EVALUATION OF VEGETATED FILTER STRIPS FOR ATTENUATION OF POLLUTANTS RESULTING FROM MILITARY ACTIVITIES

by

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Abstract

A field study was conducted at Fort Riley, Kansas from late spring to early winter of 2007 to investigate the ability of vegetated filter strips (VFS) to attenuate pollutants resulting from military activities, the impact of different management practices (i.e. burning and mowing) on VFS performance, and the effects of vegetation on hydrological components of VFS, especially infiltration and runoff. Two native tallgrass VFS sites, each comprising three plots, located in the military training area of Fort Riley were used for this study. Fifteen rainfall events were simulated on each site along with overland application of water containing nitrogen (N), phosphorous (P) and sediment. At the end of the season both VFS were managed by mowing or burning and a final rainfall simulation was done.

Variables including rainfall, infiltration, runon, runoff, above ground biomass density, pollutant concentrations of runon and runoff, and soil moisture were measured and used in the data analysis. Hydrograph development, water balance, and mass balance calculations were carried out in order to calculate the pollutant trapping efficiencies (PTE) of the VFS. Statistical analysis was done by fitting several regression models. Mean comparisons were also done for variables and variance was decomposed into time, plot and site effects at an $\alpha = 0.05$.

Results showed that on average the VFS attenuated 84 % of total nitrogen, 24 % of total phosphorous and 95 % of sediments. Regression models showed that infiltration percentage and biomass density have a positive correlation with PTE. Runoff volume and PTE were negatively correlated. Soil moisture was negatively correlated with infiltration and time to runoff. With increasing biomass density, percentage of water infiltrating and time of concentration increased. Management practices, especially burning, tended to reduce PTE. Also, both management practices reduced infiltration percentage and time of concentration. PTE reduced with intensifying rainfall and increased when rainfall faded off. Phosphorous was the most sensitive pollutant for intense storm conditions followed by nitrogen, while sediment was comparatively insensitive.

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CHAPTER 1 - Introduction and Literature Review

Water Resources and Quality

Clean water is required for all living organisms. Despite its importance, water has been exploited and now this valuable resource is scarce in some parts of the world. Even though it is available in the other parts of the world, the quality is often poor, thus not potable. Water use for agriculture, domestic, and industry can lead to degradation of water quality, which not only affects aquatic ecosystems, but also reduces clean water available for human consumption. Providing safe water to people while maintaining sustainable water resources are fundamental objectives of the Millennium Development Goals set by the UN (Carr and Neary, 2006).

Sedimentation, eutrophication, thermal pollution, depletion of dissolved oxygen, acidification, microbial contamination, salinization, pesticides, metals and hydrocarbons are the main types of damage caused by human activities (Carr and Neary, 2006). According to US Environmental Protection Agency (USEPA), in 2000, 39% of the rivers and streams were impaired for one or more use (Dressing, 2003). In the US, water quality is gaining increasing concern.

Nonpoint source pollution (NPS)

The USEPA defines nonpoint source pollution as any source of water pollution other than point source pollution. Section 502(14) of the US Clean Water Act of 1987 defines the term point source pollution as “any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged” (Dressing, 2003). NPS pollution is caused by rainfall, overland flow, infiltration, drainage, seepage, hydraulic modification, or atmospheric deposition. Runoff resulting from precipitation or snowmelt picks up pollutants as it moves on its course and finally deposits them in receiving water bodies such as rivers, lakes, wetlands, sea and ground water. Even though point source pollution has been greatly controlled by various pollution control activities, studies show that NPS pollution continues to impair water quality (Dressing, 2003).

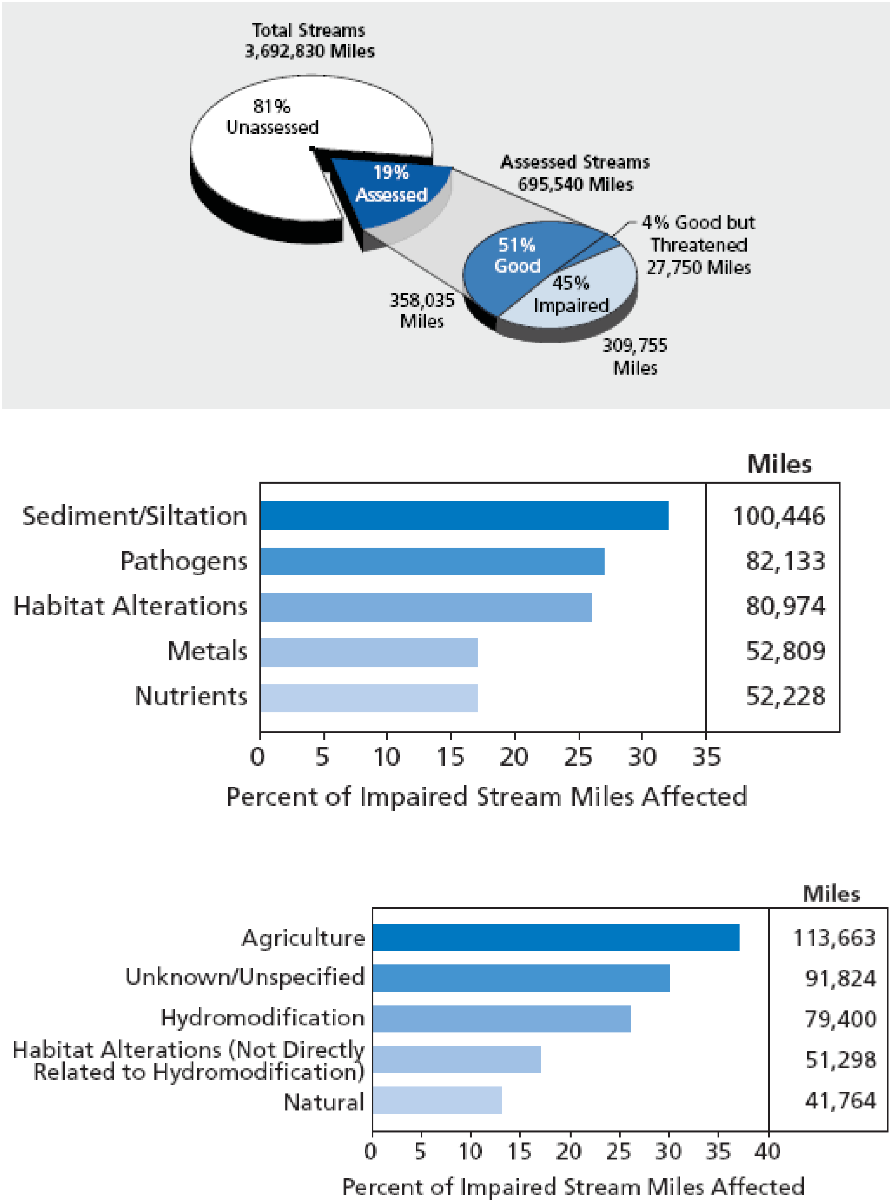
USEPA assesses the water quality status of US water bodies in two year cycles under the Section 305(b) of the Clean Water Act. In 2002, out of assessed water bodies, 45% of rivers and streams, 47% of lakes, ponds, and reservoirs, and 32% of bays and estuaries were impaired (Table 1-1) (USEPA, 2007).

Table 1-1: State of water bodies in the US from the perspective of water quality as of 2002 (USEPA, 2007)**.**

Water bodies	Total extent	Assessed (%)	Impaired (as a % of assessed)	Major causes of Pollution
Rivers and Streams	3.7 million miles	19	45	Sediments, pathogens and habitat alternations
Lakes, ponds and reservoirs	40.6 million acres	37	47	Nutrients, metals and organics/low dissolved oxygen
Bays and estuaries	87370 square miles	35	32	Metals, nutrients, and organics/low oxygen demand

According to National Water Quality Inventory, NPS pollution is the main cause of water quality impairment. Primary NPS pollutants are sediment, nutrients such as nitrogen and phosphorous, animal wastes, salts and pesticides. Main causes for the NPS pollution are agriculture, land development and hydraulic modification (USEPA, 2007). Figure 1-1 shows the status of water quality of assessed rivers and streams, top causes and sources of impairment (USEPA, 2007).

Figure 1-1: Water quality in assessed river and stream miles, top causes and sources of impairment in assessed rivers and streams (USEPA, 2007)**.**



Soil erosion

Soil erosion is the detachment and transportation of soil particles by erosive agents such as water and wind. Erosion caused by water contributes a lot to NPS pollution. The kinetic energy from raindrops and runoff water remove soil particles and deposit them in receiving water bodies, thus impairing water quality (Ward and Trimble, 2004). Sediment is the largest problem causing pollution in streams and rivers followed by pathogens. Sediment carries nutrients especially phosphorous. NPS pollution and soil erosion go hand in hand. By controlling erosion, NPS pollution can be minimized, especially in agricultural lands.

Regulatory actions by the US government

A major change in US water policy and management took place in 1972, when the federal government formulated the Clean Water Act. Since then, point sources of pollution are regulated by USEPA through the National Pollution Discharge Elimination System (NPDES) permits (USEPA, 2003). NPDES permits also require that Stormwater Pollution Prevention Plans (SWP_3) be implemented to meet the water quality requirements of stormwater runoff from construction sites and urban areas. In 1987, the Clean Water Act of 1972 was amended to control NPS pollution; and the amended version is called the 1987 Water Quality Act.

Military Maneuver and NPS pollution

Military activities can change the natural environment and make the soil vulnerable to erosion. When heavy military vehicles, such as tanks and artillery guns, are operated, they damage the soil cover extensively and expose the surface to rainfall and runoff water, thus increasing the potential for erosion. Other than tank maneuvering areas and artillery firing ranges, land development due to cantonments also contributes to NPS pollution. All army installations are required to have NPDES permits with SWP_3 (Schmid, 1996).

Soil disturbances due to military activities at Fort Riley

Military training activities, such as field maneuvers, combat vehicle operations, mortar and artillery fire, small arms fire, and aircraft flights at Fort Riley, have lead to soil disturbance. Most of the mechanized maneuvers take place on the northern 75% of Fort Riley. In addition to direct disturbances, wildfires resulting from training, management activities such as mowing, chemical weed control, prescribed burning, and small scale timber harvest have also caused soil disturbances (Althoff et al., 2006).

Figure 1-2 Soil disturbance caused by a tank on a single pass (St.Clair, 2007)

Best Management Practices (BMP)

There are several ways to control NPS pollution and they are collectively called Best Management Practices (BMPs). BMPs are designed to reduce the amount of pollutants that are generated and/or transported from the source to the receiving water body. They can be either structural (e.g. waste treatment lagoons, vegetated grass waterways) or managerial (e.g. conservation tillage, nutrient management) (Dressing, 2003). Normally BMPs are used in combination to achieve maximum benefits from them. The mechanisms by which BMPs reduce NPS pollution include reducing available pollutants at the source, preventing the transport of pollutants, and remediating by chemical or biological means (Dressing, 2003). USDA-NRCS provides guidance for BMPs (USDA-NRCS).

Since NPS pollution and soil erosion are interrelated, most BMPs tend to reduce soil erosion by reducing soil detachment, reducing sediment transport, and trapping sediment before it enters a surface water body. BMPs also reduce the volume of water reaching water bodies by increasing infiltration of water into soil. Some BMPs increase retention time and reduce peak flow to reduce the in-channel erosion.

Vegetated filter strips (VFS) as a BMP

The Natural Resources Conservation Service (NRCS) defines a VFS as “a strip or area of herbaceous vegetation situated between cropland, grazing land, or disturbed land (including forestland) and environmentally sensitive areas” (USDA-NRCS, 2003). VFS are used to reduce sediment and dissolved contaminants in runoff and to improve the quality of stormwater before it reaches a water body (Clar et al., 2004).

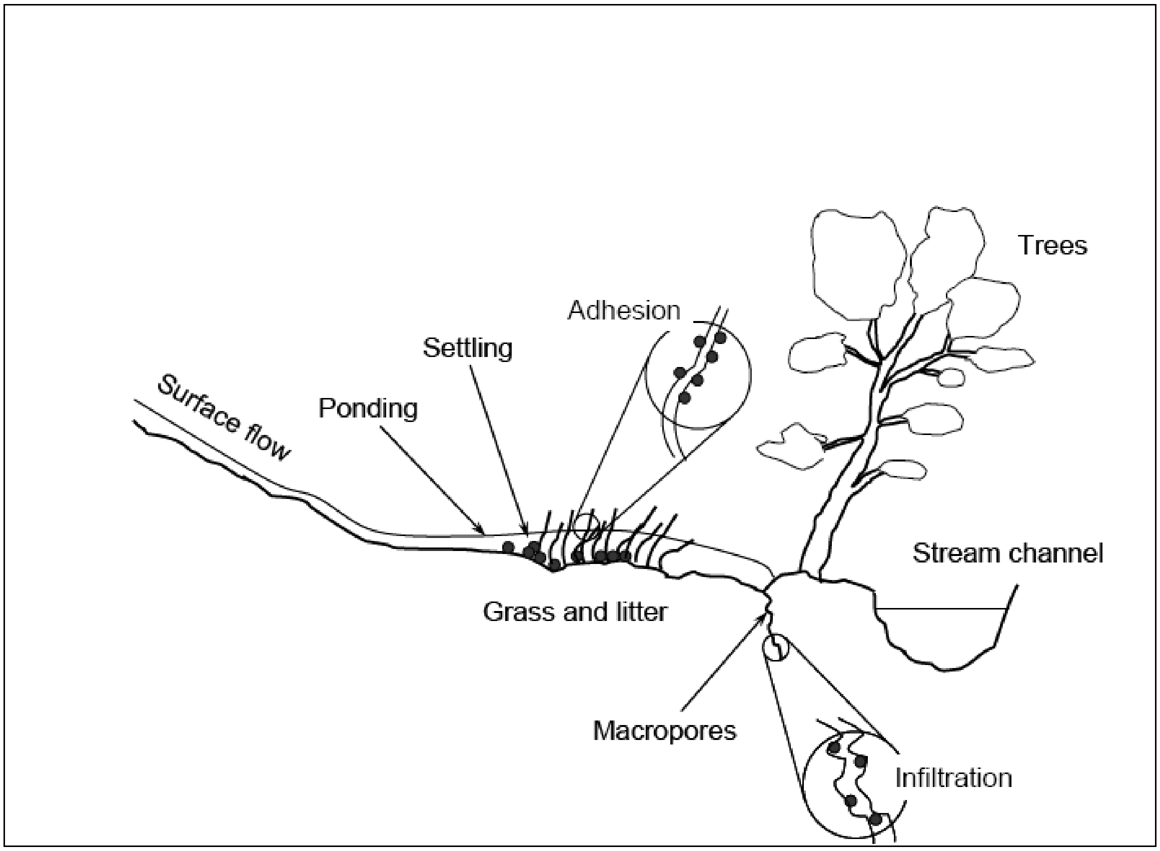
Nutrient and sediment removal mechanisms by VFS

VFS serve several purposes, such as reducing sediment, particulate organics and sediment adsorbed pollutants in runoff, reducing dissolved pollutants in runoff, and improving wildlife habitat (USDA-NRCS, 2003). Sediment deposition, infiltration and plant uptake are the major mechanisms for pollutant removal. Filter strips are more effective in trapping sediment bound nutrients than dissolved nutrients (Leeds et al.,1994). Figure 1-3 shows different processes that take place within a VFS (Newham et al., 2005). Figure 1-4 shows the different paths that a particular dissolved pollutant takes in a VFS (Barfield et al., 1998).

Deposition

A considerable amounts of fine gravels (>1000 μm), coarse sands (500-1000 μm), medium sands (250-500 μm), fine sands (100-250 μm) and very fine sands (50-100 μm) can be transported during major runoff events (Newham et al., 2005). Even though these particles are chemically inert they can physically damage vegetation (Newham et al., 2005). When runoff flows through a VFS, sediment and other suspended materials, such as organic materials, are filtered and deposited. Deposition is the most important pollutant removal process in VFS, and it occurs within the first few meters of a VFS. The velocity of the runoff is reduced when it enters the VFS; with lower velocities, sediment, especially larger particles such as sand and silt sized particles and soil aggregates, start to deposit. Depending on the runoff velocity, smaller particles such as clay may take longer to settle and travel further than larger particles. Trapping of sediments also reduces the sediment bound nutrients and chemicals (Leeds et al., 1994).

Figure 1-3 Different processes that account for pollutant removal in VFSs (Newham et al., 2005)



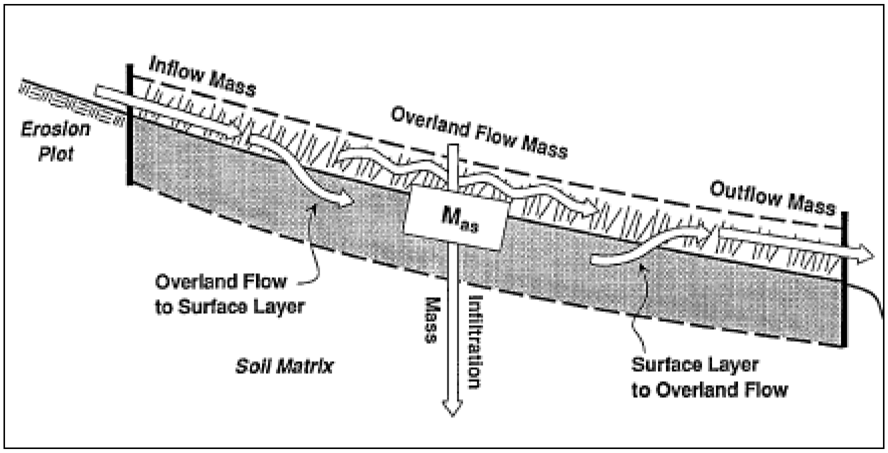
Infiltration

Infiltration of runoff within a VFS is increased by two factors, reduced runoff velocity from vegetation resistance and increased porosity from plant roots and organic matter. Reduced velocity helps to increase the time available for infiltration. By increasing infiltration the amount of runoff is reduced. Infiltration also provides additional filtration. Dissolved nutrients and chemicals in the infiltrated runoff will enter into soil so that pollutants in the runoff will be reduced (Leeds et al., 1994).

Biological and chemical process

Nutrients and chemicals trapped in the VFS may be taken up by the vegetation, degraded, or transformed in the soil. A VFS's long term effectiveness may be affected by biological and chemical process such as volatilization, degradation, adsorption, and absorption of pesticides, and N and P transformation (Leeds et al., 1994). Other processes that may take place within a VFS are uptake of nutrients, denitrification and assimilation. (Helmers et al., 2006)

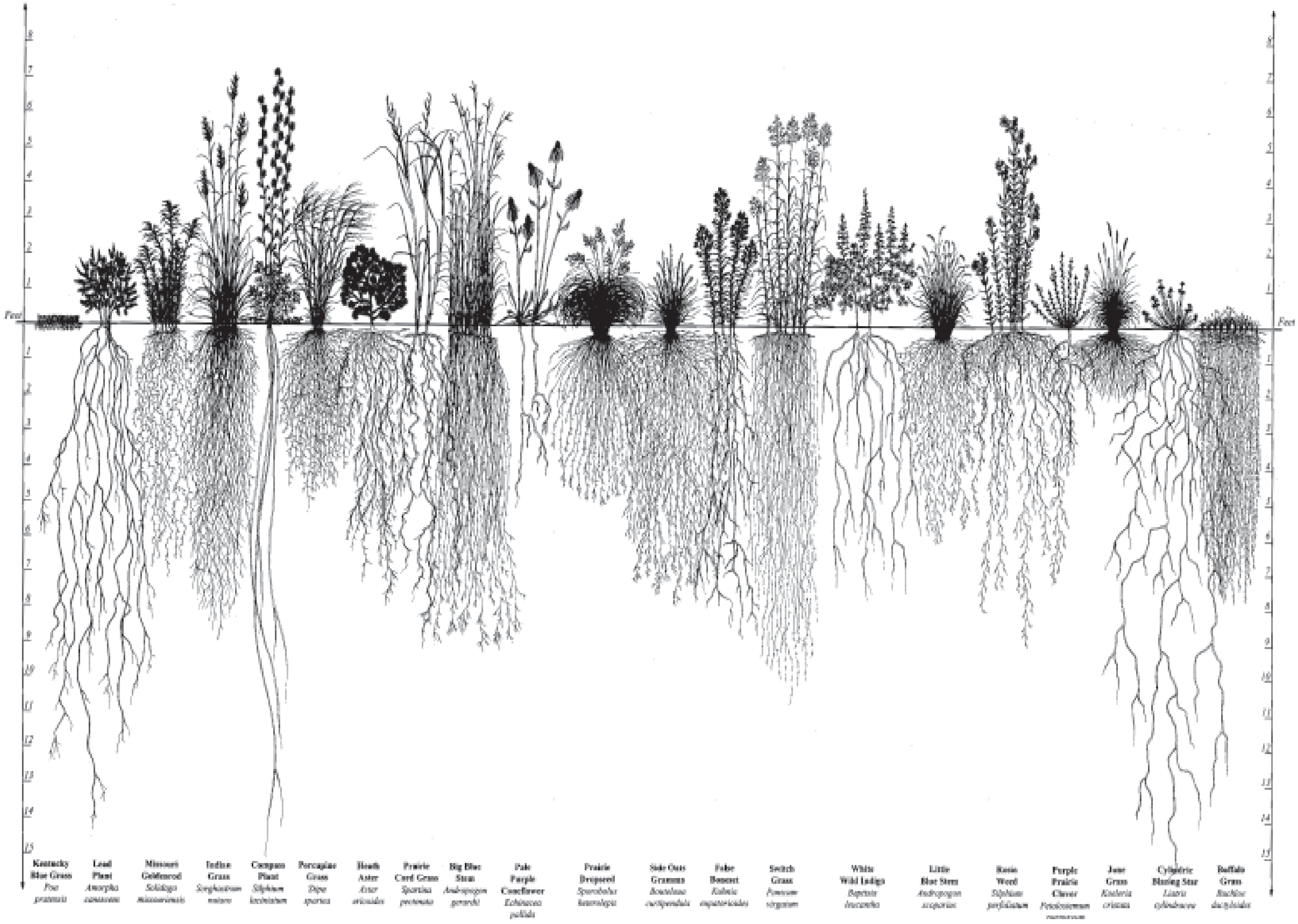
Figure 1-4 Mass balance for a particular dissolved solid on a filter strip (Barfield et al., 1998)



Native tallgrass as VFS

Native tallgrasses, such as big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and little bluestem (*Schizachyrium scoparium*), have extensive, deep root systems. Figure 1-5 shows the relative depth of tallgrass root systems compared to non-native Kentucky Bluegrass (USDA-NRCS, 2004). Native tallgrasses have greater below ground biomass compared to turf grass. Deep root systems help these plants survive extreme conditions such as fire, drought, floods or cold. The above ground biomass of the plants can absorb the erosive energy of rainfall and runoff, thus reducing erosion. Roots bind the soil together and stabilize it to prevent washed off with the runoff. Deep penetrating roots also help to enhance infiltration. Finally, sediment can be filtered out from runoff and runoff velocity is slowed by the vegetation. Overall native tallgrasses have greater potential as VFS than any other vegetation. Native tallgrasses also possess more habitat value for wildlife (USDA-NRCS, 2004).

Figure 1-5: Dense deep root system of native prairie grass in comparison Kentucky Bluegrass (first from left).(USDA-NRCS, 2004)**.**



Conditions that affect effectiveness of VFS

Several factors, such as topography, climate, and field conditions, affect the performance of a VFS (Helmers et al., 2006). Specific factors that affect the VFS's performance are flow rate, drainage area, development conditions, soils, infiltration rate, topography, depth of water table, vegetation, climate, sediment characteristiscs and characteristics of the pollutants being attenuated. (Clar et al., 2004)

Flow rate

Flow rate and VFS performance are negatively correlated. If a VFS receive a large flow volume, the flow will concentrate and start to channelize. These channels lead to "short circuiting" and reduce the effectiveness of the VFS. Deeper flows may cause erosion within the VFS and eventually lead to VFS failure. (Clar et al., 2004) If the overland flow becomes concentrated flow, then the VFS may be physically damaged. Intense precipitation also has the same impact. When designing a VFS, considerations should be made to intercept overland flow before it concentrates (Helmers et al., 2006).

Drainage area

Contributing drainage area and flow rate are related to each other, larger drainage areas result in more flow into VFS. Efforts should be made to keep the contributing area as small as possible to improve VFS function (Clar et al., 2004).

Development conditions

VFS have been proven to be successful BMPs on agricultural land. In urban areas, VFS are effective in treating runoff from small areas such as parking lots and rooftops. VFS can be used in low to medium density developments (16-21%). In higher density development areas, VFS can be used as pretreatment for a structural BMP. (Clar et al., 2004)

Soils and infiltration rate

For optimum pollutant removal, VFSs should be used in soils with good infiltration rates (0.27 in/hr or higher) such as sandy loam, loamy sand or loam. For soils with low infiltration rates, VFS with increased widths may be used. Also, the soil should be able to support the growth of vegetation (Clar et al., 2004).

Topography

Runoff from areas with steeper slopes typically delivers a greater sediment load to the VFS and reduces its performance. Runoff from steeper slopes will have increased velocity, hence reducing the contact time with the VFS. Higher flow velocities lead to erosion within VFS and may cause failures. If VFS are used with steep slopes, rills and gullies may form and reduce or eliminate sheet flow. For maintaining sheet flow conditions, the terrain should be relatively flat. In slopes greater than 15%, VFS may not function at all and with slopes between 6-15%, its effectiveness maybe reduced. Even though effectiveness of VFS is better in slopes less than 5%, effectiveness also depends on pattern and intensity of rainfall (Clar et al., 2004).

Depth of water table

Infiltration, which is one of the main mechanisms of VFS to reduce pollutants, will be reduced if the groundwater table is shallow. A VFS should be at least two feet above the groundwater level at its lowest point (Clar et al., 2004).

Vegetation and climate

A VFS performs well with dense, year-round vegetation supported by the climate and soils conducive to vegetation growth. For arid regions they are not suitable. Sediment trapping depends on density, stiffness and height of the vegetation. A VFS may not be effective in regions with cold winters or under snowmelt conditions. (Clar et al., 2004).

Evaluating the efficiency of VFS on attenuating pollutants in water

There were several studies conducted to find out the potential of VFS to reduce pollution caused by both storm water and wastewater from feeding lots (Abu-Zreig et al., 2004; Barfield et al., 1998; Blanco-Canqui et al., 2004; Dillaha et al., 1989; Gharabaghi et al., 2001; Helmers et al., 2005; Hubbard et al., 2003; Komor and Hansen 2002; Lee et al., 1999; Lim et al., 1998; Mendez et al., 1999; Sanderson et al., 2001; Schmitt et al., 1999).

A study was carried out using 20 VFS field plots with differences in design such as length and vegetation cover and simulated runoff (Abu-Zreig et al., 2004). Four different filter lengths, two different slopes, and three different types of vegetation were used. Filters with no cover were used as a control. Runoff was applied at different flow rates and sediment concentrations. Vegetation density, outflow rate, and outflow sediment concentration were measured. Inflow and outflow volumes and sediment trapping efficiencies were calculated with the average sediment trapping efficiency being 84%. Filter length, vegetation density and inflow rates affected sediment trapping. A similar study by the same research group found that average phosphorous removal efficiency was 61% (Abu-Zreig et al., 2003).

Barfield et al., (1998) evaluated naturally occurring filter strip efficiency. Filters with three different lengths and standard erosion plots (4.57 m x 22.1 m) were used. Rainfall simulators were used to simulate 10-year, 24-hr (duration) storm events over the erosion plots. Flow rates, soluble ammonium and nitrate concentration, soluble phosphorous, and sediment concentration were measured and trapping efficiencies were calculated for each pollutant. Partitioning of trapping by absorption (infiltration) and adsorption was also estimated. The results showed that the filter strips trapped more than 90% of the pollutants with infiltration being the major mechanism of trapping.

Blanco-Canqui et al., (2004) conducted an experiment to evaluate the effect of concentrated flow, as opposed to sheet flow, on VFS and stiff stemmed grass barriers. 18 plots (1.5 m * 16 M) were used with six different treatment combinations of grasses (fescue and switch grass). Rainfall was simulated using a rotating boom rainfall simulator. A fertilizer mixture was applied to the pollutant source area before each simulation. Runoff samples were collected and analyzed for sediment, nitrogen and phosphorous. Fescue grass trapped 72% of the sediment while switch grass trapped 91% of the sediment. The results showed that grass barriers have better trapping ability than filter strips. The authors also concluded that barriers (switch grass) promoted deposition of nutrients bound to sediments by ponding runoff. In a related study to evaluate VFS under different flow conditions, such as interrill and concentrated flow, it was found that barriers reduce runoff by 34%, sediment by 99% and nutrients by 70%. Effectiveness of the VFS was reduced when the interrill flow became concentrated flow. The authors concluded grass barriers could be used in conjunction with VFS for concentrated flow.

In another study, the effectiveness of VFS in reducing pollutants from farmland was investigated using rainfall simulators on nine field plots (Dillaha et al., 1989). Each plot had a orchard grass (*Dactylis glomerata*) VFS and a 5.5 m x 18.3 m contributing bare cultivation area. Croplands, at their lower ends, had a VFS with either a 0 m, 4.6 m or 9.1 m width. N, P and K fertilizers were applied to the bare land. Water samples were collected and analyzed and resulting data were analyzed for pollutant trapping efficiency. The authors concluded that VFS were effective in removing sediment but their effectiveness decreased with time due to sediment accumulation. VFS were also effective in N and P removal. It was also noticed that in some instances P and N concentration in the outflow were higher than that in the inflow, which brought down the pollutant trapping efficiency far below zero. The authors suspected that it might have been caused by resuspension of nutrients.

Another study was conducted by Gharabaghi et al. (2001) to evaluate the effect of vegetation, filter strip width and flow rate on the sediment trapping efficiency of VFSs. Six different vegetation types, five different VFS widths and flow rates of 0.3-2 L/s were used. Before each experiment, the soil profile was wetted to develop steady state infiltration conditions. Sediment-polluted, simulated overland flow was applied to the VFSs. Water samples upstream and downstream of the VFS were collected and analyzed for TSS. Results showed that when the VFS width increased from 2.5 m to 20 m, sediment trapping efficiency increased from 50% to 98%. Grass type and flow rate were also found to be significant factors that affect the efficiency of VFS.

Hubbard et al. (2003) studied nutrient removal by VFS using lagoon effluent from a swine farm. The study mainly focused on nutrient removal by vegetation uptake and assimilation in biomass. The filter strips consisted of grass, maidencane and forest vegetation. Plant samples were cut and analyzed for their nutrient content. Grass buffers with a length of 20m removed 44% of the N, 19% of the P and 23% of the K as biomass.

Another study was carried out to quantify attenuation of pollutants in feedlot runoff by grass filter strips (Komor and Hansen, 2002). Runoff entering and exiting from each filter was measured. Water samples were collected and chemically analyzed.

Chemical loads and attenuation values were calculated from these data. It was found that grass filters can remove 30-81% of Chemical Oxygen Demand (COD), -3-82% dissolved sulfate, 6-79% of dissolved chloride, 33-80% of dissolved ammonia nitrogen, 29-85% of suspended ammonia plus organic nitrogen, 14-75% of dissolved organic N, 24-82% of suspended phosphorous, 14-72% of dissolved phosphorous, and 18-79% of fecal coliform bacteria.

Lee et al. (1999) compared nutrient and sediment removal by switch grass and cool-season grass filter strips with different widths. Cool season filter strips consisted of brome grass, timothy and fescue grass. Twelve filters with two different filter sizes 1.5 m X 3 m and 1.5 m X 6 m, were used. Rainfall was simulated at a rate of 5.1 cm/hr. Runoff was applied to the filters at a rate of 40 L/min. Water and sediment flow rates, and rainfall were measured. Runon and runoff samples were collected and analyzed for sediment concentration, total N, NO_3-N, total P, and PO_4-P. The results showed that a 6 m long filter strips removed 77% of sediment, 46% of N, 42% of NO_3-N, 52% of total P and 34% of PO_4-P. Also the authors observed significant differences between different sizes as well as different vegetation and concluded that switch grass was better in pollutant removal than cool season grasses.

In another study, the effect of VFS length on removing pollutants in cattle pastureland runoff was evaluated. Kentucky -31 tall fescue plots, 30.5 m x 2.4 m, were used for this study (Lim et al., 1998). The upper 12.2 m was used to represent a pasture land and cattle manure was applied to this area. Rainfall simulators were used to simulate rainfall at intensity of 100 mm/hr. Runoff samples collected at different lengths (0, 6.1, 12.2, and 18.3 m) within VFS. Total Kjeldahl N, ammonia N, NO_3-N, PO_4-P, total P, total suspended solids (TSS), electrical conductivity (EC) and fecal coliform of runoff samples were analyzed. The concentration and runoff data were used to calculate the mass balance and pollutant removal efficiencies. Results showed that approximately 75% of the pollutants were removed within the first 6.1 m of the filter strip and at 18.3 m more than 90% of the pollutants were removed.

Mendez et al. (1999) studied the effectiveness of VFS in removing sediment and nitrogen using Kentucky 31 tall Fescue. In this study each plot had a 3.7m x 24.7m source area planted with corn. 3 different length (0m, 4.3m, and 8.5m) of VFS were assigned as 3 different treatments. Runoff samples were collected and analyzed for TSS, NO_3-N, NH_3-N, TKN and Filtered TKN. 8.5 m VFS reduced sediment, NO_3-N, NH_3-N, and TKN by 90, 77, 85, and 82 % respectively. 8.5 m and 4.3 m filters showed no significant difference in pollutant trapping efficiencies. There was no change in trapping efficiencies over an 18 month period.

A field study was carried out by Sanderson et al. (2001) to evaluate dual use of 'Alamo' Switch grass (*Panicum virgatum*) treated with dairy manure, for biomass production as well as pollutant removal. Twenty field plots, 5.2 m X 32.8 m, were used with natural rainfall and runoff. The upper half of the plot (16.4 m) was treated with dairy manure/lagoon effluent at five different doses and used for biomass production while the lower half functioned as a VFS. Changes in extractable P in the soil, NO_3-N in soil water, and P and COD of runoff water before and after VFS were analyzed. Results showed that biomass yield increased linearly with increasing manure application rate. The author concluded that switch grass filter strips were effective in reducing P and COD in runoff water from manure treatments.

Schmitt et al. (1999) conducted a study to compare the performance of different filter strip design on different pollutants as well as to evaluate the process involved in pollutant attenuation. Runoff and rainfall were simulated on VFS with different widths (7.5 m and 15 m) and vegetation (contour sorghum, 25 year old grass, 2 year old grass and two year old grass-shrub-tree stand). Inflow and outflow rates were measured and a laboratory analysis of pollutants was done. Results showed that VFS of both 7.5m and 15 m widths reduced the sediment (76-93%) and sediment bound pollutants (27-83%). The effect of VFS on dissolved pollutants was lower than that of sediment bound pollutants. In wider VFS, although infiltration and dilution increased, sediment settling did not increase. Compared to sorghum, grass performed well in reducing pollutants in the runoff. Settling, infiltration and dilution process were used by the author to explain the mechanism of pollutant removal in VFS.

Helmers et al. (2005) studied the effectiveness of VFS not controlled by artificial borders and to detect the overland flow paths in VFS. Big bluestem, switch grass and Indian grass composited of two 13m x 15 m VFSs. Runoff events were simulated using furrow irrigation. High resolution topography maps and fluorescent red dye were used to identify and analyze the flow paths within the VFS. Water samples were collected and analyzed for TSS. The results showed that the average sediment trapping efficiency was approximately 80%. Convergence ratio ranged from -1.55 to 0.34 indicating convergence and divergence took place in the VFS flow paths. Depth of flow was not distributed uniformly allover the VFS area.

Effect of Prescribed Burning on Water Quality

Wildfire and Prescribed fire

Fire is a natural abiotic factor related to succession and different species have different levels of tolerance (Nebel, B. J. and R. T. Wright, 1998). Fire climax ecosystems, such as pines and grasslands, which need fire to maintain their balance, are often managed using prescribed fire. Fire plays a major role in tallgrass prairie ecosystems as well. Research in Konza Prairie showed that burning enhanced the growth of grass over woody plants (Konza Prairie Biological Station).

Fire intensity and severity

Fire intensity is the rate at which fire produces thermal energy. Fire severity is a qualitative term to explain the degree of the post-fire effects on soil (Neary et al., 2005). Fire severity can be correlated to the disturbance made in the ecosystem. Based on severity, burns are classified as moderate and high severity. Wildfires are more intense and severe than prescribed fires (Neary et al., 2005).

Effects on soil and water

Effects of fire on a soil property depend on the severity of fire, combustion and heat transfer, magnitude and depth of soil heating, proximity of the soil property to the soil surface and the threshold temperatures of the soil properties (Neary et al., 2005).

Water repellency and its effect

During fire, organic compounds are volatilized, move downwards into the soil and condense. The layer of condensed organic matter forms a hydrophobic layer, which is water repellent (Neary et al., 2005). The water repellency depends on the severity of the fire, amount and type of organic matter present, temperature gradient across the soil profile, soil texture, and moisture level of the soil (Neary et al., 2005). Figure 1-6 shows beading up of water drops and

Figure 1-7 shows how the water repellency is formed during the fire (Neary et al., 2005).

Effects on hydrology and water quality

Since the soil surface is exposed, rain drops will directly hit the soil with more kinetic energy and dislocate soil particles. This will eventually lead to an increased level of soil erosion. Additionally, the water repellent layer reduces infiltration and forces the water to run off over the soil, thus increasing the amount of runoff water. This can cause rill erosion and the amount of soil eroded after a fire may vary from 0.1 Mg/ha/year to 369 Mg/ha/year depending on the severity of the fire (Neary et al., 2005).

Table 1-2 Table Infiltration rates under different conditions (Neary et al., 2005)**.**

Surface condition	**Infiltration rate (mm/hr)**
Intact forest floor	>160
Vegetation	5-50
Bare soil	0-25
Water repellent soil	0-10

Interception and evapotranspiration is reduced as the canopy is removed. Fire reduces the roughness of the soil by consuming organic material and vegetation, causing runoff to flow faster. The collective effect of fire on soil and vegetation, and the influence on interception, evapotranspiration and infiltration will increase the amount of overland flow (Neary et al., 2005).

Figure 1-6 Beading effect of water droplets on a water repellent soil (Neary et al., 2005).

Figure 1-7 Water repellency forming process, before, during and after fire (Neary et al., 2005).

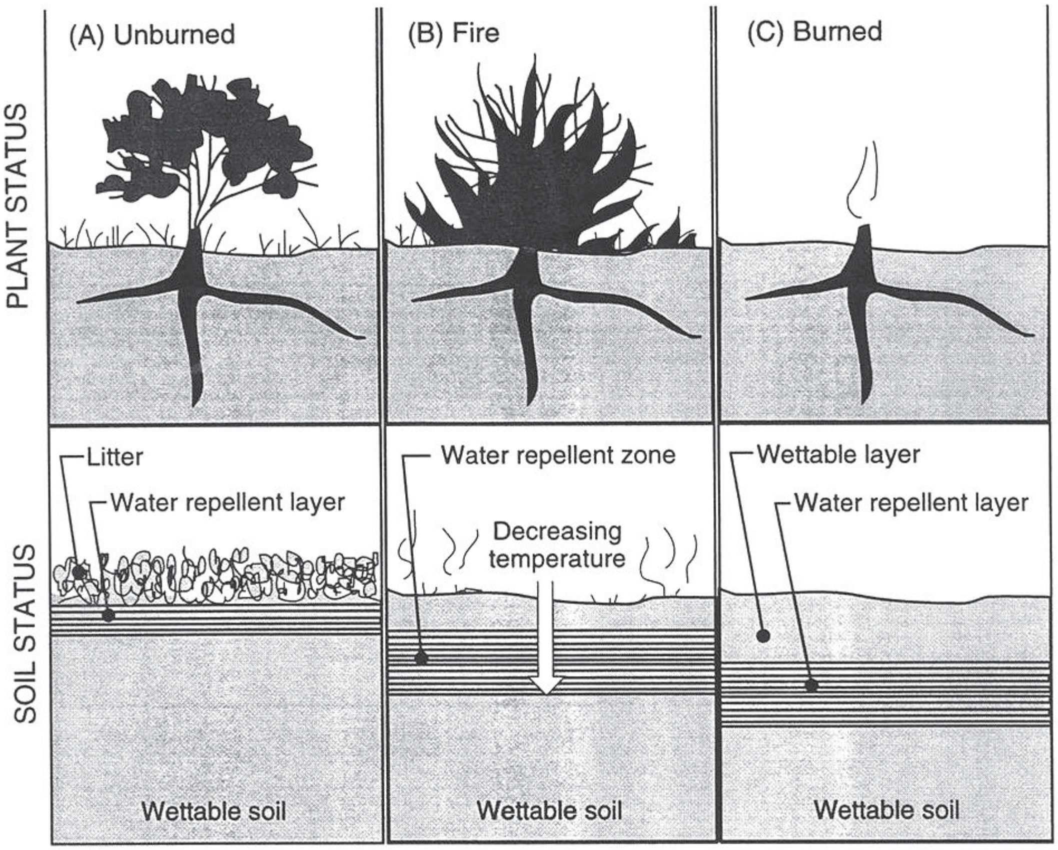
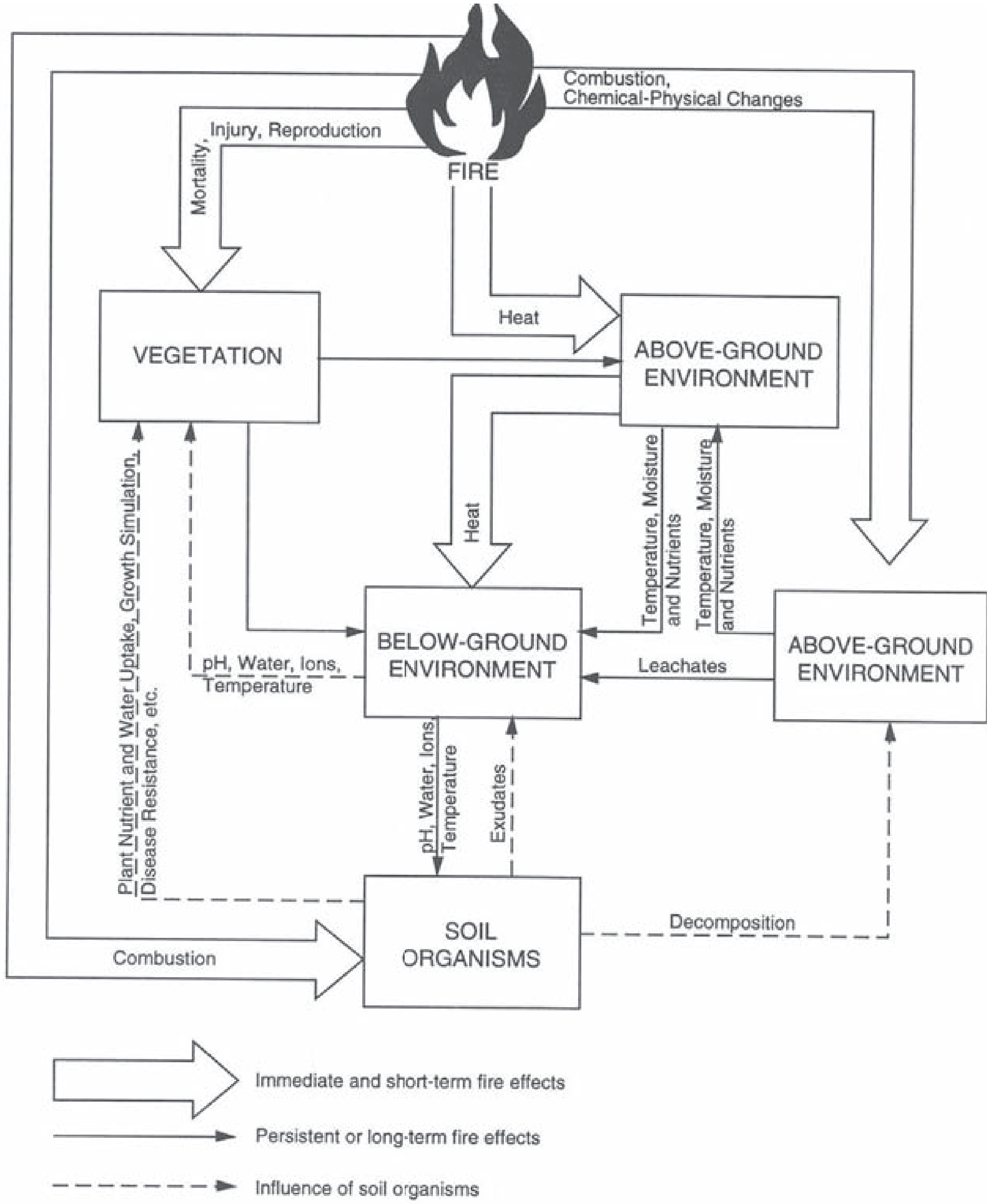


Figure 1-8 Immediate and long-term ecosystem responses to fire (Neary et al., 2005)**.**



Due to these changes in hydrology and increased overland flow, higher levels of soil erosion bring more sediment to waterways and reduce water quality. Other than sediment, turbidity, pH, dissolve chemical constituents and organic debris also affect water quality (Neary et al., 2005).

A study was conducted to find out the effects of fire on infiltration especially in forest areas (Robichaud 2000). The study was conducted at Northern Rocky Mountain, USA. Two parameters have been taken into account, surface cover or duff and hydrophobic conditions of soil. Rainfall was simulated with an intensity of 94 mm/hr. Three different treatments including undisturbed unburned, low severity burnt and high severity burnt were evaluated. Duff thickness (before and after fire) and runoff rates were measured. Hydrographs were developed using runoff rates. Prescribed fire consumed the duff layer at different rates, thus reducing the thickness of it, which eventually lead to a higher volume of runoff when compared with unburned areas. Hydrophobic conditions were observed in both low severity and high severity burned areas. Soils seemed to have hydrophobic conditions with higher runoff rates at the initial stage of a rainfall event. The higher severity burns caused more hydrophobicity. Hydrophobicity reduced infiltration (by 10-40%) and increased the runoff (Robichaud, 2000).

Emmerich and Cox (1992) conducted a study to find out the effects of vegetation removal by burning on surface runoff and soil erosion. This study compared the effect of fire on native and introduced grass. The study was conducted in southeastern Arizona, USA. Before the study, the pasture was not grazed 1.5 years. Thirty-two 25m X 25 m plots were used for this experiment. The two treatments consisted of burned and non-burned conditions. The effects were studied for seasonal variations, fall and spring. The experiment was conducted over a two year period. Split plot and randomized complete block design were used. Each year (1987/88-88/89), four plots were burned during each season. Rainfall was simulated with a rotating boom simulator at two different rates. Metal sheets were used to prevent any inflow or outflow of surface runoff. Sediment in the runoff samples was measured. This sediment concentration and discharge rate were used to calculate the total sediment load. The conclusion of study was that, there was no significant treatment effect or interaction between location, season or year for runoff and sediment. Moreover, the authors concluded that immediately after burning there was no detectable burn effects. Although there was an increase in surface runoff and sediment production, it was insignificant. The study led to a conclusion that above ground biomass has little effect on runoff. Also, the authors found that the rainfall intensities had no effect on runoff or soil erosion.

Johansen et al. (2001) conducted a study to evaluate the effect of fire on runoff and erosion in a forest land. The authors also attempted to compare the results of this study with previous studies from other ecosystems. The study area was located near Los Alamos, New Mexico, USA. Four experimental plots of 3.03 m X 10.7 m size (two burned and two unburned) were used. Parameters such as vegetation canopy cover, ground cover, surface roughness, soil bulk density, water repellency, soil moisture, and soil texture were measured. Simulated rainfall of 60 mm/hr was applied by using rotating boom type rainfall simulators, which had a kinetic energy of 80% of natural rainfall. Three rainfall events, one hr, after 24 hrs- 30 minutes, and after 30 minutes another 30 minutes, were simulated. These runs were labeled as dry, wet and very wet runs. Runoff and sediment yields were measured. After the fire, organic ground cover was reduced and the soil was exposed. Out of 120 mm applied rainfall, 71 & 35 mm became runoff in the burned plots and 26 & 27 in the unburned plots. There was a positive correlation between amount of runoff and bare soil. However runoff volumes and surface roughness were poorly correlated. Runoff initiation time was negatively correlated with extent of bare soil. Hydrographs did not confirm the effect of water repellency. Burned plots (76 kg/ha/mm) had higher sediment yields than unburned plots (3 kg/ha/mm). Due to the lower intensity of fire in grasslands compared to forested lands, the changes in soil properties were less apparent on grasslands, therefore only causing a small increase in erosion.

A study was conducted by Pierson et al. (2003) to find out the effect of wildfire on hydrological processes such as infiltration, runoff, erosion and sediment transport. The study was carried out in two locations in Idaho and Nevada. Burned and unburned sites with similar characteristics (soil type, slope, vegetation) were compared at each location. A portable oscillating arm rainfall simulator was used to simulate the rainfall. Rainfalls with intensities of 67 mm/hr and 85 mm/hr were applied on 0.5 m^2 sized plots. Runoff samples were collected for the analysis of runoff and sediment. The difference between runoff and applied rainfall was assumed to be infiltrated water. Rill development was simulated using a flow regulator and flow samples were collected at 4-m down slope. Flow velocity in each rill was measured by using electrical conductivity probe. After the burn, bare ground covered more than 95% in all sites. During the rainfall simulation initially infiltrations were reduced by 16 to 30% and after one hour there was no significant difference. This was due to the water repellency which was found to be temporary. Fire had a small but significant effect on initiation of overland flow. With increasing water release rates, runoff volume through the rills was higher in burned sites. There were differences in erosion rates between burned and unburned sites.

An experiment was conducted by Marcos (2000) to investigate the effect of fire on runoff and sediment yield. The study was conducted in a dense heathland in Northwest Spain. A plot of 18 m x 10 m size was burned. Revegetaion was done with different combinations of plant species. Rainfall was simulated on 1 m^2 before and after the burn and 1.5 years during the revegetation. Drop size distribution and median volume drop diameter were calculated. 180 mm/hr intense rainfall was applied for 5 minutes. Surface runoff was collected and sediment yields were measured. Soil chemical physical properties such as organic carbon, pH, P, CEC, moisture content, and aggregate stability were measured. There was no change in soil properties except organic carbon. There was a strong relationship between sediment yield and woody coverage percentage. Runoff rate and sediment yield were also related. With the increasing ground cover due to revegetation, runoff was reduced.

Objectives of the Study

Several studies have been conducted to evaluate the ability of VFS to attenuate pollutants coming from feedlots and croplands (Abu-Zreig et al., 2004; Barfield et al., 1998; Blanco-Canqui et al., 2004; Dillaha et al., 1989; Gharabaghi et al., 2001; Helmers et al., 2005; Hubbard et al., 2003; Komor and Hansen, 2002; Lee et al., 1999; Lim et al., 1998; Mendez et al., 1999; Sanderson et al., 2001;Schmitt et al., 1999). However, there is minimal work on VFS effectiveness for reducing pollutants resulting from military activities (Kim, 2005; St Clair, 2006). Additionally, there is only limited information on the effect of different management practices on VFS performance. Also this study, variation along the growing season was analyzed. Specific objectives of this study were:

- To evaluate the ability of vegetative filter strips for attenuating pollutants resulting from military maneuver activities;
- To study the effects of different factors, such as vegetation, infiltration, and soil moisture, on VFS pollutant trapping throughout the growing season;

- To investigate the effects of vegetation on the VFS’s hydrological parameters including infiltration, time of concentration and runoff volume;
- To compare the impacts of different management practices (mowing and burning) on performance of VFS.

CHAPTER 2 - Methodology

Description of site

Location and Topography

Fort Riley, a United States military base is located in Northeast Kansas (39°15'N, 96°50'W), along the Kansas River, between Junction City and Manhattan. It has 40273 ha dedicated to maneuver training. It is located in part of the Flint Hills region, which comprises more than 1.6 million ha of the largest, undisturbed tall grass-prairie of North America. This area covers much of eastern Kansas near the Kansas-Nebraska border and extends southwards down to northeastern Oklahoma (Althoff et al., 2006).

The elevation of Fort Riley area ranges from 301-420 m above mean sea level. The study site is located on Fort Riley and was developed during the summer of 2005 close to a tributary of the Three Mile Creek. There were two sites comprising three VFS on each site. Hereafter VFS site on the west side is referred as site 1 and the VFS site on the east side is referred as site 2 (figure 2-1).

Climate and Soil

The climate is characterized by hot summers and cold, dry winters; mean monthly temperatures range from a low of -2.7°C in January to a high of 26.6° C in July. Annual precipitation averages 835 mm with 75% of precipitation occurring during the growing season (Haydon, 1998). Based on USDA-NRCS web soil survey, soil on both sites is a Crete Silty Clay Loam.

Vegetation

Vegetation communities on Fort Riley can be broadly classified into three groups: grasslands (ca. 32,200 ha), shrublands (ca. 1600 ha), and woodlands (ca. 6000 ha). The dominant plant species in the grasslands are big bluestem (*Andropogon gerardii*), Indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and little bluestem (*Schizachyrium scoparium*) with lower level presence of other grasses and forbs.

Dominant species in shrublands are buckbrush (*Symphoricarpos orbiculatas*), smooth sumac (*Rhus glabra*), and rough-leaved dogwood (*Comus drummondii*) with a blend of grasses and forbs. Shrublands are observed along woodland edges and in isolated patches in grassland areas. Mostly woodlands are located along the waterways and consist of chinquapin oak (*Quercus muhlenbergii*), bur oak (Q. *macrocarpa*), American elm (*Ulmus americana*), hackberry (*Celtis occidentalis*), and black walnut (*Juglans nigra*) (Althoff et al., 2006).

The major species of vegetation in the VFS study sites are switchgrass (*Panicum virgatum*), big bluestem (*Andropogon gerardii*), and Indian grass (*Sorghastrum nutans*). In site 1, more than 90% of the vegetation consisted of these three native tallgrasses. However, in site 2, an invasive weed, *Sericea lespedeza,* covered approximately 50% and switch grass comprised 40% of the vegetation. At both sites around 10% of the vegetation was forbs and other grasses such as showey patridge pea, common milkweed, musk thistle, western ironweed, missouri golden rod, stiff golden rod, heath aster, pale purple corn flower, buckbrush, illinois bindle flower, round head bush clover, pitcher sage, white sage, smooth brome, side oats grama, purple love grass, canada wild rye, and green foxtail.

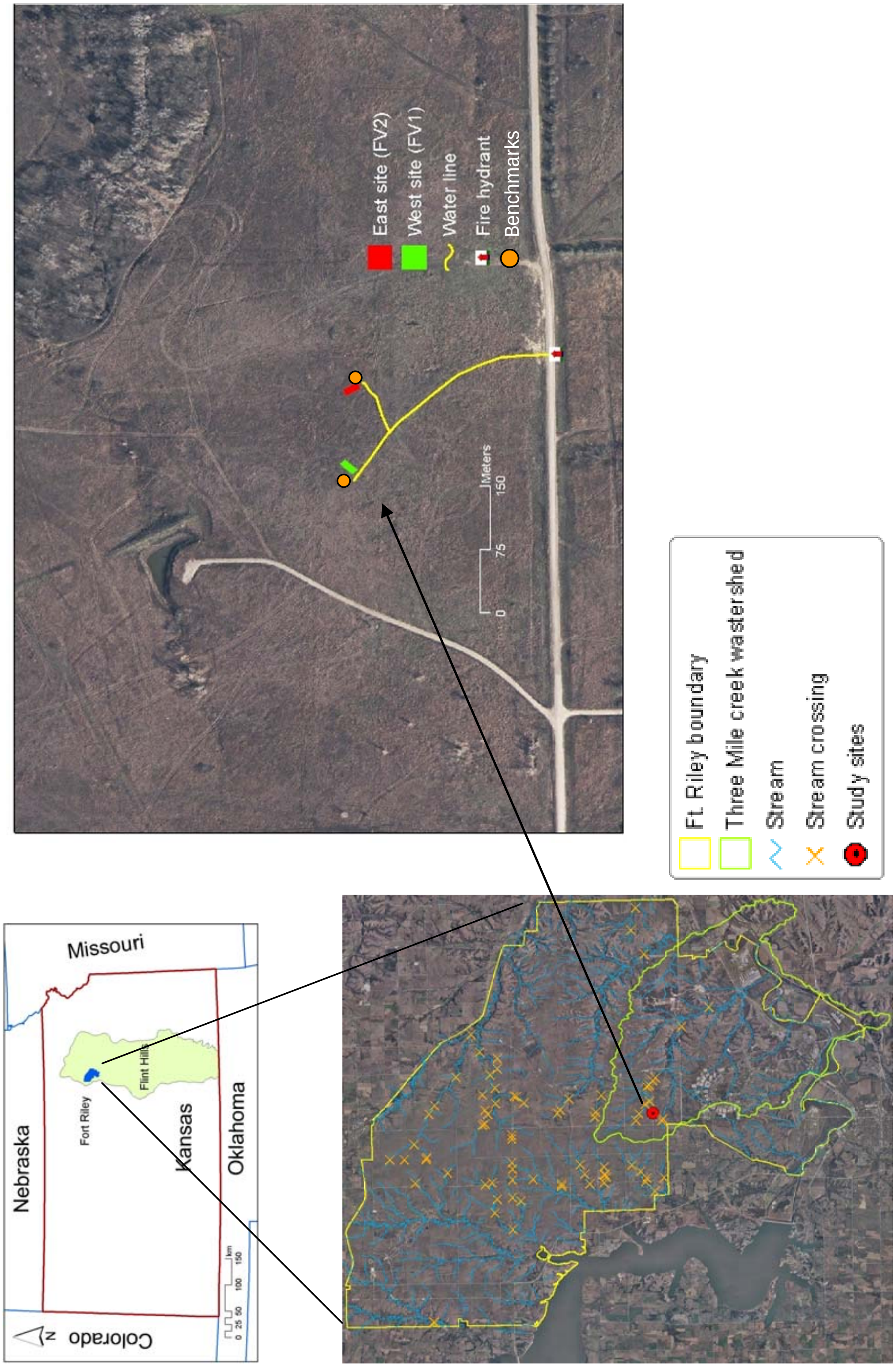
Burning of the site

The site was burned on 18th April 2007. Grass was burned to the soil surface leaving some herbaceous stubble unburned. The surface was black after burning. Much of the fuel was consumed and the remaining fuel was charred. The depth of burn seemed to be light according to USDA forest services classification (Neary et al., 2005)

Description of fuel

Since this site has been burned annually for at least three consecutive years, the duff depth was less than 2.5 cm (<1”). During the fall of 2006, all aboveground biomass was harvested so there was not much fuel left to be consumed by the fire. The fuel consisted of mainly organic litter of grass and herbaceous plants.

Figure 2-1 Map and aerial images showing the location of study area in Fort Riley, Kansas (Kim 2006)



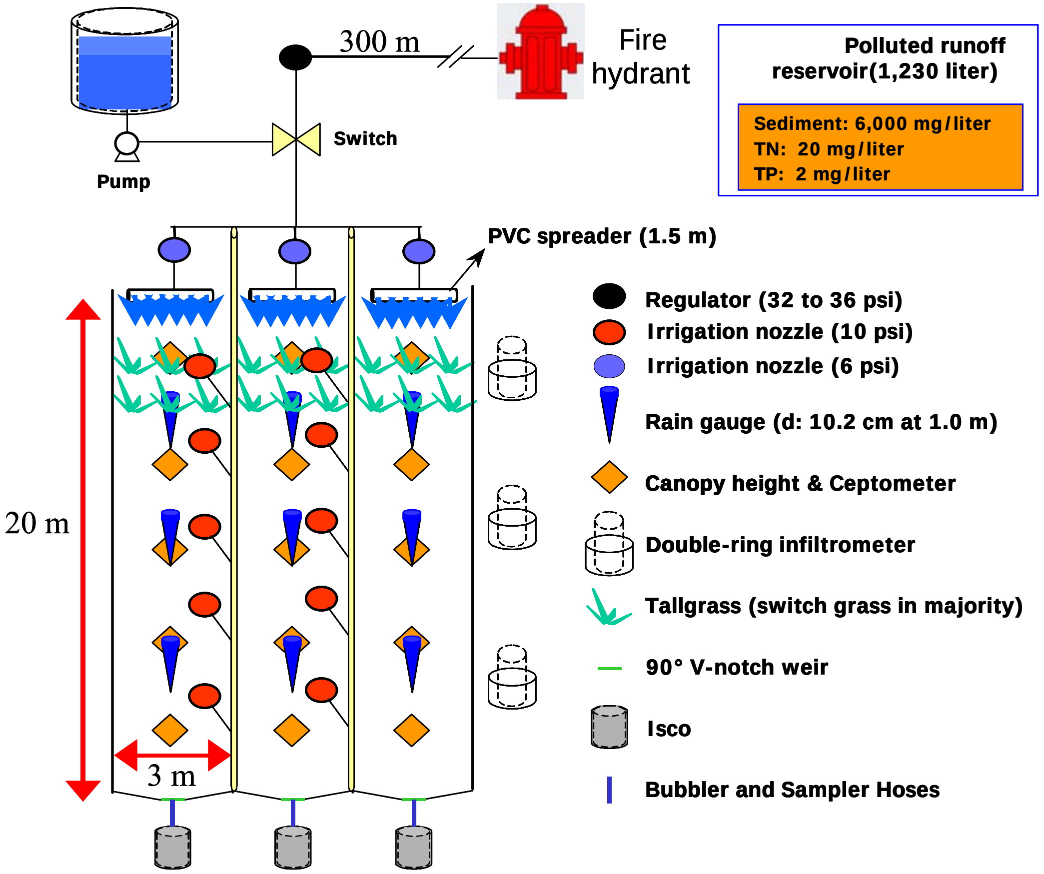
Experimental setup

The research site was developed in 2005 as part of the Strategic Environmental Research and Development Program (SERDP) grant SI-1339, assessing the Impact of Maneuver Training on NPS pollution and Water Quality. Previous work was conducted by Kim (2005) and St Clair (2006). The experiments were conducted on two blocks of three vegetated filter strips (6 total), each 20 m x 3 m. The VFS plots were laid along the slope of the land to facilitate the flow of water through the VFS and minimize cross flow. VFS plots in each block shared a common (longitudinal) boundary among them. To prevent cross flow between VFS plots metal sheets were buried along each boundary. The metal sheets created barriers 5-8 cm above and below the ground surface. The filter strips were located approximately 110 m apart. The average slope of the study area was 3.9 % (Kim 2006). Each block was equipped with a network of pipes, valves and sprinkler nozzles to simulate rainfall (Figure 2-2).

Artificial precipitation events were applied to the site using Xcel wobbler (high angle 24^{o}) (Senninger Inc.,Clermont, Florida) with 69 kPa (10 psi) pressure regulators. The water source for the experiments was a fire hydrant located approximately 500 m from the filter strips. Each VFS site had 10 nozzles on two laterals (5 nozzles per lateral). The laterals were spaced 3 m apart along the VFS boundary. Nozzles within each lateral were 3.3 m apart. Each nozzle was attached to a 1.8 m riser. The risers were anchored by iron bars pounded into soil. Each lateral had a ball valve to control the water flow which was connected to the main pipeline by a manifold. The main pipeline was connected to the outlet of the pipe, which brought water from a fire hydrant to the VFS sites. A pressure meter and ball valve on the main pipeline were used to regulate pressure and flow.

A 1230 L (325 US gallons) plastic tank was used as a reservoir to mix and store nutrient enriched water prior to application. A ball valve was fixed on the outlet of the tank for flow control. A screen was fixed inside the tank to keep big soil particles away from the pipelines. Nutrient enriched water from the reservoir was applied to the VFS as overland flow through spreaders to encourage sheet flow because VFSs perform better under sheet flow conditions (Clar et al., 2004; Blanco-Canqui et al., 2006). The spreaders were constructed from 1.5 m long and 7.6 cm diameter PVC pipe. Water was discharged through 14 holes, 0.95 cm diameter and 6.5 cm apart. Both ends of the spreaders were sealed.

Figure 2-2 Diagram showing the experimental set up at a VFS site in Fort Riley (Kim 2006)



The spreaders and reservoir were placed upslope from the VFS site. One spreader was placed across the slope of the land at the upslope end of each VFS. They were connected, using plastic hoses, to another manifold which distributed the polluted overland flow from the reservoir. The manifold had three outlets each with a ball valve, a 41.4 kPa (6 psi) pressure regulator and a number 9, 3.57 mm (9/64 in) diameter Senninger irrigation nozzle. A water pump was used to pressurize the water as well as to mix the nutrient enriched water in the reservoir. A hose from the pump carried the return flow back to the reservoir. Turbulence created by the return flow kept the sediment and sediment bound pollutants in suspension.

At the lower end of the VFS, a 90^o V-notch, sharp-crested weir was used to measure outflow from the VFS. Metal sheets were installed to route outflow over the weir. An ISCO automatic sampler (model 6712 or 6700, Teledyne Isco, Inc., Lincoln, Nebraska, USA) was assigned to each VFS to measure the depth of water flowing over the weir and take water samples at given time intervals. The ISCO samplers were attached to the bottom of the weir with two hoses, one for sample collection and one for depth measurement.

Simulation of storm events

Polluted runon from upland areas was simulated with overland flow applications of nutrient enriched water from the reservoir. Soil (8kg), urea (55g) and diammonium phosphate (5.5g) were mixed in the reservoir to simulate overland runoff carrying sediment, nitrogen and phosphorous. Even though military maneuvers do not generally result in the export of nitrogen and phosphorus, these compounds were added to gain a better understanding of overall VFS function for the primary NPS pollutants in Kansas. Air-dried soil from the site was sieved with a 2 mm sieve before adding it to the reservoir. Because bigger soil particles are not carried with runoff, only fine particles were used. Because diammonium phosphate has a low solubility in water, it was stirred with water overnight.

Altogether 15 precipitation/runoff events were carried out in each block during spring 2007 through early winter 2007. For each experimental run, rainfall was simulated using the sprinklers. Once runoff was observed, overland flow was turned on. This was to simulate actual storm events. In reality a VFS plot will receive runoff after the contributing area is saturated. In this experiment, it was assumed that the "contributing area" was saturated once the VFS was saturated. After 2/3 of the overland flow reservoir was emptied, the sprinklers were shutdown, while the overland flow continued. This was also to simulate the natural event; even after rain stops, overland flow continues from its contributing area. Once the overland flow reservoir emptied, the whole experiment was stopped. Based on the existing soil moisture conditions, the experimental runs took anywhere between 1 to 5 hours. With the capacity of the overland flow reservoir at 1230 L, on some simulations, it was necessary to apply more than that amount. On such instances, clean water was added to the tank to continue the overland flow application. The nozzles applying overland flow were checked and cleaned if they were clogged. The dates of the experimental runs and the applied precipitation and overland flow are summarized in Table 2-1.

Table 2-1 Summary of experiments conducted

Date	VFS Site	Days after burning	Applied rainfall (mm)	Applied Run on (L)	Remarks (DS-Discrete samples CS-Composite samples)
5/11/2007	1	23	29.1	1087.32	DS
5/15/2007	2	27	14.9	1119.30	DS
5/16/2007	1	28	35.3	1439.10	DS
5/17/2007	2	29	55.8	959.40	DS
6/2/2007	2	44	35.3	1247.22	DS
6/5/2007	1	47	53.3	1359.15	DS
6/13/2007	1	55	62.7	968.75	DS
6/13/2007	2	55	61.8	1279.20	DS
6/27/2007	1	69	70.8	1519.05	DS
6/27/2007	2	69	65.4	1087.32	DS
7/5/2007	1	77	62.0	1838.85	DS
7/5/2007	2	77	41.5	1439.10	DS
7/12/2007	1	84	61.6	1327.17	DS
7/12/2007	2	84	62.9	1311.18	DS
7/23/2007	1	95	31.9		Intense storm events were simulated on this week CS
7/23/2007	2	95	30.9		
7/24/2007	1	96	51.0	1599.00	
7/24/2007	2	96	46.6	1279.20	
7/25/2007	1	97	78.9	3038.10	
7/25/2007	2	97	75.1	2718.30	
7/26/2007	1	98	52.0	1838.85	
7/26/2007	2	98	46.6	1599.00	
7/27/2007	1	99	25.7	799.50	
7/27/2007	2	99	24.8	847.47	
8/17/2007	1	119	120.0	2318.55	CS
8/17/2007	2	119	87.7	1678.95	CS
10/12/2007	1	174	38.2	746.20	DS
10/12/2007	2	174	112.1	2046.72	DS
10/20/2007	1	182	24.1	724.88	After mowing/DS
11/17/2007	2	209	41.3	2478.45	After burning/DS

Simulation of intense storm events

An intense storm event was simulated from July 23-27, 2007 to study the impact of a saturated soil profile on VFS performance. The amount of applied precipitation was gradually increased by 25 mm each day, starting with 25 mm and ending with 75 mm on the third day and on the fourth day applied precipitation was reduced to 50 mm and finally to 25 mm on the last day. This was done to observe the effectiveness of the VFS under similar intense storm events.

Management practices

At the end of the growing season, two different management practices, mowing and burning, were tested. Site 1 was mowed close to the ground surface (< 10 cm) with a sickle mower on 19 October 2007 and all the grass clippings were removed from the VFS. The following day a rainfall simulation was conducted to see any effects by mowing on VFS performance.

Site 2 underwent a prescribed burn on 15 November 2007. Before burning the VFS, a strip of grass outside the VFS was mowed and sprayed with water to confine the fire within the VFS. A torch was used to ignite the grass. Since the grass was killed by the frost on previous weeks and dried, it was quickly consumed by the fire, leaving minimal unburned forb stubble. Flames were observed up to 3 m and it could be described as a moderate burn. The fire left ash and char on the VFS. A rainfall simulation was conducted two days later to observe any effects from burning on VFS performance. No natural precipitation occurred between burning and the simulation.

Measurement of variables and Sampling procedures

During each experimental run, several samples and measurements were taken including infiltration, vegetation height, runoff flow depth, and applied rainfall. Rainfall and overland flow times were recorded. Soil, water and vegetation samples were collected for lab analysis of soil moisture, pollutant concentration and above ground biomass density, respectively.

Infiltration:

Double ring infiltrometers were used to measure the infiltration. For each simulation, three infiltrometers were installed alongside the length of the VFS (Figure 2-2). Infiltration measurements were taken on either side of the VFS on alternate simulations. The infiltrometers were pounded into the ground using a hammer within the reach of sprinklers. This was to make sure that the soil moisture condition in the VFS and within the infiltrometers were the same. Both rings were filled with water using a perforated bucket to reduce disturbing the soil. The water level in the outer ring was maintained at a constant level. The water level in the inner ring was measured and recorded at 15-30 minute intervals. Water levels in both rings were frequently checked and water was added whenever necessary.

Soil moisture content:

Gravimetric soil moisture was measured by taking soil samples with a soil sampling auger (18 mm diameter). Three sampling sites within each block (one sample per VFS) were randomly chosen. According to their position in the plot, they were labeled as top, middle and bottom. At each location, samples were taken at two different depths, 0 to 7.5 cm and 7.5 to 15 cm and stored in plastic bags. In order to prevent moisture loss from collected samples, they were preserved in a cooler until they reached the laboratory.

In the laboratory, samples were placed in metal containers and weight of the soil samples (wet weight) was measured using an electronic balance. Then samples were dried in an oven for 24 hours at 105^{o} C. The weight of the soil samples was measured again after drying. The following equation was used to calculate the soil moisture at each location. Calculated values were used to estimate the average soil moisture content for the entire site.

$$Gravimetric\,moisture\,content = \frac{Wet\,weight\,of\,\,soil\,sample - Dry\,weight\,of\,\,soil\,sample}{Dry\,weight\,of\,\,soil\,sample} \times 100\%$$

Soil nutrient content:

At the end of the season, soil samples were taken and analyzed for total P and total N. Samples were collected inside and outside of the VFS to compare if there was any difference in the nutrient content due to the continuous application of nutrient rich runon.

Applied precipitation:

The amount of precipitation applied was measured using a grid of nine non-recording rain gauges for each block. Each VFS had three gauges, which were arranged along their length (Figure 2-2). Each rain gauge had a 10.2 cm (4”) diameter rainfall interceptor and a plastic bottle as collector. These rain gauges were installed approximately 1m above the soil surface on steel poles. Zip ties were used to attach the rain gauges to the steel poles.

Before each precipitation event, the bottles attached to the rain gauges were emptied to ensure that they did not contain any natural rainfall. After each rainfall simulation event, the water collected in the rain gauge was measured using a graduated cylinder and recorded.

Vegetation height:

During each rainfall simulation, the vegetation height was measured using a ruler, at ten randomly chosen points. The average height was computed from these measurements.

Above ground biomass:

Above ground biomass was measured by taking above ground biomass samples and weighing them. A steel quadrate (45.7 cm x 45.7 cm) was randomly thrown along the outer edge of the VFS and all vegetation inside the quadrate was clipped and put into polythene bags. When throwing the quadrate, two precautions were taken: (i) not to throw it out of the reach of simulated rainfall, so that the sample would represent the above ground biomass density of the vegetation inside the plots and (ii) not to throw on a place where a sample was taken previously, to ensure underrepresented samples were not taken. Also, on consequent experiments the above ground biomass sampling side was switched so as to have more sampling locations throughout the growing season.

In the laboratory, the clipped vegetation was placed in brown bags and oven dried at 75 ^{o}C for 72 hours to obtain the dry above ground biomass. Dry above ground biomass density was calculated using the following formula:

$$Biomass(dry)\,density\,(g/m^2) = \frac{Dry\,weight\,of\,\,the\,biomass\,sample\,(g)}{Area\,of\,\,the\,quadrat\,(2090\,cm^2)} \times 10000\,cm^2\,/\,m^2$$

Runoff measurement and runoff sampling:

Runon and runoff water samples were taken at the upper and lower ends of the VFS. At the upper end, runon samples were taken from the outlets of the overland flow spreaders. Two samples were taken from each outlet: one at start and other at the end of simulation. ISCO automatic samplers were used for taking samples at the lower end of the VFS at the weir. A 7.6 m long hose was placed at each weir and connected to the pump of the ISCO sampler. ISCO samplers were programmed to take constant volume (300 ml) discrete samples at frequent time intervals. Sampling interval was varied from 10-30 minutes based on the investigative requirement of the simulation. During a few simulations, ISCO samplers were programmed to take samples based on flow rate, and only a single composite sample was taken at the end of the simulation. Disposable plastic cups were used for transporting the samples to the laboratory. They were kept in a cooler with ice to minimize any changes in the chemical composition of the samples. Samples were refrigerated until they were analyzed.

For runoff, the flow was measured using bubbler modules attached to the ISCOs. Another small hose connected the bubbler module to the bottom of the weir. The bubbler module sends bubbles out through the hose and, based on the pressure required to expel the bubble from the hose, a pressure transducer in the module calculates the depth of the water flowing over the weir. Flow levels measured by ISCO samplers were cross checked with measured actual flow depth at weirs at frequent time intervals. If any discrepancies were observed, ISCO readings were adjusted accordingly.

The bubbler module also triggered the sampling by sending pulses after detecting flow at the weir. Samplers were programmed to take a depth reading every minute and a water sample based on the flow depth. Once the sampler detected that the flow was more than 3mm above the weir, the sampling was enabled. Otherwise, sampling was disabled. The samplers were powered by 12 V batteries.

Constituents of runoff water:

Runon and runoff samples were analyzed for Total Suspended Solids (TSS), total nitrogen (TN) and total phosphorous (TP). These tests were done by the soil testing laboratory in the Department of Agronomy of Kansas State University. Total phosphorous and nitrogen were analyzed by digesting the sample with Potassium Persulfate Reagent in an autoclave and then analyzed using a Technicon AutoAnalyzer II for phosphorus and an Alpkem RFA for nitrate nitrogen (cadmium reduction method) (Soil Testing Laboratory at Kansas State University 2005). TSS was analyzed by filtering 50-100 ml of the sample thru 0.45 micron filters using a vacuum. Based on the weight difference in filter before and after filtration, TSS was calculated (Soil Testing Laboratory at Kansas State University 2005). At the end of the growing season, the Chemical Oxygen Demand (COD) of the water samples from the lower ends of VFS was also analyzed for the simulations directly preceding and following the prescribed management practices (burning and mowing). COD is the amount of oxygen consumed per volume of sample, normally measured in the units of mg/L. Water samples were heated for two hours with potassium dichromate which is a strong oxidizing agent. The oxidizable organic matter in water sample reduces the dichromate ($Cr_2O_7^{2-}$) ion to chromic ion (Cr^{3+}). Remaining amount of Cr^{6+} was determined (Hach company). COD tests were carried out in the water quality laboratory of the Department of Biological and Agricultural Engineering of Kansas State University.

Data Analysis

Based on the data collected in the field and the laboratory analysis, the following data analyses were done.

Development of water balance

Components of the water balance, rainfall, runon, and runoff, were measured. Water retained was calculated and considered synonymous to infiltration, as evapotranspiration, interception and surface retention were assumed to be a very small fraction of water retained.

Water retained in the VFS

Water retained in the VFS included water intercepted by the vegetation, water infiltrated into the soil, and/or water retained in surface depressions. It was calculated by using following relationship:

$$Q_r = Q_i + Q_p - Q_o,$$

where Q_r is the volume (L) of water retained in the VFS, Q_i is the volume of runon, Q_p is the volume of applied rainfall and Q_o is the volume of runoff. Percentage of water retained was also calculated using following equation:

$$q_r = \frac{Q_r}{Q_i + Q_p} X 100\% ,$$

where q_r is the water retained (%) in a VFS as a percentage of the total water applied in the form of runon and precipitation. The relationship between infiltration and the other components of the water balance can be stated as:

Infiltration = runon + rainfall – runoff – interception – surface detention – evapotranspiration.

Since the interception, surface detention and evapotranspiration were assumed to be negligibly small, those terms can be dropped out and infiltration becomes equal to water retained.

Applied rainfall

The volume of water measured in each VFS was converted into depth of water using the following formula:

$$p = \frac{1}{8.11} X \frac{1}{3} \sum_{i=1}^{3} v_i \ ,$$

where p is the average depth (mm) of applied rainfall over a VFS, v_i is the volume of rainfall (mm) measured in each rain gauge and 8.11 is a conversion factor which is related to the cross sectional area of a 10.2 cm diameter pipe.

Then total volume of rainfall applied to each VFS was calculated using the equation below:

$$Q_p = 60 p ,$$

where Q_p is the volume of applied precipitation (L) over a VFS, p is the average depth (mm) of applied precipitation and 60 is the conversion factor related to the area of a VFS.

Rainfall intensity

Rainfall intensity was calculated for each simulation using the following relationship:

$$i = p / t ,$$

where i is the intensity of rainfall (mm/hr) and t is the total duration of the storm.

Runon

The total volume of runon was calculated by multiplying the flow rates of the sprinkler nozzles on the spreaders and the total time runon was applied to yield the following relationship:

$$Q_i=q_it,$$

Here, Q_i is the volume (L) of total runon applied and q_i is the flow rate (L/min) of the nozzle on the spreader.

Hydrology of VFS

The hydrology of the VFS was analyzed using runon flow rate, runoff flow rate, total time of runon and rainfall application, and applied precipitation. Principles of simple water and mass balances were utilized for these analyses. Runoff hydrographs were developed for every single simulation and for each VFS.

Hydrograph analysis

A hydrograph is defined as “a graph of runoff quantity or discharge versus time at the point of analysis of a drainage basin” (Gribbin 2007). In this study, each individual VFS was considered as a “catchment” and the point of analysis was the weir at the lower end. Hydrographs were developed using the data downloaded from the ISCO samplers. Depths (m) of runoff flow were transformed into flow rate (L/min). This was accomplished using the following equation given by the manufactures of the ISCO sampler for the transformation of a depth into a flow rate over a sharp crested 90° V-notch weir (Grant and Dawson 2001):

$$q_o = 1380 d_i^{2.5},$$

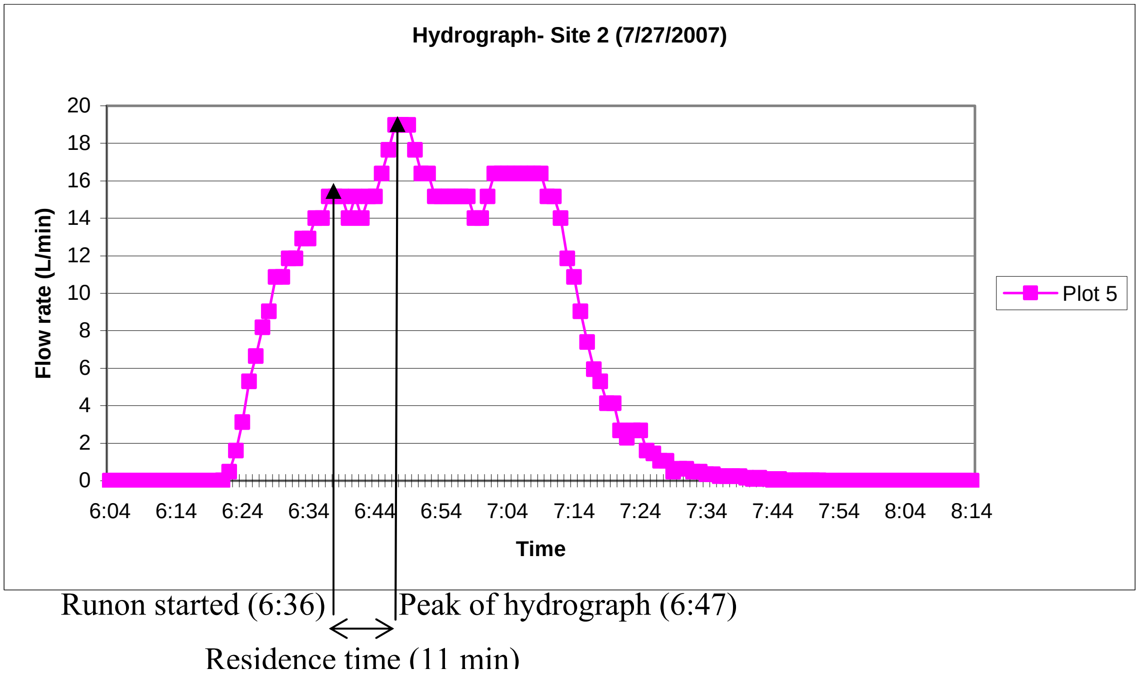
where q_o is the volume (L) of runoff flowing over the weir and d_i is the depth of flow (m) at i^{th} time increment (minute).

Time of concentration

Time of concentration is defined as “the amount of time needed for runoff to flow from the most remote point in the drainage basin to the point of analysis” (Gribbin 2007).

In this study, it was the time for runon water to travel from the upper end through the VFS to the weir at the lower end. It was calculated by taking the difference between the time when overland flow was turned on and the time of the hydrograph peak. An example is shown in Figure 2-3. The runon was started on the particular plot on the particular day at 6:36 a.m. and the hydrograph peaked at 6:47 a.m., resulting in a residence time of 11 minutes.

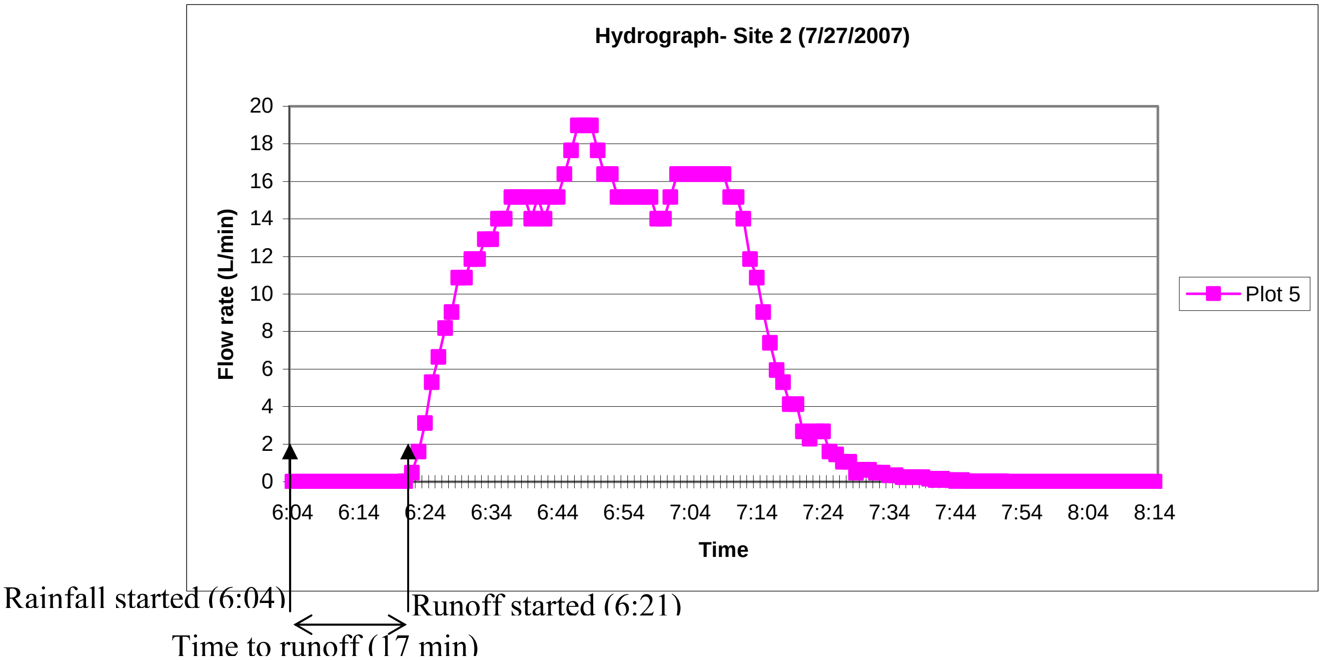
Figure 2-3 An example showing the method used to calculate the residence time.



Time to runoff

Time to runoff was calculated by estimating the difference between the time at which rainfall started and the time at which flow started at the weir as logged by the ISCO sampler. Figure 2-4 graphically shows the time to runoff, where rainfall was started at 6:04 a.m. and runoff started to flow at 6:21 a.m. resulting in a time to runoff of 17 minutes.

Figure 2-4 An example of calculating time to runoff



Total runoff volume

Total runoff volume was calculated by integrating the runoff hydrograph over the time using the following equation, where Q_o is the total volume (L) of runoff from a VFS, q_o is the runoff flow rate (L/min), and T is the total time (minutes) of the event:

$$Q_o = \int_0^T q_o dt .$$

Contributing area

The contributing area is the area above the VFS which contributes to the runon into the VFS. Based on the experimental design, the VFS have no real contributing area. The size of the contributing area can be adjusted by adjusting the amount of overland flow applied from the reservoir. For this experiment, the amount of runon was limited by the reservoir capacity and the contributing area was not assessed.

Saturated Hydraulic conductivity

Saturated hydraulic conductivity (cm/hr) was estimated by calculating the slope of the linear portion of the time versus cumulative infiltration curve. Figure 2-6 shows the cumulative infiltration graph and Figure 2-6 shows the linear portion of cumulative infiltration for site-2 on 08/17/2007.

Figure 2-5 Cumulative infiltration plotted against the time for three infiltrometers on site 2 on 08/17/2007

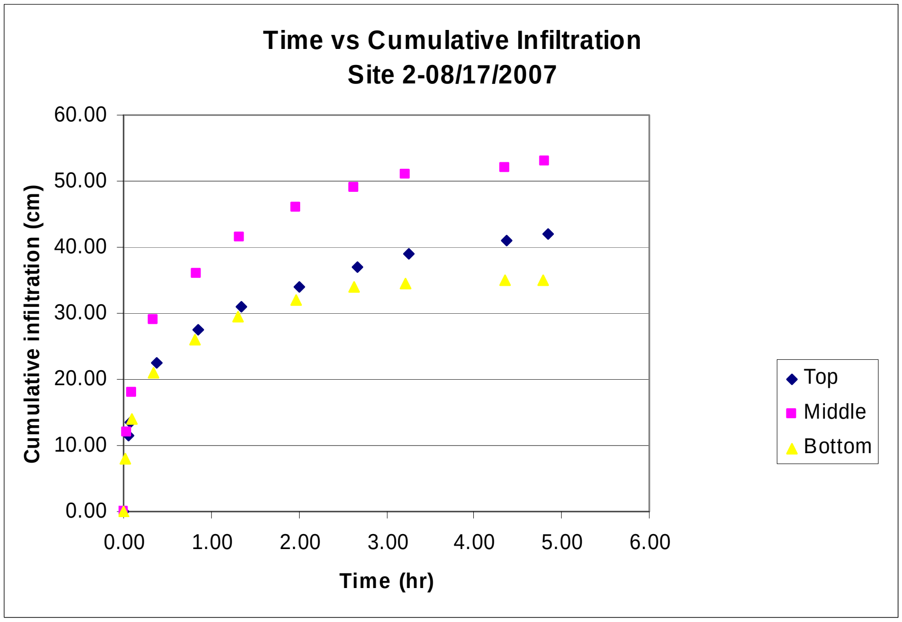
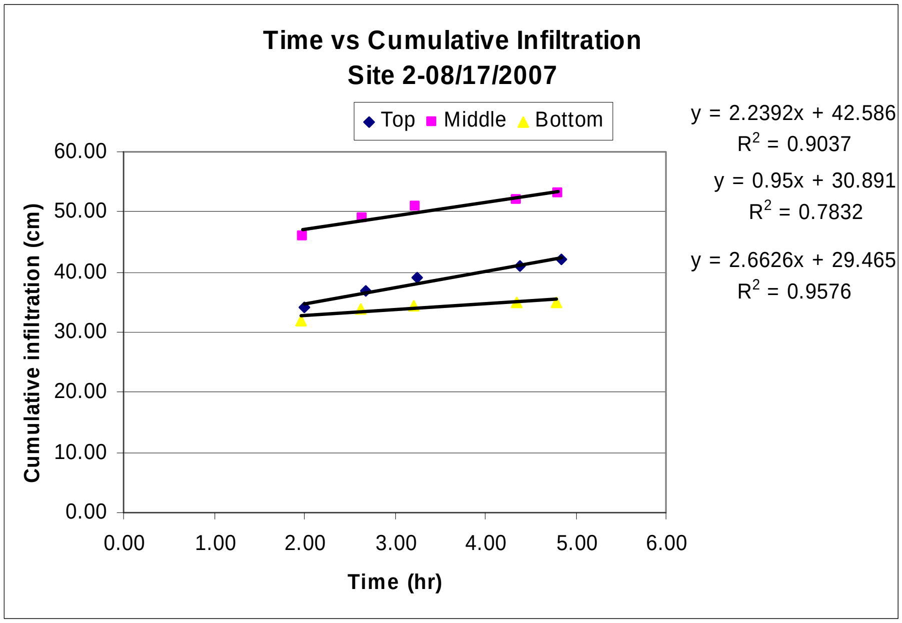


Figure 2-6 Cumulative infiltration plotted against the time (only showing the linear portion of it-for the purpose of estimation of saturated hydraulic conductivity)



Infiltration-using Green-Ampt model

The Green-Ampt model (Green and Ampt, 1911) was used to calculate the infiltration, and it was compared with the values obtained from the water balance. The Green-Ampt equation is as follows:

$$F(t) = Kt + (\theta_e - \theta_i)\psi \ \ln\left[1 + \frac{F(t)}{(\theta_e - \theta_i)\psi}\right],$$

where F is the cumulative infiltrated depth (cm), ψ is the capillary pressure at the wetting front (cm), θ_e is the effective porosity (cm^3/cm^3), θ_i is the initial soil moisture content (cm^3/cm^3), t is the duration of rainfall and K is the hydraulic conductivity (cm/hr). Since F(t) is a function of itself, the equation was solved by iterative process using an initial guess (Rawls et al., 1983b).

Initial gravimetric soil moisture (θ_i) was measured and storm duration was recorded. Gravimetric soil moisture (g/g) then was converted into volumetric soil moisture using a soil bulk density value of 1.0 g/cm^3 (Owensby, C. E. and J. Wyrill. 1973). Values for effective porosity (θ_e) and capillary pressure (ψ) were obtained from the literature. Rawls et al. (1983b) reported the average effective porosity for a silty clay loam as 0.432 cm^3/cm^3. Capillary pressure for silty clay loam is in the range of 5.67 to 131.5 cm with a weighted average of 27.5 cm (Rawls et al., 1983a). The weighted average value of capillary pressure was used for computations. Saturated hydraulic conductivity (K_s) was measured from the slope of the linear portion of cumulative infiltration graph. K_s values from the three infiltration measurements of all simulations were averaged and used for the calculations.

The relationship between hydraulic conductivity (K) used in Green-Ampt equation and saturated hydraulic conductivity (K_s) is given by the following equation (Bouwer 1966).

$$K = \frac{K_s}{2}$$

Pollutant trapping efficiency

Pollutant trapping efficiency (PTE) was the main parameter used to evaluate the effectiveness of the VFS and was calculated based on the mass balance and is given in the following equation (Barfield et al., 1998):

$$PTE = \frac{M_i - M_o}{M_i}.100\%,$$

where M_i is the mass (g) coming in and M_o is mass (g) going out from the VFS. M_i and M_o were calculated using following equations (Barfield et al., 1998):

$$M_i = q_i ct$$

$$M_o = \int_0^T q_o c_o dt$$

Here, q_i and q_o denote flow rates (L/min) of runon and runoff, and c_i and c_o stand for concentration (mg/L) of pollutants in runon and runoff. Mass coming into the VFS was calculated simply by multiplying the runon flow rate (q_i), the pollutant concentration in runon (c) and the total time (t) runon was applied. The product of runoff flow rate and the concentration of a particular pollutant in runoff was integrated over the duration of the runoff hydrograph to calculate the mass leaving the VFS.

Statistical Analysis

Statistical analysis was performed using SAS software (SAS Institute Inc., USA) Several regression models were fit and checked for statistical significance. Influential data were identified, deleted and regression models were fit again. In multiple regression models variables were selected by backward elimination. Mean comparisons were also conducted for a few variables and variance was decomposed into time, plot and site effects. A summary of the statistical analysis is given in Appendix D -. Probability for type I error- α (rejecting a true null hypothesis) was chosen as 0.05 ($\alpha = 0.05$) except for multiple regressions. For variable selection in multiple regressions, a default value of α = 0.1 was used.

CHAPTER 3 - Results and Discussion

In general the VFS trapped pollutants effectively, especially sediment and nitrogen, by infiltrating a large portion of the applied water. Phosphorous trapping was not consistent. Above ground biomass density and soil moisture were two important factors that affect the hydrology and subsequently the function of the VFS. Intense storms and different management practices altered the effectiveness of the VFS. In this chapter, the hydrology and water balance of VFS, effects of soil and vegetation on hydrology, VFS effectiveness in trapping pollution, effect of intense storms on VFS performance and effect of different management practices on pollution attenuation are discussed in detail. Only statistically significant correlations are presented in this chapter. A summary of all the correlations analyzed are given in Appendix D -.

Hydrology and water balance of filter strips

Several measured variables including simulated rainfall (amount and intensity), infiltration (total and percentage), runon, and runoff were used to understand the underlying hydrological functions of the VFS, how they change over time, and how they are correlated. Since it was difficult to estimate interception and evapotranspiration by vegetation and surface detention, they were not measured. Given that interception, evapotranspiration and surface detention are small compared to other components of hydrology, it was assumed that they were negligible. Based on that assumption, infiltration becomes equivalent to water retained, which also includes surface detention, evapotranspiration, and interception. Throughout this chapter, water retained and infiltration were considered interchangeable. The precision of the calculation of these variables depends on the accuracy of the instruments used and the field conditions existing on a particular day.

Overland flow

Overland flow was simulated to have 6000 mg/L of sediment, 20 mg/L of nitrogen (N) and 2 mg/L of phosphorous (P). However, the measured concentrations were not consistent; especially N and P which were above the expected concentration. This may be due to the non-uniform mixing of pollutants and water in the overland flow reservoir. Also, it was noticed that some soil added to the reservoir settled and remained on the bottom of the tank after the simulation was over. This would be a cause for the TSS concentrations that were lower than expected. Nozzles that apply overland flow had a flow rate of 5.33 L/min. On a few instances it was noticed that they were partially clogged with soil particles. This might have caused over estimation of overland flow on such days. The following figures (Figures 3-1 to 3-3) show the concentration of each pollutant in the overland flow for different days of simulation.

Figure 3-1 Runon total nitrogen concentration

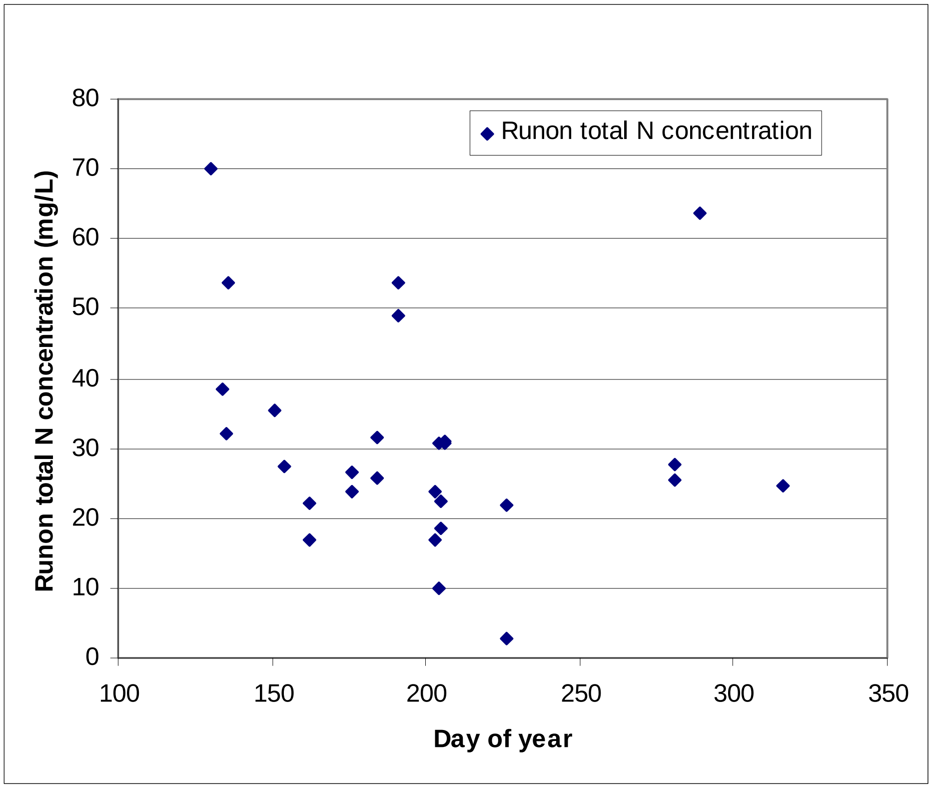


Figure 3-2 Runon total phosphorous concentration

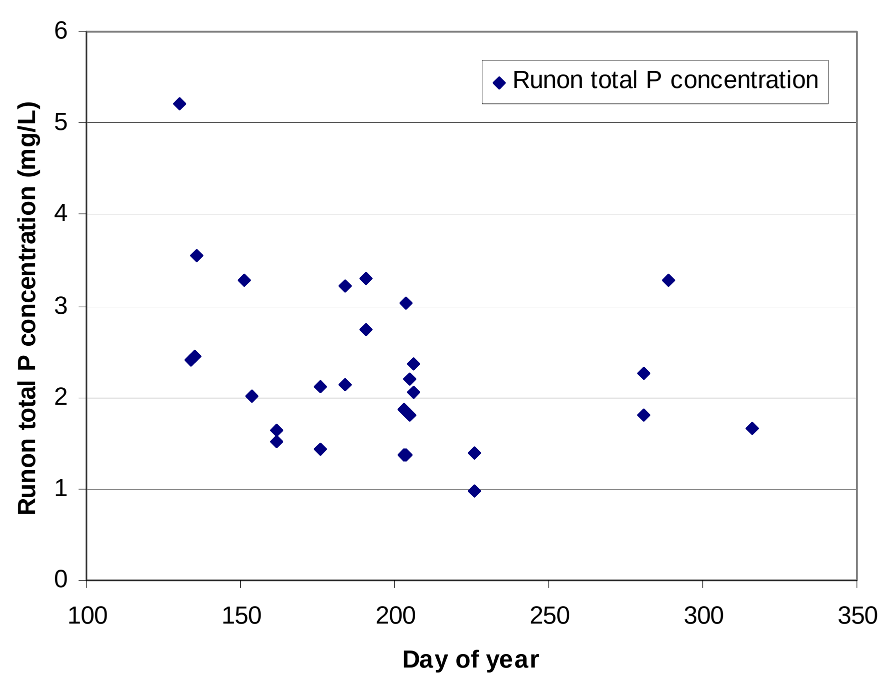
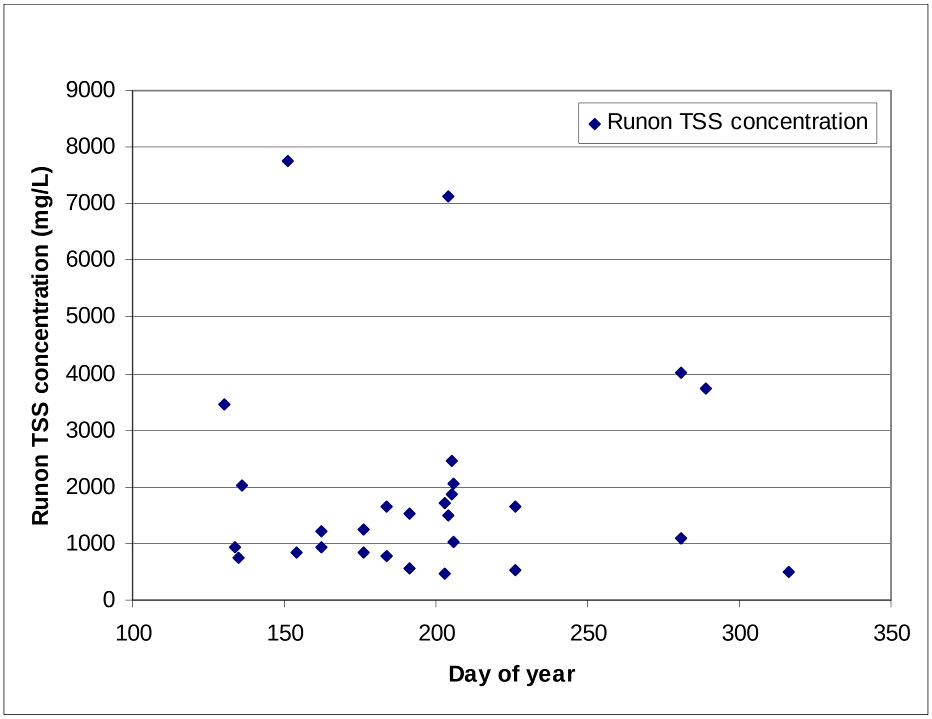


Figure 3-3 Runon TSS concentration



Runoff

Runoff significantly differed with time and plots (p<.0001). However, there was not any significant difference between sites (P=0.0508). Figure 3-4 and Figure 3-5 show the variation in the runoff among plots. A multiple regression model was fit for runoff depth (ro) with applied rainfall (ra, P=0.0002), soil moisture (sm, P=0.0003) and above ground biomass (bm, P=0.0029). The following model was found to fit with those variables with an R^2 of 0.3217:

$$ro\ (L) = -2653.7 + 22.7\ ra + 99\ sm - 2.1\ bm.$$

This model explains the variations in the runoff. As the amount of applied rainfall increased, the runoff also increased. This is because more water becomes available for runoff as more rainfall is supplied to the system. Increasing soil moisture also increases runoff since with the higher soil moisture, soil becomes saturated more quickly thus initiating runoff. On the other hand, increases in above ground biomass density reduced the amount of runoff, probably due to increased infiltration caused by belowground biomass and increased interception by aboveground biomass.

Figure 3-4 Measured runoff with time-Site 1

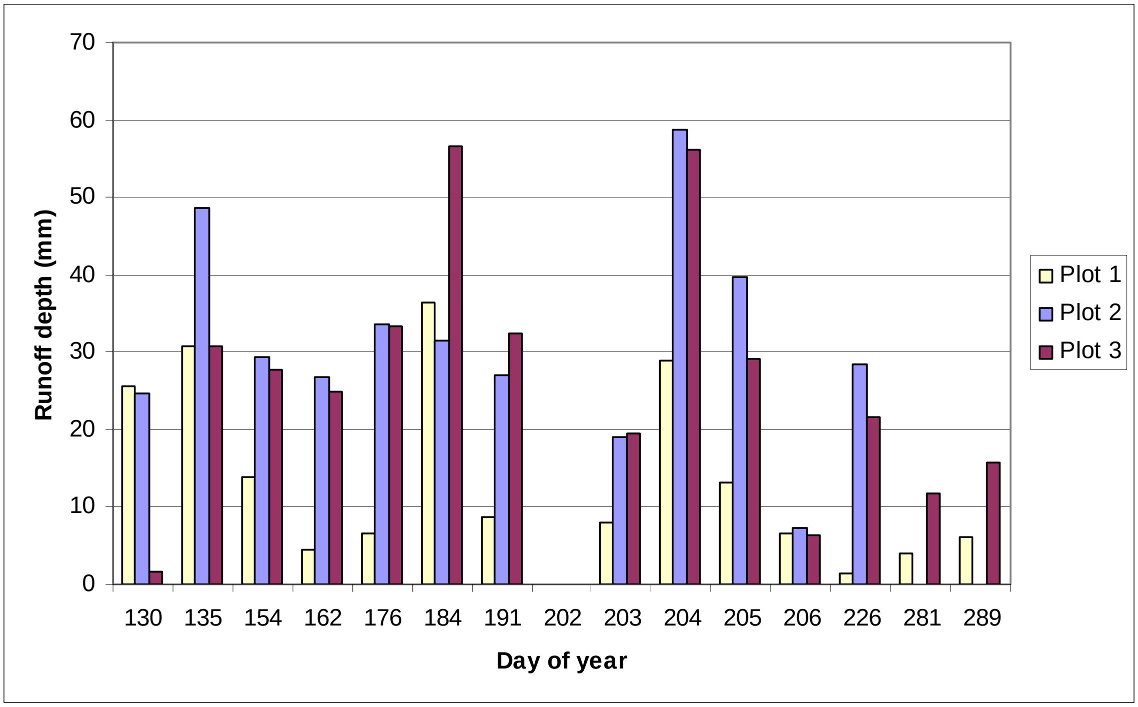


Figure 3-5 Measured runoff with time-Site 2

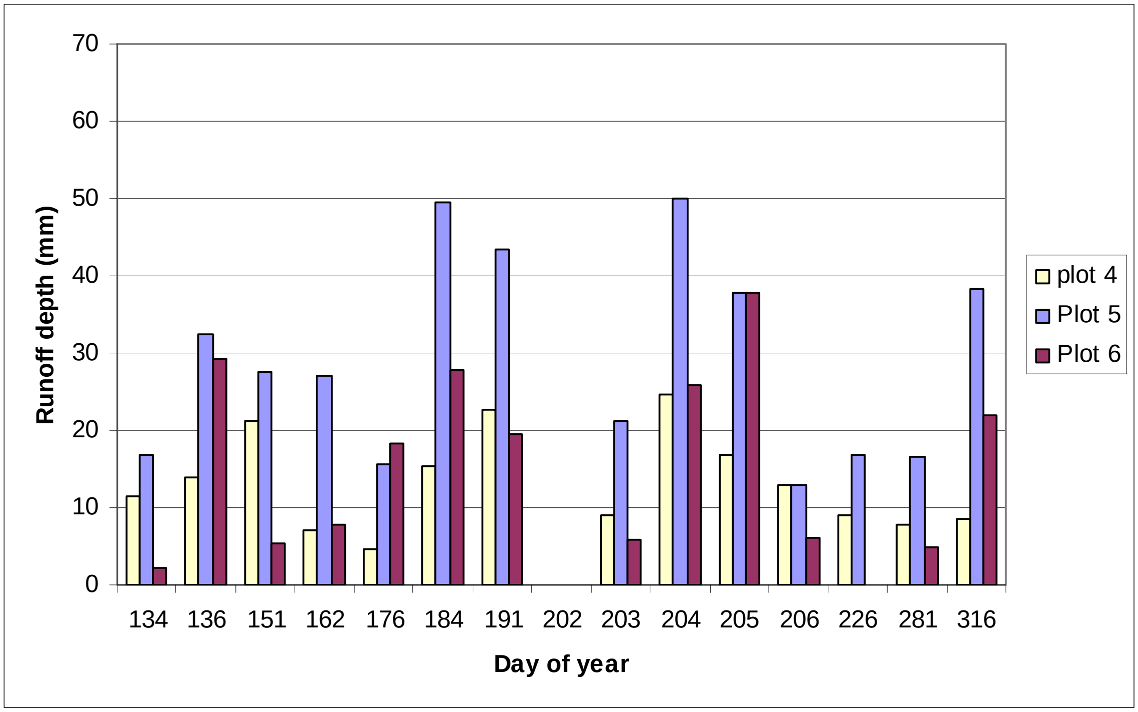
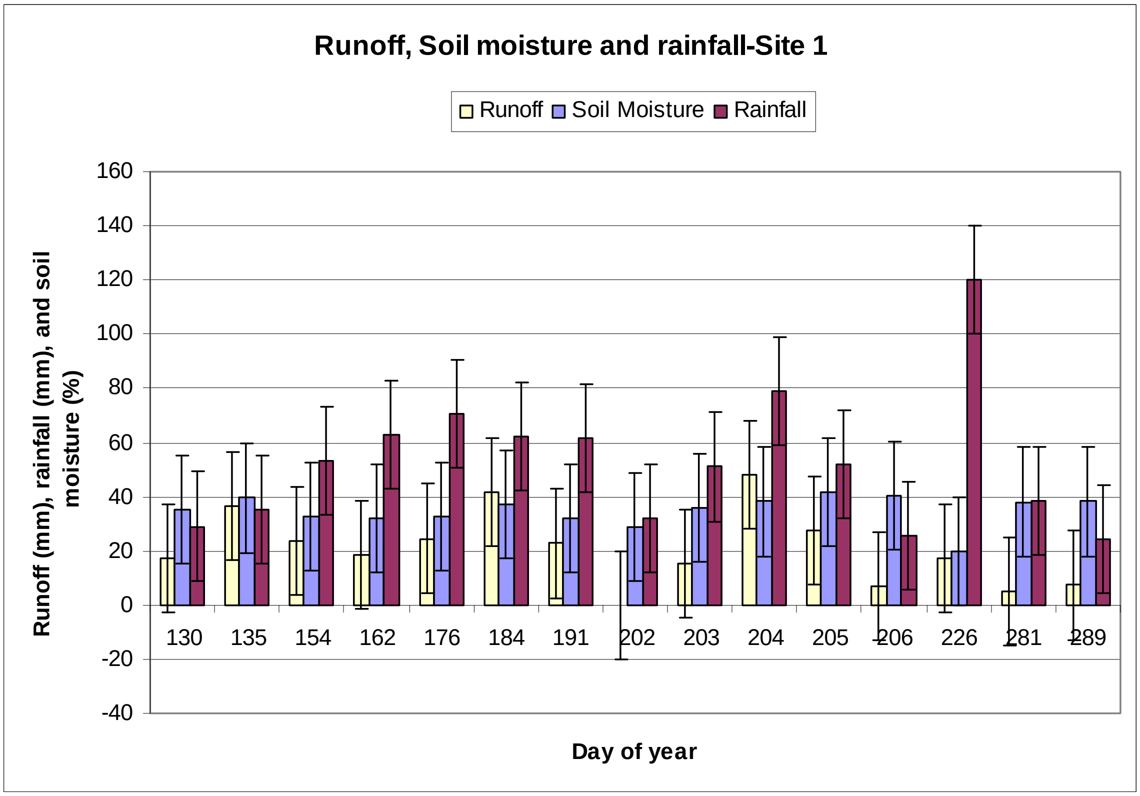


Figure 3-6 Relationship between runoff, soil moisture and simulated rainfall



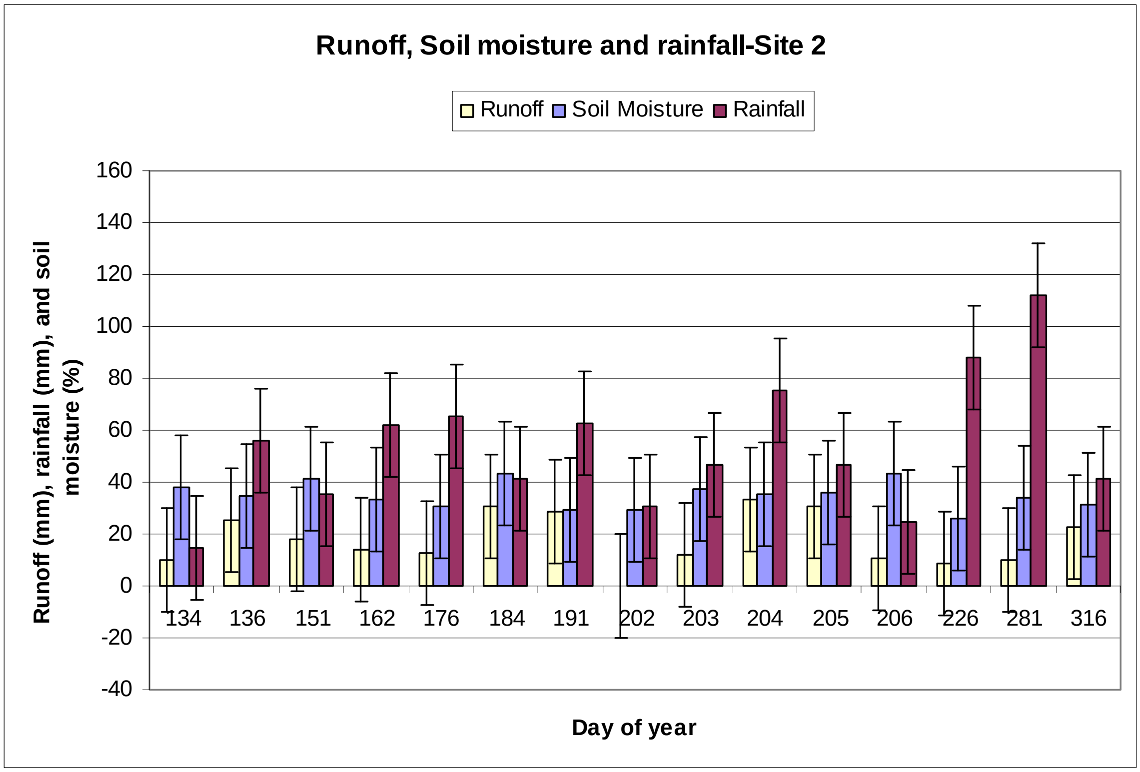
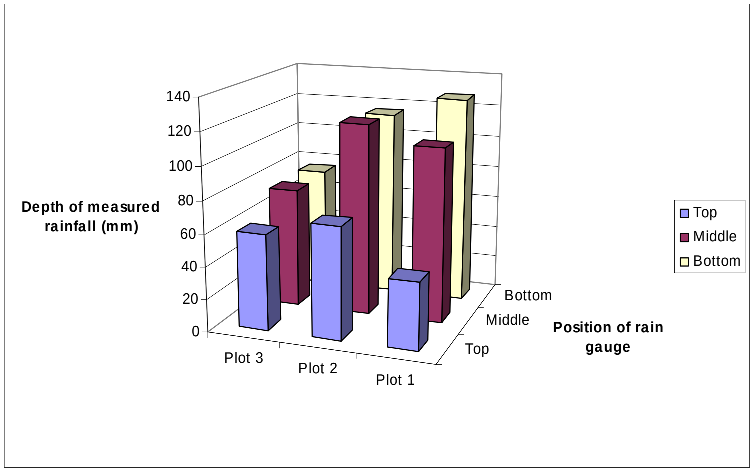


Figure 3-6 shows how runoff depth (mm), simulated rainfall (mm) and soil moisture (%) varied throughout the growing season for the sites 1 and 2. Increase in simulated rainfall and increase in soil moisture increased the runoff.

Simulated rainfall amount and rainfall intensity

The average application rate from the sprinkler system was approximately 23 mm/hr. Uniformity of water application was greatly affected by wind direction and intensity. Also, the middle plot on both sites received more simulated rainfall than the plots on either side. This was due to the overlapping of the sprinklers' reach on both laterals. Figure 3-7 shows the variability in the applied rainfall over site 2 on 8/17/2007. During that day, uniformity was highly variable with a distribution uniformity of 57.3%. Due to the variability in simulated rainfall, runoff volume also varied substantially among the plots. But this variability in simulated rainfall among plots was not statistically significant (P=0.1660).

Figure 3-7 Variability in the applied precipitation (site 2 on 8/17/2007)



The design of the sprinkler system placed a ceiling on the simulated rainfall intensity at 23 mm/hr. It was not possible to adjust the intensity and evaluate the performance of VFS under more intense simulated storms. However, there was variability among plots due to overlapping of sprinklers and wind effect. That variability was exploited to see if there is any effect of intensity on PTE.

Saturated hydraulic conductivity

Saturated hydraulic conductivity was not consistent throughout the experimental period. Statistically, it significantly varied with time ($P<0.0001$), but not significantly with site ($P=0.1463$) and infiltrometer location ($P=0.0649$). Figure 3-8 and Figure 3-9 show the variation in the saturated hydraulic conductivity among the three infiltrometers on the same day as well as the variation with time.

It should be also noted that the saturated hydraulic conductivity was estimated from the slope of the linear portion of the cumulative infiltration curve and separating the "linear portion" was subjective rather than objective.

Infiltration

Infiltration is an important parameter that affects the amount of pollutant that is attenuated during a simulation (Barfield et al., 1998). The infiltration rate was not consistent among the three double ring infiltrometers or on different days.

Figure 3-8 Saturated hydraulic conductivity for site 1

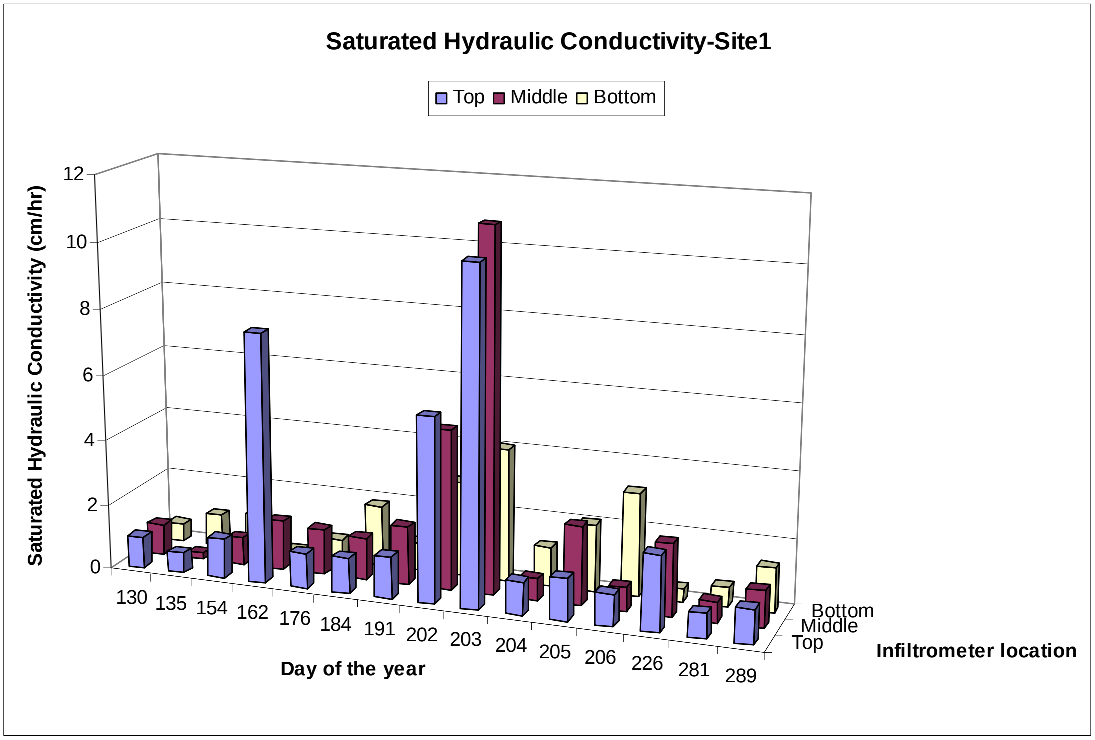
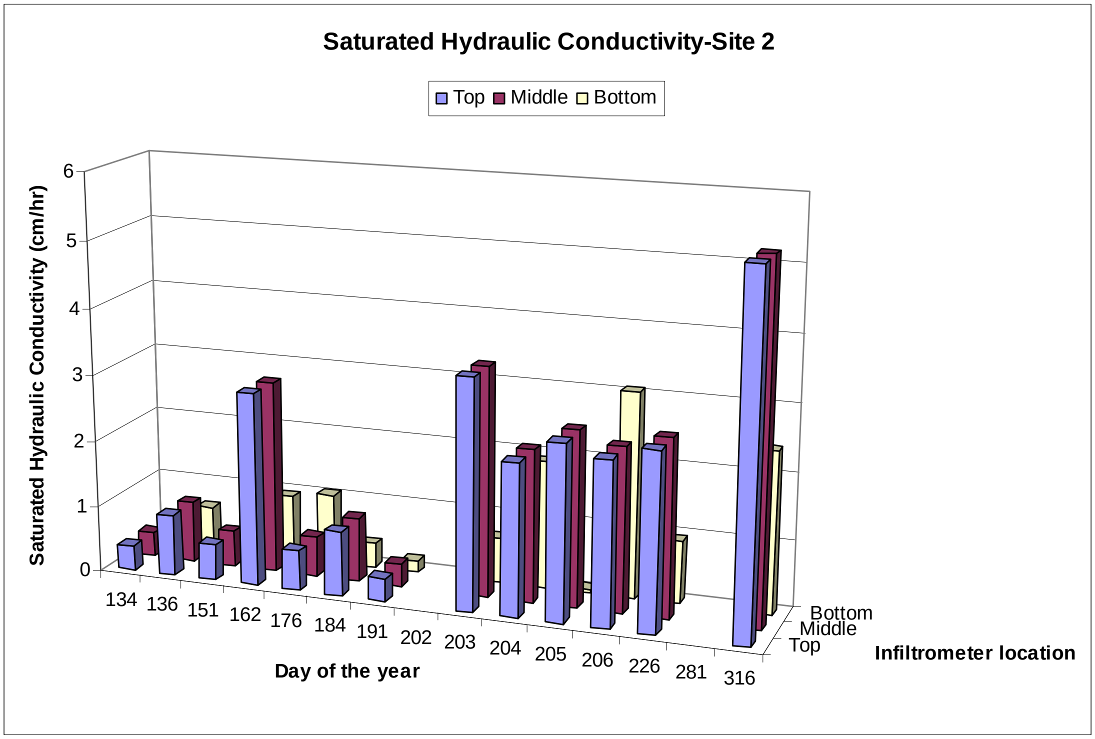


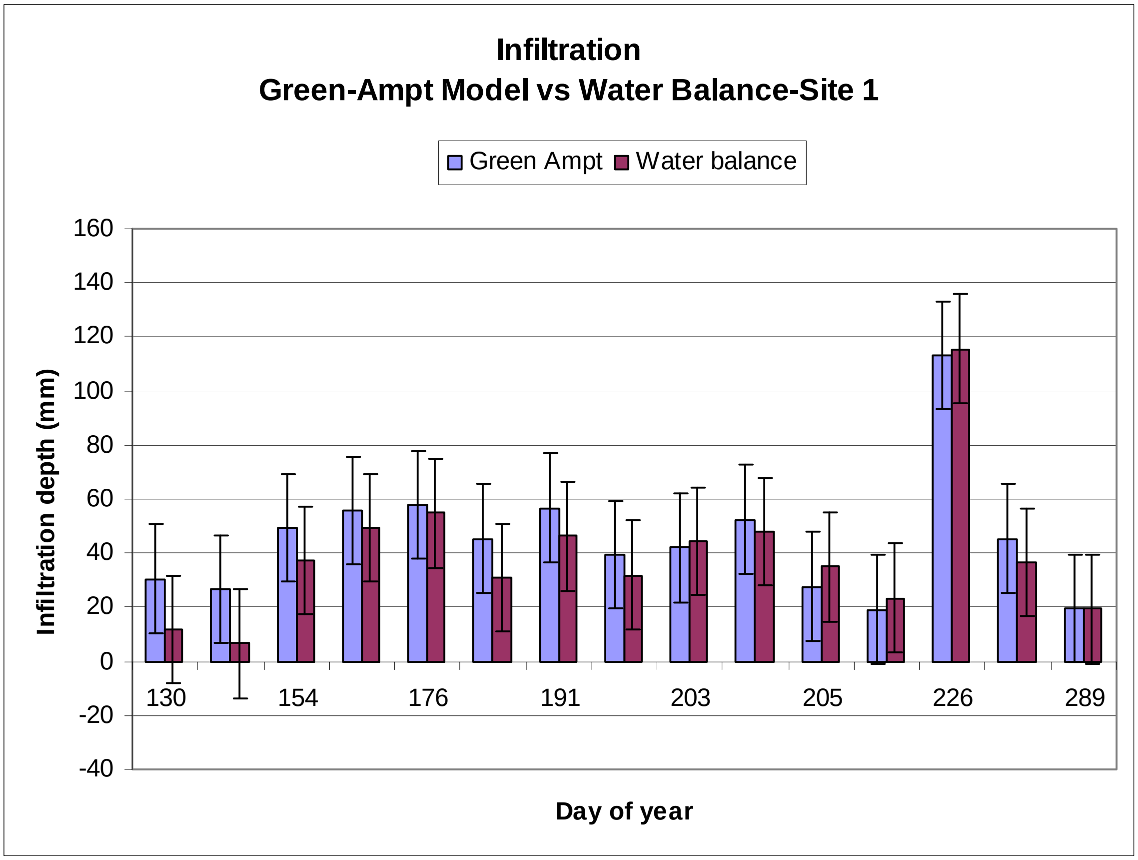
Figure 3-9 Saturated hydraulic conductivity for site 2

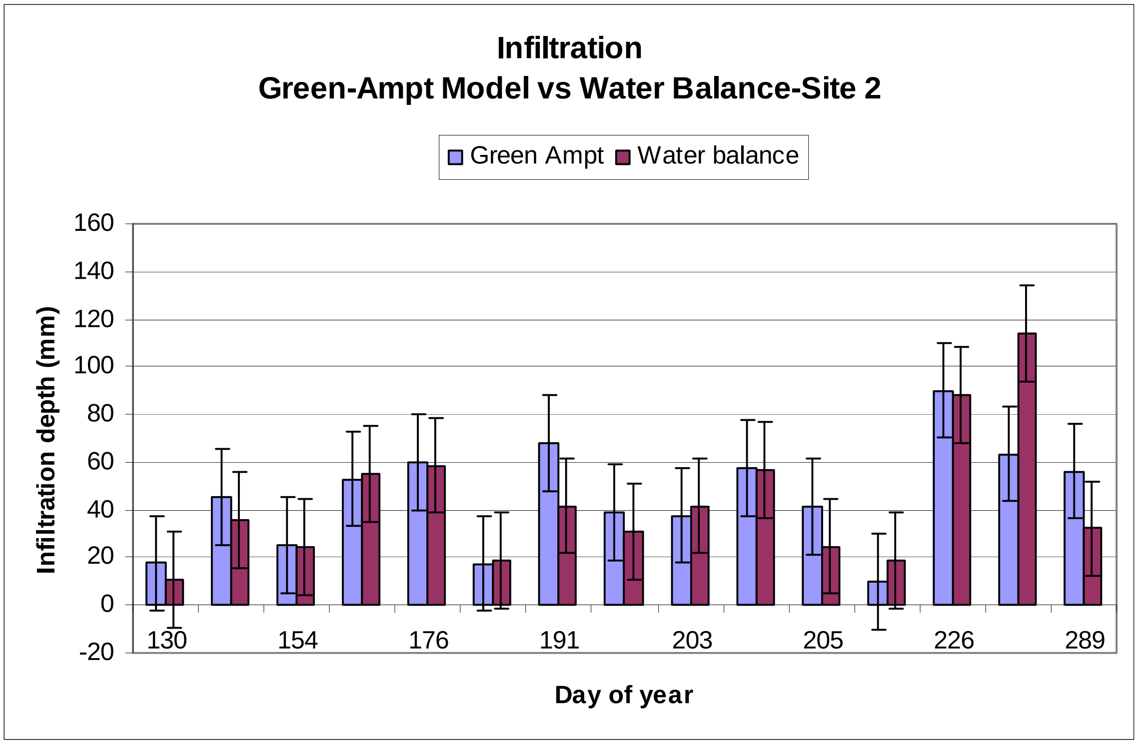


Infiltration-Green-Ampt model versus water balance method

Infiltration was estimated using both the Green-Ampt method and the water balance method (Figure 3-10). In general, the Green-Ampt method and the values obtained from the water balance method were close. For capillary pressure, the weighted average was used, though the value had a big range. Estimated saturated hydraulic conductivity was not consistent throughout the season even though it is supposed to be a constant for a given soil. This may be due to the spatial variability and development of belowground biomass. Average value of saturated hydraulic conductivity of all simulation was used in the calculations.

Figure 3-10: Estimation of infiltration using Green-Ampt Model and water balance method





Total infiltration and infiltration percentage

The regression models fit for pollutant loadings with the percentage of water retained showed a negative correlation for all three pollutants. Figure 3-12, Figure 3-12, and Figure 3-13 show the correlations between water retained and N, P, and TSS loads in runoff from VFS. As water retained reached 100 percent, pollutants that escaped with the runoff became minimal. The relationship was much stronger with nitrogen and phosphorous than sediments. This was due to the fact that sediment is not soluble and, therefore not transported the same way N and P are transported. These correlations provide good evidence that infiltration played a major role in attenuating pollutants. Regression models of the water retained percentage had R^2 values of 0.76, 0.65 and 0.44 with PTE of N, P and TSS, respectively. P value for all three correlations was <0.0001.

Figure 3-11 Correlation between water retained percentage and N load in runoff (P<0.0001)

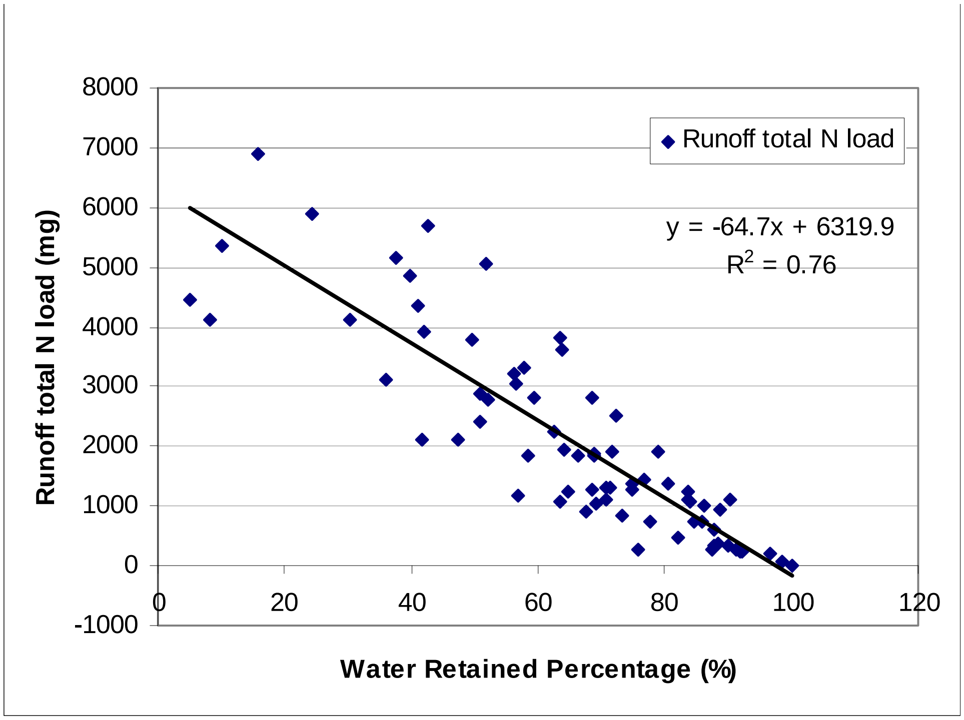


Figure 3-12 Correlation between water retained percentage and P load in runoff (P<0.0001)

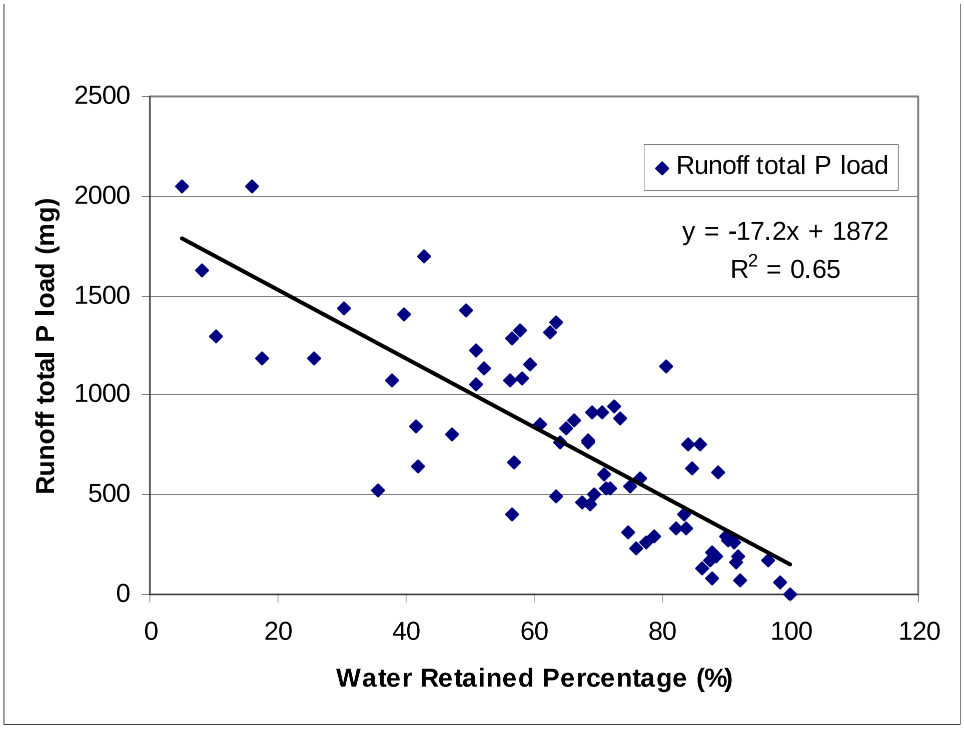
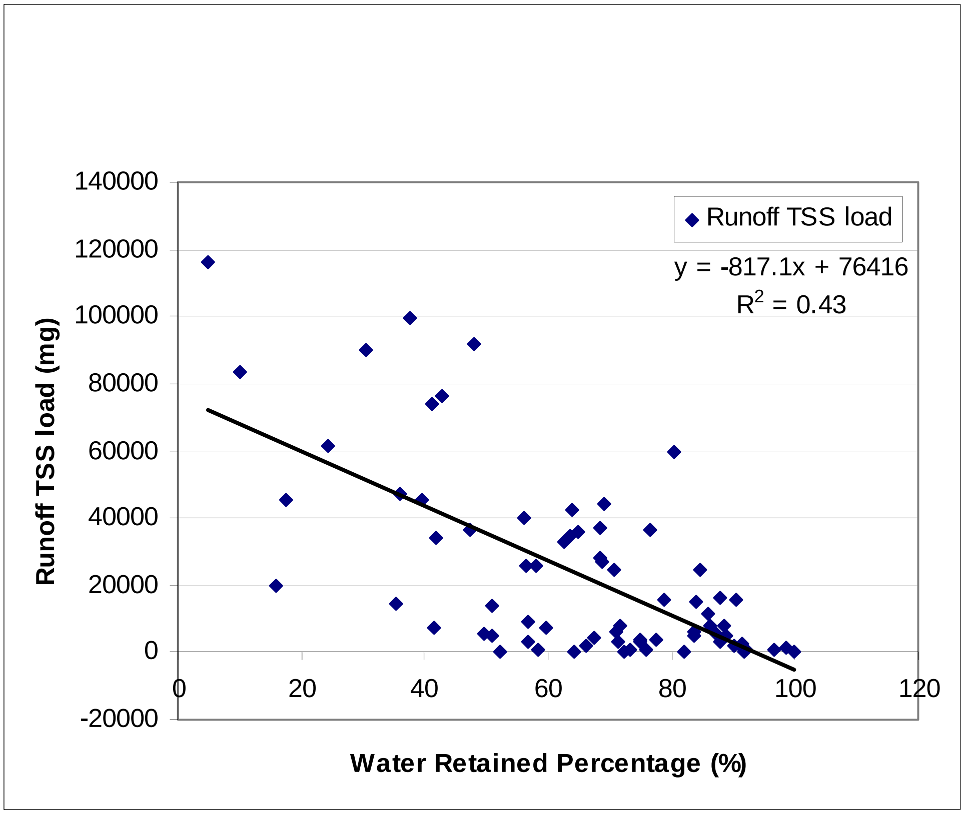


Figure 3-13 Correlation between water retained percentage and TSS load in runoff (P<0.0001)



The amount of water that infiltrated during a particular simulation greatly depended on the soil moisture. Dry soils have the ability to absorb more water than wet soils. Therefore, dry soils must receive more water to become saturated and initiate surface runoff. On the other hand, moist soils and nearly saturated soils started to generate runoff quickly. A regression model for these two variables was fit with a slope of -3.36 ($P<0.0001$) and an R^2 of 0.56 (Figure 3-12). It can be expected that a VFS with lower moisture content has the capacity to reduce more pollutants than with wet soil conditions.

Figure 3-14 Correlation between soil moisture and water retained

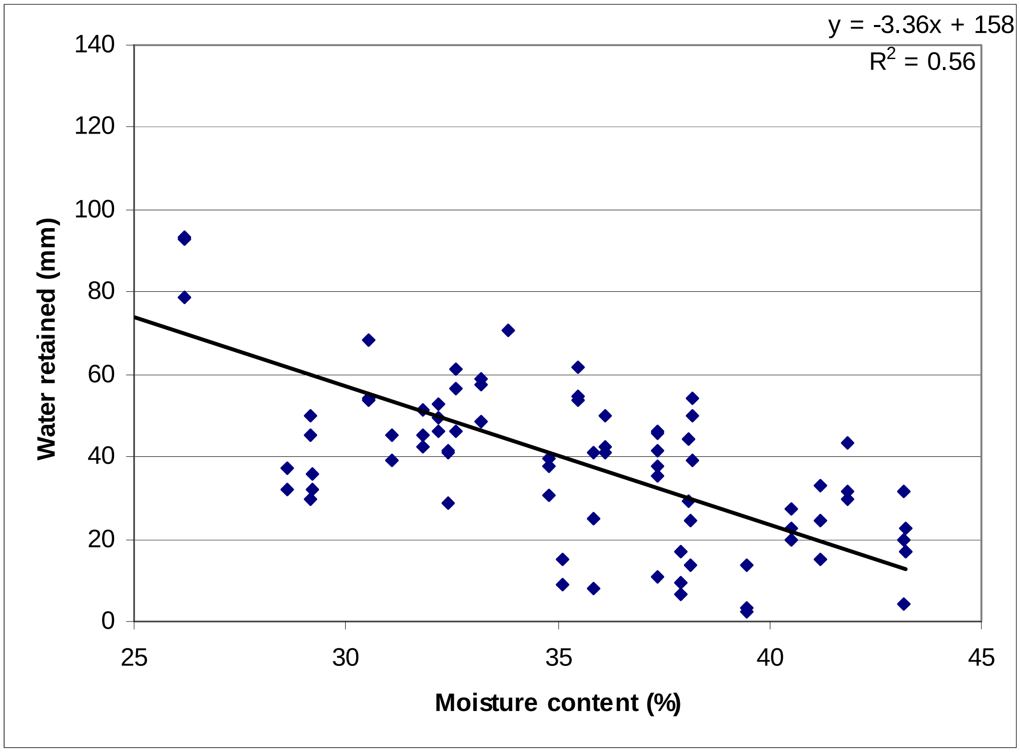


Figure 3-15 Correlation between simulated rainfall and water retained

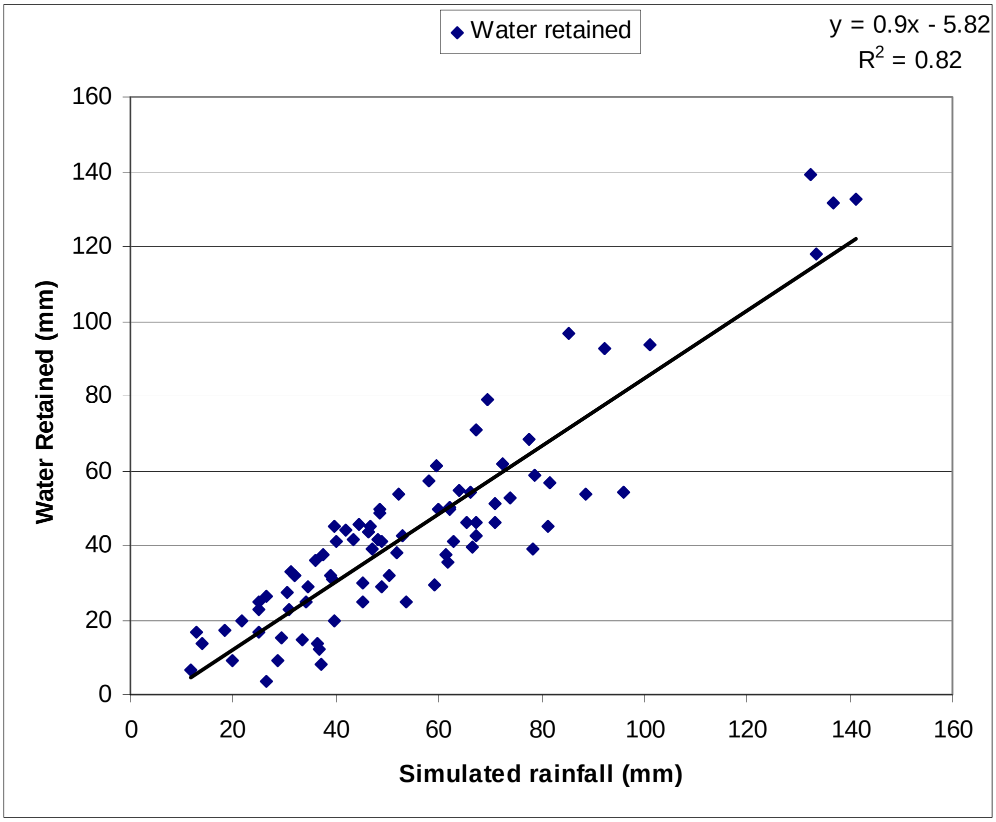


Figure 3-15 shows the correlation between water retained and applied rainfall with a slope of 0.9 and an R^2 of 0.82 ($P<0.0001$). It is understandable because as the amount of applied rainfall increases, the amount of water available for infiltration also increases.

A multiple regression model was fit for total infiltration (ti) with applied rainfall (ra, $P<0.0001$), soil moisture (sm, $P<0.0001$) and above ground biomass (bm, $P=0.0013$) as predictor variables with an R^2 value of 0.85. The resulting regression model is:

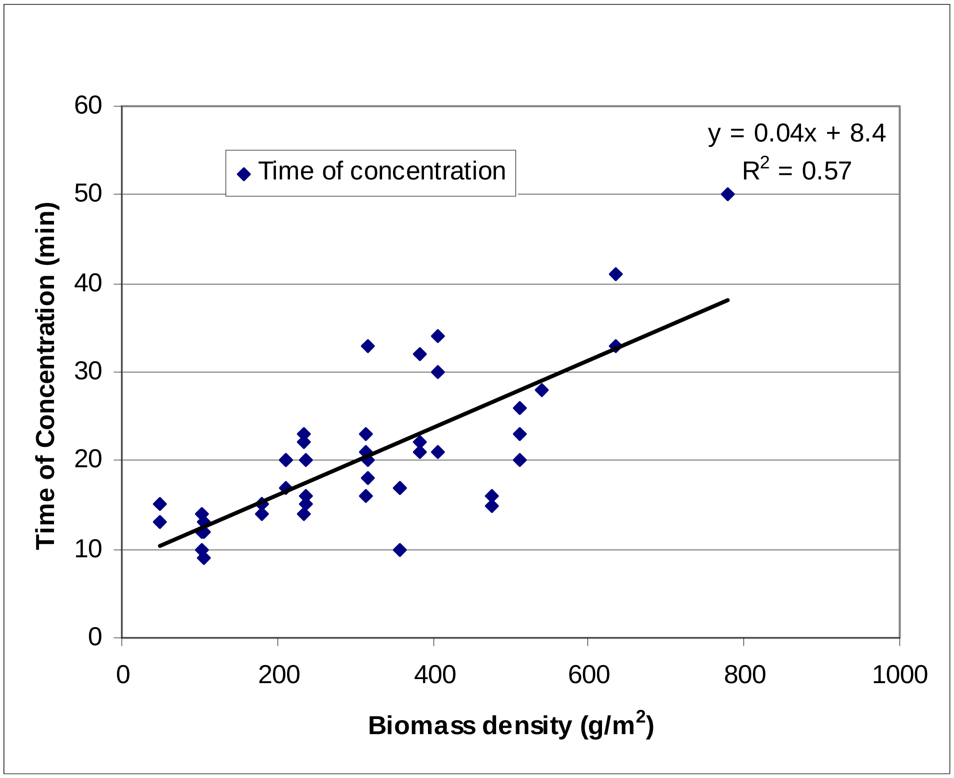
ti (L) = 4243.7 + 31.2 ra - 121.7 sm + 2 bm.

From this model, it can be seen that the total amount of water that infiltrated also varied with above ground biomass density, although the impact of above ground biomass density on infiltration was not as great as the other factors.

Time of concentration

Changes in the time of concentration were significant over time and effects of plots ($P=0.0325$), time ($P<0.0001$) and sites ($P=0.0284$). Effect of site is probably caused by the differences in the sites such as slope and vegetation composition. A regression model was fitted to see if there was any correlation between time of concentration and above ground biomass density. The model has an R^2 value of 0.57 with a significant relationship ($P<0.0001$). This relationship explains the variation due to time, since above ground biomass density and time have a positive correlation. Time of concentration directly depends on the velocity of the water that flows through the VFS. Growing vegetation stands against the flow of the water and acts as a barrier, thus reducing its velocity. Reduction in velocity increases the time of concentration. This correlation had to be approached cautiously, as the method used was peculiar. It was always difficult to find the appropriate peak points in the hydrograph. There were not many sharp peak points in the hydrograph. The accuracy level of the ISCO samplers adds more uncertainty to this method. In most instances, the difference between two points (0.001 m) was less than the accuracy of the sampler (0.003 m) given by manufactures (Teledyne ISCO 2005). Also, it could be possible that some parts of the VFS were still infiltrating and not contributing to runoff after the runoff started. This may lead to overestimation of residence time.

Figure 3-16 Correlation between above ground biomass and time of concentration



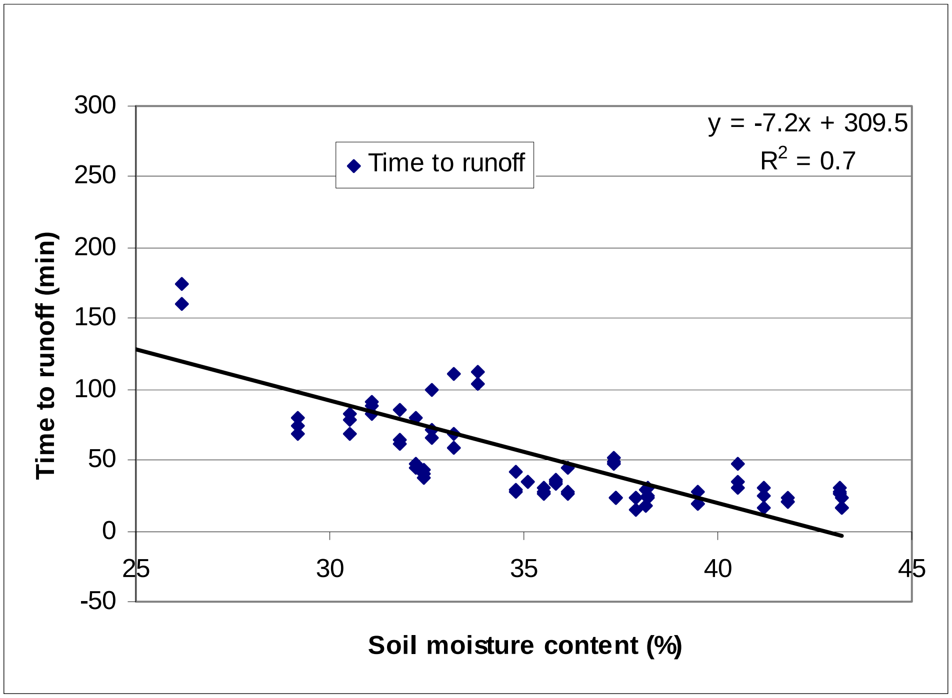
This phenomenon can be also explained by using Manning's coefficient (Jin et al., 2000). Manning's coefficient is a measure of surface roughness and changes with the growth stages of the vegetation. The higher the value of Manning's coefficient is, the greater the roughness of the surface and the greater the friction it renders to the flowing water. With the growth of grass, surface roughness increases, thus providing more friction to flowing water. Increasing friction reduces the velocity of the flow and increases the time of concentration. The reduced velocity also enhances settling of sediment particles.

Time of concentration is another parameter which can affect the performance of the VFS. The mechanisms by which pollutants are attenuated are time dependant. In other words, increased residence time gives the VFS more time to trap pollutants and increase infiltration of the water flowing through. So it can be expected that the VFS will have greater pollutant trapping efficiencies (PTE) with increasing above ground biomass density.

Time to runoff

Time to runoff changed considerably between simulations (P<0.0001) and plots (P=0.0019). The differences in the soil moisture were found to play a vital role in time to runoff. Figure 3-17 shows the regression correlation of these two variables.

Figure 3-17 Correlation between soil moisture and time to runoff

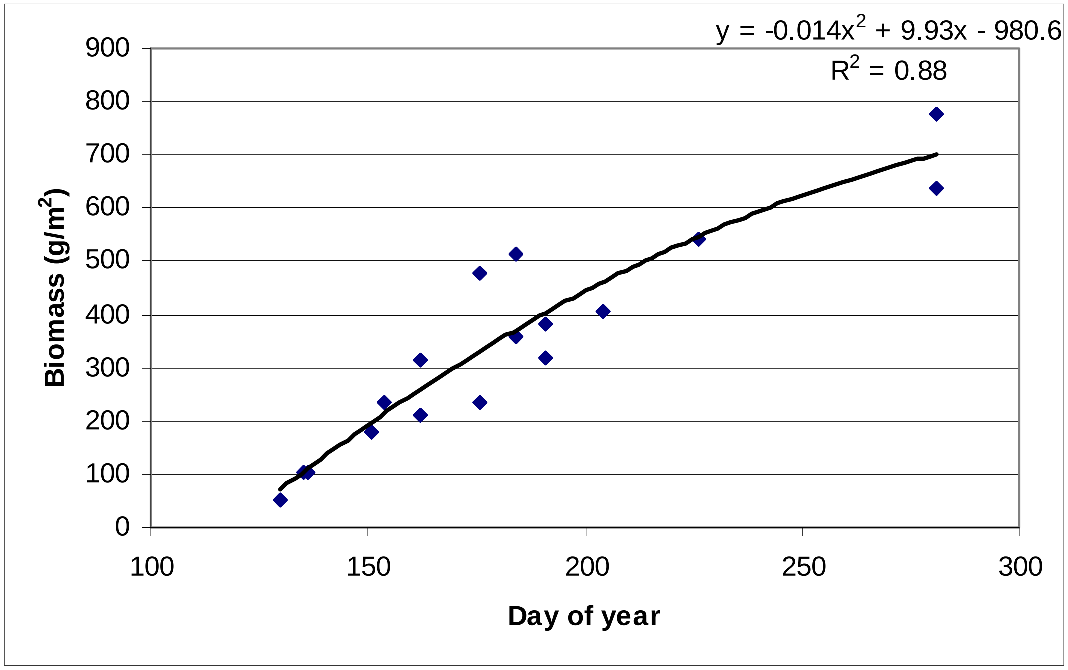


The relationship was found to be significant (P <0.0001 and R^2=0.71). There are no significant differences among sites (P=0.7066). The time to runoff directly correlated with the amount of water that is absorbed before the runoff starts, which is also called initial loss or initial abstraction. Initial abstraction depends on the soil moisture conditions. Dry soils have the ability to abstract more water than moist soils before runoff starts because more water would be required to bring the dry soils to saturated condition and to begin runoff. The variation in time to runoff among plots was probably due to the variability of the applied rainfall among plots.

Above ground biomass Density

Above ground biomass density increased with time as vegetation grew after burning. This relationship was fitted with a quadratic regression model. The relationship had an R^2 value of 0.88 and it was statistically significant ($P<.0001$). The variation in the above ground biomass was due to time and site effects ($P<.0001$).

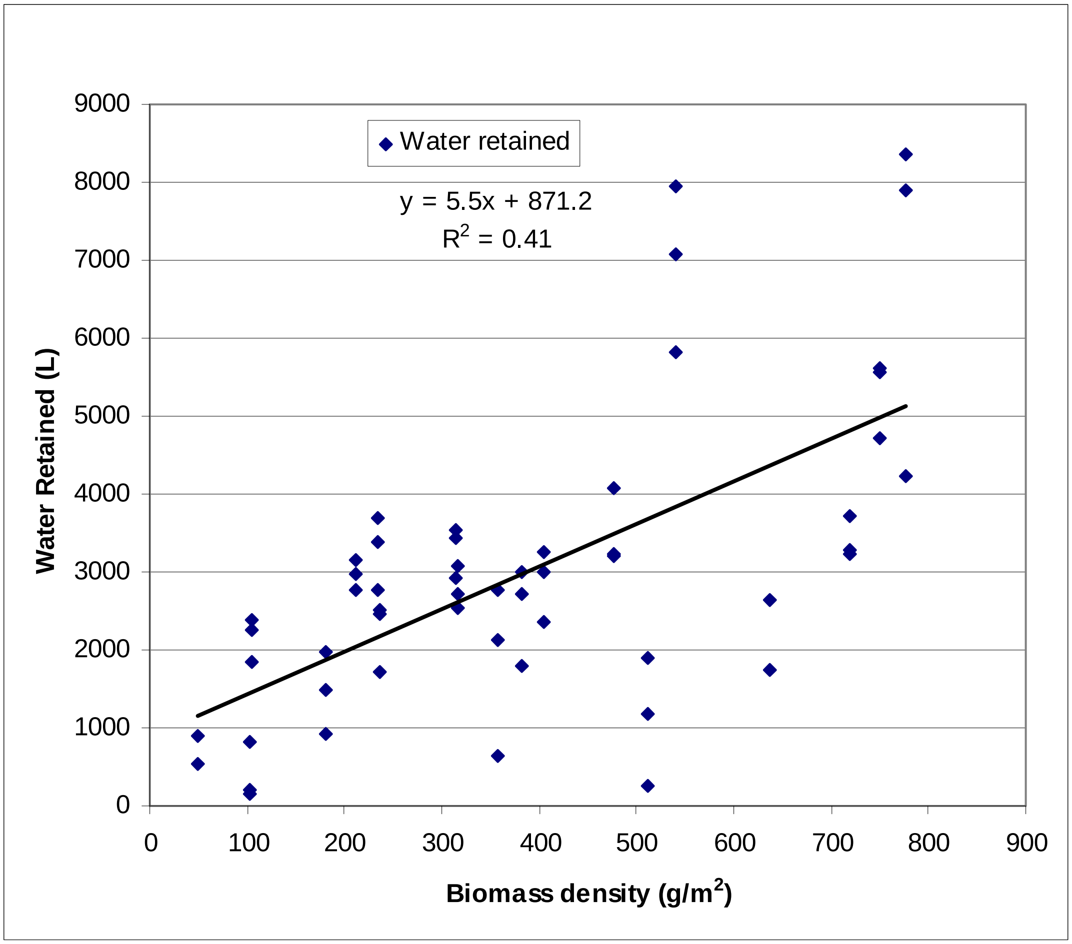
Figure 3-18 Change in above ground biomass over the time



Above ground biomass density varied among the sites mainly because of the difference in the vegetation composition. Grasses comprised over 90% of the vegetation at site 1 and included grasses such as Indian grass, big bluestem and switch grass. Site 2 had more forbs than grasses and Chinese bush clover (*Sericea lespedeza*) was the dominant vegetation (50%). These differences would have contributed to the variability in above ground biomass among the two sites. According to literature (USDA-NRCS 2004), (Tufekcioglu et al., 1999), native grasses have extensive root systems which improve the infiltration.

A regression model was fit for total infiltration volume with above ground biomass density to see if there was any relationship (Figure 3-19). The relationship was significant with a P value of <0.0001 and an R^2 value of 0.41. The output of the model agrees with the concept found in the literature (Leeds et al., 1994), that the infiltration is influenced by the root systems of the native grass. But it should be also noted that, it was soil moisture which had a greater impact on infiltration volume. However, the output of the multiple regression provides statistical evidence to claim that above ground biomass has influence over infiltration volume.

Figure 3-19 Correlation between above ground biomass and water retained



Soil moisture

Soil moisture stayed mostly within the range of 30-40 % except on a few days. Comparatively, this year was wetter than the previous years. Figure 3-20 shows the monthly precipitation over three years (Kansas State Research and Extension 2008). During the growing season (March-September) in general 2007 received more natural rainfall except in the month of August (this comparison is based on the data from Kansas State University weather station in Manhattan). It was difficult to see the effect of soil moisture, especially when the soil was dry. Statistically, soil moisture significantly changed over time (P<.0001) with no significant difference between sites (P=0.9988).

Figure 3-20 Monthly precipitation over the three year period (2005-2007) Source-Kansas State Research and Extension

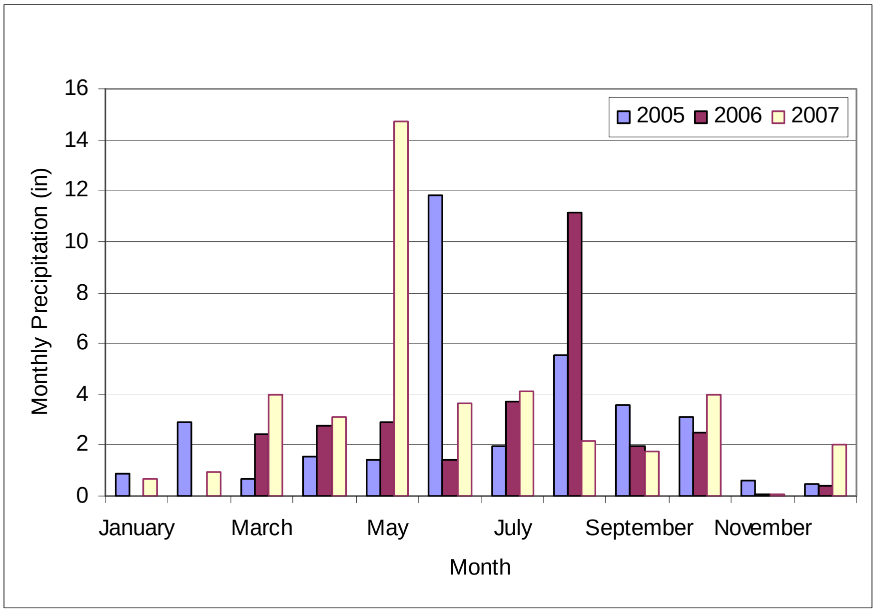
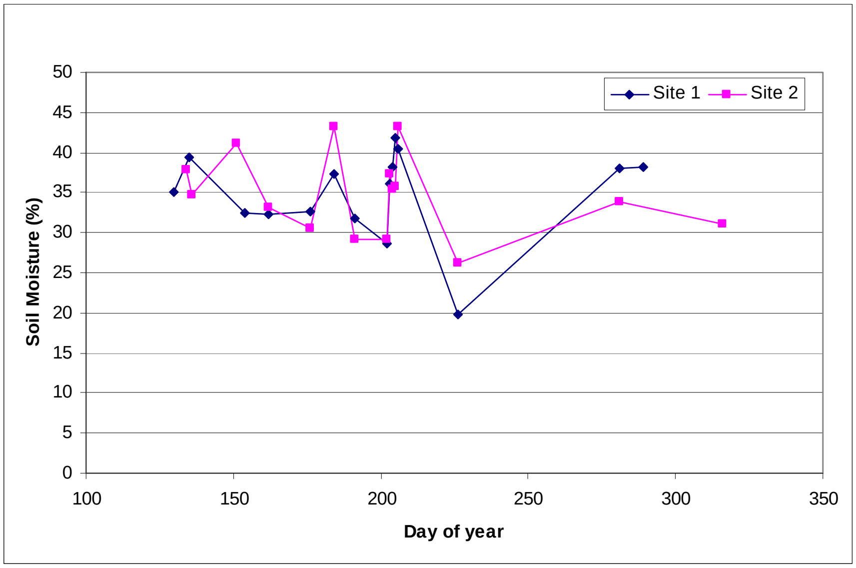


Figure 3-21 Change in soil moisture over time



Water Balance

Water balance was the base for calculating a important parameter, infiltration. It was calculated from the other measured parameters and many other parameters such as PTE were built on top of this. The calculated water balance for plot 1 is given in the following figures.

Figure 3-22 Water balance of inputs (runon and simulated rainfall) plot 1

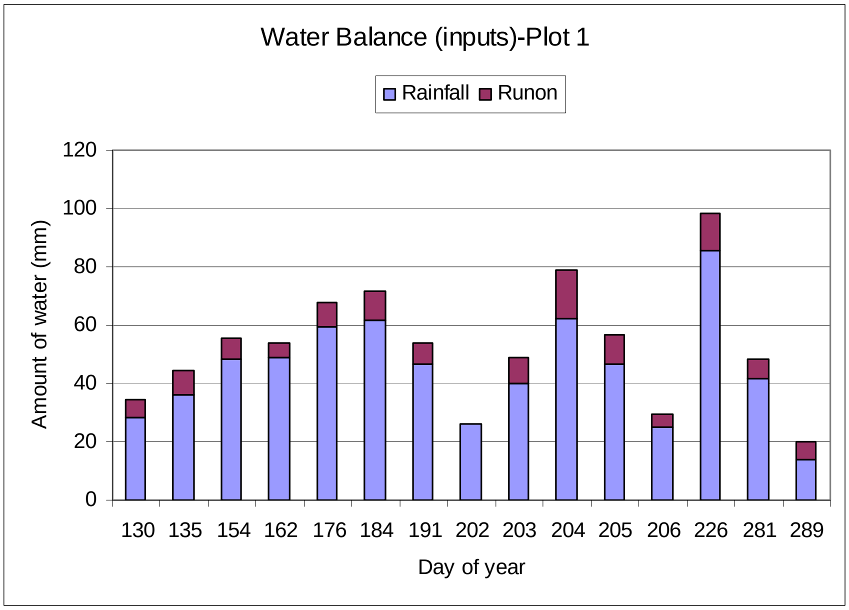
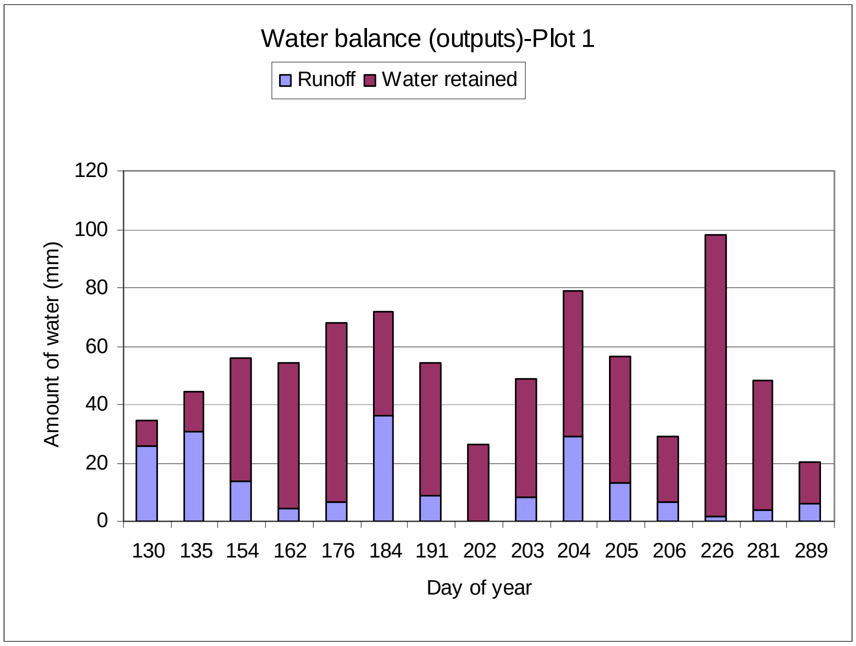


Figure 3-23 Water balance of outputs (runoff and water retained) plot 1



Pollutant Trapping Efficiency of VFS

Pollutant trapping efficiency (PTE) is used as a scale to measure the performance of the VFS. Higher pollutant trapping efficiency implies better performance by the VFS and higher pollutant attenuation. PTE values for P varied drastically while TSS and N stayed consistent. It should be noted that 100 % PTE efficiencies were obtained not because the VFS were 100 % efficient, but mainly due to analysis problems. Several runoff samples had TSS concentration below the detection level (1 mg/L) of the analysis. On simulations when discrete samples were taken, it was not a problem, since its contribution to the mass balance calculation was only for a fraction of the hydrograph. On simulations when composite samples were taken, if the TSS was below the detection level, then that led the calculation to yield 100 % PTE for TSS. On other occasions, very little runoff was produced so that no sample was pulled for analysis, which yielded 100% PTE for all pollutants (eg: 8th August 2007 on plot 6).

PTE efficiencies varied widely, especially for N and P. Summary statistics of PTE after removing outliers are given in the Table 3-1. PTE for N varied from 56% to 100% while PTE for P ranged from -75% to 100 %. For TSS, PTE was within the limit of 67-100%. PTE values for TSS were more consistent throughout the whole study and mostly of the in the range of 90-100%. For P, few negative values were observed. In earlier research negative trapping efficiencies for phosphorous were also reported and the author hypothesized that it might have been caused by the re-suspension of the phosphorous particles that were adsorbed to soil particles in the previous simulations (Dillaha et al., 1989). This study site was used for almost three seasons. Nitrogen was removed from the site through various mechanisms such as plant uptake, volatilization, leaching, nitrification and denitrification. Phosphorous is conservative in nature with lower plant use than nitrogen. It is likely that phosphorus sorbed to soil particles that accumulated in the VFS and was resuspended during subsequent precipitation simulations and caused the negative values for PTE.

Several regression models were fitted in order to understand the factors that influence and cause variation in PTE. These models are discussed in the following sections.

Table 3-1 Summary statistics of Pollutant trapping efficiencies

Statistical parameter	Nitrogen	Phosphorous	Sediment
Minimum	56	-76	68
Maximum	100	100	100
Mean	84	24	95
Median	86	40	98
Standard deviation	12	47	7
95% Confidence interval-Lower limit	82	14	94
95% Confidence interval-Upper limit	87	35	97

Runoff and pollutant trapping efficiency

Runoff influenced the amount of pollutants that were transported in the runoff and its effect was analyzed with regression models (Figure 3-24, Figure 3-25, and Figure 3-26).

Figure 3-24 Correlation between runoff volume and nitrogen TE

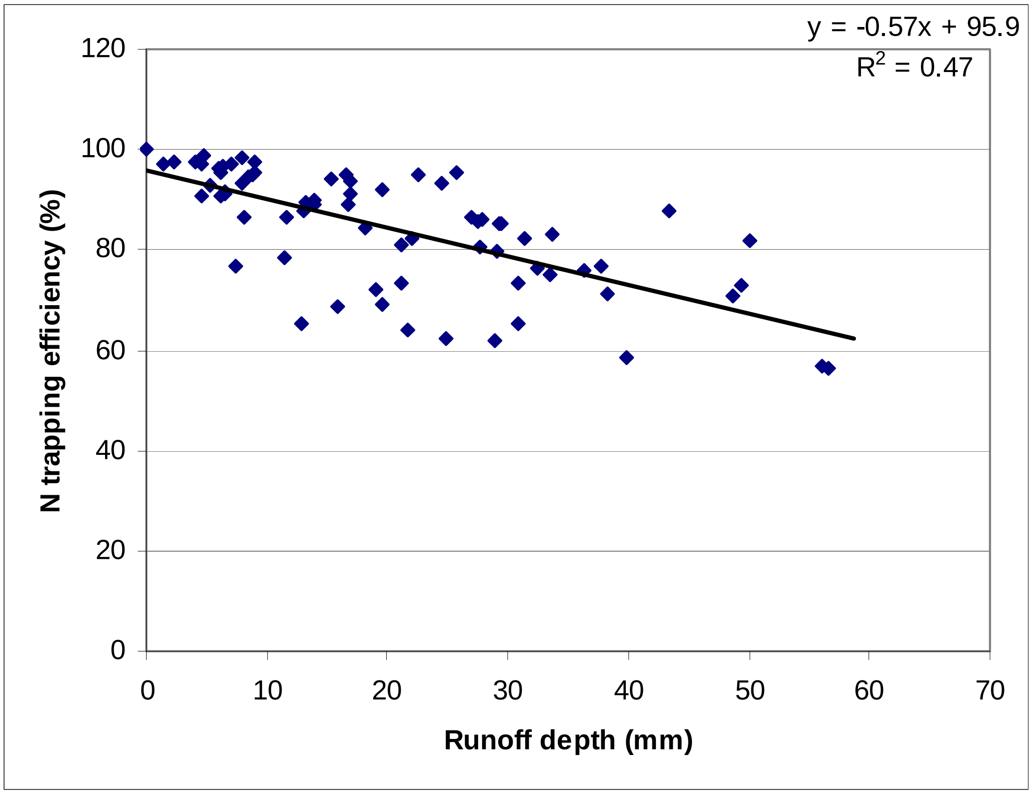


Figure 3-25 Correlation between runoff volume and phosphorous TE

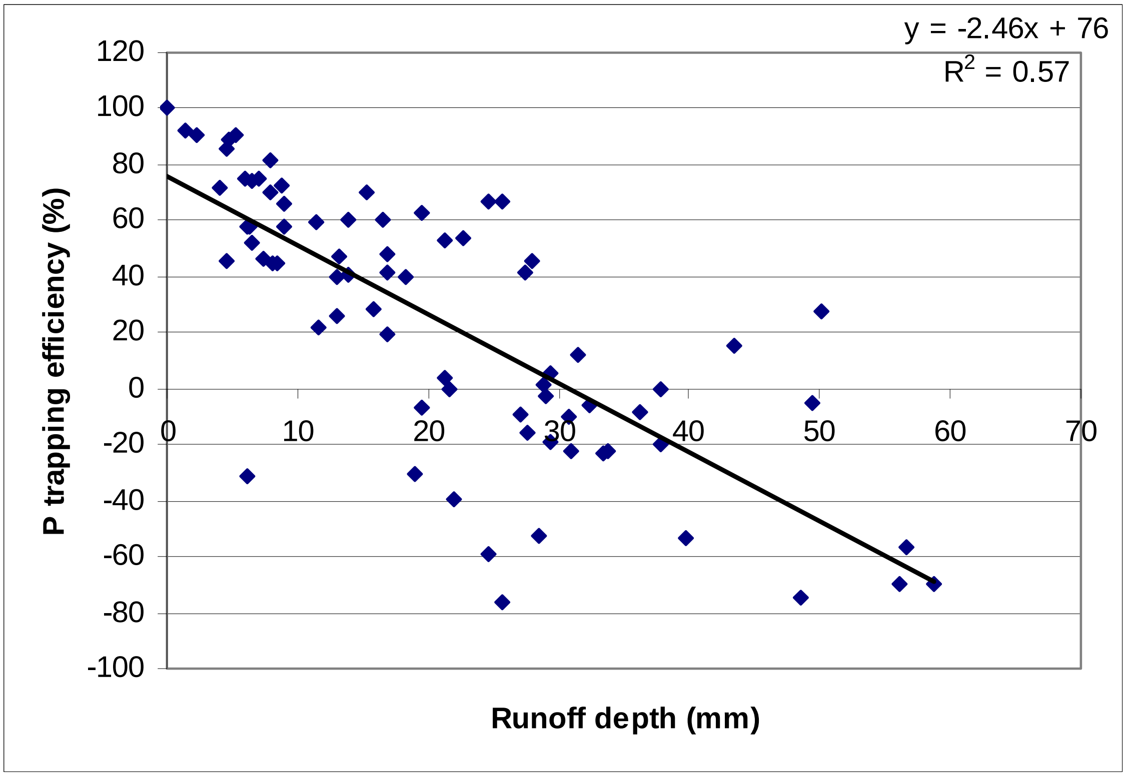
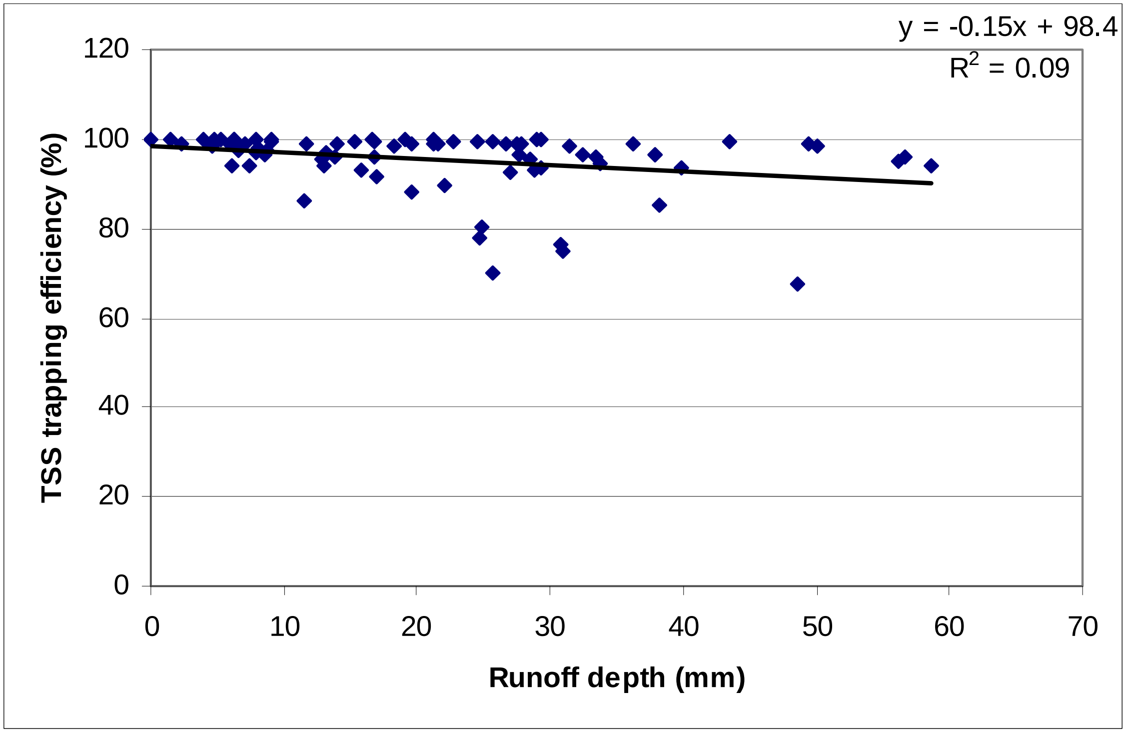


Figure 3-26 Correlation between runoff volume and sediment TE



These relationships were significant with P values of <0.0001 for N, <0.0001 for P and 0.0080 for TSS. The relationship was stronger for N (R^2=0.47) and P (R^2= 0.57) than for TSS (R^2=0.09). This difference could be due to the differences in the pollutant transport methods because nitrogen and phosphorous have soluble forms and could be transported with runoff. Sediment does not dissolve in water so it cannot be transported in solution form with runoff.

Percentage of water retained and pollutant trapping efficiency

Since pollutants were carried with water and infiltration was the main mechanism by which pollutants were attenuated, regression models were also fitted for PTE with water retained (Figure 3-27,Figure 3-28, and Figure 3-29). As expected, it was observed that increases in infiltration percentage increased the PTE. All three relationships had a P value of <0.0001 and R^2 values of 0.4 (N), 0.4 (P) and 0.3 (TSS). Also, it should be noted that N and P had nearly the same R^2 value while the R^2 value for TSS is a little bit lower. This may be due to the fact that TSS is transported differently than N and P. The results of the regression models confirm the theory that infiltration plays a major role in the pollutant attenuation as reported in the literature (Barfield et al., 1998).

Figure 3-27 Correlation between water retained % and nitrogen TE

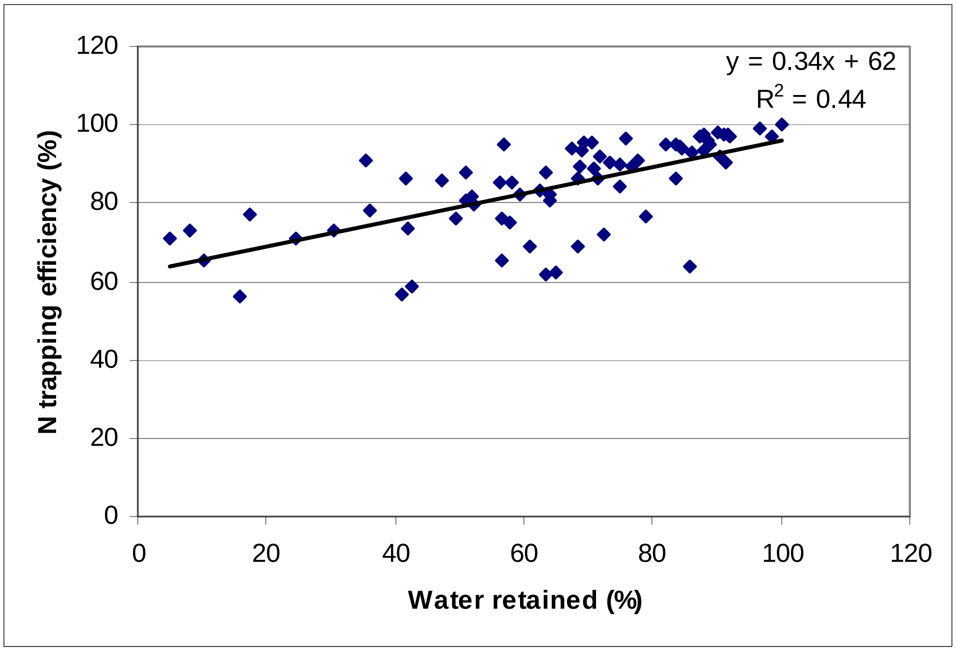


Figure 3-28 Correlation between water retained % and phosphorous TE

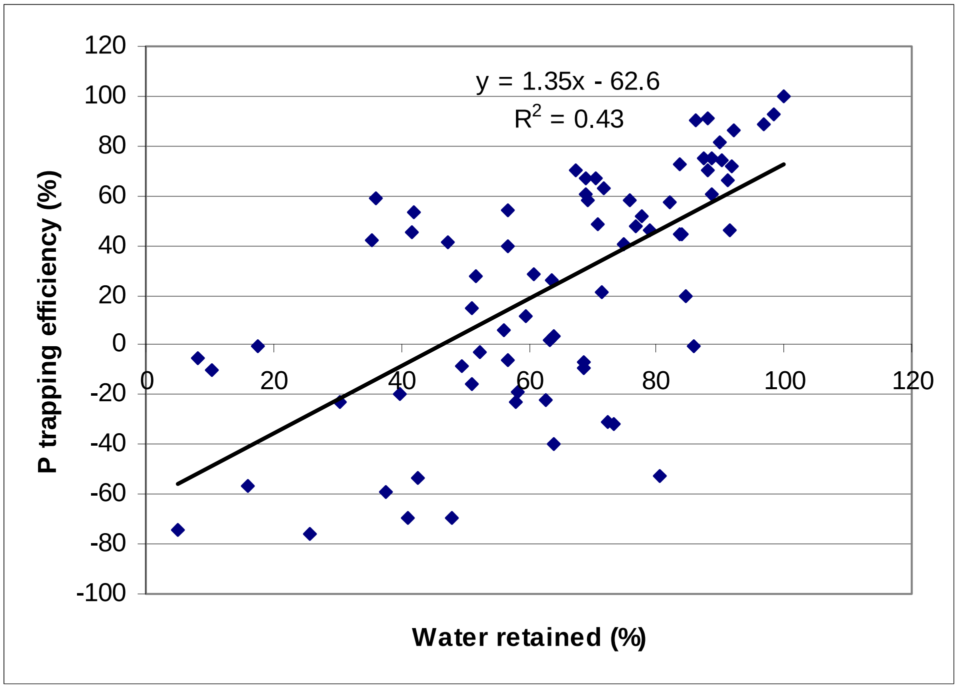
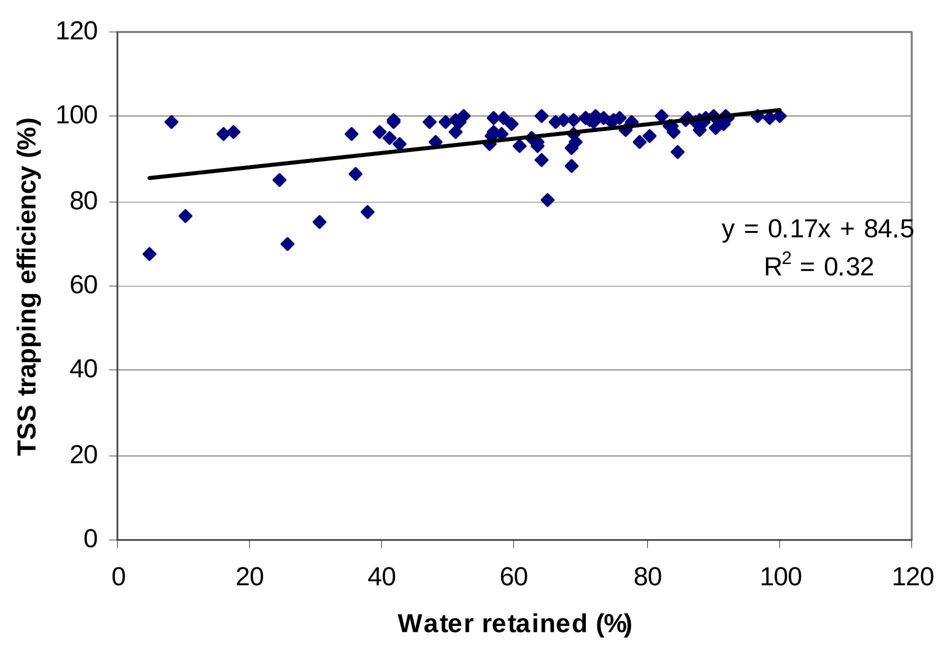


Figure 3-29 Correlation between water retained % and phosphorous TE



Above ground biomass density and pollutant trapping efficiency

Biomass is an integral part of VFS. The performance of VFS depends on how dense the vegetation is both aboveground and belowground because biomass alters the hydrological variables such as evapotranspiration, interception and infiltration. Also, these variables change with the growth of the vegetation. It can be assumed that infiltration improves with the development of roots, since they increase soil porosity. Also, vegetation at different growth stages may uptake different levels of nutrients. Regression models of PTE and above ground biomass were fit and are shown graphically in Figure 3-30, Figure 3-31, and Figure 3-32. PTE increases with the increasing above ground biomass density in all cases. P values for the relationships were 0.003, 0.001 and <0.0001 with R^2 values of 0.18, 0.2 and 0.28 for N, P and TSS, respectively.

Figure 3-30 Correlation between above ground biomass density and nitrogen TE

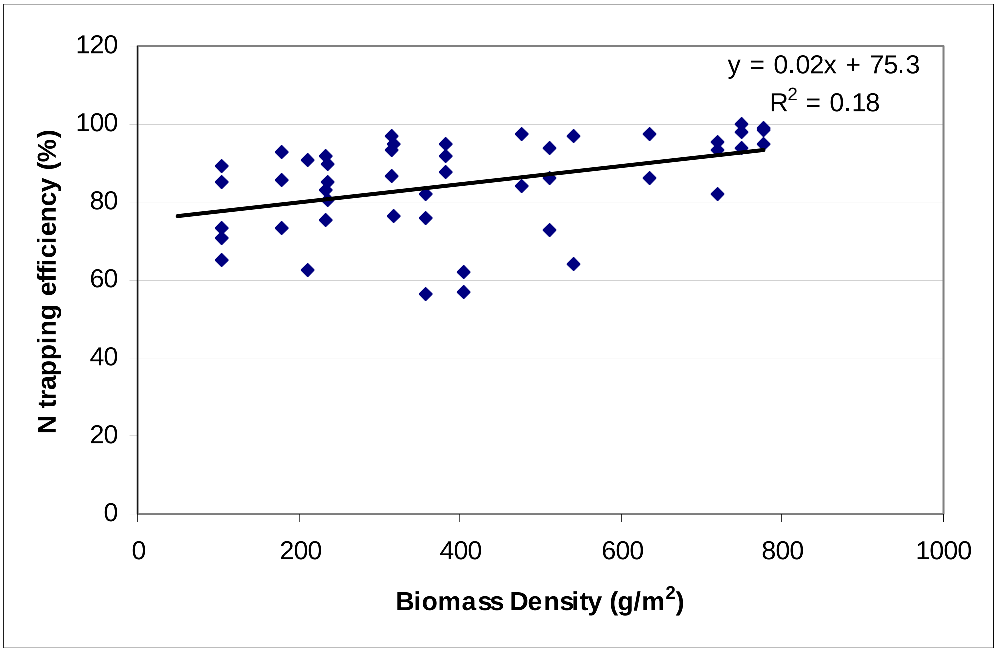


Figure 3-31 Correlation between above ground biomass density and phosphorous TE

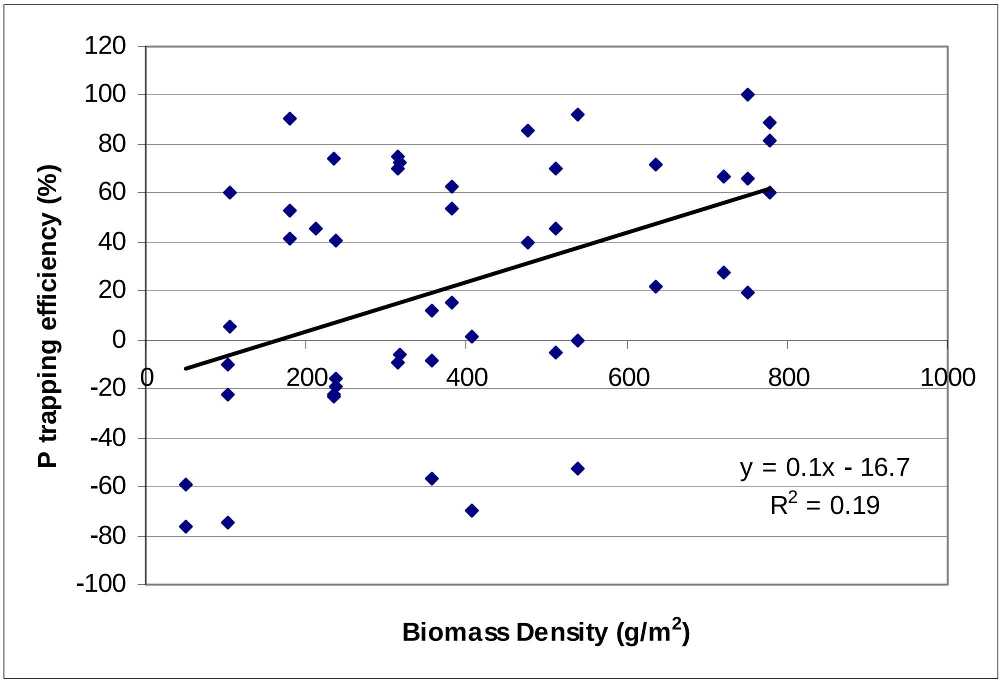
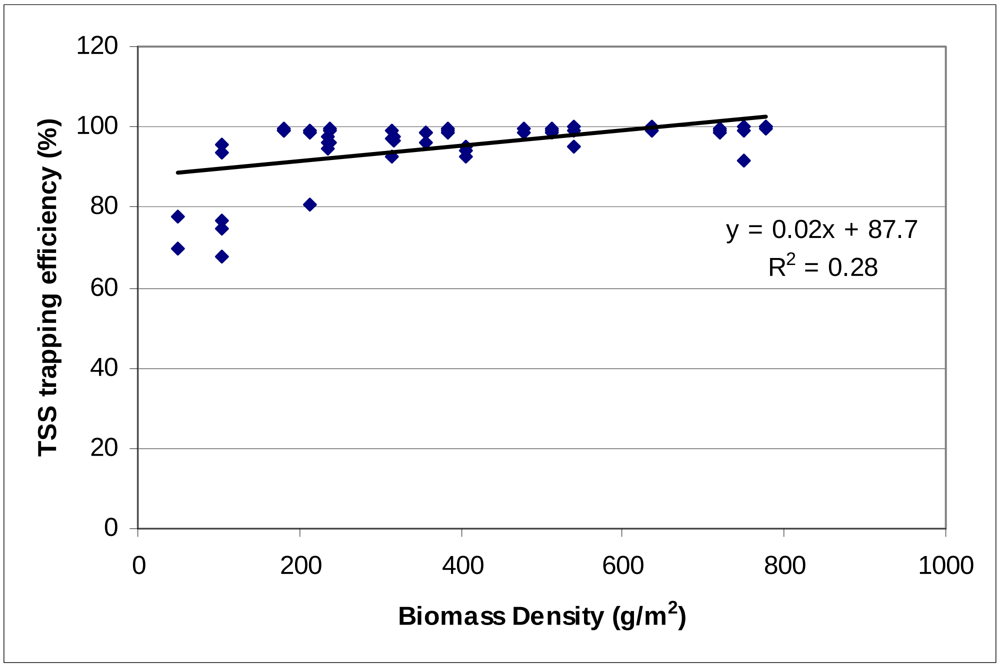


Figure 3-32 Correlation between above ground biomass density and sediment TE



Regression models were also fitted for PTE with soil moisture, applied rainfall and runon pollutant concentration, but these relationships were not statistically significant.

Multiple regression models were fit for PTE with infiltration percentage, applied rainfall, above ground biomass and soil moisture and variables were selected by backward elimination method. Variables that are significant at an α value of 0.1 are summarized in the Table 3-2.

Table 3-2 Summary of multiple regression models for PTE

	y	**Intercept**	**x_1**	**x_2**	**x_3**	R^2
1.	Nitrogen trapping efficiency	66.99	Infiltration percentage 0.38983 (P<.0001)	Applied rainfall -0.13507 (P=0.0172)		0.5506
2.	Phosphorous trapping efficiency	-48.82	Infiltration percentage 1.59235 (P<.0001)	Applied rainfall -0.96409 (P<.0001)	Biomass 0.08169 (P=0.0080)	0.7068
3.	Sediment trapping efficiency	71.91	Infiltration percentage 0.14471 (P=0.0016)	Biomass 0.01548 (P=0.0076)		0.4564

Based on the multiple regression models, infiltration percentage was the most significant parameter for all three PTE. Aboveground biomass and simulated rainfall also had effects on PTE.

Effect of different management practices on VFS performance

One of the objectives of the study was to compare the effect of different management practices (mowing and burning) used to maintain VFS. Table 3-3 provides a summary of PTE values, water retained percentage and time of concentration before and after management practices. The seasonal averages, excluding the last two simulations (which were done after management practices) for the same variables are also given for easy comparison. To determine a concrete trend, more experiments need to be done.

Table 3-3 Summary of PTE values, water retained percentage and time of concentration before and after management practices and P values for respective statistics

		Date	**Pollutant trapping efficiencies**			**Water retained %**	**Time of concentration**	**COD concentration**
			N	**P**	**TSS**			
Site 1	Before mowing	10/12/07	91.89	46.59	99.56	81.55	37.00	26.13
Site 1	After mowing	10/20/07	82.07	43.10	93.57	65.10	33.50	78.71
% change due to mowing			-9.82	-3.4	-5.99	-16.45	-3.5	52.58
Site 1 Seasonal mean without last simulation			78.61	0.04	93.31	64.17	20.69	
Site 1 - P values			0.2956	0.1790	0.5997	0.5880	0.0004	
Site 2	Before burning	10/12/07	97.37	76.80	99.91	91.84	55.67	33.56
Site 2	After burning	11/17/07	82.73	-45.30	90.33	57.49	17.00	42.34
% change due to burning			-14.64	-111.5	-9.58	-34.35	-38.67	8.78
Site 2 Seasonal mean without last simulation			89.31	46.61	97.82	69.11	22.37	
Site 2 - P values			0.1044	0.0687	0.0008	0.1511	0.0166	

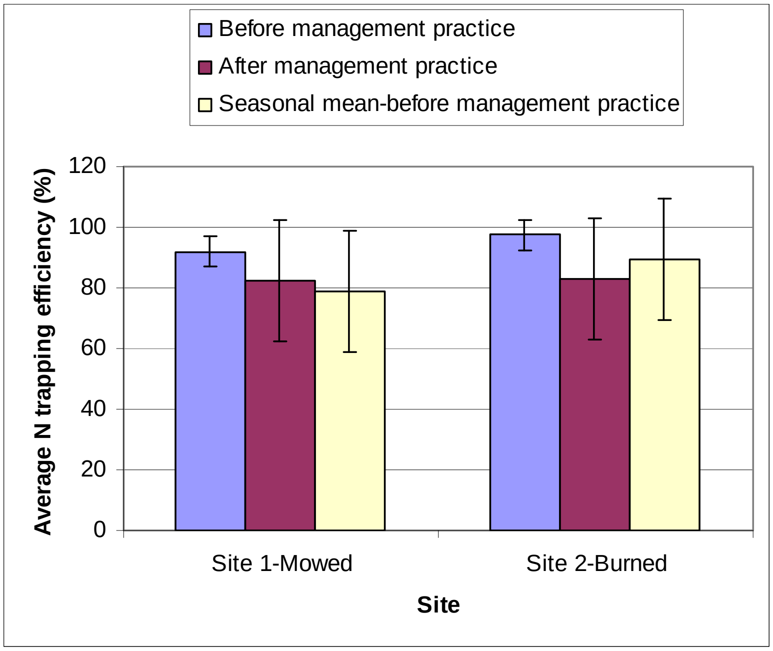
Note: Given P values are for mean comparison with a null hypothesis of all means are equal and an alternative hypothesis of at least one mean is different among others.

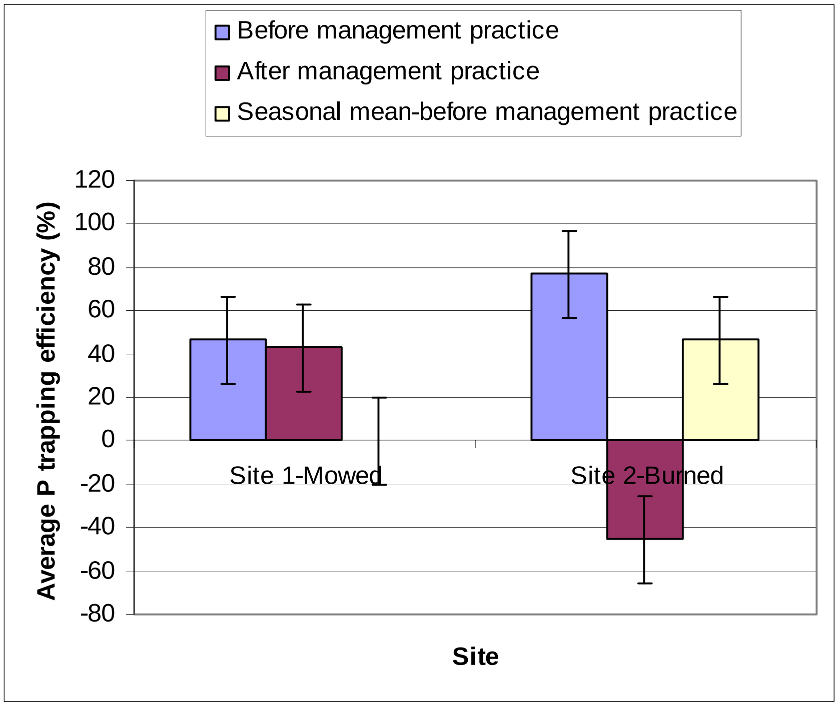
Pollutant trapping efficiencies

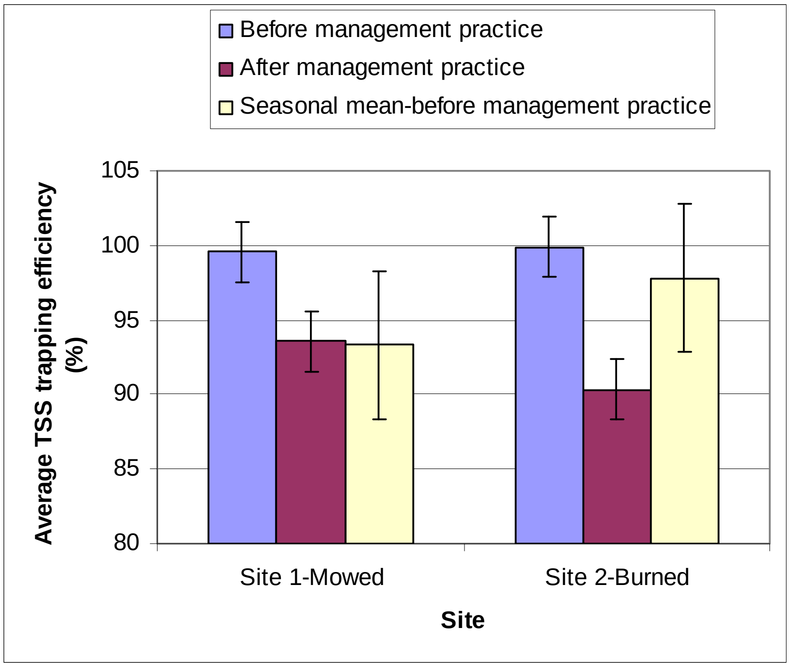
Comparisons of PTE values of simulations before and after burning are shown in Figure 3-33. On all instances, PTE values after management practices were lower than the PTE values before management practices. Also, they were less than the average for the season except for phosphorous on site 1. In general, mowing and burning management practices seem to reduce the PTE of VFS systems. This might have been caused by increased runoff due to lower amount of water retained within the VFS by the means of interception and infiltration. Once the above ground biomass is removed there will be less interception. Also, vegetation reduces the flow velocity by increasing roughness and increases infiltration. Fire consumed the organic matter on the soil which would otherwise hold water and improve infiltration (Robichaud, 2000). Increased amount of runoff would have carried more pollutants with it thus causing a reduction in

PTE. However, these reductions in PTE were not statistically significant except for sediment trapping in site 2 (see Table 3-3 for P values).

Figure 3-33 Effect of management practice on pollutant trapping efficiencies







COD concentration

COD is a key indicator of amount of organic matter in the water. Average COD concentration of runoff water is shown in Figure 3-34.

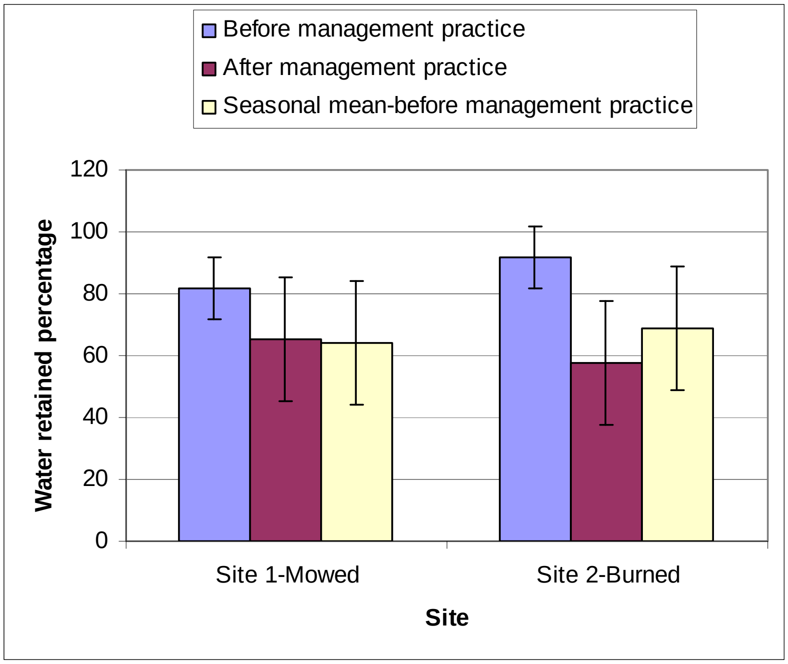
Figure 3-34 Effect of management practice on COD

There were differences in the COD concentration before and after management practices. Mowing might have left fine grass clippings on VFS and it might have been carried by the water along with the debris and caused an increase in the COD. After burning, char and debris were carried with runoff and it changed the COD concentration. The differences in the behavior between mowed site and burned site might have been caused by the grass clippings from mowed site.

Infiltration/water retained percentage

Several published studies about fire effects on infiltration caused by hydrophorbicity are available (Robichaud 2000). The percentage of water retained was reduced after management practices, especially after burning. Figure 3-35 shows the differences in water retention before and after management practices. This result could be a combination of reduced aboveground vegetation, reduced organic matter and increased hydrophobicity. Fire consumes the organic matter and reduces the surface detention. Vegetation can intercept rainfall and increase the water retained percentage. However, statistically, there was no significant difference (see Table 3-3 for P values).

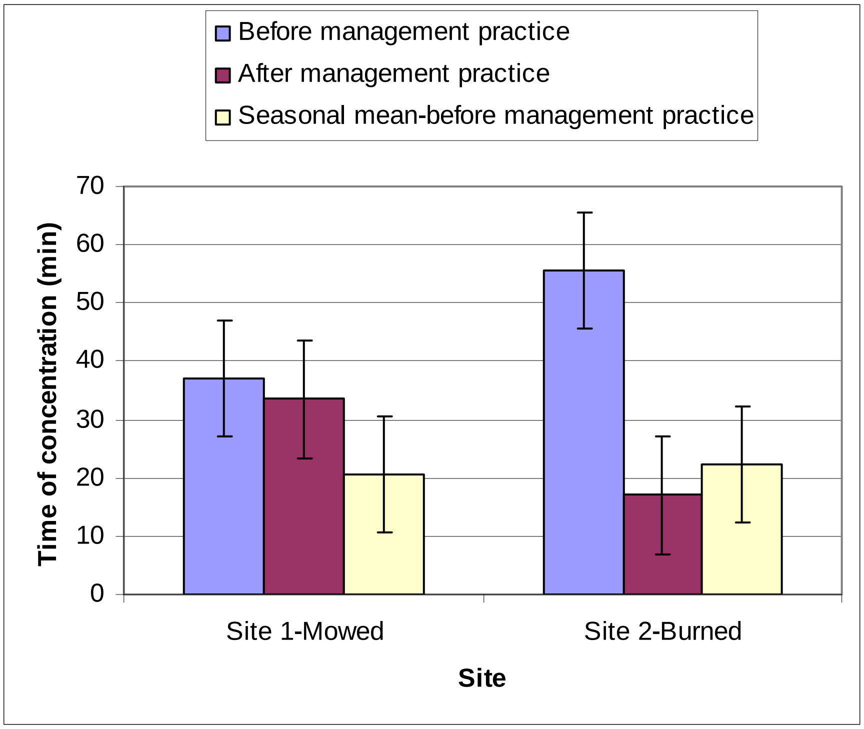
Figure 3-35 Effect of management practice on water retained percentage



Time of concentration

When comparing with the simulation just before the management practice, time of concentration was reduced after management practices on both sites (Figure 3-36). The removal of vegetation would have reduced the surface roughness, thus increasing flow velocity and reducing time of concentration, especially in the case of burning. Statistically, at least one pair of means has significant differences (see Table 3-3 for P values).

Figure 3-36 Effect of management practice on time of concentration



Effect of intense storm events on VFS performance

Intense storm events led to saturated conditions, especially after the first two days of the simulation. On the first day of the intense simulation week, there was no runoff and, therefore 100% PTE. After the first day PTE values were reduced with increasing amount of simulated rainfall and bounced back when simulated rainfall amount was reduced. Phosphorous seemed to be the most sensitive pollutant to intense storms, followed by nitrogen. Sediments were insensitive to storm intensity and showed little variation in trapping efficiency. Figure 3-37 and Figure 3-38show the effects of intense storm on PTE.

Figure 3-37 Effect of intense storm on PTE- site 1

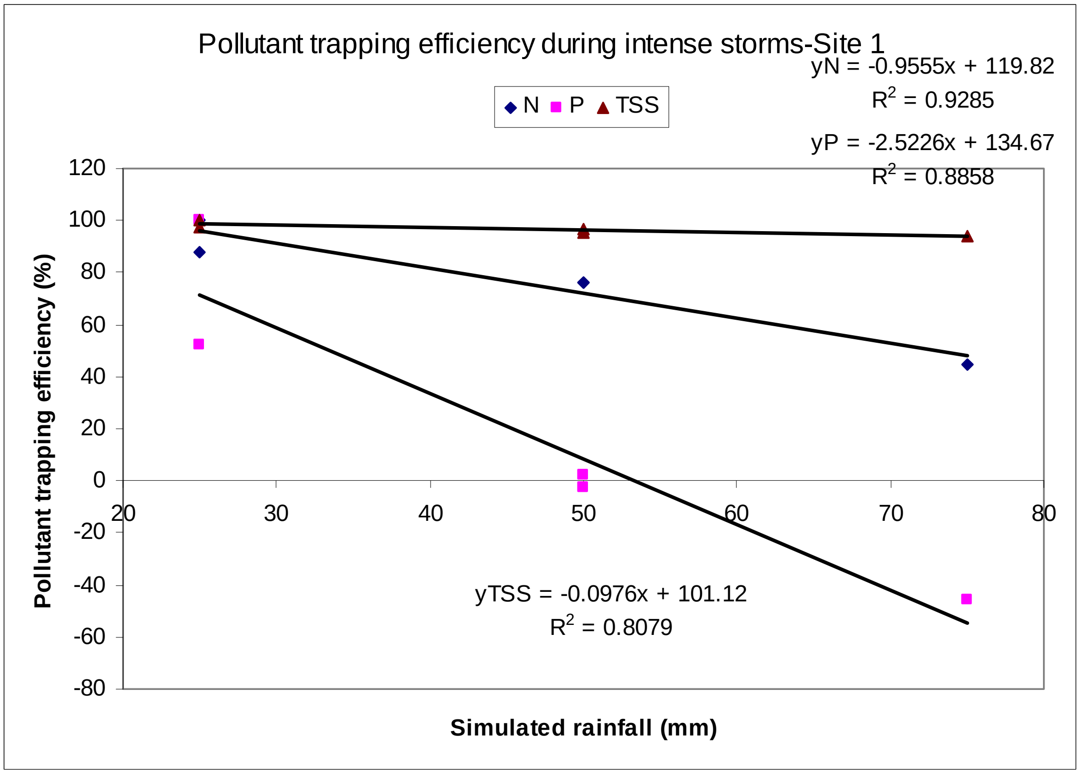
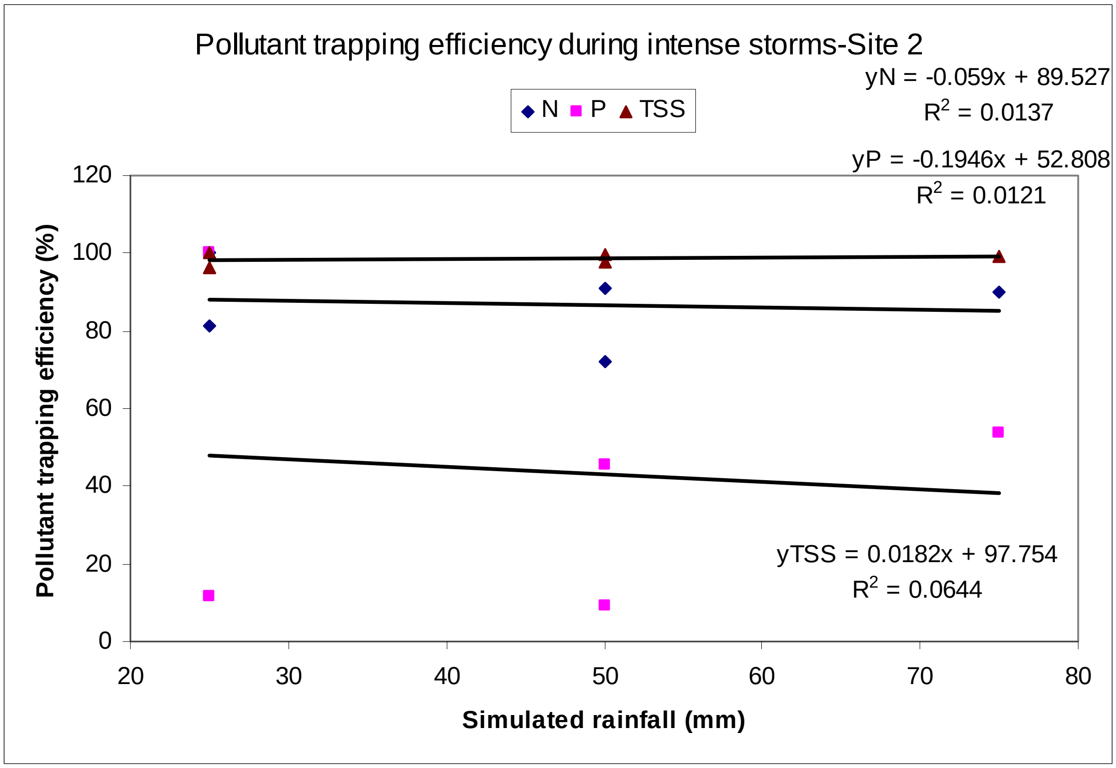


Figure 3-38 Effect of intense storm on PTE- site 2



CHAPTER 4 - Conclusions

VFS systems showed a great ability to attenuate pollutants by infiltrating a considerable portion of the applied water. Above ground biomass and soil moisture affected infiltration and runoff volume. Vegetation management practices tended to reduce the performance of the VFS. Specific conclusions drawn from the studies are:

- These VFS systems were capable of attenuating 84 % of total nitrogen, 24 % of total phosphorous and 95 % of sediments, on average;
- Percent infiltration and above ground biomass density were positively correlated with PTE, while runoff volume was negatively correlated;
- Above ground biomass density was positively correlated with infiltration percent and time of concentration;
- Soil moisture was negatively correlated with time to runoff and infiltration volume;
- Management practices, especially burning, tended to reduce PTE, as well as reduce infiltration percent and time of concentration. However it is difficult to draw a firm conclusion, as only one simulation was done after vegetation management practice;
- PTEs were reduced with intensifying simulated rainfall, but increased when simulated rainfall intensity diminished. Phosphorous was the most sensitive pollutant for intense storm conditions, followed by nitrogen, while sediment was comparatively insensitive.

Limitations and shortcomings of the experiment

- Application rate of the irrigation system was constant at around 23 mm/hr. Simulations with higher intensities were not possible with the experimental setup, which limited the ability to investigate the effect of high intensity storms on VFS performance. Even though the application rate was constant uniformity of simulated rainfall was affected by wind thus the intensity of individual plots varied.

- 100% PTE for TSS as reported on some days, was an overestimate. The analytical method used had a detection level of 1 mg/L. Anything less than that would go undetected resulting in low TE. It was suspected that negative PTE values for P were due to re-suspension. A tracer study would be helpful in determining the behavior of P.
- The accuracy level of ISCO samplers was less than the differences between two points in the hydrograph. The flow levels at the weirs were also less than the recommended level (0.06 m) for the sampler (Teledyne ISCO 2005). Accuracy of flow level measurement and subsequent calculations of water balance, mass balance, PTE and time of concentration depended on the precision of the instrument.
- Soil particles in the runon clogged the nozzles several times. Even though they were checked and cleaned frequently, there is a chance that overland flow was overestimated.
- VFS were confined by metal edges to maintain flow within the VFS and conduct flow measurement. Even though care was taken to ensure the VFS boundaries were parallel with the slope, the artificial boundaries might have changed the natural paths of the flow and forced the flow into different direction, affecting VFS performance. Also, under natural conditions, rainfall may have different kinetic energy than the simulated rainfall. The effects of simulated and natural rainfall on VFS efficiency may vary, especially when soil surface of VFS is exposed by management practices. An overland flow spreader was used to simulate sheet flow since it was reported that VFS perform well under sheet flow conditions. Anyhow, under natural flow conditions, the performance of VFS may be affected if the VFS receives concentrated flow.
- Time of concentration was calculated using a graphical method and it was not always easy to find the correct peak points on the hydrograph. Also, there was a possibility that a portion of the VFS was still not contributing to the runoff when

runon was started. Ideally, the whole VFS should contribute to the runoff for an exact calculation of time of concentration.

- Due to the design of the experiment, it was not possible to decompose the variance due to slope and composition of vegetation.
- The study deployed a simulated overland flow that could have emerged from military training activities instead of an upland contributing area of military maneuvering area. Comparison of simulated and real overland flow may have to be done before installing VFS as BMP in military training areas.

The VFS used in this study consistently showed its ability to reduce the amount of pollutants in the simulated overland flow. Previous studies done by Kim (2005) and St Clair (2006) yielded similar results. However, further studies should be done to deepen the understanding on how VFS would perform under different conditions such as natural rainfall with different storm intensities, varying design factors (slope and length), different vegetation composition, natural runoff flowing from training areas and different contributing areas. Another noteworthy result was, PTE were higher for sediment and nitrogen than for phosphorous. Further studies should be carried out in order to understand transport and fate of phosphorous in VFS. When implementing VFS, it should be designed in a way that, it only receives sheet flow instead of concentrated flow. VFS seemed to be perform better when it was mowed than when it was burned. However the evidence was not enough to draw a conclusion, because number of experiments conducted after the management practices was limited. Infiltration played a major role in reducing pollutants in the overland flow, while soil moisture and vegetation had an influence over it.

VFS can be used for removing the pollutants in the runoff from military activities, especially nitrogen and phosphorous. 20 m buffer used in this study was able to reduce considerable amount of pollutants. The same size buffer can be used between military maneuver areas and water bodies, provided that only sheet flow is occurring. However contributing area and slope may have an influence on flow conditions and they should be taken into consideration when designing the VFS. For larger and steeper contribution areas, width of the VFS should be increased. In terms of managing vegetation of the VFS systems, mowing could be used instead of burning, since it gave better results than burning.

References

Abu-Zreig, M., R. P. Rudra, M. N. Lalonde, H. R. Whiteley and N. K. Kaushik. 2004. Experimental investigation of runoff reduction and sediment removal by vegetated filter strips. *Hydrological Processes* 18(11): 2029-2037.

Abu-Zreig, M., R. P. Rudra, H. R. Whiteley, M. N. Lalonde and N. K. Kaushik. 2003. Phosphorus removal in vegetated filter strips. *Journal of environmental quality* 32(2): 613-619.

Althoff, D. P., P. S. Gipson, J. S. Pontius and P. B. Woodford. 2006. Plant community and bare ground trends on Fort Riley, Kansas: Implications for monitoring of a highly disturbed landscape. *Transactions of the Kansas Academy of Science* 109(3): 101-119.

Barfield, B. J., R. L. Blevins, A. W. Fogle, C. E. Madison, S. Inamdar, D. I. Carey and V. P. Evangelou. 1998. Water quality impacts of natural filter strips in karst areas. *Transactions of the ASAE* 41(2): 371-382.

Beche, L. A., S. L. Stephens and V. H. Resh. 2005. Effects of prescribed fire on a Sierra Nevada(California, USA) stream and its riparian zone. *Forest Ecology and Management* 218(1/3): 37-59.

Blanco-Canqui, H., C. J. Gantzer, S. H. Anderson and E. E. Alberts. 2004. Grass Barriers for Reduced Concentrated Flow Induced Soil and Nutrient Loss. *Soil Science Society of America Journal* 68(6): 1963-1972.

Blanco-Canqui, H., C. J. Gantzer and S. H. Anderson. 2006. Performance of grass barriers and filter strips under interrill and concentrated flow. *Journal of environmental quality* 35(6): 1969-1974.

Bouwer, H. 1966. Rapid field measurement of air entry value and hydraulic conductivity of soil as significant parameters in flow system analysis. *Water Resources Research* 2(4): 729-738.

Carr, G. M. and J. P. Neary. 2006. Water Quality for Ecosystem and Human Health. *Hydrol.Process.* 21.

Clar, M. L., B. J. Barfield and T. P. O'Connor, eds. 2004. *Stormwater Best Management Practice Design Guide.* Washington, DC: United States Environmental Protection Agency.

Dillaha, T. A., R. B. Reneau, S. Mostaghimi and D. Lee. 1989. Vegetative filter strips for agricultural nonpoint source pollution control. *Trans.ASAE* 32(2): 513-519.

Dressing, S. A. 2003. National Management Measures to Control Nonpoint Pollution from Agriculture-USEPA. EPA 841-B-03-004.

Emmerich, W. E. and J. R. Cox. 1992. Hydrologic characteristics immediately after seasonal burning on introduced and native grasslands. *Journal of Range Management* 45; 476-479.

Gharabaghi, B., R. P. Rudra, H. R. Whiteley and W. T. Dickinson. 2001. Sediment-Removal Efficiency of Vegetative Filter Strips. *ASAE Meeting Paper*, Paper Number: 01-2071, Sacramento, California.

Grant, D. M. and B. D. Dawson. 2001. *ISCO Open Channel Flow Measurement Handbook.* Lincoln, Nebraska, Isco.

Green, W. H. and G. A. Ampt. 1911. Studies on soil physics, 1. The flow of air and water through soils. *J.Agric.Sci* 4(1): 1-24.

Gribbin, J. E. 2007. *Introduction to hydraulics and hydrology with applications for stormwater management.* third ed. Clifton Park, NY: Thomson Delmar Learning.

Hach company. Oxygen demand, chemical method 8000 DR/2400. Hach Company. Hach Company. Available at: http://www.hach.com/fmmimghach?/CODE%3AOXYGENCOD_NONE_MID_R7566%7C1. Accessed 02/25 2008.

Haydon, B. P. 1998. Chapter 2: Regional climate and the distribution of tallgrass prairie. In *Grassland dynamics: Long term ecological research in tallgrass prairie,* 19-34. ed. A. K. KnappBriggs, J. M.Hartnett, D. C. and Collins, S. L., Oxford: Oxford University Press.

Helmers, M. J., T. Isenhart, M. Dosskey, S. Dabney and J. Strock. 2006. Buffers and vegetative filter strips. Available at: http://www.epa.gov/msbasin/taskforce/2006symposia/4BuffersVegHelmers.pdf. Assessed 03/10/2008

Helmers, M. J., D. E. Eisenhauer, M. G. Dosskey, T. G. Franti, J. M. Brothers and M. C. McCullough. 2005. Flow pathways and sediment trapping in a field-scale vegetative filter. *Transactions of the ASAE* 48(3): 955-968.

Hubbard, R. K., G. L. Newton and G. J. Gascho. 2003. Nutrient removal by grass components of vegetated buffer systems receiving swine lagoon effluent. *Journal of Soil and Water Conservation (Ankeny)* 58(5): 232-242.

Jin, C. X., M. J. M. Roemkens and F. Griffioen. 2000. Estimating Manning's roughness coefficient for shallow overland flow in non-submerged vegetative filter strips. *Transactions of the ASAE* 43(6): 1459-1466.

Johansen, M. P., T. E. Hakonson and D. D. Breshears. 2001. Post-fire runoff and erosion from rainfall simulation: contrasting forests with shrublands and grasslands. *Hydrological Processes* 15(15): 2953-2965.

Kansas State Research and Extension. 2008. Kansas State Research and Extension-Weather Data Library. Kansas State Research and Extension. Kansas State University. Available at: http://av.vet.ksu.edu/webwx/. Accessed 01/21 2008.

Kim, I. J. 2006. Identifying the Roles of Overland Flow Characteristics and Vegetated Buffer Systems for Nonpoint Source Pollution Control. PhD diss. Kansas State University.

Komor, S. C. and D. S. Hansen. 2002. Attenuation of Runoff and Chemical Loads in Grass Filter Strips at Two Cattle Feedlots, Minnesota, 1995-98. *Water Resources Investigations Report. United States Geological Survey*24.

Konza Prairie Biological Station. Prairie Fires. Konza Prairie Biological Station. Konza Prairie Biological Station. Available at: http://www.konza.ksu.edu/keep/firemgt.asp#Konza. Accessed 02/05 2008.

Lee, K. H., T. M. Isenhart, R. C. Schultz and S. K. Mickelson. 1999. Nutrient and sediment removal by switchgrass and cool-season grass filter strips in Central Iowa, USA. *Agroforestry Systems* 44(2): 121-132.

Leeds, R., L. C. Brown, M. R. Sulc and L. VanLieshout. 1994 Vegetative Filter Strips: Application, Installation and Maintenance. FactSheet AEX-467–94, Ohio State University Extension, Food, Agricultural and Biological Engineering. Ohio state university. Available at: http://ohioline.osu.edu/aex-fact/0467.html. Accessed 05/10 2007.

Lim, T. T., D. R. Edwards, S. R. Workman, B. T. Larson and L. Dunn. 1998. Vegetated filter strip removal of cattle manure constituents in runoff. *Transactions of the ASAE* 41(5): 1375-1381.

Marcos, E. 2000. Comparative Analysis of Runoff and Sediment Yield with a Rainfall Simulator After Experimental Fire. *Arid Soil Research and Rehabilitation* 14(3): 293-307.

Mendez, A., T. A. Dillaha and S. Mostaghimi. 1999. Sediment and nitrogen transport in grass filter strips. *Journal of the American Water Resources Association* 35(4): 867-875.

Neary, D. G., K. C. Ryan and L. F. DeBano. 2005. Wildland Fire in Ecosystems: Effects of Fire on Soil and Water, USDA Forest Service, Ogden, Utah.

Nebel, B. J. and R. T. Wright. 1998. *Environmental Science: The Way the World Works.* Prentice Hall PTR, 102-103.

Newham, L. T. H., J. C. Rutherford and B. F. W. Croke. 2005. A conceptual model of particulate trapping in riparian buffers, CSIRO Land and Water Technical Report, Canberra, Australia.

Owensby, C. E. and J. Wyrill. 1973. Effects of range burning on Kansas Flint Hills Soil. *Journal of Range Management* 26(3): 185-188.

Pierson, F. B., P. R. Robichaud, K. E. Spaeth and C. A. Moffet. 2003. Impacts of fire on hydrology and erosion in steep mountain big sagebrush communities. *Proceedings of the First Interagency Conference on research in the Watersheds* 625-630.

Rawls, W. J., D. L. Brakensiek and B. Soni. 1983a. Agricultural Management Effects on Soil Water Processes; Part I: Soil Water Retention and Green and Ampt Infiltration Parameters. *Transactions of the American Society of Agricultural Engineers* 26(6): 1753-1759.

Rawls, W. J., D. L. Brakensiek and N. Miller. 1983b. Green-Ampt Infiltration Parameters from Soils Data. *Journal of Hydraulic Engineering* 109(1): 62-70.

Robichaud, P. R. 2000. Fire effects on infiltration rates after prescribed fire in Northern Rocky Mountain forests, USA. *Journal of Hydrology(Amsterdam)* 231(1): 220-229.

Sanderson, M. A., R. M. Jones, M. J. McFarland, J. Stroup, R. L. Reed and J. P. Muir. 2001. Nutrient movement and removal in a switchgrass biomass-filter strip system treated with dairy manure. *Journal of environmental quality* 30(1): 210-216.

Schmid, F. J. 1996. Assessment of Nonpoint Source (NPS) pollution Potential at Military Bases. Public Works Technical Bulletin 420-46-5A1-C5.

Schmitt, T. J., M. G. Dosskey and K. D. Hoagland. 1999. Filter strip performance and processes for different vegetation, widths, and contaminants. *Journal of environmental quality* 28(5): 1479-1489.

Soil Testing Laboratory at Kansas State University. 2005. Procedures for analysis of water samples. Department of Agronomy, Kansas University. Kansas State University.

Available at: http://www.oznet.ksu.edu/Agronomy/SoilTesting/w_analysis_offered.htm. Accessed 02/05 2008.

St.Clair, A. K. 2007. Suitability of tallgrass prairie filter strips for control of non-point source pollution originating from military activities. Masters diss. Manhattan, Kansas, USA: Kansas State University.

Teledyne ISCO. 2005. *730 Bubbler module-Installation and operation guide.* Teledyne ISCO.

Tufekcioglu, A., J. W. Raich, T. M. Isenhart and R. C. Schultz. 1999. Fine root dynamics, coarse root biomass, root distribution, and soil respiration in a multispecies riparian buffer in Central Iowa, USA. *Agroforestry Systems* 44(2): 163-174.

USDA. Web Soil Survey. USDA-NRCS. Kansas State University. Available at: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx. Accessed 11/23 2007.

USDA-NRCS. 2004. Illinois Native Plant Guide. USDA-NRCS. Available at: http://www.il.nrcs.usda.gov/technical/plants/npg/index.html. Accessed 12/10 2007.

USDA-NRCS. 2003. Filter strip CODE 393. In *National Conservation Practice Standards,* ed. Anonymous , USDA-NRCS.

USDA-NRCS. National Conservation Practice Standars. USDA-NRCS. Available at: http://www.nrcs.usda.gov/technical/Standards/nhcp.html. Accessed 01/29 2008.

USEPA. 2007. National Water Quality Inventory: 2002 Report. Office of Water, Washington DC.

USEPA. 2003. Introduction to clean water act. USEPA. USEPA. Available at: http://www.epa.gov/watertrain/cwa/index.htm. Accessed 01/29 2008.

Ward, A. D. and S. W. Trimble. 2004. Chapter 9: Soil conservation and sediment budgets. In *Environmental Hydrology,* 255-290.CRC Press.

CHAPTER 5 - Appendices

Appendix A - Water Balance

Figure 5-1 Water balance of inputs (runon and rainfall) plot 2

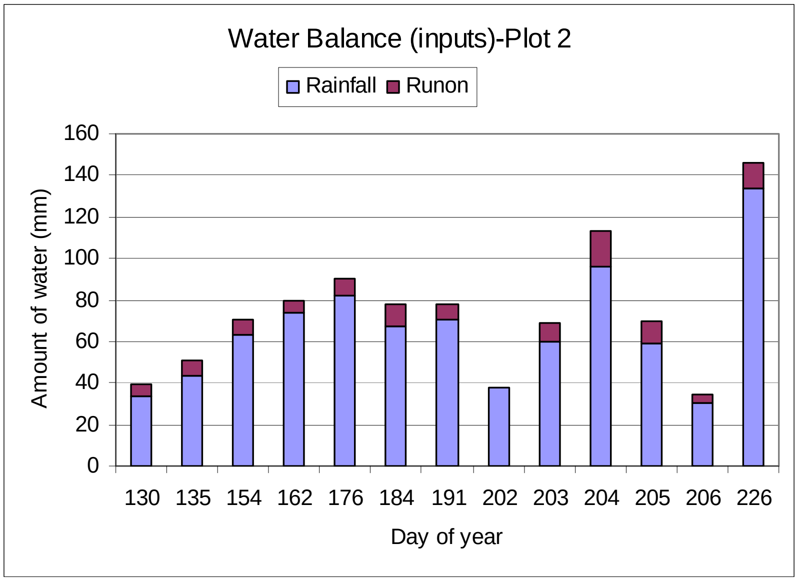


Figure 5-2 Water balance of outputs (runoff and water retained) plot 2

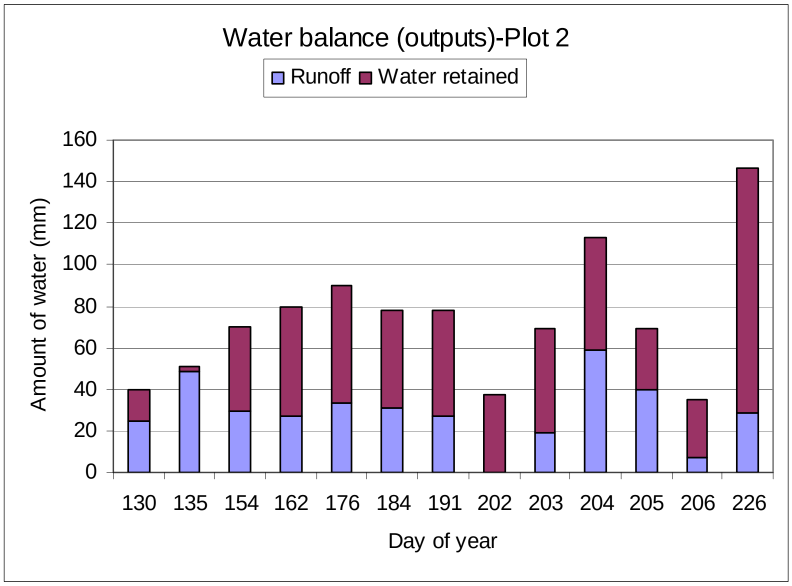


Figure 5-3 Water balance of inputs (runon and rainfall) plot 3

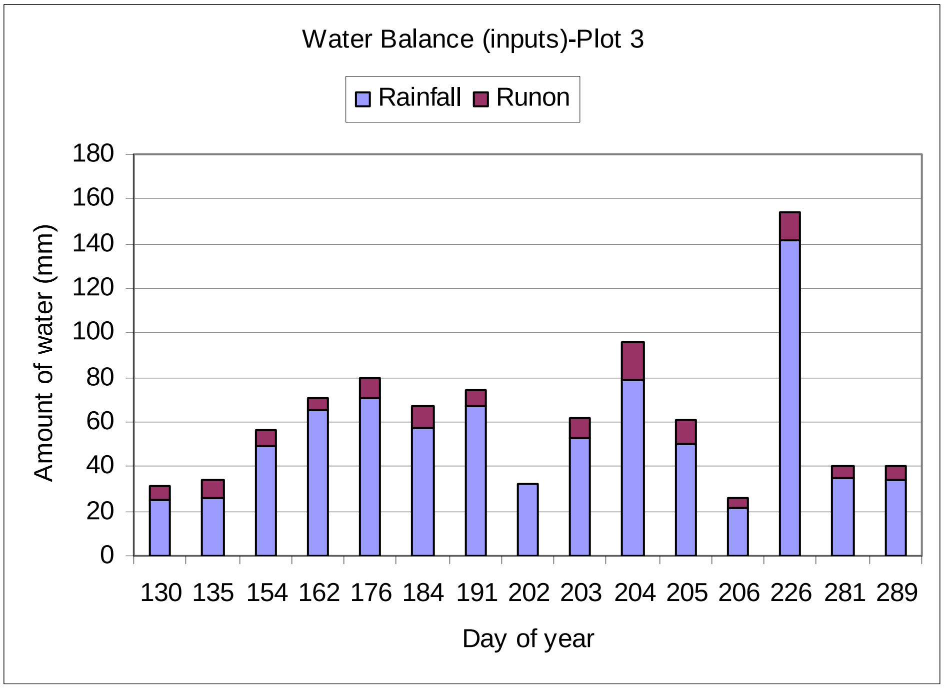


Figure 5-4 Water balance of outputs (runoff and water retained) plot 3

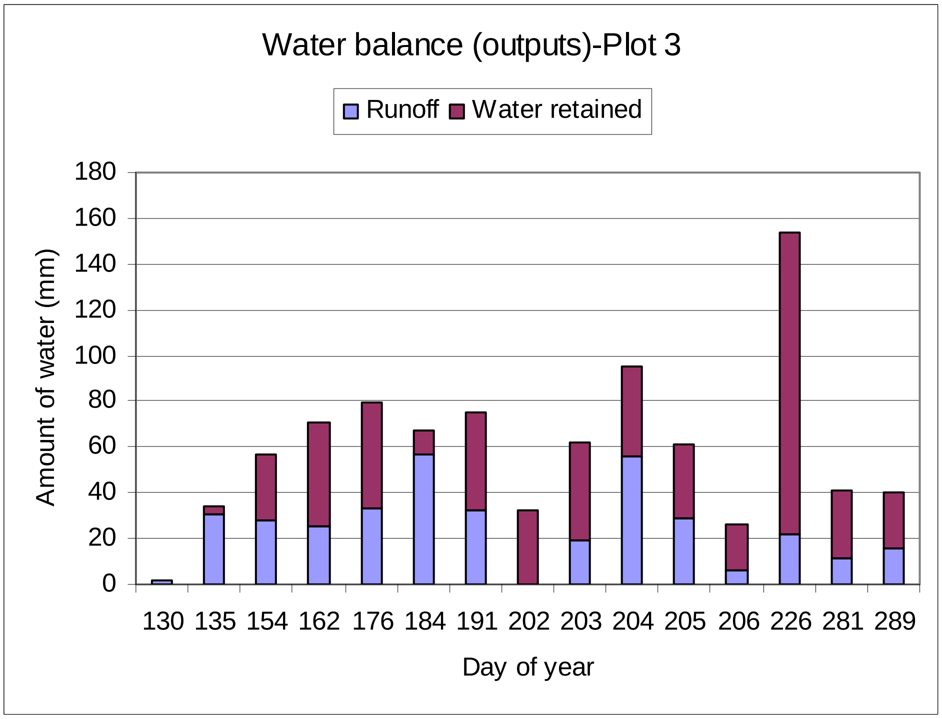


Figure 5-5 Water balance of inputs (runon and rainfall) plot 4

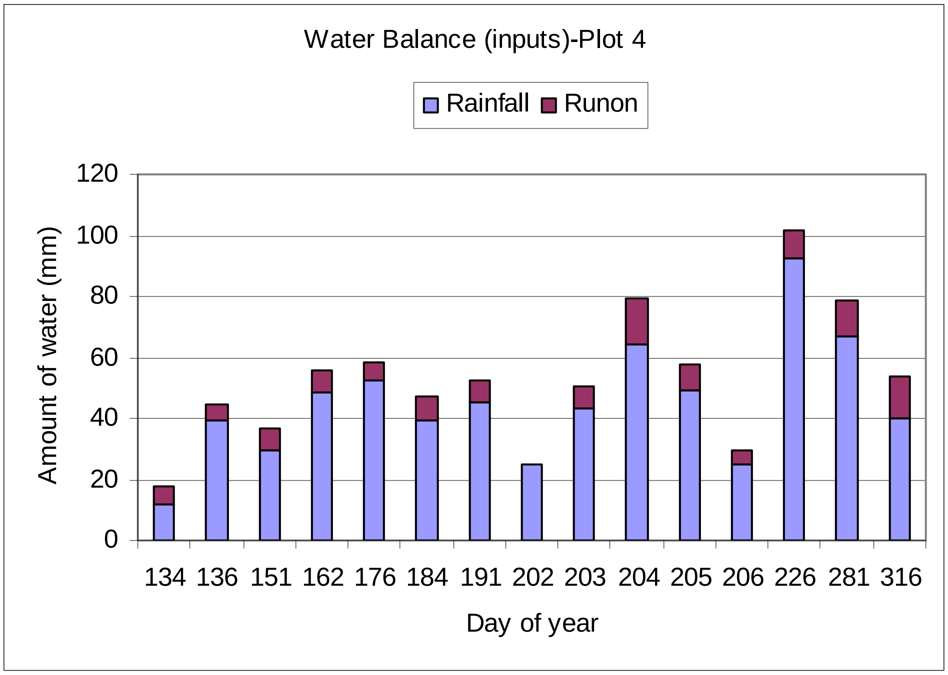


Figure 5-6 Water balance of outputs (runoff and water retained) plot 4

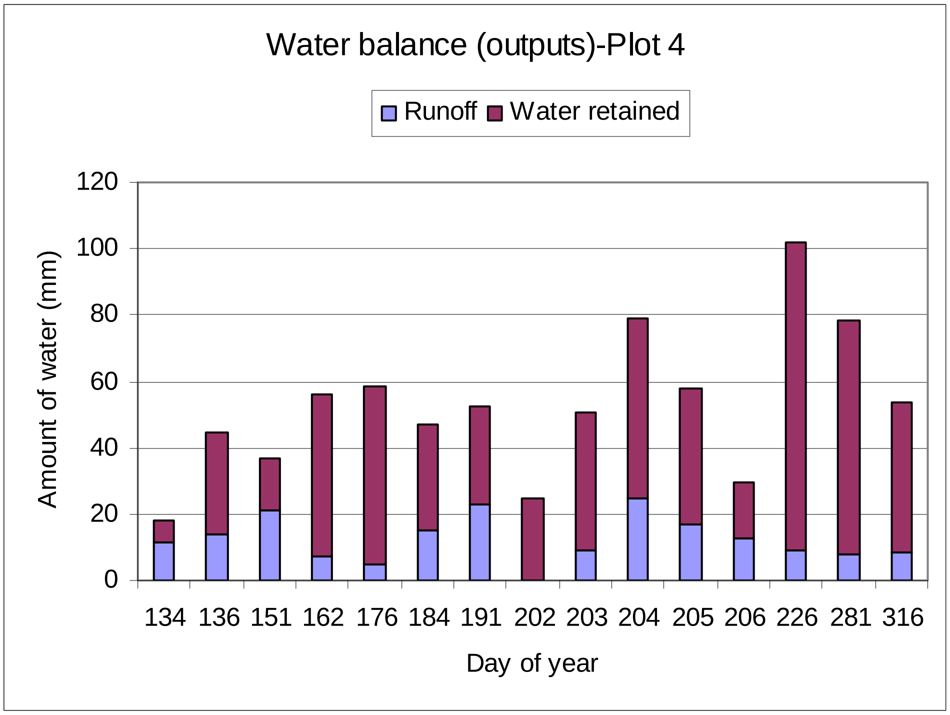


Figure 5-7 Water balance of inputs (runon and rainfall) plot 5

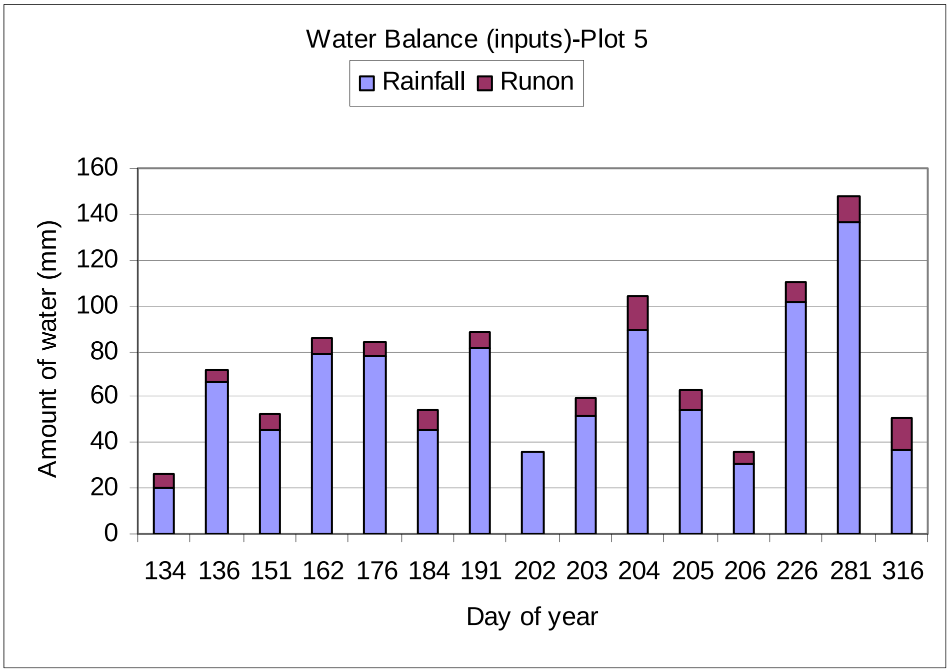


Figure 5-8 Water balance of outputs (runoff and water retained) plot 5

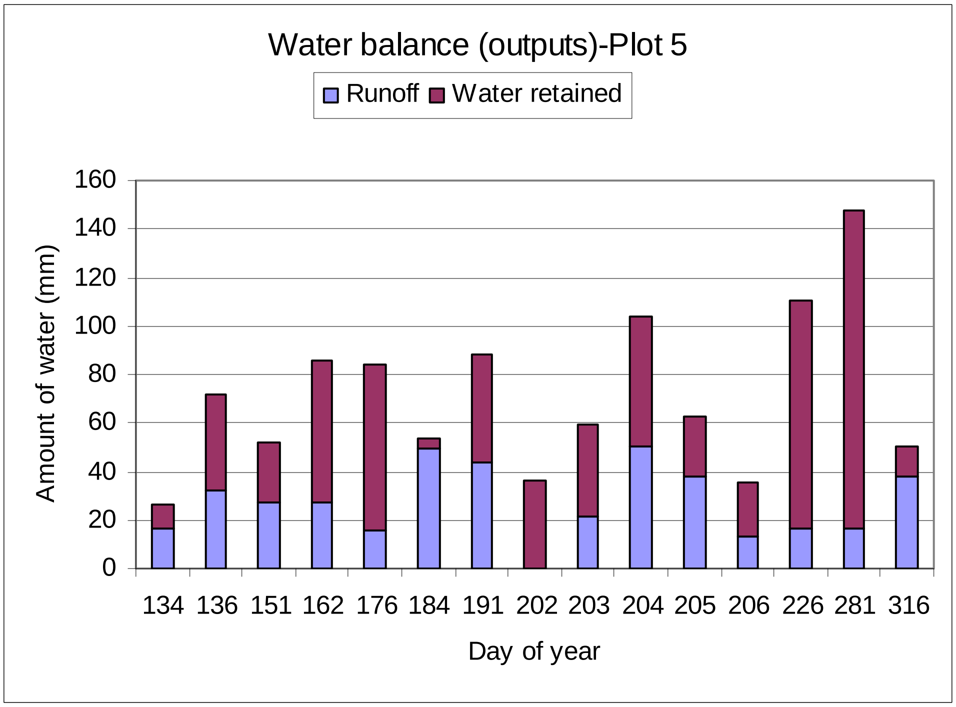


Figure 5-9 Water balance of inputs (runon and rainfall) plot 6

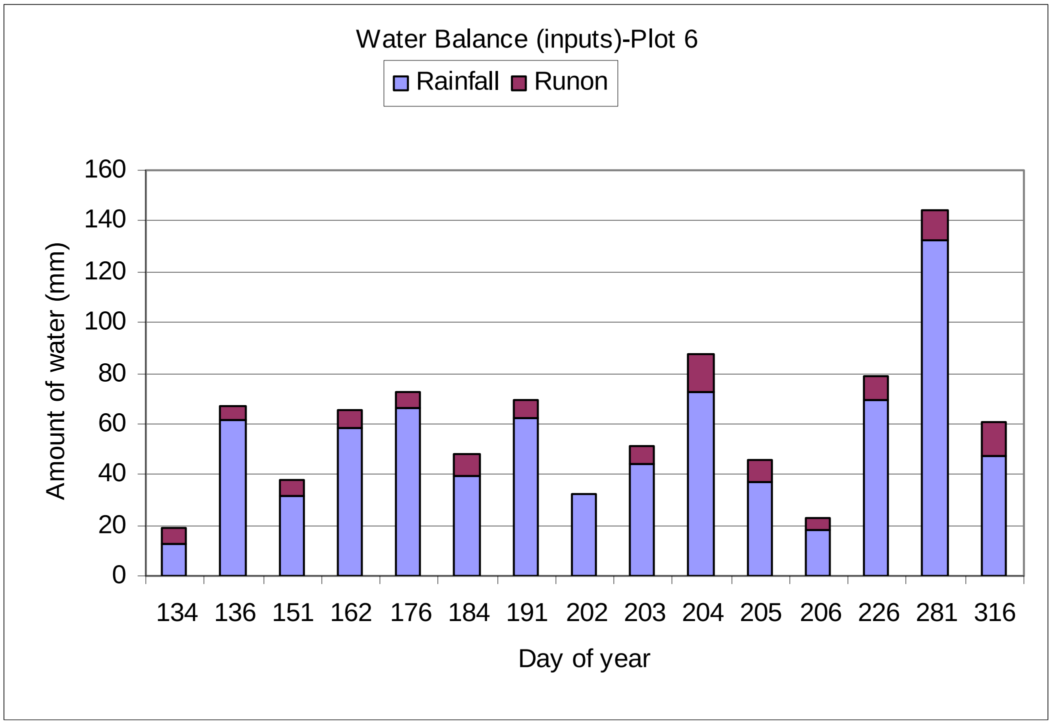
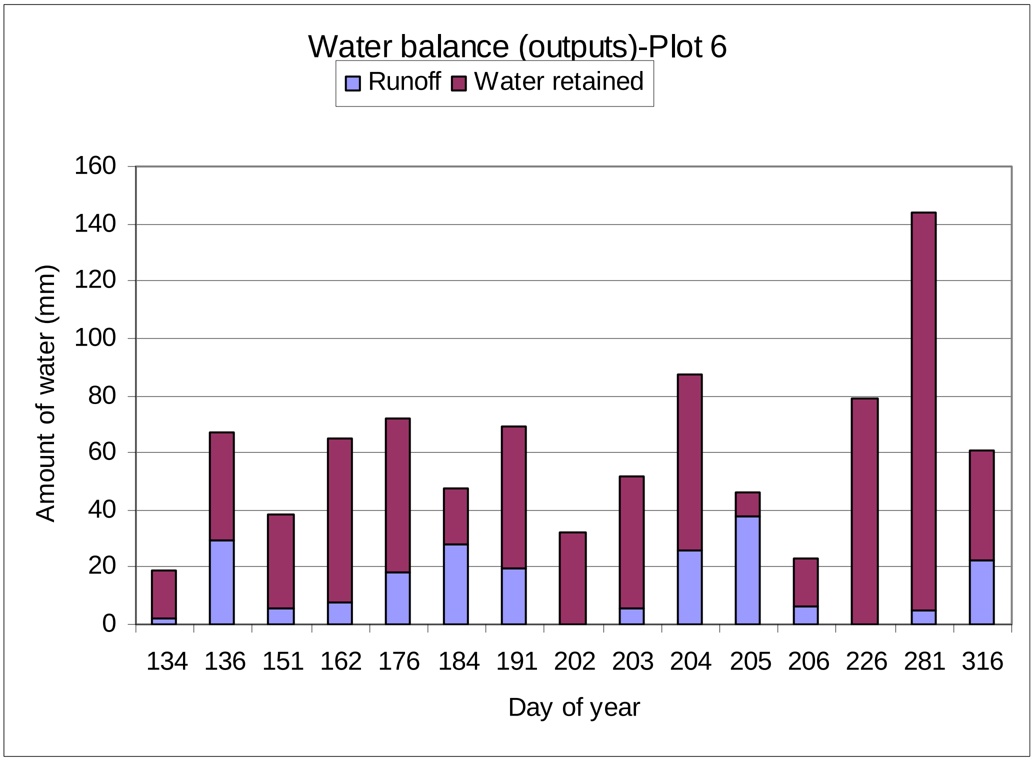


Figure 5-10 Water balance of outputs (runoff and water retained) plot 6



Appendix B - Hydraulic Conductivities

Table 5-1 Saturated hydraulic conductivities estimated on different days of simulation

Saturated hydraulic conductivity by location of infiltrometer								
Date	**Location**	**K_{sat}(cm/hr)**	**Date**	**Location**	**K_{sat}(cm/hr)**	**Date**	**Location**	**K_{sat}(cm/hr)**
5/11/07	1	0.97	5/11/07	3	0.57	5/15/07	5	0.34
5/16/07	1	0.62	5/16/07	3	0.99	5/17/07	5	0.30
6/5/07	1	1.21	6/05//2007	3	1.16	6/2/07	5	0.07
6/13/07	1	7.60	6/13/07	3	0.15	6/13/07	5	2.28
6/27/07	1	1.08	6/27/07	3	0.66	6/27/07	5	0.52
7/5/07	1	1.10	7/5/07	3	1.87	7/5/07	5	1.06
7/12/07	1	1.29	7/12/07	3	0.86	7/12/07	5	0.98
7/23/07	1	5.63	7/23/07	3	2.89	7/23/07	5	
7/24/07	1	10.19	7/24/07	3	4.06	7/24/07	5	4.87
7/25/07	1	1.01	7/25/07	3	1.20	7/25/07	5	0.59
7/26/07	1	1.28	7/26/07	3	2.03	7/26/07	5	1.98
7/27/07	1	0.97	7/27/07	3	3.14	7/27/07	5	2.17
8/17/07	1	2.30	8/17/07	3	0.39	8/17/07	5	2.24
10/12/07	1	0.76	10/12/07	3	0.61	10/12/07	5	
10/20/07	1	1.04	10/20/07	3	1.35	11/17/07	5	5.30
5/11/07	2	0.94	5/15/07	4	0.37	5/15/07	6	0.38
5/16/07	2	0.19	5/17/07	4	0.92	5/17/07	6	0.64
6/5/07	2	0.83	6/2/07	4	0.54	6/2/07	6	0.04
6/13/07	2	1.51	6/13/07	4	2.90	6/13/07	6	0.96
6/27/07	2	1.38	6/27/07	4	0.60	6/27/07	6	1.04
7/5/07	2	1.28	7/5/07	4	0.97	7/5/07	6	0.37
7/12/07	2	1.79	7/12/07	4	0.34	7/12/07	6	0.17
7/23/07	2	4.87	7/23/07	4		7/23/07	6	
7/24/07	2	10.98	7/24/07	4	3.44	7/24/07	6	0.68
7/25/07	2	0.67	7/25/07	4	2.28	7/25/07	6	1.91
7/26/07	2	2.42	7/26/07	4	2.63	7/26/07	6	0.06
7/27/07	2	0.73	7/27/07	4	2.46	7/27/07	6	3.08
8/17/07	2	2.20	8/17/07	4	2.66	8/17/07	6	0.95
10/12/07	2	0.62	10/12/07	4		10/12/07	6	
10/20/07	2	1.14	11/17/07	4	5.33	11/17/07	6	2.42

Note: Location denotes the location of the infiltrometer on the experimental sites. Location numbers and corresponding locations are: 1-Site 1Top, 2-Site 1 Middle, 3-Site 1 Bottom, 4-Site 2 Top, 5-Site 2 Middle, 6-Site 2 Bottom.

An example is given in chapter 2 describing the method used for estimating hydraulic saturated conductivity. All the graphs that were used for calculating the saturated hydraulic conductivity are given in the excel spreadsheet in the CD provided. These graphs can be found in the “Infiltration” worksheet.

Appendix C - Summary of Data Analysis

Date	Plot	Day of year	Biomass -Dry (g/m2)	Soil moisture (%)	N (mg/l) average concentration in run on	N (mg/l) average concentration in run off	P (mg/l) average concentration in run on	P (mg/l) average concentration in run off	TSS (mg/l) average concentration in run on	TSS (mg/l) average concentration in run off	Rainfall (L)	Rainfall (mm)	Run on volume (L)	Run off volume (L)
5/11/07	1	130	49.87	35.10	70.08	8.76	5.21	0.75	3451.00	66.46	1713.81	28.56	362.44	1541.79
5/11/07	2	130	49.87	35.10	70.08	8.12	5.21	0.70	3451.00	57.33	2009.72	33.50	362.44	1477.85
5/11/07	3	130	49.87	35.10	70.08	1.43	5.21	0.76	3451.00	107.00	1516.54	25.28	362.44	100.71
5/15/07	4	134		37.90	38.58	7.88	2.42	0.49	926.00	71.73	702.79	11.71	373.10	687.37
5/15/07	5	134		37.90	38.58	1.63	2.42	0.49	926.00	21.60	1195.97	19.93	373.10	1012.07
5/15/07	6	134		37.90	38.58	3.34	2.42	0.59	926.00	25.60	776.76	12.95	373.10	138.86
5/16/07	1	135	102.99	39.48	32.07	4.75	2.44	0.83	747.00	147.53	2182.33	36.37	479.70	1853.24
5/16/07	2	135	102.99	39.48	32.07	2.76	2.44	0.74	747.00	52.80	2589.21	43.15	479.70	2916.19
5/16/07	3	135	102.99	39.48	32.07	4.67	2.44	0.69	747.00	44.00	1578.19	26.30	479.70	1847.95
5/17/07	4	136	104.69	34.79	53.73	4.09	3.56	0.56	2012.67	35.25	2354.95	39.25	319.80	834.03
5/17/07	5	136	104.69	34.79	53.73		3.56		2012.67		3994.78	66.58	319.80	1942.69
5/17/07	6	136	104.69	34.79	53.73	2.39	3.56	0.61	2012.67	23.14	3686.54	61.44	319.80	1757.55
6/2/07	4	151	179.83	41.19	35.45	4.87	3.29	0.50	7750.67	55.47	1775.46	29.59	415.74	1274.32
6/2/07	5	151	179.83	41.19	35.45	3.39	3.29	0.50	7750.67	46.46	2712.51	45.21	415.74	1650.34
6/2/07	6	151	179.83	41.19	35.45	4.81	3.29	0.44	7750.67	49.64	1874.10	31.23	415.74	316.96
6/5/07	1	154	236.55	32.44	27.54	1.33	2.01	0.63	828.00	7.71	2885.12	48.09	453.05	835.42
6/5/07	2	154	236.55	32.44	27.54	3.58	2.01	0.59	828.00	11.00	3772.85	62.88	453.05	1763.60
6/5/07	3	154	236.55	32.44	27.54	3.15	2.01	0.63	828.00	27.27	2934.44	48.91	453.05	1660.31
6/13/07	1	162	211.71	32.21	16.85	0.79	1.52	0.56	940.00	18.67	2922.11	48.70	322.92	274.54
6/13/07	2	162	211.71	32.21	16.85	0.99	1.52	0.49	940.00	16.00	4438.65	73.98	322.92	1603.90
6/13/07	3	162	211.71	32.21	16.85	1.12	1.52	0.53	940.00	27.33	3933.13	65.55	322.92	1496.17
6/13/07	4	162	314.69	33.20	22.02	0.70	1.64	0.41	1203.67	17.33	2922.11	48.70	426.40	422.65
6/13/07	5	162	314.69	33.20	22.02	1.22	1.64	0.42	1203.67	28.00	4722.23	78.70	426.40	1621.09

Date	Plot	Day of year	Biomass -Dry (g/m2)	Soil moisture (%)	N (mg/l) average concentration in run on	N (mg/l) average concentration in run off	P (mg/l) average concentration in run on	P (mg/l) average concentration in run off	TSS (mg/l) average concentration in run on	TSS (mg/l) average concentration in run off	Rainfall (L)	Rainfall (mm)	Run on volume (L)	Run off volume (L)
6/13/07	6	162	314.69	33.20	22.02	1.66	1.64	0.43	1203.67	52.00	3489.27	58.15	426.40	473.09
6/27/07	1	176	234.33	32.61	26.52	3.85	2.13	0.85	1233.33	246.55	3575.58	59.59	506.35	393.77
6/27/07	2	176	234.33	32.61	26.52	1.19	2.13	0.66	1233.33	22.80	4907.17	81.79	506.35	2022.45
6/27/07	3	176	234.33	32.61	26.52	2.46	2.13	0.61	1233.33	16.25	4266.03	71.10	506.35	07.90
6/27/07	4	176	476.73	30.54	23.87	0.92	1.43	0.27	849.67	7.27	3131.71	52.20	362.44	277.24
6/27/07	5	176	476.73	30.54	23.87		1.43		849.67		4660.58	77.68	362.44	933.32
6/27/07	6	176	476.73	30.54	23.87	1.39	1.43	0.28	849.67	2.92	3970.12	66.17	362.44	1092.51
7/5/07	1	184	356.79	37.37	25.75	1.66	2.13	0.64	782.67	3.18	3698.87	61.65	612.95	2178.38
7/5/07	2	184	356.79	37.37	25.75	1.83	2.13	0.58	782.67	4.58	4044.10	67.40	612.95	1885.15
7/5/07	3	184	356.79	37.37	25.75	2.83	2.13	0.59	782.67	5.68	3427.62	57.13	612.95	3397.35
7/5/07	4	184	511.87	43.15	31.65	2.04	3.22	0.48	1652.00	9.07	2342.62	39.04	479.70	916.85
7/5/07	5	184	511.87	43.15	31.65	2.51	3.22	0.53	1652.00	12.24	2749.50	45.82	479.70	2967.43
7/5/07	6	184	511.87	43.15	31.65	2.98	3.22	0.55	1652.00	12.85	2385.77	39.76	479.70	1673.42
7/12/07	1	191	317.39	31.82	49.13	1.66	2.75	0.63	574.00	11.20	2798.81	46.65	442.39	527.45
7/12/07	2	191	317.39	31.82	49.13		2.75		574.00		4253.70	70.90	442.39	1617.85
7/12/07	3	191	317.39	31.82	49.13	4.97	2.75	0.68	574.00	0.00	4044.10	67.40	442.39	1942.99
7/12/07	4	191	382.79	29.18	53.73	0.85	3.31	0.48	1529.00	1.73	2712.51	45.21	437.06	1359.14
7/12/07	5	191	382.79	29.18	53.73	2.05	3.31	0.44	1529.00	2.67	4882.51	81.38	437.06	2607.41
7/12/07	6	191	382.79	29.18	53.73	1.36	3.31	0.47	1529.00	6.17	3723.53	62.06	437.06	1171.74
7/23/07	1	202		28.61							1578.19	26.30		
7/23/07	2	202		28.61							2243.98	37.40		
7/23/07	3	202		28.61							1923.41	32.06		
7/23/07	4	202		29.20							1491.88	24.86		
7/23/07	5	202		29.20							2157.68	35.96		
7/23/07	6	202		29.20							1923.41	32.06		
7/24/07	1	203		36.12	16.95	2.56	1.36	0.83	454.00	10.00	2404.27	40.07	533.00	483.65
7/24/07	2	203		36.12	16.95	2.20	1.36	0.83	454.00	0.00	3600.24	60.00	533.00	1141.90
7/24/07	3	203		36.12	16.95	2.39	1.36	0.66	454.00	24.00	3181.03	53.02	533.00	1171.11
7/24/07	4	203		37.34	23.94	0.90	1.86	0.62	1724.00	0.00	2607.70	43.46	426.40	542.25

Date	Plot	Day of year	Biomass -Dry (g/m2)	Soil moisture (%)	N (mg/l) average concentration in run on	N (mg/l) average concentration in run off	P (mg/l) average concentration in run on	P (mg/l) average concentration in run off	TSS (mg/l) average concentration in run on	TSS (mg/l) average concentration in run off	Rainfall (L)	Rainfall (mm)	Run on volume (L)	Run off volume (L)
7/24/07	5	203		37.34	23.94	1.53	1.86	0.60	1724.00	0.00	3119.38	51.99	426.40	1273.93
7/24/07	6	203		37.34	23.94	1.08	1.86	0.55	1724.00	22.00	2663.19	44.39	426.40	354.71
7/25/07	1	204	405.69	38.19	9.94	2.21	1.38	0.79	1487.00	62.00	3723.53	62.06	1012.70	1734.18
7/25/07	2	204	405.69	38.19	9.94	2.45	1.38	0.67	1487.00	26.00	5770.24	96.17	1012.70	3521.35
7/25/07	3	204	405.69	38.19	9.94	1.29	1.38	0.70	1487.00	22.00	4709.90	78.50	1012.70	3368.45
7/25/07	4	204	719.99	35.50	30.67	1.27	3.04	0.62	7140.00	30.00	3846.83	64.11	906.10	1475.29
7/25/07	5	204	719.99	35.50	30.67	1.68	3.04	0.66	7140.00	30.00	5326.38	88.77	906.10	3006.04
7/25/07	6	204	719.99	35.50	30.67	0.84	3.04	0.59	7140.00	16.00	4352.34	72.54	906.10	1544.89
7/26/07	1	205		41.82	22.38	1.84	1.80	0.73	1872.00	46.00	2786.48	46.44	612.95	792.02
7/26/07	2	205		41.82	22.38	2.38	1.80	0.71	1872.00	32.00	3550.92	59.18	612.95	2387.34
7/26/07	3	205		41.82	22.38	1.59	1.80	0.65	1872.00	0.00	3033.08	50.55	612.95	1743.64
7/26/07	4	205		35.83	18.61	1.09	2.20	0.60	2474.00	6.00	2934.44	48.91	533.00	1009.69
7/26/07	5	205		35.83	18.61	2.14	2.20	0.62	2474.00	20.00	3230.35	53.84	533.00	2268.91
7/26/07	6	205		35.83	18.61	1.01	2.20	0.52	2474.00	20.00	2219.32	36.99	533.00	2268.91
7/27/07	1	206		40.54	30.75	1.88	2.06	0.67	1036.00	10.00	1491.88	24.86	266.50	392.95
7/27/07	2	206		40.54	30.75	4.34	2.06	0.67	1036.00	36.00	1824.78	30.41	266.50	441.66
7/27/07	3	206		40.54	30.75	0.76	2.06	0.61	1036.00	2.00	1306.93	21.78	266.50	378.74
7/27/07	4	206		43.21	30.89	3.92	2.37	0.52	2040.00	34.00	1504.21	25.07	282.49	775.70
7/27/07	5	206		43.21	30.89	1.37	2.37	0.63	2040.00	44.00	1861.77	31.03	282.49	782.65
7/27/07	6	206		43.21	30.89	2.22	2.37	0.54	2040.00	2.00	1109.66	18.49	282.49	371.21
8/17/07	1	226	539.85	19.78	2.71	0.71	0.97	0.65	1656.00	16.00	5122.94	85.38	772.85	86.29
8/17/07	2	226	539.85	19.78	2.71	0.80	0.97	0.67	1656.00	35.00	8001.89	133.36	772.85	1708.66
8/17/07	3	226	539.85	19.78	2.71	0.58	0.97	0.58	1656.00	9.00	8470.42	141.17	772.85	1298.68
8/17/07	4	226	749.61	26.18	21.81	0.52	1.40	0.49	516.00	4.00	5548.31	92.47	559.65	539.70
8/17/07	5	226	749.61	26.18	21.81	0.74	1.40	0.62	516.00	24.00	6066.15	101.10	559.65	1013.62
8/17/07	6	226	749.61	26.18	21.81	0.00	1.40	0.00	516.00		4167.40	69.46	559.65	0.05
10/12/07	1	281	636.19	38.10	25.43	1.03	1.81	0.80	1080.91	0.57	2515.23	41.92	373.10	238.39
10/12/07	2	281	636.19	38.10	25.43		1.81		1080.91					
10/12/07	3	281	636.19	38.10	25.43	1.21	1.81	0.77	1080.91	2.82	2071.37	34.52	373.10	700.41

Date	Plot	Day of year	Biomass -Dry (g/m2)	Soil moisture %	N (mg/l) average concentration in run on	N (mg/l) average concentration in run off	P (mg/l) average concentration in run on	P (mg/l) average concentration in run off	TSS (mg/l) average concentration in run on	TSS (mg/l) average concentration in run off	Rainfall (L)	Rainfall (mm)	Run on volume (L)	Run off volume (L)
10/12/07	4	281	777.65	33.83	27.61	0.75	2.26	0.63	4005.84	4.04	4031.77	67.20	682.24	471.35
10/12/07	5	281	777.65	33.83	27.61	1.12	2.26	0.63	4005.84	9.55	8199.17	136.65	682.24	993.38
10/12/07	6	281	777.65	33.83	27.61	0.75	2.26	0.63	4005.84	2.54	7952.58	132.54	682.24	285.74
10/20/07	1	289		38.14	63.69	2.98	3.29	1.30	3728.94	182.57	838.41	13.97	362.44	368.63
10/20/07	2	289		38.14	63.69		3.29		3728.94					
10/20/07	3	289		38.14	63.69	6.96	3.29	0.91	3728.94	108.51	2059.04	34.32	362.44	946.94
11/17/07	4	316		31.07	24.75	2.35	1.65	1.51	495.95	28.76	2391.94	39.87	826.15	511.24
11/17/07	5	316		31.07	24.75	2.68	1.65	1.44	495.95	33.53	2206.99	36.78	826.15	2292.61
11/17/07	6	316		31.07	24.75	2.74	1.65	1.62	495.95	32.76	2835.80	47.26	826.15	1320.64

Date	Plot	Day of year	N (mg)-Total in runoff	P (mg)-Total in runoff	TSS (mg)-Total in runoff	N removal (%)	P removal (%)	TSS removal (%)	Water retained (L)	Water retained %	Time of concentration (minutes)	Time to runoff (minutes)	Storm duration (minutes)	Storm intensity (mm/hr)
5/11/07	1	130	7147.00	1183.16	134015.80	21.04	-75.90	69.94	534.46	25.74	15	35	75	22.85
5/11/07	2	130	5161.16	1070.57	99653.88	42.98	-59.16	77.64	894.31	37.70	13	35	75	26.80
5/11/07	3	130											75.00	20.22
5/15/07	4	134	3122.09	366.89	47025.32	78.31	59.28	86.39	388.52	36.11	14	23	40.00	17.57
5/15/07	5	134	1282.70	524.97	14501.55	91.09	41.74	95.80	557.00	35.50	8	15	40.00	29.90
5/15/07	6	134	327.75	83.17	3036.11	97.72	90.77	99.12	1011.01	87.92	9	23	40.00	19.42
5/16/07	1	135	4127.37	1437.21	89954.42	73.17	-22.66	74.90	808.80	30.38	14	19	90.00	24.25
5/16/07	2	135	4459.94	2046.84	116140.10	71.01	-74.69	67.59	152.72	4.98	10	19	90.00	28.77
5/16/07	3	135	5340.68	1293.04	83691.57	65.28	-10.36	76.64	209.94	10.20	12	27	90.00	17.54
5/17/07	4	136	1859.88	449.70	27024.17	89.18	60.48	95.80	1840.72	68.82	12	42	135.00	17.44
5/17/07	5	136							2371.89	54.97	9	27	135.00	29.59
5/17/07	6	136	3213.28	1070.90	40262.19	85.24	5.89	93.74	2248.79	56.13	13	29	135.00	27.31
6/2/07	4	151	3920.97	639.34	33988.04	73.40	53.19	98.95	916.88	41.84	15	25	104.00	17.07
6/2/07	5	151	2106.57	802.60	36369.81	85.71	41.23	98.87	1477.91	47.24	15	17	104.00	26.08
6/2/07	6	151	1021.64	132.79	7935.25	93.07	90.28	99.75	1972.88	86.16	14	31	104.00	18.02
6/5/07	1	154	1277.49	541.61	3459.38	89.76	40.42	99.08	2502.75	74.97	15	43	135.00	21.37
6/5/07	2	154	1857.83	1082.78	1105.09	85.11	-19.10	99.71	2462.30	58.27	20	38	135.00	27.95
6/5/07	3	154	2404.11	1049.63	13796.11	80.73	-15.46	96.32	1727.18	50.99	16	41	135.00	21.74
6/13/07	1	162	307.61	159.11	2862.17	90.57	45.79	98.43	2970.49	91.54	20	80	160.00	18.26
6/13/07	2	162	1851.22	869.94	2100.72	43.28	-196.37	98.85	3157.66	66.32	20	45	160.00	27.74
6/13/07	3	162	1227.16	834.04	35636.93	62.40	-184.14	80.43	2759.88	64.85	17	48	160.00	24.58
6/13/07	4	162	272.50	172.43	5457.65	97.10	75.32	98.94	2925.86	87.38	23	68	156.00	18.73
6/13/07	5	162	1267.10	760.56	37104.97	86.51	-8.87	92.77	3527.53	68.51	16	58	156.00	30.27
6/13/07	6	162	622.44	209.40	15996.61	93.37	70.03	96.88	3442.58	87.92	21	111	156.00	22.37
6/27/07	1	176	1117.96	274.38	15452.92	91.67	74.50	97.53	3688.16	90.35	22	100	173.00	20.67
6/27/07	2	176	2239.48	1314.85	32769.51	83.32	-22.20	94.75	3391.07	62.64	14	66	173.00	28.37
6/27/07	3	176	3329.27	1323.14	25912.04	75.20	-22.97	95.85	2764.49	57.93	23	71	173.00	24.66
6/27/07	4	176	240.74	72.23	1105.08	97.22	86.03	99.64	3216.91	92.07	15	83	166.00	18.87

Date	Plot	Day of year	N (mg)-Total in runoff	P (mg)-Total in runoff	TSS (mg)-Total in runoff	N removal (%)	P removal (%)	TSS removal (%)	Water retained (L)	Water retained %	Time of concentration (minutes)	Time to runoff (minutes)	Storm duration (minutes)	Storm intensity (mm/hr)
6/27/07	5	176							4089.70	81.42	13	69	166	28.08
6/27/07	6	176	1360.50	309.22	4084.53	84.27	40.20	98.67	3240.05	74.78	16	78	166	23.92
7/5/07	1	184	3786.61	1420.74	5668.25	76.00	-8.65	98.82	2133.44	49.48	17	24	159	23.26
7/5/07	2	184	2819.258	1154.638	7322.494	82.13	11.70	98.47	2771.90	59.52	17	24	159	25.43
7/5/07	3	184	6889.294	2044.663	19643.18	56.34	-56.36	95.91	643.22	15.92	10	24	159	21.56
7/5/07	4	184	916.85	464.63	4510.48	93.96	69.92	99.43	1905.47	67.51	23	28	110	21.30
7/5/07	5	184	4111.984	1629.497	10312.25	72.91	-5.49	98.70	261.76	8.11	20	26	110	25.00
7/5/07	6	184	2110.975	844.0645	7430.828	86.10	45.36	99.06	1192.05	41.60	26	30	110	21.69
7/12/07	1	191	1112.82	333.67	6183.14	94.88	72.53	97.57	2713.76	83.73	33	85	162	17.28
7/12/07	2	191							3078.24	65.55	18	61	162	26.26
7/12/07	3	191	5144.999	1286.218	9219.832	76.33	-5.88	96.37	2543.50	56.69	20	65	162	24.96
7/12/07	4	191	1181.90	666.12	3350.12	94.97	53.90	99.50	1790.43	56.85	32	74	192	14.13
7/12/07	5	191	2896.881	1225.555	5192.176	87.66	15.18	99.22	2712.16	50.98	21	68	192	25.43
7/12/07	6	191	1906.156	534.4784	8180.375	91.88	63.01	98.78	2988.85	71.84	22	80	192	19.39
7/23/07	1	202							1578.19	100.00			80.00	19.73
7/23/07	2	202							2243.98	100.00			80.00	28.05
7/23/07	3	202							1923.41	100.00			80.00	24.04
7/23/07	4	202							1491.88	100.00			80.00	18.65
7/23/07	5	202							2157.68	100.00			80.00	26.97
7/23/07	6	202							1923.41	100.00			80.00	24.04
7/24/07	1	203	1238.15	401.43	4836.51	86.30	44.62	98.00	2453.62	83.53	35	44	130.00	18.49
7/24/07	2	203	2512.17	947.77	0.00	72.19	-30.75	100.00	2991.34	72.37	23	26	130.00	27.69
7/24/07	3	203	2798.94	772.93	28106.53	69.02	-6.63	88.38	2542.92	68.47	20	28	130.00	24.47
7/24/07	4	203	488.02	336.19	0.00	95.22	57.61	100.00	2491.86	82.13	40	48	121.00	21.55
7/24/07	5	203	1949.11	764.36	0.00	80.91	3.62	100.00	2271.86	64.07	26	52	121.00	25.78
7/24/07	6	203	383.08	195.09	7803.54	96.25	75.40	98.94	2734.88	88.52	42	49	121.00	22.01
7/25/07	1	204	3832.54	1370.00	107519.25	61.91	1.61	92.86	3002.05	63.38	34	30	205.00	18.16
7/25/07	2	204	8627.31	2359.31	91555.15	14.25	-69.43	93.92	3261.59	48.09	21	25	205.00	28.15
7/25/07	3	204	4345.30	2357.91	74105.87	56.81	-69.33	95.08	2354.15	41.14	30	23	205.00	22.98

Date	Plot	Day of year	N (mg) Total in runoff	P (mg) Total in runoff	TSS (mg) Total in runoff	N removal (%)	P removal (%)	TSS removal (%)	Water retained (L)	Water retained %	Time of concentration (minutes)	Time to runoff (minutes)	Storm duration (minutes)	Storm intensity (mm/hr)
7/25/07	4	204	1873.62	914.68	44258.71	93.26	66.79	99.32	3277.64	68.96	30	28	198.00	19.43
7/25/07	5	204	5050.16	1983.99	90181.34	81.83	27.97	98.61	3226.43	51.77	36	26	198.00	26.90
7/25/07	6	204	1297.70	911.48	24718.16	95.33	66.91	99.62	3713.55	70.62	25	30	198.00	21.98
7/26/07	1	205	1457.32	578.18	36433.12	89.38	47.60	96.82	2607.41	76.70	25	23	130.00	21.43
7/26/07	2	205	5681.87	1695.01	76394.89	58.58	-53.63	93.34	1776.53	42.67	17	20	130.00	27.31
7/26/07	3	205	2772.39	1133.37	0.00	79.79	-2.72	100.00	1902.38	52.18	26	21	130.00	23.33
7/26/07	4	205	1100.56	605.81	6058.12	88.90	48.34	99.54	2457.75	70.88	15	33	125.00	23.48
7/26/07	5	205	4855.46	1406.72	45378.11	51.05	-19.97	96.56	1494.44	39.71	28	36	125.00	25.84
7/26/07	6	205	2291.59	1179.83	45378.11	76.90	-0.62	96.56	483.42	17.56	27	35	125.00	17.75
7/27/07	1	206	738.75	263.28	3929.54	90.99	52.04	98.58	1365.42	77.65	13	47	65.00	22.95
7/27/07	2	206	1916.81	295.91	15899.78	76.61	46.10	94.24	1649.62	78.88	14	31	65.00	28.07
7/27/07	3	206	287.84	231.03	757.48	96.49	57.92	99.73	1194.69	75.93	18	34	65.00	20.11
7/27/07	4	206	3040.73	403.36	25687.71	65.15	39.75	95.54	1011.00	56.58	8	16	65.00	23.14
7/27/07	5	206	1072.24	493.07	34436.79	87.71	26.35	94.02	1361.60	63.50	11	17	65.00	28.64
7/27/07	6	206	824.09	879.77	742.42	90.56	-31.41	99.87	1020.94	73.34	25	24	65.00	17.07
8/17/07	1	226	61.26	56.09	1380.58	97.07	92.52	99.89	5809.50	98.54	50	265	318.00	16.11
8/17/07	2	226	1366.93	1144.80	59802.99	34.74	-52.71	95.33	7066.09	80.53	28	172	318.00	25.16
8/17/07	3	226	753.23	753.23	11688.11	64.04	-0.48	99.09	7944.59	85.95	43	180	318.00	26.64
8/17/07	4	226	280.64	264.45	2158.79	97.70	66.25	99.25	5568.26	91.16	42	175	265.00	20.94
8/17/07	5	226	750.08	628.44	24326.89	93.85	19.79	91.58	5612.18	84.70	34	160	265.00	22.89
8/17/07	6	226	0.00	0.00	0.00	100.00	100.00	100.00	4726.99	100.00	0	261	265.00	15.73
10/12/07	1	281	241.03	191.74	168.30	97.46	71.61	99.96	2649.94	91.75	41	130	167.00	15.06
10/12/07	2	281												
10/12/07	3	281	1297.70	529.69	3396.17	86.32	21.56	99.16	1744.06	71.35	33	107	167.00	12.40
10/12/07	4	281	334.48	289.67	1926.72	98.22	81.21	99.93	4242.66	90.00	50	113	209.00	19.29
10/12/07	5	281	949.72	608.99	4888.00	94.96	60.50	99.82	7888.02	88.82	58	104	209.00	
10/12/07	6	281	204.18	174.53	599.45	98.92	88.68	99.98	8349.07	96.69	59	123	209.00	
10/20/07	1	289	1053.97	500.59	78887.47	95.43	57.98	94.16	832.22	69.30	38	29	77.00	10.89
10/20/07	2	289												

Date	Plot	Day of year	N (mg)- Total in runoff	P (mg) Total in runoff	TSS (mg) Total in runoff	N removal (%)	P removal (%)	TSS removal (%)	Water retained (L)	Water retained %	Time of concentration (minutes)	Time to runoff (minutes)	Storm duration (minutes)	Storm intensity (mm/hr)
10/20/07	3	289	7224.84	854.92	94959.60	68.70	28.23	92.97	1474.54	60.89	29	18	77.00	26.74
11/17/07	4	316	1081.32	753.13	15164.82	94.71	44.86	96.30	2706.85	84.11	25	91	155.00	15.43
11/17/07	5	316	5893.50	3292.78	61344.96	71.17	-141.07	85.03	740.54	24.41	10	83	155.00	14.24
11/17/07	6	316	3619.56	1908.07	42390.35	82.30	-39.69	89.65	2341.31	63.94	16	88	155.00	18.30

Appendix D - Summary of Statistical Analysis

Table 5-2 Summary of all mean comparison

	Variable	**Plot**	**Time**	**Site**	**Model**
1.	Nitrogen trapping efficiency	0.0012	0.1581	0.0002	0.0004
2.	Phosphorous trapping efficiency	<.0001	0.0097	0.0001	<.0001
3.	Sediment trapping efficiency	0.3001	<.0001	0.0620	<.0001
4.	Runoff volume	<.0001	<.0001	0.0508	<.0001
5.	Total infiltration	0.3433	<.0001	0.2648	<.0001
6.	Infiltration percentage	<.0001	<.0001	0.7811	<.0001
7.	Time of Concentration	0.0325	<.0001	0.0284	<.0001
8.	Time to runoff	0.0019	<.0001	0.7066	<.0001
9.	Soil moisture	1.0000	<.0001	0.9988	<.0001
10.	Biomass	1.0000	<.0001	<.0001	<.0001
11	Rainfall	0.1660			0.1660
12	Saturated Hydraulic conductivity	0.0649	<.0001	0.1463	<.0001
			Site 1	**Site 2**	
13	Nitrogen trapping with management practices		0.2956	0.1044	
14	Phosphorous trapping with management practices		0.1790	0.0687	
15	Sediment trapping with management practices		0.5997	0.0008	
16	Water retained % with management practices		0.5880	0.1511	
17	Time of concentration with management practices		0.0004	0.0166	

Notes:

Mean comparison was done and variance was decomposed into three effects such as plot, time and site.

Model H_o: $\mu_{ijk}=\mu$

H_a: $\mu_{ijk}=\mu + \alpha_i + \beta_j + \gamma_k$

(Here α, β, and γ denotes the effects caused by site, plot and time)

In mean comparison # 12 (saturated hydraulic conductivity) plot number is used to classify the location of double ring infiltrometers. Numbers 1 to 6 corresponds to site 1-top, site1- middle, site 1-bottom, site 2-top, site 2- middle, site 2-bottom.

Table 5-3 Summary of all analyzed single regression correlations

	Regression Correlation	**β_1**	**P**	**r^2**
1.	Runoff volume vs N trapping	-0.00957	<.0001	0.4653
2.	Runoff volume vs P trapping	-0.04105	<.0001	0.5672
3.	Runoff volume vs TSS trapping	-0.00243	0.0080	0.0890
4.	Water retained % vs N trapping	0.34119	<.0001	0.4413
5.	Water retained % vs P trapping efficiency	1.35335	<.0001	0.4341
6.	Water retained % vs TSS trapping efficiency	0.17056	<.0001	0.3153
7.	Soil moisture % vs N trapping efficiency	-0.52149	0.0523	0.0528
8.	Soil moisture % vs P trapping efficiency	-0.79728	0.4389	0.0082
9.	Soil moisture % vs TSS trapping efficiency	-0.11557	0.4438	0.0077
10.	Time vs N trapping efficiency	0.03442	0.2539	0.0186
11.	Time vs P trapping efficiency	0.17537	0.1532	0.0277
12.	Time vs TSS trapping efficiency	0.04021	0.0181	0.0714
13.	Biomass vs N trapping efficiency	0.02331	0.0034	0.1756
14.	Biomass vs P trapping efficiency	0.10115	0.0014	0.1934
15.	Biomass vs TSS trapping efficiency	0.01908	<.0001	0.2772
16.	Rainfall vs N trapping efficiency	0.00336	0.9502	0.0001
17.	Rainfall vs P trapping efficiency	-0.17950	0.3647	0.0113
18.	Rainfall vs TSS trapping efficiency	0.05427	0.0596	0.0459
19.	Runon N concentration vs N trapping	0.17824	0.1191	0.0344
20.	Runon P concentration vs P trapping	-1.80295	0.7832	0.0010
21.	Runon TSS concentration vs TSS trapping	0.000523	0.2266	0.0192
22.	Biomass vs time of concentration	0.03833	<.0001	0.5744
23.	Runon vs runoff concentration-N	0.07808	<.0001	0.4238
24.	Runon vs runoff concentration-P	0.01755	0.3538	0.0118
25.	Runon vs runoff concentration-TSS	0.00301	0.0056	0.1047
26.	Time vs Biomass	4.12586	<.0001	0.8527
27.	Soil moisture vs water retained	-201.667	<.0001	0.5575
28.	Soil moisture vs time to runoff	-7.24523	<.0001	0.7083
29	Biomass vs water retained	5.48700	<.0001	0.4081
30	Rainfall intensity vs N trapping	-1.62179	0.0003	0.1654
31	Rainfall intensity vs P trapping	-5.29851	0.0004	0.1555
32	Rainfall intensity vs TSS trapping	-0.24784	0.1715	0.0251
33	Water retained % vs total n load in runoff	-64.7210	<.0001	0.7620
34	Water retained % vs total p load in runoff	-17.205	<.0001	0.6547
35	Water retained % vs total TSS load in runoff	-817.119	<.0001	0.4368
36	Applied rainfall vs water retained volume	54.29997	<.0001	0.8200

r^2	R square value of the regression correlation
β_1	Slope of the regression correlation
P	P value for β_1. H_o: $\beta_1=0$

Table 5-4 Summary of all analyzed multiple regression correlations

	y	x_1	x_2	x_3	r^2
1.	Nitrogen trapping efficiency	Infiltration percentage 0.38983 (<.0001)	Applied rainfall -0.13507 (0.0172)		0.5506
2.	Phosphorous trapping efficiency	Infiltration percentage 1.59235 (<.0001)	Applied rainfall -0.96409 (<.0001)	Biomass 0.08169 (0.0080)	0.7068
3.	Sediment trapping efficiency	Infiltration percentage 0.14471 (0.0016)	Biomass 0.01548 (0.0076)		0.4564
4	Runoff volume	Applied rainfall 22.72905 (0.0002)	Soil moisture 99.00609 (0.0003)	Biomass -2.14245 (0.0029)	0.3217
5	Total infiltration (water retained)	Applied rainfall 31.19423 (<.0001)	Soil moisture -121.663 (<.0001)	Biomass 1.97868 (0.0013)	0.8537
6	Infiltration percentage	Soil moisture -2.03240 (0.0003)	Biomass 0.04937 (0.0014)		0.4210

Notes:
Multiple regression was done with four variables such as infiltration percentage, applied rainfall, biomass and soil moisture. Backward elimination method was used to choose the variables.
x_1, x_2, x_3 are variables left in the model and are significant at the 0.1000 level. Under each variable, numerical estimate and its P value are given.
r^2 R square value of the regression correlation.

Outliers:

Outliers were identified using studentized residual for each data value and comparing it with a critical value. First six outliers were identified and deleted based on the R^2 value. If the R^2 value reduced then, outliers were not deleted. They were deleted only if R^2 is increased by the deletion. In some correlations all six were deleted and in others less than six outliers were deleted or none were deleted. In the SAS outputs given in the “statistical analysis” document in the CD, first three outliers were marked with red outline and second three outliers were marked with blue outline. To see exactly which data points were deleted, check the worksheets “stat1” and “stat2” in the “data.xls” spreadsheet in the CD provided. Deleted data points are marked with red outline on those worksheets. R^2 values for different correlations are given for both cases, before and after deletions.