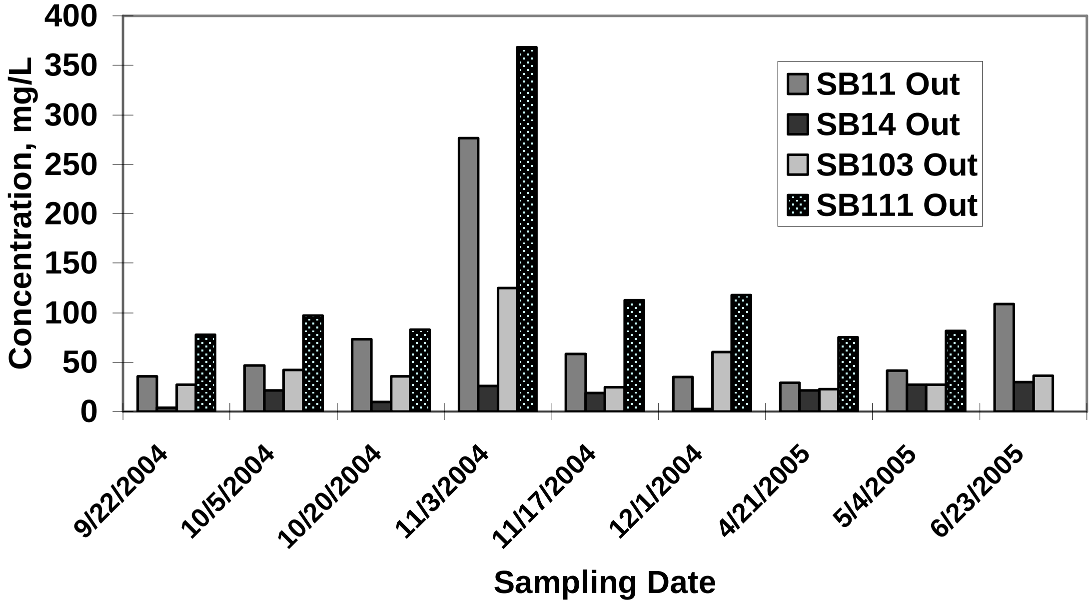

Figure 9. Total calcium concentration in the pond outlets for each sampling trip

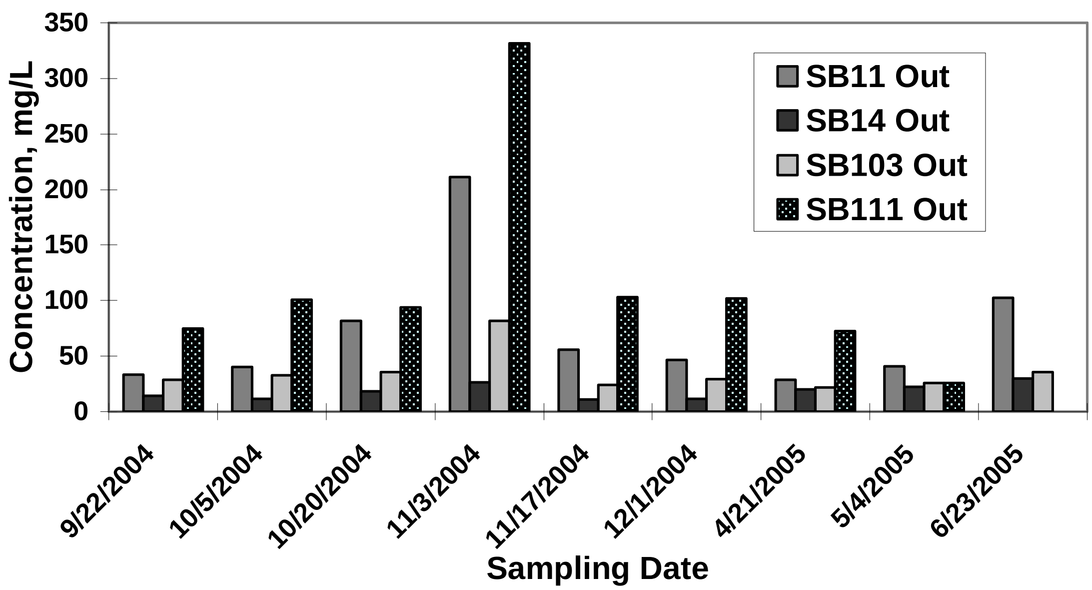

Figure 10. Dissolved calcium concentration in the pond outlets for each sampling trip

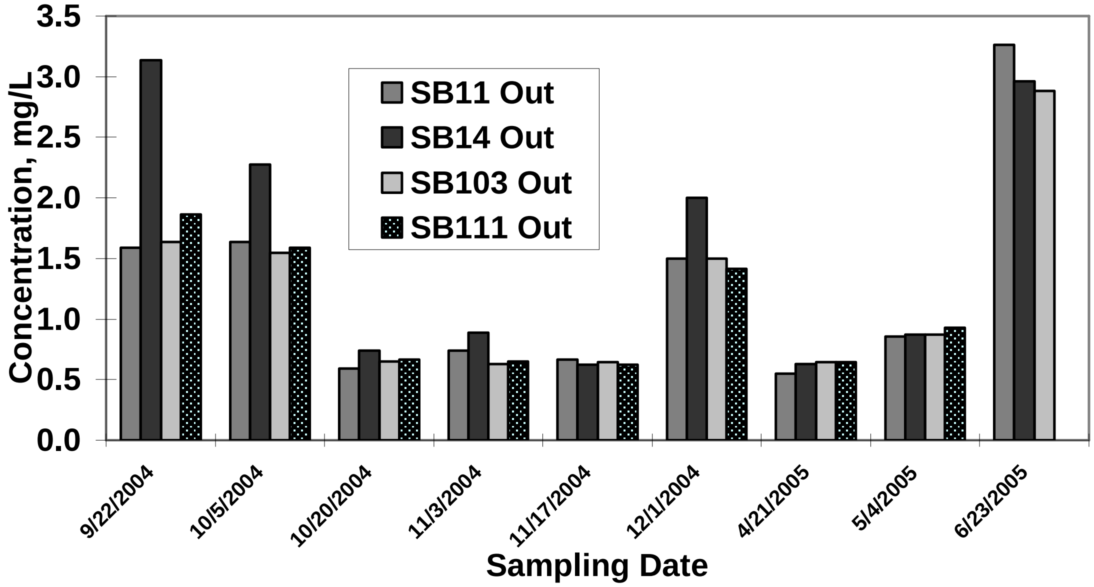

Figure 11. Total aluminum concentration in the pond outlets for each sampling trip

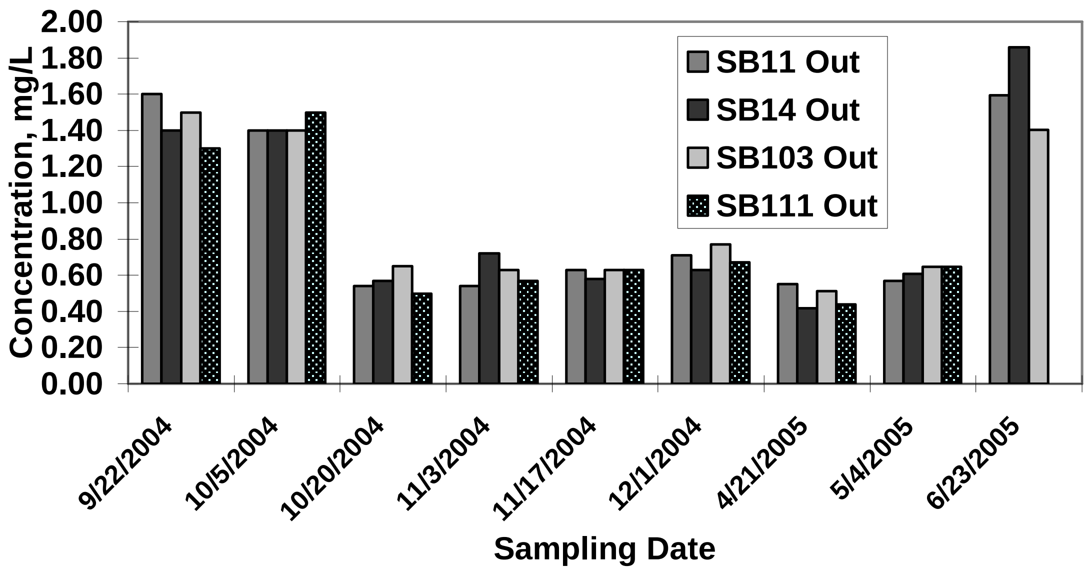

Figure 12. Dissolved aluminum concentration in the pond outlets for each sampling trip

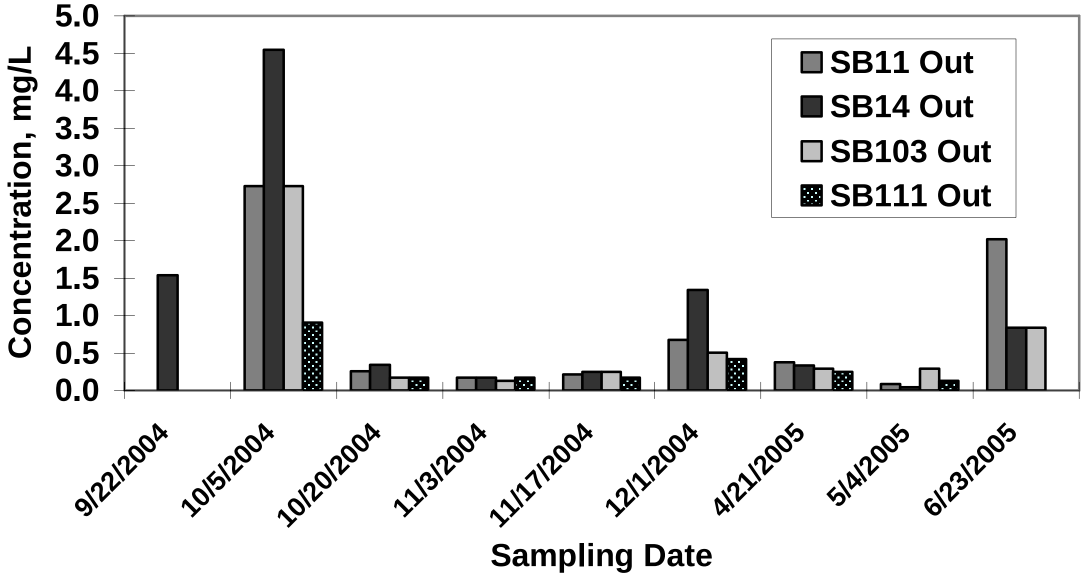

Figure 13. Total phosphate concentration in the pond outlets for each sampling trip

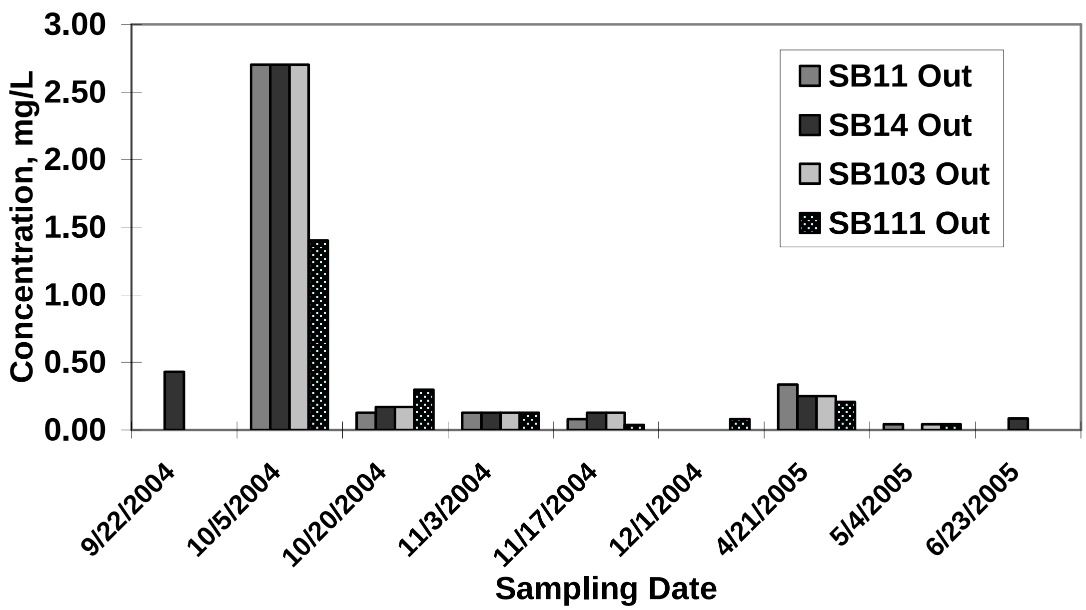

Figure 14. Dissolved phosphate concentration in the pond outlets for each sampling trip

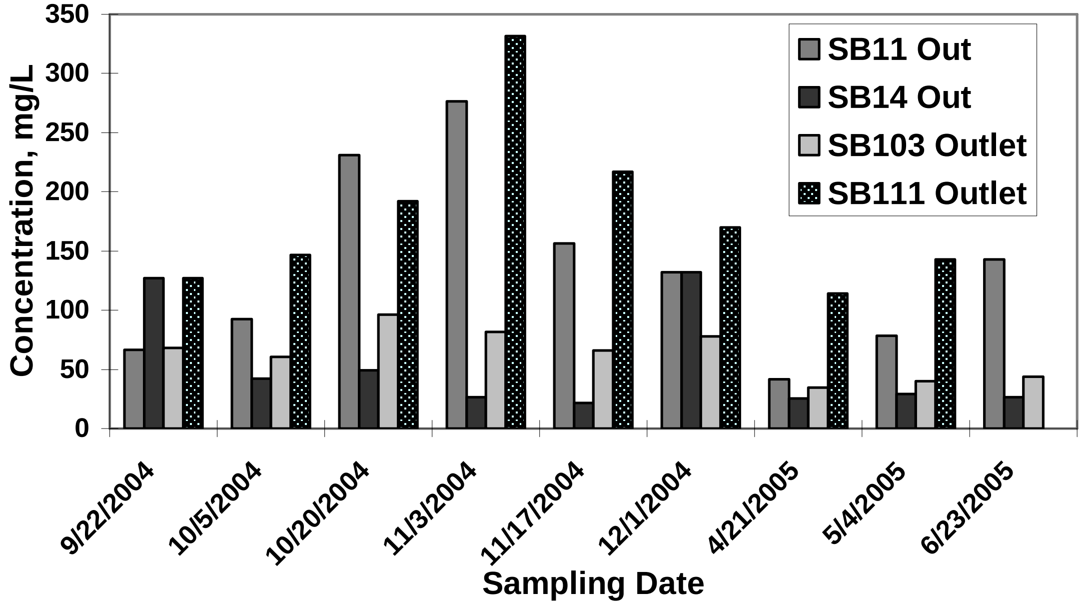

Figure 15. Total sulfate concentration in the pond outlets for each sampling trip

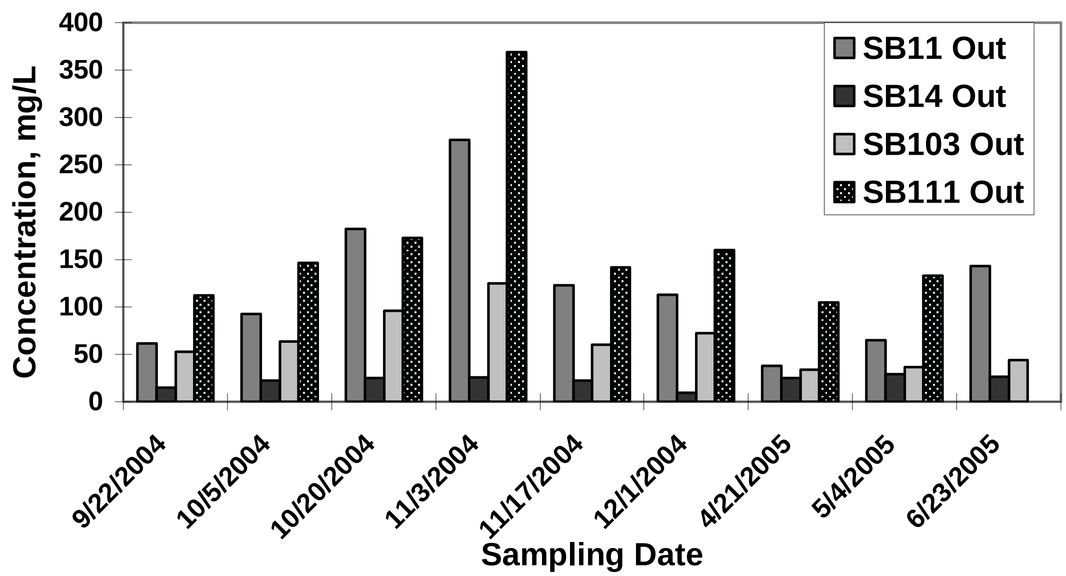

Figure 16. Dissolved sulfate concentration in the pond outlets for each sampling trip

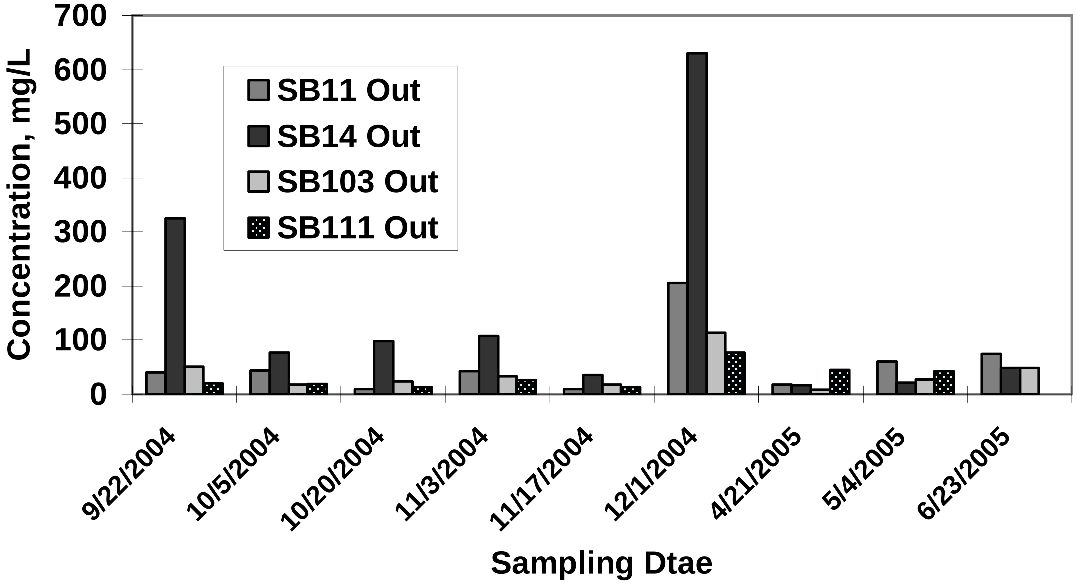

Figure 17. TSS concentration in the pond outlets for each sampling trip

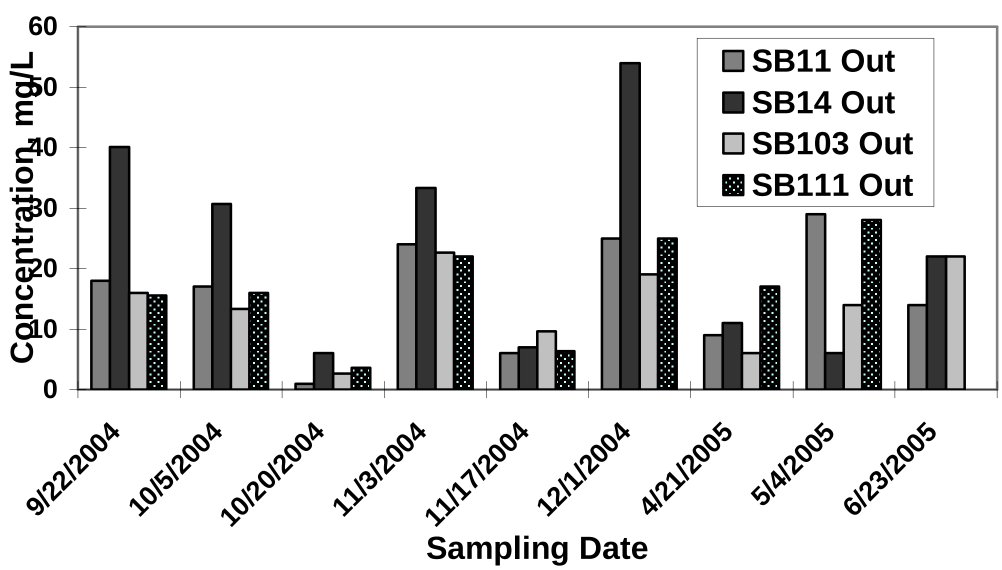

Figure 18. VSS concentration in the pond outlets for each sampling trip

Figure 3 to Figure 18 help in observing the variation in iron, magnesium, manganese, calcium, aluminum, phosphate, total suspended solids (TSS) and volatile suspended solids (VSS) in the SBs. It can be observed that total and dissolved magnesium, calcium and sulfate are generally high in SB111 effluent. This may be due to the presence of dolomite (as found in the geological investigation of the highway construction location), rich in calcium and magnesium sulfate in the drainage basin of SB111 (Skelly & Loy, 2006). SB14 was observed to be generally high in turbidity during field visits. It can be seen from Figure 17 that SB14 also has higher TSS concentration compared to the other basins. Due to high TSS concentration SB14 also has high concentrations of particulate contaminants such as iron, phosphate, VSS and aluminum to some extent. While phosphate appears to occur primarily in the basin sediments, its presence cannot be explained by geology. During field visits it was observed that the side slopes of the basins were heavily fertilized. It would be reasonable to assume that the fertilizers used to promote vegetation on the basin side slopes resulted in dissolved phosphate in the runoff which then got adsorbed to the basin sediments. Hence SB14 with high TSS concentration also has high phosphate and VSS concentration. SB103 shows high concentration of dissolved manganese, probably due to the presence of naturally occurring mildly acidic seeps (pH 5-6) in the vicinity of this basin. The average dissolved aluminum concentration in the basin outlets is about 0.9 mg/L for all the four basins (Table 11) suggesting that this concentration may be the solubility limit for aluminum at the existing pH and geological conditions in the basins.

3.4 SUSPENDED SOLIDS REMOVAL BY THE BASIN

The National Pollution Discharge Elimination System (NPDES) permit for construction activities in PA requires meeting the existing "PA Chapter 102, Erosion Control Rules and Regulations" and emphasizing pollution prevention through the use of BMPs. The program requires all earthmovers to develop, implement, and maintain erosion control measures and facilities that are detailed in an erosion and sedimentation (E&S) plan. But specific effluent limits and sampling requirements are not required (Commonwealth of Pennsylvania, 2006; PADEP, 2004).

As one example, storm water limits for industrial sites (Table 3) have been suggested and can be considered a possible basis for highway construction site point discharges as well. The proposed discharge limits for some of the acid rock treatment basins on the I-99 construction site according to PADEP National Pollution Discharge Elimination System Permit (Dated: October 16, 2006) are summarized in Table 3.

Table 3. Effluent TSS limits (mg/L) for stormwater discharge from industrial sites[a]

Runoff Type	Instantaneous Maximum	Daily Maximum	Weekly Average	Monthly Average	Annual Average
Industrial storm water runoff	60-100	45-100	45	30	50
I-99 acid rock treatment basin runoff	16-90	12-70	-	8-35	-

[a]At the present time there are no generalized numeric effluent limits of construction site storm water runoff (PADEP, 2005).

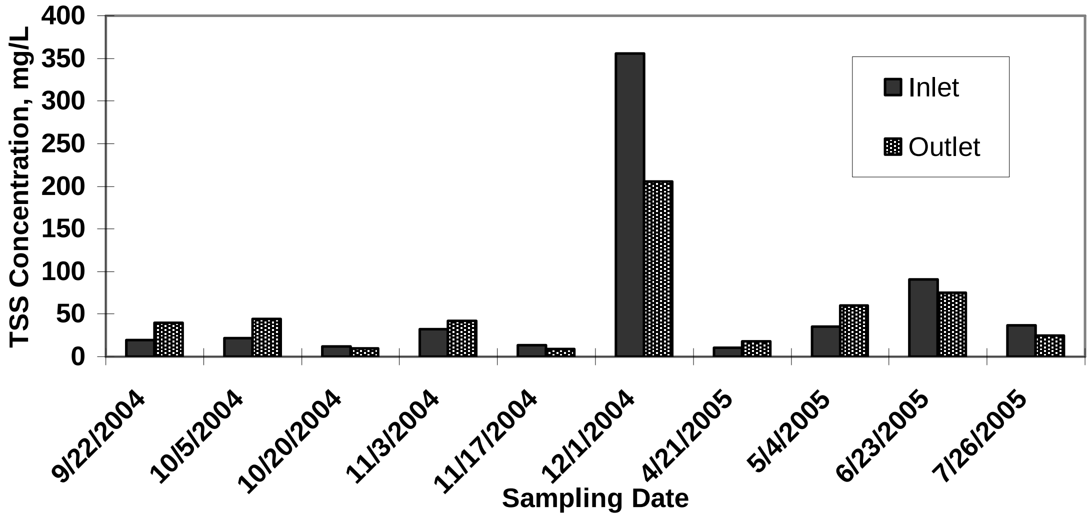

Figure 19. Variation in average inlet and outlet concentration for SB11[a]

[a]There appears to be no significant difference in the inlet and outlet TSS concentration except for one sample where the influent TSS concentration is very high (>300 mg/L). At some points the TSS concentration in the outlet is higher than the inlet. The figure shows the basins are not efficient at removing particulates at low concentrations and there may be sediment mobilization.

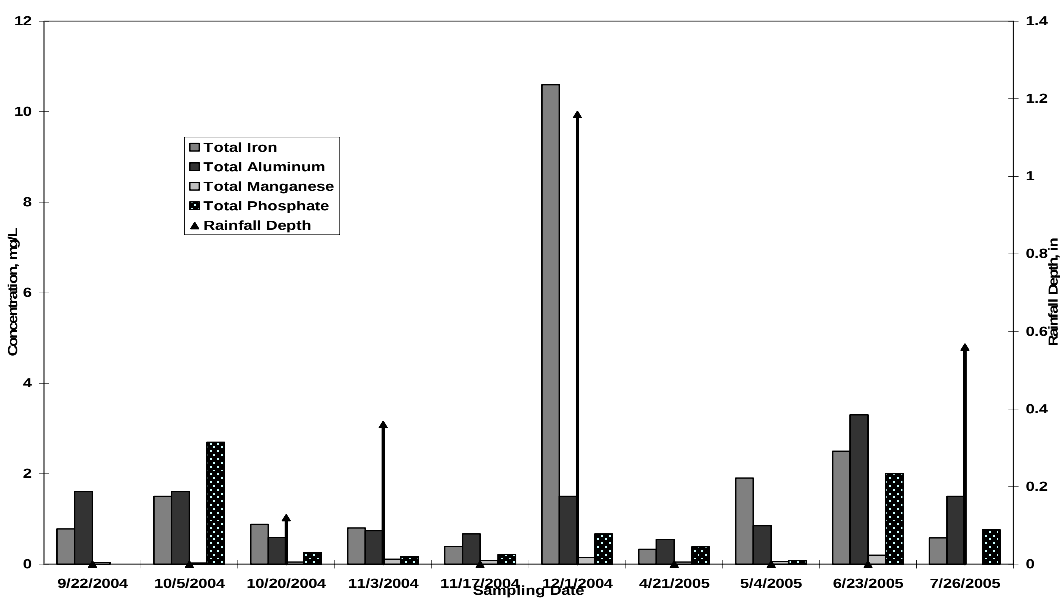

Figure 20. Variation in particulate contaminants in SB11 outlet with rainfall peaks[b]

[b]Peaks in total iron, total aluminum, total manganese and total phosphate can be observed to match with rainfall peaks indicating that SB11 is not very efficient in attenuating sediment and pollutant peaks during high flow conditions.

Table 4. Total suspended solid concentration (mg/L) for SB samples[a]

Sample Date	SB11 Inlet-1	SB11 Inlet-2	SB11 Avg Inlet	SB11 Outlet	Removal %	SB14 Inlet-1	SB14 Inlet-2	SB14 Avg Inlet	SB14 Outlet	Removal %
09/22/04	23	16	19.5	40.0	-105	No flow	No flow	No flow	325	
10/5/04	25	18	21.5	44.0	-105	No flow	No flow	No flow	77	
10/20/04	12	12	12.0	10.0	17	No flow	No flow	No flow	98	
11/3/04	37	28	32.5	42.0	-29	No flow	No flow	No flow	107	
11/17/04	16	11	13.5	9.0	33	No flow	No flow	No flow	35	
12/1/04	62	650	356	206	42	1442	168	805	630	21.7
4/21/05	12	9	10.5	18.0	-71	No flow	No flow	No flow	17	
5/4/05	46	24	35.0	60.0	-71	No flow	No flow	No flow	21	
6/23/05	91	No flow	91.0	75.0	18	No flow	No flow	No flow	48	
7/26/05	40	34	37.0	25.0	32	No flow	No flow	No flow	54	
Avg	36	89	63	53	-24	1442	168	805	141	22
Max	91	650	356	206	42	1442	168	805	630	22

[a]"No Flow" indicates that no samples were available due to absence of flow in the inlets or outlets during some sampling trips. When ever two inlets are provided to the basin the average concentration of the two inlets were used as influent concentration.

Table 4. Continued[a]

Sample Date	SB103 Inlet	SB 103 Outlet	Removal %	SB111 Inlet	SB111 Outlet	Removal %
Sep/22/04	No flow	51		No flow	20	
Oct/5/04	No flow	18		No flow	19	
Oct/20/04	No flow	24		4	13	-225
Nov/3/04	No flow	33		No flow	26	
Nov/17/04	No flow	17		No flow	13	
Dec/1/04	91	114	-25	116	77	33.6
Apr/21/05	No flow	8		No flow	45	
May/4/05	No flow	27		No flow	43	
Jun/23/05	No flow	48		No flow	No flow	
Jul/26/05	No flow	40		No flow	No flow	
Average	91	38	-25	60	32	-96
Maximum	91	114	-25	116	77	34

[a]"No Flow" indicates that no samples were available due to absence of flow in the inlets or outlets during some sampling trips. When ever two inlets are provided to the basin the average concentration of the two inlets were used as influent concentration.

A TSS data summary from laboratory analysis of SB influent and effluent is shown in Table 4. These data indicate that TSS removal is significant only when the TSS concentration at the inlet is close to 100 mg/L (Figure 19, Table 4). Furthermore, the average TSS concentration in the outlet is greater than 50 mg/L, which is the suggested average annual TSS concentration for industrial stormwater runoff as shown in Table 3. For both SB11 and SB14, several peaks in TSS concentration can be observed where TSS exceeds 100mg/L (instantaneous maximum). From the TSS data summary in Table 4, and the variation in inlet and outlet TSS concentration for SB11 in Figure 19, it appears that the SBs have not been designed for particle removal or attenuation of peaks in particulate pollutant concentration during high flow conditions. From Figure 20 it can be seen that the there is an increase in contaminant concentration when there is a peak in the rainfall event. Also we see from Table 4 that there are several instances were the SB effluent exceeds TSS effluent limits listed in Table 3.

The data presented in Table 3 and Table 4, show that if in the future stringent effluent limits are applied to construction sites, then the present system of designing SBs will not provide the desired particle removal. Further it appears from Figure 20 that the current design of SBs has to be improved further to attenuate peaks in particulate pollutant concentration during heavy rainfall events. In order to optimize the performance of sedimentation basins it is necessary to develop a methodology for designing SBs such that desired levels of particulate removal and attenuation of peaks in particulate pollutants can be achieved under both low and high flow conditions.

3.5 RAINFALL DATA CORRELATION

Twenty four hour rain fall data was obtained from “Automatic Flood Warning Systems” database for a location about 3 miles from the construction site (Station No: 2871, Flat Rock, Center County, PA,) and for the days on which the SB samples were collected. The concentrations of various contaminants obtained from laboratory analysis of SB samples were plotted along with rainfall data (as a function of time). Laboratory analysis of SB samples showed that the percentage of particulate fraction of iron, phosphate, manganese and aluminum were 91%, 65%, 56% and 38% respectively. It can be seen from Figure 21 to Figure 25 that peaks in iron, phosphate, manganese, aluminum and TSS concentration correlated with rainfall peaks.

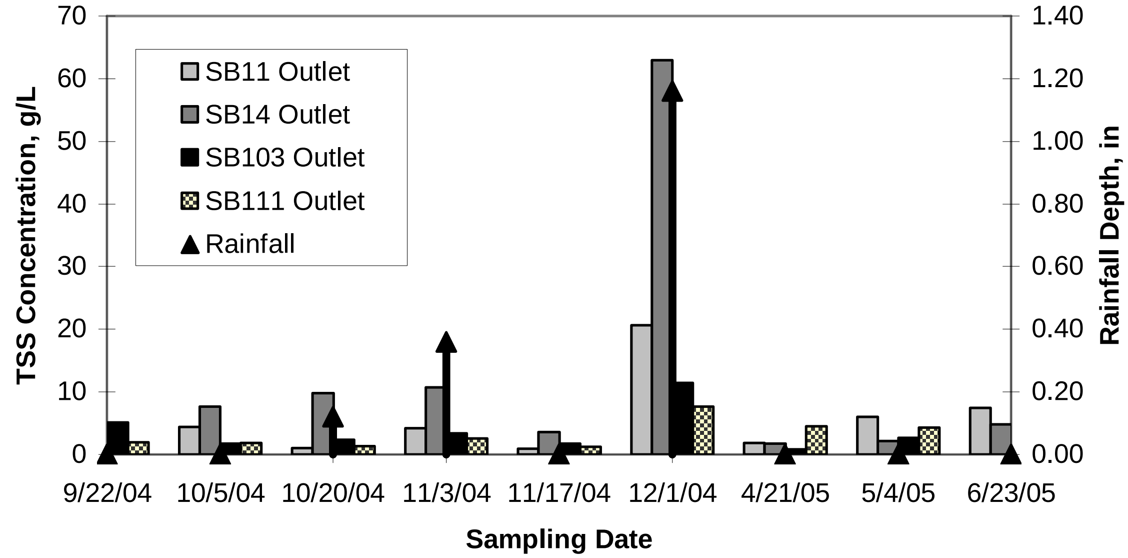

Figure 21. Variation in outlet TSS concentration with rainfall peaks

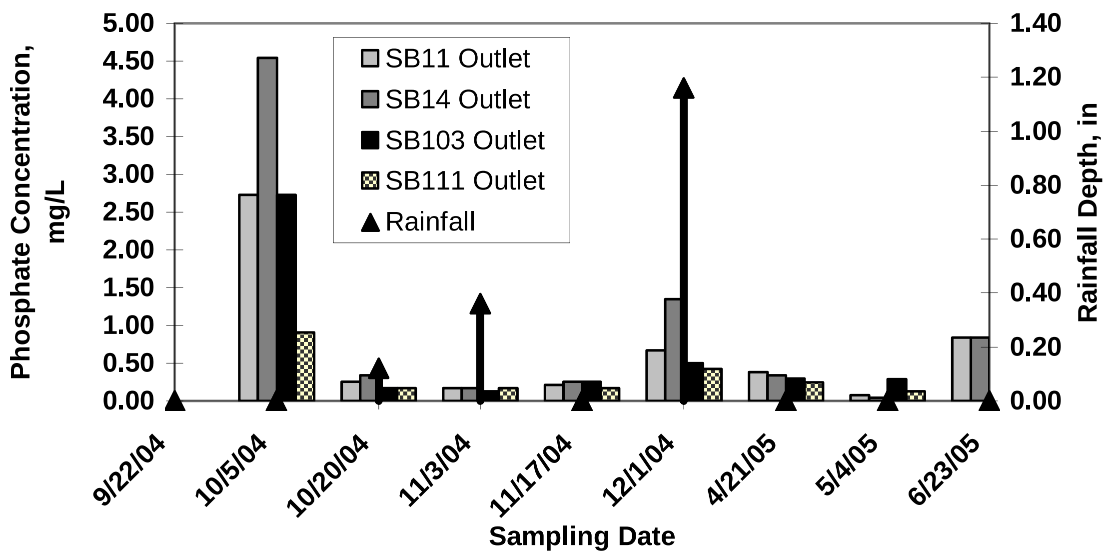

Figure 22. Variation in outlet total phosphate concentration with rainfall peaks

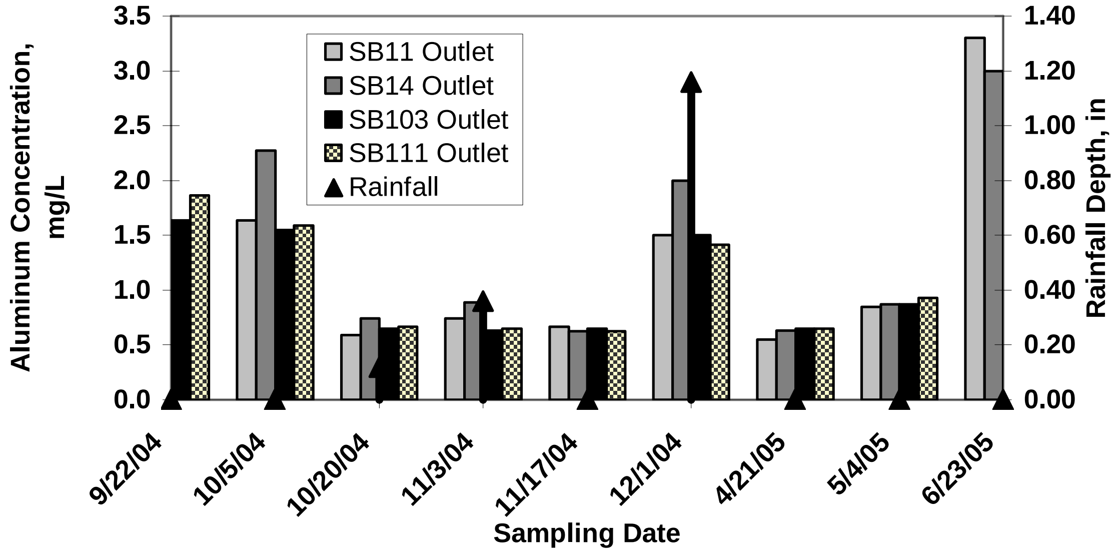

Figure 23. Variation in outlet total aluminum concentration with rainfall peaks

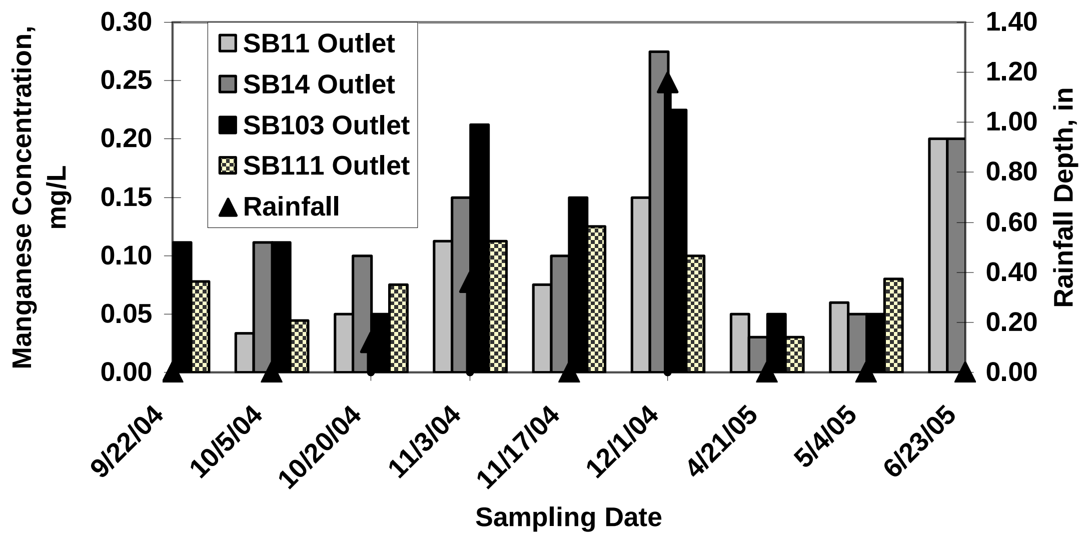

Figure 24. Variation in outlet total manganese concentration with rainfall peaks

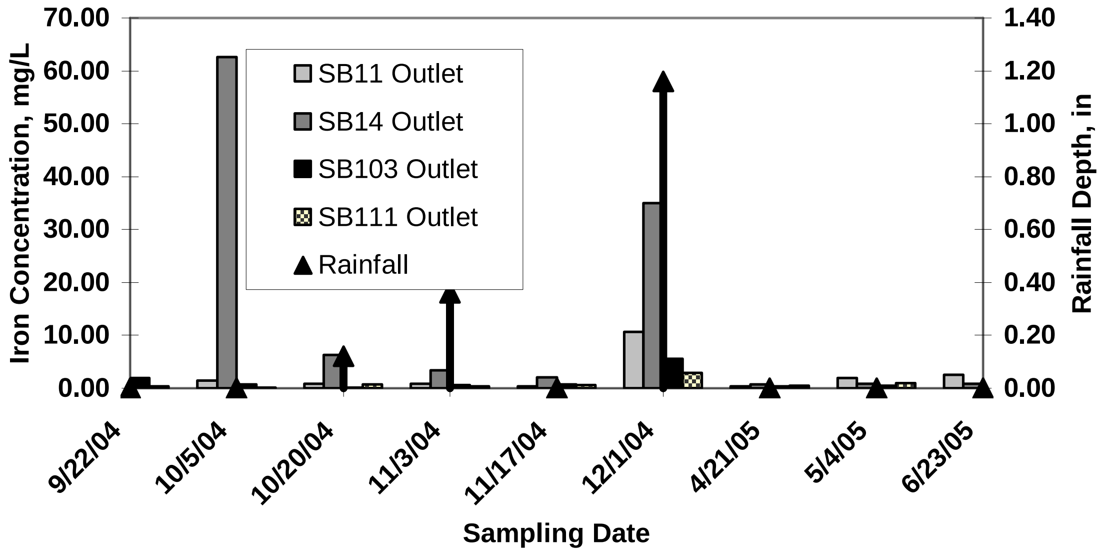

Figure 25. Variation in outlet total iron concentration with rainfall peaks

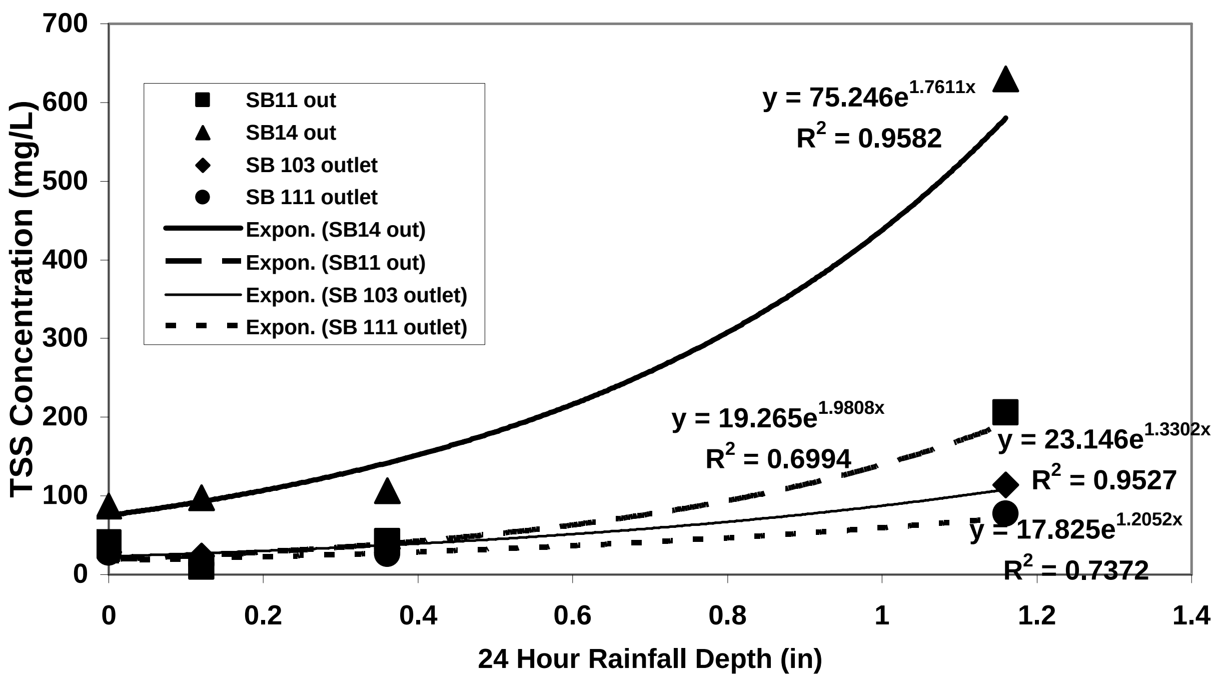

Figure 26. Variation in outlet total TSS concentration with rainfall peaks

Figure 21 to Figure 25 show 24 hr rainfall and concentration of TSS, total iron, phosphate, manganese and aluminum for the four SBs studied. A correlation between rainfall and total suspended solids is shown in Figure 26. The base flow TSS concentration at zero rainfall was obtained by averaging the TSS concentrations on sampling days that had zero rainfall. It can be seen from Figure 26 that TSS concentration increases exponentially with rainfall. TSS data for basins SB14 and SB103 fit an exponential curve with correlation coefficient of 0.95. Hence it can be said that basins SB14 and SB 103 are not designed effectively to capture peaks in TSS during high rainfall conditions. Whereas for SB11 and SB111 the correlation coefficient is around 0.7, hence basins SB11 and SB111 are relatively better designed to capture particulates compared to SB14 and SB103.

From analyzing the current design of SBs it was seen that the basin has tapering sides and the basin area increases as we move from the bottom of the basin to the top of the basin (Figure 40 on page 83). Hence the incremental volume of the basin also increases from the bottom to the top of the basin. To accommodate the increase in volume and to maintain basin dewatering time of 4-6 days as suggested by the existing PADEP BMPs, the outflow rate is also increased along with the basin area. But the increase in the outflow rate is much greater than the increase in basin area. As a result overflow rate (which relates to settling velocity and is a measure of particle removal in the basin) which is calculated by dividing the basin outflow rate by the corresponding basin area increases several times as we move from the basin bottom to the basin surface. This means that, when the basin is full during a storm event, the outflow rate and the overflow rate are higher and hence results in the removal of a larger particle when the flow to the basin is greater and a relatively smaller particle compared to low flow conditions. As a consequence a greater percentage of the influent sediment is released during heavy rainfall events and peaks in particulate contaminant concentration are enhanced during storm events as shown Figure 26. The analysis explained above demonstrates the need for designing SBs for particulate peak attenuation during high flow events.

3.6 INTER-CORRELATION OF CONCENTRATION

An attempt to correlate the concentration of different contaminants with each other revealed that the various elements present in the runoff such as iron, magnesium, sulfate, aluminum, manganese, calcium and phosphate do not correlate with each other in any particular manner. When the sum of concentrations of iron, manganese, magnesium, aluminum and calcium was plotted versus the concentration of sulfate, the data appeared to plot roughly along a straight line with a slope of little above 1 in the case of SB11 outlet (Figure 27 and Figure 28). This may be suggestive of the fact that the sulfates of metals are formed at the outlet with the dominant valence state of the metals being +2 in the outlet for this particular pond. The same correlation did not result for the outlet of other ponds.

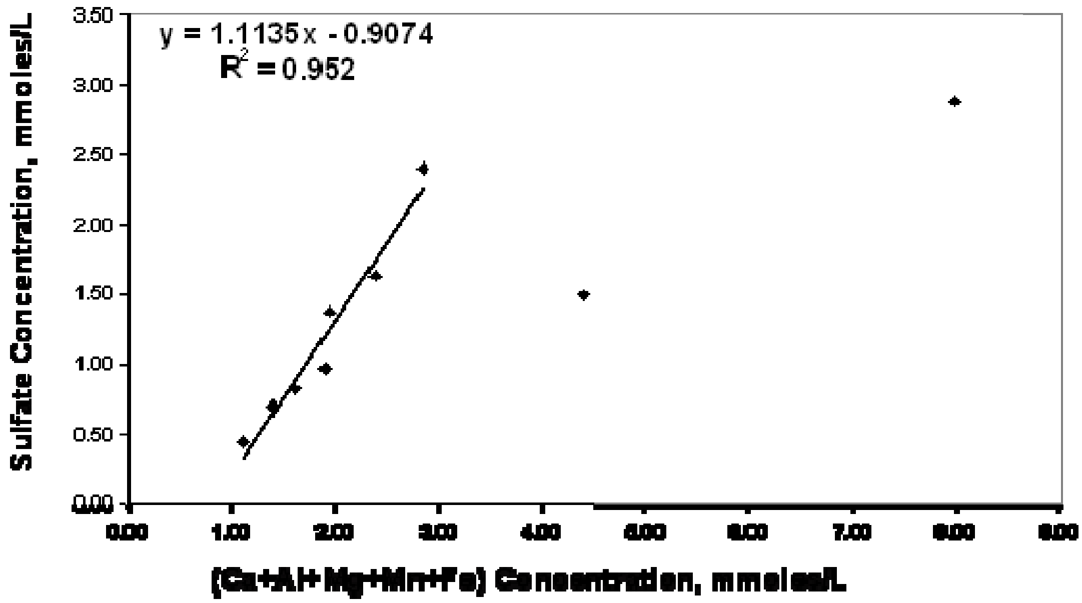

Figure 27. Total sulfate concentration vs. sum of total Ca, Fe, Mg, Mn & Al for SB11 outlet

Sulfate combines with metals that exist in 2+ as well as 3+ valence states, further the total concentration of a metal does not occur as sulfate alone, but exists as other complexes, precipitated solids or also as free metal ions. Similarly sulfate also exists as free sulfate. When one of the above conditions dominates then the ratio of sulfate to metal concentration will deviate from 1. Any of the above discussed causes could be the reason for two points not lying on the straight line in Figure 27 and Figure 28.

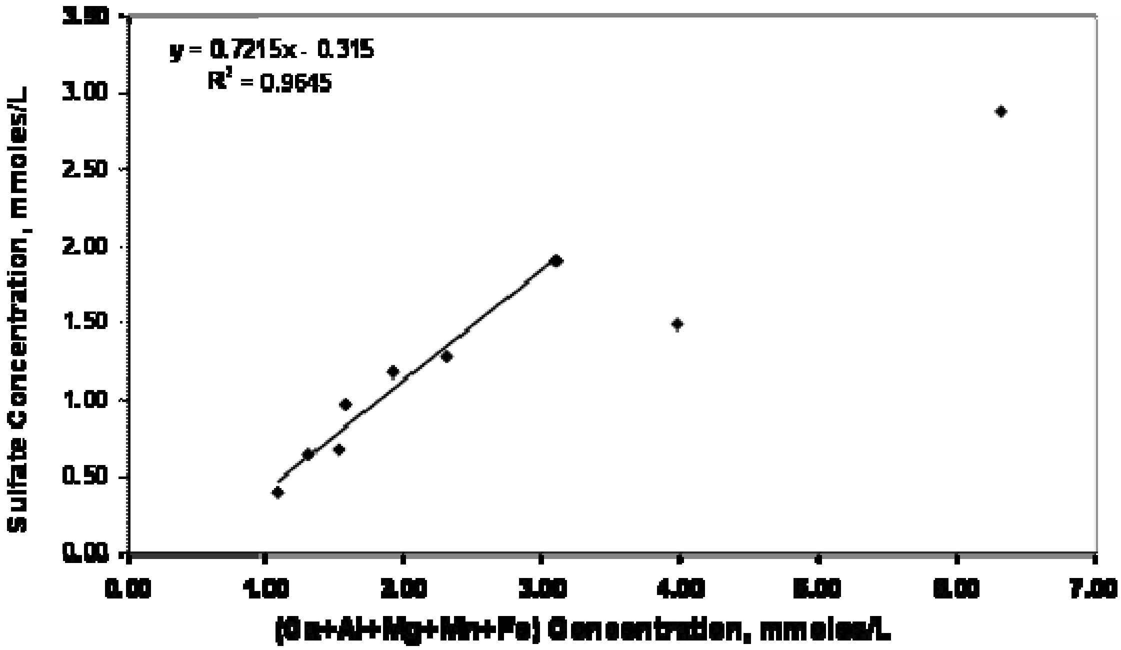

Figure 28. Dissolved sulfate vs. sum of dissolved Ca, Fe, Mg, Mn & Al for SB11 outlet

3.7 CONCLUSIONS FROM CORRELATIONS

Water quality data obtained from SBs at the I-99 construction site show that the methodology of designing sedimentation basins at the present is not sufficient to yield significant particle removal and to control particulate pollutants during storm events or to control particle re-suspension in the basin. Current operating information demonstrates the need for developing a new methodology for designing SBs for both runoff capture and particle removal. BMPs are also required for basins structural design including basin shape, baffle placement, type of inlet and outlet structure and drainage time.

In order to improve particle removal in the basin, any new design methodology should incorporate mechanisms for identifying the runoff capture volume (based on the percentage of runoff to be captured in a given duration), sediment volume and sediment dredging frequency (to control sediment re-suspension) and design overflow rate (to achieve desired particle removal and attenuate peaks in particulate contaminants during high flow conditions). Based on the results discussed above, two BMPs are suggested.

1. A new methodology is required for designing sedimentation basins by integrating runoff capture, particle removal and sediment dredging frequency requirements. This methodology of design should arrive at sedimentation basin area, settling volume, sediment volume and outflow rate based on the volume of storm water to be captured. The size of the particle to be removed in the basin must be determined to attenuate peaks in particulates in the basin outlet. Further, the frequency of sediment dredging should be identified to prevent sediment re-suspension in the basin.
2. Constant overflow rate should be maintained at all depths of the basin to attenuate peaks in particulate pollutants during high flow conditions.

3.8 NATURALLY OCCURING MILDLY ACIDIC SEEPS

3.8.1 Field visit and observation

During field visits several naturally occurring mildly acidic seeps were noticed on the down slope sides of the highway, just above the SBs (see Figure 29). The pH of these seeps was in the range of 5-6.5. A sample of a seep near SB103 was taken and analyzed for water chemistry data. The analysis results showed that the seep had significantly high concentrations of aluminum, iron, magnesium, manganese, phosphate and sulfate compared to the SB samples. The water chemistry data obtained from seep analysis is tabulated in Table 5. Additional acidic seeps were observed along the banks of SB103 during field visits 3, 4, 5 and 6. A large number of seeps draining into the basins may lower the pH of basin water and lead to dissolution of particulate contaminants including iron, aluminum, manganese, calcium and phosphate.

Table 5. Water analysis data for an acidic seep draining into SB103

Field pH	5.5
Lab pH	6.8
Apparent color (lab)	Off scale (>500)
True color	15
TSS (mg/L)	671
VSS (mg/L)	81
Dissolved[a] Mg (mg/L)	30
Dissolved[a] Mn (mg/L)	2.0
Dissolved[a] Ca (mg/L)	223
Dissolved[a] Fe (mg/L)	1.5
Dissolved[a] Al (mg/L)	14
Turbidity (NTU)	0.92
Dissolved[a] Orthophosphate (mg/L)[b]	2.6
Dissolved[a] Sulfate (mg/L)	149

[a]Dissolved concentrations were measured on filtered samples
[b]Although seep sample shows a high concentration of phosphate, presence of phosphate is not mentioned in the geological study of the construction site and it is assumed that phosphate in the seeps have their source from fertilizers added for slope vegetation

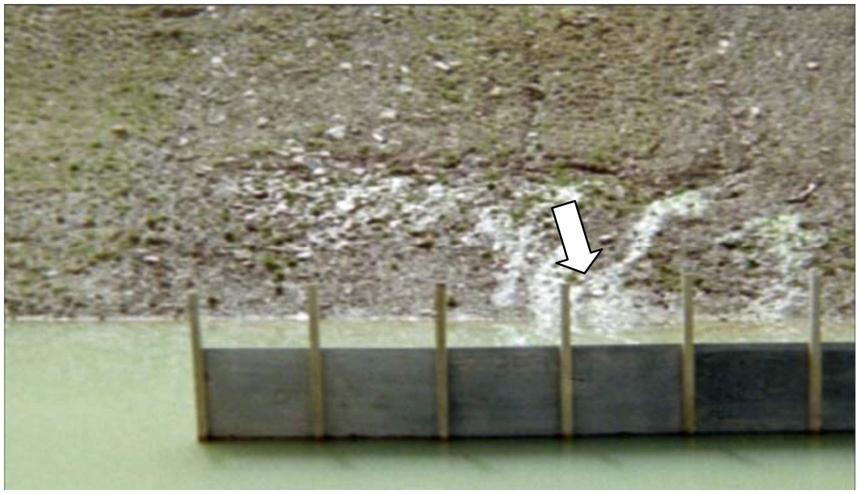

Figure 29. Trip 4 (Nov/3/04) - seep in the bank fill area of SB14 draining into the pond

3.8.2. Mineql modeling

The chemical equilibrium modeling software Mineql+ was used to simulate the aqueous chemistry in the basin and seep waters (Schecher and McAvoy, 1998). Mineql+ is a chemical equilibrium modeling system that can be used for calculating aqueous speciation, solid phase saturation states, precipitation-dissolution, and adsorption on low temperature (0-50^{o}C), low to moderate ionic strength (<0.5M) aqueous systems. Dissolved ions in solution interact with each other (form complexes), interact with particulate surfaces (adsorb) and possibly form solid phases (precipitate). In a typical natural aqueous system there may be 10 to 20 major chemical components dissolved in solution. These components have the potential to form hundreds of dissolved chemical complexes, solids phases or adsorbed species. Mineql+ uses the principle of chemical equilibrium and helps to create systems by selecting chemical components from a menu, scanning the thermodynamic database and running the calculations. Chemical equilibrium assumes that all reactions have gone to completion and are in equilibrium with one another. Using the chemical equilibrium approach, Mineql+ provides a thermodynamic snapshot of the system: the pH, ionic strength, the distribution of dissolved chemical species, how much solid phase is formed, etc. Mineql+ however does not address time dependent reactions that have kinetic restrictions (Schecher and McAvoy, 1998).

To understand the extent to which acidic seeps can cause dissolution of particulate contaminants, water chemistry data obtained from analysis of SB11 inlets and outlet samples and the data from the analysis of the acidic seep sample were used and the increase in dissolution of particulate contaminants with reduction in pH was modeled using the chemical equilibrium computer software “Mineql+”. Since samples from SB11 inlets and outlet were available throughout the sampling period, water chemistry data of this SB was used for modeling purposes. pH and average total concentrations of iron, magnesium, manganese, calcium, aluminum, sulfate, and phosphate were used as inputs to Mineql+ software. The input data used for modeling pond water chemistry are tabulated in Table 6.

Table 6. Total average concentration from laboratory analysis (input data for Mineql+)[a]

Average total concentration (moles/liter)							
Ca	**Mn**	**Mg**	**Fe**	**Al**	**Sulfate**	**PO_4^{3-}**	**LAB pH**
SB11 inlet 38							
2.58×10^{-3} ± 2.15×10^{-3} (103 ± 86 mg/L)	7.27×10^{-7} ± 7.27×10^{-7} (0.04 ± 0.04 mg/L)	1.03×10^{-3} ± 6.74×10^{-4} (25 ± 16 mg/L)	1.57×10^{-5} ± 1.02×10^{-5} (0.88 ± 0.57 mg/L)	4.33×10^{-5} ± 2.67×10^{-5} (1.2 ± 0.72 mg/L)	1.52×10^{-3} ± 9.30×10^{-4} (146 ± 89 mg/L)	7.47×10^{-6} ± 8.42×10^{-6} (0.71 ± 0.80 mg/L)	7.6
SB11 inlet 39							
1.63×10^{-3} ± 1.70×10^{-3} (65 ± 68 mg/L)	1.46×10^{-6} ± 1.64×10^{-6} (0.08 ± 0.09 mg/L)	6.11×10^{-4} ± 2.82×10^{-4} (15 ± 6.8 mg/L)	9.09×10^{-5} ± 2.43×10^{-4} (5.1 ± 14 mg/L)	4.19×10^{-5} ± 2.04×10^{-5} (1.1 ± 0.55 mg/L)	1.11×10^{-3} ± 6.44×10^{-4} (107 ± 62 mg/L)	6.74×10^{-6} ± 9.26×10^{-6} (0.64 ± 0.88 mg/L)	7.8
SB11 outlet							
1.99×10^{-3} ± 1.85×10^{-3} (79 ± 74 mg/L)	1.40×10^{-6} ± 1.09×10^{-6} (0.08 ± 0.06 mg/L)	8.26×10^{-4} ± 3.52×10^{-4} (20 ± 8.4 mg/L)	3.63×10^{-5} ± 5.52×10^{-5} (2.0 ± 3.1 mg/L)	4.78×10^{-5} ± 3.07×10^{-5} (1.3 ± 0.83 mg/L)	1.32×10^{-3} ± 7.18×10^{-4} (127 ± 69 mg/L)	7.61×10^{-6} ± 9.58×10^{-6} (0.7 ± 0.91 mg/L)	7.9
Acidic seep							
7.81×10^{-3} (312 mg/L)	9.09×10^{-5} (5 mg/L)	2.08×10^{-3} (50 mg/L)	3.16×10^{-3} (177 mg/L)	1.52×10^{-3} (41 mg/L)	4.88×10^{-3} (468 mg/L)	1.07×10^{-4} (10 mg/L)	6.8

[a]The average values of component concentrations obtained from laboratory analysis along with the standard deviation is shown in the table above. The average concentrations were used as input to the Mineql+ model.

The average total concentrations given in Table 6 were obtained by analyzing the water samples without filtering. In order to obtain total metal concentration, samples containing suspended solids were completely digested using a microwave digester. The digested samples were analyzed for Ca, Mg, Mn, Al and Fe according to Standard Methods using Atomic Absorption. Sulfate was measured on undigested samples, and digested samples were analyzed for phosphate as orthophosphate using Hach methods. While using the analysis data for Mineql+ modeling, it was assumed that calcium occurred as Ca^{2+}, magnesium as Mg^{2+}, manganese as Mn^{2+} and Mn^{3+}, aluminum as Al^{3+} and iron as Fe^{2+} and Fe^{3+}. As the ratio of Mn^{2+} to Mn^{3+} was unknown, it was assumed that manganese occurred in equal proportion in both the oxidation states. In the case of iron, laboratory analysis data showed that about 90% of iron occurred in particulate form. Assuming Fe^{3+} is mostly in particulate form and Fe^{2+} is mostly dissolved, dissolved iron obtained from laboratory analysis was input to Mineql+ model as Fe^{2+} and the rest was input as Fe^{3+}. Further an approximate concentration of silica ($1x10^{-5}$ moles/L) was added as $Si(OH)_4$. Although Si was not measured in the lab, it was added to Mineql+ calculations because silica may be present in the form of clay as alumino silicates in suspended solids.

An investigation of construction site geology by Skelly & Loy, Inc., for PADEP revealed the presence of dolomite ($CaMgCO_3$), ankerite ($Ca(Fe^{2+},Mg,Mn^{2+})(CO^3)_2$), kutnohorite ($Ca(Mn,Mg,Fe^{2+})(CO_3)^2$), quartz ($SiO_2$), barite ($BaSO_4$), gypsum ($CaSO_4.2H_2O$), goethite ($Fe^{3+}O(OH)$), limonite ($FeO(OH).nH_2O$, ("limonite" is most commonly the mineral species goethite, but can also consist of varying proportions of other iron oxides), calcite ($CaCO_3$), manganese oxides and oxyhyroxides and minor quantities of pyrite (FeS_2) and chalcopyrite ($CuFeS_2$) (Skelly & Loy, 2006; Mindat, 2006; Webmineral, 2006). The solids dolomite, goethite, calcite, quartz, hydrated jarosite, lepidocrosite and gypsum were included in the Mineql+ model based on the geologic investigation. As geologic study showed the presence of shale rich in alumino silicates, kaolinite was added to the list of solids considered for Mineql+ modeling. According to geological investigation manganese in present in the form of ankerite ($Ca(Fe^{2+},Mg,Mn^{2+})(CO_3)_2$), kutnohorite ($Ca(Mn,Mg,Fe^{2+})(CO_3)_2$) and as manganese oxides and oxyhydroxides in the form of Psilomelane ($(Ba,H_2O)2Mn_5O_{10}$. Ankerite and kutnohorite could not be included because these solids are not present in the Mineql+ database. In order to include them in the database a reference for their log K or solubility is required and the values of these constants could not be found from the review of published literature. Psilomelane was not added as barium was not measured for the samples. Instead manganese was added in the form of bixibyite and pyrochroite from the list of solids presented by Mineql+ as they compensated for the presence of other manganese oxide forms and matched well with the experimental data. Although bixibyite is a rare mineral it was included merely to compensate for the presence other forms of manganese oxides and hydroxides whose equilibrium constants are not available. Pyrite, chalcopyrite and barite were not included as they were present only in minor quantities. Comparison of experimental values in Table 7 with Mineql+ model values in Table 8 shows that there is a good match between experimental and model values (also see Figure 30 and Figure 31). Table 9 tabulates the primary forms in which each of the ions exist as seen from Mineql+ results.

Table 7. Average dissolved concentration data for SB11 and acidic seep (experimental values)

Sample Name	Average Dissolved Concentration (moles/Liter)							
	Ca	**Mn**	**Mg**	**Fe**	**Al**	**Sulfate**	**Phosphate**	**pH**
SB11 inlet 38	$2.32 \times 10^{-3} \pm 1.7 \times 10^{-3}$ (93 ± 68 mg/L)	$3.64 \times 10^{-7} \pm 3.37 \times 10^{-7}$ (0.02 ± 0.02 mg/L)	$9.93 \times 10^{-4} \pm 6.66 \times 10^{-4}$ (24 ± 16 mg/L)	$7.14 \times 10^{-7} \pm 5.36 \times 10^{-7}$ (0.04 ± 0.03 mg/L)	$3.33 \times 10^{-5} \pm 1.44 \times 10^{-5}$ (0.90 ± 0.39 mg/L)	$1.45 \times 10^{-3} \pm 8.13 \times 10^{-4}$ (139 ± 79 mg/L)	$4.00 \times 10^{-6} \pm 8.63 \times 10^{-6}$ (0.38 ± 0.82 mg/L)	7.6
SB11 inlet 39	$1.47 \times 10^{-3} \pm 1.07 \times 10^{-3}$ (59 ± 43 mg/L)	$5.45 \times 10^{-7} \pm 3.37 \times 10^{-7}$ (0.03 ± 0.02 mg/L)	$5.90 \times 10^{-4} \pm 2.88 \times 10^{-4}$ (14 ± 6.9 mg/L)	$8.93 \times 10^{-7} \pm 7.14 \times 10^{-7}$ (0.05 ± 0.04 mg/L)	$3.22 \times 10^{-5} \pm 1.33 \times 10^{-5}$ (0.87 ± 0.36 mg/L)	$1.04 \times 10^{-3} \pm 6.73 \times 10^{-4}$ (99 ± 65 mg/L)	$4.63 \times 10^{-6} \pm 9.05 \times 10^{-6}$ (0.44 ± 0.86 mg/L)	7.8
SB11 outlet	$1.81 \times 10^{-3} \pm 1.38 \times 10^{-3}$ (73 ± 55 mg/L)	$5.27 \times 10^{-7} \pm 5.27 \times 10^{-7}$ (0.03 ± 0.03 mg/L)	$7.80 \times 10^{-4} \pm 3.29 \times 10^{-4}$ (19 ± 7.9 mg/L)	$7.14 \times 10^{-7} \pm 5.36 \times 10^{-7}$ (0.04 ± 0.03 mg/L)	$3.52 \times 10^{-5} \pm 1.78 \times 10^{-5}$ (0.95 ± 0.48 mg/L)	$1.29 \times 10^{-3} \pm 7.22 \times 10^{-4}$ (164 ± 69 mg/L)	$4.22 \times 10^{-6} \pm 8.74 \times 10^{-6}$ (0.40 ± 0.83 mg/L)	7.9
Acidic Seep	5.59×10^{-3}	3.64×10^{-5}	1.25×10^{-3}	2.68×10^{-5}	5.07×10^{-4}	1.55×10^{-3}	2.74×10^{-5}	6.8

Table 8. Dissolved concentrations obtained from Mineql+ model[a]

Dissolved concentration (moles/liter)							
Ca	**Mn**	**Mg**	**Fe**	**Al**	**Sulfate**	**PO_4^{3-}**	**pH**
SB11 inlet 38							
2.58×10^{-3} (103 mg/L)	3.63×10^{-7} (0.02 mg/L)	1.03×10^{-3} (25 mg/L)	7.14×10^{-7} (0.04 mg/L)	3.34×10^{-5} (0.90 mg/L)	1.52×10^{-3} (146 mg/L)	7.47×10^{-6} (0.71mg/L)	7.6
SB11 inlet 39							
1.63×10^{-3} (65 mg/L)	7.30×10^{-7} (0.04 mg/L)	6.11×10^{-4} (15 mg/L)	8.93×10^{-7} (0.05 mg/L)	3.21×10^{-5} (0.90 mg/L)	1.11×10^{-3} (107 mg/L)	6.74×10^{-6} (0.64 mg/L)	7.8
SB11 outlet							
1.99×10^{-3} (80 mg/L)	7.00×10^{-7} (0.04 mg/L)	8.26×10^{-4} (20 mg/L)	7.14×10^{-7} (0.04 mg/L)	3.8×10^{-5} (1.0 mg/L)	1.32×10^{-3} (127 mg/L)	7.61×10^{-6} (0.72 mg/L)	7.9
Acidic seeps							
7.81×10^{-3} (312 mg/L)	4.54×10^{-5} (2.5 mg/L)	2.08×10^{-3} (50 mg/L)	2.68×10^{-5} (1.5 mg/L)	1.42×10^{-3} (38 mg/L)	4.88×10^{-3} (132 mg/L)	1.07×10^{-4} (10 mg/L)	6.8

[a]The values shown above are the concentration given by Mineql+ software, when total concentration from laboratory analysis was used as input. Mineql+ calculates these values through equilibrium relationships for total and dissolved concentrations at the given pH

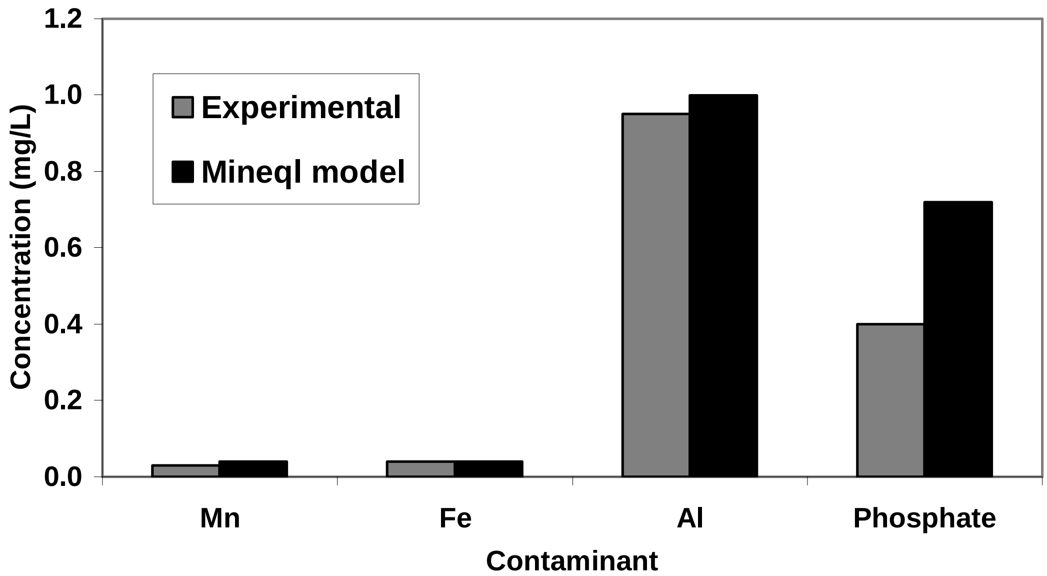

Figure 30. Comparison of experimental and Mineql+ model values[a]
[a]Dissolved contaminant concentrations for Mn. Fe, Al & phosphate in SB11 outlet sample

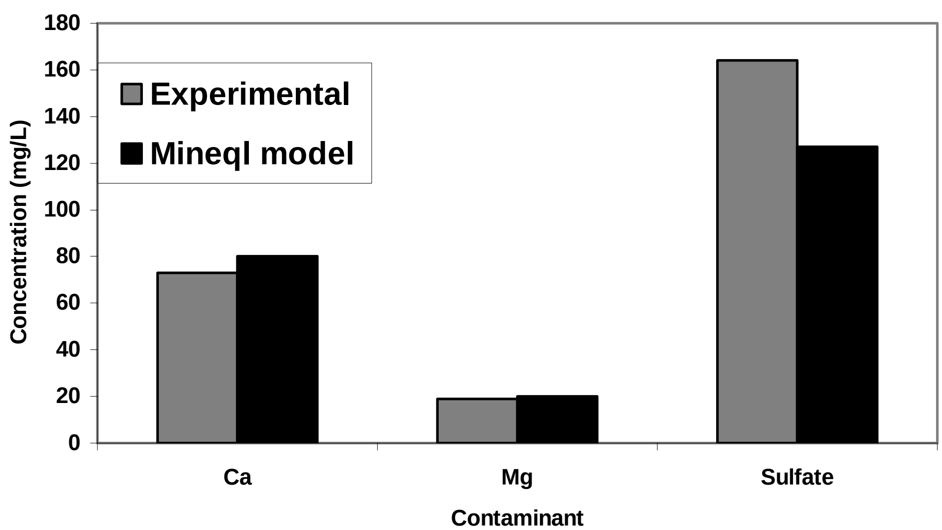

Figure 31. Comparison of experimental and Mineql+ model values[a]
[a]Dissolved contaminant concentrations for Ca. Mg, & sulfate in SB11 outlet sample

Table 9. Primary dissolved complexes and precipitated solids predicted by Mineql+ model

	Dissolved Complexes	Precipitated/Dissolved Solids
Ca^{2+}	Ca^{2+}, $CaSO_4$ (aq)	Dolomite, calcite
Mg^{2+}	Mg^{2+}, $MgSO_4$ (aq)	Dolomite
Mn^{2+}	Mn^{2+}, $MnSO_4$ (aq)	Oxides and Hydroxides
Mn^{3+}		Oxides and Hydroxides
Al^{3+}	$Al(OH)_4^-$	Kaolinite
Fe^{2+}	Fe^{2+}, $FeSO_4$ (aq)	-
Fe^{3+}		Goethite
SO_4^{2-}	SO_4^{2-}, HSO_4^-, $AlSO_4^+$, $MgSO_4$(aq), $CaSO_4$(aq)	Dolomite, calcite
PO_4^{3-}	$CaH_2PO_4^+$, $MgHPO_4$(aq), $H_2PO_4^-$, H_3PO_4	-

The variation in dissolved manganese, calcium, magnesium, iron, sulfate, phosphate and aluminum with change in pH obtained from Mineql+ model for SB11 inlet sample is shown in Table 10. From Table 10, Figure 32 and Figure 33 it can be seen that change in pH does not affect the dissolved concentration of manganese, iron and sulfate in the SB inlet samples. Precipitation of magnesium in the form of dolomite and calcium in the form of calcite and dolomite occurs when pH increase above 8 as shown in Figure 34. Iron exists as goethite in solid phase and goethite solubility increases slightly below pH 4. Manganese is present as oxides and hydroxides in solid form and their solubility is negligible in the pH range 3 to 9.

The pH in the SBs varies between 5 and 9, hence the variation in dissolved concentration of contaminants have been analyzed for a pH change in this range. From Table 10 and Figure 34, we see that dissolved calcium does not vary in the pH range 5-8 and all of the calcium exists in dissolved form but when pH increases above 8 precipitation of calcium occurs in the form of calcite and dolomite. Magnesium behaves in the same fashion as calcium and is precipitated in the form of dolomite when pH increases above 8. Calcium and magnesium were originally present in the form of dolomite as predicted by geologic investigation and matched by Mineql+ model (Skelly & Loy, 2006). Dissolved iron, manganese and sulfate concentrations do not vary significantly in the pH range 5-9. Thus from Mineql+ model values it appears that the seeps may not cause dissolution of manganese, magnesium, calcium, iron or sulfate. From the field and lab pH measurements the average basin influent pH was observed to vary from 5-8 and outlet pH was observed to vary from 6-9. In general the pH at the outlet was slightly higher than the inlet. It appears from the model that there may be precipitation of magnesium and calcium in the SBs before storm water leaves the basin.

Table 10. Dissolved concentrations vs. pH (SB11 outlet Mineql+ results)

Run no	**pH**	**Mn mg/L**	**Al mg/L**	**Fe mg/L**	**PO_4^{3-} mg/L**	**Ca mg/L**	**Mg mg/L**	**SO₄2- mg/L**
1	3.00	2.00E-02	1.17E+00	4.79E-02	7.10E-01	1.03E+02	2.47E+01	1.46E+02
2	3.54	2.00E-02	1.17E+00	4.14E-02	7.10E-01	1.03E+02	2.47E+01	1.46E+02
3	4.09	2.00E-02	1.17E+00	4.04E-02	7.10E-01	1.03E+02	2.47E+01	1.46E+02
4	4.64	2.00E-02	1.17E+00	4.01E-02	7.10E-01	1.03E+02	2.47E+01	1.46E+02
5	5.18	2.00E-02	9.13E-01	4.00E-02	7.10E-01	1.03E+02	2.47E+01	1.46E+02
6	5.73	2.00E-02	8.99E-01	4.00E-02	7.10E-01	1.03E+02	2.47E+01	1.46E+02
7	6.27	2.00E-02	8.99E-01	4.00E-02	7.10E-01	1.03E+02	2.47E+01	1.46E+02
8	6.82	2.00E-02	8.99E-01	4.00E-02	7.10E-01	1.03E+02	2.47E+01	1.46E+02
9	7.36	2.00E-02	9.02E-01	4.00E-02	7.10E-01	1.03E+02	2.47E+01	1.46E+02
10	7.91	2.00E-02	9.07E-01	4.00E-02	7.10E-01	1.03E+02	2.47E+01	1.46E+02
11	8.46	2.00E-02	9.23E-01	4.00E-02	7.10E-01	1.00E+01	4.15E+00	1.46E+02
12	9.00	2.00E-02	9.88E-01	4.00E-02	7.10E-01	1.06E+00	3.98E-01	1.46E+02

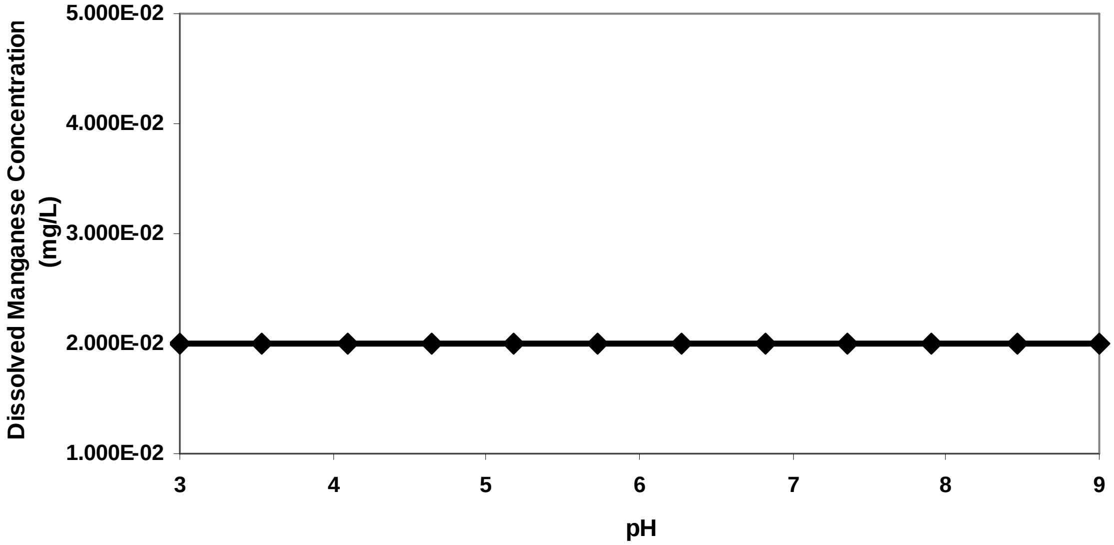

Figure 32. Mineql+ results for SB11 outlet **-** dissolved manganese concentration versus pH

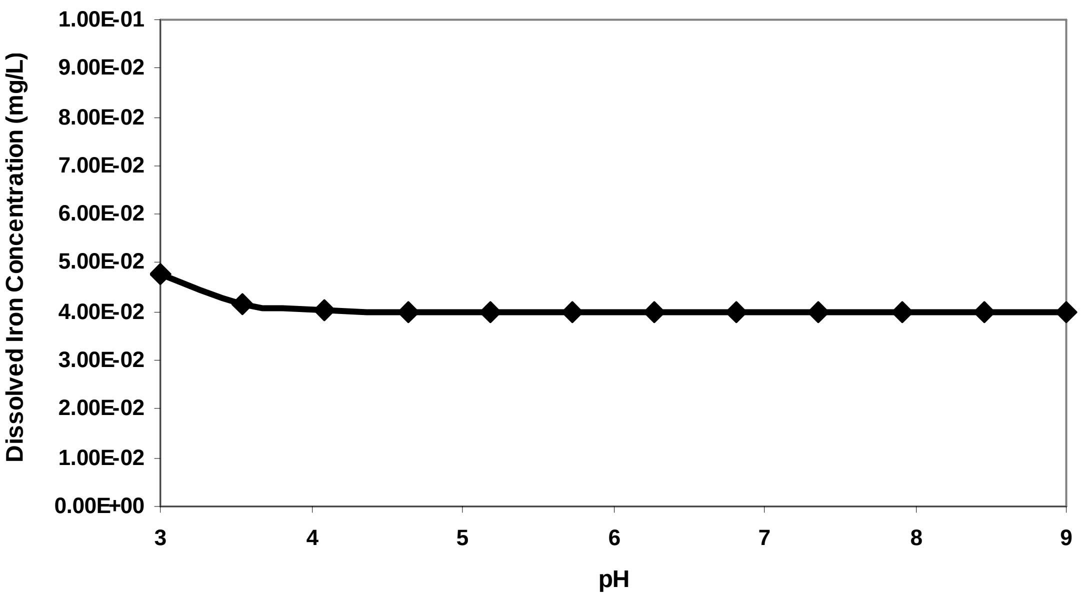

Figure 33. Mineql+ model results for SB11 outlet **-** dissolved iron concentration vs. pH

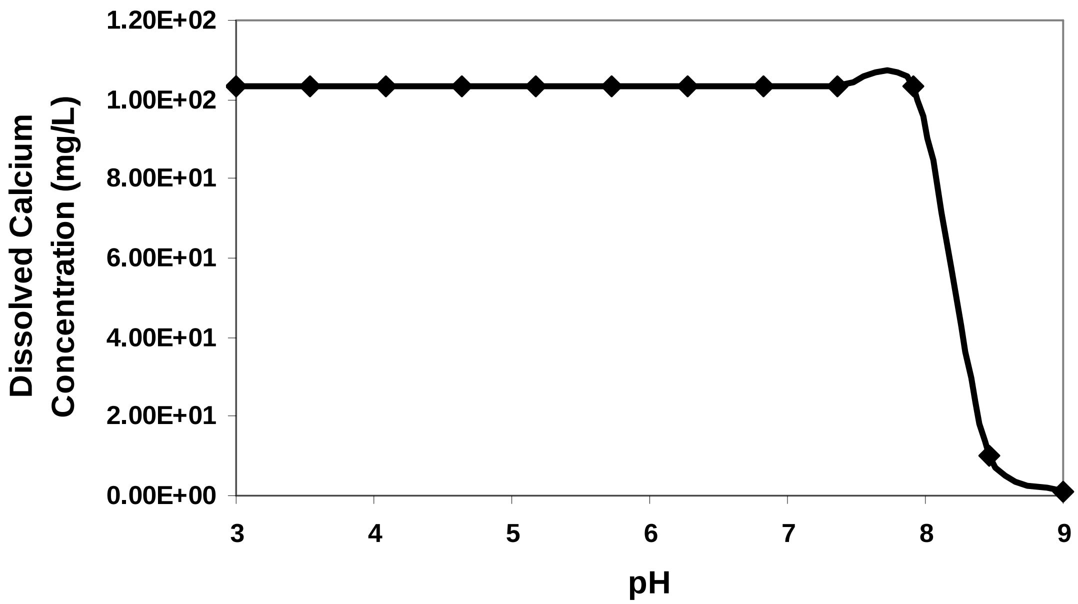

Figure 34. Mineql+ model results for SB11 outlet - dissolved calcium concentration vs. pH

3.8.3 Acidic seep and aluminum concentration

The average total and dissolved aluminum concentration in each of the SBs is shown in Table 11. EPA's national recommended water quality criteria for the protection of aquatic life in surface water for aluminum is 0.750 mg/l (acute) and 0.087 mg/L (chronic) (USEPA, 2005). The average total aluminum concentrations for the basins as shown in Table 11 are often higher than the recommended water quality level for aluminum. Conventional precipitation technology for aluminum management is to bring the solution pH to a value of about 6. The logic for this is illustrated on Figure 35, however, as shown on Figure 35, the EPA suggested limit of 0.75 mg/L appears to be below the expected aluminum solubility level. The solid that controls aluminum dissolution in the Mineql+ model is kaolinite and from Figure 35 it appears that the minimum dissolved aluminum concentration that can be achieved through aluminum precipitation is about 0.9 mg/L. This suggests that conventional management of aluminum discharges by pH control will not be sufficient to meet EPA suggested discharge limitations.

Table 11. Average total and dissolved Al concentration from laboratory analysis[a]

SB	Average Aluminum Concentration (mg/L)									
	Inlet					Outlet				
	Tot[b]	**SD[c]**	**Dis[d]**	**SD[c]**	**Par[e] Al %**	**Tot[b]**	**SD[c]**	**Dis[d]**	**SD[c]**	**Par[e] Al %**
SB11	1.2	0.74	0.92	0.38	18	1.3	0.83	0.95	0.48	20
SB14	2.4	None[f]	0.58	None[f]	72	1.6	0.97	0.95	0.50	32
SB103	1.3	None[f]	0.60	None[f]	54	1.2	0.72	0.95	0.41	18
SB111	1.0	0.64	0.71	0.06	68	1.1	0.5	0.8	0.4	24

[a]EPA's national recommended water quality criteria for the protection of aquatic life 0.750 mg/l (acute) and 0.087 mg/L (chronic) (USEPA, 2005).
[b]Total Aluminum (measured on undigested samples)
[c]SD (Standard Deviation)
[d]Dissolved Aluminum (measured on filtered samples)
[e]Percentage Particulate Aluminum
[f]Only one sample was available from SB14 and SB103 inlet due to absence of flow in the inlets

Aluminum dissolution increases when pH reduces below 5. Acidic seeps with pH below 5 will cause an increase in dissolved aluminum concentration. Laboratory data and Mineql+ model values suggest that if seeps with high dissolved aluminum concentration enter the basins, then aluminum will be precipitated so as to maintain the dissolved aluminum concentration at about 1 mg/L which is the solubility of aluminum at the pH and water chemistry conditions in the basins. Aluminum exists in dissolved form as dissolved kaolinite ($Al_2Si_2O_5(OH)_4$) and aluminum hydroxide complex ($Al(OH)^-$) in the basin water. It can be seen from Figure 35 that the aluminum concentration of the seep varies with pH but for the SBs it remains almost constant around 1 mg/L. Hence when seep water enters the basin, there is a buffering effect due to which the pH of basin does not vary but causes the pH of the seep to increase and results in precipitation of excess aluminum present above the solubility limit. A schematic representation of this effect is shown in Figure 36. The discussion above shows that the basins are capable of buffering and controlling dissolution of clay bound aluminum caused by acidic seeps. Further increasing $Si(OH)_4$ concentration from 10^{-3} to 10^{-5} moles/L resulted in precipitation of Aluminum as Aluminum silicate. Additional investigation is necessary to identify if precipitation by adding excess silicate is a potential treatment method for reducing aluminum concentration in sedimentation basin effluent.

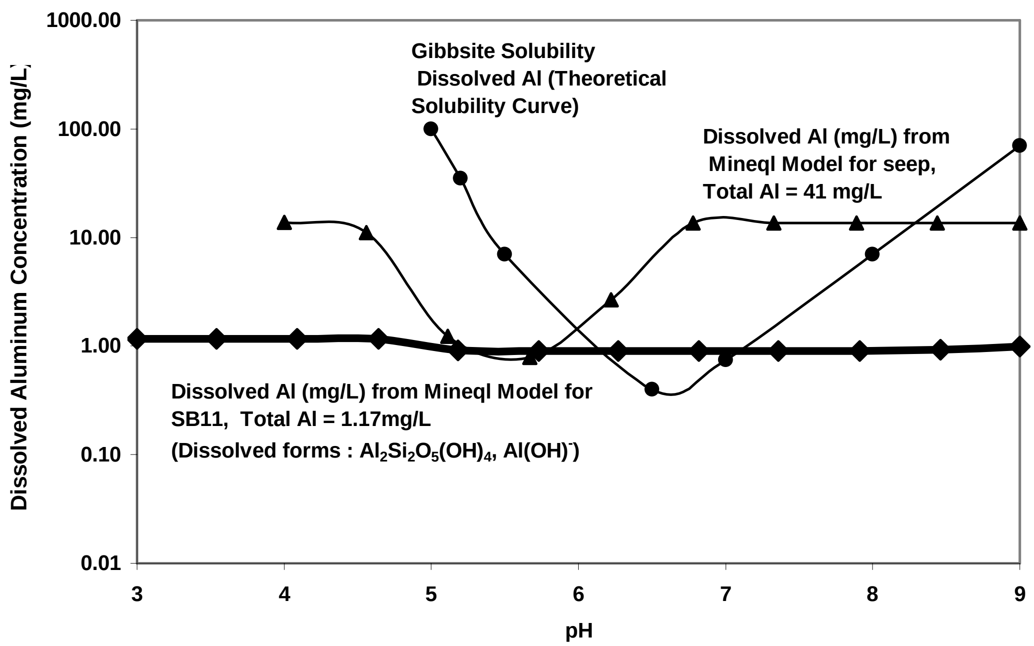

Figure 35. Dissolved aluminum concentration vs. pH (Mineql+ results & theoretical solubility)

Analysis of particulate removal in the basin shows that the percentage of particulate aluminum in the SB inlet samples varies from 18% to 72% (Table 11). This large variation is due to the large increase in total suspended solids and particulate aluminum during storm events. It can also be seen from Table 11 that the dissolved aluminum concentration in the basin outlet is almost constant at around 0.9 ± 0.5 mg/L for all the four basins. This indicates that the storm water in the basin is in a state of equilibrium and the concentration of dissolved aluminum is at its solubility limit at the conditions existing in the basin. Improving basin design to improve particle removal will help in capturing the peaks in particulate aluminum during storm events but if it is required to reduce the total aluminum concentration below 1 mg/L consistently, then chemical treatment of storm water is necessary.

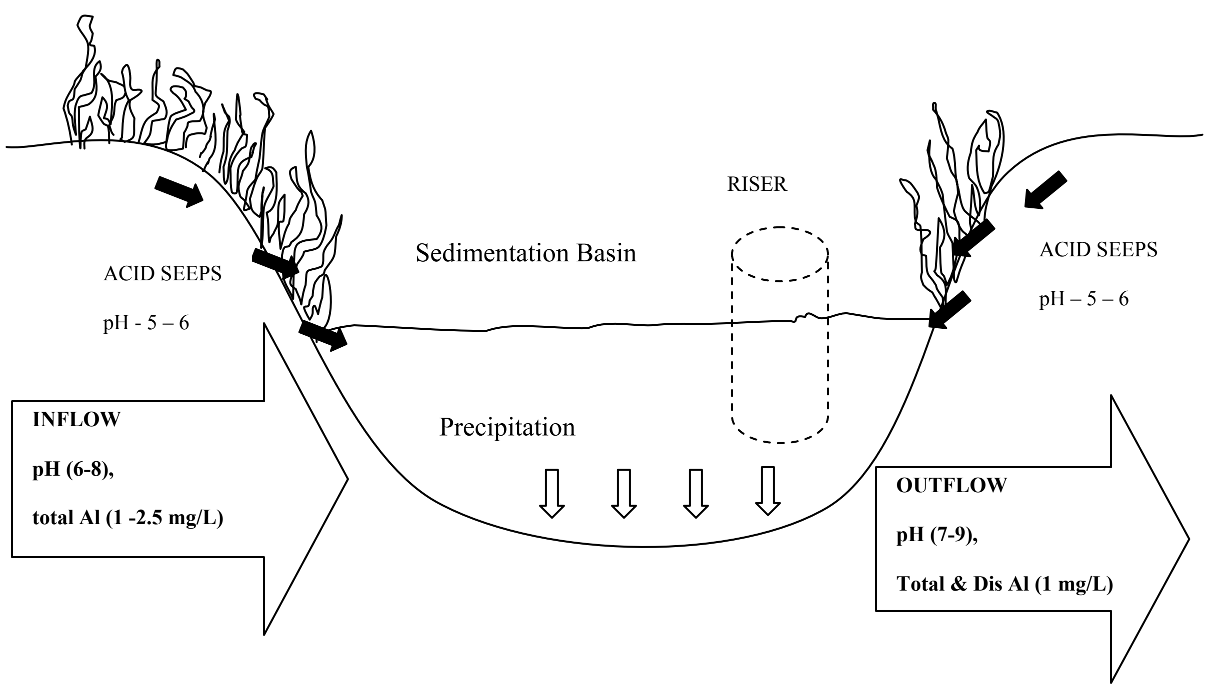

Figure 36. Schematic representation precipitation of dissolved contaminants in the basin

3.8.4 Phosphate concentration and algae growth

The photographs of the four basins taken during each sampling trip were analyzed for any obvious changes in the nature of the SBs over time. Site visits of the basins were also made to observe changes in the basin behavior. The photographs revealed that SB-14 had a slight green coloration throughout the sampling period. The analysis data of SB-14 showed that it has an overall high concentration of volatile suspended solids and total phosphate compared to the other three basins as shown in Table 12. Comparing the SB pictures with the analysis data showed that the pale green color of basins may be indicative of algae (high phosphate and volatile suspended solids, Table 14). This is confirmed by laboratory analysis of basin sediments showing the presence of chlorophyll (Table 13). According to EPA's "Quality Criteria for Water" (USEPA, 1986), to prevent the development of biological nuisances and to control accelerated or cultural eutrophication, total phosphate as phosphorus (P) should not exceed 0.05 mg/L (0.15 mg/L total phosphate) in any stream at the point where it enters any lake or reservoir, nor 0.025 mg/L within the lake or reservoir. Table 12 shows that the total phosphate concentration in the basin outlets is above EPA suggested value of 0.15 mg/L.

Table 12. Average phosphate concentration in the SBs – laboratory analysis results

SB	Average Phosphate Concentration (mg/L)									
	Inlet					Outlet				
	Tot[a]	SD[b]	Dis[c]	SD[b]	% Part[d] PO_4^{3-}	Tot[a]	SD[b]	Dis[c]	SD[b]	% Part[d] PO_4^{3-}
SB11	0.72	0.83	0.40	0.82	55	0.72	0.91	0.40	0.83	45
SB111	0.30	0.18	0.09	0.12	71	0.28	0.27	0.27	0.47	2

[a]Total Phosphate (measured on undigested samples)
[b]Standard Deviation
[c]Dissolved Phosphate (measured on filtered samples)
[d]Percentage Particulate Aluminum

The presence of phosphate in mineral form is not mentioned in the geological investigation of the construction site. During field visits it was noticed that fertilizers were added to the slopes of SB-14 the basin for the growth of vegetation. Vegetation along the slopes of the basin is preferred as it helps to control soil erosion. Based on this observation it is assumed that phosphate in the samples have their source from the fertilizers added for slope vegetation. Mineql+ modeling of water chemistry in the pond shows that phosphate occurs primarily in dissolved form as complexes ($CaH_2PO_4^+$, $MgHPO_4(aq)$, $H_2PO_4^-$, H_3PO_4), but laboratory experiments show the existence of particulate phosphate. Hence it is further assumed that the presence of particulate phosphate is due to the absorption of dissolved phosphate from fertilizers to soil rather than the presence of phosphate in mineral form. Phosphate adsorbed to sediments may lead to growth of vegetation and algae in the basins as observed during field visits. Variation of dissolved phosphate with change in pH for SB11 outlet sample (Figure 37) shows that dissolved phosphate concentration does not vary significantly with change in pH.

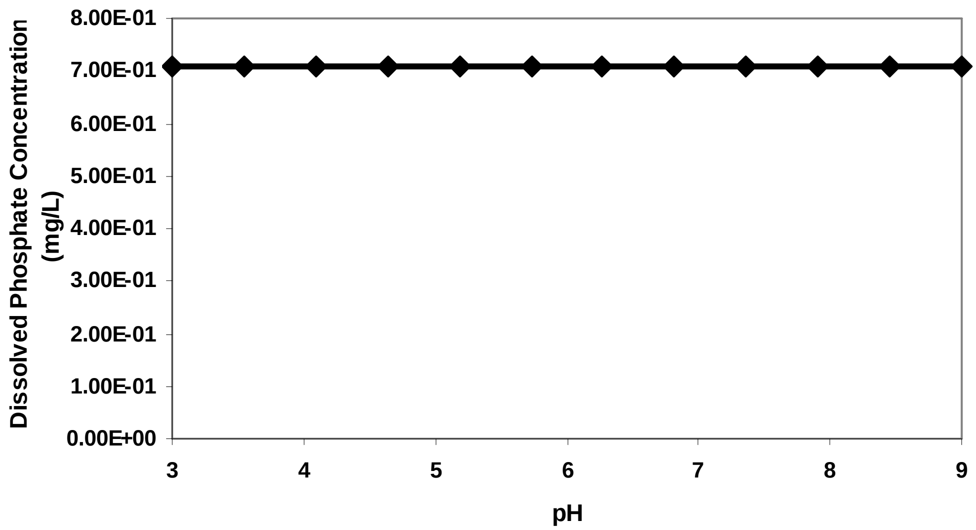

Figure 37. Mineql+ model results for SB11 outlet dissolved PO_4^{3-} concentration vs. pH

Water-sediment slurry samples containing algae were collected from SB11 and SB111 and chlorophyll present in these samples were measured according to EPA method 445 (USEPA, 1997). The samples were extracted with 90% acetone solution and centrifuged at 1,000 G for 5 minutes. The fluorescence of the prepared samples was measured using a Barnstead/Thermolyne Turner Quantech Digital Filter Fluorimeter (model no: FM109525). Chlorophyll concentrations have been used to understand the trophic conditions of lakes. Chlorophyll concentrations of 3 – 7 μg/L indicate mesotrophic conditions in lakes. It is said that mesotrophy increases the probability of "*Hypolimnetic anoxia*" a condition were sediments become anoxic and lead to internal nutrient loading (release of ammonia and orthophosphate from sediments) reinforcing eutrophication. It is also said that "*Hypolimnetic anoxia*" can result in the loss of salmonoids in lake water (Carlson and Simpson, 1996; Boström et al. 1988, Ahlgren et al. 1994; Ryding and Rast, 1989). The chlorophyll concentrations measured from the basin samples are in the mesotrophic (a trophic state of water body in between oligotrophy or oxic condition and eutrophy or anoxic condition) range and hence best management practices to control algae growth will protect the trophic state (a state that describes the biological condition of a water body) of surface waters downstream of the construction site.

Table 13. Chlorophyll a concentration in sediment samples from basins 11 and 111[a]

Replicate No	SB11 Chlorophyll a Concentration (µg/L)	SB111 Chlorophyll a Concentration (µg/L)
1	5.59	5.90
2	3.98	5.44
3	2.09	6.05
Average	3.89	5.79

[a]Chlorophyll a concentrations given above are values not corrected for Chlorophyll b interference. Chlorophyll a is the most common from of algae and is found in all algae, cyanobacteria and plants. Chlorophyll b is found only in green algae and plants. Chlorophyll levels in surface water are generally reported in terms of Chlorophyll a.

Table 14. Average VSS concentration in the SBs

SB	Outlet VSS Concentration Mg/L	Standard Deviation
SB11	15.6	8.9
SB14	22.4	16.6
SB103	13.8	6.5
SB111	16.7	8.5

The phosphate rich sediments in the basin lead to algae growth in the basin resulting in basin eutrophication. It was observed during field visits that SB11 had less algae growth than SB111 which was completely covered with floating filamentous algae. SB11 was dredged once after it was installed; whereas sediment in SB111 has never been dredged. This suggests that dredging sediments after the growing season should remove some of the phosphate absorbed to the sediment in the basin and can be expected to control basin eutrophication. Based on observations and analysis BMPs suggested for the control of basin eutrophication are (i) controlled use of phosphatic fertilizers and (ii) dredging of sediments after the growing cycle.

3.8.5 Observations from acidic seep modeling

Analysis of sedimentation basin acid chemistry suggests that SBs help to buffer acidic drainages, and may control increases in dissolved concentration of aluminum, magnesium and calcium through precipitation of excess dissolved salts. The water quality data obtained through lab analysis does not indicate a significant increase in dissolved concentrations of contaminants in the basin outlets due to the presence of acidic seeps. Phosphate in the basin comes primarily from the fertilizers applied for side slope fertilization. BMPs for the control of basin eutrophication due to phosphate in the runoff are controlled use of fertilizers and dredging of phosphate rich sediments from the basin after the growing season was observed to reduce algae growth in the basin.

4.0 INTEGRATED DESIGN FOR SEDIMENTATION BASINS

The following steps illustrate the method developed by this research leading to an integrated design and suggested Best Management Practice for SBs. Each design step is explained by application to the re-design of a sedimentation basin based on the drainage area of the I-99 basin labeled SB 111. The basin design is developed for two different runoff capture and sediment dredging frequency conditions and a comparison between existing and developed designs is presented.

4.1 RAINFALL PROBABILITY PLOT AND SETTLING ZONE VOLUME

Precipitation frequency estimates up to an Average Reoccurrence Interval (ARI) of 1,000 years can be obtained from National Oceanic and Atmospheric Administration's National Weather Service Database (Bonnin et al., 2004). Precipitation frequency data for 24-hour storm up to a 100-year return period obtained from National Weather Service Database for State College, PA (Bonnin et al., 2004) is given is Table 15. The exceedence probability, P, can be calculated from the average reoccurrence interval (also called the return period) using the relation (Chow et al., 1988)

$$P = \frac{1}{ARI} \tag{1}$$

where,

P = Exceedence probability (ratio, dimensionless)

ARI = Average Reoccurrence Interval (or return period) in years

Table 15. Rainfall frequency estimates for State College, PA

ARI (years)	**Precipitation Depth (24 hr) In (cm)**	**Exceedence Probability**	**Non-Exceedence Probability**	**Runoff Volume SB111 ft^3 (m^3)**
2	2.65 (6.7)	50	50	50,041 (1,416)
5	3.29 (8.4)	20	80	62,126 (1,758)
10	3.83 (9.7)	10	90	72,323 (2,047)
25	4.60 (11.7)	4	96	86,863 (2,458)
50	5.23 (13.3)	2	98	98,759 (2,795)
100	5.92 (15.0)	1	99	111,789 (3,164)

If reoccurrence interval data is not available then the rainfall data has to be ranked in descending order, and the exceedence probability of the ranked data can be found by Weibull's formula (Chow et al., 1988),

$$P = \frac{m}{n+1} \qquad (2)$$

where,

n is the number of data points (dimensionless)

m is the rank of a data point (dimensionless)

The exceedence probability P_m of the m^{th} ranked data point can be defined as the probability that precipitation X will exceed the value X_m. If P_m is the exceedence probability of the m^{th} ranked data, then the probability that precipitation will not exceed X_m is given by $1-P_m$. Thus 10% exceedence probability would relate to 90% probability of not exceeding a rainfall event X_m and can also be interpreted as 90% probability of capturing all storm events in any given time period. In order to identify, the settling volume of the SB, a plot of non-exceedence probability $(1-P_m)$ and runoff volume is developed. Runoff volume V_R can be calculated using the relation

$$V_R = aRA\alpha \tag{3}$$

where,

V_R = Runoff volume (ft^3 or m^3)

R is the precipitation depth, (in or cm)

A is the drainage area (ft^2 or m^2)

a is the conversion factor (0.0833 in/ft for US units, 0.01cm/m for SI units)

α is the ratio of rainfall that contributes to runoff (dimensionless).

Runoff volume can also be calculated by applying the Soil Conservation Service (SCS) method for calculating excess rainfall, where direct runoff

$$P_e = \frac{(R-0.2S)^2}{(R+0.8S)} \tag{4}$$

where,

P_e = excess rainfall (in or cm)

S is a dimensionless factor and can be calculated using the relation,

$$S = \frac{1000}{CN} - 10 \tag{5}$$

where,

CN is the curve number estimated based on land use pattern (dimensionless)

The curve number "CN" is selected based on the land use and soil conservation practice at the construction site and is available from the "Soil Conservation Service" database (Chow et al., 1988; Soil Conservation Service, 1972). Runoff volume can be calculated as a product of drainage area and excess rainfall. Once runoff volume is calculated, a graph is plotted with non-exceedence probability on a probability scale versus runoff volume on a logarithmic scale. This graph should yield a straight line, and based on desired storm capture requirement, a non-exceedence probability can be chosen. The runoff volume corresponding to the non-exceedence probability chosen gives the settling volume of the SB.

4.1.1 Basin design – stormwater versus sediment control

If the SBs will be eventually used for both stormwater management and runoff capture in addition to sediment removal, then it would likely be necessary to design sedimentation basins for 99% non-exceedence probability (based on 100-year rainfall frequency estimates) as it corresponds to capture of a 100-year storm. This is necessary because current PADEP regulations require that stormwater management basins should be able to capture the flood resulting from a 100-year storm (PADEP, 2003; PACD, 1998). On the other hand if the only purpose of the SB is to retain sediments and maintain water quality during infrastructure construction, then the policy for basin design can accept a lower non-exceedence probability such as 90% (capture of 10-yr storm), 80% (capture of 5-year storm) or even a 50% (capture of 2-year storm) depending on the duration of the construction project. Since storms with a large return period are expected to occur less frequently during the life of the construction project, their contribution to water quality is less compared to storms with small return period that occur more frequently during the life of the construction project. As an example, the probability of a 100-year storm to occur is once in 100 years and hence may occur probably just once during the construction phase of the project. Even if the pond were not designed to capture particles effectively from a 100-year storm, the discharge may violate permit limits just once during the construction phase. But if the basin overflow rate is not sufficient to capture particles effectively from a 5-year storm, then there may be peaks in suspended solids and discharge may exceed permit limits several times during the construction phase of the project. Construction of basins that capture a 100-year storm and retain sediments effectively may require a very large surface area which is costly. On the contrary, designing water quality SBs for lower non-exceedence probability (smaller return periods) may result in smaller basins that cost less to install while offering the necessary environmental sediment removal protection.

For application to the design of SB111, assuming a runoff ratio α of 0.9, and using a drainage area of 5.96 acres (259,618 ft^2, 24,120 m^2) (as obtained from elevation map of the drainage basin), the runoff volume, V_R can be calculated from equation 3 (PADEP, 2000), as below:

$$V_R = 0.9 \times 259618 \times R \tag{6}$$

The runoff coefficient α varies from 0.2 to 0.9 depending upon the type of land use. A runoff coefficient of 0.9 has been used as an example in this section. A runoff coefficient of 0.7 has been used for basin design purposes in the following sections as a conservative estimate that is more typical of construction sites (PADEP, 2000). Table 15 shows the rainfall frequency estimates for State College, PA, the location of the construction site (Bonnin et al., 2004). The corresponding values of runoff volume and non-exceedence probability are also shown in Table

15. Figure 38 shows the probability plot developed from 100-year rainfall frequency estimates (Table 15). Once vehicular traffic uses the highway, sedimentation basins at this construction site will eventually be used for both runoff capture and sediment removal. Therefore, a basin settling volume corresponding to 99% non-exceedence probability was used for this design. The runoff volume corresponding to 99% storm capture is 110,000 cubic feet (3,080 m^3). Thus the settling volume for SB111 for capturing runoff from 100-year storm will be 110,000 cubic feet (3,080 m^3).

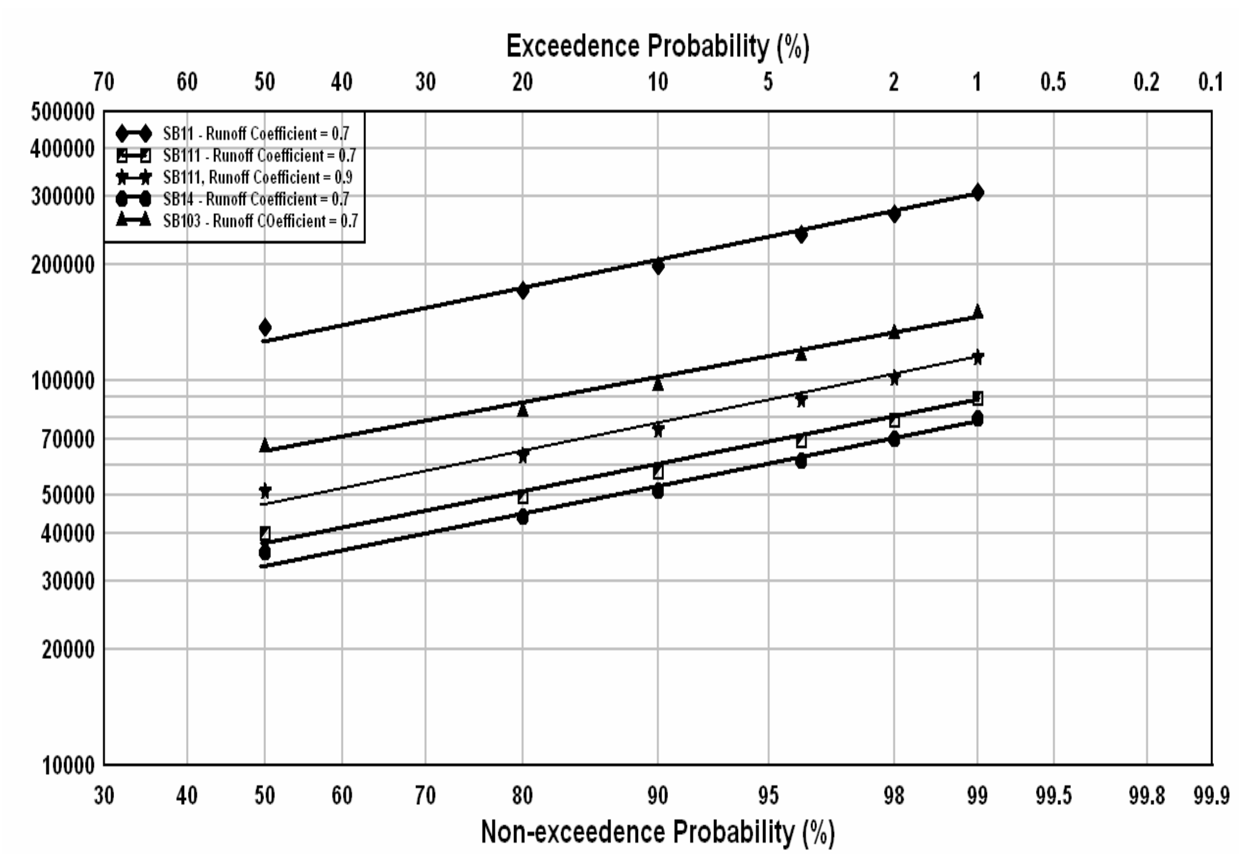

Figure 38. Probability plot for SB11, SB14, SB103 & SB111 (100 yr rainfall frequency data)

4.2 RUSLE2 FOR CALCULATING SEDIMENT ZONE VOLUME

RUSLE is a set of mathematical equations that estimate average annual soil loss and sediment yield resulting from interrill and rill erosion. It was developed by scientists from various fields including agricultural engineers, civil engineers, agronomists, soil scientists, geologists, hydrologists, geomorphologists and soil conservationists of the Soil and Water Conservation Society in 1993. It was derived from the theory of erosion processes, using more than 10,000 plot-years of data from natural rainfall plots and numerous rainfall-simulation plots (Renard et al., 1997). The latest version of RUSLE is RUSLE2. The earlier version of RUSLE, namely RUSLE1, had several subversions (RUSLE 1.02 - RUSLE 1.06). The difference between RUSLE1 and RUSLE2 is that RUSLE2 is more powerful than RUSLE1, has improved computational procedures, and produces a more detailed output than RUSLE1. Further RUSLE2 is a windows-based program and has a user-friendly graphical user interface compared to the DOS-based interface of RUSLE1.

The basin relationship of RUSLE, which retains the structure of its predecessor, the Universal Soil Loss Equation (Wischmeier et al, 1978) is:

$$A = RKLSCP \tag{7}$$

Where:

A = Average annual soil loss $\dfrac{tons}{acre\ year}$ $\left(\dfrac{tonnes}{m^2\ year}\right)$

R = Rainfall/runoff erosivity $\dfrac{foot - tonf - inch}{acre - hour - year}$ $\left(\dfrac{m - kN - cm}{m^2 - hour - year}\right)$

(1 tonf = 1short ton x gravity = 907 x 9.81 ≈ 8.89 kilo Newton)

K = Soil erodability $\frac{ton - acre - hour}{acre - foot - tonf - inch}$ $\left(\frac{tonnes - m^2 - hour}{m^3 - kN - cm}\right)$

L = Slope length $\frac{foot}{foot}$ $\left(\frac{m}{m}\right)$

S = Hill slope steepness (dimensionless)

C = Cover-management (dimensionless)

P = Support practice (dimensionless)

RUSLE2 can be used to calculate soil loss from construction sites, mined land and reclaimed lands in addition to agricultural lands. Some of the applications of RUSLE2, with respect to construction sites are (1) assessment of alternative hill slope configurations (convex, uniform, concave, and complex), (2) obtaining erosion-control or erosion-reduction credit for the surface rock fragment covers and (3) analyses of the effects of straw mulch, random roughness, soil consolidation, sediment deposition, and changes through time due to mulch decomposition and deterioration of surface roughness due to rainfall (Office of Surface Mining, 1998). The sediment yield calculated from RUSLE2 can be used for identifying the sediment volume required for SB.

Searching the literature reveals that RUSLE2 has not been applied to SB design in the past. RUSLE2 can be used to calculate sediment yield from SB drainage area and the sediment yield thus calculated can be used to set the sediment storage volume and the frequency of sediment removal for the basin. As an example, the Windows-based computer version of RUSLE, namely RUSLE2, was used to calculate the sediment yield from the SB111 drainage area. The drainage area as shown on an elevation map was divided into five segments of varying slopes. The slope length and slope steepness of each segment was input into the RUSLE2 program. Table 16 gives the slope length and steepness of each segment.

Table 16. Slope length and percentage steepness of SB111 sample drainage basin

Segment No	Slope Length (Along Slope) Ft (m)	Slope Length (Horizontal length) ft (m)	Slope Steepness %
1	40 (12.2)	38 (11.6)	35
2	40 (12.2)	40 (12.2)	5.0
3	50 (15.2)	49 (14.9)	20
4	50 (15.2)	50 (15.2)	4.0
5	160 (48.8)	150 (45.7)	43

RUSLE2 is used to calculate soil loss and sediment yield at the toe of the slope resulting from rill and interrill erosion. The RUSLE2 program calculates the soil yield at the toe of the drainage area by adding the soil loss from each segment and subtracting the local soil deposition, if any, to yield the final value. In addition to slope length and steepness, inputs including soil, vegetation, type of soil management and climate data were also provided. The climate data for Centre County, PA was imported from the climate database provided in the NRCS (Natural Resources Conservation Service, 2004) website for use with RUSLE2. Similarly data files on soil types and soil management for Center County, PA were also imported into the program from the NRCS database. The soil type for the drainage basin was identified to be "LDF LAIDIG Extremely Stony Loam" from Soil Survey for Centre County, PA (USDA Soil Conservation Service, 1981). As inputs for soil management, the input variable of "a single year special seed clover" was chosen for the segments of the drainage area where vegetation was used as a management practice. A construction site template defined within RUSLE2 was used as management type for the segments of drainage area, where earth movement was prevalent due to construction.

4.3 RUSLE RESULTS AND DISCUSSION

The soil yield and the soil loss calculated by RUSLE2 were 160 tons/acre/year (36 kg/m^2/year) and 320 tons/acre/year (72 kg/m^2/year) respectively. The value of soil yield at the toe of the slope is less than the annual average soil loss due to intermediate deposition of soil along the hill slope before reaching the toe. As the soil deposited along the hill slope can be further eroded during subsequent storm events or construction activity, the average of soil loss and soil yield values have been used as an estimate of soil delivered into the sedimentation basins. Thus an average estimate of soil delivered into the SB111 from its drainage area is 240 tons/acre/year (54 kg/m^2/year). Applying this value as the average soil yield from the drainage basin that enters the SB, the sediment volume that is required to be provided and the frequency of the sediment dredging cycle can be arrived at, as shown below:

Drainage area for SB111	=	5.96 Ac (259618 ft^2, 24120 m^2)
Sediment delivery t/ac/yr	=	240 tons/Ac/yr (54 kg/m^2/year)
Assuming SG of sediment	=	2.65 (Davison et al., 2000)
Sediment storage volume	=	240 x 907.2 [kg/Ac/yr] x 5.96 [Ac] / 2650 [kg/m^3]
	≅	17,000 [ft^3/yr] (481 [m^3/yr])

If a sediment dredging frequency of n years is preferred for maintenance purposes, then the sediment volume can be calculated as (n x 17,000) ft^3.(481 m^3) Thus, considering a sediment dredging frequency of 2 years, the sediment volume for SB111 would be 2 x 17,000 ≅ 34,000 ft^3 (962 m^3). The present sediment volume of SB111 is 15,228 ft^3 (431 m^3), which would require sediment dredging every 11 months.

The volume of sediment accumulated in basins SB11 and SB111 was measured during a field visit in June 2006. The sediment depth in SB111 was found to be 3 ft (0.9 m), which is 1.5 ft (0.5 m) above the design sediment storage zone. The volume of the accumulated sediment is about 33,000 ft^3 (935 m^3). In the case of SB11, the sediments had completely filled the outflow structure of the basin and sediment existed in any basin discharge. The sediment depth in SB11 was measured to be 6 ft, which is approximately 3.4 ft above the design sediment zone, corresponding to a sediment volume of 107,806 ft^3 (3,053 m^3). According to the soil yield from RUSLE2, the volume of sediment collected in the basin from April 2004 (basin installation date) to June 2006 should be about 37,000 ft^3 (1,048 m^3). The field measured value of SB111 sediment volume was 33,000 ft^3 (935 m^3). Although somewhat smaller than the RUSLE2 predicted soil volume, this volume of sediment appears to be reasonable as some soil may have been lost due over time to sediment re-suspension and release in the outlet. It was noted that SB11 was dredged once in January 2004. Therefore the sediment volume for SB11, as calculated from RUSLE2 for the period of January 2004 to April 2006 is 112,571 ft^3 (3,188 m^3). The field measured value of sediment volume was 107,806 ft^3 (3,053 m^3). The field value closely matches with RUSLE2 calculated sediment yield results, thus providing a measure of "calibration" and confidence in the overall technique.

4.4 OVERFLOW RATE AND PARTICLE REMOVAL

The expression for terminal settling velocity for a single particle settling in a fluid is derived below (Gregory et al., 1999). The forces acting on a particle settling in a fluid (unhindered by other particles) are drag force f_d, buoyancy force f_b and force of gravity f_g. The equation for terminal settling velocity of a single particle can be derived by equating the forces as follows:

$$f_d = f_g - f_b \tag{8}$$

The drag force on a particle traveling in a resistant fluid is given by the relation (Prandtl and Tietjens, 1957):

$$f_d = \frac{C_D v^2 \rho A}{2} \tag{9}$$

where,

C_D is the drag coefficient

v is the settling velocity

ρ is the density of the liquid

A is projected area of particle in the direction of flow

When the particle reaches a constant settling velocity v_t (terminal settling velocity),

$$f_g - f_b = Vg(\rho_p - \rho) \tag{10}$$

where,

V is the effective volume of the particle

g is the gravitational constant of acceleration

ρ_P is the density of the particle

Rearranging equation 10,

$$v_t = \left[\frac{2g(\rho_p - \rho)V}{C_D \rho A} \right]^{1/2} \tag{11}$$

for a spherical solid particle,

$$\frac{V}{A} = \frac{4}{6} d \tag{12}$$

Substituting equation 12 in equation 11, we have

$$v_t = \left[\frac{4g(\rho_p - \rho)d}{3C_D \rho} \right]^{1/2} \tag{13}$$

In the laminar flow region,

$$C_D = \frac{24}{R_e} \tag{14}$$

where,

$$R_e = \frac{\rho v d}{\mu} \tag{15}$$

Substituting equations 14 and 15 in equation 13, we get the expression for terminal settling velocity of the particle which is also called Stokes' equation for laminar flow condition (Gregory et al., 1999)

$$v_t = \frac{g(\rho_p - \rho)d^2}{18\mu} \tag{16}$$

In a horizontal-flow rectangular tank, the settling of a particle has both vertical and horizontal components as shown in Figure 39.

Surface Area = A

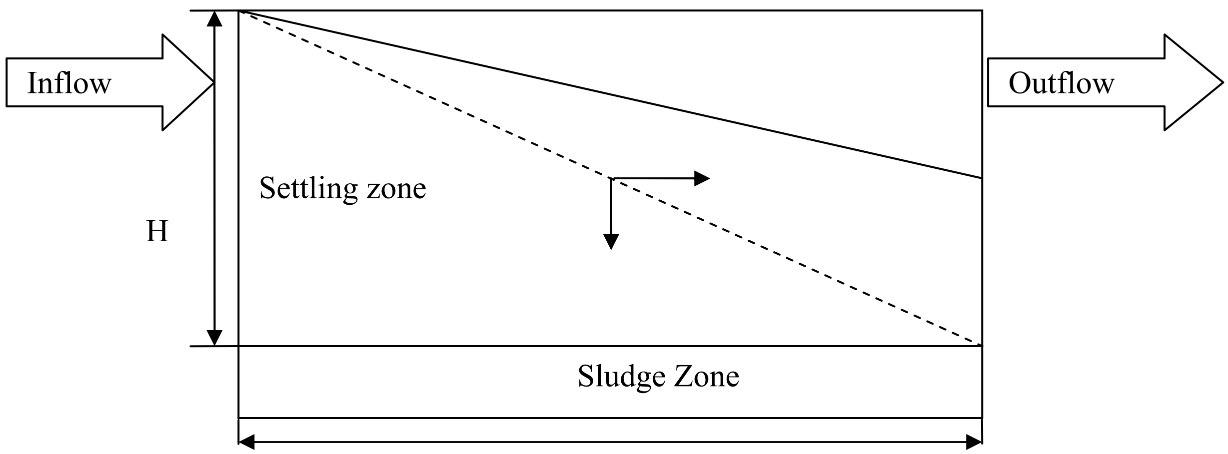

Figure 39. Schematic representation of particle settling in a rectangular sedimentation tank

L = horizontal distance traveled

t = time of travel

H = depth of width

W = width of tank

If t is the detention time in the basin then,

$$t = \frac{HWL}{Q} \tag{17}$$

If the vertical distance traveled by the particle in time "t" is "h",

$$h = vt \tag{18}$$

where,

v is the settling velocity of the particle

Substituting in equation 18, and writing in terms of v,

$$v = \frac{hQ}{HLW} \tag{19}$$

For a particle to be completely removed in the basin, the particle should travel a distance H in time t. Thus for the critical case when h = H,

$$v^* = \frac{Q}{LW} = \frac{Q}{A} \tag{20}$$

Overflow rate is thus defined as:

$$v^* = \frac{Q}{A} \tag{21}$$

The velocity of a particle settling under quiescent conditions is given by Stokes equation. From the above derivation it can be understood that setting the overflow rate of the basin equal to stokes settling velocity of a nominal size particle, will result in complete removal of all particles equal to or greater than the nominal particle size considered.

4.5 BASIN OUTFLOW RATE AND AREA

The required design overflow rate for particle removals can be calculated by determining the size of the particle that has to be removed completely in the basin. Either a nominal particle size can be chosen for removal or the particle size distribution data (PSD) of the runoff from the site can be analyzed to identify the particle size for removal. PSD of storm water runoff sample from construction sites in the region may also be analyzed to identify the nominal particle size for removal if that is the best data available. As sedimentation basins are constructed before construction activities begin at the site, samples obtained from the site to study PSD before construction will be different from that during construction activity; hence the suggestion of comparing the particle size distribution at other construction sites in the region is being made herein, for the identification of nominal particle size to be removed in the basin. It appears that there is a need to classify soil particle size distribution in various geographic locations, so that representative PSD is available for different locations and this could one of the areas of future research. If PSD data is available then the procedure explained below can be used with more confidence for SB design.

The settling velocity for the nominal particle size can be calculated from Stokes's law (Gregory et al., 1999). Design overflow rate for the basin is given by V/A, where V is the volume of the basin and A is the surface area. Overflow rate has units of velocity that can be associated with the smallest particle that is removed completely in the basin. Therefore, the design overflow rate of the basin is set equal to the settling velocity of that particle (Gregory et al., 1999). The PSD of SB111 sediment samples were analyzed using hydrometer testing. The data obtained from hydrometer analysis (ASTM D 422) of the sediment sample has been shown in Table 17. Forty grams of dry sediment sample obtained from SB111 was used for the hydrometer analysis. The sediment sample was soaked for 24 hours in 500 mL water containing 40 g sodium meta phosphate (deflocculant). The sample was then blended well with a mechanical blender to homogenize the solution and made up to 1,000 mL in a 1 Liter graduated cylinder. The cylinder was inverted to mix the contents, and a hydrometer (number 152 H) was suspended in the solution. Hydrometer readings were taken at regular intervals up to 76 hrs. A solution blank was also prepared with DI water and hydrometer readings were taken at each time interval for the blank. Temperature was also measured along with each hydrometer reading. The results obtained in terms of PSD are shown in Table 17.

If we assume that the PSD of inflow to the basin is similar to that of basin sediments, then from the sediment PSD data in Table 17, we see that removing particles with diameter 2 micron would constitute to roughly 85% particle removal by weight. For example, if the influent TSS concentration was 100 mg/L, then setting the overflow rate corresponding to 2 micron particle removal will result in an effluent TSS concentration of 15 mg/L. Thus, to achieve 85% particle removal, the design overflow rate for SB111 would be set to 1.0 feet per day (7.48 gal/ft^2/day, 0.3 m/day), which is the settling velocity corresponding to 2 micron particle as calculated from Stokes law at 25°C assuming particle density of 2,650 kg/m^3 (Gregory et al., 1999, Davison et al., 2000). The PSD data used herein was obtained from basin sediment sample. Realistically however, the PSD of influent to the basin should be used, however due to absence of flow in the inlets during several field visits; the PSD data from collected sediments have been used.

Table 17. Particle size distribution data for SB111 sediment sample from hydrometer analysis

Particle Size Range Particle Diameter μm	Mass Percentage Less than Diameter
45	57
33	51
27	49
24	46
21	46
15	42
13	39
9.1	34
6.5	31
4.7	27
3.3	24
2.3	17
1.4	12
0.8	7

4.6 SEDIMENTATION BASIN DESIGN AND CONFIGURATION

To ensure structural stability, a typical SB such as at the I-99 construction site is constructed with tapering side walls as shown in Figure 40. Due to its shape, the area of the SB varies along the depth of the basin. The outflow device used to release storm water from the basin is usually a perforated riser (Figure 41). While designing the sedimentation basin, the area and volume of basin at different depths of the basin has to be calculated. The outflow rate through the outflow structure also varies along the depth of the basin. It can be seen from Figure 41, that the riser has a number of discharge openings along its length. As the water level in the pond increases, the discharge flow through the riser also increases since it intercepts additional exit holes.

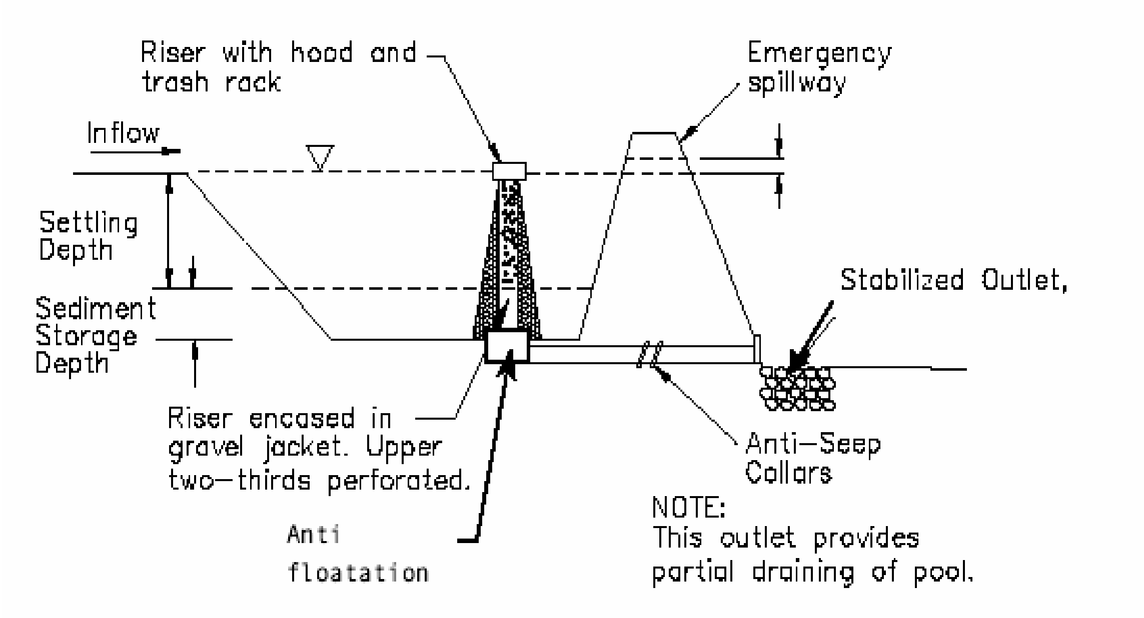

Figure 40. Sedimentation basin (CA Stormwater BMP Handbook, 2003)

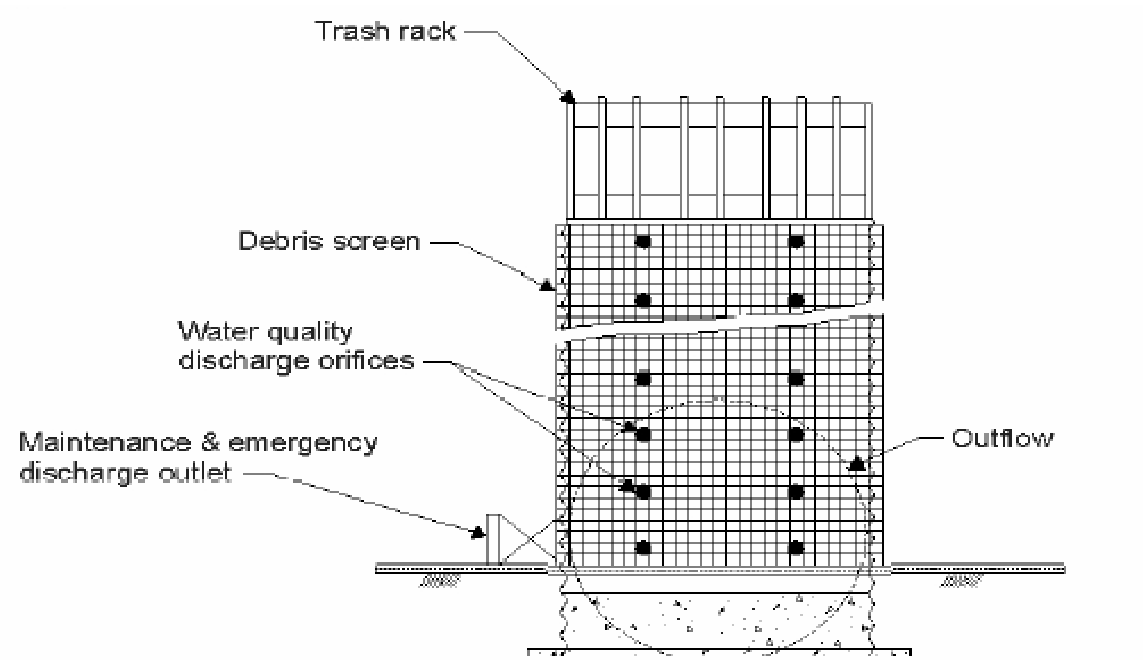

Figure 41. Multiple orifice outlet riser (CA Stormwater BMP Handbook, 2003)

In order to set a minimum design overflow rate, the outflow through the riser must be designed such that the outflow rate at any depth divided by the corresponding area yields a minimum overflow rate. That is

$$\frac{Q(d)}{A(d)} = OR(d) \tag{22}$$

where,

Q(d) is the outflow rate as a function of depth d, ft^3/day (m^3/day)

A(d) is area at depth d, ft^2 (m^2)

OR(d) is the overflow rate at depth d, ft/day (m/day)

There is no outflow from the basin in the sediment zone, as this volume is reserved for sediment storage. Drainage of water from the basin takes place only in the settling zone.

4.7 SEDIMENTATION BASIN DESIGN PARAMETERS

The design parameters for SB111 were developed by applying the method discussed above. Two alternative designs were developed and compared with the existing design, 1) for a 100-year design storm (99% storm capture in any given year), runoff coefficient of 0.90, 2 micron particle removal and 2-year dredging frequency and 2) for a 5-year design storm (80% storm capture), runoff coefficient of 0.7, 2 micron particle removal and 1-year dredging frequency. Figure 42 shows the sequence of steps to be followed for designing the sedimentation basin. The formulas used for calculation and an Excel template showing step by step calculations for basin design are shown in Appendix C.

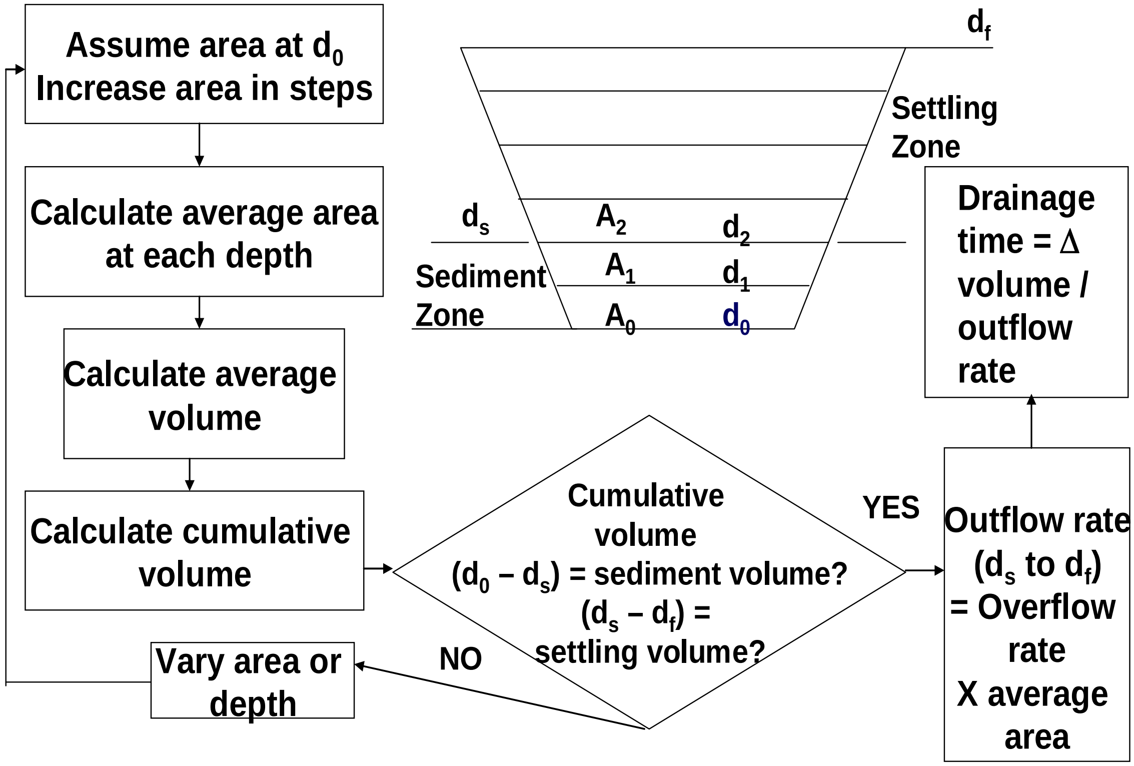

Figure 42. Flow diagram of steps to be followed for designing sedimentation basins

Table 18 and Table 19 show a design summary of the two design scenarios considered. In Table 18 and Table 19, the first column is the depth of the basin. The depth, length and breadth of the basin can be varied accordingly to attain the design sediment storage volume and settling zone volume. The outflow rate is the product of average area and design overflow rate, and the drainage time is obtained by dividing the average incremental basin volume by outflow rate. From Table 18 it can be seen that, for the capture of 99% of storms in a year (capture of a 100-year storm), runoff coefficient of 0.9, for the removal of particles with diameter of 2 microns and above and for a dredging frequency of 2 years, a basin 7 ft (2.1 m) in depth, having an area of approximately 29,400 ft^2 (2,731 m^2) at the surface and having a drainage time of 5 days, is sufficient applying the integrated design method. Similarly for the capture of 80% of storms in a year, for a runoff coefficient of 0.7, for the removal of particles with diameter 2 microns and above and for a dredging frequency of 1 year, a basin 9 ft in depth, having an area of approximately 14,600 ft^2 (1,360 m^2) area at the surface and having a drainage time of 4.8 days is sufficient (Table 19) applying the integrated design method.

Table 18. Design summary of SB111 (100-yr storm, RC = 0.9, 2-yr dredging frequency)[a]

Elevation from the basin bottom Ft	**Basin dimensions**			**Avg[b] area ft^2**	**Cum[c] basin volume Ft^3**	**Outflow rate ft^3/day**	**Overflow rate gal/ft^2/day**	**Drainage time Day**	**Zone**
	Length ft	**Breadth Ft**	**Area ft^2**						
0	160	80	12800						Sediment Zone
0.5	164	84	13776	13288	6644				
1.0	168	88	14784	14280	13784				
1.5	172	92	15824	15304	21436				
2.0	176	96	16896	16360	29616				
2.3	178	98	17555	17225	34784	17227	7.48	5.0	
2.5	180	100	18000	17777	38339	17779	7.48	4.7	Settling Zone
3.0	184	104	19136	18568	47623	18569	7.48	4.5	
3.5	188	108	20304	19720	57483	19721	7.48	4.0	
4.0	192	112	21504	20904	67935	20906	7.48	3.5	
4.5	196	116	22736	22120	78995	22122	7.48	3.0	
5.0	200	120	24000	23368	90679	23370	7.48	2.5	
5.5	204	124	25296	24648	103003	24650	7.48	2.0	
6.0	208	128	26624	25960	115983	25962	7.48	1.5	
6.5	212	132	27984	27304	129635	27306	7.48	1.0	
7.0	216	136	29376	28680	143975	28682	7.48	0.5	

[a]2 micron particle removal, [b]Average, [c]Cumulative

Table 19. Design summary of SB111 (5-yr storm, RC = 0.7, 1-yr dredging frequency)[a]

Elevation from Basin Bottom Ft	Basin Dimension			Avg[b] Area ft^2	Cum[c] Basin Volume Ft^3	Outflow Rate ft^3/day	Overflow Rate gal/ft^2/day	Drainage Time Day	Zone
	Length ft	Breadth Ft	Area ft^2						
0	80	20	1600						Sediment Zone
1.0	88	28	2464	2032	2032				
2.0	96	36	3456	2960	4992				
3.0	104	44	4576	4016	9008				
4.0	112	52	5824	5200	14208				
4.5	116	56	6496	6160	17288				
5.0	120	60	7200	6848	20712	6849	7.48	4.8	Settling Zone
6.0	128	68	8704	7952	28664	7953	7.48	4.3	
7.0	136	76	10336	9520	38184	9521	7.48	3.3	
8.0	144	84	12096	11216	49400	11217	7.48	2.3	
9.3	155	95	14635	13366	67176	13367	7.48	1.3	

[a]2micron particle removal, [b]Average, [c]Cumulative

The existing design of SB11 is summarized in Table 20 and a comparison of the existing and developed design parameters is shown in Table 21. Comparing the existing design of SB111 with the design parameters developed using the integrated method, shows that this methodology helps to design sedimentation basin according to requirements and offers more choices in terms of basin performance and cost. From Table 21 it can be seen that if both runoff capture from a 100-year storm as well as effective particle removal has to be achieved in the same basin, then a basin with large volume and surface area is required. On the contrary, if the decision policy is that runoff capture can be reduced for instance from 99% storm capture (100 year storm) to 80% storm capture (5-year storm) then basin volume, and area required can be reduced significantly and would result in cost savings in terms of reduced basin volume and area requirements and reduced excavation costs during basin construction. It must be noted that the trade-off for surface area reduction is cost of drainage time i.e., decreasing surface area would also require an increase in basin depth, and would result in an increase in drainage time.

Table 20. Summary of existing SB111 design at the I-99 construction site[a]

Elevation from Basin Bottom Ft	Basin Dimension		Average Area ft^2	Average Basin Volume ft^3	Cumulative Basin Volume ft^3	Outflow Rate ft^3/day	Overflow Rate gal/ft^2/day	Drainage Time Day
	Length Ft	Breadth Ft						
0.0	160	57						
1.0	-	-	9745	9745	9745			
1.5	-	-	10966	5483	15228			
1.9	-	-	11816	4372	19600	0.02	1.09	4.92
2.0	-	-	8546	1111	20711	0.03	2.27	2.39
3.0	-	-	12239	12239	32950	0.13	6.86	1.96
4.0	-	-	13561	13561	46511	0.25	11.9	0.87
4.7	-	-	14723	10306	56817	0.80	35.1	0.24
5.0	-	-	15423	4627	61444	4.04	169	0.10
6.0	-	-	16357	16357	77801	7.51	296	0.08
7.0	-	-	17829	17829	95630	7.51	272	0.06
8.0	-	-	19152	19152	114782	7.51	253	0.03

[a]Erosion and Pollution Control Narrative (PENNDOT, 2002)

Table 21. Comparison of calculated results using existing and alternative design parameters

Design Parameter	Existing Design	99 % storm capture, 2 μ particle removal, 2 yr dredging frequency, runoff coefficient = 0.9	Comments	80 % storm capture, 2 μ particle removal, 1 yr dredging frequency, runoff coefficient = 0.7	Comments
Basin Volume	115,000 ft^3 (3,255 m^3)	144,000 ft^3 (4,075 m^3)	Increased by 25 %	67,000 ft^3 (1,900 m^3)	Reduced by 42 %
Basin Area at Basin Surface	19,000 (1,765 m^2)	29,000 (2,694 m^2)	Increased by 53 %	14,600 (1,360 m^2)	Reduced by 23 %
Particle Removal	0.8 – 12.5 micron	2 micron	Improved particle removal	2 micron	Improved particle removal
Drainage Time	5.0 days	5.0 days	Same	4.8 days	Decreased by 4 %
Sediment Volume	15,200 ft^3 (430 m^3)	34,000 ft^3 (962 m^3)	2 year dredging frequency	17,000 ft^3 (480 m^3)	1 year dredging frequency

Increase in basin area would reduce basin depth and basin drainage time. The logical effect of reducing basin drainage time is a likely reduction in algae growth and mosquito breeding. It should be noted that a typical mosquito life cycle varies from 7 to 18 days and maintaining pond detention time under seven days, will help destroy the mosquito life cycle helping in controlling mosquito breeding in the basins (National Center for Infectious Diseases, 2004; Westchester County Department of Health, 2006; Cornell University Center for the Environment, 2002, The American Mosquito Control Association, 2006; University of Florida, 1995).

In the existing SB111 design, the outflow rate increases from the bottom of the basin to the basin surface. This means that as the water level in the basin increases, the size of the particle removed increases. Thus when the basin is almost full during a storm event, the basin particle removal is reduced and a greater amount of suspended solids are released in the basin outlet. Hence peaks in TSS and particulate pollutants are not attenuated as confirmed by the collected data. The alternative design developed by the "integrated methodology" provides for a constant overflow rate, and at all depths the minimum particle size that can be removed in the basin remains the same. Consequently, significant attenuation of particulate peaks can also be expected when designing SBs using the proposed integrated method. Furthermore, the "integrated design" methodology allows for sedimentation basin designs based on decision variables of storm capture, particle removal and sediment dredging frequency requirements.

Comparison of the existing design of SB111 with the design parameters developed using the integrated method, shows that the integrated design yields a basin of larger volume (increased by 25%) and larger area (increased by 53 %) for capturing a 100-year storm and a basin of smaller volume (reduced by 42%) and smaller area (reduced by 23 %) for capturing the runoff from a 5-year storm. It must be noted that the 25% increase in volume for capturing a 100-year storm is due to the assumption that 90% of the rainfall contributes to runoff. The comparison demonstrated the effect of two important factors on pond design, namely the runoff ratio, and the decision regarding storm capture. The new design also yields smaller depths and drainage time. The drainage (surface) area is increased for both cases presented. Increasing basin area is essential to maintain overflow rate and improve particle removal. It must be noted that area required can be reduced if necessary at the cost of drainage time i.e., decreasing area would require an increase in basin depth, and would result in an increase in drainage time since the same overflow rate has to be maintained. Increase in basin area would reduce basin depth and basin drainage time.

The integrated design methodology discussed above shows the application of rainfall probability plots to determine basin settling volume, RUSLE2 to identify sediment zone volume and sediment dredging frequency, and overflow rate to determine minimum particle size that can be removed in the basin and required basin area. The conclusion that can be reached by comparing the existing design of SB111 and design developed for SB111 based on the integrated design methodology are as follows:

1. The volume of the sedimentation basin can be varied depending upon storm capture requirements. When the basin is allowed to be designed to capture storms that have short return periods, the basin volume and the associated construction costs can be considerably reduced.
2. The desired percentage of particle removal can be achieved by designing the pond with an overflow rate equal to the settling velocity of the particle to be removed. Depending upon the volume of the basin, maintaining the design overflow rate may lead to an increase in basin surface area compared to existing design practice.
3. Improved particle removal and suspended solids peak attenuation during high flow events can be attenuated by maintaining a constant overflow rate at all depths of the pond.
4. The pond drainage time can be varied depending upon storm water capture requirements, basin area and the minimum particle size removal requirement. Reduced drainage can be instrumental in controlling mosquito breeding.
5. By applying RUSLE2 the average annual sediment delivery to the SB can be better predicted. Thus for a given sediment volume, the sediment dredging frequency in years

can be calculated. This would give an estimate of how often a field inspection should be conducted to inspect pond sediment level and dredge sediments if necessary.

In conclusion the integrated design methodology for sedimentation pond design helps to address both runoff capture and particle removal requirements. It yields a design that helps in suspended solid peak attenuation during high flow events. It shows that basin drainage time can be reduced if necessary and issues of algae formation and mosquito breeding can be controlled. Further it presents a method to arrive at sediment storage volume, settling zone volume and sediment dredging frequency specific to the construction site which would help in controlling sediment re-suspension. It can thus be said that the integrated design methodology offers more choices in terms of performance and cost and will be a significant advance to the existing methodology of designing sedimentation basins.

4.8 SENSITIVITY ANALYSIS

The objective of this analysis is to identify the sensitivity of total basin volume to the changes in input parameters such as runoff coefficient, non-exceedence probability and RUSLE parameters such as soil type and vegetation type. In order to understand the variation in total basin volume with change in non-exceedence probability, sensitivity analysis was performed on basin volume by changing the exceedence probability. The results are summarized in the Table 22 below:

Table 22. Variation in total basin volume with change in non-exceedence probability

% Non-exceedence Probability	Runoff Volume ft^3	Sediment Volume ft^3	Sediment Dredging Frequency (yr)	Total Basin Volume ft^3	% Change in Total Basin Volume
90	72000	34000	2	106000	-
80	62000	34000	2	96000	9
70	58000	34000	2	92000	13
60	54000	34000	2	88000	17
50	50000	34000	2	84000	21

It appears from Table 22 that variation in exceedence probability can change total volume of the basin significantly (Figure 43). It must be noted that changing exceedence probability has no effect on sediment volume or sediment dredging frequency as they are dependent only on the characteristics of drainage basin and RUSLE parameters. Figure 43 below shows the variation of total basin volume with change in non-exceedence probability. Non-exceedence probability is a decision variable which may be chosen according to the runoff capture requirements.

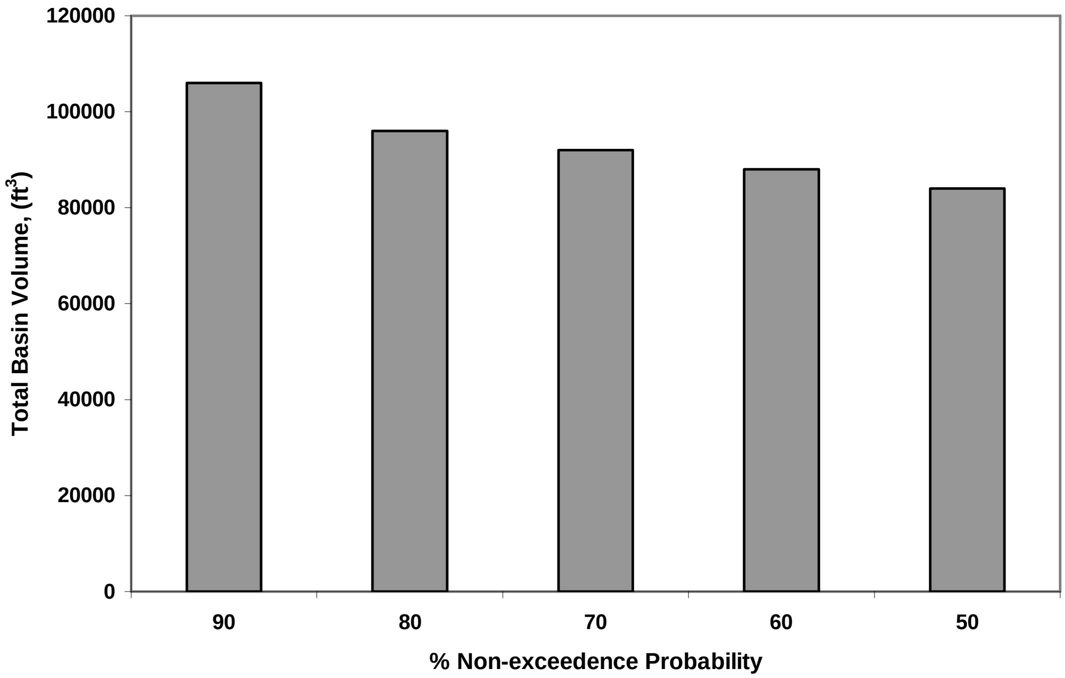

Figure 43. Sensitivity Analysis – total basin volume vs. non-exceedence probability[a]
[a]Constant sediment volume and runoff coefficient

The runoff coefficient was assumed to be 0.9 (a conservative estimate) for an example basin design. Runoff coefficient for construction sites can vary from 0.6 to about 0.9. A sensitivity analysis was performed to understand the extent of variation of basin total volume with runoff coefficient. The results are summarized in Table 23 and Figure 44.

Table 23. Variation of total basin volume with change in runoff coefficient

Runoff Coefficient	% Non-exceedence Probability	Runoff Volume ft^3	Sediment Volume ft^3	Sediment Dredging Frequency (yr)	Total Basin Volume ft^3	% Change in Total Basin Volume
0.9	90	72000	34000	2	106000	-
0.8	90	64000	34000	2	98000	8
0.7	90	56000	34000	2	90000	15
0.6	90	48000	34000	2	82000	23

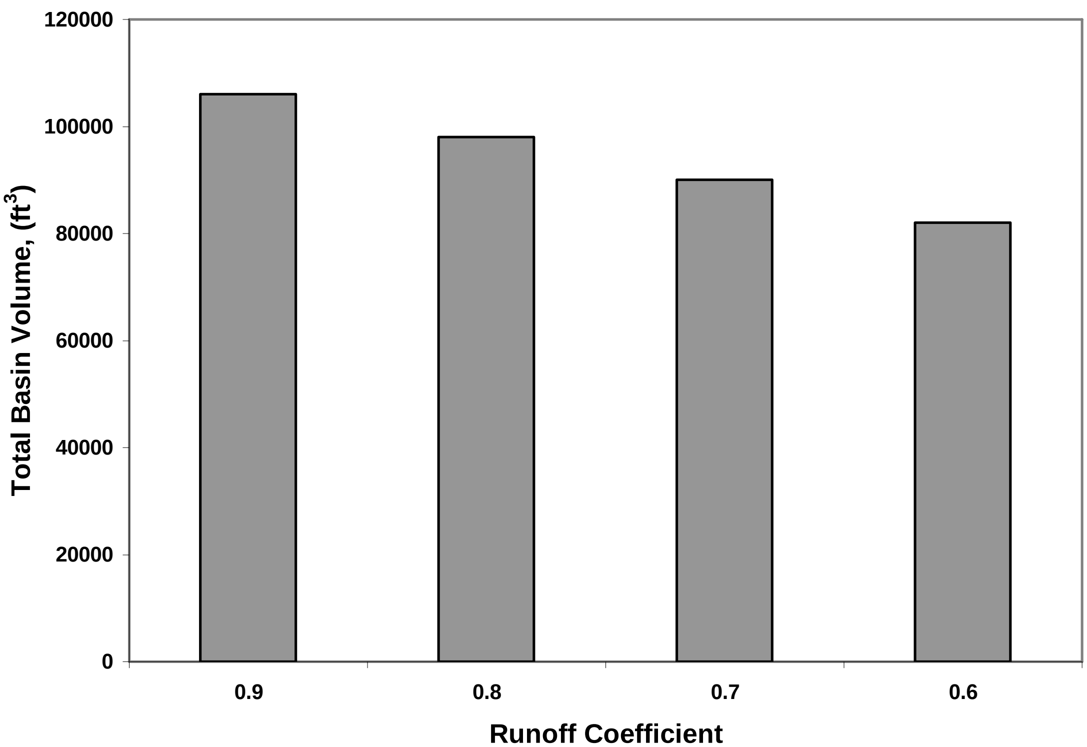

Figure 44. Sensitivity analysis - total basin volume vs. runoff coefficient[a]
[a]90% non-exceedence probability and constant sediment volume

From Table 23 and Figure 44 it can be seen that change in runoff coefficient from 0.9 to 0.6 reduces the basin volume by almost 25 %. The value of runoff coefficient depends on land use pattern at the construction site. Thus we can say that identifying the appropriate runoff coefficient or runoff volume may help in reducing the basin volume and construction costs. Variation in runoff coefficient will not affect sediment volume or sediment dredging frequency. The sediment yield obtained from RUSLE2 depends upon inputs to RUSLE which includes soil type, slope management and the type of crop grown on the slopes of the basin, drainage basin area and drainage basin slope. Slope length and slope steepness are parameters of the drainage basin and were identified from the drainage basin maps. The type of soil for the location of construction site was identified from Soil Survey of Centre County, PA, (USDA SCS, 1981). Data on slope management practice and the type of plants grown on the basin slope are based on maintenance procedure adopted by PENNDOT at the construction site. The effect of variation in soil type or crop type on the sediment yield was evaluated by performing a sensitivity analysis, by varying the following inputs and examining variations in calculated sediment yields. The purpose of doing this sensitivity analysis was to evaluate the magnitude of change that may result when input parameters were varied. The results of the sensitivity analysis are summarized in Table 24, Table 25 and Figure 45 to Figure 50.

Five different crop types namely, 1 year clover, 2 yr clover, cool season grass 1 yr, cool season grass 2yr and 2 year Alfalfa (Fall seed) was used. Five different soil types were incorporated as found in the locations close to the construction site. The soil types were identified from the Soil Survey for Centre County, PA (USDA Soil Conservation Service, 1981), this information is also available as an online file called soil data mart at the NRCS website (USDA, 2006). The soil types identified were

1- LCD - Laidig extremely stony loam, appear in 8 to 30% slopes, it is characterized by 43% sand, 38.5% silt, and 18.5% clay.

2- LDF - Laidig extremely stony loam, steep, appears in 8 to 25% slopes, it is characterized by 43.3% sand, 39.7% silt and 17.0 % clay.

3- BxD - Buchanan extremely stony loam, appears in 8 to 25% slopes, it is characterized by 43% sand, 38.5% silt and 18.5% clay.

4- AoC - Andover very stony loam, appears in 8 to 15% slopes, it is characterized by 29.1% sand, 53.4% silt and 17.5% clay.

5- AnC - Andover channery loam, appears in 8 to 15% slopes, It is characterized by 43.0% sand, 39.0% silt and 18.0% clay

Table 24. Variation in RUSLE2 results with change in input variable (management type)

Management Type	Sediment Delivery tons/acre/yr	% Change in Sediment Delivery	Sediment Zone Volume ft^3	% Change in Sediment Zone Volume	Total Basin Volume	% Change in Total Basin Volume	Dredging Frequency	% Change in Dredging Frequency
Clover 1 yr	240	-	17303	-	127303	-	1.00	-
Clover 2 yr	235	2	16943	2	126943	0.3	1.02	2
Alfalfa fall seed 2 yr	235	2	16943	2	126943	0.3	1.02	2
Cool season grass 1 yr	235	2	16943	2	126943	0.3	1.02	2
Cool season grass 2 yr	235	2	16943	2	126943	0.3	1.02	2

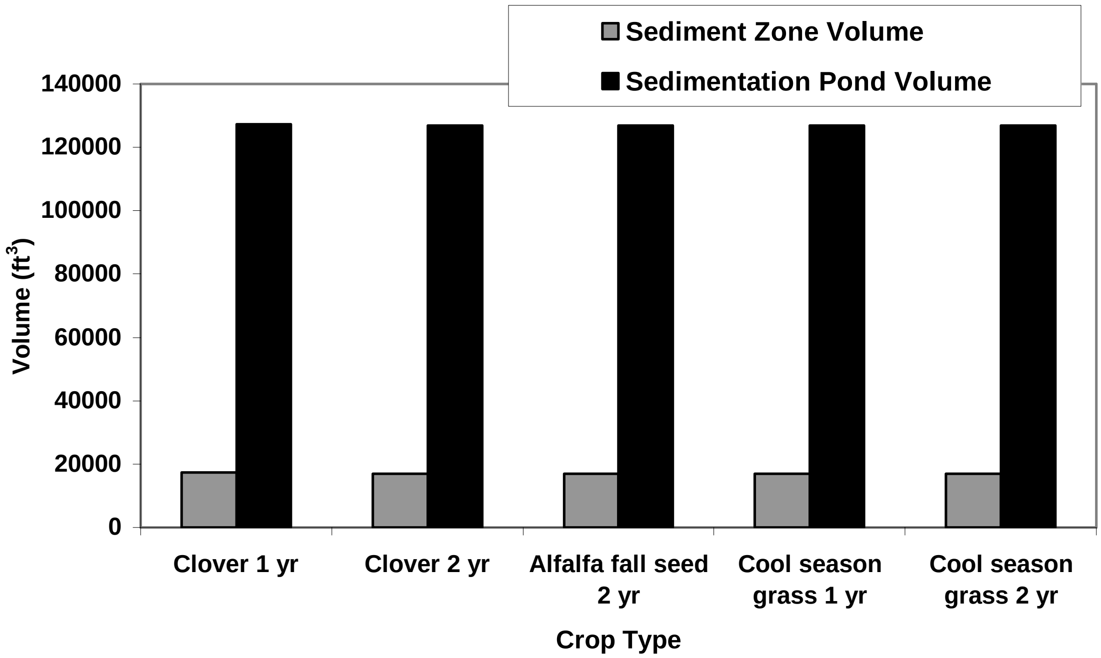

Figure 45. Variation of sediment zone volume and basin volume with crop type[a]

[a]Clover 1 yr and cool season grass 1 yr are one year crops, other crops are two year growth period crops. 2 yr crops have better developed roots compared to one year crops. The effect of crop change does not have significant impact on total basin volume as it affects only the sediment delivery and sediment zone volume and generally the sediment zone volume in only a small fraction of the total basin volume

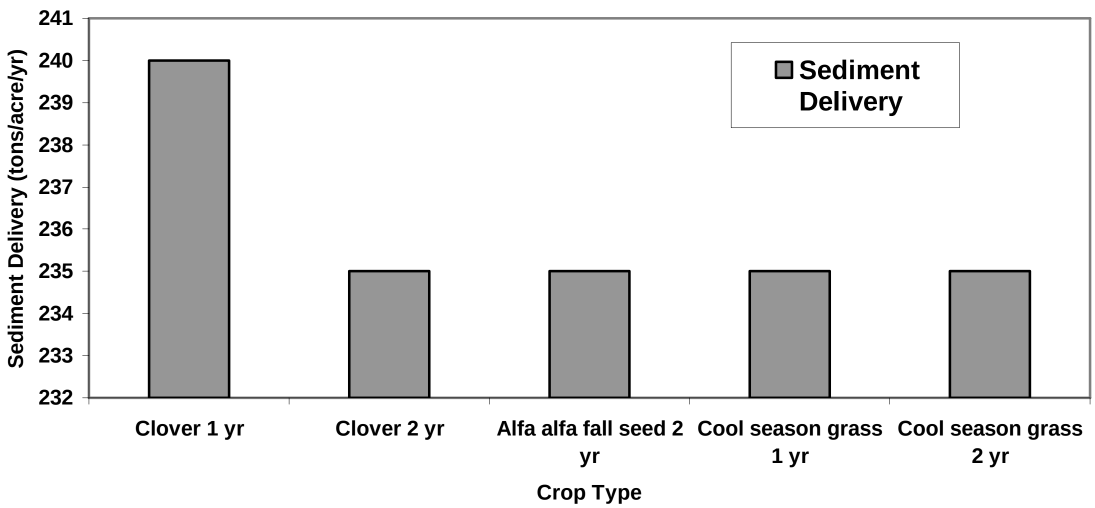

Figure 46. Variation of sediment delivery to the basin with change in crop type[a]

[a]Clover 1 yr and cool season grass 1 yr are one year crops, other crops are two year growth period crops. 2 yr crops have better developed roots compared to one year crop. The effect of crop change has a significant impact on sediment zone volume as a crop with well developed root system holds the soil better and reduces soil delivery to the basin and hence the sediment volume required.

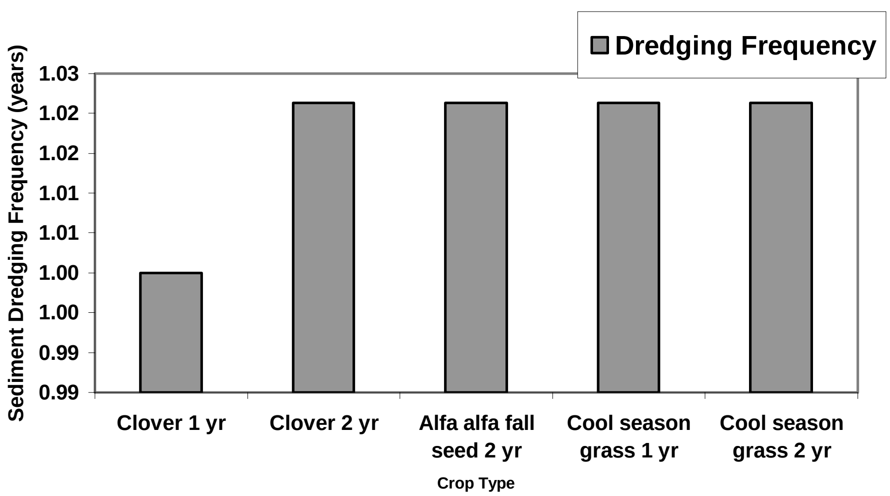

Figure 47. Variation in sediment dredging frequency with change in crop type[a]

[a]Clover 1 yr and cool season grass 1 yr are one year crops, other crops are two year growth period crops. 2 yr crops have better developed roots compared to one year crop. The effect of crop change has a significant impact on sediment zone volume as a crop with well developed root system holds the soil better and reduces soil delivery to the basin and hence the sediment volume and sediment dredging frequency required.

Variation in crop type does not result in a significant change in the sediment yield and sediment dredging frequency (Table 24, Figure 45 to Figure 47). This is because only a small section of the drainage area is vegetated; hence its effect on soil loss is not significant. On the contrary if a large area of the drainage basin was vegetated then, the minimum sediment volume is given by 2 year Alfalfa fall seed which has the best root system that holds soil firmly and yields a minimum sediment volume. Cool season grass (2 year crop) appears to have the next best root system, followed by 2 year Clover, Cool season grass (1 year crop) and Clover (1 year crop). It appears that a crop with longer growth period allows for better development of root system and hence has greater erosion control potential. From the above analysis it appears that BMPs for slope protection must consider vegetation of crop with longer life cycle or growth period.

Table 25. Variation in RUSLE2 results with change in soil type

Soil Type	Sediment Delivery tons/acre/yr	% Change in Sediment Delivery	Sediment Zone Volume ft^3	% Change in Sediment Zone Volume	Total Basin Volume ft^3	% Change in Total Basin Volume	Dredging Frequency Yr	% Change in Dredging Frequency
LDF- Laidig extremely stony loam, steep	240	-	17,303	-	127,303	-	1.0	-
LCD - Laidig extremely stony loam, 8-25% slope	240	0	17,303	9	127,303	0	1.0	0
BxD - Buchanan extremely stony loam	230	4	16,582	13	126,582	1	1.0	4
Anc - Andover channery loam	205	15	14,780	23	124,780	2	1.2	17
AoC - Andover very stony loam	205	15	14,780	23	124,780	2	1.2	17

The sensitivity of sediment volume, sediment dredging frequency and total basin volume to soil type is shown in Table 25 and Figure 48 to Figure 50. The analysis shows that change in soil type can result in about 15 % change in sediment volume and sediment dredging frequency where as the change in total basin volume is within 5%.

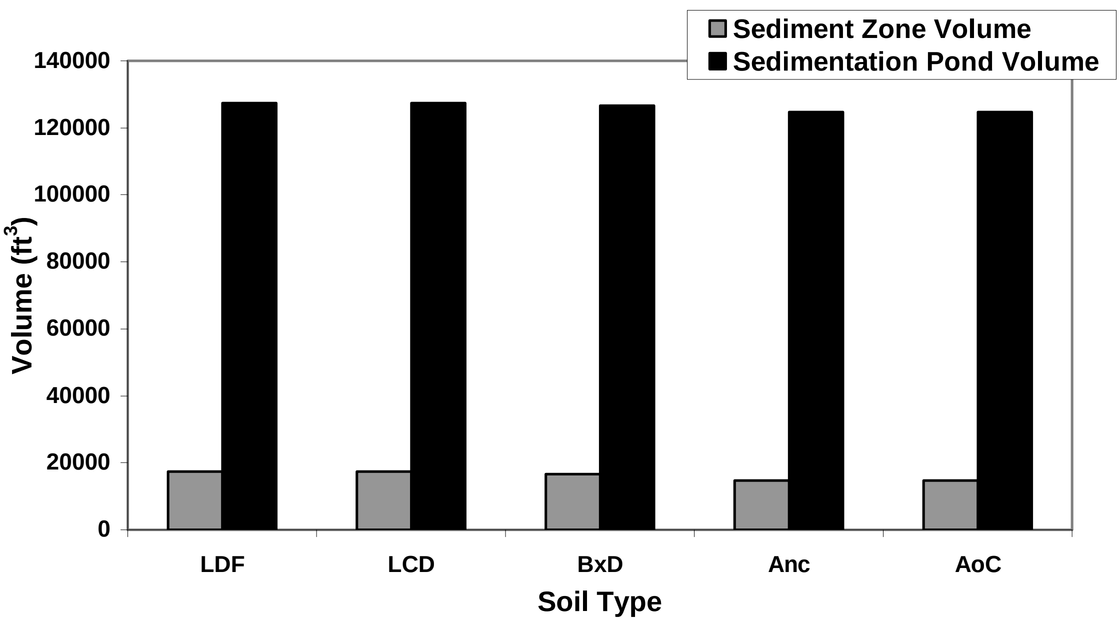

Figure 48. Sensitivity analysis: variation in sediment zone and basin volume with soil type[a]
LCD - Laidig extremely stony loam, appear in 8 to 30% slopes, it is characterized by 43% sand, 38.5% silt, and 18.5% clay; LDF - Laidig extremely stony loam, steep, appears in 8 to 25% slopes, it is characterized by 43.3% sand , 39.7% silt and 17.0 % clay; BxD - Buchanan extremely stony loam, appears in 8 to 25% slopes, it is characterized by 43% sand, 38.5% silt and 18.5% clay; AoC - Andover very stony loam, appears in 8 to 15% slopes, it is characterized by 29.1% sand, 53.4% silt and 17.5% clay.; AnC - Andover channery loam, appears in 8 to 15% slopes, It is characterized by 43.0% sand, 39.0% silt and 18.0% clay

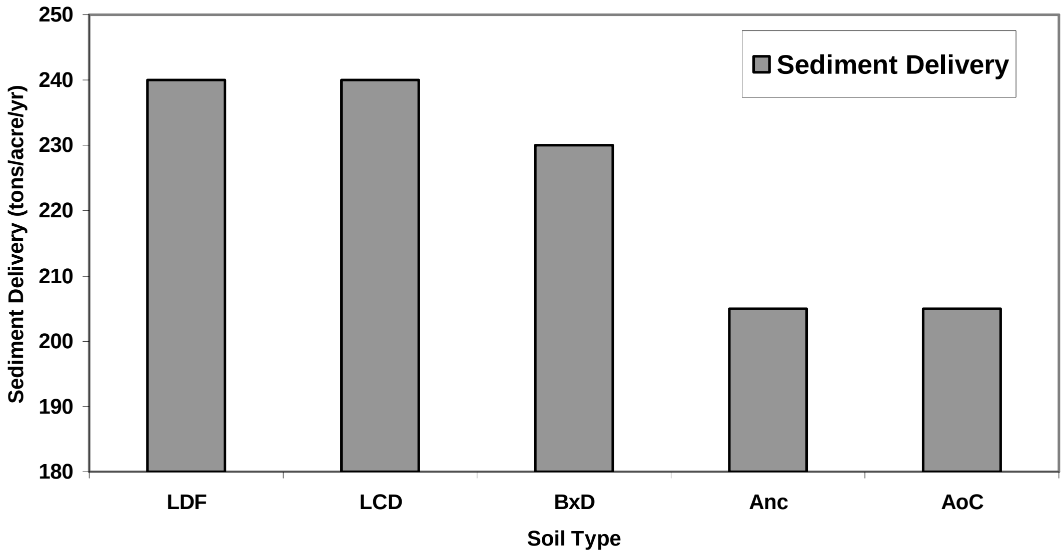

Figure 49. Sensitivity analysis: change in sediment delivery with change in soil type[a]

[a]LCD - Laidig extremely stony loam, appear in 8 to 30% slopes, it is characterized by 43% sand, 38.5% silt, and 18.5% clay; LDF - Laidig extremely stony loam, steep, appears in 8 to 25% slopes, it is characterized by 43.3% sand , 39.7% silt and 17.0 % clay; BxD - Buchanan extremely stony loam, appears in 8 to 25% slopes, it is characterized by 43% sand, 38.5% silt and 18.5% clay; AoC - Andover very stony loam, appears in 8 to 15% slopes, it is characterized by 29.1% sand, 53.4% silt and 17.5% clay.; AnC - Andover channery loam, appears in 8 to 15% slopes, It is characterized by 43.0% sand, 39.0% silt and 18.0% clay

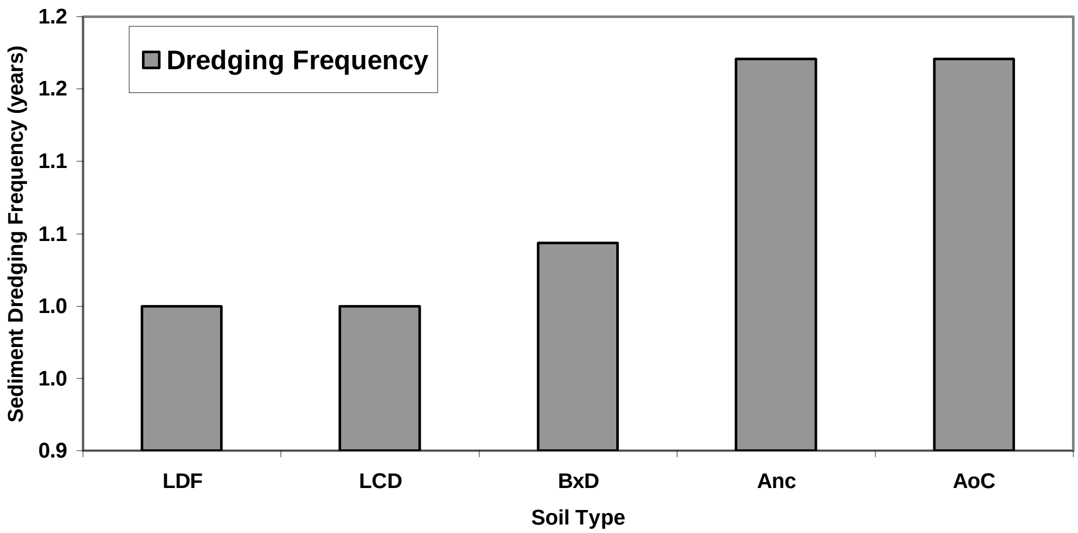

Figure 50. Sensitivity analysis: variation in sediment dredging frequency with soil type[a]

[a]LCD - Laidig extremely stony loam, appear in 8 to 30% slopes, it is characterized by 43% sand, 38.5% silt, and 18.5% clay; LDF - Laidig extremely stony loam, steep, appears in 8 to 25% slopes, it is characterized by 43.3% sand , 39.7% silt and 17.0 % clay; BxD - Buchanan extremely stony loam, appears in 8 to 25% slopes, it is characterized by 43% sand, 38.5% silt and 18.5% clay; AoC - Andover very stony loam, appears in 8 to 15% slopes, it is characterized by 29.1% sand, 53.4% silt and 17.5% clay.; AnC - Andover channery loam, appears in 8 to 15% slopes, It is characterized by 43.0% sand, 39.0% silt and 18.0% clay

The following observation can be arrived at from the sensitivity analysis

1. The major factors that affect the total basin volume are the storm capture level given by the non-exceedence probability and the runoff coefficient. Total basin volume can change by 10%-30% depending on the values chosen for these input variables. But these two factors do not affect the sediment volume or sediment dredging frequency.
2. Depending on the extent of vegetation in the drainage basin vegetation has a proportional impact on sediment delivery and sediment dredging frequency. For a change in soil type; sediment delivery, sediment volume and sediment dredging frequency change within 25%. These parameters affect only the sediment delivery and the total basin volume is less sensitive to these parameters. A crop with longer growth cycle appears to be the best for erosion control as it has a better developed root system.

4.9 RE-DESIGN OF I-99 SEDIMENTATION BASINS 11, 14 & 103

The designs for sedimentation basins SB11, SB14 and SB103 were also developed by following the design procedure as discussed for SB111 in the earlier sections. The basins were re-designed for 80 % probability or to capture the flood resulting from a 5-year storm and for sediment dredging frequency of 1 year and a runoff coefficient of 0.7. The details of the design and the comparison between existing and developed designs are showed in the Table 26 to Table 31 below.

Table 26. SB11 re-design

Basin depth from bottom Ft	Basin dimensions			Average area ft^2	Cumulative basin volume ft^3	Outflow rate ft^3/day	Overflow rate gal/ft^2/day	Drainage time Day	Zone
	Length Ft	Breadth Ft	Area ft^2						
0	220	40	8800						Sediment zone
1	228	48	10944	9872	9872				
2	236	56	13216	12080	21952				
3	244	64	15616	14416	36368				
3.6	248	68	16991	16303	45335				
5	260	80	20800	18895	72733	18897	7.48	6.2	Settling Zone
6	268	88	23584	22192	94925	22194	7.48	4.8	
7	276	96	26496	25040	119965	25042	7.48	3.8	
8	284	104	29536	28016	147981	28018	7.48	2.8	
9.8	298.2	118	35231	32383	205299	32386	7.48	1.8	

The design above was developed for SB11, based on 5-year storm capture assuming a runoff coefficient of 0.7 and a sediment dredging frequency of 1 yr. Comparing the above basin configuration to the existing design, we see that the developed design has reduced area (by 8%), reduced volume (by 13%), and improved particle removal at a constant particle size of 2 microns compares to the varied particle removal of the present design from 1-3 micron. A construction cost-pond volume relationship (California Water Quality Association, 2003; Brown and Schueler 1999) as shown in equation 23, can be used to calculate the construction cost of the basin.

$$Cost\ in\ \$ \quad = \quad \left[Pond\ Volume\left(ft^3\right)\right]^{0.76} \tag{23}$$

It can be calculated from the above equation that for the new SB11 design, construction cost is reduced by \$ 26,000 and land costs will also be reduced by 8%. If maintenance cost is assumed to be about 4% of construction costs (maintenance is suggested to be 3-5% construction costs, EPA, 1999) then maintenance cost is reduced by \$ 1,000/yr.

Table 27. SB14 re-design

Basin depth from bottom Ft	Basin Dimension			Average Area ft^2	Cumulative Basin Volume ft^3	Overflow Rate $gal/ft^2/day$	Drainage Time day	Zone
	Length Ft	Breadth Ft	Area ft^2					
0	60	15	900					Sediment Zone
1	68	23	1564	1232	1232			
2	76	31	2356	1960	3192			
3	84	39	3276	2816	6008			
4	92	47	4324	3800	9808			
5	100	55	5500	4912	14720			
6.8	114	69	7866	6683	26415			
7	116	71	8236	8051	28428	7.48	5.7	Settling Zone
8	124	79	9796	9016	37444	7.48	3.9	
9	132	87	11484	10640	48084	7.48	3.7	
10	140	95	13300	12392	60476	7.48	2.7	
10.7	145.52	100.52	14628	13964	70111	7.48	1.7	

SB14 was observed have a highly turbid discharge and also indicated an overall high concentration of total suspended solids and particulate contaminants such as iron. The Design for SB14 according to the suggested design procedure is shown in Table 27. RUSLE results show that the soil loss from the SB14 drainage basin is much higher than that from the drainage area of other basins. According to the existing design a sediment zone of 2,000 cubic feet per acre drainage area has been provided for all the basins alike. The results from RUSLE show that SB14 need more sediment zone volume to account for the additional sediment delivered from its drainage area. The design shown in Table 27 provides the sediment volume needed for SB14 for a period of 1 year. The above design will ensure effective sediment capture and sediment containment for the basin provided the sediments are dredged every year. Further the new design has reduced volume by 37% which will result in construction cost reduction of $ 28,000 applying equation 23 and reduction in annual maintenance cost by $ 1,100 (4 % of construction costs).

Table 28. SB103 re-design

Basin Depth from Bottom Ft	Basin Dimension			Average Area ft^2	Cumulative Basin Volume Ft^3	Overflow Rate $gal/ft^2/day$	Drainage Time Day	Zone
	Length Ft	Breadth Ft	Area ft^2					
0	210	42	8820					Sediment Zone
1	212	44	9328	9074	9074			
2.1	214.2	46.2	9896	9612	19647			
3	216	48	10368	10132	28766	7.48	7.0	Settling Zone
4	218	50	10900	10634	39400	7.48	6.1	
5	220	52	11440	11170	50570	7.48	5.1	
6.0	222	54	11988	11714	62284	7.48	4.1	
7	224	56	12544	12266	74550	7.48	3.1	
8	226	58	13108	12826	87376	7.48	2.1	
9	228	60	13680	13394	100770	7.48	1.1	
9.15	228.3	60.3	13766	13723	102829	7.48	0.1	

The design presented above (Table 28) for SB103 has significantly improved particle removal (2 micron) compared to the existing design (1-12 micron), reduced surface area (by 9%) and reduced volume (10 %). For the capture of one in a 5-year storm the developed design yields increased particle removal without increasing basin volume or area. The new design results in construction cost savings of $ 16,000 and maintenance cost saving of $ 600/yr.

The new design developed for SB111 yields an improved particle removal from a variable 1-13μ to a constant 2μ. The new design also has a reduced volume (by 41 %) and area (23 %) resulting in construction cost reduction by $ 45,000 and maintenance cost reduction by about $ 2,000/yr.

The exceedence probability curves for the four basins using a runoff coefficient of 0.7 are shown in Table 29. RUSLE2 results for soil delivery from the basin drainage areas for the four basins are tabulated in Table 30. A comparison of the existing basin design at I-99 site and the developed designs is presented in Table 31.

Table 29. Non-exceedence probability and runoff volume for a runoff coefficient of 0.7

ARI Yr	**24 Hr Storm In**	**Non-exceedence Probability**	**Runoff Volume SB11 ft^3**	**Runoff Volume SB14 ft^3**	**Runoff Volume SB103 ft^3**	**Runoff Volume SB111 Ft^3**
2	2.65	50	128613	35688	66932	40133
5	3.29	80	159674	44307	83097	49825
10	3.83	90	185882	51580	96736	58003
25	4.6	96	223252	61950	116185	69664
50	5.23	98	253828	70434	132097	79205
100	5.92	99	287316	79726	149525	89655

Table 30. RUSLE2 results – sediment delivery to the basins

Sedimentation Basin	Soil Loss (ton/acre/yr)	Sediment Delivery (tons/acre/yr)	Average Annual Sediment Delivery to the Basin
SB11	230	160	195
SB14	400	400	400
SB103	180	140	160
SB111	320	160	240

Table 31. Comparison of existing and developed design

Basin Name	Parameter	Existing Design	New Design
SB11	Settling Volume	184,202 ft^3	160,000 ft^3
	Sediment Volume	38,298 ft^3	45,000 ft^3
	Surface Area	38,390 ft^2	35,200 ft^2
	Particle Removal	1 – 3 micron	2 micron
	Drainage Time	6.6 days	6.2 days
	Sediment Dredging Frequency	10 months	1 yr
SB14	Settling Volume	69,790 ft^3	44,000 ft^3
	Sediment Volume	9,836 ft^3	26,000 ft^3
	Surface Area	13,379 ft^2	14,600 ft^2
	Particle Removal	1-4 micron	2 micron
	Drainage Time	3.3 days	5.7 days
	Sediment Dredging Frequency	5 months	1 yr

Table 31. Continued

Basin Name	Parameter	Existing Design	New Design
SB103	Settling Volume	114,723 ft^3	102,500 ft^3
	Sediment Volume	20,250 ft^3	19,500 ft^3
	Surface Area	~15,000 ft^2	13,800 ft^2
	Particle Removal	1-12 micron	2 micron
	Drainage Time	5.5 days	7 days
	Sediment Dredging Frequency	1 yr	1 yr
SB111	Settling Volume	115,000 ft^3	67,000 ft^3
	Sediment Volume	15,200 ft^3	17,000 ft^3
	Surface Area	19000 ft^2	14600 ft^2
	Particle Removal	1-13 micron	2 micron
	Drainage Time	5 days	4.8 days
	Sediment Dredging Frequency	11 months	1 yr

Table 31 presents the comparison between existing and developed designs for basins 11, 14, 103 and 111. Comparing the existing design with the developed design the following observations can be made:

1. SB11 is well designed at the existing level of particle capture and storm water capture. If an increased particle capture or runoff capture is required, then it can be achieved only at the cost of increasing the basin volume or area or both.
2. In the case of SB14, the developed design offers an improved particle removal (1-4 micron to a constant 2 micron) compared to the existing design, but with an increase in basin area. The major change that is required in the design of SB14 is the increase in sediment volume. As explained before, the soil delivery from SB14 drainage area is twice that for the other basins. Hence in spite of efficient design in terms of overflow rate and

area, SB14 still has turbid discharge as it has insufficient sediment volume leading to sediment re-suspension. This issue is addressed in the developed design by providing an increased sediment volume for SB14.

3. The developed design proves to be a definite improvement in the case of SB103. The developed design offers an improved particle removal (2 micron compared to 1-12 micron) that can attenuate TSS peaks during storm events. The area is decreased by about 9% and the volume of the basin is reduced by 10 %.
4. The developed design for SB111 is also a good improvement over the existing design at the I-99 site. In the developed design the volume of the basin was reduced by 42%, area was reduced by 23% and particle removal was improved from 1-13 microns to a constant 2 micron at all levels of the basin.

4.10 CONCLUSIONS FOR BASIN DESIGN

The designs presented for sedimentation basins 11, 14, 103 and 111 were developed to show the application of the design methodology developed by this research. Comparison of existing and developed design leads to the following conclusions.

1. The decision on the extent of storm capture is the primary factor that decides the volume of the basin. Capturing a storm with a larger return period requires a larger sedimentation basin. By varying the extent of storm capture based on need, the volume of the sedimentation basin can be varied significantly and can be used as a cost reducing measure for basins that need to function over a few years.

2. The characteristic of the drainage basin is an important factor that decides the sediment volume of the basin. The basin sediment volume should be arrived at on a case-by-case basis for each basin and depending upon the sediment dredging frequency needed.
3. The basin surface area depends on the minimum particle size to be removed by the basin. Designing a basin by applying the principle of overflow rate helps in estimating the performance of the basin at the design stage and will thus help in ensuring that effluent permit limits are met.
4. The design methodology discussed above presents a procedure by which the basin can be designed according to performance requirements. Basin volume, area, drainage time and sediment dredging frequency can all be varied depending upon the effluent requirement and cost restrictions to arrive at an optimum basin design.

5.0 DESIGN CURVES

Applying the sedimentation basin design methodology discussed above a set of design curves were developed in order to understand the effect of change in decision variables such as storm capture, sediment dredging frequency or runoff coefficient on basin design parameters such as basin volume and sediment volume so that associated change in cost can be arrived at. The design curves presented below were developed based on rainfall frequency estimates for State College, PA.

Figures 51 – 54 show the variation in runoff volume or settling volume of the basin based on change in non-exceedence probability (measures extent of storm capture), basin drainage area and runoff coefficient. Figure 51, Figure 52, Figure 53 and Figure 54 were developed for drainage area in the range of 5-10, 10-15, 15-20 and 20-25 acres drainage area respectively. The design curves are developed such that for a runoff coefficient ranging from 0.5 to 0.9 and a basin drainage area between 5-25 acres, the runoff volume or the settling volume of the basin can be arrived at.

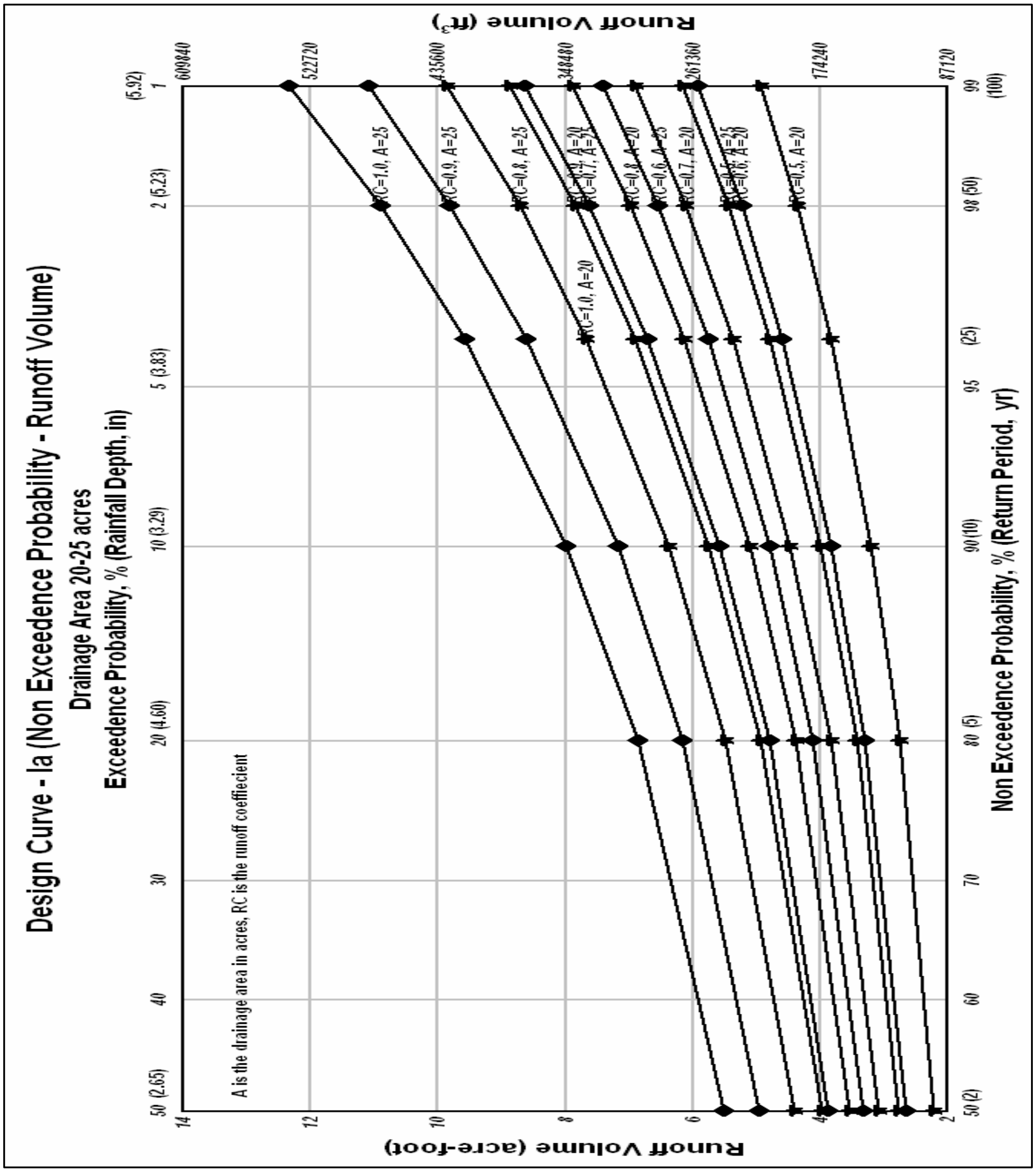

Figure 51. Design curve I a – (Non-exceedence probability – runoff volume)

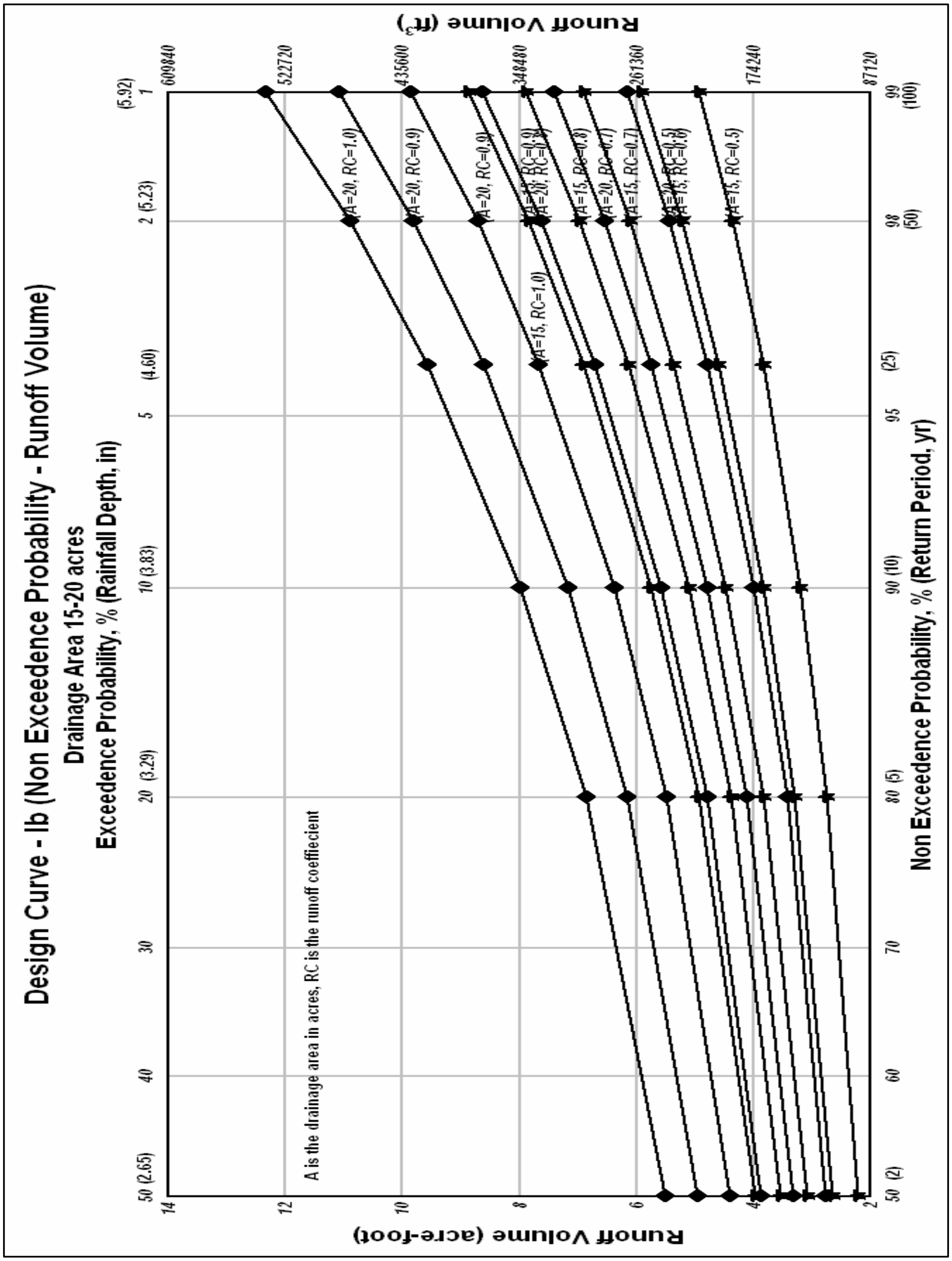

Figure 52. Design curve I b – (Non-exceedence probability – runoff volume)

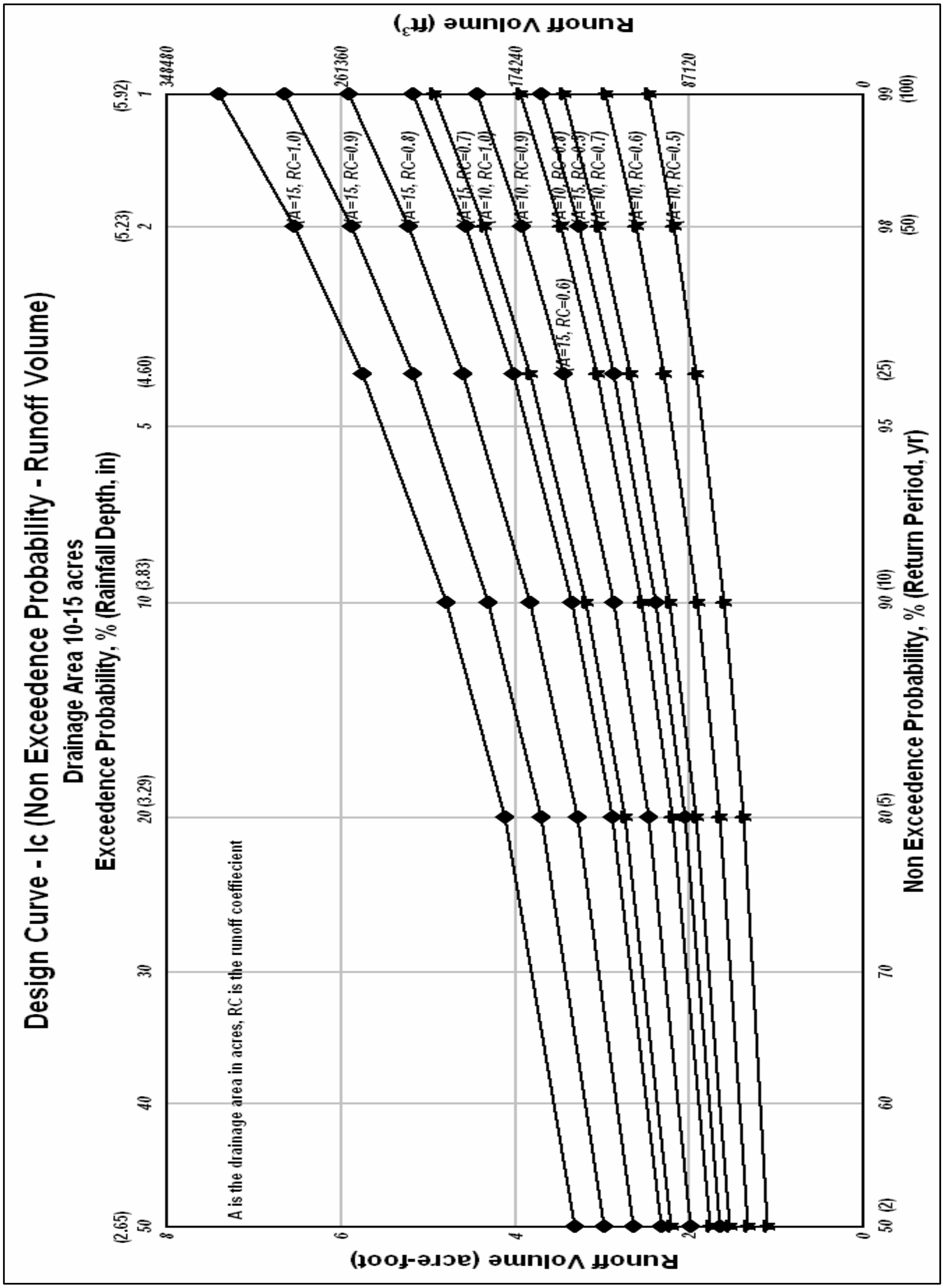

Figure 53. Design curve I c – (Non-exceedence probability – runoff volume)

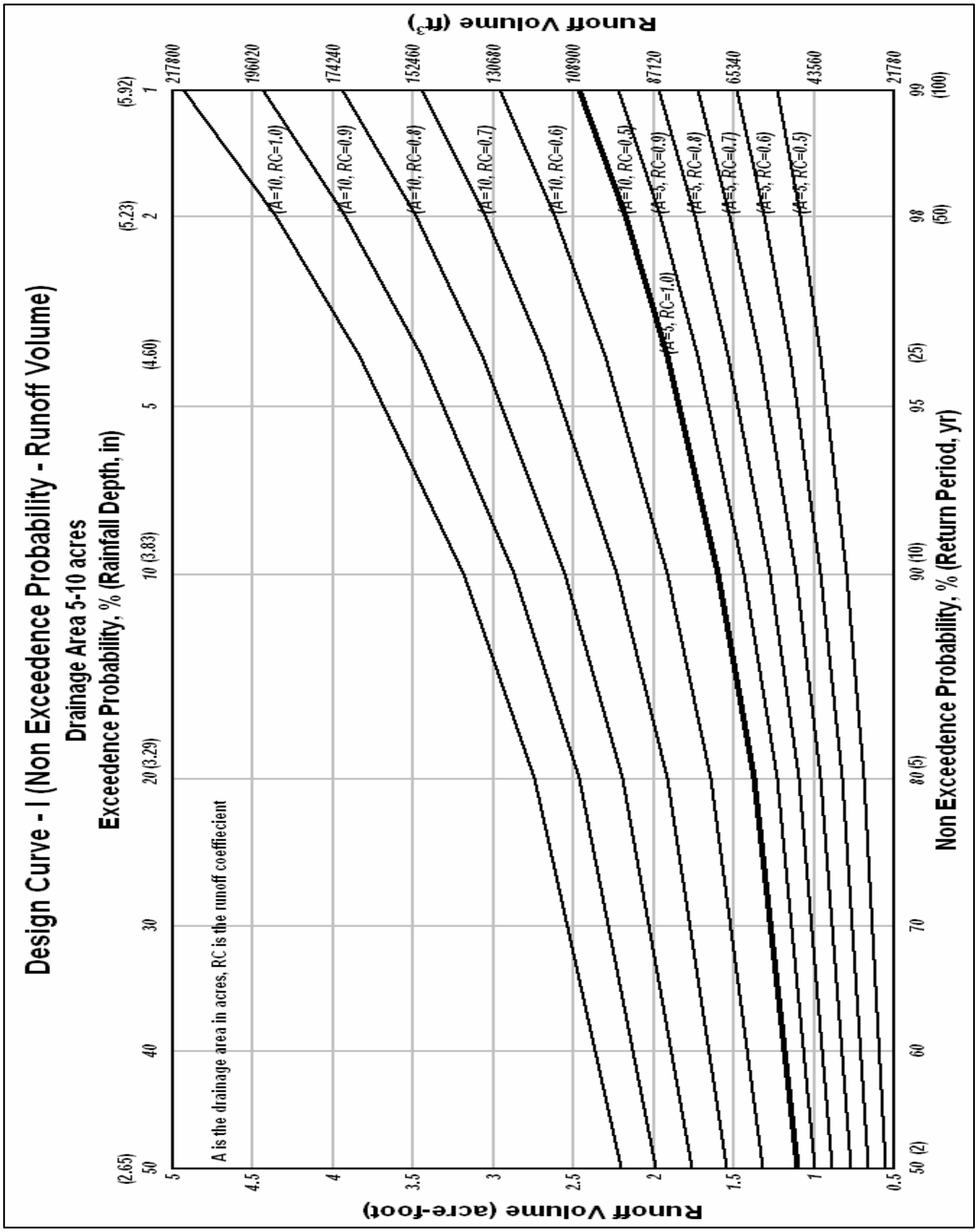

Figure 54. Design curve I d – (Non-exceedence probability – runoff volume)

Figure 55 shows the design curve that was developed to show the changes in sediment volume and basin volume with change in sediment frequency for I-99 construction site. The curves have been developed for a set of three different sediment dredging frequencies namely 2, 5 and 10 years. Intermediate dredging frequency values can be interpolated. For a given non-exceedence probability, runoff coefficient and sediment dredging frequency, the volume of the sedimentation basin and the volume of sediment zone can be arrived at using the design curves in Figure 55.

The design curves presented in this section help in understanding the impact of decision variable such as extent of storm capture, sediment dredging frequency and runoff coefficient on basin volume. As an example, from Figure 54 we can identify the runoff or settling volume for a basin with 5-acre drainage area at 90% non-exceedence and at 80% non-exceedence. We can compare these two values and understand the increase in basin volume for increase in exceedence probability from 80% to 90%. If this difference is too large then it may then make economic sense to choose 80% exceedence probability as it may yield a basin with smaller volume. We can use Figure 54 to calculate and compare runoff volume for basins serving a drainage basin of anywhere between 5 to 10 acres, for runoff coefficient of 0.5 to 1 and for an exceedence probability range of 50 % to 99 %. Thus through the help of the design curves an optimum design for the basin can be developed based on performance requirements and cost restrictions.

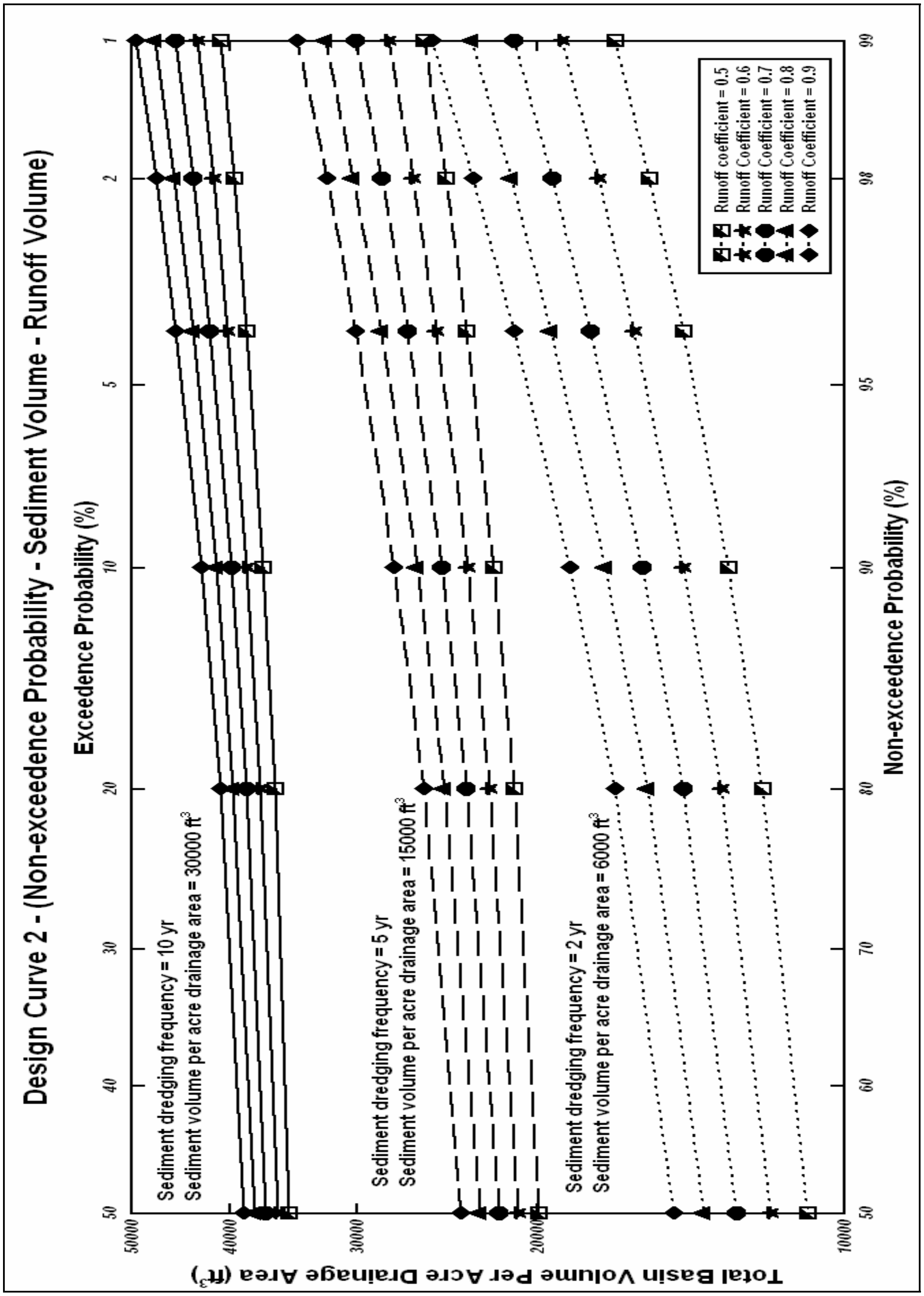

Figure 55. Design curve 2 – (Exceedence probability, sediment volume and runoff volume)

6.0 DESIGN SUGGESTIONS FOR SEDIMENTATION BASINS

Field observations of SB structural design indicate the need for some improvements in the present design of SBs, such as proper placing of inlets and outlets and placement of well designed baffles within the SB. It was seen that some of the SBs on site had two inlets such that one inlet was positioned close to the outlet. A baffle had been used across the basin as shown in Figure 56, to prevent short circuiting from the inlet (that is closer to the outlet) to the outlet. The provision of a baffle within the SB results in mixing at the point where the runoff flows around the baffle and hence sedimentation efficiency of the basin is reduced. In order to optimize basin performance it would be better to have only one inlet and one outlet. This would also eliminate the need for providing baffles within the SB. From observing the design of SBs it appears that there is still room for design improvements. To improve design of SBs, it may be useful to extend some of the practices used in conventional sedimentation tank design as discussed below.

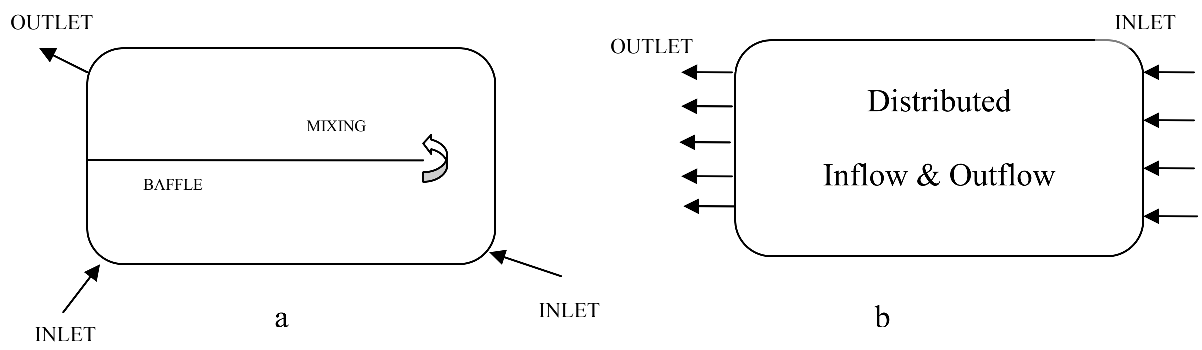

Figure 56. Improving current SB design
a) Current flow scheme b) Proposed flow scheme

Design convention for settling tanks suggest that inlet baffling be provided (Figure 57), as the influent jet to the sedimentation basin may have high amount kinetic energy which needs to be dissipated as well as it helps in distributing the influent thorough out the depth and the width of the tank. Further care must also be taken to centre the inlet in order to achieve uniform distribution of the influent. Similarly the effluent must also be distributed evenly to the outlet (Droste, 1997; American Water Works Association, (1991)).

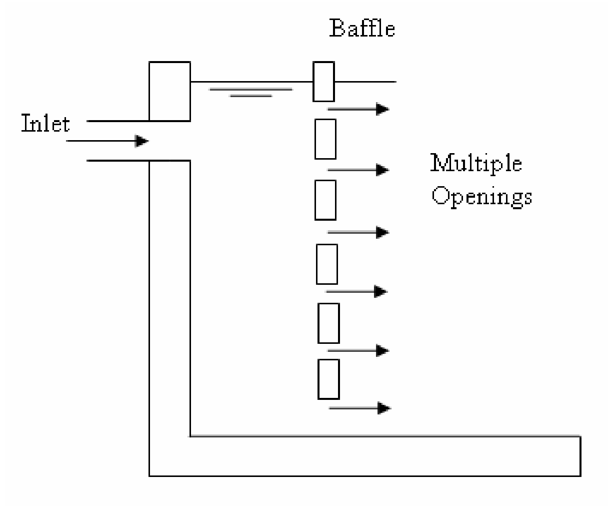

Figure 57. Inlet baffling to reduce influent kinetic energy[a]
[a]Adapted from (Droste, (1997); McGhee, (1991))

It has been pointed out in the literature that for storm water detention basin, the bigger the basin the better its performance. It is suggested that storm water detention basins should be wedge shaped, and narrowest at the inlet and widest at the outlet. A minimum length to width ratio of 3:1 and a depth of 3-6 ft should be used. It is also suggested that the side slope should be no steeper than 3:1 (Schueler, 1987; Mays, 2004). Horizontal flow tanks with small length-to-width ratios may be dominated by end effects. While a length-to-width ratio of 20 may be necessary to approach plug flow, a lower and more economically acceptable ratio of 5 may give acceptable efficiency when the flow distribution is good. A higher length-to-width ratio can be achieved by placing baffles along the length of the basin (American Water Works Association, 1991; Hamlin and Wahab, 1970; Marske and Boyle, 1973). Although depth is not a factor that affects discrete particle settling, in practice increasing depth increases settling efficiency and helps to avoid scour of the settled sediment. Sludge must be removed periodically from the basin or allowance must be provided for sediment accumulation so that settling efficiency is not affected (American Water Works Association, (1991)).

Another suggestion for designing basins with smaller area and capture sediments during the construction period as well as capture a 100-year storm after the construction activity is complete is as follows:

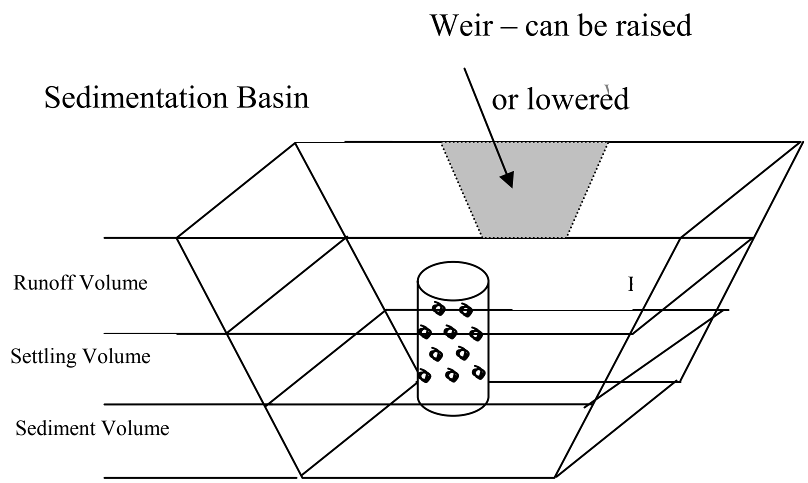

Figure 58. Sedimentation basin design at I-99 construction site

i. A weir can be provided above the basin settling zone such that it can be raised or lowered to control flow as shown in Figure 58.

ii. The basin settling volume and sediment zone volume can be designed to capture a 10- or 20-year storm based on the duration of the construction project. This portion of the sedimentation basin has to be designed by providing sufficient area to maintain overflow rate. A temporary riser may be provided to maintain the appropriate outflow rate, overflow rate and basin drainage time.

iii. Excess volume (a runoff zone) can be provided above the settling zone to capture a 100-year storm without increasing basin area.

iv. During the construction period the position of the weir should be lowered to allow outflow from the runoff zone. This will result in failure to capture a 100 year storm during the construction period, but sediments from the construction site will be captured effectively since the zones below the runoff zone are designed to maintain overflow rate and to capture storms during the construction phase.

v. At the end of construction the weir can be raised to the top of the runoff zone to serve as an emergency spillway. The temporary riser can be replaced by a permanent outflow structure that will allow drainage from the basin such that the drainage time is 4-7 days. Since sediment release will be greatly reduced after construction, maintaining a small overflow rate will not be necessary after construction.

vi. Designing sedimentation basins as suggested above will help construct SBs for both water quality control (during construction) and runoff control (after construction). It will help in constructing smaller basins which may will be a great economic advantage where land is expensive and providing area for the basis is a major constraint but storm water management and effective runoff control will become effective only after the construction phase.

7.0 SUMMARY AND SIGNIFICANT RESULTS

Sedimentation basins are currently designed for runoff capture rather than for sediment removal. This includes sedimentation basin designs used by PENNDOT. Overflow rate, which is a fundamental basis for particle removal, is not currently incorporated into basin design for particle capture. Sedimentation basins at the I-99 construction site are used for both runoff control and storm water management. Hence in addition to providing 1,000 cubic ft of sediment zone volume per disturbed acre of the drainage basin and 5,000 cubic feet of settling zone volume, per area of the drainage basin, additional volume is provided to capture the runoff from a 100-year flood. In the current design basin volume is increased to capture a 100-year flood, basin surface area is not increased proportionately to maintain the same overflow rate. The overflow rate varies along the depth of basin with the maximum overflow rate being at the surface of the basin. As a result particle capture is significantly reduced during high flow conditions when the basin is filled. Consequently suspended solids containing particulate forms of iron, manganese, phosphate and aluminum are not attenuated and high concentrations of sediments and metal-containing particulate contaminants are released into the environment. Further inlet and outlet total suspended solids concentration for the basins showed the possibility of sediment mobilization and scour in the basin resulting in increased sediment release in the effluent. In addition several natural occurring acidic seeps drained into the basin and there was evidence of algae growth in the basin. This research has considered all the above issues related to sedimentation basin design and maintenance and has suggested a new methodology for designing sedimentation basins and several BMPs to improve maintenance and performance of sedimentation basins.

This research has produced the following significant results:

1. A new design methodology was developed by integrating particle removal, site specific data of rainfall runoff capture and sediment containment. This design methodology helps to design basins according to the decision variables of storm capture, predetermined level of particle removal and design sediment dredging frequency. This design methodology helps in designing sedimentation basins that capture total suspended solids and particulate contaminants containing iron, phosphate, aluminum and manganese effectively. It helps in controlling sediment re-suspension by estimating the sediment volume required for a basin by applying RUSLE. It also helps in attenuating peaks in particulate pollutants during storm events by using the principle of settling velocity and overflow rate for particle removal.
2. The design methodology presented offers flexibility to vary the basin design parameters such as area, volume, drainage time, depth and sediment dredging frequency according to design and regulatory requirements.
3. A set of design curves were developed to understand the change in basin volume with change in runoff coefficient, extent of storm capture, basin drainage area and sediment dredging frequency. These curves will help in arriving at an optimum design for sedimentation basin that balances performance and cost requirements.
4. Changes in basin water chemistry due to the presence of naturally occurring seeps were modeled using Mineql software to show basins can remediate acidic seeps and cause

excess dissolved contaminants (aluminum, phosphate, iron and manganese) to be precipitated.

5. The following performance and maintenance BMPs were suggested for sedimentation basins

   a. Dredging basin sediments after the growing season to remove nutrient rich sediments from the basin and help control algae growth.
   b. Maintaining basin drainage time within 5 days to control mosquito breeding
   c. Providing baffled inlets that distribute inflow uniformly
   d. Maintaining a length-to-width ratio of 5 or above or introducing baffles along the length of the basin with baffled inlet and outlet to increase length to width ratio
   e. Fitting rectangular basins with baffled inlets and outlets or wedge shaped basins with a single inlet and a riser as an outlet structure

8.0 SUGGESTIONS FOR FUTURE RESEARCH

The following suggestions are presented as areas of future research on BMPs for highway construction site erosion and sedimentation control, stormwater quality and sedimentation basin design.

1. The design methodology suggested through this research can be applied to the design of sedimentation basin for a new stretch of highway and its performance efficiency in capturing total suspended solids and particulate metals, sediment containment and storm water capture can be tested through a filed study. The developed design methodology can also be applied to existing basins to identify if the particle capture, sediment accumulation rate and storm capture matches with that suggested by the design procedure.
2. Background data: It would be ideal to collect background data on water quality parameters at the construction site before construction activity begins as the data will be useful in comparing water quality parameters before and after construction. Total and dissolved concentrations of iron, aluminum, zinc, manganese, lead, zinc, cadmium, chromium, sulfate, phosphate, ammonia, nitrate, total suspended solids, acidity, alkalinity, COD and BOD are some of the water quality parameters that should be considered. A geological investigation of the construction site will also prove useful in geological regions where acid rock drainages are prevalent. Geological investigation will help identify the minerals present at the site and hence the contaminants such as metals that can be expected in the runoff. Based on

geological investigation changes can be made to the list of water quality parameters suggested above for the background data collection. Water quality data and geological investigation must be carried out for different corridors of the construction site, as the parameters may vary from one section to another.

3. A database of particle size distribution related to construction activity can be developed for various regions in Pennsylvania. This data will be useful in designing sedimentation basins and identifying the optimum particle size for removal. Runoff samples from construction sites in all geographic regions can be collected and analyzed for particle size distribution. The data can be stored in an accessible database which can be used to choose the reference particle size during sedimentation basins design.
4. Flow measurement devices should be installed upstream and down stream of a sedimentation basin to calculate subsurface flow, inflow and outflow in order to obtain an estimate of total inflow and outflow for the basins (Figure 59). This data will be useful in calculating mass balances for contaminants and understanding basin water chemistry better.
5. The chemistry of aluminum precipitation and the forms aluminum can be precipitated in can be investigated further. The water chemistry modeling shows that aluminum's primary source is clay or Kaolinite and the aluminum concentration in the basin outlet cannot be reduced below 1 mg/L without using chemical precipitation methods. Since dissolved aluminum from clay can be expected in any construction site, it is important to investigate whether permit levels for aluminum below 1 mg/L is achievable.

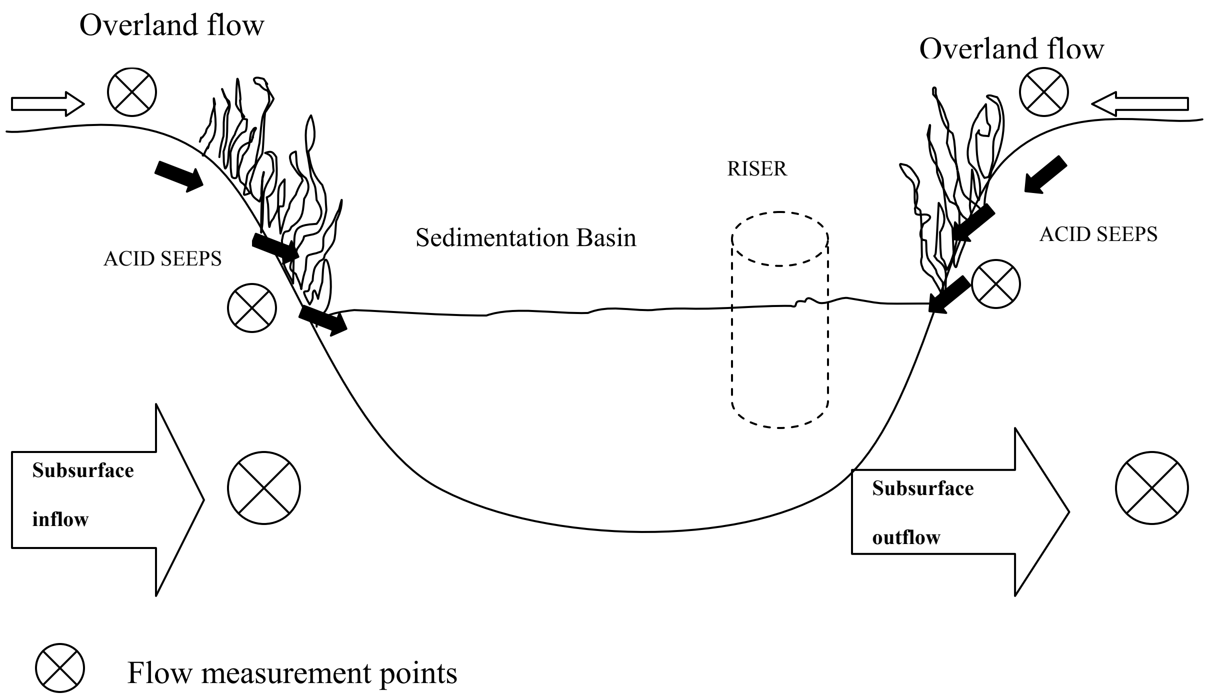

Figure 59. Schematic representation of flow measurements for sedimentation basins

6. Addition of polymer to basins to enhance particle capture during high flow conditions was considered in this research. One set of jar test experiments were carried to understand the feasibility of polymer flocculation in the basin. The results of the jar test experiments are shown in Appendix H. The jar test experiments did not show a significant particle removal in comparison to the sedimentation basin effluent sample with no polymer. Since these results are based on a single set of experiment it is suggested that further study with different types of polymer and different concentrations be carried out to understand the feasibility of polymer enhanced flocculation for the sedimentation basins.

APPENDIX A

SEDIMENTATION BASIN WATER CHEMISTRY DATA

The purpose of this Appendix is to present analytical data from field samples. All analysis presented below was conducted within the University of Pittsburgh except for field pH, and field color.

Table 32. Chemical analysis data for the 1st set of samples (Sep/22/2004)

	SB-11 inlet 38	SB-11 inlet 39	SB-11 Outlet	SB-14 Outlet	SB-103 Outlet	SB-111 outlet
Field pH	6.8	6.8	7.0	5.8	6.8	7.0
Lab pH	8.2	8.8	9.1	7.3	8.2	8.0
Apparent color (field)	5	5	5	>100 (off scale)	45	5
Apparent color (lab)	10	4	7	>100 (off scale)	26	2
True color	0	0	0	8	1	0
TSS (mg/L)	23	16	40	325	51	20
VSS (mg/L)	16	16	18	40	16	16

Table 32. Continued

	SB-11 inlet 38		SB-11 inlet 39		SB-11 Outlet		SB-14 Outlet		SB-103 Outlet		SB-111 outlet	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	10.1	9.9	8.9	9.0	10.0	10.6	5.3	6.1	9.2	9.1	18.6	19.0
Mn (mg/L)	0.02	0.04	0.02	0.04	0.02	0.04	0.02	0.20	0.02	0.11	0.02	0.08
Ca (mg/L)	36.7	36.3	33.1	34.1	33.3	35.6	14.2	3.7	28.9	27.1	74.7	77.8
Fe (mg/L)	0.03	0.77	0.04	0.76	0.06	0.78	0.04	22.9	0.04	1.9	0.04	0.33
Al (mg/L)	1.4	1.3	1.2	1.6	1.6	1.6	1.4	3.1	1.5	1.6	1.3	1.9
Turbidity (NTU)	0.59	15	0.75	5.7	0.53	40	2.0	350	1.8	70	0.62	3.6
Phosphate (mg/L of PO_4^{3-})	0.00	0.26	0.00	0.00	0.00	0.00	0.43	1.5	0.00	0.00	0.00	0.00
Sulfate (mg/L of SO_4^-)	70.3	72.3	45.4	43.9	61.5	66.4	14.6	127.0	52.7	68.4	112.3	127.0

Table 33. Chemical analysis data for the 2nd set of samples (Oct/5/2004)

	SB-11 inlet 38	SB-11 inlet 39	SB-11 Outlet	SB-14 Outlet	SB-103 Outlet	SB-111 outlet
Field pH	6.3	8.0	9.0	6.6	8.0	8.0
Lab pH	7.9	8.2	8.5	7.3	8.0	7.8
Apparent color (field)	5	5	10	70	25	5
Apparent color (lab)	12	11	4	75	9	6
True color	1	2	0	3	5	0
TSS (mg/L)	25	18	44	77	18	19
VSS (mg/L)	18	12	17	31	13	16

Table 33. Continued

	SB-11 inlet 38		SB-11 inlet 39		SB-11 Outlet		SB-14 Outlet		SB-103 Outlet		SB-111 outlet	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	11.7	14.6	11.9	15.0	12.3	15.7	7.0	8.6	9.7	13.0	34.4	41.1
Mn (mg/L)	0.03	0.04	0.04	0.07	0.04	0.03	0.02	0.11	0.03	0.11	0.03	0.04
Ca (mg/L)	44.7	52.8	45.4	57.8	40.4	46.4	11.3	21.1	32.8	41.8	100.9	97.3
Fe (mg/L)	0.08	0.74	0.08	0.83	0.04	1.5	0.03	62.6	0.04	0.67	0.03	0.18
Al (mg/L)	0.95	1.3	1.5	1.5	1.4	1.6	1.4	2.3	1.4	1.5	1.5	1.6
Turbidity (NTU)	0.62	15.0	0.7	7.0	0.62	25.0	1.8	100.0	0.63	13.0	1.7	4.0
Phosphate (mg/L of PO_4^{3-})	2.7	2.7	2.7	2.7	2.7	2.7	2.7	4.5	2.7	2.7	1.4	0.9
Sulfate (mg/L of SO_4^-)	92.8	87.9	69.3	63.5	92.8	92.8	22.5	42.0	63.5	60.5	146.5	146.5

Table 34. Chemical analysis data for the 3rd set of samples (Oct/20/2004)

	SB-11 inlet 38		**SB-11 Inlet 39**		**SB-11 Outlet**		**SB-14 Outlet**	
Field pH	6.8		7.1		7.1		5.9	
Lab pH	7.8		7.9		7.6		7.6	
Apparent color (field)	5		15		3		40	
Apparent color (lab)	6		10		12		58	
True color	5		3		6		0	
TSS (mg/L)	12		12		10		98	
VSS (mg/L)	2.2		1.8		0.9		6.0	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	33.3	32.0	26.3	25.5	24.6	23.4	7.3	7.3
Mn (mg/L)	0.05	0.03	0.05	0.08	0.05	0.05	0.05	0.10
Ca (mg/L)	125.4	118.3	69.4	65.6	81.9	73.1	18.3	9.6
Fe (mg/L)	0.09	0.78	0.14	0.84	0.09	0.88	0.13	6.3
Al (mg/L)	0.65	0.48	0.61	0.56	0.54	0.59	0.57	0.74
Turbidity (NTU)	2.2	14	0.96	15	0.74	1.0	0.83	90
Phosphate (mg/L of PO_4^{3-})	0.17	0.34	0.13	0.26	0.13	0.26	0.17	0.34
Sulfate (mg/L of SO_4^{-})	192.3	288.5	168.3	192.3	182.7	230.8	25.0	49.0

Table 34. Continued

	SB-103 Outlet		SB-111 inlet 127		SB-111 Outlet	
Field pH	6.1		7.1		7.1	
Lab pH	7.1		7.5		7.6	
Apparent color (field)	8		5		5	
Apparent color (lab)	15		16		12	
True color	3		5		8	
TSS (mg/L)	24		4.0		13	
VSS (mg/L)	2.7		4.0		3.6	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	12.0	11.9	39.9	38.0	22.6	20.9
Mn (mg/L)	0.05	0.15	0.03	0.04	0.05	0.08
Ca (mg/L)	35.9	32.8	196.1	181.4	94.0	82.9
Fe (mg/L)	0.15	2.0	0.13	0.14	0.13	0.73
Al (mg/L)	0.65	0.61	0.67	0.59	0.50	0.67
Turbidity (NTU)	0.92	36	0.95	6.0	3.0	20.0
Phosphate (mg/L of PO_4^{3-})	0.17	0.17	0.17	0.17	0.30	0.17
Sulfate (mg/L of SO_4^{-})	96.2	88.5	192.3	250.0	173.1	192.3

Table 35. Chemical analysis data for the 4th set of samples (Nov/4/2004)

	SB-11 inlet 38		SB-11 inlet 39		SB-11 Outlet		SB-14 Outlet	
Field pH	6.9		7.0		7.4		6.0	
Lab pH	7.8		8.2		8.4		7.2	
Apparent color (field)	5		5		5		30	
Apparent color (lab)	7		4		17		24	
True color	2		0		0		3	
TSS (mg/L)	37		28		42		107	
VSS (mg/L)	31		28		24		33	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	24.5	24.8	22.5	22.5	24.0	24.3	8.5	8.8
Mn (mg/L)	0.06	0.10	0.06	0.11	0.08	0.11	0.08	0.15
Ca (mg/L)	250.0	320.5	168.3	240.4	211.5	276.4	26.4	25.6
Fe (mg/L)	0.06	0.40	0.08	0.21	0.04	0.80	0.08	3.34
Al (mg/L)	0.56	0.76	0.65	0.70	0.54	0.74	0.72	0.89
Turbidity (NTU)	0.69	9.0	0.79	4.0	0.70	18.0	0.78	50.0
Phosphate (mg/L Of PO_4^{3-})	0.21	0.21	0.21	0.26	0.13	0.17	0.13	0.17
Sulfate (mg/L Of SO_4^-)	320.5	250	240.4	168.3	276.4	211.5	25.6	26.4

Table 35. Continued

	SB-103 Outlet		SB-111 Outlet		SB-103 Seep	
Field pH	5.8		7.4		5.5	
Lab pH	7.1		7.7		6.8	
Apparent color (field)	5		5		-	
Apparent color (lab)	14		13		off scale	
True color	1		1		15	
TSS (mg/L)	33		26		671	
VSS (mg/L)	23		22		81	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	13.5	13.5	37.8	37.3	30.0	50.0
Mn (mg/L)	0.10	0.21	0.09	0.11	2.0	5.0
Ca (mg/L)	81.7	125.0	331.7	368.6	223.6	312.5
Fe (mg/L)	0.06	0.63	0.09	0.35	1.50	177.00
Al (mg/L)	0.63	0.63	0.57	0.65	13.7	31.1
Turbidity (NTU)	0.59	10	0.63	7.0	0.92	330
Phosphate (mg/L of PO_4^{3-})	0.13	0.13	0.13	0.17	2.6	10.2
Sulfate (mg/L of SO_4^-)	125.0	81.7	368.6	331.7	149.0	468.8

Table 36. Chemical analysis data for the 5th set of samples (Nov/17/2004)

	SB-11 inlet 38		SB-11 Inlet 39		SB-11 Outlet		SB-14 Outlet		SB-103 Outlet		SB-111 Outlet	
Field pH	7.0		6.8		7.1		5.8		6.4		7.0	
Lab pH	8.0		8.2		8.1		8.0		7.4		8.0	
Apparent color (field)	5		5		5		15		10		5	
Apparent color (lab)	15		17		10		30		10		10	
True color	3		3		5		7		0		3	
TSS (mg/L)	16		11		9.0		35		17		13	
VSS (mg/L)	7.7		8.3		6.0		7.0		9.7		6.3	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	18.5	18.3	17.0	16.3	21.3	21.3	8.00	8.50	10.5	10.5	33.5	34.5
Mn (mg/L)	0.05	0.08	0.03	0.10	0.04	0.08	0.05	0.10	0.05	0.15	0.05	0.13
Ca (mg/L)	58.8	58.0	51.3	48.5	55.8	58.5	11.0	19.0	24.3	24.5	103	113
Fe (mg/L)	0.05	0.60	0.04	0.83	0.05	0.39	0.06	2.06	0.05	0.78	0.06	0.55
Al (mg/L)	0.50	0.58	0.63	0.75	0.63	0.67	0.58	0.63	0.63	0.65	0.63	0.63
Turbidity (NTU)	0.55	5.4	0.60	6.5	0.50	3.7	0.60	32	0.50	3.9	0.55	3.0
Phosphate (mg/L of PO_4^{3-})	0.13	0.29	0.13	0.25	0.08	0.21	0.13	0.25	0.13	0.25	0.04	0.17
Sulfate (mg/L of SO_4^{-})	123	150	94.3	110	123	157	22.2	21.7	60.4	66.0	142	217

Table 37. Chemical analysis data for the 6th set of samples (Dec/1/2004)

	SB-11 inlet 38		SB-11 Inlet 39		SB-11 Outlet		SB-14 Inlet 44		SB-14 Inlet 45		SB-14 Outlet	
Field pH	7.1		7.4		7.4		6.8		6.5		6.5	
Lab pH	8.0		7.9		7.9		7.9		7.5		7.6	
Apparent color (field)	10		60		30		90		70		90	
Apparent color (lab)	20		0ff scale		50		0ff scale		70		off scale	
True color	3		5		0		3		10		5	
TSS (mg/L)	62		650		206		1442		168		630	
VSS (mg/L)	16		52		25		102		38		54	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	36.0	40.5	16.5	19.0	17.5	19.5	7.3	11.0	5.0	5.0	7.0	9.0
Mn (mg/L)	0.03	0.05	0.05	0.30	0.05	0.15	0.05	0.45	0.06	0.15	0.05	0.28
Ca (mg/L)	94.0	116	34.8	7.5	46.5	35.0	14.8	20.0	11.0	6.3	11.5	2.5
Fe (mg/L)	0.04	2.1	0.04	41.3	0.08	10.6	0.10	80.0	0.19	12.5	0.08	35.0
Al (mg/L)	0.73	1.5	0.73	2.1	0.71	1.5	0.56	3.3	0.60	1.5	0.63	2.0
Turbidity (NTU)	0.85	27	0.92	375	0.69	130	0.85	550	3.0	175	0.92	400
Phosphate (mg/L of PO_4^{3-})	0.00	0.59	0.00	1.4	0.00	0.67	0.00	2.4	0.00	0.59	0.00	1.3
Sulfate (mg/L of SO_4^-)	179	189	91.5	170	113	132	14.2	302	15.6	67.0	9.4	132

Table 37. Continued

	SB-103 Inlet		SB-103 Outlet		SB-111 Inlet		SB-111 Outlet	
Field pH	5.0		6.5		7.1		7.4	
Lab pH	5.0		7.3		7.4		7.8	
Apparent color (field)	15		30		15		10	
Apparent color (lab)	25		40		25		30	
True color	3		0		0		0	
TSS (mg/L)	91		114		116		77	
VSS (mg/L)	17		19		19		25	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	6.8	7.0	11.3	11.0	42.0	47.5	27.5	30.0
Mn (mg/L)	0.30	0.35	0.08	0.23	0.06	0.10	0.05	0.10
Ca (mg/L)	15.0	26.3	29.3	60.0	142	265	102	118
Fe (mg/L)	0.08	3.7	0.08	5.5	0.06	2.4	0.08	3.0
Al (mg/L)	0.60	1.3	0.77	1.5	0.75	1.5	0.67	1.4
Turbidity (NTU)	0.75	45	0.62	110	0.66	33	0.66	55
Phosphate (mg/L of PO_4^{3-})	0.00	0.34	0.00	0.50	0.00	0.42	0.08	0.42
Sulfate (mg/L of SO_4^{-})	56.6	59.4	72.6	77.8	189	189	160	170

Table 38. Chemical analysis data for the 7th set of samples (Apr/21/2005)

	SB-11 inlet 38		SB-11 Inlet 39		SB-11 Outlet		SB-14 Outlet		SB-103 Outlet		SB-111 Outlet	
Field pH	7.1		7.4		9.0		6.5		6.8		7.1	
Lab pH	6.8		6.9		8.0		5.6		6.4		7.0	
Conductivity (µS)	263		243		237		193		186		707	
Apparent color (field)	0 -15		0 -15		10 - 20		0 - 15		0 – 15		0 – 10	
Apparent color (lab)	5		5		10		15		5		13	
True color	2		2		2		0		0		3	
TSS (mg/L)	12		9		18		17		8		45	
VSS (mg/L)	8		7		9		11		6		17	
Nitrate (mg/L of NO_3^- - N)	2.7		1.6		1.1		1.1		1.1		5.4	
Ammonia (mg/L)	0.09		0.08		0.15		0.06		0.08		0.11	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	8.9	9.0	6.8	6.8	8.3	8.4	9.1	9.4	6.5	6.6	33	33
Mn (mg/L)	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.03	0.01	0.05	0.00	0.03
Ca (mg/L)	34	35	32	34	29	29	20	21	22	23	73	75
Fe (mg/L)	0.01	0.35	0.00	0.18	0.01	0.33	0.06	0.75	0.05	0.41	0.00	0.53
Al (mg/L)	0.63	0.66	0.57	0.63	0.55	0.55	0.42	0.63	0.51	0.65	0.44	0.65
Turbidity (NTU)	0.75	3	0.62	3	0.63	5	0.50	8	0.52	5	0.62	23
Phosphate (mg/L Of PO_4^{3-})	0.21	0.46	0.29	0.38	0.34	0.38	0.25	0.34	0.25	0.29	0.21	0.25
Sulfate (mg/L Of SO_4^-)	54.3	54.3	47.6	47.6	38.1	41.9	25.2	25.2	33.8	34.8	105	114

Table 39. Chemical analysis data for the 8th set of samples (May/4/2005)

	SB-11 inlet 38		SB-11 Inlet 39		SB-11 Outlet		SB-14 Outlet		SB-103 Outlet		SB-111 Outlet	
Field pH	7.1		6.5		8.7		7.1		6.8		7.1	
Lab pH	7.0		7.0		7.2		6.8		6.5		7.4	
Conductivity (μS)	316		248		315		190		180		714	
Apparent color (field)	0-15		0-15		30		0-10		0-10		0-10	
Apparent color (lab)	5		5		10		7		7		8	
True color	0		0		0		0		0		0	
TSS (mg/L)	46		24		60		21		27		43	
VSS (mg/L)	19		16		29		6		14		28	
Nitrate (mg/L of NO_3^- - N)	1.1		1.1		1.1		0.5		0.0		1.1	
Ammonia (mg/L)	0.13		0.08		0.12		0.16		0.20		0.08	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Mg (mg/L)	11	11	7.1	7.3	12	12	10	10	7.0	7.0	30	40
Mn (mg/L)	0.00	0.00	0.03	0.03	0.01	0.06	0.01	0.05	0.00	0.05	0.01	0.08
Ca (mg/L)	44	46	40	40	41	42	22	27	26	27	81	82
Fe (mg/L)	0.01	0.39	0.03	0.15	0.00	1.90	0.04	0.90	0.01	0.45	0.03	0.93
Al (mg/L)	0.65	0.76	0.66	0.82	0.57	0.85	0.61	0.87	0.65	0.87	0.63	0.93
Turbidity (NTU)	0.49	5	0.43	3	0.41	52	0.38	15	0.45	10	0.37	13
Phosphate (mg/L of PO_4^{3-})	0.04	0.08	0.00	0.00	0.04	0.08	0.00	0.04	0.04	0.29	0.00	0.13
Sulfate (mg/L Of SO_4^-)	71.4	71.4	57.1	59.0	64.8	78.6	29.0	29.0	36.7	40.0	133	143

Table 40. Chemical analysis data for the 9th set of samples (Jun/23/2005)

	SB-11 inlet 38	SB-11 Outlet	SB-14 Outlet	SB-103 Outlet
Field pH	-	-	-	-
Lab pH	7.6	7.0	6.7	6.1
Conductivity (μS)	612	709	201	215
Apparent color (field)	-	-	-	-
Apparent color (lab)	6	20	10	24
True color	4	8	3	6
TSS (mg/L)	91	75	48	48
VSS (mg/L)	21	14	22	22
Nitrate (mg/L of NO_3^- - N)	2.2	3.2	3.2	2.2
Sulfate* (mg/L of SO_4^-)	143	143	27	44
Ammonia (mg/L NH_3)	0.11	0.07	0.04	0.07
Chloride (mg/L)	5.2	7.0	5.7	5.2
COD (mg/L)	0.0	0.0	11.3	0.0
TOC (mg/L)	9	2	2	4
Alkalinity (mg/L $CaCO_3$)	79.7	105	74.5	63.1

Table 40. Continued

	SB-11 inlet 38		SB-11 Outlet		SB-14 Outlet		SB-103 Outlet	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Na (mg/L)	26.3	33.5	29.0	36.0	21.8	27.0	21.8	29.5
Mg (mg/L)	24.3	27.5	32.3	36.0	11.0	12.0	10.0	12.0
Mn (mg/L)	0.0	0.1	0.0	0.2	0.0	0.2	0.0	0.2
Ca (mg/L)	94.5	99.0	102.8	109.0	30.0	30.0	35.5	36.5
Fe (mg/L)	0.00	1.6	0.00	2.5	0.00	0.8	0.00	0.9
Al (mg/L)	1.5	2.9	1.6	3.3	1.9	3.0	1.4	2.9
Turbidity (NTU)	2.2	27	2.4	35	2.2	15	2.6	21
Phosphate (mg/L of PO_4^{3-})	0.17	1.5	0.00	2.0	0.08	0.84	0.00	0.84

Table 41. Chemical analysis data for the 10th set of samples (Jul/26/2005)

	SB-11 Inlet 38	**SB-11 Inlet 39**	**SB-11 Outlet**	**SB-14 Outlet**	**SB-103 Outlet**
Field pH	-	-	-	-	-
Lab pH	7.4	7.5	7.2	7.1	6.9
Conductivity (μS)	1183	342	655	203	197
Apparent color (field)	-	-	-	-	-
Apparent color (lab)	10	14	12	25	90
True color	2	1	2	7	3
TSS (mg/L)	40	34	25	54	40
VSS (mg/L)	14	14	13	14	13
Nitrate (mg/L of NO_3^- - N)	0.0	0.0	1.1	1.1	2.2
Sulfate* (mg/L of SO_4^-)	143	81	143	24	31
Ammonia (mg/L NH_3)	1.35	0.28	0.35	0.27	0.24
Chloride (mg/L)	4.1	3.1	2.6	2.6	3.1
COD (mg/L)	11.3	7.5	15.0	11.3	25.6
TOC (mg/L)	1.0	1.0	1.0	1.0	1.8
Alkalinity (mg/L $CaCO_3$)	117	99	65	85	61

Table 41. Continued

	SB-11 inlet 38		SB-11 Inlet 39		SB-11 Outlet		SB-14 Outlet		SB-103 Outlet	
Metal analysis	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**	**Fil**	**Unfil**
Na (mg/L)	3.1	4.0	4.0	4.3	2.8	2.9	2.1	2.3	1.6	1.8
Mg (mg/L)	60.0	60.0	10.5	10.5	25.0	27.0	10.0	10.3	9.0	10.0
Mn (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Ca (mg/L)	145.5	150.0	56.5	57.0	82.8	92.3	30.5	30.8	28.5	31.0
Fe (mg/L)	0.03	1.03	0.03	0.75	0.00	0.58	0.05	0.58	0.05	2.23
Al (mg/L)	1.4	1.5	1.3	1.5	1.4	1.5	1.3	1.4	1.4	1.4
Turbidity (NTU)	1.5	25	2.1	23	2.5	17	1.7	49	1.6	86
Phosphate (mg/L of PO_4^{3-})	0.17	0.67	0.50	0.50	0.59	0.76	0.34	0.42	0.17	0.25

APPENDIX B

STATISTICAL ANALYSIS FOR SB11

The purpose of this Appendix is to present statistical analysis data to show that there is no significant difference between inlet and outlet average concentrations of Total suspended solids and metals in the basin. The average concentration of six set of samples were used for this analysis. Since the number of samples is a small (n=6), an inference about the normality of the population could not be made. Hence results are presented using both methods, namely: T Test (for paired samples, normal distribution) and Wilcoxon signed rank test (for non-normal distribution). Both the methods show that there is no significant difference between the inlet and outlet concentrations of TSS and metals.

B.1 TOTAL SUSPENDED SOLIDS (mg/L)

Table 42. T-test for paired samples (normal distribution)

Set No	**SB11 Inlet 38**	**SB11 Inlet 39**	**Avg of Inlets**	**SB11 Outlet**	**d_i**
			1	**2**	**(1-2)**
Set 1	23	16	19.5	40	-20.5
Set 2	25	18	21.4	44	-22.6
Set 3	12	12	12.0	10	2.0
Set 4	37	28	32.3	42	-9.7
Set 5	16	11	13.5	9	4.5
Set 6	62	650	356	206	150.0
μ			**75.79**	**58.50**	**17.29**
Std dev d_i = 65.96					
T = 0.641934					
T_α = 2.015					

Null Hypothesis* $H_o = \mu_1 - \mu_2 \leq 0$

*Mean of outlet concentration is greater or equal to inlet concentration that is SB not functioning well

Alternate Hypothesis $H_a = \mu_1 - \mu_2 > 0$

$t<t_\alpha$ Therefore we accept the null hypothesis that the mean outlet concentration of suspended solids is greater than or equal to the inlet concentration. Hence we can say that the SBs are not functioning effectively.

Table 43. Wilcoxon signed-rank test (non-normal distribution)

Field	Difference	Rank	Sign
1	-20.5	4	Negative
2	-22.6	5	Negative
3	2.0	1	Positive
4	-9.7	3	Negative
5	4.5	2	Positive
6	150.0	6	Positive
T- = 12			
T+ = 9			
Z = 0.314485			
z_α = 2			
A = 0.05			

Null Hypothesis*

H_o - The distribution of differences is symmetrical around 0

*means no significant difference between inlet and outlet concentrations

Alternative Hypothesis**

H_a - The differences tend to be larger than 0

** The input concentration is greater than output concentration, ie., the SB is functioning well. We find that $z > -z_{\alpha}$, therefore we accept null hypothesis that the distribution of differences is symmetrical about zero, or there is no significant difference between inlet and outlet concentrations.

B.2 TOTAL IRON (mg/L)

Table 44. T-test for paired samples (normal distribution)

Set No	SB11 Inlet 38	SB11 Inlet 39	Avg of Inlets	SB11 Outlet	d_i
			1	**2**	**(1-2)**
Set 1	0.77	0.76	0.77	0.78	-0.02
Set 2	0.74	0.83	0.79	1.50	-0.72
Set 3	0.78	0.84	0.81	0.88	-0.07
Set 4	0.40	0.21	0.31	0.80	-0.50
Set 5	0.60	0.83	0.72	0.39	0.33
Set 6	2.10	41.30	21.70	10.60	11.10
μ			**4.18**	**2.49**	**1.69**
Std dev d_i = 4.63					
T = 0.894086					
T_α = 2.015					

Null Hypothesis* $H_o = \mu_1 - \mu_2 \leq 0$

*Mean of outlet concentration is greater or equal to inlet concentration that is SB not functioning well

Alternate Hypothesis $H_a = \mu_1 - \mu_2 > 0$

$t < t_\alpha$ Hence we accept null hypothesis that the SBs are not functioning properly.

Table 45. Wilcoxon signed-rank test (non-normal distribution)

Field	Difference	Rank	Sign
1	-0.02	1	Negative
2	-0.72	5	Negative
3	-0.07	2	Negative
4	-0.50	4	Negative
5	0.33	3	Positive
6	11.10	6	Positive
T- = 12			
T+ = 9			
Z = 0.314485			
z_α = 2			
A = 0.05			

Null Hypothesis*

H_o - The distribution of differences is symmetrical around 0

*Means no significant difference between inlet and outlet concentrations

Alternative Hypothesis**

H_a - The differences tend to be larger than 0

** The input concentration is greater than output concentration, i.e., the SB is functioning well

We find that $z > -z_\alpha$, therefore we accept null hypothesis that the distribution of differences is symmetrical about zero, or there is no significant difference between inlet and outlet concentrations.

B.3 TOTAL ALUMINUM (mg/L)

Table 46. T-test for paired samples (normal distribution)

Set No	SB11 Inlet 38	SB11 Inlet 39	Avg of Inlets	SB11 Outlet	d_i
			1	**2**	**(1-2)**
Set 1	1.30	1.30	1.30	1.60	-0.30
Set 2	1.30	1.50	1.40	1.60	-0.20
Set 3	0.48	0.56	0.52	0.59	-0.07
Set 4	0.76	0.70	0.73	0.74	-0.01
Set 5	0.58	0.75	0.67	0.67	-0.01
Set 6	1.50	2.10	1.80	1.50	0.30
μ			**1.07**	**1.12**	**-0.05**
Std dev d_i = 0.21					
T = -0.56573					
T_α = 2.015					

Null Hypothesis* $\mathbf{H_o = \mu_1 - \mu_2 \leq 0}$

*Mean of outlet concentration is greater or equal to inlet concentration that is SB not functioning well

Alternative Hypothesis $\mathbf{H_a = \mu_1 - \mu_2 > 0}$

$t<t_\alpha$ Hence accept null hypothesis that the SBs are not functioning properly.

Table 47. Wilcoxon signed-rank test (non-normal distribution)

Field	Difference	Rank	Sign
1	-0.30	5.5	Negative
2	-0.20	4	Negative
3	-0.07	3	Negative
4	-0.01	1.5	Negative
5	-0.01	1.5	Negative
6	0.30	5.5	Positive
T- = 15.5			
T+ = 5.5			
Z = 1.048285			
z_{α} = 2			
A = 0.05			

Null Hypothesis*

H_o - The distribution of differences is symmetrical around 0

*Means no significant difference between inlet and outlet concentrations

Alternative Hypothesis**

H_a - The differences tend to be larger than 0

** The input concentration is greater than output concentration, i.e., the SB is functioning well

We find that $z > -z_{\alpha,}$ Therefore we accept null hypothesis that the distribution of differences is symmetrical about zero, or there is no significant difference between inlet and outlet concentrations.

B.4 TOTAL MANGANESE (mg/L)

Table 48. T-test for paired samples (normal distribution)

Set No	SB11 Inlet 38	SB11 Inlet 39	Avg of Inlets	SB11 Outlet	d_i
			1	**2**	**(1-2)**
Set 1	0.04	0.04	0.04	0.04	0.00
Set 2	0.04	0.07	0.06	0.03	0.03
Set 3	0.03	0.08	0.06	0.05	0.01
Set 4	0.10	0.11	0.11	0.11	0.00
Set 5	0.08	0.10	0.09	0.08	0.01
Set 6	0.05	0.30	0.18	0.15	0.03
μ			**0.09**	**0.08**	**0.01**
Std dev d_i = 0.01					
T = 1.94					
T_α = 2.015					

Null Hypothesis* $H_o = \mu_1 - \mu_2 \leq 0$

*Mean of outlet concentration is greater or equal to inlet concentration that is SB not functioning well

Alternative Hypothesis $H_a = \mu_1 - \mu_2 > 0$

$t < t_\alpha$ Hence accept null hypothesis that the SBs are not functioning properly.

Table 49. Wilcoxon signed-rank test (non-normal distribution)

Field	Difference	Rank	Sign
1	0.00	None	
2	0.03	3.5	Positive
3	0.01	1.5	Positive
4	0.00	None	
5	0.01	1.5	Positive
6	0.03	3.5	Positive
$T- = 0$			
$T+ = 10$			
$Z = -1.83$			
z_{α} = not given for n<4			
A = 0.05			

Null Hypothesis*

H_o - The distribution of differences is symmetrical around 0

*Means no significant difference between inlet and outlet concentrations

Alternative Hypothesis**

H_a – The differences tend to be larger than 0

** The input concentration is greater than output concentration, i.e., the SB is functioning well

B.5 TOTAL MAGNESIUM (mg/L)

Table 50. T-test for paired samples (normal distribution)

Set No	SB11 Inlet 38	SB11 Inlet 39	Avg of Inlets	SB11 Outlet	d_i
			1	**2**	**(1-2)**
Set 1	9.90	10.00	9.95	10.60	-0.65
Set 2	14.60	15.00	14.80	15.70	-0.90
Set 3	32.00	25.50	28.75	23.40	5.35
Set 4	24.80	22.50	23.65	24.30	-0.65
Set 5	18.30	16.30	17.30	21.30	-4.00
Set 6	40.50	19.00	29.75	19.50	10.25
μ			**20.70**	**19.13**	**1.57**
Std dev d_i = 5.23					
T = 0.73416					
T_α = 2.015					

Null Hypothesis* $H_o = \mu_1 - \mu_2 \leq 0$

*Mean of outlet concentration is greater or equal to inlet concentration that is SB not functioning well

Alternative Hypothesis: $H_a = \mu_1 - \mu_2 > 0$

$t < t_\alpha$ Hence accept null hypothesis that the SBs are not functioning properly.

Table 51. Wilcoxon signed-rank test (non-normal distribution)

Field	Difference	Rank	Sign
1	-0.65	1.5	Negative
2	-0.90	3	Negative
3	5.35	5	Positive
4	-0.65	1.5	Negative
5	-4.00	4	Negative
6	10.25	6	Positive
T- = 10			
T+ = 11			
Z = -0.10483			
z_{α} = 2			
A = 0.05			

Null Hypothesis*

H_o - The distribution of differences is symmetrical around 0

*Means no significant difference between inlet and outlet concentrations

Alternative Hypothesis**

H_a - The differences tend to be larger than 0

** The input concentration is greater than output concentration, i.e., the SB is functioning well

We find that $z > -z_{\alpha}$ therefore we accept null hypothesis that the distribution of differences is symmetrical about zero, or there is no significant difference between inlet and outlet concentrations.

APPENDIX C

SAMPLE CALCULATIONS FOR SB DESIGN

The purpose of this appendix is to show example calculation for designing a sedimentation basin starting from raw data. The following steps should be followed to design a sedimentation basin according to the integrated design approach explained in this manuscript.

C.1 DATA COLLECTION

The data requirements for sedimentation basin calculation are as follows:

1. Rainfall data: Rainfall frequency estimates can be obtained from National Weather Service Website Database: http://hdsc.nws.noaa.gov/hdsc/pfds/. Select the appropriate state to get the frequency estimates. On the next webpage select “NOAA Atlas 14 Precipitation Frequency Estimates” for “Data Type”, select “Partial Duration” for “Partial Duration or Annual Maxima Based Results”, select “US” for rainfall data in inches or “metric” for rainfall data in “mm”, select the observing site closest to the construction site or submit latitude and longitude if know, then click submit. This will bring up the

screen with rainfall frequency estimates. The data fields required are ARI (average reoccurrence interval) and 24 hr rainfall.

i. Value of runoff coefficient can be obtained from state BMP handbooks or design manuals for construction site erosion and sedimentation control practices. Pennsylvania Erosion and Sediment Pollution Control Manual gives runoff coefficient values for various land use patterns (PADEP, 2000).

ii. RUSLE Inputs: topographical maps identifying drainage areas and location of sedimentation basins are required to measure slope length and percentage slope for input to RUSLE. A representative stretch of the drainage basin should be selected from the map and further divided into subsections, if stretches of varying slopes are found within the representative stretch. The slope length (measured along slope), percentage slope and horizontal slope length should be measured for the representative section and for each subsection. Area of the drainage basin should also be measured. The type of vegetation grown, if any on the construction site of other management practices followed in the construction site should be identified. Soil type at the construction site can be identified from US geological survey records. (Additionally files for rainfall data, management practice and soil type for the region where the construction site is located can be imported into RUSLE2 program from NRCS website. RUSLE2 program can also be downloaded from the NRCES website. http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm

C.2 DEVELOPMENT OF RAINFALL PROBABILITY PLOT

To develop probability plot from precipitation frequency estimate follow the steps given below:

7. Calculate exceedence probability P using the relation $P = \frac{1}{ARI}$

8. Calculate non-exceedence probability P_m using the relation $\overline{P_m} = 1 - P_m$

9. Calculate runoff volume V_r, using the relation $V_r = R \times A \times \alpha$ where R is the 24hr rainfall depth, A is the area of the drainage basin and α is the runoff coefficient. For the purpose of sample calculations let us assume A=5.78 acres and $\alpha = 0.9$

10. The calculations are shown in the Figure 60 below

ARI (years)	24 Hr Storm In	Exceedence Probability %	Non-Exceedence Probability %	Runoff Volume SB111 ft³
2	2.65	$= \frac{1}{ARI} \times 100 = \frac{1}{2} \times 100 = 50$	$= 100 - \textit{exceedence probability}$ $= 100 - 50 = 50$	$V_r = R \times A \times \alpha$ $= 2.65 \times 5.78 \times 0.9 \times \frac{43560^*}{12}$ $= 50041$
5	3.29	$= \frac{1}{ARI} \times 100 = \frac{1}{5} \times 100 = 20$	$= 100 - 20 = 80$	62126
10	3.83	10	90	72323
25	4.60	4	96	86863

Figure 60. Rainfall frequency estimates for State College, PA – Sample calculations

Create a probability plot with non-exceedence probability on Y axis (probability scale) and runoff volume on X axis (log scale). The plot will yield a straight line and the runoff volume corresponding to the non-exceedence probability chosen can be read from the graph as shown in Figure 61.

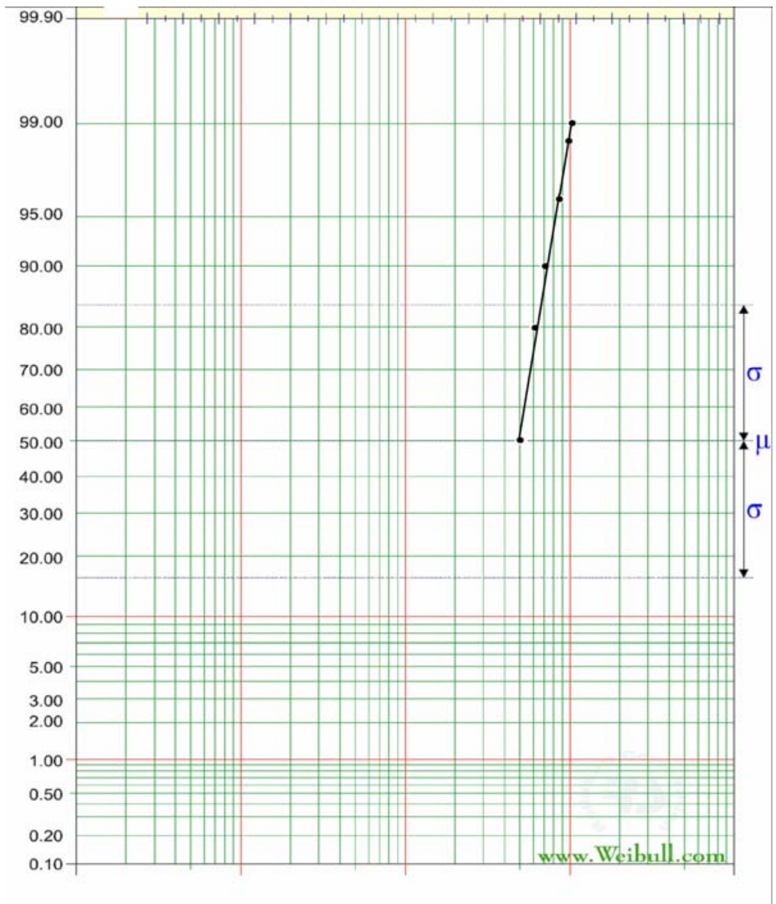

Figure 61. Example non-exceedence probability plot[a]
[a]The runoff volume obtained from the graph gives the settling volume of the basin

C.3 CALCULATION OF SOIL YIELD WITH RUSLE2

Input RUSLE parameters, slope length, slope steepness, horizontal slope length and select appropriate location for rainfall, soil type and management type with in the RUSLE2 program. A construction site template given within RUSLE can be used for management type for areas of the drainage basin where no particular management is followed. A step by step user guide for the RUSLE2 program is available at the NRCS website which can be used for understanding the program(http://fargo.nserl.purdue.edu/rusle2_dataweb/userguide/RUSLE2%20Program%20Users%20Guide.pdf).

The RUSLE2 program yields sediment delivery into the sedimentation basin in tones/acre/year. To calculate the sediment volume per year and sediment dredging frequency follow the calculations below:

Drainage basin area = 5.96 Ac (example value)

Sediment delivery t/ac/yr = 94 tons/Ac/yr (RUSLE2 Output)

Assuming SG of sediment = 2.65 (Davison et al., 2000) (specific gravity for common soils)

Sediment storage volume

Required per year = 94,000 [kg/Ac/yr] x 5.96 [Ac] / 2,650 [kg/m^3]

= 211.41 [m^3/yr] = 211.41/0.0283 [ft^3/yr]

= 7,470.32 [ft^3/yr]

Hence if a dredging period of 5 years is preferred, then

Sediment volume = 7,470.32 x 5 = 37,352 ≅ 37,000 ft^3

Settling volume = 72,000 ft^3 (from probability plot for 90% non exceedence probability)

Total basin volume = Settling Volume + Sediment Zone volume

= 72,000 + 37,000 = 109,000 ≅ 110,000 ft^3

C.4 CALCULATION OF BASIN DESIGN OVERFLOW RATE

The first step to calculating overflow rate is to choose a nominal particle size for removal in the basin (e.g., 2 micron diameter particle). Calculate the settling velocity for the particle using Stokes' law: Settling velocity,

$$v_t = \frac{g(\rho_p - \rho)d^2}{18\mu}$$

If μ = viscosity of water at 25 C, ρ_p is the density of the particle, assumed to be 2.65 g/cm^3 (density of common soils, Gregory et al., 1999, Davison et al., 2000), g is the acceleration due to gravity, ρ is the density of water at 25 C and d is the diameter of the particle (assumed to be 2 micron for sample calculations) then,

$$v_t = \frac{981\frac{cm}{s^2}(2.65-1)\frac{g}{cm^3}\left(2\times10^{-4}\right)^2 cm^2}{18\times0.01\frac{g}{cm\,s}\times\left(3600\times24\frac{s}{day}\right)\times\left(30.48\frac{cm}{ft}\right)} = 1\frac{ft}{day}$$

Thus the design overflow rate for 2 micron particle removal is 1 ft/day = 7.48 gal/ft^2/day.

C.5 CALCULATION OF BASIN DESIGN PARAMETERS

To arrive at the basin design parameters namely basin area, depth, outflow rate and drainage time an excel template as shown in the Figure 62 below can be used.

	Elevation from Basin Bottom ft	Basin Dimension			Avg Area ft^2	Avg Basin Volume ft^3	Cumulative Basin Volume ft^3	Outflow Rate Ft^3/day	Overflow Rate Gal/ft^2/day	Drainage Time Day
		Length Ft	Breadth Ft	Area ft^2						
Sediment Zone	$d_0 = 0$	Assume 180	Assume 70	Length x breadth = 12600	-	-	-	No outflow in the sediment zone 0	0	
	$d_1 = d_0 + h$ = 0 + 0.5 = 0.5 Assume h for calculation purposes	Length increase with increase in depth due to tapering structure 184	breadth increases with increase in depth due to tapering structure 74	13616	= [A(d0) + A(d1)]/2 =13108	= average area x 0.5 = 13108 x 0.5 = 6554	$= V_0 + V_1 =$ 0 + 6554 = 6554	0	0	
	1	188	78	14664	14140	7070	= 6554 + 7070 =13624	0	0	
	1.5	192	82	15744	15204	7602	21226	0	0	
	2	196	86	16856	16300	8150	29376	0	0	
	2.5	200	90	18000	17428	8714	38090	= (Overflow rate x average area) = 7.48 x 1 ft/day x 17428 ft^2 = 17428	Design value for particle removal 7.48	3.7
Settling Zone	3	204	94	19176	18588	9294	47384	18588	7.48	3.2
	3.5	208	98	20384	19780	9890	57274	19780	7.48	2.7
	4	212	102	21624	21004	10502	67776	21004	7.48	2.2
	4.5	216	106	22896	22260	11130	78906	22260	7.48	1.7
	5	220	110	24200	23548	11774	90680	23548	7.48	1.2
	5.5	224	114	25536	24868	12434	103114	24868	7.48	= outflow rate / incremental volume + 0.2 = 0.7
	5.74	228	118	26904	26220	6293	109407	26220	7.48	= outflow rate / incremental volume = 0.2

Figure 62. Sample calculations for SB design parameters

APPENDIX D

SEDIMENTATION BASIN MAPS

This section shows the elevation maps of the sedimentation basins SB11, SB14, SB103 and SB111.

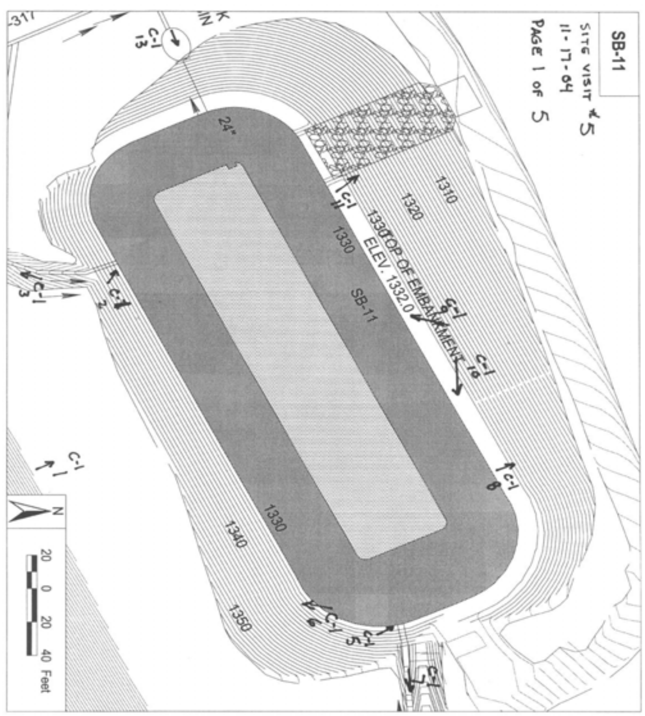

Figure 63. Elevation of SB11 showing basin topography inlets and outlet

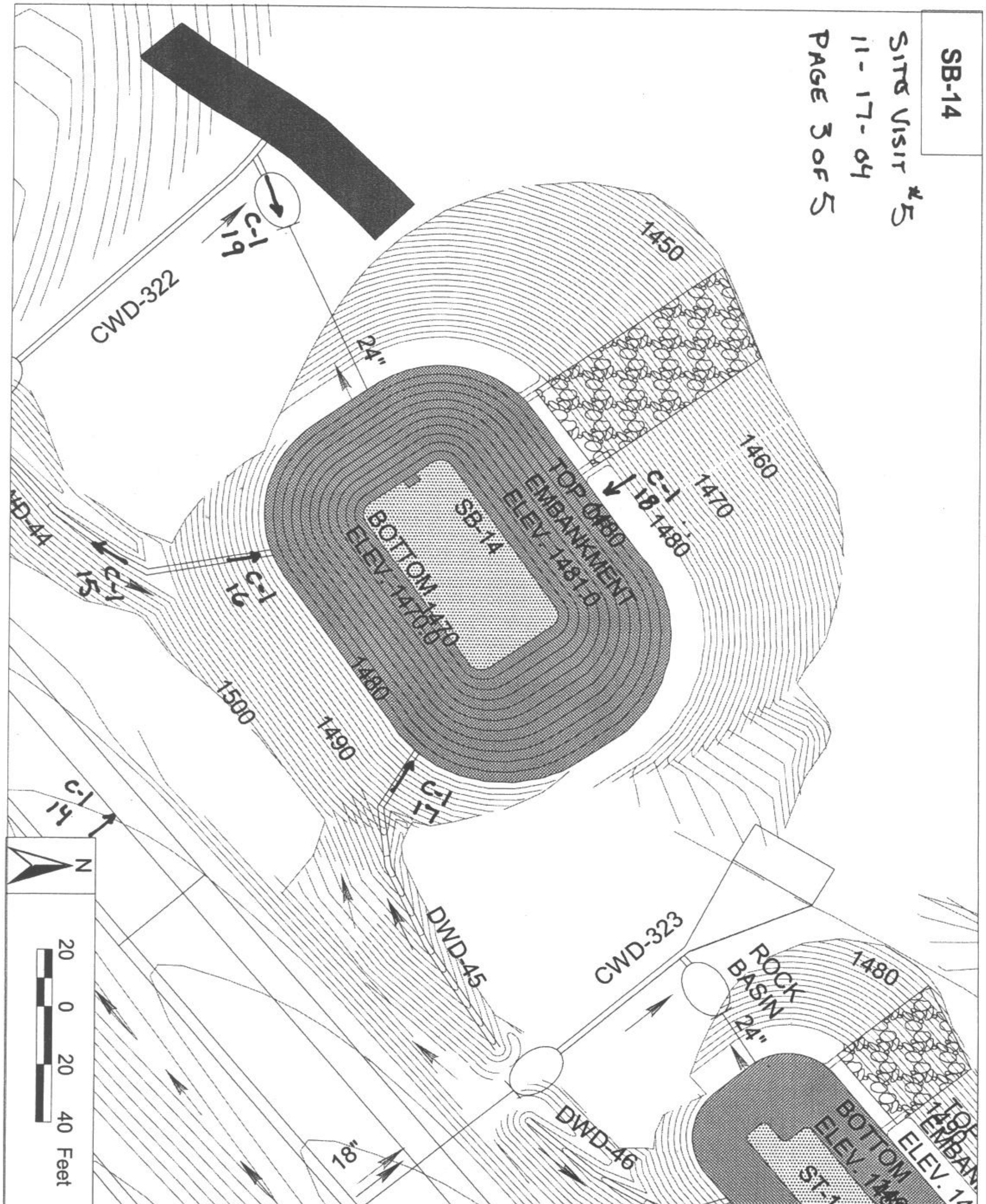

Figure 64. Elevation of SB103 showing basin topography, inlet and outlet

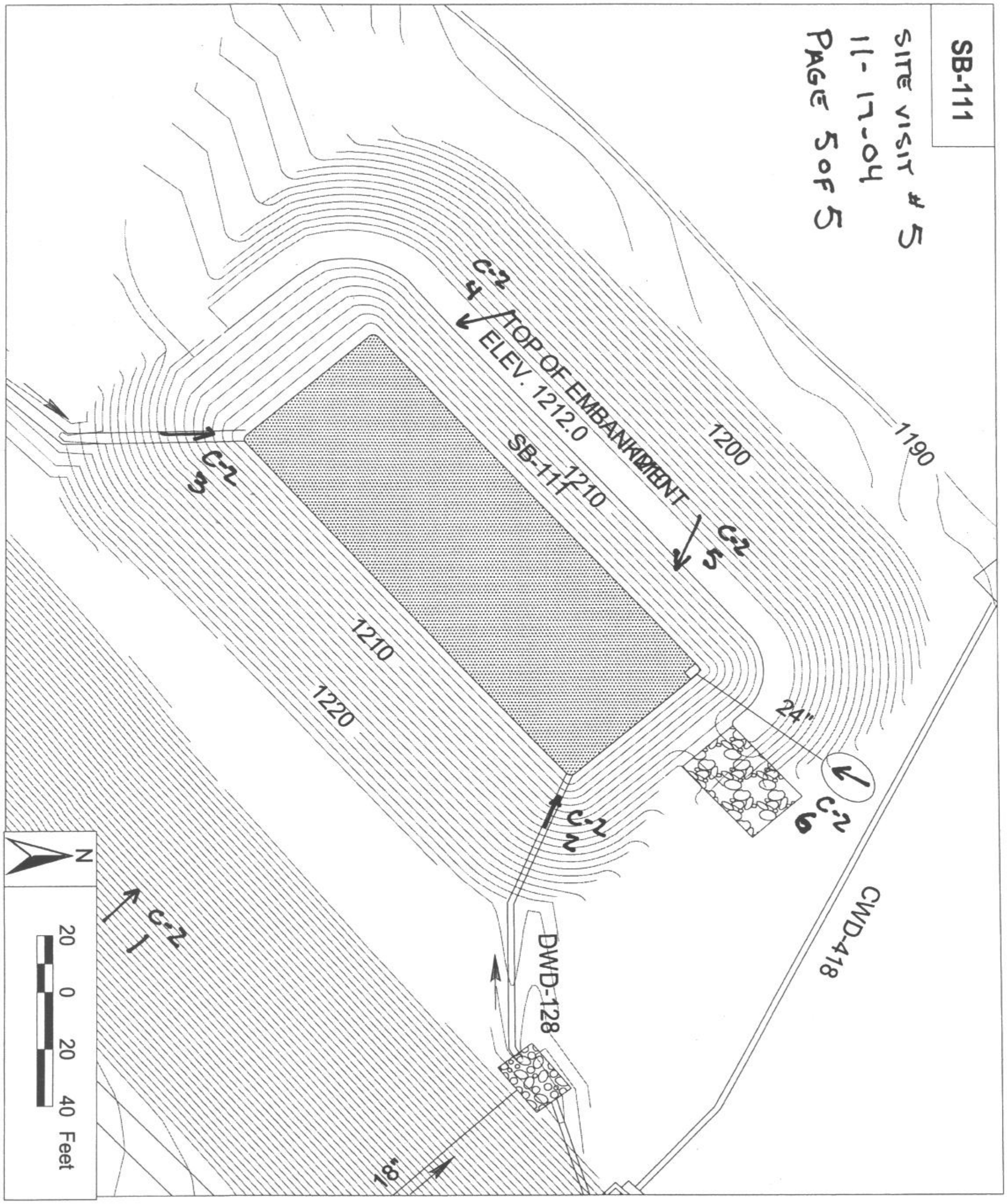

Figure 65. Elevation of SB111 showing basin topography, inlets and outlet

APPENDIX E

RUSLE2 RESULTS FOR SEDIMENTATION BASINS

The purpose of this appendix is to present results obtained from RUSLE2 program. The RUSLE2 was initially developed to calculate soil loss and to identify conservation practices at agricultural sites. Most of the parameters shown in the RUSLE reports are those applicable to agricultural sites. The output that is of interest to our calculations (soil delivery and soil loss in tons/acre/year for the drainage) has been extracted and presented in the sections below:

E.1 RUSLE2 RESULTS FOR SB11

Rusle Program Version: Oct 19 2005

Rusle Science Version: 7/1/2005

Data Base: moses

RUSLE2 Erosion Calculation Record

Segment	Management	Segment length (horizontal), ft	Is this a rotation?	Soil loss, t/ac/yr	Sediment delivery, t/ac/yr
1	CMZ 65 Single Year Single Crop Templates forage systems clover sp seed clover ss 1yr; fcst z65	65	No	86	86
2	CMZ 65 Construction Site Templates Default	39	No	120	94
3	CMZ 65 Construction Site Templates Default	58	No	140	110
4	CMZ 65 Construction Site Templates Default	39	No	150	110
5	CMZ 65 Construction Site Templates Default	150	No	**230**	**160**

E.2 RUSLE2 RESULTS FOR SB14

Rusle Program Version: Oct 19 2005

Rusle Science Version: 7/1/2005

Data Base: moses

RUSLE2 Erosion Calculation Record

Segment	Management	Segment length (horizontal), ft	Is this a rotation?	Soil loss, t/ac/yr	Sediment delivery, t/ac/yr
1	CMZ 65 Single Year Single Crop Templates forage systems clover sp seed clover ss 1yr; fcst z65	580	No	390	390
2	CMZ 65 Construction Site Templates Default	210	No	**400**	**400**

E.3 RUSLE2 RESULTS FOR SB103

Rusle Program Version: Oct 19 2005

Rusle Science Version: 7/1/2005

Data Base: moses

RUSLE2 Erosion Calculation Record

Segment	Management	Segment length (horizontal), ft	Is this a rotation?	Soil loss, t/ac/yr	Sediment delivery, t/ac/yr
1	CMZ 65 Single Year Single Crop Templates forage systems clover sp seed clover ss 1yr; fcst z65	220	No	160	160
2	CMZ 62 Construction Site Templates Default	40	No	200	170
3	CMZ 62 Construction Site Templates Default	60	No	240	180
4	CMZ 62 Construction Site Templates Default	50	No	-330	110
5	CMZ 62 Construction Site Templates Default	250	No	**180**	**140**

E.4 RUSLE2 RESULTS SB111

Rusle Program Version: Oct 19 2005

Rusle Science Version: 7/1/2005

Data Base: moses

RUSLE2 Erosion Calculation Record

Segment	Management	Segment length (horizontal), ft	Is this a rotation?	Soil loss, t/ac/yr	Sediment delivery, t/ac/yr
1	CMZ 65 Single Year Single Crop Templates forage systems clover sp seed clover ss 1yr; fcst z65	38	No	5.4	5.4
2	CMZ 65 Construction Site Templates Default	40	No	12	8.9
3	CMZ 65 Construction Site Templates Default	49	No	36	20
4	CMZ 65 Construction Site Templates Default	50	No	13	18
5	CMZ 65 Construction Site Templates Default	150	No	**320**	**160**

APPENDIX F

MINEQL+ SOFTWARE

F.1 OVERVIEW OF MINEQL

The purpose of this appendix is to provide a brief overview of Mineql+ water chemistry modeling software and how it works. The chemistry of water is typically very complicated. Chemical constituents that are dissolved in water may form chemical complexes, precipitate as solid phases, de-gas from the system or adsorb onto particulate surfaces. All of these reaction pathways are affected by, and will affect, water quality parameters such as pH, alkalinity or ionic strength. The chemical equilibrium approach offers a way in which to understand these chemical interactions in a straight forward, unified manner. A schematic representation of the equilibrium approach and chemical interactions is shown in Figure 66.

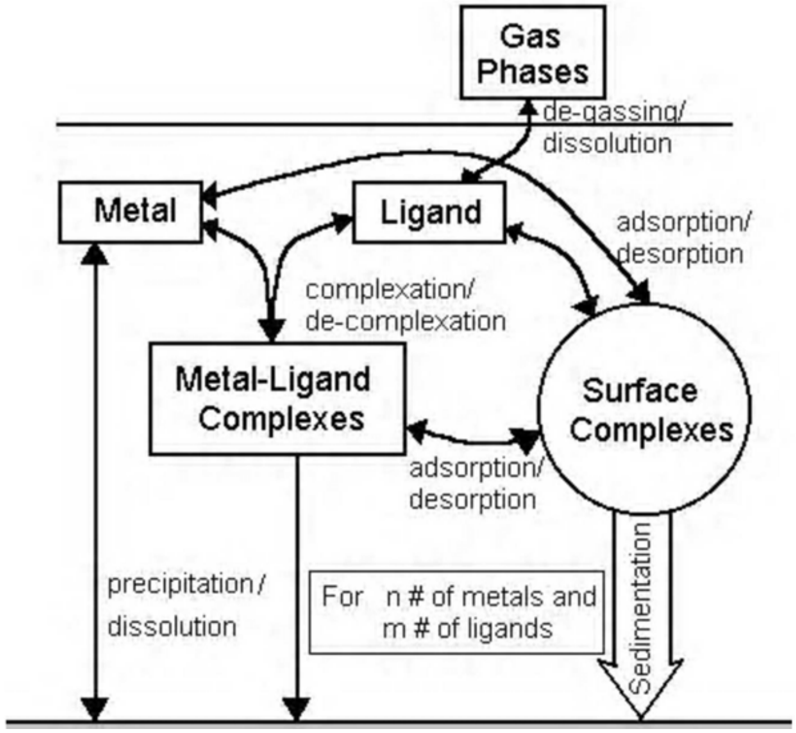

Figure 66. A schematic representation of the equilibrium approach and chemical interactions

F.2 MINEQL OUTPUT RESULTS FOR SB11 OUTLET SAMPLE

MINEQL+ Ver 4.5 Page 1

Data Extracted from: OUTPUT.MDO

SINGLE RUN SUMMARY

This report compiles the output data (concentration, Log C, Log K) for all species within a single run.

~

MINEQL+ Ver 4.5 Page 2

Data Extracted from : OUTPUT.MDO

Run: 1

ID Species	Conc.	Log C	Log K
Type I - COMPONENTS			
2 H2O	1.000E+00	0.000	0.000
3 H(+)	1.580E-08	-7.800	0.000
8 Al(3+)	1.150E-13	-12.938	0.000
16 Ca(2+)	1.690E-03	-2.773	0.000
23 CO3(2-)	8.970E-07	-6.047	0.000
32 Fe(2+)	1.480E-05	-4.829	0.000
33 Fe(3+)	1.230E-23	-22.909	0.000

41 Mg(2+)	5.350E-04	-3.271	0.000
42 Mn(2+)	6.400E-07	-6.194	0.000
43 Mn(3+)	1.900E-24	-23.722	0.000
54 PO4(3-)	6.990E-11	-10.156	0.000
64 Si(OH)4	1.800E-07	-6.744	0.000
68 SO4(2-)	7.460E-04	-3.127	0.000

Type II - COMPLEXES

3800 OH-	(-1) 6.350E-07	-6.197	-14.000
4300 Al(OH)2+	(+1) 3.700E-08	-7.432	-10.090
4400 Al(OH)3 (aq)	4.690E-07	-6.329	-16.790
4500 Al(OH)4-	(-1) 3.750E-05	-4.426	-22.690
4600 AlOH+2	(+2) 7.320E-11	-10.135	-5.000
7300 CaOH+	(+1) 2.140E-08	-7.670	-12.700
13900 Fe(OH)3-	(-1) 3.810E-11	-10.420	-28.990
14000 Fe(OH)2 (aq)	1.890E-10	-9.723	-20.490
14100 FeOH+	(+1) 3.750E-07	-6.426	-9.400
14300 FeOH+2	(+2) 5.060E-18	-17.296	-2.190
14400 Fe(OH)2+	(+1) 1.250E-12	-11.903	-4.590
14500 Fe2(OH)2+4	(+4) 8.470E-34	-33.072	-2.850
14600 Fe(OH)3 (aq)	8.530E-13	-12.069	-12.560
14700 Fe(OH)4-	(-1) 5.050E-14	-13.297	-21.590
14800 Fe3(OH)4+5	(+5) 1.530E-44	-43.815	-6.290

17900 MgOH+	(+1) 1.350E-07	-6.868	-11.400
18000 MnOH+	(+1) 1.020E-09	-8.991	-10.600
18100 Mn(OH)3-	(-1) 2.550E-18	-17.594	-34.800
18101 Mn(OH)4-2	(-2) 5.230E-24	-23.282	-48.290
28400 CaHCO3+	(+1) 9.530E-06	-5.021	11.600
28403 CaH2PO4+	(+1) 2.480E-08	-7.605	20.920
28700 CaHPO4 (aq)	2.030E-06	-5.693	15.040

~

MINEQL+ Ver 4.5 Page 3

Data Extracted from : OUTPUT.MDO

Run: 1

ID Species	Conc.	Log C	Log K

Type II - COMPLEXES

31700 H2CO3 (aq)	1.080E-05	-4.966	16.680
31800 HCO3-	(-1) 3.030E-04	-3.518	10.330
31901 FeHCO3+	(+1) 5.670E-08	-7.247	11.430
32000 MgHCO3+	(+1) 1.660E-06	-5.779	11.340
32100 MnHCO3+	(+1) 3.880E-09	-8.412	11.630
35500 FeH2PO4+	(+1) 4.880E-09	-8.311	22.270
35501 FeHPO4 (aq)	1.550E-07	-6.809	15.980
36000 FeHPO4+	(+1) 2.680E-19	-18.573	22.290

36001 FeH2PO4+2	(+2) 1.540E-25	-24.813	23.850
36701 MgH2PO4+	(+1) 1.690E-08	-7.771	21.260
37500 MgHPO4 (aq)	8.870E-07	-6.052	15.180
41000 H2PO4-	(-1) 6.570E-07	-6.183	19.570
41100 HPO4-2	(-2) 2.630E-06	-5.581	12.380
41200 H3PO4	1.460E-12	-11.835	21.720
43500 H2SiO4-2	(-2) 6.540E-15	-14.184	-23.040
43600 H3SiO4-	(-1) 1.640E-09	-8.784	-9.840
43900 HSO4-	(-1) 1.160E-09	-8.937	1.990
62700 AlSO4+	(+1) 6.680E-13	-12.175	3.890
62800 Al(SO4)2-	(-1) 5.340E-15	-14.273	4.920
71800 CaCO3 (aq)	2.400E-06	-5.620	3.200
71902 CaPO4-	(-1) 3.400E-07	-6.468	6.460
72300 CaSO4 (aq)	2.880E-04	-3.540	2.360
95300 MgCO3 (aq)	4.000E-07	-6.398	2.920
114900 FeSO4 (aq)	2.720E-06	-5.566	2.390
120400 FeSO4+	(+1) 1.030E-22	-21.986	4.050
120500 Fe(SO4)2-	(-1) 1.650E-24	-23.783	5.380
132801 MgPO4-	(-1) 1.690E-09	-8.773	4.650
133400 MgSO4 (aq)	7.270E-05	-4.139	2.260
136200 MnSO4 (aq)	8.490E-08	-7.071	2.250

Type III - FIXED ENTITIES

175300	CO2 (g)	21.650
3801	H2O (Solution)	0.000
175310	pH (+1)	7.800

Type IV - PRECIPITATED SOLIDS

184700	KAOLINITE	4.910E-06	0.000	-7.440
194300	GOETHITE	4.550E-03	0.000	-0.490
197900	BIXBYITE	3.650E-07	0.000	0.640

~

MINEQL+ Ver 4.5 Page 4

Data Extracted from : OUTPUT.MDO

Run: 1

ID	Species	Conc.	Log C	Log K

Type IV - PRECIPITATED SOLIDS

Type V - DISSOLVED SOLIDS

194200	LEPIDOCROCITE	-0.880	-1.370
195200	H-JAROSITE	-23.881	12.100
204700	GYPSUM	-1.290	4.610

208800 QUARTZ	-2.744	4.000	
218900 CALCITE	-0.340	8.480	
219200 DOLOMITE (ordered)	-1.048	17.090	
219201 ~	-1.598	16.540	
224400 SIDERITE	-0.636	10.240	
197600 PYROCHROITE	-5.788	-15.190	

Type VI - SPECIES NOT CONSIDERED

181900 DIASPORE	3.880E+03	3.589	-6.870
182000 Al2O3	1.870E+01	1.272	-19.650
182100 BOEHMITE	7.650E+01	1.884	-8.580
182300 GIBBSITE	1.480E+02	2.171	-8.290
182900 HERCYNITE	6.340E+08	8.802	-22.890
187400 HYDROXYLAPATITE	6.340E+07	7.802	44.330
213600 MnHPO4	1.780E+01	1.251	25.400
224800 RHODOCHROSITE	2.180E-02	-1.661	10.580
229700 Mn3(PO4)2	8.600E-16	-15.065	23.830
229800 MnSO4	1.250E-12	-11.904	-2.580
193800 MAGNETITE	2.240E+08	8.350	-3.400
184800 Al4(OH)10SO4	2.630E+00	0.420	-22.700
183900 SPINEL	2.540E-04	-3.596	-36.850
184600 HALLOYSITE	7.240E-03	-2.140	-9.570
184900 AlOHSO4	9.220E-06	-5.035	3.230

186700 LIME	1.340E-20	-19.872	-32.700
186800 PORTLANDITE	1.050E-10	-9.977	-22.800
186801 Ca4H(PO4)3:3H2O	5.270E-03	-2.278	47.080
186802 CaHPO4:2H2O	1.850E-02	-1.733	19.000
190800 ARTINITE	2.570E-07	-6.590	-9.600
190900 HYDROMAGNESITE	6.620E-17	-16.179	8.770
193600 WUSTITE -0.11)	2.110E-01	-0.675	-11.690
193700 Fe(OH)2	1.610E-03	-2.793	-13.560
193900 Fe3(OH)8	3.400E-09	-8.469	-20.220
194000 GREENALITE	1.040E-02	-1.984	-20.810
194400 HEMATITE	2.510E+02	2.400	1.420

~

MINEQL+ Ver 4.5 Page 5

Data Extracted from : OUTPUT.MDO

Run: 1

ID Species	Conc.	Log C	Log K

Type VI - SPECIES NOT CONSIDERED

194500 FERRIHYDRITE	2.000E-03	-2.700	-3.190
194600 MAGHEMITE	3.940E-06	-5.404	-6.390
194800 MAGNESIOFERRITE	2.820E-04	-3.549	-16.860
196600 PERICLASE	5.550E-10	-9.255	-21.580

196700 BRUCITE	3.050E-05	-4.515	-16.840
196702 Mg(OH)2 (active)	3.420E-07	-6.465	-18.790
196701 MgHPO4:3H2O	8.870E-04	-3.052	18.180
196900 SEPIOLITE	4.620E-12	-11.336	-15.760
197100 SEPIOLITE (A)	4.410E-15	-14.356	-18.780
197300 CHRYSOTILE	1.980E-09	-8.703	-32.200
205800 NESQUEHONITE	2.250E-05	-4.648	4.670
206500 VIVIANITE	1.600E+01	1.203	36.000
206600 MELANTERITE	1.790E-06	-5.747	2.210
206700 STRENGITE	2.160E-07	-6.665	26.400
207100 EPSOMITE	5.350E-05	-4.272	2.130
208400 CRISTOBALITE	4.030E-04	-3.394	3.350
208500 SiO2 (am,ppt)	9.900E-05	-4.004	2.740
208600 CHALCEDONY	6.390E-04	-3.194	3.550
208700 SiO2 (am,gel)	9.240E-05	-4.034	2.710
210800 CaHPO4	3.520E-02	-1.453	19.280
218800 ARAGONITE	3.020E-01	-0.520	8.300
219100 HUNTITE	1.560E-07	-6.807	29.970
234300 Ca3(PO4)2 (beta)	1.950E+00	0.290	28.920
219900 ANHYDRITE	2.880E-02	-1.540	4.360
224700 MAGNESITE	1.390E-02	-1.858	7.460
227400 Fe3(PO4)2	1.600E+01	1.203	36.000
227700 Fe2(SO4)3	3.420E-52	-51.466	3.730

229300 Mg3(PO4)2	1.430E-07	-6.846	23.280
229900 Mn2(SO4)3	7.680E-52	-51.115	5.710
182200 Al(OH)3 (am)	4.590E-01	-0.338	-10.800

Other Species

900003	Activity of H+	1.580E-08	-7.800	0.0

APPENDIX G

SAMPLE FIELD VSIT FORMS

Several field visits were performed during the course of this research project to collect samples and to monitor site conditions. Examples of forms presented by field inspection personal are shown in this appendix. The sample forms presented are

1. Trip report
2. Chain of custody form
3. Field sampling data form
4. Photo log
5. Photo location maps

Uni-Tec Consulting Engineers

TRIP REPORT: I-99 Project
Task A – Field Sampling
Report Date: 11/18/2004
Page 1 of 2

Trip Number	5
Trip Date	November 17, 2004
Trip Duration	8:00 am to 2:00 pm: 4.0 hours + travel time
Weather and road conditions	Overcast with intermittent drizzle, 45 to 59 degrees F. Light wind. Travel on construction roads dry and unproblematic. Construction activity busy.
Most recent precipitation event	Four days prior to the trip (11/13/04), approximately 1/2". Significant precipitation was forecasted but that did not materialize.
Attendance	Paul Meister, Uni-Tec John Segursky, Uni-Tec
Documents and materials submitted to Dr. Neufeld:	1. Fourteen (12) labeled water sample jars in transport cooler with icepacks 2. Chain of custody form (1 page) 3. Field sampling data forms (1 page) 4. Three disposable cameras 5. Photo log (3 pages) 6. Drawings showing location and direction of photographs 7. Walking survey forms (2 pages) 8. Windshield survey form (1 page) 9. Trip Report (2 pages)
Sampling and Evaluation comments	1. Due to the time of year approaching it will be difficult to be able to schedule site visits in conjunction with precipitation events. As previously stated, it appears that the only situation in which we will be able to collect stormwater from the inlets is during a heavy precipitation event. 2. Next visit is scheduled to take place during the first week of the Pennsylvania Antlered Deer hunting season. 3. Site Visit No. 5 did show evidence of ice in selected locations. This condition will only worsen as the visits get deeper into the winter months. 4. It is possible that heavy precipitation events may preclude travel on the construction site. 5. Vegetation is now lying down so that the condition and

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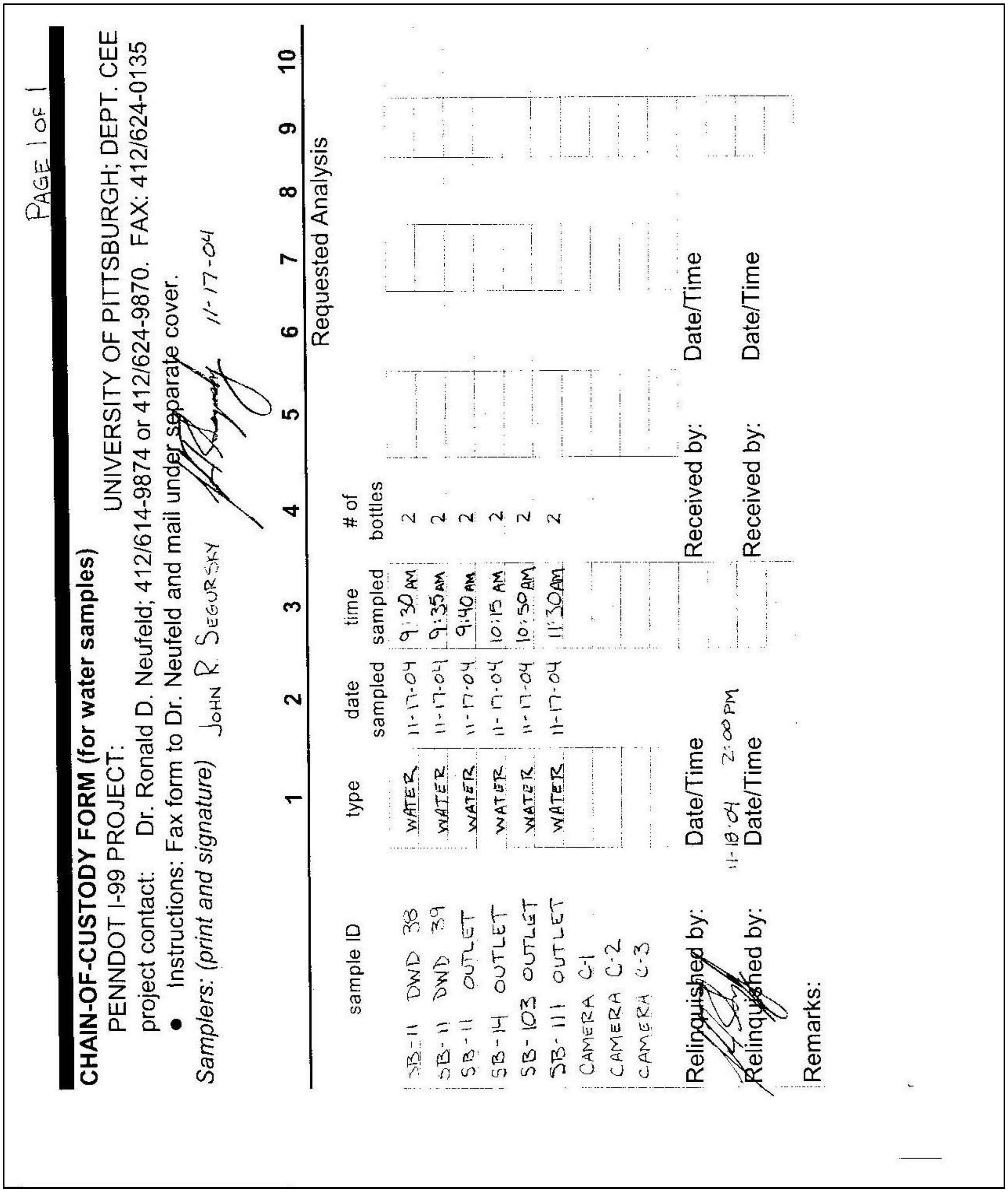
ph (814) 238-8223 fx (814) 238-7808 www.uni-tec.com

Figure 67. Sample trip report



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CHAIN-OF-CUSTODY FORM (for water samples)

PENNDOT I-99 PROJECT: UNIVERSITY OF PITTSBURGH; DEPT. CEE

project contact: Dr. Ronald D. Neufeld; 412/614-9874 or 412/624-9870. FAX: 412/624-0135

- Instructions: Fax form to Dr. Neufeld and mail under separate cover.

Samplers: (print and signature) JOHN R. SEGURSKY 11-17-04

	1	2	3	4	5	6	7	8	9	10
					Requested Analysis					
sample ID	type	date sampled	time sampled	# of bottles						
SB-11 DWD 38	WATER	11-17-04	9:30 AM	2						
SB-11 DWD 39	WATER	11-17-04	9:35 AM	2						
SB-11 OUTLET	WATER	11-17-04	9:40 AM	2						
SB-14 OUTLET	WATER	11-17-04	10:15 AM	2						
SB-103 OUTLET	WATER	11-17-04	10:50 AM	2						
SB-111 OUTLET	WATER	11-17-04	11:30 AM	2						
CAMERA C-1										
CAMERA C-2										
CAMERA C-3										

Relinquished by: Date/Time 11-18-04 2:00 PM Received by: Date/Time

Relinquished by: Date/Time Received by: Date/Time

Remarks:

Figure 68. Sample chain of custody form

PAGE 1 OF 1

FIELD SAMPLING DATA FORM: . . . . DATE OF SAMPLING: 11-17-04

PENNDOT I-99 PROJECT

NAME OF SAMPLER, COMPANY & Phone #: JOHN SEGURSKY PAUL MEISTER, UNITEC 814 238 8223

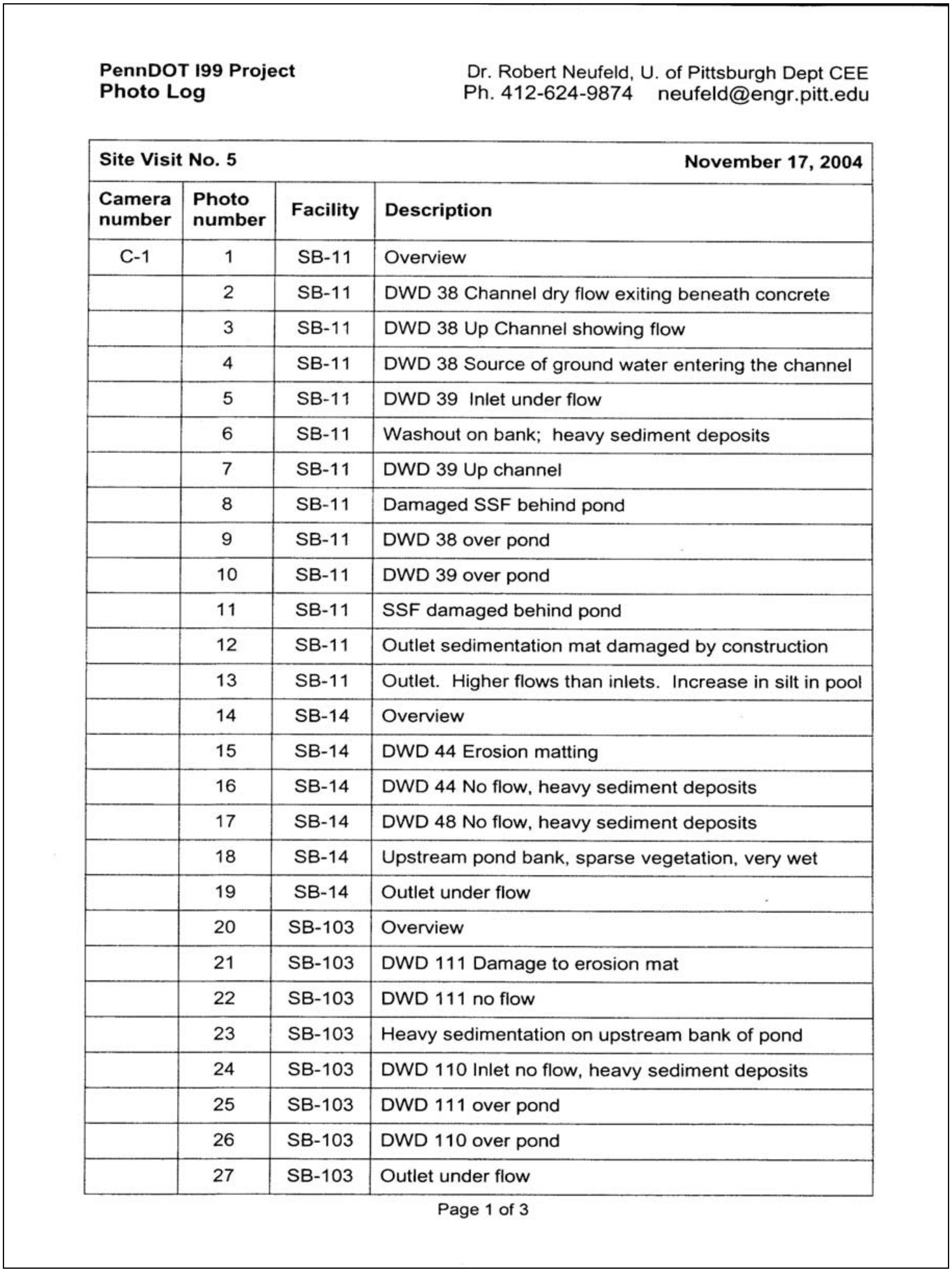
Return Bottles and cameras via UPS to:

Dr. Ronald D. Neufeld, Department of Civil & Environmental Engineering,
949 BEH, University of Pittsburgh, Pittsburgh, PA 15261

		1	2	3	4	5	6
MONITORING POINT: WATER		Picture #	Sample #'s (duplicates)	Temp.	pH	Days since last rain?	Color & otherObservations
SB-11 inlet	DWD 38	SEE PHOTO LOG	1, 2	48.4	7.0		COLOR ±5
	DWD 39		1, 2	44.5	6.8		COLOR ±5
SB-11 outlet			1, 2	43.7	7.1		COLOR ±5
SB-14 inlet			INLETS DRY	NO SAMPLES			SEEP T 50.6 Ph 5.8
SB-14 outlet			1, 2	42.3	5.8		COLOR ± 15
SB-103 inlet			INLETS DRY	NO SAMPLES			
SB-103 outlet			1, 2	42.7	6.4		COLOR ± 10
SB-111 inlet			INLETS DRY	NO SAMPLES			
SB-111 outlet			1, 2	44.8	7.0		COLOR ± 5
Condition: Erosion Control Mats			SEE PHOTO LOG				
Condition: Water Channels SB-110 to SB-115			SEE PHOTO LOG				
Condition: Erosion Control Mats SB-10 & SB-11; SB-14; SB-103; SB- 110 to SB-115			SEE PHOTO LOG				

* SIMPLE RAIN GAUGE PLACED NEAR DWD 38 RECORDED 1.1" OF RAIN SINCE LAST VISIT

Figure 69. Sample field sampling data form



PennDOT I99 Project
Photo Log

Dr. Robert Neufeld, U. of Pittsburgh Dept CEE
Ph. 412-624-9874 neufeld@engr.pitt.edu

Site Visit No. 5			November 17, 2004
Camera number	Photo number	Facility	Description
C-1	1	SB-11	Overview
	2	SB-11	DWD 38 Channel dry flow exiting beneath concrete
	3	SB-11	DWD 38 Up Channel showing flow
	4	SB-11	DWD 38 Source of ground water entering the channel
	5	SB-11	DWD 39 Inlet under flow
	6	SB-11	Washout on bank; heavy sediment deposits
	7	SB-11	DWD 39 Up channel
	8	SB-11	Damaged SSF behind pond
	9	SB-11	DWD 38 over pond
	10	SB-11	DWD 39 over pond
	11	SB-11	SSF damaged behind pond
	12	SB-11	Outlet sedimentation mat damaged by construction
	13	SB-11	Outlet. Higher flows than inlets. Increase in silt in pool
	14	SB-14	Overview
	15	SB-14	DWD 44 Erosion matting
	16	SB-14	DWD 44 No flow, heavy sediment deposits
	17	SB-14	DWD 48 No flow, heavy sediment deposits
	18	SB-14	Upstream pond bank, sparse vegetation, very wet
	19	SB-14	Outlet under flow
	20	SB-103	Overview
	21	SB-103	DWD 111 Damage to erosion mat
	22	SB-103	DWD 111 no flow
	23	SB-103	Heavy sedimentation on upstream bank of pond
	24	SB-103	DWD 110 Inlet no flow, heavy sediment deposits
	25	SB-103	DWD 111 over pond
	26	SB-103	DWD 110 over pond
	27	SB-103	Outlet under flow

Page 1 of 3

Figure 70. Sample photo log

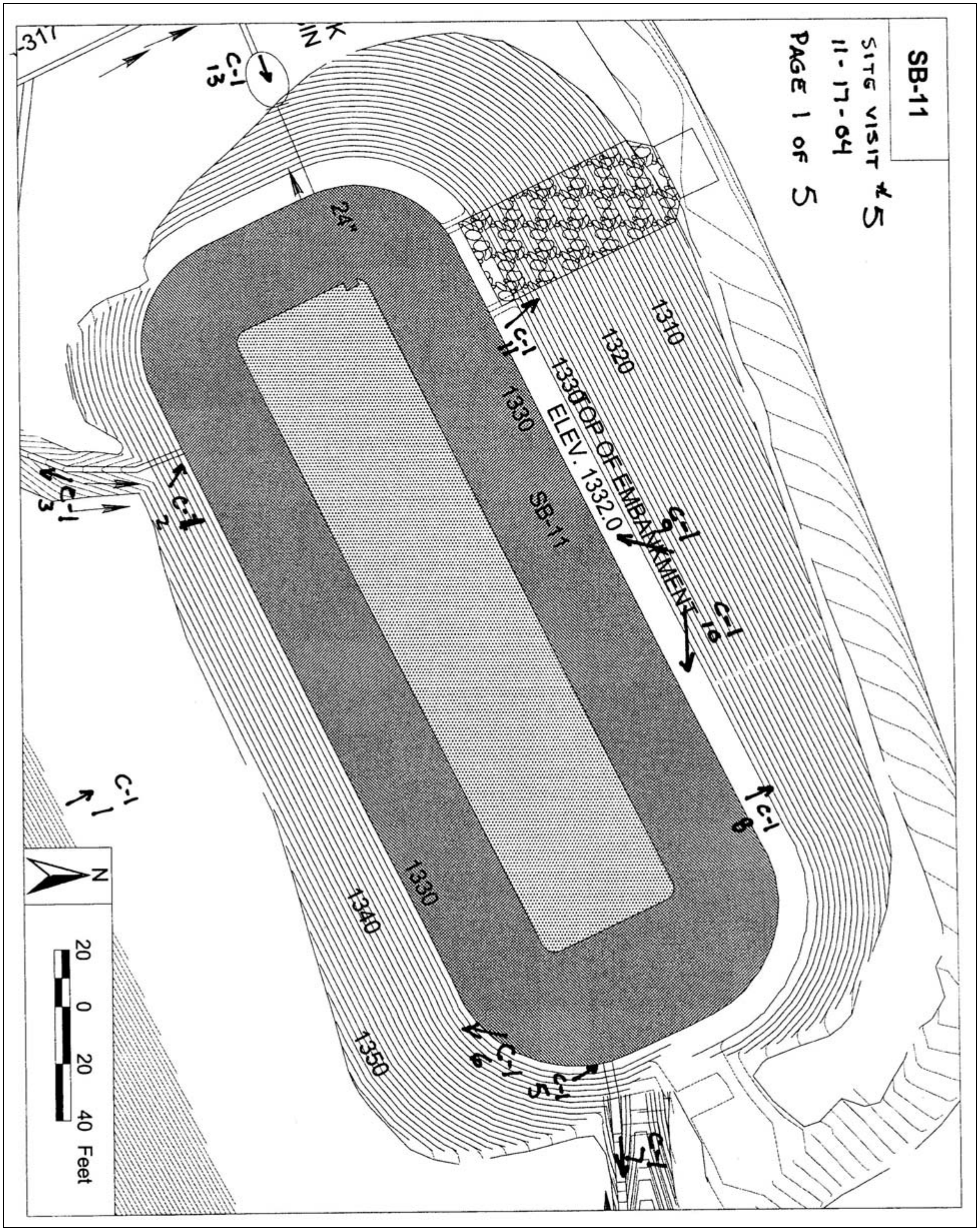


Figure 71. Sample photo location map

APPENDIX H

POLYMER FLOCCULATION

The purpose of this activity was to “round out” the overall study to further suggest a means of dealing with wet weather events. During storm events, high flows and heavy sediment loads are faced by the basins. Capturing sediments during high flow conditions may require very large basins with long retention times. In order to achieve particle removal during high flow conditions in smaller (and less expensive) basins, polymer aided flocculation used in water treatment processes can be extended to construction site SBs. The sedimentations basins can be designed such that a part of the inflow to the basin is diverted into a chamber constructed to be contained within the basin for polymer addition and for high flow conditions. Mixing in the chamber can be introduced by means of an impeller driven by influent water velocity. The runoff mixed with polymer can be released into the SB for settling. Addition of polymer will help to enhance flocculation and removal of sediments to a greater extent. A schematic representation of the polymer addition chamber and the SB are shown in Figure 72.

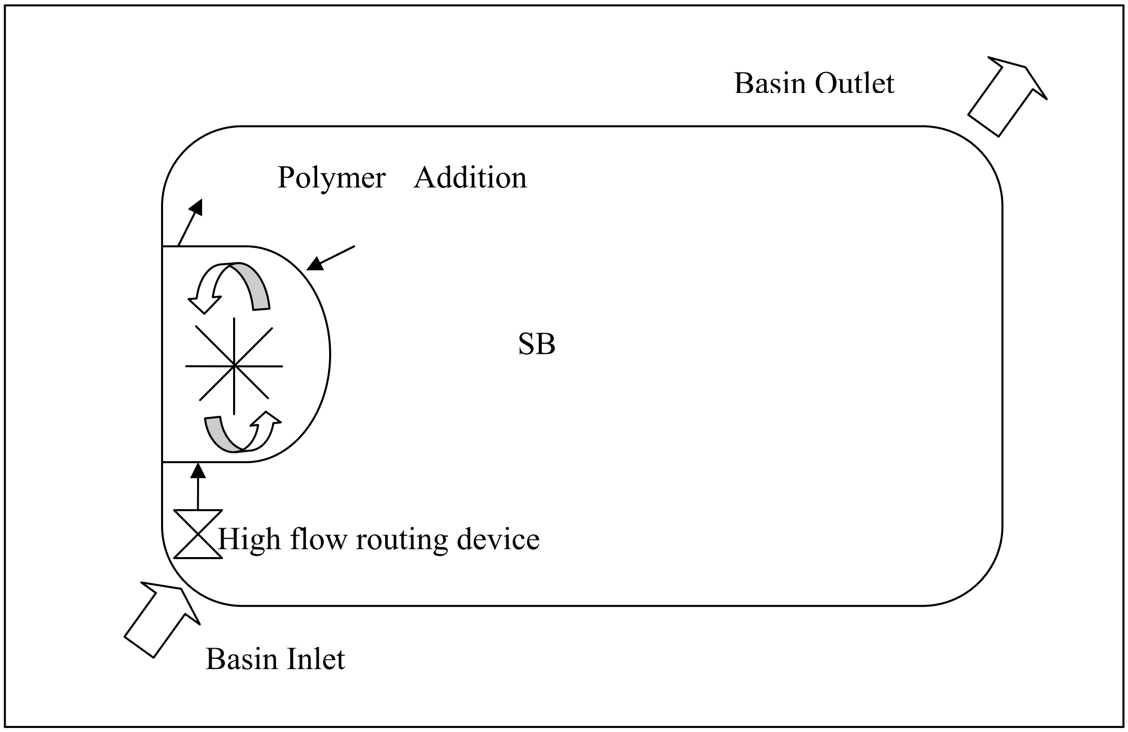


Figure 72. Schematic representation of polymer treatment under high inflow conditions

H.1 RUSLE2 RESULTS FOR SB14

The feasibility of polymer flocculation in SBs was studied by conducting jar tests using polymer used by Skelly & Loy for sludge dewatering at the PENNDOT site. The polymer is termed “EverFloc 200W” and is manufactured by Chemstream Corporation, Jennerstown, PA. It is an inorganic coagulant containing polyaluminum hydroxyl chlorosulfate. It is NSF approved for use to treat potable water for up to a concentration of 250 ppm. It is biodegradable and has a specific gravity of 1.2 and freezing point of -18 F.

The jar tests to study polymer flocculation were carried out using conventional jar test apparatus as shown in Figure 73. The original concentration of the polymer as obtained from the manufacturer was diluted to a concentration of 10^3 ppm. Then 20, 40, 60, 80 and 100 mL of the solution was added to 980, 960, 940, 920 and 900 mL of runoff sample making jar test concentrations of 20, 40, 60, 80 and 100 ppm respectively. Thus the experiment was conducted by varying polymer dosage in the range of 20 - 100 ppm to identify optimum polymer dosage and show proof of principle.

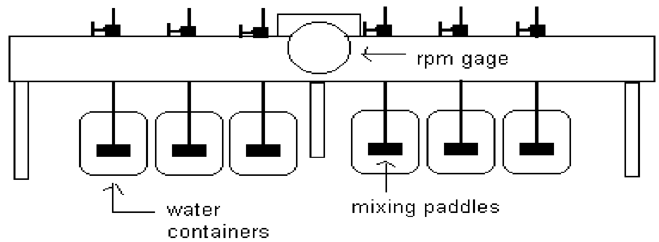


Figure 73. Jar testing device

The jar test procedure involved the following steps:

1. Runoff sample was obtained from SB14 and additional sediment from the basin was added to the sample until the sample looked muddy (having a TSS of 3,267 mg/L) and typical of storm water during storm events obtained from sedimentation basins at I-99 site.
2. The sample prepared as above was mixed well and analyzed for pH, turbidity, total suspended solids, particle size distribution, iron, magnesium, manganese, calcium and aluminum.
3. The jar testing apparatus as shown in Figure 73 was filled with the prepared runoff samples. One container was used as a control and no polymer was added to this jar, while

polymer was added to the other five containers to make the final polymer concentrations of 20, 40, 60, 80 and 100 ppm respectively..

4. Mixing helps disperse the polymer and promotes floc formation by enhancing particle collisions. During the jar test experiments the contents of the jars very mixed rapidly for 1 minute at 80 rpm and then slowly mixer at 15 rpm for 20 min. The rapid mix speed in usually 100 rpm and slow mixing speed about 30-40 rpm for typical jar test experiments. The speed used in both the rapid and slow mixing stage was kept low in order to simulate mixing conditions in sedimentation basins.
5. The mixers were turned off after slow mixing and the containers were allowed to settle for 3 hours.
6. The supernatant from the jars test containers were analyzed for turbidity, total suspended solids, particle size distribution, iron, magnesium, manganese, calcium and aluminum.

H.2 POLYMER STUDIES: RESULTS AND DISCUSSION

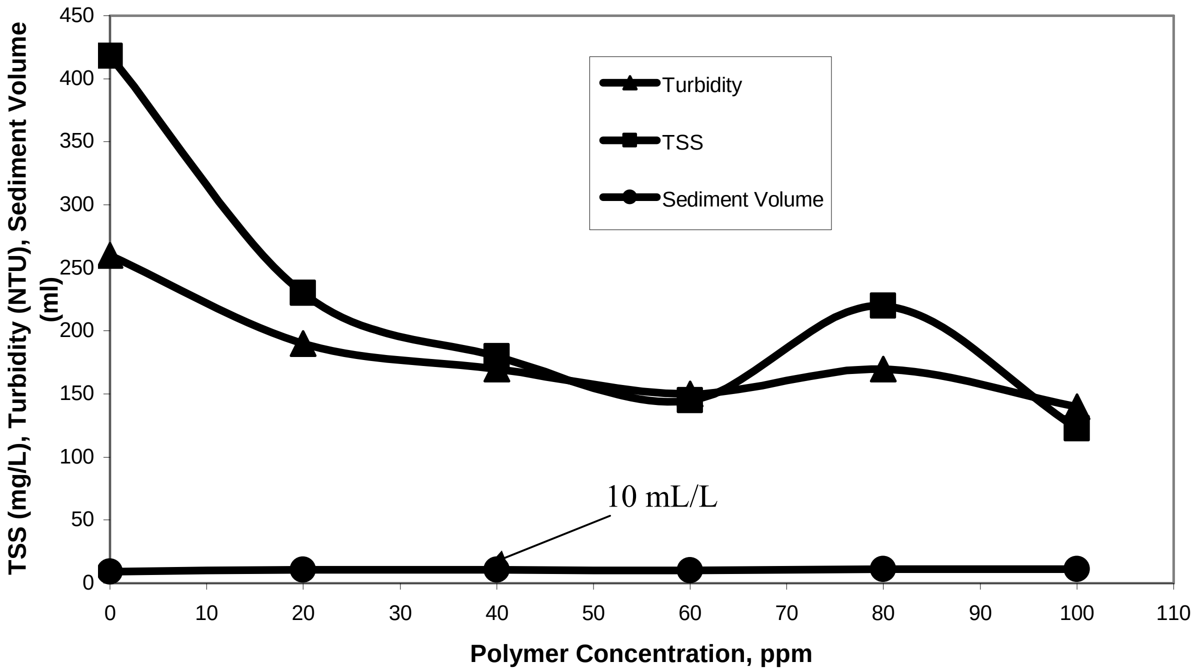


Figure 74. Polymer flocculation – jar test experiment results

Data for turbidity, total suspended solids and sediment volume for the different polymer concentration indicates that maximum particle removal occurs at a polymer dosage range of 50-60 ppm (see Figure 74). Increase in polymer dosage above 60 ppm polymer dosage leads to charge reversal leading to an increase in TSS and turbidity, but increase in polymer dosage beyond 80 ppm results in sweep floc formation. So for the runoff sample used for the jar test experiment 50-60 ppm of polymer dosage appears to be optimum for enhancing flocculation and particle removal. The sample used for the experiment had an initial TSS of about 3000 mg/L, if runoff has lesser TSS concentrations then polymer dosages lesser than 50 ppm may be sufficient for polymer flocculation. The sediment volume shown in Figure 75 was measured after 72 hours of settling. It can be observed that polymer addition does not affect the sediment volume significantly.

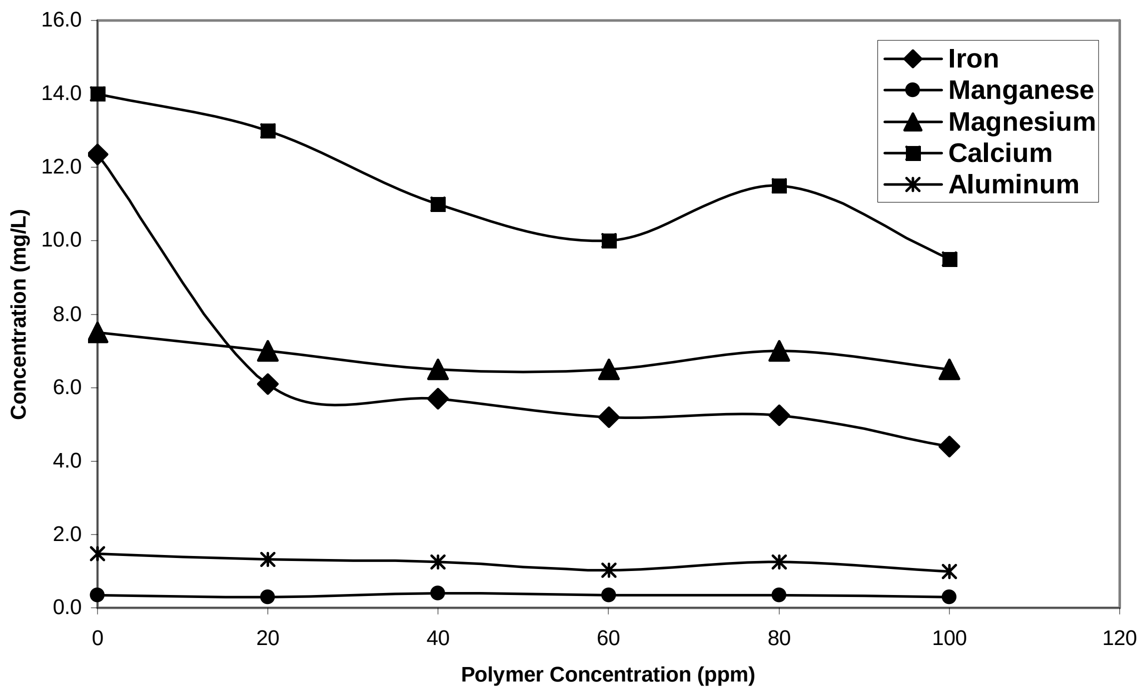


Figure 75. Jar test experiments – total contaminant concentrations

Figure 75 shows the variation in iron, calcium, magnesium, calcium, and aluminum concentration for the jar test experiment samples. A slight decrease in total concentrations of Iron, calcium and aluminum show can be observed. Iron, which is a particulate contaminant is reduced in concentration significantly even for low polymer dosage of 200 ppm. Maximum calcium concentration decrease is observed at the optimum polymer dosage of 60 ppm.

Significant change in concentration cannot be observed in the case of magnesium as it exists primarily in dissolved form. The variation in manganese concentration cannot be observed due to its very low concentration. A slight decrease in aluminum concentration from 1.5 to 1.0 mg/L is observed at polymer dosage of 60 ppm. Mineql model shows that aluminum is mostly in dissolved form in the basins with a total concentration of about 1.5 mg/L and a dissolved concentration of about 1 mg/L. This is confirmed by the polymer experiments and aluminum removal is only up to a concentration of 1 mg/L which is the dissolved concentration of aluminum. Hence polymer addition may not reduce aluminum concentration in the runoff significantly.

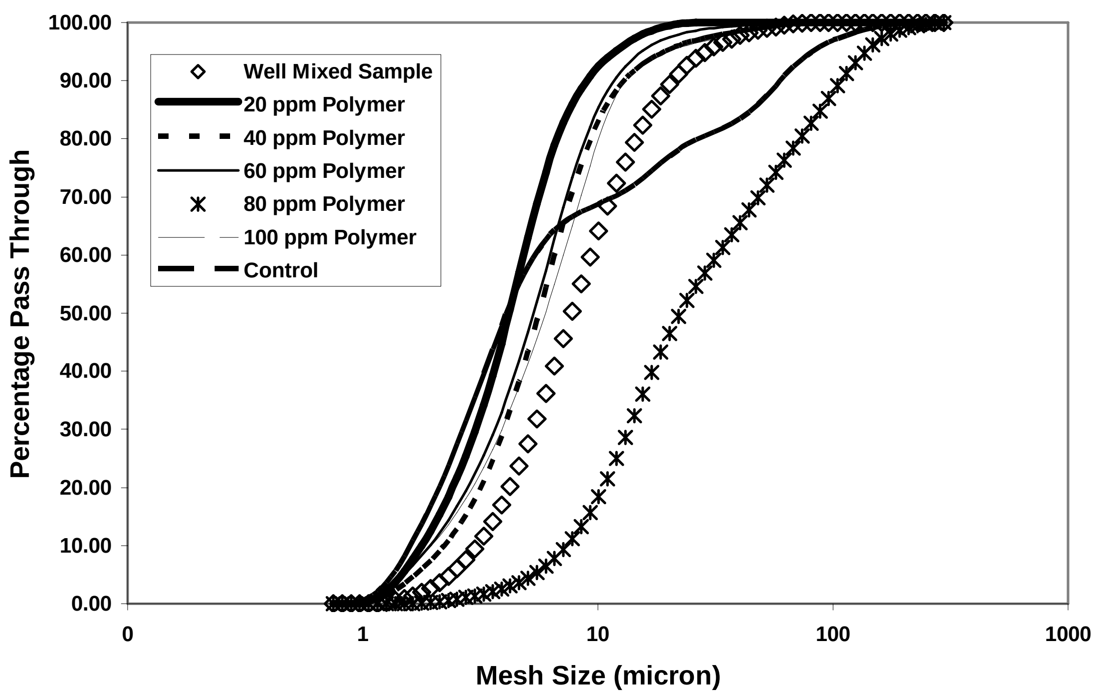


Figure 76. Particle size distribution based on particle volume

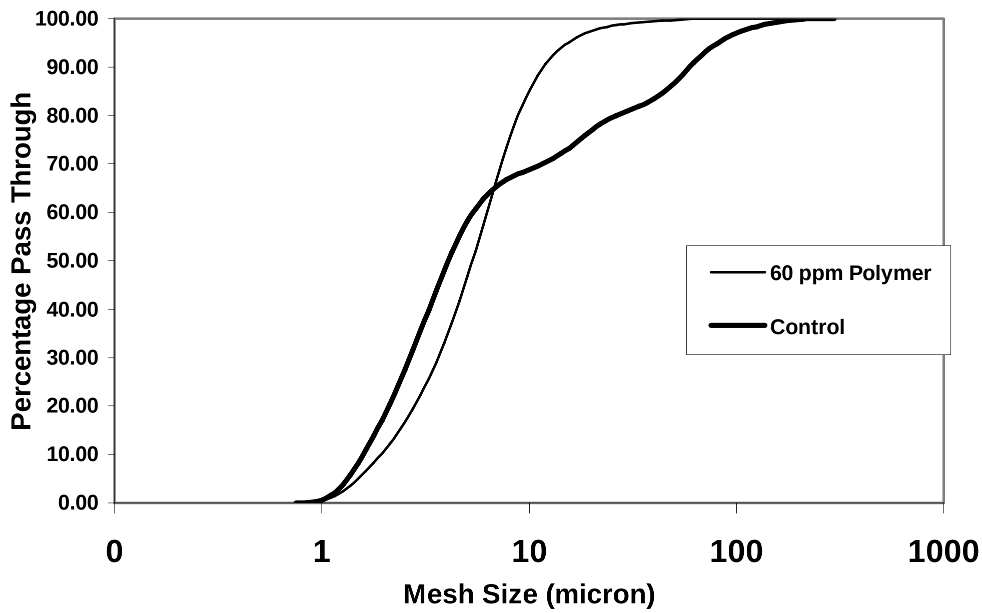


Figure 77. Particle size distribution based on particle volume

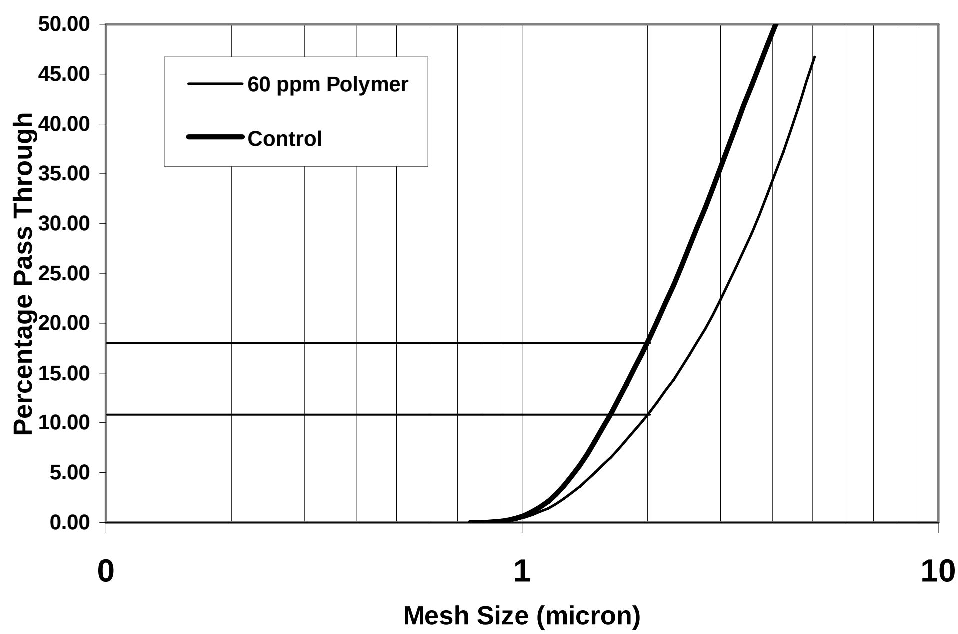


Figure 78. Particle size distribution based on particle volume – enlarged to show 2 μ region

Particle size distribution data was obtained for the jar test samples using a Microtrac Flex particle counter. The particle size distribution data based on volume is represented in Figure 76, Figure 77 and Figure 78. While Figure 60 shows the distribution for all samples, Figure 77 and Figure 78 show the distribution curve for the control and optimum polymer dosage of 60 ppm clearly. It can be seen from figures 76-78, that due to polymer addition flocculation of smaller particles takes place leading to a decrease in percentage pass through at lower mesh sizes where as there is a decrease in percentage pass though for larger mesh size as the large particle have settled out of the solution.

The results of jar tests experiments do not show significant removal of TSS of metals. Further tests may have to be conducted using different types of polymers under different conditions to identify the feasibility of applying polymer flocculation to sedimentation basins. Successful polymer flocculation will help design smaller SBs that can capture particles effectively during heavy sediment inflow conditions especially when construction of large basins is not feasible to obtain the required level of particle removal.

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