Report for 2004IA63B: Vegetative Filter Education and Assessment in the State of Iowa.

Publications

- There are no reported publications resulting from this project.

Report Follows

Vegetative Filter Education and Assessment in the State of Iowa

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Problem and Research Objectives

At present, quality of water is the largest issue globally, with concerns for the alarming death rate of aquatic organisms, human health hazards, and aesthetic beauty of the world's famous water bodies. In order to combat pollution resulting from diffuse sources, the U.S. government is taking considerable measures towards mitigation by means of employing Best Management Practices (BMPs). Vegetated filter strips (VFS) is one of the best management practices that helps reduce the transport of these substances to receiving waters. Reduction of sediment and nutrients in surface runoff to rivers and lakes is important to Iowa's initiative to reduce the number of impaired water bodies. VFS help to reduce the deterioration of the surface waters through retention of the sediments and nutrients from surface runoff from agricultural fields. VFS have been shown to be most effective for shallow, uniform surface runoff conditions, but it has also been shown that in case of heavy overland flows, the flow concentrates and only a portion of the vegetative filters proves to be effective in sediment and nutrient retention in the filter. Determining the most important design considerations for VFS is important for maximizing the water quality benefits for the VFS. Therefore, the on-site assessment of existing vegetative filter strips to examine and document critical design criteria is highly significant. It is also important to extend the findings and knowledge found in the field assessment to the stakeholders and upcoming generation so that they implement these designs and protect the environment. Therefore, the following objectives are considered important to be achieved in relevance to the existing scenario. The objectives include:

1. Identification of VFS sites for in-field data collection and assessment.
2. Development of an assessment tool for evaluating the effectiveness of VFS using past and current research literature findings.
3. Determination of the effectiveness of VFS by visual field observation and validation by flow mapping procedures in ArcGIS 9.
4. Comparison of the area ratios and percentage of flow along each stream segment at various resolutions (5X5, 10X10, 20X20 and 30X30) for different sizes of the survey data sets.
5. Comparison of the flow routing for USGS 7.5 Quad Angle values and spatial analysis of the elevation data at resolution of 30X30.
6. Education of grade school, junior high, and high school students on VFS performance and surface water runoff issues related to water quality and biodiversity.

Methodology

Using data from past and current research projects on VFS, an on-site assessment tool has been developed to evaluate the performance of Iowa's VFS in key impaired water bodies. The major component of this study constitutes assisting grade school, junior high, and high school students in evaluating current VFS in an impaired watershed(s) close to their location. The Rock Creek Watershed next to Newton, Iowa was selected by the research team for this purpose (shown in Figure 1). This site was selected since it was in the extension Agricultural Engineer's (Kapil Arora) region and due to the ease of collaboration with the local NRCS county office and the local educators.

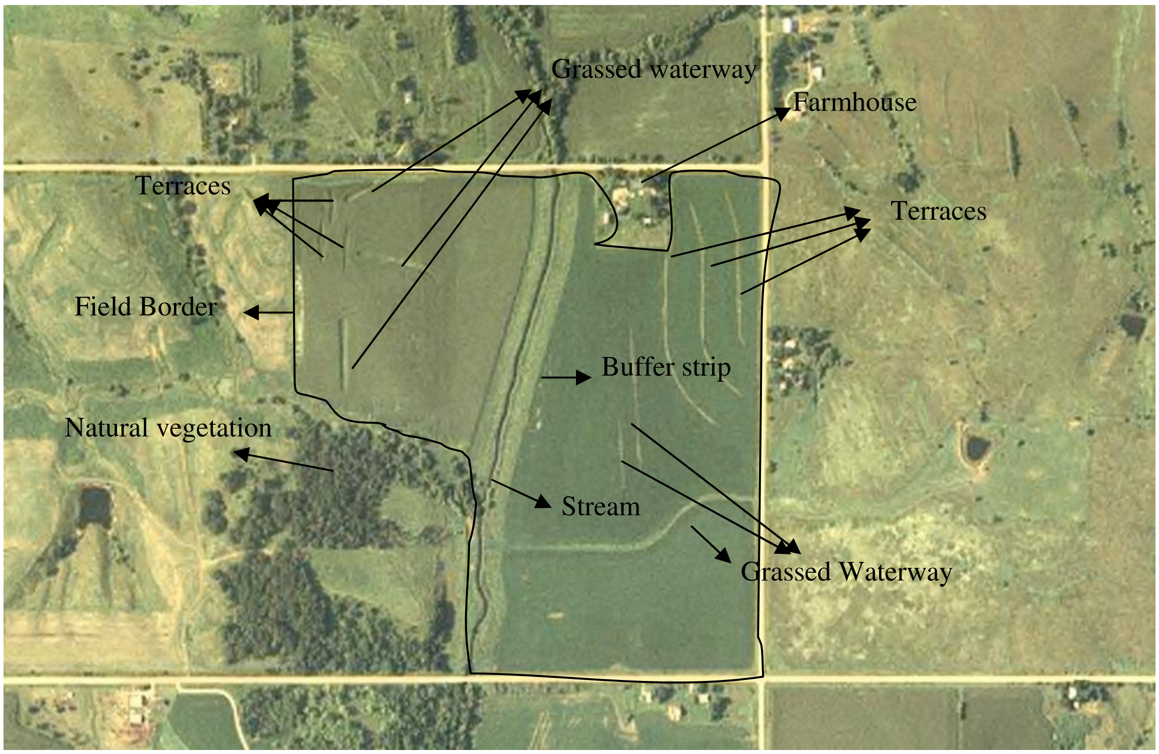

Fig. 1. Rock Creek Watershed field layout

The team visited the Rock Creek Lake Watershed in November 2004 and conducted a training session for high school students. The students made an efficient site evaluation with the guidance of the field staff and research team. The site evaluation included the parameters like vegetative filter length and width, type of vegetation, uniformity/space distribution of vegetation, rill and gully erosion evidence, etc. Validation checks were made at each subwatershed site within the Rock Creek watershed by the research team. Through visual observation and in-field surveying, it was found that the buffer strips are ineffective in sediment and chemical retention, as the surface runoff does not flow through the VFS. Owing to the presence of undulations in the field, the flow leads towards the natural vegetation instead of draining into buffer strips which led to significant growth in this region. Some traces of sedimentation at the buffer edge were seen which makes it evident that there were times when runoff reached the buffer strips, but from the topographic observations, it is possible only in the case of a larger rainfall event. Another training session was conducted for grade school students in September 2005. Grinnell High School FFA, Newton Senior High School FFA, and Structure of Intellect (SOI) at Thomas Jefferson Elementary in Newton showed keen interest and participation in the project. These training sessions helped the students to better understand the processes and impacts of nutrients from agriculture on water quality and the impact of sediment accumulation on aquatic life in lakes and streams. Using the past research, we have come up with an extension bulletin which includes an assessment form for the VFS site. This document would facilitate both qualitative and quantitative assessment at a given VFS site. Qualitative measurements on the form will have supportive rubrics attached that more adequately describe various levels of quality related to a specific measurement. Please find this document as an attachment to the report.

The team also met NRCS staff in September 2004 in regard to acquisition of the data where it was decided to conduct the site surveys in relation to the drainage and the filter area. As a result of this meeting, several potential sites were identified based on their vegetation growth, time (years since establishment), filter width, and drainage area served. Out of these sites, land owners of three sites agreed to partner in this project and provide access to the sites for the team to carry out their evaluations. These three sites were surveyed by the NRCS team in Fall 2005. In the meantime, the literature was reviewed to gain knowledge about the sediment trapping and pesticide retention with the help of VFS.

The elevation data for the sites was recorded throughout the field by the local NRCS office staff using Global Positioning System (GPS) Real Time Kinematics (RTK) equipment. Geographic Information Systems (GIS) was employed for validation of the visual observation regarding the flow accumulation and outlet points in the field. This software combines the site evaluation data of each point on the field into layers of information at that point on the map of the watershed to give a better understanding of the runoff hydrology at that point. The technique of Digital Elevation Model (DEM) helps obtain the digital representation of the topographic surfaces as a regular grid of spot heights. In our case, elevation data for the field was used to obtain the flow routing in ArcGIS 9 and validate our visual observations regarding the effectiveness of the buffer strip. Elevations at equal and uniform intervals in the watershed were interpolated from the collected data (which was at unequal spacing) through a method called Kriging.

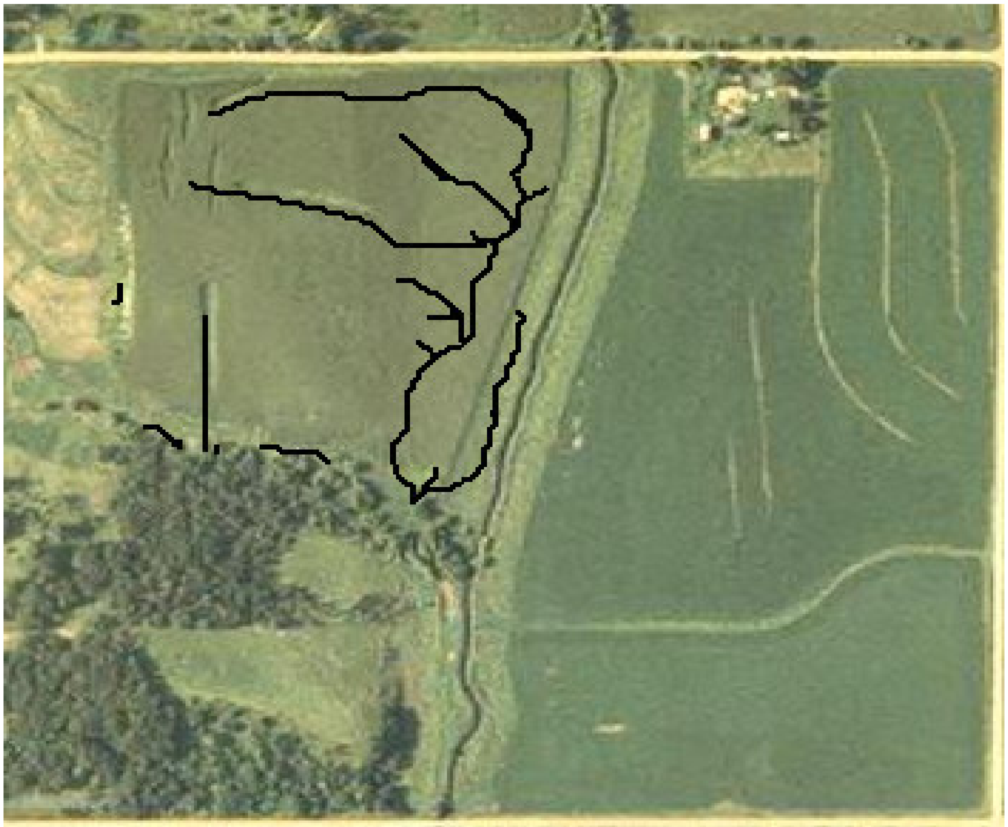

Fig. 2. Stream network of a subwatershed in Rock Creek watershed field

DEM helped identify the sinks in the drainage area, generate flow accumulation and drainage/stream network of the watershed for the collected data through ArcView 3.3. The stream network delineated by the software for a subwatershed of Rock Creek watershed field, shown in Figure 2 above, was found in congruence with the visual observation, which lies as a major objective of this study.

As per the objectives, stream network for four different resolutions of DEM, namely 5X5, 10X10, 20X20 and 30X30 was also delineated. The stream network for a subwatershed has been delineated for all four datasets at a resolution of 5X5 of the collected data. These layers were laid on top of one another, as shown in Figure 3 below. We can clearly see the difference in the stream network delineation for four datasets at the same resolution. We aim to quantify these differences in terms of area ratios and percent of flow along each stream segment for four different sizes of the dataset.

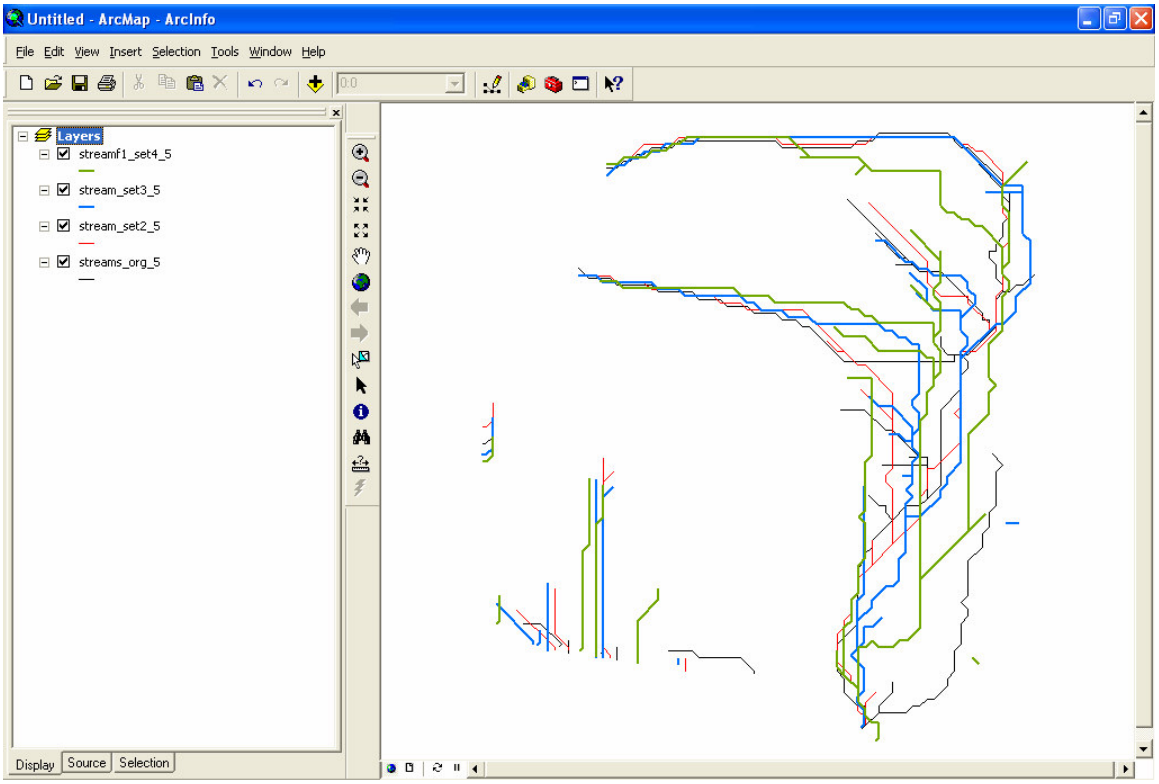

Fig. 3. Stream network for all four datasets at 5X5 resolution

Another objective aimed at comparison of the flow routing for USGS 7.5 Quad Angle values and spatial analysis of the elevation data of the field at a resolution of 30X30. The DEM of USGS 7.5 Quad Angle 30X30 values were extracted from Iowa data found at ftp://gis.iastate.edu and the stream network was delineated in ArcView 3.3. Flow routing for this showed well-organized streams heading towards the buffer before draining into streams. This was laid on top of 30X30 resolution of the collected data, as shown in Figure 4. Apparently, delineated stream network for collected data was far different from that of USGS data at resolution of 30X30. But it was seen that the delineated stream network for dataset 4, the smallest data size, at resolution of 30X30 was close to that of USGS 30X30, as shown in Figure 4. This clearly implies that the number of data points for USGS 30X30 lies close to the number of data points in Set 4.

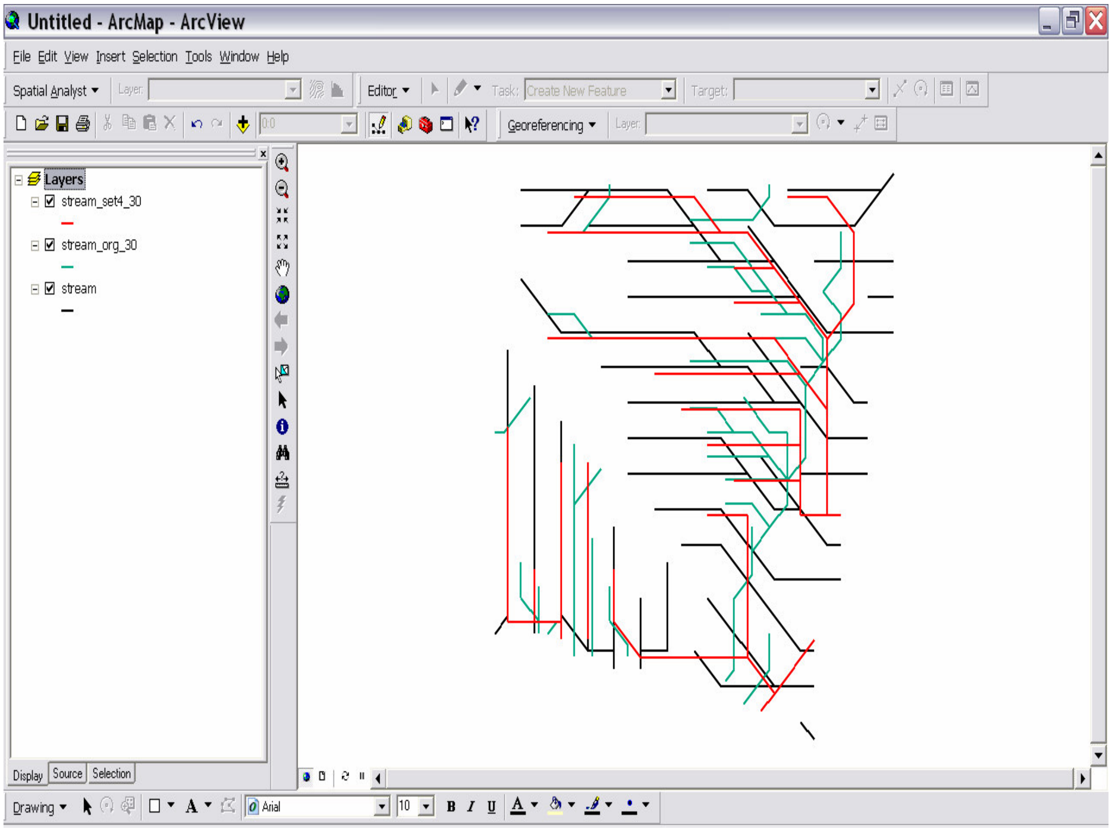

Fig. 4. Overlay of USGS, Dataset 1 and Dataset 4 stream network at 30X30 resolution

The differences in the flow accumulation at various resolutions (5X5, 10X10, 20X20 and 30X30) of the different survey data sets for the field will be quantified in terms of area ratios and percentage of flow along each stream segment. From the spatial analysis of the different datasets of one subwatershed, it has been concluded that the smallest dataset is least accurate in terms of flow routing, with results being far different from visual observation. In addition to this it was seen that the resolution of 5X5 gives good estimate even with the smallest dataset.

Principal Findings and Significance

The majority of the year 2004 has been spent on reviewing the key literature related to VFS for the purpose of designing the best on-site VFS assessment tool. Significant time was also given to developing the assessment tool, choosing the correct watershed, collecting in-field survey data, and setting up collaboration with the Newton educators. The following section summarized the findings from the literature review.

The transport of the sediments and the range of applied agrochemicals from the agricultural fields into the surface water bodies is one of the major environmental threats. This transport is a result of heavy rainfalls or huge amounts of overland flow. Controlling the amount of the agrochemicals and the sediments available for potential loss to the environment by planting close growing vegetation or tall, stiff grasses is a significant management practice that helps reduce the transport of these substances to receiving waters. VFS are the bands of planted or indigenous vegetation situated down slope of cropland or animal production facilities to filter nutrients, sediment, organics, pathogens, and pesticides from agricultural runoff before it reaches a water system (Dillaha et al., 1989). These VFS offer important advantages where runoff concentrates. These have been considered to be effective in slowing down the runoff velocity and filtering sediment. VFS prove as an impediment to the movement of the suspended material in the runoff, hence promoting the settling of the suspended solids which are sediments and applied chemicals. Therefore, it is important to assess the effectiveness of the VFS in removal of the sediments and nutrients from the runoff. The effectiveness of the strip is dependent on the width, types of vegetation, age, level of development, and many more factors. Following is the key literature regarding various aspects related to the use of VFS, such as hydraulic characteristics, sediment/pesticide removal, and their effectiveness/ineffectiveness owing to various factors.

Hydrology & Characteristics of VFS

There are studies that quantify the effectiveness of VFS in terms of length, slope, and hydraulic characteristics. Here are some of those studies which proved to be helpful in better understanding about VFS.

Length. Gharabhaghi et al. (2001) studied the variations in sediment removal efficiency with variation in flowpath of vegetative filter strips. Lengths of 2.44, 4.88, 9.67 and 19.52 m were considered for 1.22 m wide field with a slope 5.1–7.2%. From 58 runs of experiments and 348 runoff samples, it was concluded that the first five meters play a significant role in removal of the suspended solids and aggregates greater than 40 microns in runoff. It was found that the performance of the VFS doesn't increase by appreciable margin by increasing the flowpath length beyond 10 m. High turbulence keeps finer particles in suspension which makes it difficult to remove them from runoff. However, the study pertains to the fact that infiltration is the only mechanism that helps in the removal of the smaller size sediments. The vegetative filter strip model VFSMOD was calibrated and validated using the observed data from the field experiments. The model was observed to possess high accuracy in predicting the sediment removal efficiencies of the vegetated filter strips.

Lee et al. (2003) conducted a study to determine the effectiveness of a multi-species riparian buffer in removing non-point source (NPS) pollutants carried by cropland runoff. The experimentation involved installation of three plots where each of the cropland source areas was matched with no buffer, switchgrass buffer (7 m), and a switchgrass/woody plant buffer (16.3 m). This study is a perfect example of functional differences between the long and short buffers. It is attributed to sediment trapping efficiency figures as high as >92% and >97% after passage of runoff from switchgrass and switchgrass/woody buffer respectively. It was concluded that the switchgrass is an effective measure for coarse particles unlike switchgrass/woody buffer, which is more suitable for finer particles. Sediment transported through no buffer was 13 times more than that from switchgrass/woody buffer. Sediment size distribution was found to be another significant factor that determines the performance of VFS. In this case, more than 90% of the sediment in the surface runoff from the buffered plots was in the <0.05 mm size fraction. During infiltration of nutrients, suspended fine soil particles with adsorbed chemicals also enter the profile, thus decreasing the surface runoff and sediment transport capacity. The results, therefore, indicated that the selection of buffer vegetation should take care of problems and conditions of the site.

M. Abu Zreig et al. (2004) conducted twenty field experiments to study sediment removal in VFS with variations in filter length, filter slope, and type of vegetation. Experiments were conducted with incoming sediment load of 2700 mg/l on filter lengths of 2, 5, 10, and 15 m, slopes of 2.3 and 5%, and three different types of vegetation. It was concluded that the length of the filter was the most important factor affecting the VFS sediment trapping efficiency. It was observed that increase in length of filter beyond 10m didn't increase the sediment trapping efficiency. Rather, an exponentially decreasing trend between sediment trapping efficiency and length beyond 10 m was seen. The sediment trapping efficiency was observed to increase with decrease in inflow rates and decrease in soilwater content of soil due to enhanced infiltration. Although vegetation has a secondary effect on sediment trapping efficiency, greater vegetation densities resulted in lesser erosion and lesser transport capacity of the runoff, eventually leading to greater settling of the sediments.

Hydraulic Characteristics. Infiltration is the underlying mechanism responsible for the trapping of the suspended solids and applied chemicals carried by the runoff. Infiltration is the downward entry of the water into the soil profile. Gharabhagi et al. (2001) stands by the fact that infiltration is the sole mechanism that helps the removal of smaller sized sediments. The vegetative cover helps in reducing the velocity of incoming runoff and increases the residence time, the time for water to infiltrate. Consequently, ponding occurs at the upstream end of the filter and some of the sediments and suspended solids get filtered out as the water flows through the filter and settles on the top of the filter. Stem diameter, density, stiffness, and hedge width affected the depth of ponding (Meyer et al., 1995).

Ree et al. (1949) studied the hydraulic characteristics of vegetation. It was observed that Manning's coefficient 'n' decreases as the submerged grass in a waterway bends over owing to high flow rates. Due to the bending of the grasses, there is a decrease both in the turbulence creating ability of the stems and area blocking effect. Whereas, in the case of the non-submerged channel, grass stands erect which helps retard the flow in a better way. Ree indicated that grass remains erect until submergence is complete. In other words, the study concluded that the non-submerged conditions form an ideal case for maximum flow retardation and the minimum sediment transport capacity.

Van Dijk et al. (1996) identified the use of grass vegetation as grass hedges, grass strips, buffer zones, and grass channels as an effective measure to reduce sediment transport to surface waters. This study discusses the retention of water and sediment in each of these field arrangements and concluded that the underlying mechanism is the same for all the arrangements, i.e., infiltration and sedimentation. The experiment was conducted so as to derive the comparative results regarding the sediment trapping efficiency of grasses with two different ages and agricultural management practice. It was seen that the older grass was much more effective in reducing erosion than the younger grass which was credited to frequent mowing activities. Certain differences in the water retention of two grasses were observed which were attributed to difference in the grass density at two locations. Sediment trapping efficiency of grass filters of length 1, 4-5 and10m was recorded as 50-60, 60-90, and 90-99% respectively.

M. Abu Zreig (2001) studied the factors affecting VFS performance using computer simulation by means of VFSMOD. Length of the filter was seen to have the greatest effect on sediment trapping. It was observed that sediment trapping efficiency decreases exponentially beyond 10 m. Greater vegetation densities, and therefore a greater Manning's roughness coefficient 'n' resulted in greater contact time between the runoff and vegetation resulting in less erosive power and less transport capacity of the runoff and therefore, greater trapping efficiency. Also, the effect of length of the filter was seen in combination with 'n' and it was concluded that practicality of situation lies with the fact that higher trapping efficiencies can be achieved by increasing the length of the filter than maintaining a good vegetation cover. Filter performance also depends on the size of the incoming sediment. Trapping efficiencies of 0% and 47% for clay particles over filter lengths of 1 m and 15 m respectively were observed through experimentation which implies that smaller sized particles take longer length to filter out. Different soil types have different saturated hydraulic conductivities, which have a significant effect on trapping efficiency by effecting infiltration.

Sediment & Nutrient Removal. Young et al. (1980) performed a 2-year study to evaluate the effectiveness of VFS to remove the pollutants in runoff from livestock feedlots under simulated rainfall conditions. The experiment was conducted on a field 111.25 m X 54.86 m and 6 VFS strips, each 4.06 m wide and 41.15 m long with 4% slope. Out of the length of 41.15 m, 13.72 laid within the feedlot. Cropped fields of corn, orchardgrass, sorghum-sudangrass, and oat plots were used to reduce the runoff, total solids, and nutrients. The results showed that the total nitrogen, NH_4-N, total Phosphorus, and PO_4-P were seen to have reduced by 84, 63, 83, and 76%, respectively. Suspended sediment was reduced by 86, 66, 82, and 75% for corn, orchardgrass, sorghum-sudangrass, and oats, respectively. It was seen that NO_3-N values rose, which was attributed to collection of NO_3-N by runoff from sorghum-sudangrass and oat plots. In case of corn the reductions in runoff, nutrient and suspended sediment were appreciably higher than reductions from other fields. This was credited to across the slope plantation of the corn. As the runoff passed through the vegetated buffer strips, a decrease in the indicator organisms in runoff was seen. In this case, a length of 36 m was seen to be sufficient enough to reduce nutrients, micro-organisms, and suspended solids in feedlot to acceptable levels.

Magette et al. (1989) experimented to study the effectiveness of VFS in nutrient and sediment removal. Urea-Ammonium-Nitrate, a source of N and broiler litter was applied to 22 m X 5.5 m field at the rate of 112 kg N/ha and 8.9 wet metric tons/ha, respectively. VFS of lengths 4.6 m and 10 m were employed in each set of experiment. The field soil was rich in P; therefore, no supplemental P was applied. This study assumed P movement to be dependent on total soluble solids (TSS) transport; whereas N can move in soluble form more freely. The results showed higher losses of P during UAN tests than broiler litter tests. This was attributed to the mulching effect of the litter, which eventually minimized the TSS losses. Losses of TN, TP, and TSS were seen to decrease by 0, 27, and 66%, respectively, with the use of VFS. This clearly indicated that VFS is not as effective in removing the nutrients from cropland runoff as in removing suspended soils.

Concentrated Flow. Concentrated flow or non-uniform distribution of flow limits the performance of VFS. In another study by Meyer et al., 1995, strips of tall, stiff grasses were planted across the slope in order to study their sediment trapping efficiency. It was observed that the practice of perpendicular plantation helped achieve higher trapping efficiencies by retarding the flow concentration. Flow concentration was seen to have a detrimental effect on the filtering effectiveness of the VFS. Experiments were conducted to analyze the effectiveness of the vegetative filter strips using transparent wall flumes and root boxes (grass boxes). Root boxes were placed in a pit such that the grass surface was leveled with the base of the flume. Sediment mixed with water was fed at the upper end of the flume, which passed the grass boxes. This experimentation setup helped us understand the hydrology involved in sediment removal. It was seen that the grasses retarded the flow, resulting in a hydraulic jump formation several meters upslope of the hedge, which apparently led to the deposition of the incoming sediment. The formation of the hydraulic jump and sediment deposition further helped the flow retardation and deepened the ponded flow. Sediment trapping resulted mostly from the upslope ponding due to grass hedges rather than by filtering action. It was concluded that the sediment trapping was primarily a result of sufficient settling time in the ponded flow and not because of the failure of sediment to pass through the voids in the grass. Results emphasize the effectiveness of stiff grasses as high as 80% for sand-sized sediment. This clearly implies that the trapping effectiveness largely depends upon the size distribution of the incoming sediment and we require longer path lengths for fine silt or clay-sized sediment.

Dosskey et al. (2002) conducted an assessment of the riparian buffers. It was seen that concentration of flow from agricultural fields considerably hampers the potential of the riparian buffers to remove pollutants. Concentration/non-uniform distribution of flow occurs when runoff meets only a small fraction of the gross area owing to factors like topography, flow rate, etc. The methodology employed four study farms for studying the impact of the flow on sediment trapping efficiency, evaluated with the help of a numerical model using regression equations based on the ratio of the buffer area to field runoff area. This model yielded trapping efficiencies of 99%, 67%, 59%, and 41% in contrast to 43%, 15%, 23%, and 34% for uniform and non-uniform flow conditions respectively, all other parameters held constant. It was noted that sediment trapping could only be improved by avoiding the concentrated flow, which is generally caused due to the deposition of the soils from channelization activities within the buffer zone.

Pesticide Retention

Pesticides can be applied in various ways, such as aerial spraying, incorporation or injection into the soil, or application in solution form. Similarly, these have various loss pathways such as volatilization or aerial drift, adsorption onto the soil particles, or degradation into simpler forms over a period of time. But the loss of pesticides as runoff to surface water bodies or leaching into groundwater profile is the one that is of major concern to environmentalists. The fate and transport of pesticides is largely dependent on their chemical properties, like solubility, persistence, etc. The pesticides that are highly soluble have a tendency to leach down to groundwater profile, while the ones which are highly volatile vaporize during application. There are many factors that influence the fate and transformation of the pesticides and have been described as follows:

Adsorption and Solubility. When a pesticide enters soil, some of it will stick to soil particles through a process called adsorption. Some of the pesticide will dissolve and mix with the water between soil particles. The active sites for sorption of the pesticide are mainly the clays and soil organic matter. As more water enters the soil through rain or irrigation, the adsorbed pesticide molecules may be detached from soil particles through a process called desorption. The solubility of a pesticide and its sorption on soil are inversely related, which means the more soluble the pesticide, the lesser the tendency to be adsorbed/sorbed. The pesticides that are highly soluble have an affinity to leach down through the soil to the groundwater and are referred to as *weakly adsorbed pesticides*. These can also be lost to surface waters due to high amounts of irrigation water or due to overland flow resulting from heavy rainfalls. The *strongly adsorbed pesticides* do not readily leach to the underground water but can be found bound to the soil particles. There is another type of pesticide called *moderately adsorbed*. Infiltration is the key process for retention by the buffer strips for moderately adsorbed pesticides (Arora et al., 1996). Furthermore, adsorption is also affected by various factors, as follows:

Partition Coefficient. One of the most useful indices for quantifying pesticide adsorption on soils is the partition coefficient (K_{oc}). The K_{oc} value is defined as the ratio of pesticide concentration in the adsorbed state and the solution phase. Thus, for a given amount of pesticide applied, a smaller K_{oc} value implies a greater concentration of pesticide in solution or, in other words, the more soluble the pesticide. Pesticides with small K_{oc} values are more likely to be leached compared to those with large K_{oc} value.

Persistence. Another most important factor in deciding the fate of the pesticides is persistence. This factor is commonly evaluated in terms of half-life, which is the time that it takes for a pesticide to reach half its concentration through degradation/transformation. Pesticides with longer half lives could be persistent. Pesticides are classified on the basis of their persistence:

- Non-persistent: 30 days or less
- Moderately persistent: Longer than 30 days but less than 100 days
- Persistent: Longer than 100 days

Vapor Pressure. Also, pesticides with high vapor pressures are generally not recommended for application. This is because the greater the vapor pressure, the greater is the fraction of the molecules that can escape the liquid by gaseous diffusion.

Soil Properties. Soil properties like hydraulic conductivity and organic matter content and structure are important factors to determine the fate of the pesticides. Coarse-textured soils have higher hydraulic conductivities than do fine-textured soils. The travel time of the dissolved pesticide is shorter in coarse-textured soils than in fine-textured because of the fine pores and slow permeabilities in fine-textured soils. Therefore, the chances for pesticides to leach down easily are greater in coarse-textured soils. Also, the high clay and organic matter content of fine-textured soils leads to greater sorption, thus making pesticides less susceptible to leaching in fine-textured soils. Soil structure is another factor that has a significant effect on the fate of the pesticides. Macropores or wide cracks established by earthworms or farm machinery operations help in the preferential movement of the pesticides through the soil profile to the underground water resources. In such cases, pesticides lose the opportunity to be adsorbed.

Site Conditions. From the study of Gilliam et al., 1993, it has been found that in the case of shallow vadose zone, which is prevalent mostly in humid areas, pesticides get lesser opportunity to get adsorbed. The nature of the underlying strata governs the direction and rate of chemical movement. If this stratum is a permeable layer, the leaching is much easier and the chemical generally follows in a vertical direction in contrast to hard pan or an impermeable stratum which would actually contribute to the lateral flow of shallow groundwater, hence polluting the surface waters. Sometimes cracks and fractures convey water rapidly. Warmer weather conditions accentuate the rate of chemical, biological, and physical processes involved in the fate of the pesticides such as microbial degradation, volatilization, etc.

Management Practices. The best management practices involve the use of site-specific and crop-specific pesticides. Amount and time of application needs are especially taken care of.

Baker and Laflen (1979) studied the combined effect of wheel track compaction and method of incorporation on runoff losses of herbicides, namely, propachlor, atrazine, and alachlor. A rainfall simulation study was carried out with 122 mm of rainfall on nine plots each 1.5 m X 9.1 m, Clarion sandy loam soil. The experiment was conducted both with surface applied/soil incorporated herbicide application and with/without wheel tracks to deduce results regarding the effect of two factors. The pesticide losses that were measured from plots with wheel tracks were about 3.7 times higher than those from plots without wheel tracks where the herbicides were applied to a soil surface. It was concluded that incorporation practice for herbicides is superior to surface application/broadcasting as the herbicide losses in surface applied plots were around 3.5 times larger than those from plots where herbicides were incorporated by disking.

Arora et al. (1996) carried out a study to investigate herbicide retention by VFS from runoff at the Swine Nutrition Center, Iowa State University for two years under natural rainfall conditions. Six VFS, 1.52 m wide X 20.12 m long downstream of 0.41 ha of source area were established with brome grass to study the performance of buffer strips in retaining the three herbicides, namely atrazine, metolachlor and cyanazine present in runoff. Also, the effect of drainage to buffer strip ratio of 15:1 and 30:1 on herbicide retention was another objective of the study. Herbicide concentrations associated with water was seen to fall in outflow than in inflow which indicates retention/adsorption by soil and plant surfaces. The average K (adsorption/partition coefficient) values were seen to be 22, 18, and 15 in later runoff events in contrast to 15, 10, and 8 in the first five events. Values $\geq$ 8 indicate higher herbicide concentrations as adsorbed to sediment than in solution. The results showed that herbicide concentration associated with sediment higher in outflow than inflow for metalachlor, unlike atrazine and cyanazine. This was accredited to the difference in the adsorption properties of these herbicides. Not an appreciable difference was seen in the percent retentions for different area ratios and was reasoned as the nature of moderately adsorbed herbicides, which follow similar processes of infiltration and interception-adsorption. Efficiencies of the studied buffer strips were seen to vary between 40 and 100%.

Patty et al. (1997) studied the effectiveness of buffer strips to remove pesticides, nitrate, and soluble phosphorus compounds from runoff water by conducting experiments on three research farms at Brittany, France with VFS of 6, 12, and 18 m length perpendicularly sown with rye. Pesticides Isoproturon, atrazine, Diflufenican, and lindane as pollutants were used. Isoproturon and atrazine are water-soluble and moderately adsorbed on soil in contrast to Diflufenican and lindane, which have very low solubility in water. The results showed that the pesticide losses depend on the time elapsed between the time of application and rainfall event. It is owing to the sorption of the pesticides onto the surface of organic matter, soil particles, etc which also adds to the sediment removal efficiency of the VFS. Direction of sowing was another factor that contributed towards the effectiveness of buffer strip and proved to be advantageous in removing the nutrient and sediment load in runoff. The results showed nitrate and soluble phosphorus losses reduction by 47–100% and 22–89% respectively.

Arora et al. (2003) aimed at determining the performance of vegetated buffer strips in reducing pesticide transport under simulated runoff conditions. Experiments were conducted on six *20.12m long X 1.52m wide* buffer strips to determine their retention efficiency for three pesticides of different adsorption properties, namely atrazine, metolachlor, and chlorpyrifos. In addition to trapping efficiency, the effect of area ratios, 15:1 and 30:1, on the pesticide retention of the buffer strips was evaluated. The results showed that sediment concentration in outflow was reduced by 60–80%. A combination of infiltration and sediment retention was observed as an active process of retention. The results showed lesser sediment adsorbed concentrations of chlorpyrifos in outflow than inflow, unlike atrazine and metolachlor. Chlorpyrifos is a strongly adsorbed pesticide, unlike atrazine and metolachlor, which are moderately adsorbed pesticides. This is explained by the fact that chlorpyrifos gets easily adsorbed onto heavier/larger particles which get trapped by VFS, while finer sediment particles are seen in outflow. These fine particles have larger specific areas, owing to which the sediment associated concentrations are found to be higher in outflow than inflow, which is the case here for atrazine and metolachlor. The effect of adsorbing properties on retention of these pesticides was clearly reflected in the results. Another noteworthy observation regarding the retention of pesticides was lower concentrations of atrazine and metolachlor in runoff outflow than inflow, unlike chlorpyrifos. This was attributed to the fact that most of the retention of moderately adsorbed pesticides, like atrazine and metolachlor, occurs through infiltration. On the other hand, pesticides like chlorpyrifos were trapped through sediment adsorption and retention by buffer strips. Although this study showed an insignificant trend of lower retention at the higher area ratio, there was no appreciable difference between the performances of buffer strips at two different area ratios.

Wu et al. (2003) conducted experiments in order to compare the effectiveness of switchgrass, tall fescue filter strips, and bare soil in removing the copper pesticide from runoff under simulated conditions. The experiment was conducted on artificially constructed beds, 0.9m X 2m and 3% slope with A-horizon of Bojac sandy loam soil. Lime and fertilizer, as a source of Cu, were packed in top 10 cm of beds. The soil used had 0.5ppm of exchangeable Cu. Two flow rates of 6 L and 2.7 L were used for this experiment. The results showed that the infiltrated amount of runoff was about 21% for no grass, 33% for switchgrass, 28% for tall fescue filter strips for 6.0 L flow rate in contrast to 77% for no grass, 97% for switchgrass, and 100% for tall fescue strips. It was found that at the slower flow rate, buffers could remove all of applied Cu, while the efficiency of removal was just 60% for the faster flow rate. The retention of Cu was attributed to the phenomenon of adsorption to soil. Thus, it implies that this metal has a very small potential for contaminating the groundwater. The copper adsorbed by the soil was calculated as the difference between the initial concentration and the equilibrium concentration. In the case of tall fescue grasses, results emphasized major Cu retention in the first one-third of the filter, which implies that relatively smaller filter lengths are required for tall fescue grasses. The study recommended use of two filter strips according to the flow rate, i.e., tall fescue is more suitable for removal in areas where runoff is not expected to travel at a fast flow rate.

Boyd et al. (2005) aimed at determination of the effectiveness of brome grass VFS for sediment and pesticide retention from subsurface drainage and runoff. The study conducted experiments with pesticides, namely atrazine, acetochlor, and chlorpyrifos in central Iowa under natural runoff conditions. Infiltration and adsorption of pesticide onto sediment particles were found to be predominant processes in retention. The results substantiate the similarities in the partitioning properties of acetochlor and atrazine, categorized as moderately adsorbed pesticides. Their fate is governed by infiltration of runoff as it was observed that the major portion of these pesticides moved within the water phase. Chlorpyrifos, a strongly adsorbed pesticide, unlike acetochlor and atrazine, was highly adsorbed to the sediment which resulted in its higher sediment retention by buffer strips. In addition to the study of pesticide retention, the effect of area ratios, 15:1 and 45:1, was studied on the pesticide retention in the buffer strips. It was also concluded that higher area ratios led to higher flow rates and easy saturation of the VFS, reducing its removal efficiency. Not a very significant difference was seen in the performance of buffer strips with difference in area ratios. The results showed considerable concentrations of moderately adsorbed pesticides in tile flow.

Geographic Information Systems

For a long time, scientists and engineers have studied the world as maps and models. But as time passed, a need arose for models beyond maps and globe that could also serve as tools of analysis. Geographic Information Systems(GIS) is one such sophisticated model that is capable of developing, using, visualizing, and analyzing the geospatial data. Various tasks that are performed using this software are:

- Input
- Manipulation
- Management
- Query & Analysis
- Visualization

Nowadays, many fields are employing GIS for data analysis, such as Natural Resources, Land Use Planning, Landscape Architecture, Transportation, Real Estate and Property Taxation, etc. The advantage of this model on other models is that a part of the data can be ripped from another for suitable analysis. In GIS, the geographic data is in the form of *layers*. For example, to study the world map, data would be in distinct layers of oceans, continents, countries, states, rivers, etc. For example, it is possible to study the geography of world and TMDL of the rivers in India separately in spite of them being one geospatial dataset. The object that a particular layer depicts is called a *feature,* having a set of attributes. Features have particular shapes and sizes. All the geographic objects in GIS can be represented as one of only three shapes—point, line, or polygon. Data in the form of these shapes is called *Vector* data. But geospatial data has properties like slope, temperature, and elevation which can't be represented as one of the above shapes. This type of data is represented in the form of *Raster* or, in other words, represented as surfaces. Data in raster form has numeric values rather than shapes. The numeric values represent the intensity of that particular property in geography. The higher the numeric value assigned to a particular point on the map, the higher would be the property, like temperature, slope, etc. The boundaries of rasters are depicted by squared cells of the same dimension, and each cell carries a numeric value. Every point on a GIS map is referred to in the form of (x, y) coordinates, which is relative to the origin of that particular coordinate system.

Some of the literature has been reviewed to emphasize the importance of GIS in the field of environment protection, planning, and management and also to enhance the understanding of various tools of GIS that are used for projects dealing with watershed analysis.

GIS and Non-Point Source Pollution. Subra and Water (1996) employed GIS modeling technique in the identification of areas contributing towards NPS pollution in a 20 x 20 mile section of Calcasieu River Basin, Southwest Louisiana. This study also quantified and prioritized the areas that were of importance in regard to water contamination through NPS pollution. ERDAS Imagine Spatial Modeler helped in the selection of layers that were of importance to this project, such as hydrography, distance to water, slope, and soil permeability. The watershed boundaries and data for the layers were digitized from sources like water quality management basins map (Water Resources, Louisiana), United States Geologic Survey DLG data, and General Soil maps (Department of Agriculture, USDA). USGS Digital Elevation model was not available; therefore, contours were digitized from 1:62,500 quad sheets. The maximum distance to water was set to 254 pixels. Soil permeability divided soils in 4 categories : poorly to moderately well drained soils, poorly drained soils, very poorly drained soils, and open water. It was concluded that major pollution was a result of industrial and commercial services. This paper recommends the use of GIS for setting up of industries and commercial facilities at apt locations and employing specific management practices in order to prevent pollution.

GIS and Stormwater Runoff Management. Sieker and Klein (1998) studied the case of water quality of Rummelsberg Lake, Berlin, Germany. Emissions from a nearby catchment called MHG, spreading on an area of 22 km^2 were seen to have a detrimental effect on the water quality of the lake. The soil of the catchment was of low infiltration capacity except a part where the soil was of high infiltration capacity but simultaneously high groundwater levels. Various measures like central/decentral stormwater treatment plants and their pros and cons with regard to factors like groundwater level, infiltration capacity, soil contamination, slope of ground, etc. were evaluated, but a large scale model known as KOSIM was found to be the best for simulation of the settling processes in pollution load transport. An arrangement of central and semi-central stormwater management measures were found to be working the best for the current situation in the watershed. GIS was used as a tool to explore the possibilities of enforcing decentralized stormwater treatment plant to this area.

GIS and Pesticide Contamination. Dabrowski et al. (2002) conducted sampling over a 3-yr period with pesticides, namely azinphos-methyl (AZP), chlorpyrifos (CPF), and endosulphan (END) in the Lourens River watershed, South Africa, spread on an area of 44 km^2, consisting of eight subwatersheds. The study employed a GIS-based runoff model to validate the results of pesticide contamination. All the activities occurring in the upstream areas cause pollution in tributaries that drains each of the subwatersheds and joins the main stream. Data for watershed boundary, land use patterns, slope and contours were digitized and converted to shapefiles for use as layers in ArcView 3.1 GIS. The advantage of using a GIS-based runoff model was that it could predict the contamination with consideration of catchment variables (i.e., slope of the land, soil type, etc.), pesticide properties (i.e., adsorption, solubility, etc.), etc. for each of the subcatchments, while any other mathematical model employed numerous variables at a time and is not that accurate in prediction. A positive correlation was seen between the predicted and observed values. Pesticide application in the months October to February in the growing area of 4 km^2 was considered responsible for the contamination of waters of Lourens River. It was concluded that the lack of best management practices in the watershed was one reason for pollution in the river.

GIS and Waste-water Management Planning. Apfel et al.(2004) presented a GIS planning tool for McHEnry County, Illinois. As this county lies northwest of Chicago, it is experiencing tremendous pressure of growth, hence leading to exploitation of natural resources like groundwater. Glacial activities in this region further added to it by disturbing the geophysical conditions in that region, like increasing the permeability of soil, creating expansive wetlands, etc. Therefore, the wastewater management and planning was a significant contemplation to help conserve the groundwater resources, for which GIS was used as a tool of planning. The study emphasizes that for an onsite risk assessment, what is necessary to protect the environment should be the guiding principle rather than the use of traditional technology, where GIS proves to be a helpful and useful effort. Parameters that were used as input to the project were soil types, wetlands inventory, municipal boundaries, municipal sewer service areas, transportation tracks, surface waters and groundwater aquifer maps. It was concluded that GIS is the best tool as it provides a visual format with efficient graphics to the map which is very useful for public settings. In addition to this, it was seen that resource information in GIS provided very efficient analysis.

The work is under progress.

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Rubric: Assessment tool for Vegetative Filter Strips

Design Parameters	*Excellent*	*Good to Fair*	*Poor*
a *Ratio of drainage area to buffer area*	1:1–8:1	8:1–40:1	* > 40:1
***b* *Length of the filter (ft)*	> 20	20	< 20
c, d *Density of buffer vegetation (stems / m^2)(approx.)* - Bermuda grass - Grass	Thick cover 9000 3600	Average cover 7100–3600 2900–1450	Sparse cover 1800 700
Soil Type	Sandy Loam	Loam	Clay Loam

*It forms the most viable situation practically, but the effectiveness has not been validated by research studies.
**Filter strip flow length shall be based on the field slope percent and length, and on the filter strip slope percent, erosion rate, amount and particle size distribution of sediment delivered to the filter strip, density and height of the filter strip vegetation, and runoff volume associated with erosion producing events. The quoted flow length is based on the recommended values for field slope area of 1–10%.

Design Parameters	*Excellent*	*Good to Fair*	*Poor*
a ***Maintenance***	1) Frequent inspections 2) Absence of erosion channels. 3) A uniform vegetation cover. 4) Mow height of 6-inch, upright vegetation. 5) Good health of plants. 6) No evidence of unwanted trees, bushes, and noxious weeds. 7) No evidence of animal traffic.	1) Not very frequent number of inspections but, an instantaneous inspection after intense rains or long runoff events. 2) No evidence of gullies and rills, but small diversions paths or channels that are not very deep. 3) Good cover of vegetation with some patches of no or less cover. 4) Sward height a little more or less than 6 inches. Little evidence of bent over grasses at spots. 5) Diminutive yellow colored patches on vegetation. 6) Little evidence of weeds and unwanted plants. 7) Traffic with minimum damage due to grazing.	1) A few inspections in a year. 2) Evidence of rills and small channels that hinder the sheet flow. 3) Inadequate/sparse ground cover. 4) Uneven height of the grasses that necessitates mowing. Significant evidence of bent over grasses due to heavy runoff or vehicular traffic. 5) Unhealthy plants with broken, burnt and rotten leaves, brown in color. 6) Significant indication of weeds and unwanted bushes. 7) Evidence of livestock traffic, damage to vegetation due to overgrazing.

Design Parameters	*Excellent*	*Good to Fair*	*Poor*
e ***Wildlife Evidence***	1) No evidence of animal foot, grazing patches etc.	1) A few voids in cover that indicate grazing.	1) Large patches in cover that indicate grazing. 2) Evidence of wildlife traffic due to presence of animal hooves at many spots in vegetation. 3) Loss in filter width over years due to encroachment.
E ***Vehicular Traffic in VFS***	1) No damage to the VFS vegetation due to vehicular traffic. No evidences seen.	1) Little evidences seen due to loss of grasses along a path.	1) Evidence of diverted flow pattern because of vehicular traffic. 2) Established pathway seen in the VFS which indicates pedestrian or two-wheeler traffic.

Design Parameters	***Excellent***	***Good to Fair***	***Poor***
f ***Type of flow***	*Sheet Flow* 1) Shallow, uniform flow all along the length of the filter.	Uniform flow for most of the distance but mild evidence of channel or gully formation.	*Concentrated flow* 1) Significant evidence of deep gullies and rills. 2) Tendency of runoff to flow into topographic swales before entry into buffers.
Number of concentrated passes	No concentrated flow passes observed.	Single or few concentrated flow passes seen.	Multiple concentrated flow passes seen along the width of the VFS.

Design Parameters	*Excellent*	*Good to Fair*	*Poor*
e ***Drainage***	1) Efficient drainage along downstream VFS. 2) Even topography with no hills and depressions. 3) No inundation seen throughout the VFS. 4) Effective in sediment removal and nutrient reduction with efficient drainage.	1) A few, small height depressions and hills found in topography. 2) Little evidence of inundation with established drainageways.	1) Accumulation of surface runoff in natural drainage ways within fields before it reached the VFS. 2) Runoff from the drainage ways crossed the VFS, totally inundating the filters and rendering them ineffective for sediment and nutrient reduction. 3) Undesirable topography which hinders the proper drainage.

VEGETATIVE FILTER STRIP (VFS) ASSESSMENT FORM

Assessed By ______________________ Date _______________

Location of investigation (County / State) __________________________

Adjacent water body type __________________________

Quantitative Analysis :

1. Ratio of drainage area to VFS area ____________________
2. Length of the VFS (ft) ____________________
3. Slope of the drainage area upslope of VFS (%) ____________________
4. Density of vegetation in VFS (stems/m^2) ____________________
5. Slope of the VFS (%) ____________________
6. Filter Cover (Bare, Warm Season, Cool Season) ____________________

Qualitative Analysis :

	Poor	Good- Fair	Excellent
1. Ratio of drainage area to VFS area	☐	☐	☐
2. Length of the VFS (ft)	☐	☐	☐
3. Density of vegetation in VFS	☐	☐	☐
4. Soil type in VFS	☐	☐	☐
5. Maintenance of VFS	☐	☐	☐
6. Wildlife Evidence in VFS	☐	☐	☐
7. Vehicular Traffic in VFS	☐	☐	☐
8. Type of flow	☐	☐	☐
9. Number of concentrated passes	☐	☐	☐
10. Drainage	☐	☐	☐

NOTE: If you find more than 3 poor parameters on the VFS, then the VFS should be considered for modification in design.