NATURAL RESOURCES CONSERVATION SERVICE

STEMPLE CREEK

CONSERVATION EFFECTS PROGRAM (CEAP)

FINAL REPORT

MAY 2008

I. Summary

II. Stemple Creek Watershed Water Quality Analysis

David Lewis, University of California, Cooperative Extension Service, Sonoma County

III. Stemple Creek Watershed CEAP Special Emphasis Project Final Report (Draft)

Dr. Ron Bingner, Agricultural Research Service, Oxford, MI

IV. Riparian Ecosystem Management Model Simulations to Assess the Potential of Riparian Buffers in Stemple Creek Watershed

R. Richard Lowrance, Agricultural Research Service, Tifton, GA

Background

Stemple Creek is located in Marin and Sonoma Counties, California, approximately 40 miles northwest of San Francisco. The creek flows westward to the Estero de San Antonio. The Estero then empties into Bodega Bay. The Estero is viewed as an important coastal resource and is included in the Gulf of the Farallones National Marine Sanctuary.

The creek has had water quality issues, particularly high levels of ammonia, low dissolved oxygen, and sediment. The 2002 California 303 (d) listing of impaired water bodies mentions nutrients and sediment as the pollutants of concern. Some of the causes listed as potential sources for these concerns include: agriculture, grazing, irrigated crop production, intensive animal feeding operations, agricultural storm runoff, among others.

Local dairy operators are willing to help resolve the problems but would like to know that they are investing in the most cost-effective and efficient practices. The lack of acreage for disposal along with steep slopes can make nutrient management difficult at times.

A Sediment TMDL focused primarily on sediment and did not address other water quality issues and stream habitat. The TMDL target levels for water quality parameters also include targets for un-ionized ammonia, dissolved oxygen, and temperature. Surprisingly, the "Fresh Water Shrimp – *Syncaris pacifica,*" thrives in an area listed as water quality impaired.

Purpose of CEAP Program

The goal of the Stemple Creek CEAP Project is to validate the AnnAGNPS and watershed model, use the Riparian Ecosystem Management Model (REMM) to investigate the expected impacts of riparian buffers, and establish linkages between on-site treatments using conservation practices and off-site effects. The Project is a joint effort between NRCS (tracking the use of and assisting in the implementation of conservation practices through the use of EQIP and other Resource Conservation District (RCD), state, and local programs), Cooperative Extension Service (performing the surface water monitoring), and ARS (collecting soils and other information needed for the models, setting up GIS data layers, run model simulations to validate).

The local Cooperative Extension office has monitored the creek in three locations for two years and has obtained an extensive data set for suspended sediment, turbidity, ammonia, TKN, nitrate, dissolved oxygen, and temperature. The ARS collected the information needed for running the models and created the GIS data. NRCS worked with landowners in the area to verify applied and proposed practices. The Southern Sonoma County and Marin RCDs provided outreach and field assistance.

An evaluation of current practices was performed using AnnAGNPS. Alternative management practices and conditions were modeled to evaluate the impact conservation measures have had or could have on the watershed water quality. Stemple Creek provides the only western U.S. non-irrigated watershed in the CEAP program, so a unique perspective is provided.

The REMM model was used to examine the effectiveness various buffer scenarios have on reducing nutrient and sediment loading to streams.

The Stemple Creek CEAP Project Plan evaluated the environmental benefits and effects of USDA and RCD conservation programs that include Best Management Practices (BMPs) implemented to enhance water quality and stabilize upland erosion to reduce sediment yield. Specific BMPs addressed were Dairy Nutrient Management Systems and Riparian Restoration. This watershed offers tremendous opportunities to study legacy impacts of previous land uses and to gather more information about the requirements of an endangered species. It is also an excellent example of legacy land use impacts. About 50 years ago, farmers ceased growing potatoes and other field crops and started dairy and livestock operations. Thus, farmers changed from practices which greatly disturb the soil to practices which involve less soil disturbance.

Riparian restoration work would include practices needed to protect and improve the riparian corridor by improving grazing management on adjacent uplands and re-vegetation in the corridor itself to accelerate the recovery. Work on rangeland would focus on improving livestock distribution. Installed practices would include fencing to manage grazing within the riparian corridor and control livestock access to the creek, alternative water sources for the livestock, and seeding to improve cover. Management practices would include prescribed grazing. Re-vegetation within the riparian corridor would include planting of trees, shrubs, sedges, and grasses. These would be irrigated where needed. The tree species used would provide a canopy of 40 to 60 percent when mature. Work would be done along about 33 miles of stream and 13,000 acres of adjacent grazing land.

Conclusions

- Most of the sediment and nutrients in the area are produced in the months of November through January during the time of high rainfall.
- Significant erosion occurs in the steep terrain of the downstream portion of the watershed that is the source for much of the sediment and nutrients at the outlet of the Estero.
- The application of various rangeland and pasture practices by themselves do not have as much of an effect on reducing nutrient and sediment loadings unless combined with a reduction of manure applications within the watershed and the subsequent soil disturbance. The combined effort can result in reducing nutrient and sediment loadings by 85%.
- Results of the REMM simulations indicate that 25 – 30% more nitrogen is retained by flat buffers than steep ones, while more phosphorus is retained by steep buffers. Steep buffers provide more sediment phosphorus output but less dissolved phosphorus output.

- The area with the largest amount of sediment output is not associated with the largest amount of nitrogen and phosphorus, suggesting that much of the nitrogen and phosphorus is coming from the dissolved phase and is not attached to the sediment.
- Flat buffers retain on average 5 – 10% more sediment than steep buffers. The fraction of sand, silt, and clay will have an impact on the amount of sediment transport within the buffer, and ultimately retention, with higher amounts of sand leading to greater retention.
- Ranchers and farmers can work around the weather, and the subsequent stream flow generation and nutrient and sediment delivery, to take actions such as herd rotation or manure spreading.
- The application of riparian vegetation and sediment traps would reduce the delivery of all types of landscape erosion and nutrients without much disruption to the existing management throughout the watershed.
- Previous water quality monitoring data combined with results from this study confirm a downward trend in ammonia concentrations in the Stemple Creek Watershed.

Stemple Creek Watershed Water Quality Analysis

prepared for

USDA Conservation Effectiveness Assessment Program

prepared by

University of California Cooperative Extension,
County of Sonoma

and

University of California, Davis
Land Air and Water Resources and Plant Sciences Departments

January 2008

Project Team

David Lewis, UCCE Watershed Management Advisor
Kenneth W. Tate, UCD Watershed Hydrology Specialist
Michael Lennox, Watershed Research Associate
Miguel Huerta, Project Field Technician
Betsy Huang, Project Laboratory Technician
Hattie Brown, Project Laboratory Technician
Randy Dahlgren, UCD Professor of Biogeochemistry

Reference report as: Lewis, D.J., K.W. Tate, M.S. Lennox, M.Huerta, B. Huang, H. Brown, and R. Dahlgren. Stemple Creek Water Quality Analysis. Prepared for US Department of Agriculture Natural Resources Conservation Service Conservation Effectiveness Assessment Program. University of California Davis, Land, Air, and Water Resources and Plant Sciences Department and University of California Cooperative Extension, County of Sonoma. Santa Rosa, California. 48 pgs.

Acknowledgements: Stemple Creek Landowner Group members were invaluable for permitting access to project study sites. Project accomplishments would not be possible without the support and collaboration of the Natural Resources Conservation Service's State and Petaluma Field Offices and the Southern Sonoma County and Marin Resource Conservation Districts. In particular, the contributions from Vern Finney, Watershed Planning Geologist (retired), Charlette Epifanio, District Conservationist and Paul Sheffer, Engineering Technician were critical in forming the project team and forging effective working relationships with producers in the Stemple Creek Watershed.

Cover photos: Flotsam demarking stream stage height during the December 31, 2005 storm event (upper). Study site instrumentation with an ISCO auto sampler and YSI Data Sonde.

TABLE OF CONTENTS

INTRODUCTION

Stemple Creek is a California coastal watershed approximately 40 miles northwest of San Francisco. The headwaters begin west of the City of Petaluma, flowing to the Estero de San Antonio and the Pacific Ocean. This estuary is included as part of the Gulf of the Farallones National Marine Sanctuary. Land-use history in the 52.5 square mile watershed included cereal crop and potato production from the 1850s to the early 1900s. This was in conjunction with and then replaced by livestock grazing and dairy production to the present.

Since the 1970s, water and habitat quality in Stemple Creek Watershed has received increased attention. In 1990, the North Coast Regional Water Quality Control Board (RWQCB) listed the watershed as impaired for nutrients and dissolved oxygen under Section 303 (d) of the United States of America Clean Water Act. This attention and designation have lead to water quality investigations, as well as delivery of educational, technical and financial resources to agricultural managers for improving water quality in the watershed.

Regional Board staff conducted water quality sampling and analysis for nutrients, pH, and dissolved oxygen in 1992 and 1993 at 12 sampling locations (Winchester et al., 1995). In general, results from this investigation indicated that nutrient concentrations decreased in a downstream direction. Staff concluded that un-ionized ammonia concentrations in Stemple Creek exceeded national criterion throughout the watershed at different times of the year. Specifically, acute toxic concentrations were documented during spring sampling rounds and were attributed to the interaction of nutrient loading from dairy manure and increased stream temperature. It was noted, however, that concentrations from this study were lower than results from 1988 to 1992 (Prunuske Chatham, Inc., 1994).

From 1991 to 2002, the California Department of Fish and Game (CDFG) conducted biweekly water quality monitoring during winter months (Rugg, 2003). Results from this program indicated that concentrations of un-ionized ammonia were initially above toxic values. Measured concentrations decreased during the monitoring program period. Results from this program were shared monthly at the Sonoma-Marin Animal Resources Committee which in turn worked with ranchers and farmers located above sampling sites to improve manure management and its potential impacts on Stemple Creek.

Water quality studies and monitoring for sediment within the watershed have been limited. There are, however, a few studies that identify trends in sedimentation and provide direction for implementation of practices to improve water quality. Underlying geology of the watershed includes marine sediments of the Franciscan and Wilson formations that result in fine sandy and silt loam soils (Miller, 1972; Kashiwagi, 1985). In 2002 and 2003, Ritchie et al. (2004) documented sedimentation rates from 1954 to the present. Their results indicate that rates from 1954 to 1967 are greater than those from 1968 to the present. Explanations for this change in rates include the transition from row crop agriculture to livestock agriculture in the 1930s and 1940s.

Local farmers and ranchers participated in water quality education programs during the 1980s and 1990s. These have been organized and implemented by University of California Cooperative Extension (UCCE), United States Department of Agriculture's

Natural Resources Conservation Service (NRCS), and both the Southern Sonoma and Marin Resource Conservation Districts (RCD). These included the Dairy Quality Assurance Program, Ranch Water Quality Planning Shortcourse (Rilla et al. 1995) and others. Producers participating in those programs are now cooperating with the two RCDs to implement water quality improving practices and measures through a program funded by State bond measures. In addition, farmer and rancher application for technical and financial assistance through the NRCS' Environmental Quality Incentives Program (EQIP) continues annually. Lastly, the Petaluma Field and California State offices of the NRCS are shepherding an approved PL566 Small Watershed Program Plan for over five million dollars of implementation assistance (NRCS, 2004).

The earlier water quality investigations, by RWQCB and CDFG, indicate that there has been some improvement to water quality as a result of the farmer and partnering agency conservation efforts. In order to meet water quality criteria this trend needs to continue including further implementation of beneficial practices and decreases in nutrient and sediment loading to the watershed. For this reason the RWQCB adopted the *Total Maximum Daily Load and Attainment Strategy for the Stemple Creek Watershed* in 1997 (Salisbury, 1997).

Evaluating the benefits and effects of implemented best management practices (BMP) to enhance water quality in the Stemple Creek Watershed requires a water quality sampling and analysis program that can account for the annual, seasonal, storm, and diurnal variability in nutrient and dissolved oxygen levels. In addition, the objective to evaluate BMP influence on water quality involves the establishment of a baseline or pre-implementation conditions from which trends can be developed.

The national need for documenting BMP effectiveness has recently been led by the NRCS' Conservation Effectiveness Assessment Program (CEAP). Stemple Creek Watershed was designated as one of 24 NRCS Special Emphasis Watersheds for the purposes of evaluating water quality benefits of dairy waste management systems, riparian restoration, and soil and water conservation practices.

In contribution to this evaluation, UCCE Sonoma County and the Departments of Land Air and Water Resources and Plant Sciences at the University of California, Davis conducted water quality analysis. This report provides an overview of the work completed, including steps taken to instrument sampling sites, number of samples collected per site for storm and 24-hour cycle sampling components, and methods of sample analyses. In addition, brief analysis and provisional summary graphs and tables are provided. A compact disc containing project raw data, also accompanies this report. This document finalizes the reporting requirements in the cooperative agreement (65-9104-4-417) between the University of California Division of Agriculture and Natural Resources and NRCS.

METHODS

Field work performed for the project began August 19, 2004 and ended June 6, 2006 (Appendix A). Laboratory sample processing and data analyses continued beyond that date to the writing of this report. Accordingly, activities and actions performed included site instrumentation, sample collection and analysis, and data analysis. In addition, the project team participated in a number of meetings with watershed landowners, Agricultural Research Service (ARS) researchers, and NRCS and RCD staff. The 2004-2005 water year field season began with instrument deployment in August 2004 and was completed on July 28, 2005 when samplers and instrumentation were removed from the field after stream sites had dried. Downstream ISCO samplers were redeployed for the 2005-2006 water year field season on November 2, 2005. Samplers were removed from the field on June 6, 2006 after downstream sites went dry.

Site Description

The four primary study sites included three mainstem sites - Sites 1, 2, and 3 from downstream to upstream. Site 4 is downstream of a holding area and upstream of a vegetative filter strip on a small tributary between Sites 2 and 3. Per instructions from NRCS Watershed Planning Geologist Vern Finney, Site 5 was added for the 2005-2006 water year several miles downstream of Site 1 and upstream of any tidal influence. Drainage area and location description for each site are provided in Table 1. Combined, these sites serve to represent the conditions of the entire watershed at large. This includes the scale and variability in hydrology, livestock agricultural activities, and implementation of conservation practices to improve water quality and habitat.

Table 1: Site drainage area and description.

Site #	Drainage Area acre (hectare)	Description
1	3,088 (1,250)	North Fork mainstem behind historical marker.
2	2,902 (1,174)	North Fork mainstem below conservation practices.
3	472 (191)	North Fork mainstem in upper watershed.
4	< 4 (<2)	Below holding area at dairy with 30+ head year round.
5	20,171 (8,163)	Stemple mainstem above tidal influence.

Site Instrumentation

Instrumentation of the five project sites consisted of installation of Teledyne ISCO, Inc. sampling equipment and Yellow Springs Instruments (YSI) 6820 data sondes. Working cooperatively with Vern Finney, we installed ISCO Model 6712 water quality samplers, with Model 730 bubblers to record stage height, and Model 674 tipping bucket rain gauges to measure wet precipitation at each site. All ISCO equipment installation was completed by the end of November each fall before any rainfall occurred (Appendix A). All sondes recorded data for nitrate, ammonium, turbidity, pH, temperature, electrical conductivity, and dissolved oxygen on a 15-minute interval.

2004-2005

We initiated calibration and deployment of the data sonde at Site 1 on December 21, 2004. We completed calibration and deployment of sondes at Sites 1, 2, and 3, including correct calibration of the ion specific electrodes for ammonium and nitrate with pH probes on February 4 and 8, 2005. Deployment of a sonde at Site 4 was not feasible because of the intermittent nature of stream flow that prevented the instrument from being continually submerged. The delay in sonde deployment resulted from the need to acquire the appropriate calibration fluids and pH probes that facilitated correct calibration and deployment of the nitrate-nitrogen and ammonium-nitrogen ion specific probes.

2005-5006

We initiated calibration and deployment of the YSI 6820 data sonde at Site 2 on November 28, 2005. We completed calibration and deployment of sondes at Sites 1, 2, and 3 on December 21, 2005. Site 5 was installed with a calibrated sonde on January 25, 2006. Similar to the previous winter, deployment of a sonde at Site 4 was not feasible because of the intermittent and shallow nature of stream flow that prevented the instrument from being continually submerged.

Sample Collection

2004-2005

We were prepared to begin sampling on October 1, 2004. Rain sufficient to generate runoff and allow for sampling did not occur until middle November for Site 4, late November for Site 3, and early December 2004 for Sites 1 and 2. Water quality samples were collected on a storm event basis at Sites 1 through 4 and a 24 – hour cycle basis at Sites 1 through 3. Sampling for the 24-hour cycle was not feasible at Site 4 because of the intermittent nature of flow in response to precipitation. Sample collection began on November 27, 2004, with initiation of in-stream flows, and continued into July 2005 until stream flow ceased. Site 3 continued to support base flow conditions all summer. As a result, the ISCO sampler remained deployed in the field until July 28, 2005 in order to monitor water level for stream flow calculations. A total of 468 samples were collected during the 2004-2005 water year (Table 2), including duplicates for quality control.

2005-2006

Similar to the previous year, water quality sampling required sufficient precipitation to generate stream flow. First opportunities for sampling occurred in early November 2005 for Sites 3 and 4, middle November for Sites 1 and 2, and early December for Site 5. Water quality samples were collected on a storm event basis at all sites until December 31, 2005, as agreed. One major revision to the work plan was the halting of 24-hour water quality sampling at Sites 1 through 3 to accommodate the addition of Site 5, at which storm sampling, continuous stage height, and water quality parameter recording were conducted. A total of 77 samples were collected for laboratory analysis from the four storms that occurred between October 1, 2005 and December 31, 2005, including duplicates for quality control (Table 2).

Table 2: Inventory of water quality samples collected at the five sites for CEAP water quality analysis on Stemple Creek Watershed in the 2004-2005 and 2005-2006 water years.

Site	Number of storms sampled	Number of storm samples collected	Number of 24 – hour cycles sampled	Number of 24 – hour cycle samples collected
2004-2005				
1	10	111	3	69
2	11	117	4	78
3	10	99	4	95
4	11	99	-	-
	subtotals	426		242
2005-2006				
1	3	17	-	-
2	3	18	-	-
3	2	13	-	-
4	2	15	-	-
5	2	14	-	-
	subtotals	77		

Sample Analysis

Collected water samples were preserved and transported at 4 ^{o}C to the water quality laboratory at UC-Davis (Drs. Randy Dahlgren and Ken Tate's analytical laboratories). Samples were analyzed for pH, electrical conductivity, total suspended solids (organic and inorganic), volatile suspended solids (organic), turbidity, total nitrogen (TN), ammonium/ammonia (NH_4/NH_3), and nitrate ($N0_3$). Values of ammonium/ammonia combined with instream measurements of pH and temperature were used to calculate the respective concentration of un-ionized ammonia (Emerson et al. 1975). Particle size analysis was completed on a subset of the samples collected in the 2004-2005 water year field season. Analytical methods and quality control/quality assurance protocols are briefly described below.

Analytical Methods

1. Nitrate and Ammonium/Ammonia - Nitrate and ammonium/ammonia concentrations were determined on samples filtered through a 0.45 µm Nuclepore membrane filter (filters are pre-rinsed with sample). Nitrate and ammonium/ammonia were quantified simultaneously using an automated membrane diffusion/conductivity detection method (Carlson, 1978, 1986). The method allows for analysis of high ionic strength solutions without dilution of samples. This allowed us to obtain excellent detection limits. The stated method detection limit for the instrument is 1 ppb N. Under standard operating conditions for river waters from the Stemple Creek Watershed, we have determined a limit of detection of about 10 ppb calculated as three times the standard deviation of a distilled/deionized water blank. This limit of detection resulted in very few "less than detection" values for Stemple Creek water. Recovery of ammonium/ammonia and nitrate from spiked samples were >95% within the concentration range of Stemple Creek water. Repeated analyses of analytical standards had a coefficient of variation (CV) consistently <5%.

2. Total N - Total nitrogen was determined on non-filtered samples. Total nitrogen is determined conductimetrically (as described above) following persulfate oxidation (Yu et al., 1994). We used a 1% persulfate oxidant concentration, a sample:oxidant ratio of 1:1 (V/V), and heating in an autoclave. The limit of detection was a function of the nitrogen contamination content of the reagent chemicals. We used a high-purity potassium persulfate reagent that provides a limit of detection of about 50 ppb N. This detection level was low enough to quantify total nitrogen in all of the Stemple Creek waters. Recovery of total nitrogen was statistically identical to the Kjeldahl total nitrogen method that we have used in a comparison study utilizing several reagent grade, organic nitrogen compounds.

3. Suspended solids - Suspended solids were quantified by filtration of a known volume of water sample through a Gelman A/E glass fiber filter (about 0.45 µm) and weighing the filter before and after filtration. The glass fiber filters were preheated to 525^{o} C for 1 hour to purge the filters of any volatile contaminants. The filters were stored in a desiccater prior to the filtration step. Following filtration, the filter, with suspended solids, was dried for 24 hours in a desiccater and then weighed again. Drying in a desiccator is preferred to oven drying because some organic compounds are unstable with heating resulting in some volatilization of the suspended solids. To determine volatile suspended solids (organic matter), we combust the filter at $525\,^{o}C$ for 4 hours and subtract the lost in mass from the pre-combusted mass. We used a

four-place balance (0.0001 g or 0.1 mg) for measurements. The detection limit was a function of the amount of water filtered through the filter. If a liter of river water was filtered, the limit of detection was about 0.5 mg/L given a plus/minus variation of 0.2 mg from the analytical balance and two weight determinations per sample (before and after filtration).

4. Particle size - Particle size distribution was analyzed by removing the organic solids (volatile) fraction from the samples and then analyzing the inorganic solids (nonvolatile) fraction using a Coulter® laser particle analyzer. Removal of the organic fraction was done by adapting the peroxide treatment for samples described by Klute (1986).

QA/QC protocols

Quality Assurance and Quality Control (QA/QC) measures consisted of our standard laboratory protocols including spikes, blind samples/duplicate samples, reference materials, setting of control limits, criteria for rejection and data validation methods.

1. Sondes – The 6820 data sondes were maintained by scheduled laboratory calibration and field cleaning. Due to particulates and algal growth, we determined regular maintenance of equipment in the field was essential in order to obtain accurate sonde data. We carefully cleaned all water quality probes on a weekly basis. Calibration of nutrient probes was especially important. We timed calibration of probes immediately prior to deploying sondes in the field.

2. Spikes – Our normal protocol was to run spiked samples at the onset of the project. Once we had established that we obtained a consistent and acceptable recovery from spiked samples, we periodically processed spiked samples for confirmation. Our frequency of running spiked samples was typically quarterly. We set an acceptable recovery at 85%.

3. Blind samples/duplicate samples – Approximately 5-10% of our unknown samples were run as duplicates. Because the individual who prepares the samples for analysis (filtering & pouring off samples) was different from the individual doing the analytical analysis, all duplicate samples were effectively blind samples. Within an analytical run, we reanalyzed all samples if duplicate samples were not within 10-20% of each other (20% if the value is less than 10 times the limit of detection; 10% if the value is greater than 10 times the limit of detection).

4. Reference materials – We utilized <u>certified</u> quality assurance standards for methods when commercially available. Certified "nutrient" and "mineral" standards containing nitrate and ammonium were used in this study. The reference standard was run immediately after instrument calibration to verify that our working standards were correct. We had a ±10% limit of acceptability from the certified value. For the total N, we digest reference standard to determine the recovery of the inorganic

nutrient species. We were not aware of any reference standards available for total N that were based on organic forms of these nutrients.

5. Blanks, standards and standard curves – At the onset of an analytical run, we used a series of distilled-deionized and/or digested matrix blanks. Working standards were prepared fresh from dilution of a stock solution on at least a monthly basis. Standards were stored at 3 ^{o} C and in the dark. All analytical standards were purchased from Fisher Scientific. A standard curve was then run from a series of standards which defines the working range of analysis. The standard curve was verified by running the certified reference standard. The standard curve was rejected if it did not determine the values of the certified reference standard within ±10%. The standard curve was reanalyzed every 20-30 samples to verify that no instrument drift has occurred. Drift in excess of 10% resulted in rejection of all values determined since the previous standardization and re-analysis of those samples. Standards were also analyzed at the end of each analytical run to determine that the instrument remained stable through completion of all samples.

6. Sample handling – Upon receipt, samples were logged into a spreadsheet and verified against the chain of custody form. Each sample was assigned a laboratory number that serves to track the sample through the analytical analysis. Samples were stored at 3^{o} C in the Water Quality Laboratory. A subsample of each sample was frozen and retained for up to six month or until the data had been examined by the contractor.

7. Data validation – Most data were collected electronically so that data transfer errors were minimized. For those methods requiring hand entry of data, data was verified by graphical and observation techniques to spot outliers. For complete chemistry analysis, we used charge balance and solute/EC relationships to validate concentrations. For long-term monitoring programs, temporal data were plotted to look for inconsistent relationships in the data record. Prior to releasing the data, the laboratory manager/principal investigator independently examined the data. All raw data were held for a minimum of one year.

RESULTS AND DISCUSSION

Precipitation and Stream Discharge

Results from ISCO instrumentation included wet precipitation and stage height or stream level recording on an event and 15-minute interval basis, respectively. We used the precipitation data to quantify 24-hour and annual cumulative rainfall at each site during the two water years. This is illustrated for Site 1 in Figure 1. Similar graphs for all sites are contained in Appendix B.

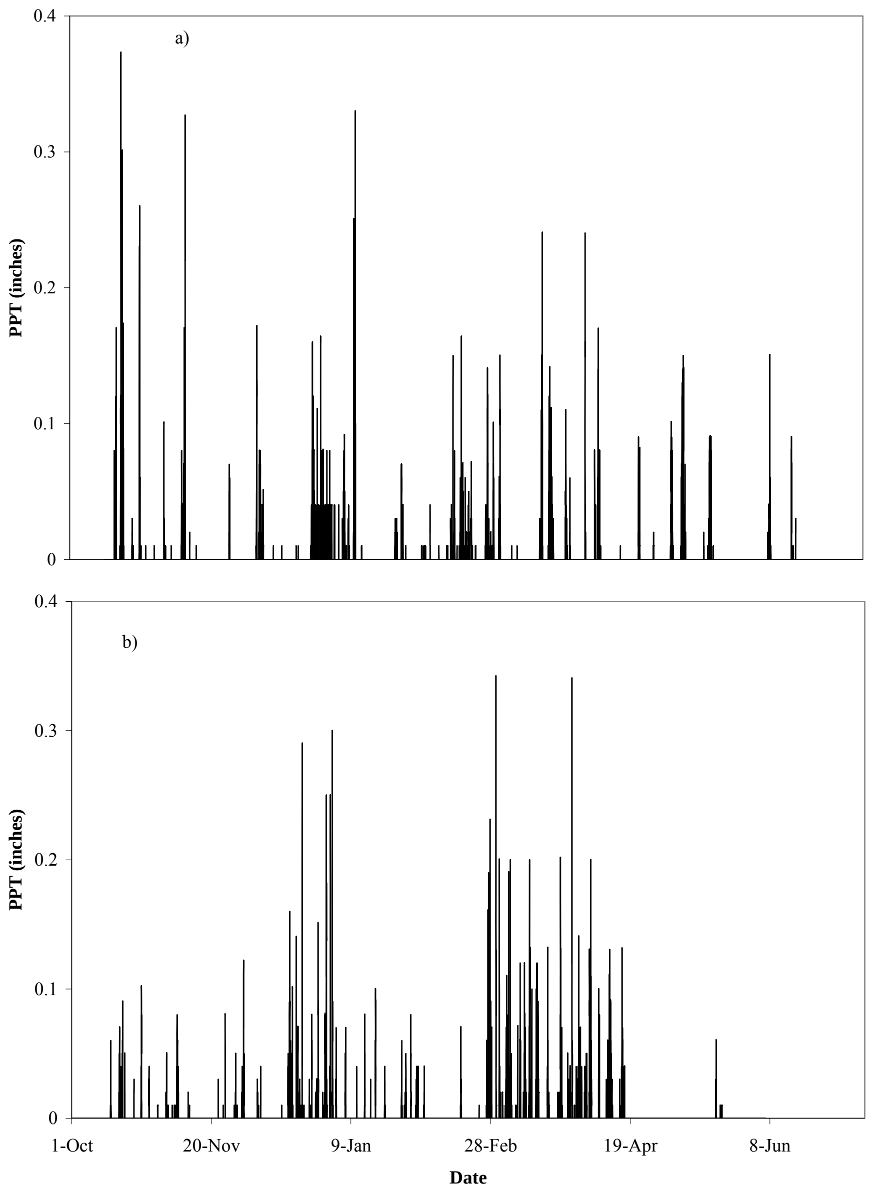


Figure 1: Corrected precipitation for Site 1 during the a) 2004-2005 and b) 2005-2006 water years.

We used the stage height data to calculate flow rate and volume. The measured cross-sectional area at each site, Manning's N of 0.045, and slope were input into the Teledyne ISCO software (Flowlink Version 4.16) to make these calculations in conjunction with the recorded stage height. The calculations were then calibrated with field measurements of stage height and flow rate. We made these calculations for all sites in both water years to generate corrected discharge. This is demonstrated for Site 1 in Figure 2. A complete set of annual hydrographs is presented in Appendix C.

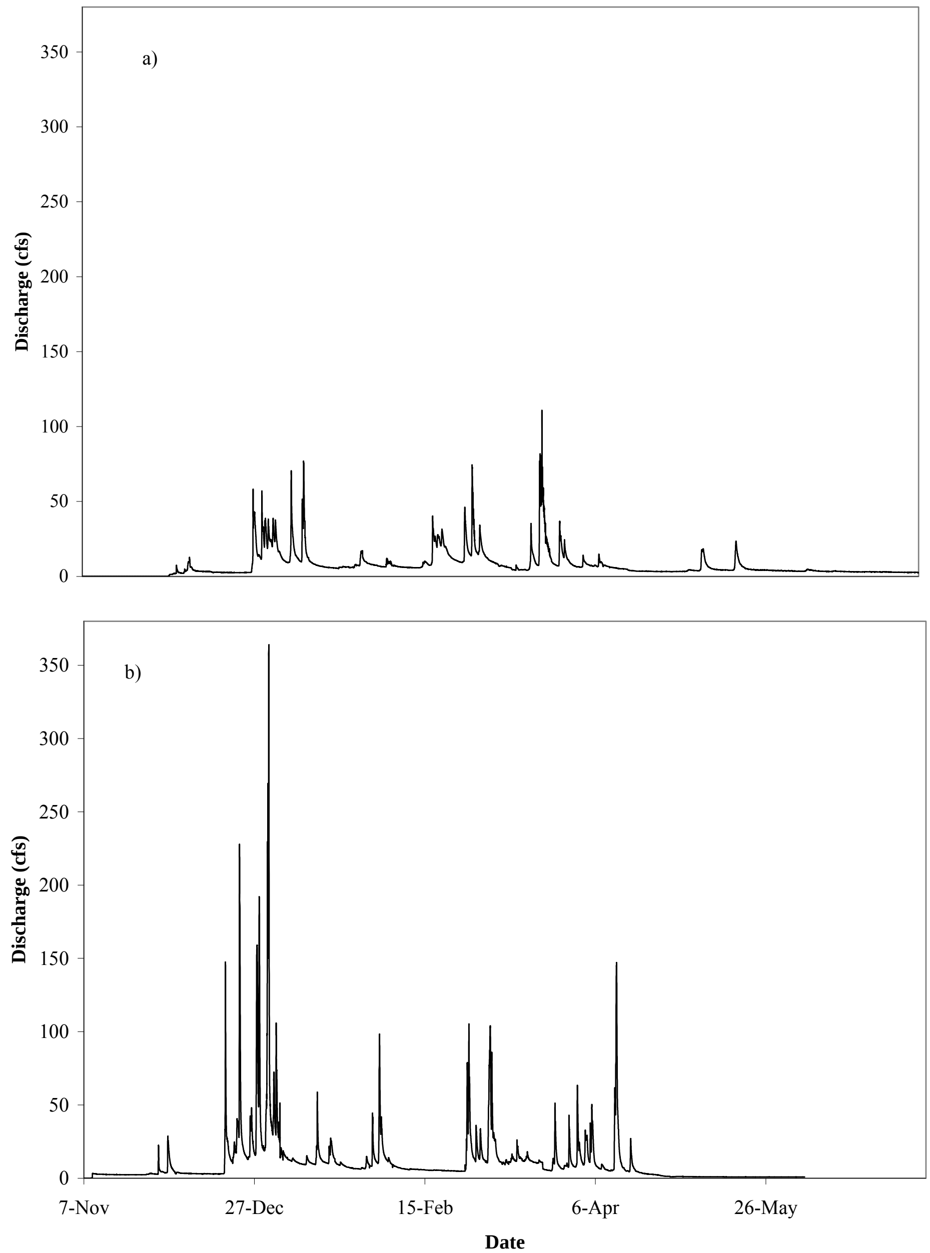


Figure 2: Corrected discharge for Site 1 during the a) 2004-2005 and b) 2005-2006 water years.

Comparing and contrasting the rainfall and stream flow in the 2004-2005 and 2005-2006 water years clearly demonstrates the annual and seasonal variability in hydrology that is common in California Mediterranean watersheds. Cumulative annual rainfall for 2004-2005 ranged from 28 to 31.5 inches compared to a range of 33.5 to 38 inches in 2005-2006. This difference of 5 to 7 inches parallels a difference in annual cumulative stream flow between the two years. For example, a total of 3,674 acre-feet moved past Site 1 in 2004-2005 compared with 4,875 acre-feet in 2005-2006.

Seasonally, there are more subtle rainfall and stream flow similarities and differences between the two years. The onset of stream flow followed a similar pattern in both years. Generally, a few early storms of minimal rainfall amounts contributed to relatively small storm responses in stream flow, followed by a rapid return to low base flow stream discharge values. In both years, substantial and sustained stream flow was initiated in December after the preliminary storms primed the watershed. From the onset of stream flow in early December to approximately April in each water year, rainfall intensity and duration was greater in 2005-2006 than in 2004-2005. This translated to the 2005-2006 water year having the highest single storm discharge value (Figure 3), greatest number of stream flow storm responses, and elevated storm season base flow values relative 2004-2005. Conversely, 2004-2005 was marked by a protracted storm season that extended into late May and early June of 2005. This resulted in more elevated and extended baseflow and appreciable storm response in 2004-2005 than in 2005-2006.

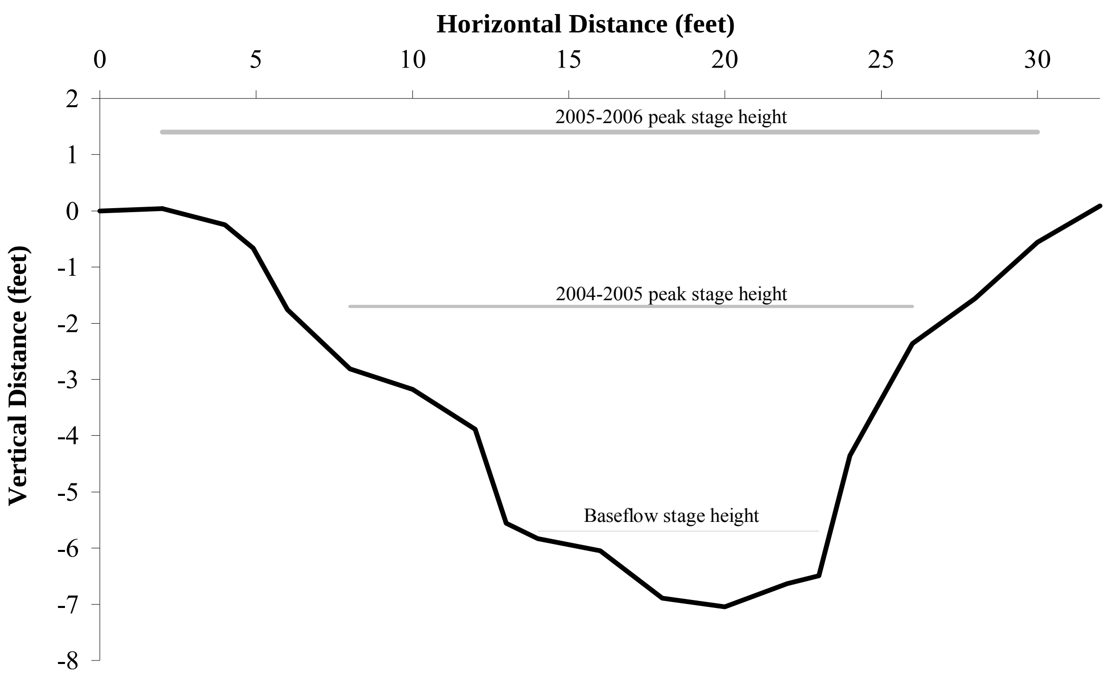


Figure 3: Channel cross section at Site 1 with peak stage height for both water years and baseflow stage height indicated.

Combined, these annual and seasonal observations illustrate that while annual cumulative rainfall is related to annual discharge, the timing, intensity, and duration of precipitation across seasons has a more significant effect on the release of water in the

Stemple Creek Watershed. The implication of these results for water quality management are that seasonal and storm scale precipitation and stream flow characteristics derive the critical pollutant delivery paths, not annual totals.

Laboratory Analysis

Results from laboratory analysis for both years consistently indicate that runoff from Site 4 has higher levels of sediment, nutrients, and other water quality parameters than stream water from the other four sites (Appendix D). For example, concentrations of TSS and volatile-TSS are two to three orders of magnitude higher in Site 4 samples (Figure 4). Similarly, nutrient constituents such as TN and general chemistry constituents such as electrical conductivity were also orders of magnitude higher in Site 4 samples than in the other site samples (Figure 5). Additionally, the relationship between the two at Site 4 was direct compared with indirect at the other study sties.

These kinds of multiple constituent comparisons provide an illustrative method for comparing and identifying relationships in water quality at multiple sites. For example, volatile-TSS is on average 25 and 29 percent of TSS in samples from Sites 3 and 5, respectively. By comparison, volatile-TSS as a percentage of TSS in samples from Sites 1, 2, and 4 is 42, 43, and 46, respectively. This difference in sediment composition between the two groups indicates that the sources of sediment contributing to each are different. More specifically, high-use areas, like those represented by Site 4 may be delivering volatile-TSS and other constituents to reaches of the study area near Sites 1 and 2 but not sites 3 and 5. Site 3 is upstream of any holding areas and Site 5 is the site furthest downstream, with water quality conditions likely influenced by larger scale watershed sediment transport factors.

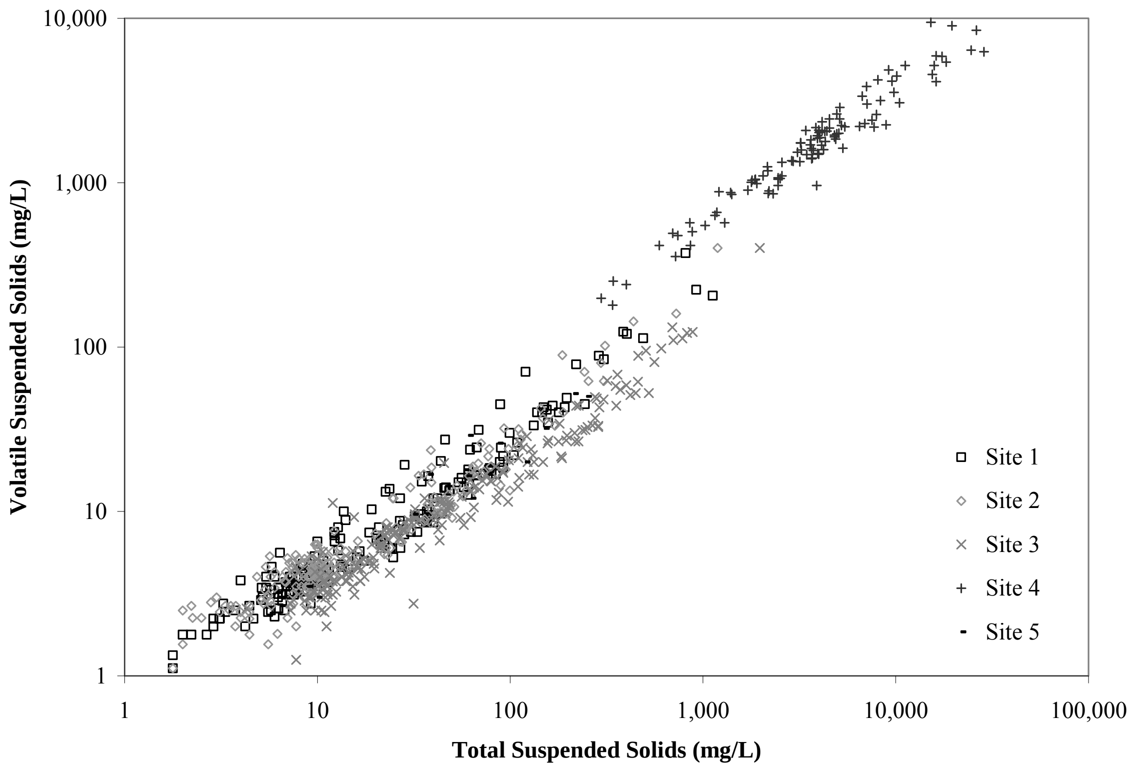


Figure 4: Volatile suspended solids as a function of total suspended solids by site for both water years.

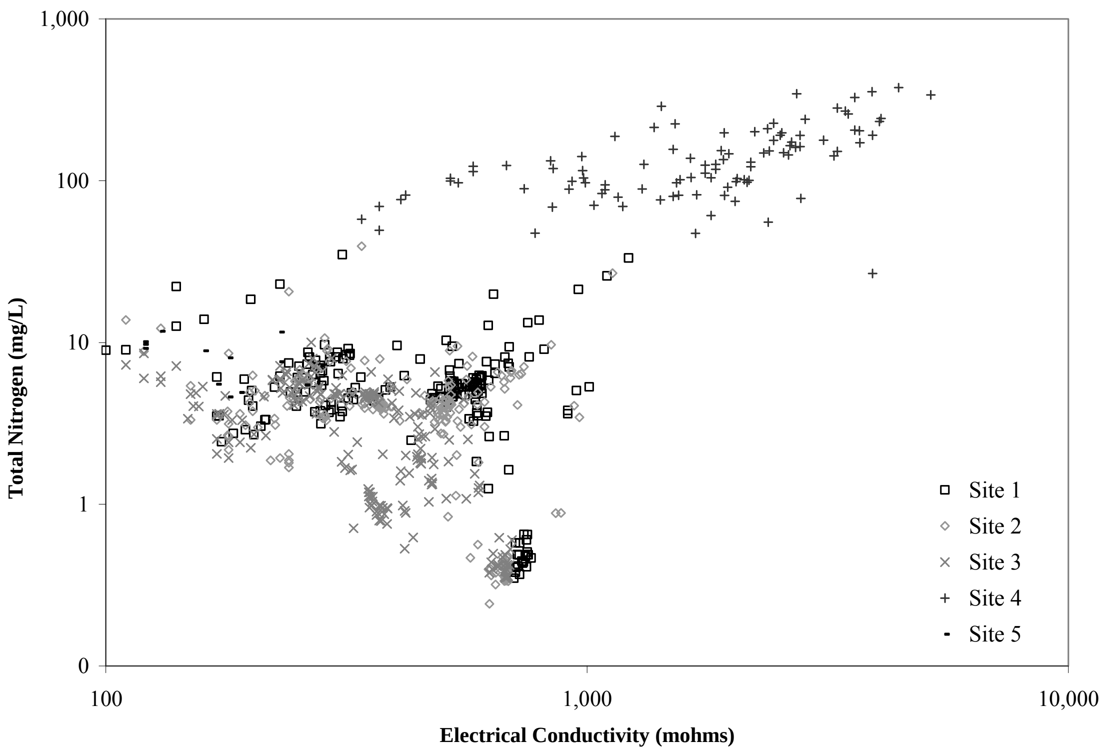


Figure 5: Total nitrogen as a function of electrical conductivity by site for both water years.

This delivery is constituent specific and dependent upon the implementation of management practices to reduce it. A useful and compelling example is un-ionized ammonia. As discussed, CDFG monitored the watershed for un-ionized ammonia during the 1990's (Rugg 2002). We compiled the data from that monitoring with results from this water quality analysis to identify any potential trends in water quality over time (Figure 6). An important distinction between the CDFG and CEAP data is the fundamental timing of sample collection. The CEAP samples were collected during storm events and peak flow, while CDFG samples were collected biweekly regardless of flow conditions. Additionally, all of the CDFG samples were collected from mainstem locations, compared to the small scale and close proximity to a potential source that Site 4 of the CEAP effort represents.

From 1991 to 2002 there is a decrease in the concentration of un-ionized ammonia. This is encouraging documentation that reductions in acute toxicity of this pollutant have been achieved in the watershed, through sharing monitoring results with local ranchers and farmers and corrective action being taken by these agriculturalists. This parallels an increase in knowledge, planning, and management measure implementation following water quality education delivered statewide to rangeland owners and operators (Larson et al. 2005).

Results from the CEAP study indicate that the gains made through 2001 have been at least maintained, if not furthered. There were 58 samples out of the total 441 collected over the two years of study that had concentrations of un-ionized ammonia above the 0.025 mg/L criteria set by the U. S. Environmental Protection Agency. Of these, 36 were from Site 4 with the remaining 22 being mainstem samples. The maximum was 2.89 mg/L compared with the maximum of 2.66 mg/L identified by the RWQCB in 1995 (Winchester, 1995) and 9.89 determined by CDFG in 1991 (Rugg, 2002).

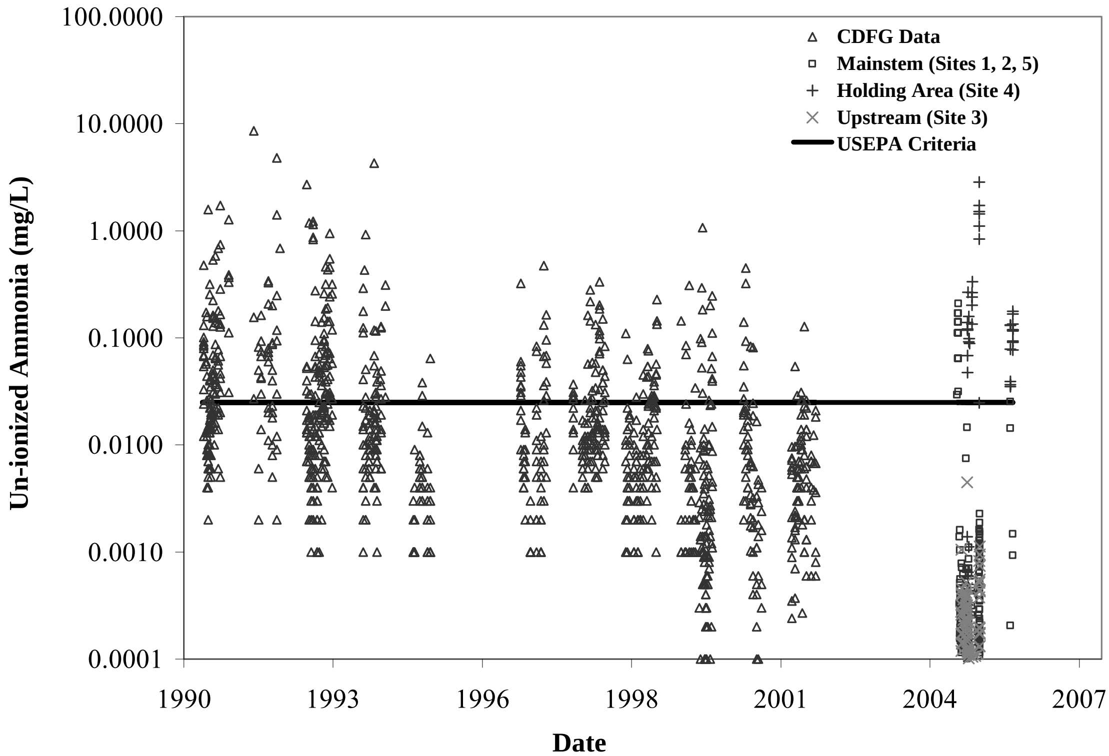


Figure 6: Un-ionized Ammonia (NH_3) concentration from 11-year dataset conducted by California Department of Fish Game in Stemple Creek Watershed combined with the two years of water quality analysis for this CEAP water quality analysis.

The effects of sample collection timing during storm events on water quality was discharge and parameter dependent. For example, a clear linear relationship between and TSS and discharge exists at all sites except Site 4 (Figure 7). Similar but less pronounced relationships are demonstrated for ammonium (Figure 8) and nitrate (Figure 9). These figures also graphically illustrate that concentrations for the three constituents are greatest in samples from Site 4, which has the smallest drainage area of the five study sites.

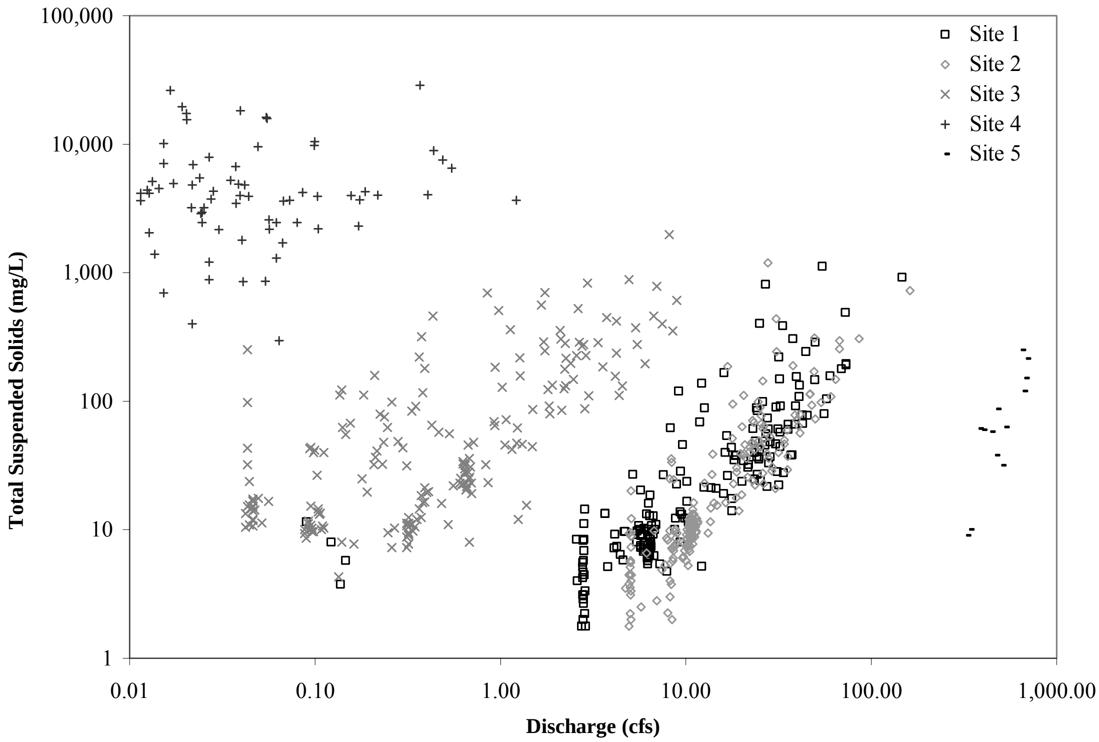


Figure 7: Total Suspended Solids concentration from laboratory analysis of water samples as a function of stream discharge from at all study sites in both water years.

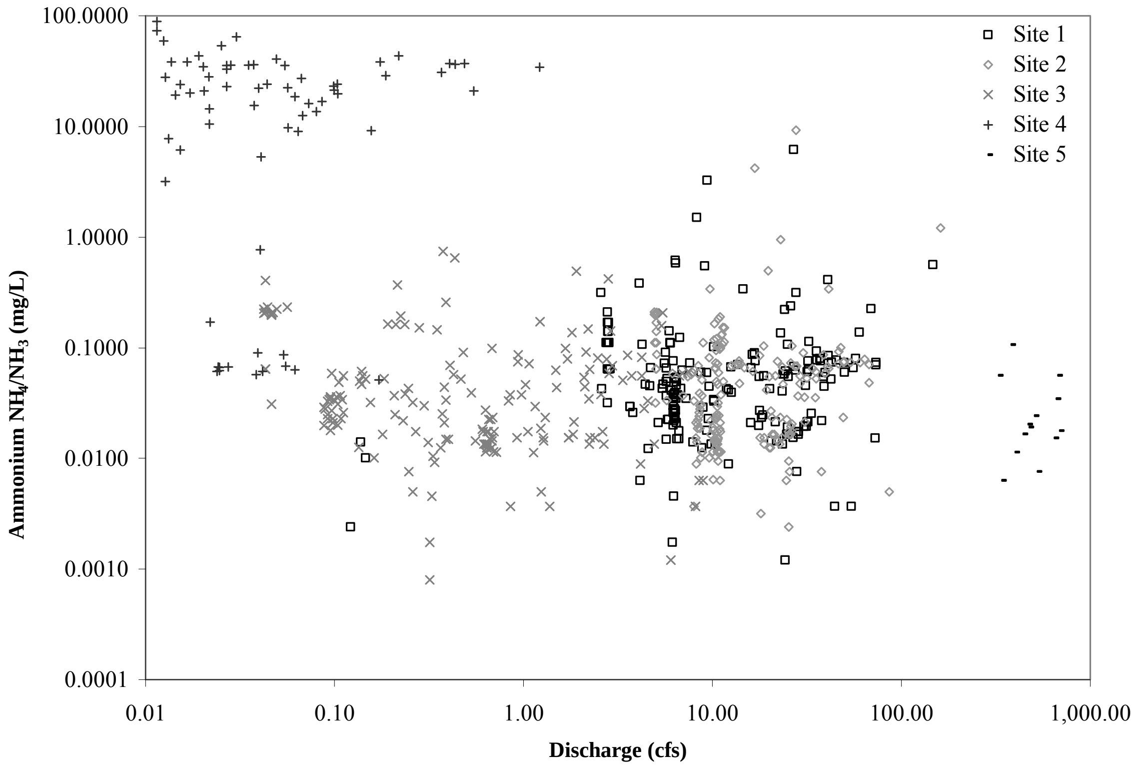


Figure 8: Ammonium (NH_4/NH_3) concentration from laboratory analysis of water samples as a function of flow collected at all sites over both water years.

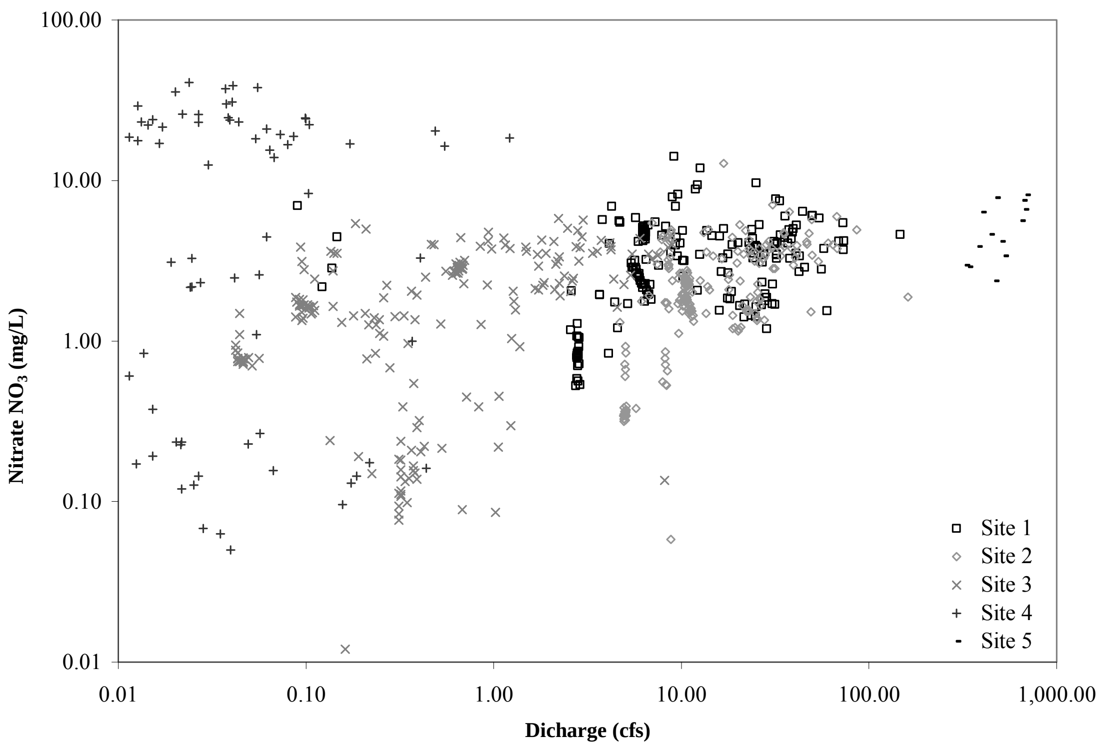


Figure 9: Nitrate (NO_3) concentration from laboratory analysis of water samples as a function of flow collected at all sites over both water years.

YSI Sondes

Calibration of the analytical laboratory and sonde values were conducted through linear regression for the parallel constituents. This included nitrate, ammonium, temperature, turbidity, conductivity, and pH for sites 1 through 3 for both years (Table 3). This was done as a quality control measure and to correlate water quality parameter values between the respective measurement methods. To reiterate, only Sites 1, 2, and 3 were instrumented in 2004-2005 and 2005-2006, with Site 5 added in the second year.

Use of the continual data recording sondes generated a more continuous data record for selected water quality constituents than was possible with the sampling and analysis conducted on a storm or 24-hour basis. This affords better documentation of the storm and seasonal variability that exists for the transport and delivery of water quality constituents. For example, values for both nitrate and ammonium demonstrate a seasonal flushing dynamic. They are highest early in the season and taper off through the water year (Figure 10a and b). In addition, they demonstrate a consistent rising and falling with discharge. It is interesting to note that the highest nitrate concentrations were documented during peak storm activity and flood conditions between December 18, 2005 and January 2, 2007. This flushing and storm response has been demonstrated in other California Mediterranean watersheds.

Table 3: Summary of statistical results for correlating Sonde data with analytical laboratory and temperature field data.

Site	Parameter	R^2	Correlation *P*-value	Regression Equation	*P*-value
1	Nitrate	0.54	<0.0001	Sonde = 2.2 + 0.9 * (Lab)	<0.0001
	Ammonium	0.03	0.0696	Sonde = 0.3 + 0.3 * (Lab)	<0.0001
	Temperature	0.99	<0.0001	Sonde = 0.1 + 1.0 * (Logger)	<0.0001
	Turbidity	0.02	0.0446	Sonde = 37.9 + 0. * (Lab)	<0.0001
	Conductivity	0.84	<0.0001	Sonde = 44.4 + 0.9 * (Lab)	0.0621
pH		not significant			
2	Nitrate	0.27	<0.0001	Sonde = 5.0 + 1.3 * (Lab)	<0.0001
	Ammonium	0.23	<0.0001	Sonde = 0.4 + 5.8 * (Lab)	<0.0001
	Temperature	0.62	<0.0001	Sonde = 5.6 + 0.6 * (Logger)	<0.0001
	Turbidity	0.81	<0.0001	Sonde = 0.9 + 1.2 * (Lab)	0.6883
	Conductivity	0.93	<0.0001	Sonde = 5.7 + 1.0 * (Lab)	0.6545

pH		not significant			
3	Nitrate	0.31	<0.0001	Sonde = -23.7 + 29.4 * (Lab)	0.0068
	Ammonium	0.02	0.0610	Sonde = 0.4 + 2.5 * (Lab)	<0.0001
	Temperature	0.72	<0.0001	Sonde = 2.6 + 0.8 * (Logger)	<0.0001
	Turbidity	0.92	<0.0001	Sonde = -6.4 + 1.3 * (Lab)	0.0490
	Conductivity	0.88	<0.0001	Sonde = -26.1 + 1.0 * (Lab)	0.0538
pH		not significant			

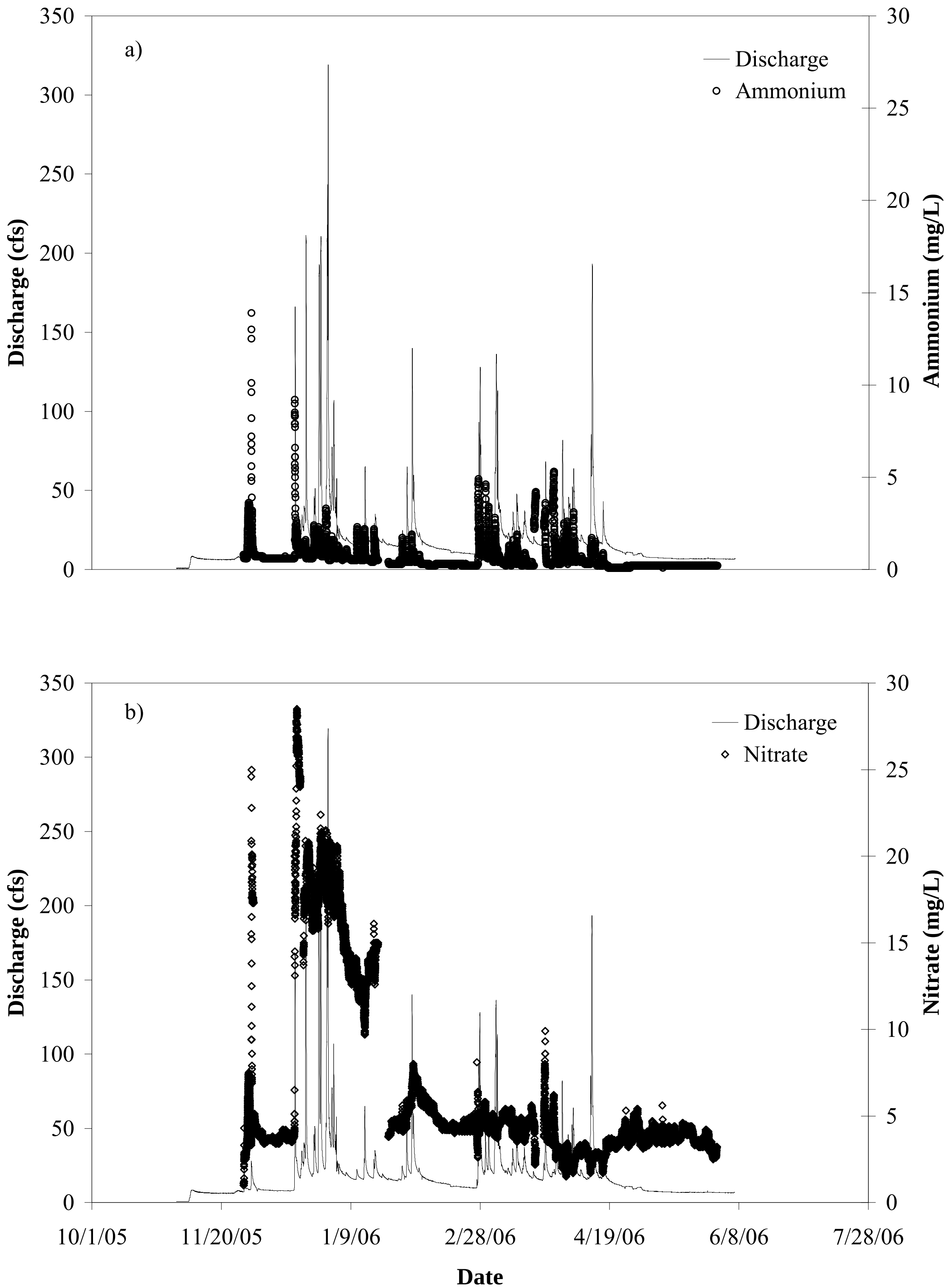


Figure 10: Discharge (cfs) and sonde measured ammonium (mg/L)(a) and nitrate (mg/L)(b) at Site 2 in 2005-2006 water year.

Loads

The combination of parameter concentration and discharge measurements provided us the opportunity to calculate total storm load or flux of specific water quality constituents. These loads were calculated for each site during the respective storms studied. A complete table of all storm load values for study Sites 1 through 5 is presented in Appendix E. These calculations were only possible for two storms at Site 5 during the second year of the study.

Similar to the discussion on parameter concentration, Site 4 consistently demonstrated the greatest total storm loads for the water quality parameters studied. This is compelling in that the area of Site 4 is three to four orders of magnitude smaller than the other four sites (Table 1). Also, on a standard comparison of unit area there is as much as three to fours orders of magnitude greater flux of selected suspended solids or nutrients moving past Site 4 than the other study sites (Figure 11). This is particularly true for Ammonium and Ammonia. Another interesting observation is that values for many constituents at Site 1 are consistently lower than for those upstream at Site 2.

While the difference between Site 4 and the other sites is clear, it is important to recognize the variability in storm loads at each site because of individual storm intensity and precipitation volume (Figure 12). For example, the greatest storm loads at all sites were consistently experienced on January 11 and 12, 2005 and December 18, 2005, compared with lowest the storm loads experienced on November 15, 2005 (Appendix E).

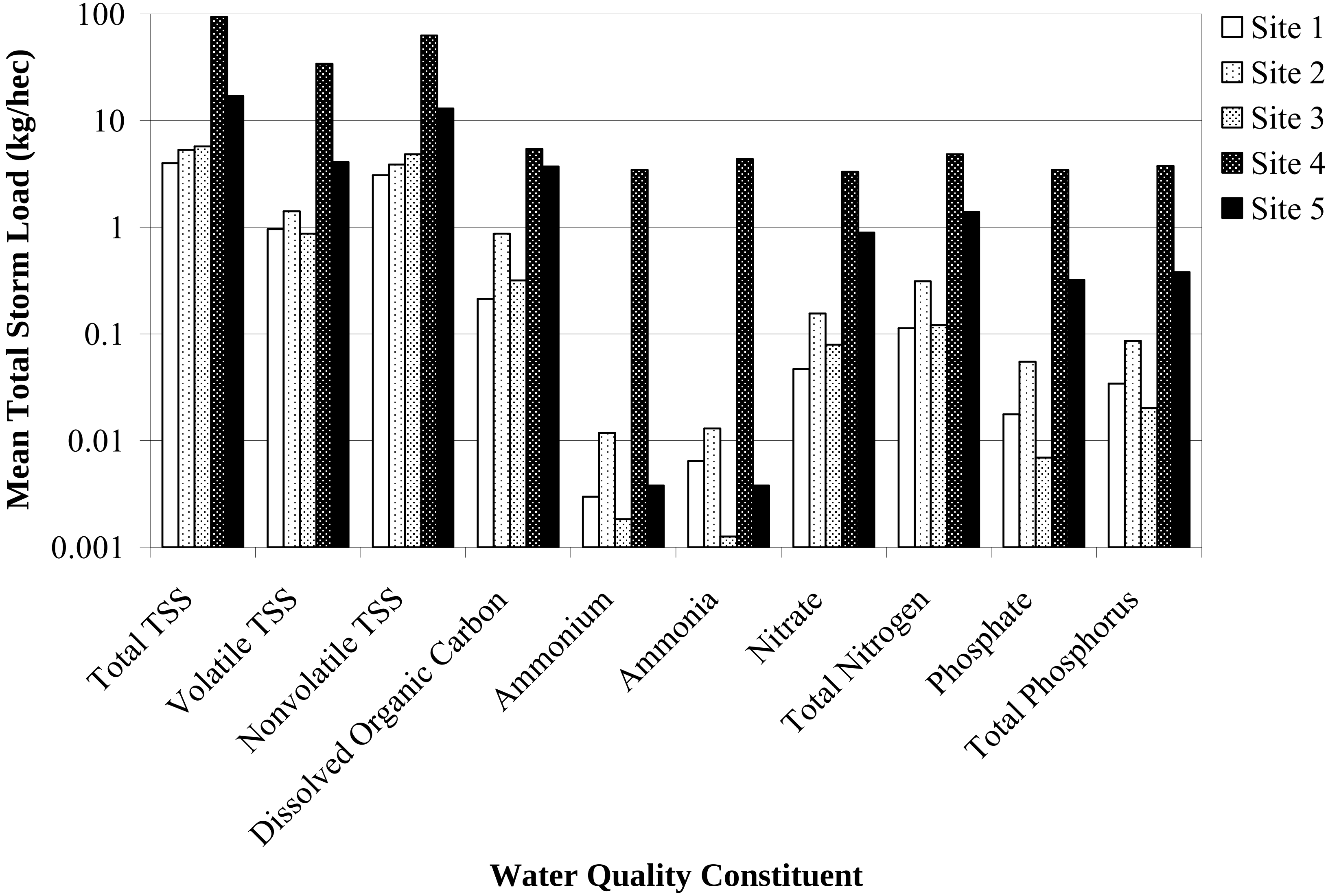
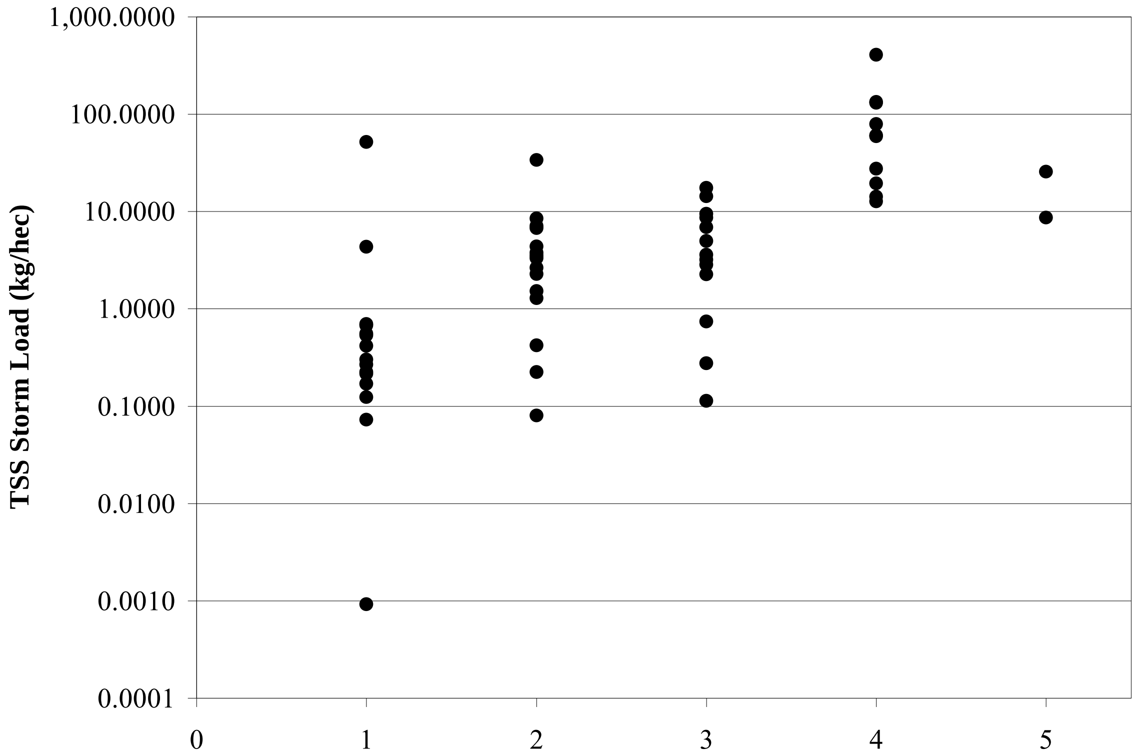


Figure 11: Mean total storm loads for studied water quality constituents on a per unit area basis. The units of kilograms per hectare convert approximately to pounds per acre. For example 100 kilograms/hectare equates roughly to 100 pounds/acre.



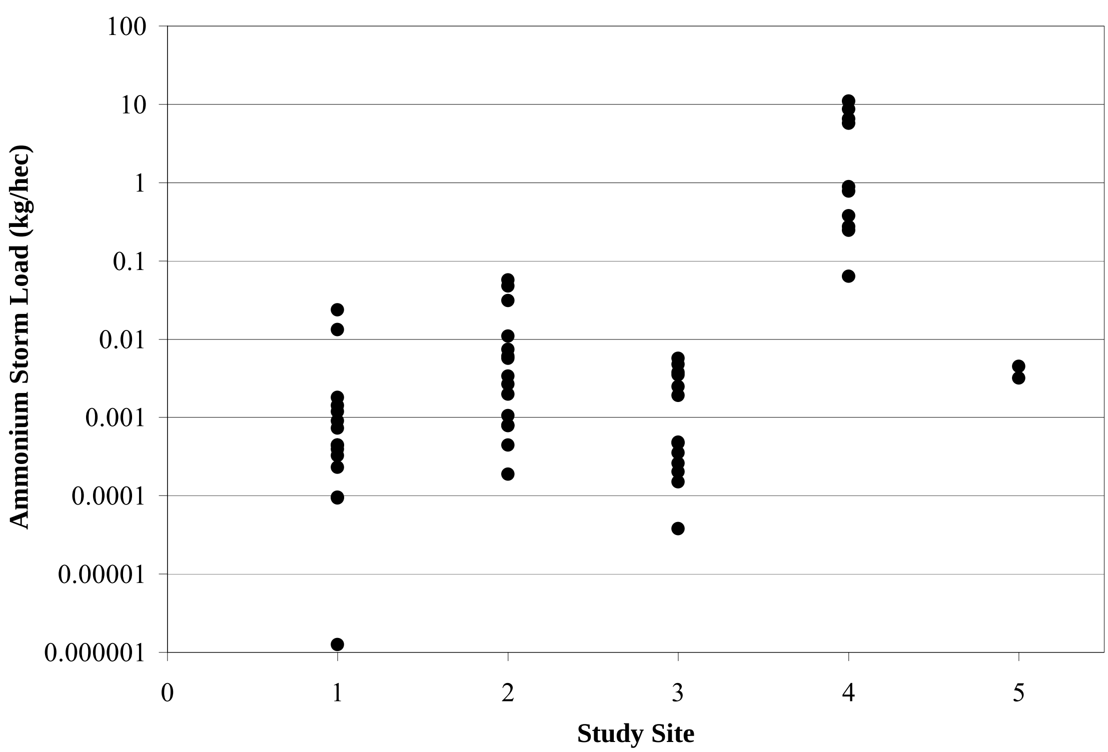


Figure 12: Storm loads for TSS (upper) and ammonium (lower) at all five study sites.

SUMMARY

The combined results of hydrology, precipitation and water quality from this endeavor provide the data to model water quality and the role BMP implementation can have in reducing agricultural, and specifically livestock agriculture, impacts on water quality. Complimentary to any modeling, the results of this water quality analysis document the annual, seasonal, and storm scale variability in stream flow generation and water quality. They also facilitate prioritization of efforts to assist agriculture in its use of management measures to improve water quality and maintain the viability of its operations.

Stream discharge generation at the study sites was typical of California's Mediterranean climate. In both study years, an initial volume of rainfall was required to prime the watershed prior to the initiation of stream flow. From that point in the water year, discharge at each sample site rose and fell with each subsequent storm, until the end of the season. The time period from early fall up to and including the watershed priming period represents an important opportunity for the management of livestock and manure to reduce potential water quality impacts. Ranchers and farmers can take actions, such as herd rotation or manure spreading and incorporation, in advance of stream flow generation and the delivery of any sediment or nutrients from the uplands to area streams. Inevitably, there will be storms and storm series that exceed management capacity to reduce the transport of sediment and nutrients. Such conditions were experienced during the last week of December 2005 and first week in January 2006. In this saturated state, the watershed is fully connected hydrologically.

Water quality samples from Site 4 had concentrations of nutrients and sediment that were orders of magnitudes greater than those at Sites 1, 2, 3, and 5. Conversely, stream flow volumes were at a minimum an order of magnitude less at Site 4 than the other sites. This is not unexpected. As noted, this site represents a high use area needed by dairy farms and ranches for concentrating and handling livestock during some portion of the year. These areas have many common names including exercise lots, sick pens, calving pens, calf corrals, feeding areas, and loafing areas and are important production components for area dairies and ranches. They contribute to herd health by providing lactating animals a place to exercise that is near to milking facilities. They facilitate supplemental feeding in a cost-effective way. Producers, alternatively, use these areas as nurseries or sick pens, allowing them to monitor groups of animals that require direct and timely attention. Admittedly, the use of these areas results in surfaces where vegetation may be absent or slow to regenerate. This increases the susceptibility of these areas to erosion and subsequent transport of nutrients and sediment in runoff from these sites during winter storms.

The resulting management challenge for these areas is how to maintain animal productivity, health and welfare while reducing impacts to water quality. And given the relatively high concentrations and low flow volumes measured at Site 4, the question is raised as to the loading potential of sites like Site 4 for the studied constituents. In the actual case of Site 4, runoff from the area is directed through a grassed waterway prior to entering an intermittent tributary of the main stem of Stemple Creek. Because the objective of this water quality analysis was to generate data at differing scales for modeling purposes, we did not conduct above and below water quality monitoring to determine the effectiveness of this specific measure. Additional analysis of the data and further study designed to investigate this specific question are required to achieve that objective. However, the preliminary analysis presented in this report indicates that there is potential loading from high use areas and other intensive agricultural operations like Site 4. For example, similar and higher values for volatile-TSS as a percent of TSS in samples from Sites 1, 2, and 4 relative to Sites 3 and 5 indicate that there may be loading of fine solids from high use areas like Site 4 upstream of Sites 1 and 2. And consistently the concentrations and loads for all studied parameters were lowest in Site 3 samples, the study site furthest upstream and above intensive agricultural operations such as high use areas and pastures receiving spread manure.

This is not to say that Site 4 is the source of increased nutrient and sediment concentrations at Sites 1, 2, and 5. There are spatial scales and multiple activities between these study sites, including the implemented management measure described above, that prevent any differentiation or association to be made. More generally, the results and this preliminary analysis offer indications that water quality is changing from upstream to downstream and that loading from intensive agricultural operations is a potential source for these changes. Accordingly, these areas and locations on the farms and ranches within the watershed should be the first point of intervention for further soil and water conservation measure implementation. Previous water quality monitoring data combined with the results from this water quality analysis confirm a downward trend in ammonia concentrations in the Stemple Creek Watershed. This record parallels previous and ongoing collaboration with watershed farmers and ranches to improve water quality. They should serve as the motivation that continuation of these conservation programs and actions will be effective in achieving that resource goal.

REFERENCES

Carlson, R.M. 1978. Automated separation and conductimetric determination of ammonia and dissolved carbon dioxide. Anal. Chem. 50:1528-1531.

Carlson, R.M. 1986. Continuous flow reduction of nitrate to ammonia with granular zinc. Anal. Chem. 58:1590-1591.

Emerson, K., R.C. Russo, R.E. Lund, and R.V. Thurston. 1975. Aqueous ammonia equilibrium calculations: effect of pH and temperature. J. Fish. Res. Board Can. 32(12): 2379-2383.

Kashiwagi, J.H. 1985. Soil survey of Marin County, California. U.S. Department of Agriculture, Soil Conservation Service, Davis, California.

Klute, A. (editor). 1986. Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods. Second Edition. American Society of Agronomy, Inc., Soil Science Society of America, Inc. Madison, WI.

Larson, S. K. Smith, D. Lewis, J. Harper, and M. George. 2005. Evaluation of California's Rangeland Water Quality Education Program. Rangeland Ecology & Management. 58(5):514-522.

Miller, V.C. 1972. Soil survey of Sonoma County, California. U.S. Department of Agriculture, Forest Service and Soil Conservation Service, Davis, California.

NRCS. 2004. Stemple Creek Watershed Project. Marin and Sonoma Counties, California. Final Watershed Project Plan and Environmental Assessment. Marin Resource Conservation District, Southern Sonoma County Resource Conservation District, and USDA Natural Resources Conservation Service. Davis, California. 46 pgs.

Prunuske Chatham, Inc. 1994. Stemple Creek/Estero de San Antonio Watershed Enhancement Plan. Occidental, California.

Rilla, E., S. Larson, L. Bush, D. Livingston, P. Olin, L. Krieshok, and N. Perrott. 1995. Final Report of The Marin Coast Watershed Enhancement Project. University of California Cooperative Extension Marin County. Novato, California. 89 pgs.

Ritchie, J.C., V.L. Finney, K.J. Oster, and C.A. Ritchie. 2004. Sediment deposition in the flood plain of Stemple Creek Watershed, northern California. Geomorphology, 31: 347-360.

Rugg, M.E. 2002. Marin-Sonoma Counties Agricultural Runoff Influence Investigation: 2000-2001 Summary. Department of Fish and game – Central Coast Region. P.O. Box 47, Yountville, CA 94599.

Salisbury, D. 1997. Total Maximum Daily Load and Attainment Strategy for the Stemple Creek Watershed. California Regional Water Quality Control Board North Coast Region. Santa Rosa, California. 38 pgs.

Winchester, W. D., R. L. Raymond, D. L. Salisbury. 1995. Stemple Creek Water Quality Characteristics and a Maximum Daily Load Process Marin and Sonoma Counties. California Regional Water Quality Control Board North Coast Region, Santa Rosa, California. 33 pgs.

Yu, Z., R.R. Northup and R.A. Dahlgren. 1994. Determination of dissolved organic nitrogen using persulfate oxidation and conductimetric quantification of nitrate-nitrogen. Commun. Soil Sci. Plant Anal. 25:3161-3169.

APPENDIX A

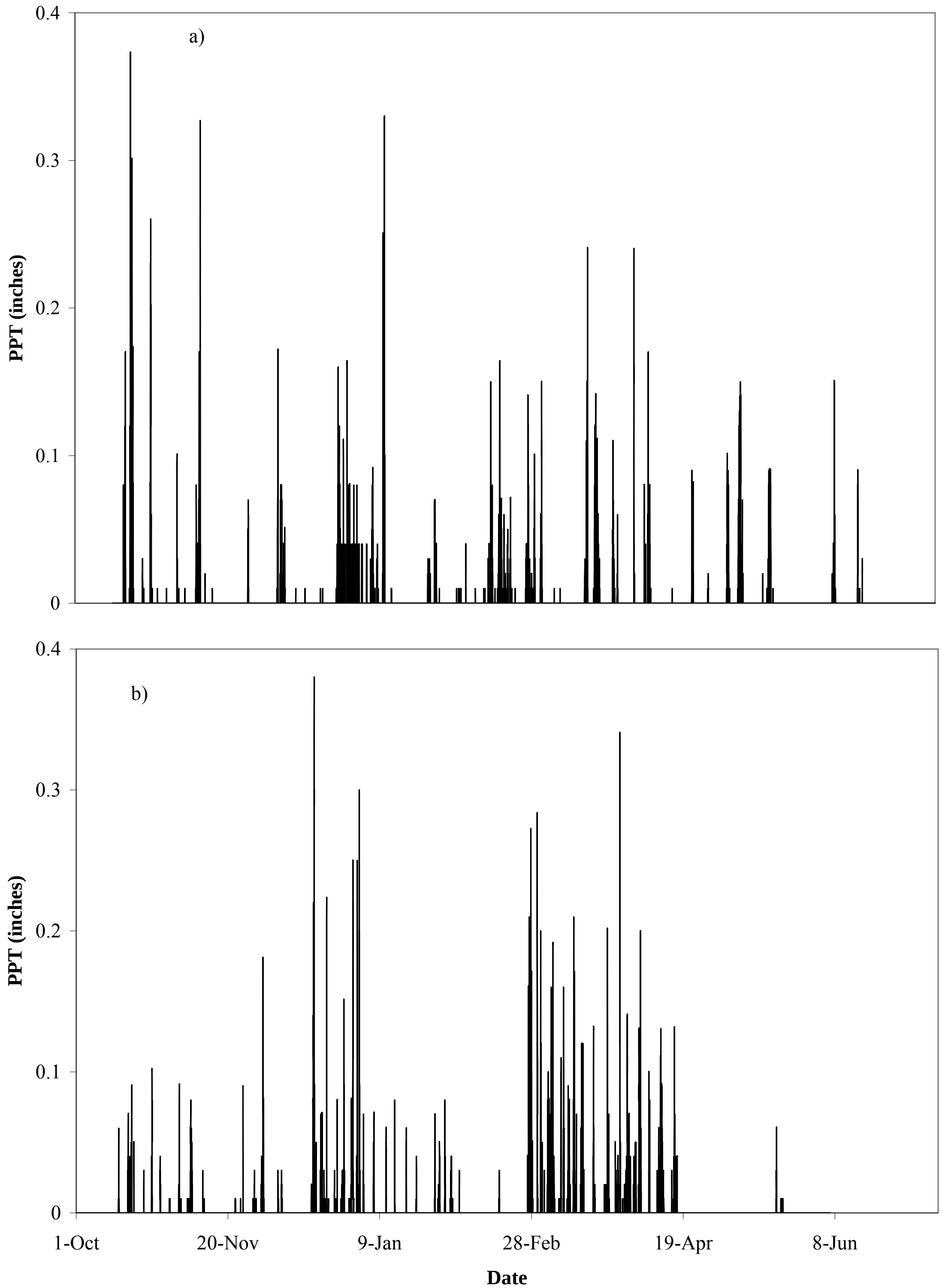
Activities and actions performed to conduct CEAP water quality analysis on Stemple Creek Watershed.

Date	Activity and Action
8/19/04	Meeting with Stemple Creek Watershed landowners to introduce the project.
9/13-24/04	Installation of water quality samplers, stage height recorders, and rain gauges at four project sites.
11/10/04	Measured project sites cross-sectional areas.
12/2/04 - ongoing	Water samples collected and analyzed. ISCO and YSI instrument data collected.
12/2-3/04	Field tour and meeting to coordinate with AGNPS researchers.
12/21/04	Sonde deployed at Site 1 without pH probe and correct calibration of ammonium and nitrate probes.
1/6/05	Sondes deployed at Sites 2 and 3 without pH probes and correct calibration of ammonium and nitrate probes.
1/21/05	Sondes removed for correct calibration of ammonium and nitrate probes with pH probes.
1/28/05	Field tour with UC Davis researchers.
2/4/05	Sonde programmed and deployed at Site 2 with correct calibration of ammonium, nitrate, and pH probes.
2/8/05	Sondes programmed and deployed at Sites 1 and 3 with correct calibration of ammonium, nitrate, and pH probes.
4/11/05	Sonde removed from all 3 sites for calibration.
4/21/05	Sondes redeployed to all 3 sites.
6/22/05	Sondes removed for calibration and storage over summer.
7/28/05	ISCO samplers removed from field Sites 1,2 and 3 for cleaning, maintenance and storage.

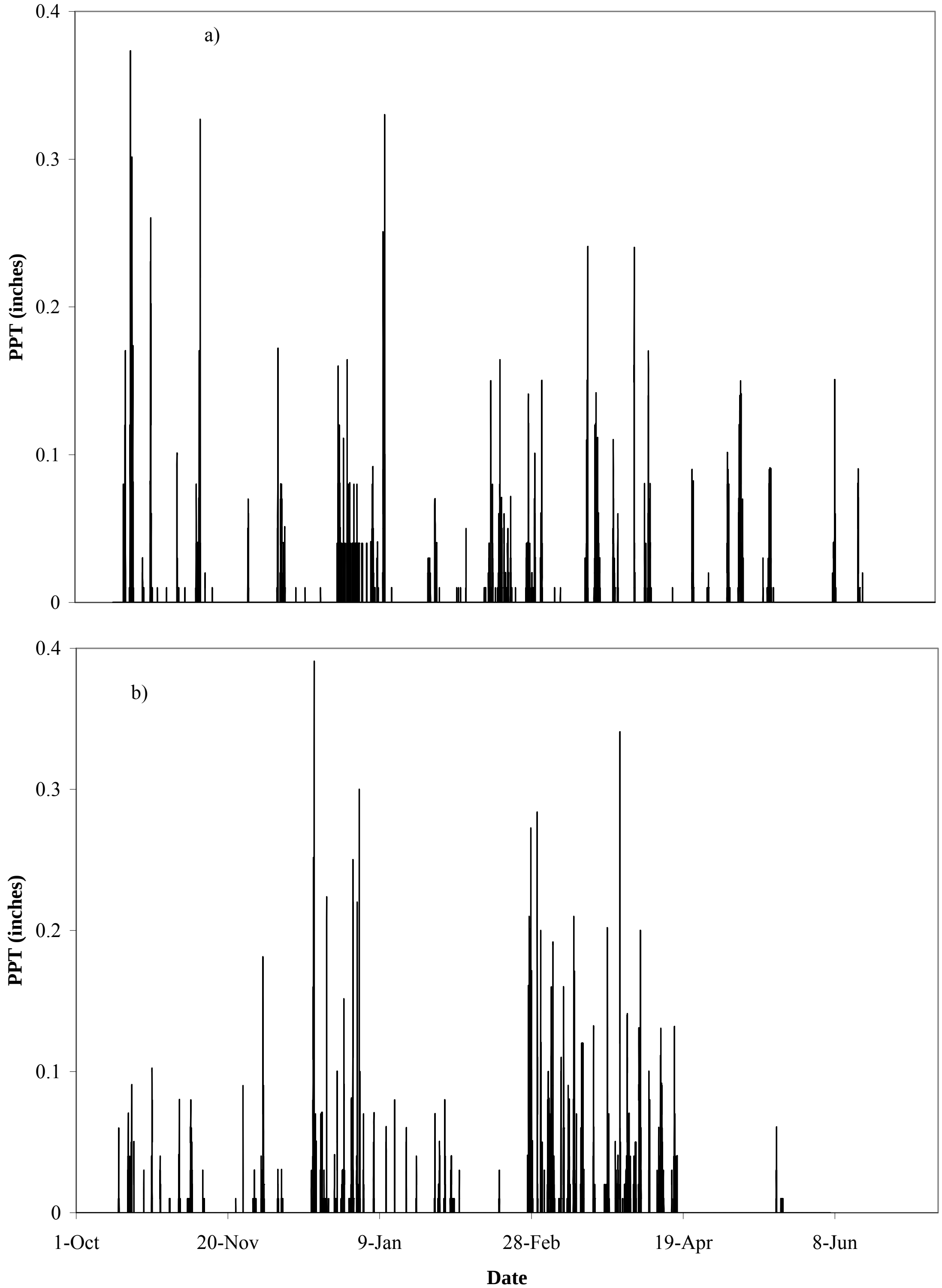
10/31/05	Groundwater wells near stream sites were sampled.
11/2/05	ISCO samplers were deployed at the four project sites.
11/22/05	ISCO sampler deployed at new Site 5.
11/28/05	Sonde installed at Site 2.
12/1/05 - ongoing	Water samples collected and analyzed. ISCO and YSI instrument data collected.
12/21/05	Sondes installed at Sites 1 and 3. Sonde replaced at Site 2.
1/19/05	Sondes removed from Sites 1, 2 and 3 for calibration.
1/23/05	Sondes redeployed to Sites 1, 2 and 3.
1/25/05	Sonde deployed at Site 5.
2/10/05	Sonde removed from Site 5.
2/15/05	Groundwater wells near stream sites were sampled.
2/16/05	Sonde redeployed to Site 5.
3/21/06	Sondes removed from all 5 sites for calibration.
3/24/06	Sondes redeployed to all 5 sites.
5/30/06	Sondes removed from all 5 sites.
6/6/06	ISCO samplers removed from all five sites.
6/27/06	Tour sites with state and federal NRCS staff.
5/1/07	Meeting with Stemple Creek Watershed landowners to share preliminary project results.

APPENDIX B

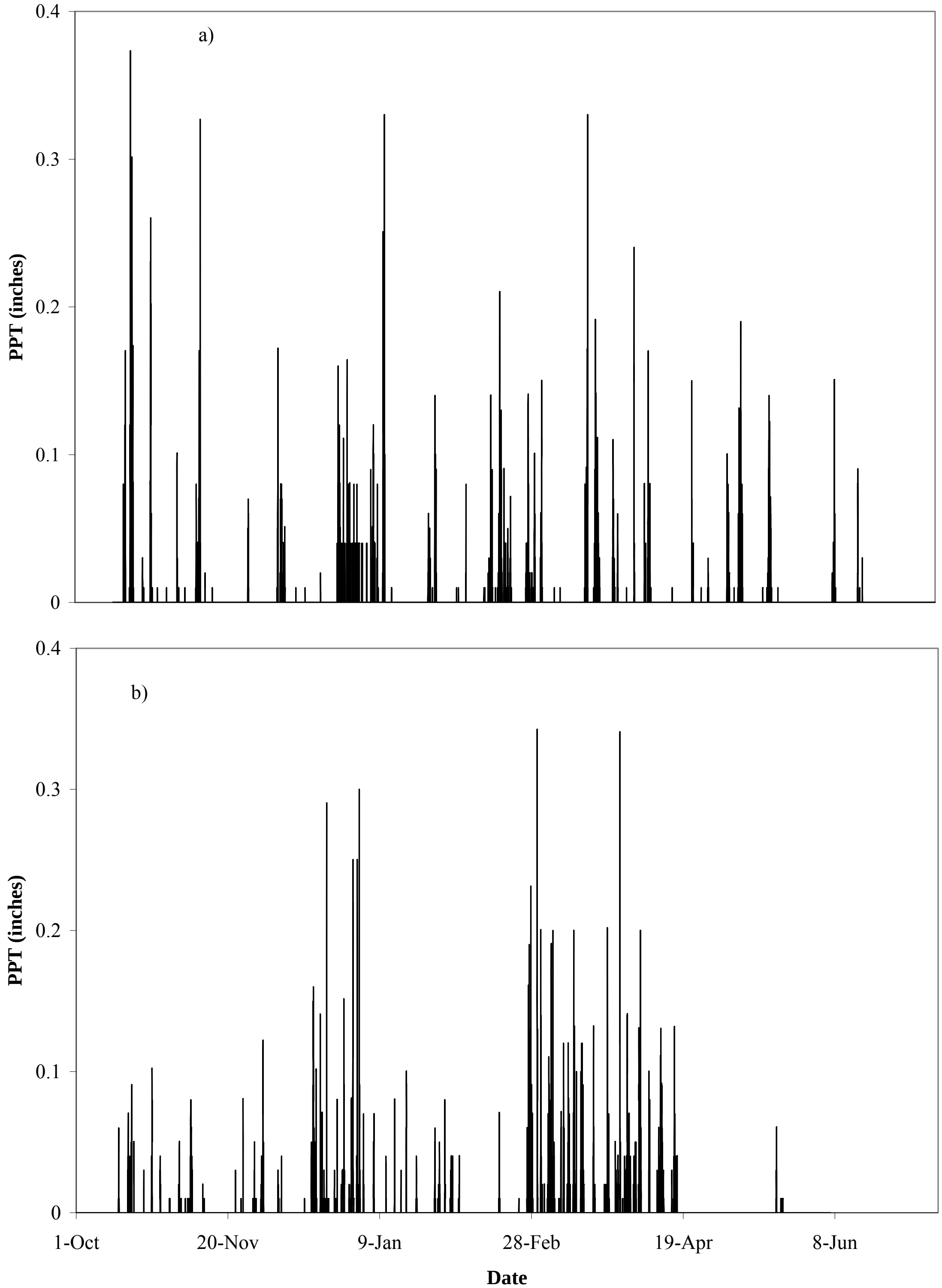
Annual precipitation for Site 1 over both water years - 2004-2005 (a) and 2005-2006 (b).



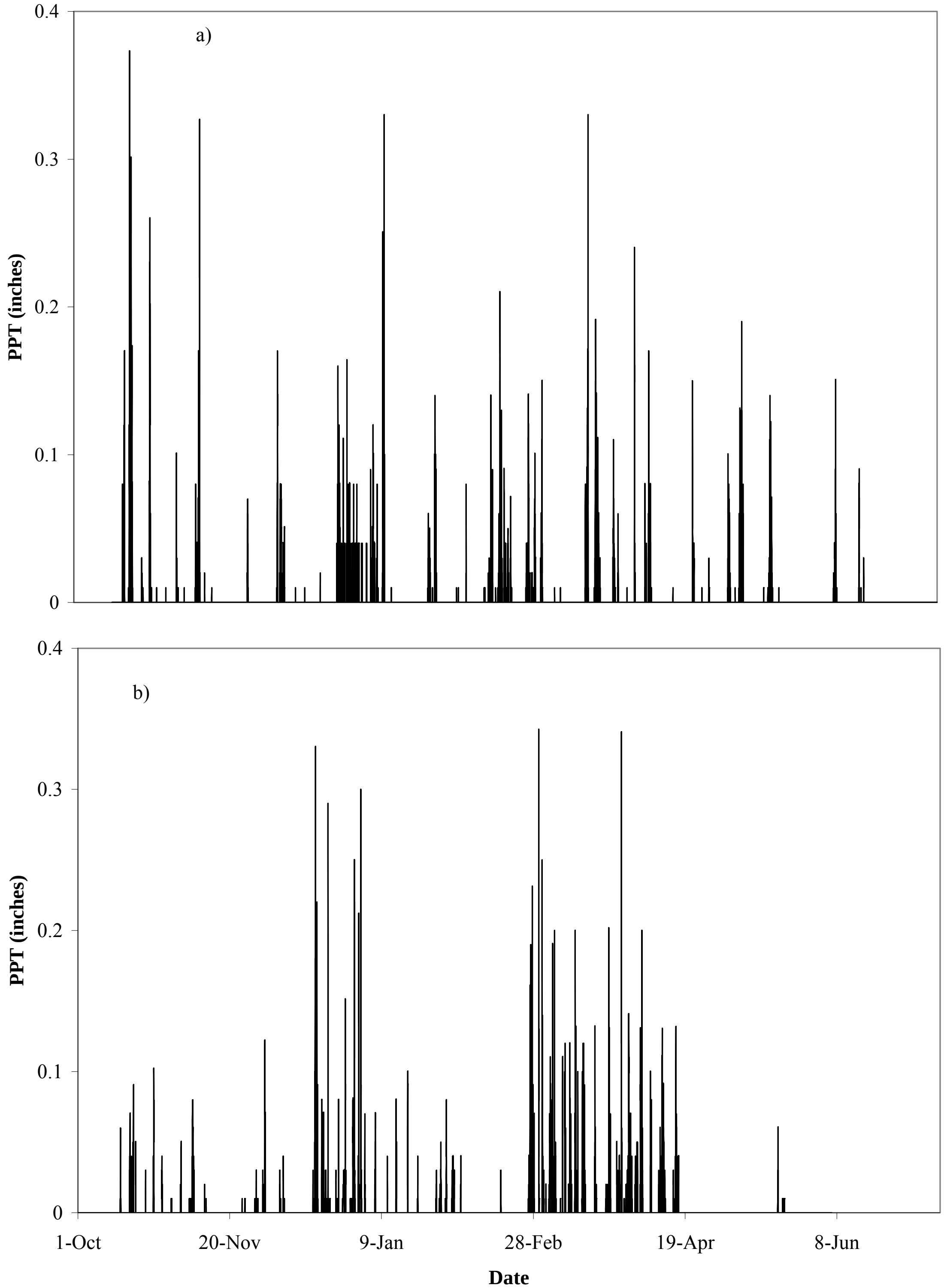
Annual precipitation for Site 2 over both water years - 2004-2005 (a) and 2005-2006 (b).



Annual precipitation for Site 3 over both water years - 2004-2005 (a) and 2005-2006 (b).

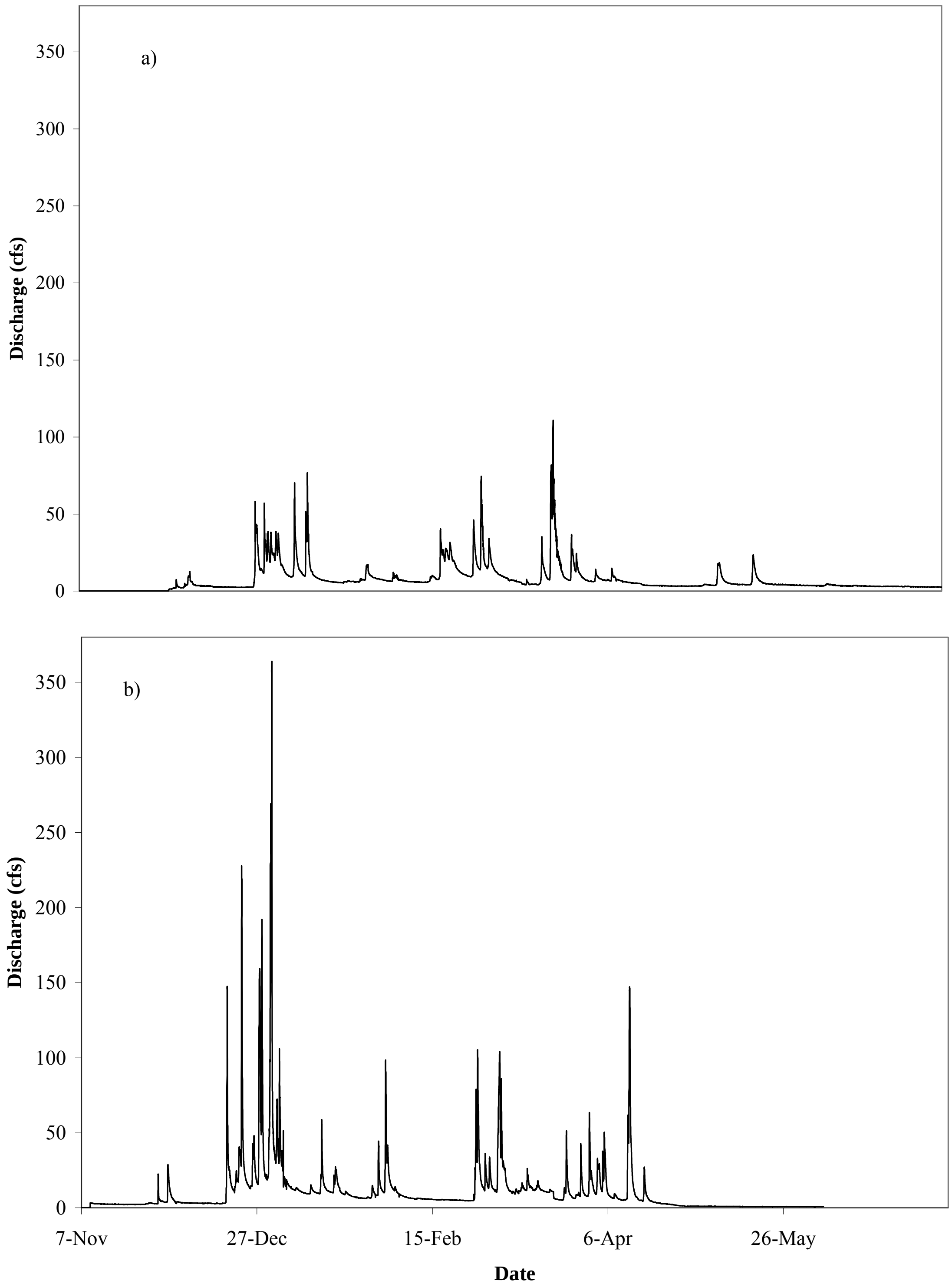


Annual precipitation for Site 4 over both water years - 2004-2005 (a) and 2005-2006 (b).

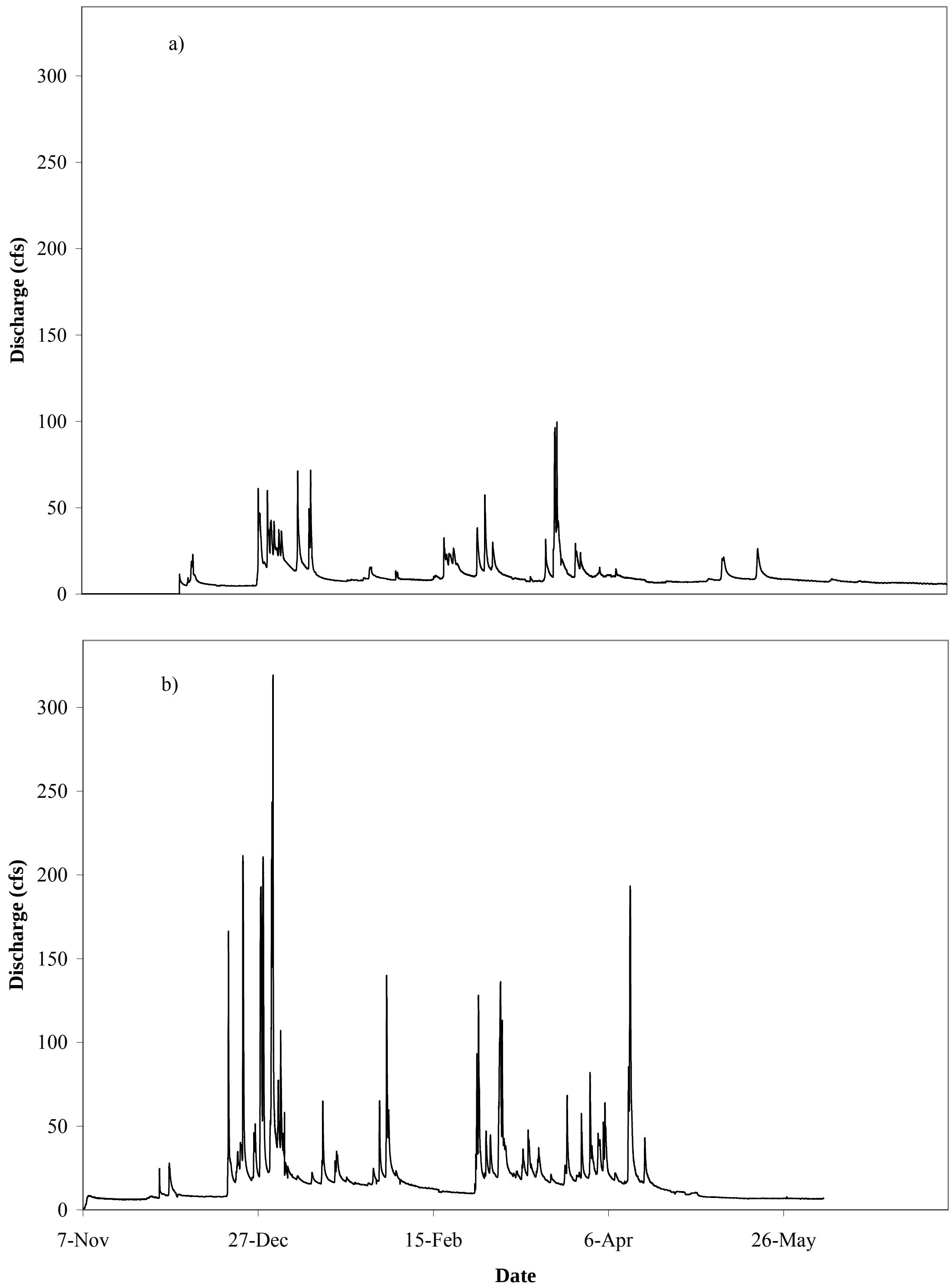


APPENDIX C

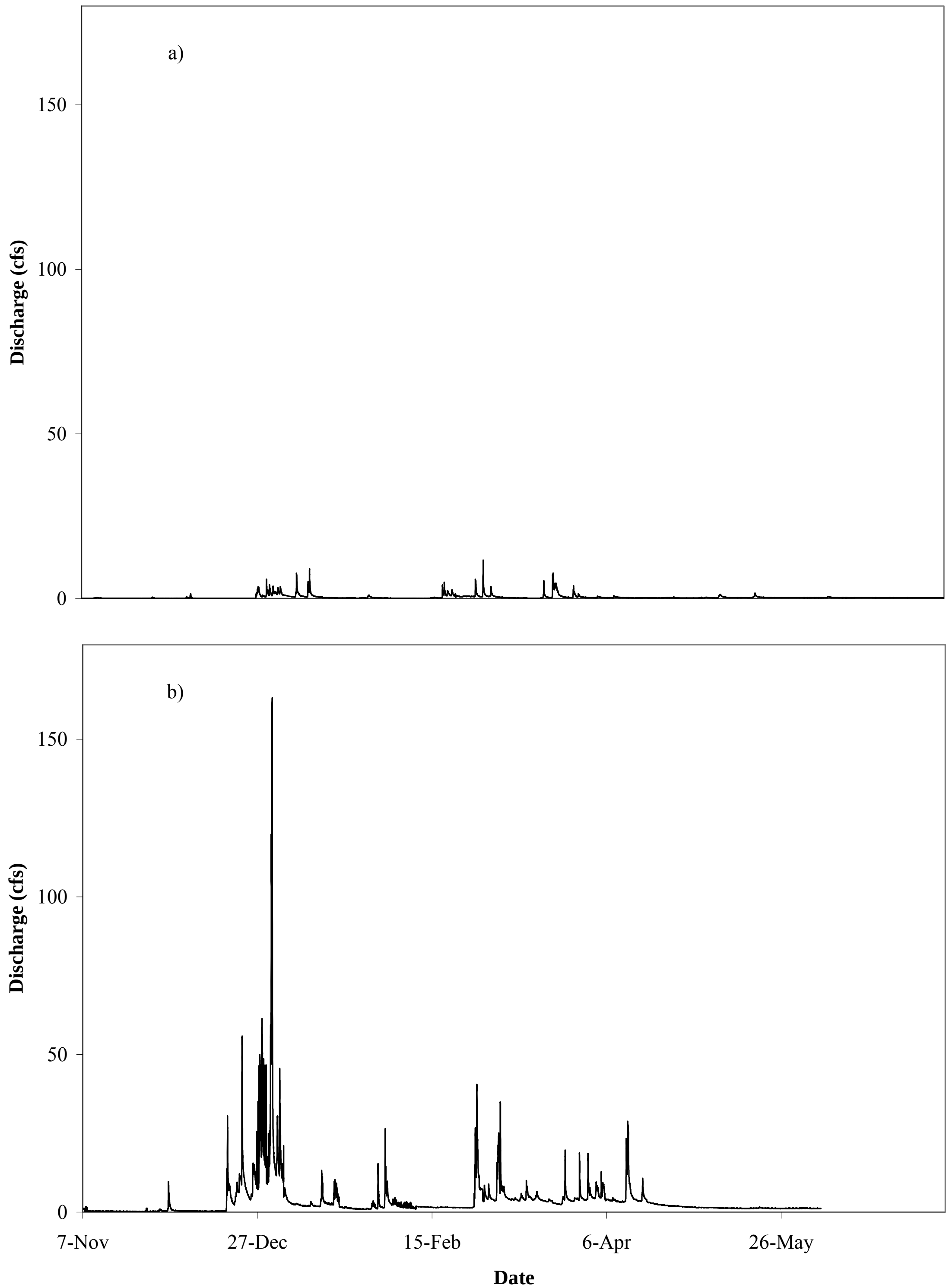
Annual hydrographs for Site 1 over both water years - 2004-2005 (a) and 2005-2006 (b).



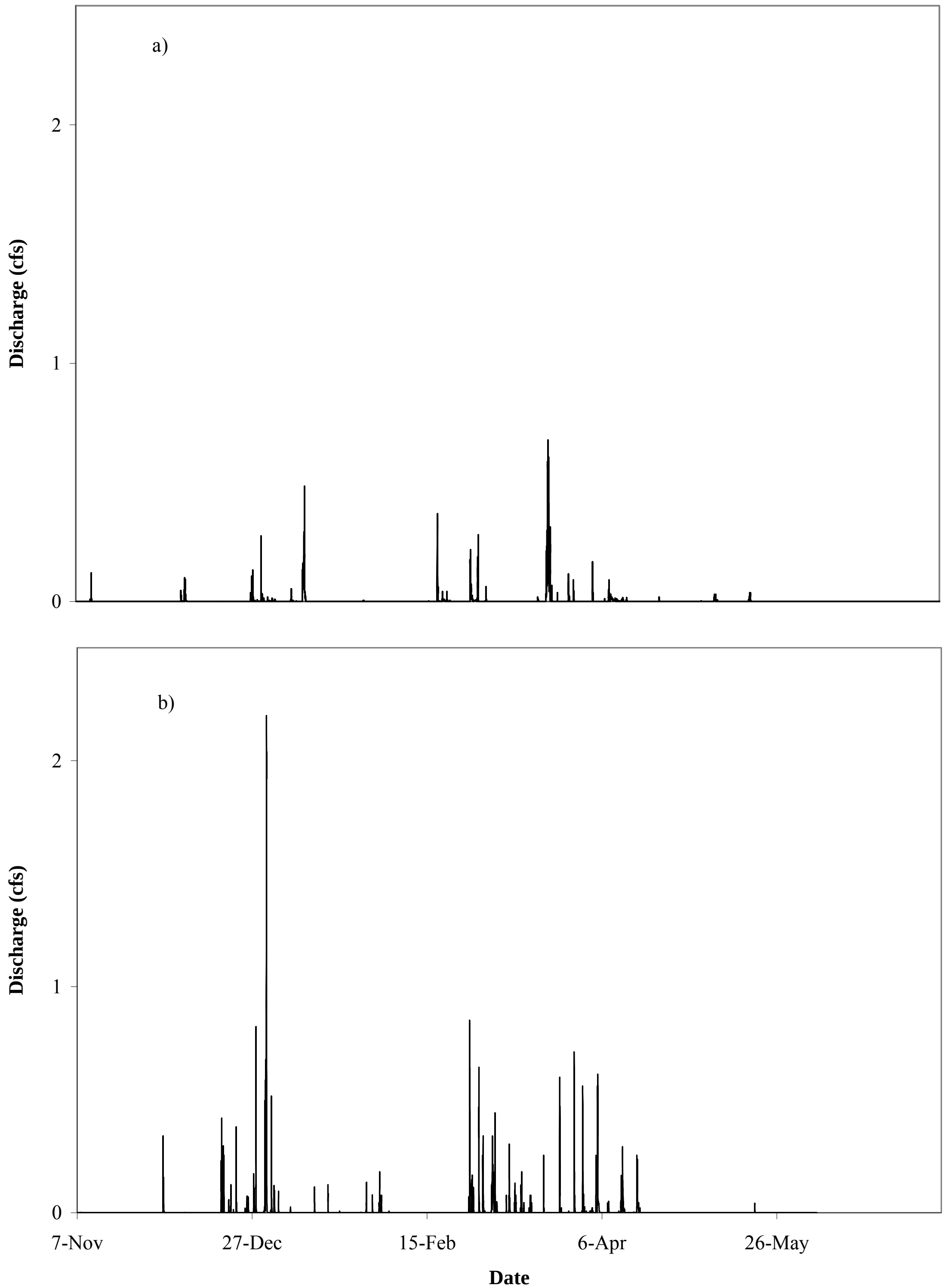
Annual hydrographs for Site 2 over both water years - 2004-2005 (a) and 2005-2006 (b).



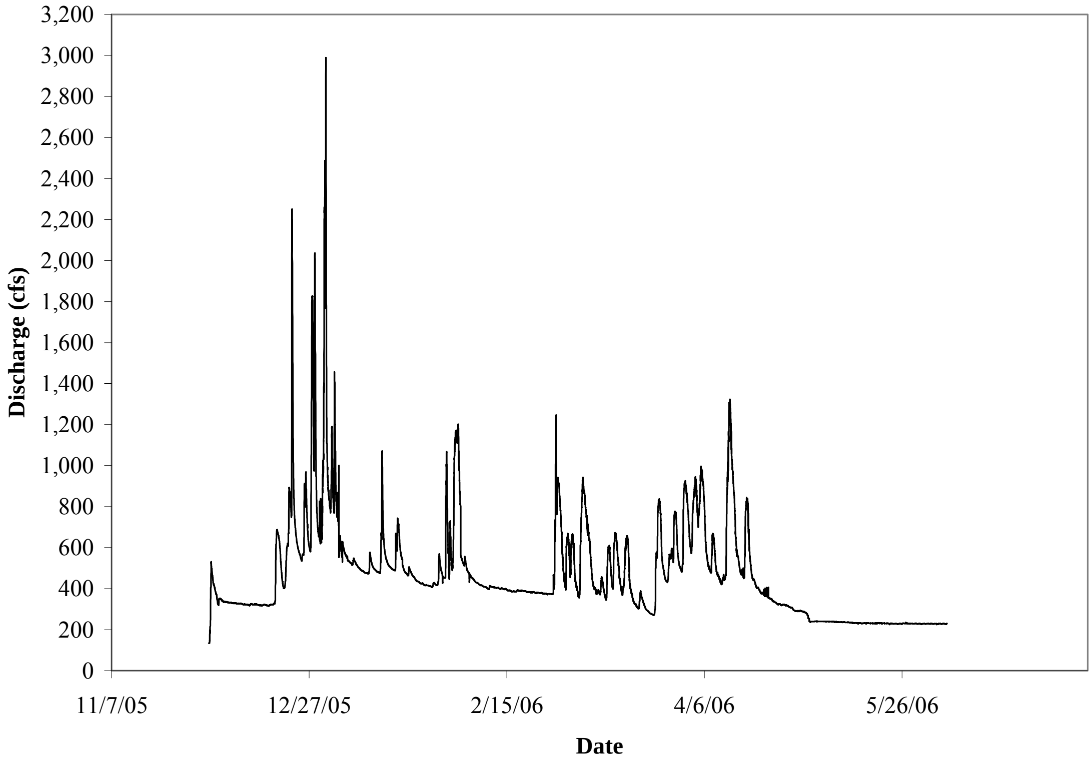
Annual hydrographs for Site 3 over both water years - 2004-2005 (a) and 2005-2006 (B).



Annual hydrographs for Site 4 over both water years - 2004-2005 (a) and 2005-2006 (b).



Annual hydrograph for Site 5 over the 2005-2006 water year.



APPENDIX D

Basic statistics for chemistry, turbidity and suspended sediment concentrations by year and site.

Water Year	Site	pH Mean	pH Std. Error	pH Median	pH Min.	pH Max.	Electrical Conductivity (uS/cm) Mean	EC Std. Error	EC Median	EC Min.	EC Max.	Turbidity (mg/L) Mean	Turbidity Std. Error	Turbidity Median	Turbidity Min.	Turbidity Max.
2004-2005	1	7.5	0.015	7.5	7.0	7.8	502	15.2	530	26	1,100	31	3.8	9.6	1.4	493
2004-2005	2	7.5	0.014	7.5	6.9	7.9	465	13.0	488	179	1,130	24	2.2	9.9	1.2	195
2004-2005	3	7.5	0.019	7.5	6.7	8.0	391	10.3	365	148	698	66	6.3	27.0	4.2	527
2004-2005	4	7.8	0.043	7.8	7.0	9.0	2,212	106.2	2,040	114	5,180	281	11.9	275.5	12.6	474
2005-2006	1	7.0	0.040	7.0	6.7	7.3	282	62.7	320	100	1,220	117	31.3	51.2	1.5	332
2005-2006	2	7.1	0.047	7.2	6.8	7.5	197	13.5	185	110	340	71	24.9	13.2	0.8	352
2005-2006	3	7.1	0.068	7.2	6.7	7.3	153	9.1	155	110	200	103	37.9	48.9	4.8	418
2005-2006	4	7.4	0.036	7.4	7.2	7.7	569	44.9	540	340	850	127	23.0	105.0	12.6	306
2005-2006	5	7.5	0.015	7.0	7.0	7.8	182	15.0	180	120	280	75	16.1	51.7	12.7	197

Water Year	Site	Total Suspended Solids TSS (mg/L) Mean	TSS Std. Error	TSS Median	TSS Min.	TSS Max.	Volatile TSS (mg/L) Mean	Volatile Std. Error	Volatile Median	Volatile Min.	Volatile Max.	Non-volatile TSS (mg/L) Mean	Non-volatile Std. Error	Non-volatile Median	Non-volatile Min.	Non-volatile Max.
2004-2005	1	36	3.9	13	1.8	307	11.5	1.1	5.8	1.1	89	25	2.8	7.0	0.2	223
2004-2005	2	32	3.5	11	1.8	310	9.8	1.0	5.1	0.7	102	22	2.6	6.6	0.0	216
2004-2005	3	105	11.7	32	4.3	884	17.9	1.7	8.6	1.3	132	87	10.0	24.0	1.7	760
2004-2005	4	5,385	615.6	3,712	296.4	33,120	2,211.6	209.6	1,695.0	180.0	10,820	3,174	426.4	1,980.0	90.7	22,410
2005-2006	1	276	88.3	84	3.3	1,123	75.9	25.8	16.9	0	373	200	66.2	67.6	0.5	917
2005-2006	2	179	74.9	28	2.3	1,190	50.5	23.4	6.9	2.0	400	128	52.2	20.9	0.0	790
2005-2006	3	289	161.6	67	7.3	1,970	55.0	32.4	12.7	2.8	400	234	129.4	56.2	0.8	1,570
2005-2006	4	7,886	1,690.6	5,320	400.0	24,600	2,639.3	443.6	2,050.0	240.0	6,400	5,247	1,278.9	3,700.0	160.0	18,200
2005-2006	5	89	20.9	61	9.0	250	22.2	4.3	17.9	3.0	52	66	17.0	43.4	5.5	200

Basic statistics for chemistry, turbidity and suspended sediment concentrations by year and site.

Water Year	Site	Dissolved Organic Carbon (mg/L)					Total Nitrogen (mg/L)					Ammonium NH_4/NH_3 (mg/L)				
		Mean	Std. Error	Median	Min.	Max.	Mean	Std. Error	Median	Min.	Max.	Mean	Std. Error	Median	Min.	Max.
2004-2005	1	15.9	0.41	16	5.8	50	5.265	0.260	5.187	0.348	25.787	0.103	0.022	0.053	0.002	3.26
2004-2005	2	14.8	0.36	14	7.6	59	4.186	0.198	4.099	0.242	26.865	0.098	0.023	0.056	0.003	4.196
2004-2005	3	11.6	0.15	12	7.9	18	3.088	0.153	2.801	0.349	10.016	0.075	0.008	0.035	0.000	0.741
2004-2005	4	192.1	7.95	182	13.6	623	151.547	7.571	139.420	26.677	376.640	23.545	2.002	22.950	0.051	89.263
2005-2006	1	19.9	3.31	14	11.6	62	12.917	2.442	8.941	3.138	34.939	0.407	0.362	0.010	0.000	6.174
2005-2006	2	19.7	2.81	15	7.9	58	7.527	2.246	3.320	1.686	39.358	0.591	0.516	0.007	0.000	9.289
2005-2006	3	11.8	0.42	12	9.6	14	4.537	0.719	4.112	1.928	8.572	0.004	0.001	0.004	0.000	0.009
2005-2006	4	169.0	43.49	126	40.5	682	92.252	7.205	97.081	47.373	132.765	21.721	2.898	20.925	9.177	43.534
2005-2006	5	22.7	2.10	22	13.2	40	8.045	0.675	8.042	4.595	11.722	0.030	0.008	0.019	0.006	0.106

Water Year	Site	Nitrate NO_3 (mg/L)					Ammonia NH_3 (mg/L)				
		Mean	Std. Error	Median	Min.	Max.	Mean	Std. Error	Median	Min.	Max.
2004-2005	1	3.41	0.15	3.3	0.526	14.1	0.013	0.003	0.0002	0.00001	0.210
2004-2005	2	2.37	0.11	2.2	0.058	12.8	0.0004	0.00005	0.0002	0.00003	0.002
2004-2005	3	1.95	0.10	1.7	0.012	5.8	0.00025	0.00004	0.0002	0.00001	0.004
2004-2005	4	17.92	1.76	18.0	0.050	103.8	0.339	0.108	0.092	0.001	2.839
2005-2006	1	6.34	1.34	4.6	1.967	25.8	0.0009	0.0008	0.00002	0.00001	0.014
2005-2006	2	2.37	0.49	1.5	0.530	7.1	0.0015	0.0014	0.00002	0.00001	0.025
2005-2006	3	2.40	0.53	1.3	0.136	5.7	0.00001	0.00001	0.00001	0.00001	0.00005
2005-2006	4	0.18	0.01	0.2	0.096	0.3	0.103	0.011	0.115	0.035	0.177
2005-2006	5	5.09	0.56	4.6	2.370	8.1	0.00005	0.00001	0.00003	0.00001	0.0002

Basic statistics for chemistry, turbidity and suspended sediment concentrations by year and site.

Water Year	Site	Total Phosphorus (mg/L)					Ortho Phosphate PO_4 (mg/L)				
		Mean	Std. Error	Median	Min.	Max.	Mean	Std. Error	Median	Min.	Max.
2004-2005	1	1.1	0.080	0.8	0.094	7.485	0.834	0.056	0.6	0.184	6.4
2004-2005	2	0.9	0.064	0.7	0.043	8.789	0.701	0.044	0.6	0.143	6.5
2004-2005	3	0.5	0.031	0.3	0.020	3.498	0.170	0.014	0.1	-0.957	1.9
2004-2005	4	41.7	2.354	34.0	5.989	108.454	23.764	0.695	23.0	5.520	42.4
2005-2006	1	3.5	0.895	1.8	0.765	14.451	2.026	0.541	1.0	0.488	9.0
2005-2006	2	2.7	0.990	0.9	0.479	17.682	1.500	0.611	0.6	0.301	11.2
2005-2006	3	1.1	0.348	0.6	0.469	4.718	0.223	0.026	0.2	0.030	0.4
2005-2006	4	54.6	4.855	49.5	27.240	97.525	28.823	3.366	26.2	17.792	71.8
2005-2006	5	2.1	0.282	1.8	0.818	3.915	1.831	0.261	1.7	0.210	3.3

APPENDIX E

Total storm loads for Site 1.

Date	Total TSS Storm Load (kg)	Volatile TSS Storm Load (kg)	Nonvolatile TSS Storm Load (kg)	Dissolved Organic Carbon Storm Load (kg)	Ammonium Storm Load (kg)	Nitrate Storm Load (kg)	Total Phosphorus Storm Load (kg)	Total Nitrogen (kg)	Phosphate Storm Load (kg)	Ammonia Storm Load (kg)
12/8/04	1,291.3	671.1	620.2	645.2	7.8	163.8	86.4	296.6	63.0	
12/27/04	9,348.1	2,312.5	7,035.7	1,502.6	15.7	371.9	171.4	678.3	132.8	0.058
12/31/04	3,662.4	858.2	2,804.2	1,096.8	5.2	290.3	88.6	482.3	71.7	0.024
1/2/05	2,896.9	746.7	2,150.2	1,546.8	4.9	399.7	120.4	677.4	90.7	0.022
1/3/05	1,876.9	496.1	1,380.8	1,197.2	4.3	283.0	88.2	452.6	68.4	0.024
1/8/05	7,631.0	1,970.3	5,660.7	1,866.6	11.0	401.4	143.5	510.3	111.3	0.029
1/11/05	5,509.1	1,504.4	4,004.8	845.5	2.9	184.8	82.9	245.6	65.1	0.009
1/12/05	9,855.7	2,347.5	7,508.2	2,045.6	8.9	388.5	150.7	431.6	121.2	0.027
2/16/05	419.6	263.2	156.4	384.7	9.8	136.1	18.0	161.2	14.2	0.044
2/19/05	6,854.3	2,009.0	4,845.3	1,214.7	1.1	156.8	116.5	443.6	78.1	0.004
2/21/05	2,472.0	679.6	1,792.3	1,074.1	1.1	93.2	58.2	249.9	50.7	0.008
5/8/05	1,006.9	468.9	537.9	721.2	2.3	93.8	64.7	228.3	41.2	0.008
11/9/05	1.1	0.5	0.6	2.2	0.002	0.7	0.2	0.9	0.2	0.00001
12/1/05	5,391.1	2,199.6	3,191.5	284.3	29.5	64.6	97.7	260.9	62.7	0.068

Date	Total TSS Storm Load (kg)	Volatile TSS Storm Load (kg)	Nonvolatile TSS Storm Load (kg)	Dissolved Organic Carbon Storm Load (kg)	Ammonium Storm Load (kg)	Nitrate Storm Load (kg)	Total Phosphorus Storm Load (kg)	Total Nitrogen (kg)	Phosphate Storm Load (kg)	Ammonia Storm Load (kg)
12/18/05	64,682.8	14,212.8	50,469.7	2,087.8	16.5	465.7	409.7	1,293.7	167.3	0.027

Total storm loads for Site 2.

Date	Total TSS Storm Load (kg)	Volatile TSS Storm Load (kg)	Nonvolatile TSS Storm Load (kg)	Dissolved Organic Carbon Storm Load (kg)	Ammonium Storm Load (kg)	Nitrate Storm Load (kg)	Total Phosphorus Storm Load (kg)	Total Nitrogen (kg)	Phosphate Storm Load (kg)	Ammonia Storm Load (kg)
12/8/04	3,118.5	1,443.9	1,674.7	1,199.4	55.6	231.5	151.9	465.2	106.7	
12/27/04	4,410.9	1,215.5	3,195.4	905.4	12.8	193.6	109.8	367.5	78.2	
12/31/04	3,910.7	872.3	3,038.5	1,097.3	8.7	262.2	75.3	477.4	56.4	
1/2/05	1,780.2	438.0	1,342.2	836.0	2.3	201.0	66.9	339.1	41.2	
1/3/05	1,502.8	398.0	1,104.8	906.6	3.9	223.9	58.2	354.0	50.1	
1/8/05	8,311.9	2,149.5	6,162.4	1,770.2	7.1	398.6	137.1	511.2	111.8	
1/11/05	4,120.2	1,295.4	2,824.8	751.0	3.1	163.4	72.1	228.8	56.5	
1/12/05	7,949.4	1,881.0	6,068.4	1,454.9	6.7	276.4	105.1	385.9	81.2	
2/16/05	262.8	163.1	99.8	362.2	0.5	63.8	14.4	113.2	10.9	0.003
2/19/05	5,131.7	1,450.6	3,681.1	994.5	0.9	110.1	74.3	331.8	55.3	0.004
2/21/05	2,688.7	641.9	2,046.8	837.4	0.9	82.0	33.9	147.5	36.9	0.007
5/8/05	493.9	235.1	258.8	375.0	1.2	59.6	30.7	126.1	20.0	0.016
11/9/05	94.3	59.6	34.7	280.1	0.2	17.5	19.3	45.3	13.5	0.001
12/1/05	9,914.7	3,188.2	6,726.5	435.3	66.7	61.4	153.5	370.2	97.5	0.182
12/18/05	39,555.7	9,363.6	30,192.0	3,113.0	36.4	395.5	410.0	1,201.2	149.7	0.045

Date	Total TSS Storm Load (kg)	Volatile TSS Storm Load (kg)	Nonvolatile TSS Storm Load (kg)	Dissolved Organic Carbon Storm Load (kg)	Ammonium Storm Load (kg)	Nitrate Storm Load (kg)	Total Phosphorus Storm Load (kg)	Total Nitrogen (kg)	Phosphate Storm Load (kg)	Ammonia Storm Load (kg)

Total storm loads for Site 3.

Date	Total TSS Storm Load (kg)	Volatile TSS Storm Load (kg)	Nonvolatile TSS Storm Load (kg)	Dissolved Organic Carbon Storm Load (kg)	Ammonium Storm Load (kg)	Nitrate Storm Load (kg)	Total Phosphorus Storm Load (kg)	Total Nitrogen (kg)	Phosphate Storm Load (kg)	Ammonia Storm Load (kg)
12/8/04	430.9	82.2	348.7	14.5	0.1	4.2	1.9	5.7	0.3	
12/27/04	1,321.4	193.1	1,128.3	67.4	0.7	19.8	4.8	33.2	3.5	
12/31/04	948.9	119.7	829.2	58.7	0.4	17.0	4.0	28.2	1.3	
1/2/05	683.5	115.1	568.5	133.7	1.1	38.9	6.7	58.8	2.7	
1/3/05	607.3	78.2	529.0	65.8	0.5	17.4	3.2	28.4	1.3	
1/8/05	1,796.3	243.9	1,552.4	96.9	0.9	24.2	5.3	23.4	1.8	0.0022
1/11/05	3,335.2	485.4	2,849.8	113.1	0.7	32.3	7.2	33.7	2.5	0.0021
2/16/05	52.5	12.4	40.1	10.2	0.04	1.3	0.3	2.3	0.1	0.0003
2/19/05	1,650.2	251.5	1,398.7	68.2	0.1	10.1	5.2	26.3	1.2	0.0003
2/21/05	539.6	72.2	467.4	37.6	0.05	5.6	1.2	11.2	0.7	0.0003
5/8/05	140.6	31.3	109.3	23.7	0.1	0.6	0.9	4.2	0.3	0.0011
11/9/05	21.6	11.4	10.2	19.8	0.007	1.9	1.1	3.9	0.5	0.00004
12/1/05	2,723.9	478.2	2,245.7	79.5	0.03	24.1	8.4	40.6	1.0	0.00005

Total storm loads for Site 4.

Date	Total TSS Storm Load (kg)	Volatile TSS Storm Load (kg)	Nonvolatile TSS Storm Load (kg)	Dissolved Organic Carbon Storm Load (kg)	Ammonium Storm Load (kg)	Nitrate Storm Load (kg)	Total Phosphorus Storm Load (kg)	Total Nitrogen (kg)	Phosphate Storm Load (kg)	Ammonia Storm Load (kg)
12/8/04	161.3	64.3	97.0	6.0	0.6	0.9	2.3	4.5	1.0	
12/27/04	25.3	13.5	11.8	1.0	0.1	0.2	0.2	0.9	0.2	
12/31/04	28.4	15.9	14.2	2.2	1.8	1.8	1.9	2.4	1.8	
1/8/05	118.6	51.1	80.4	15.5	13.2	13.0	13.4	14.6	13.2	
1/11/05	262.3	89.7	172.7	7.5	0.8	0.8	1.4	5.1	0.9	
2/19/05	813.0	238.3	590.4	26.5	17.1	16.6	18.8	26.5	17.0	15.710
2/21/05	54.8	35.6	40.9	23.1	21.9	21.8	22.1	22.8	22.0	21.803
5/8/05	38.8	25.5	24.4	12.9	11.4	11.2	11.4	12.7	11.2	11.102
12/1/05	121.5	42.6	78.9	8.5	0.5	0.007	1.5	2.4	1.0	0.004
12/18/05	266.5	112.2	154.3	6.0	1.6	0.008	2.6	5.4	1.1	0.006

Total storm loads for Site 5.

Date	Total TSS Storm Load (kg)	Volatile TSS Storm Load (kg)	Nonvolatile TSS Storm Load (kg)	Dissolved Organic Carbon Storm Load (kg)	Ammonium Storm Load (kg)	Nitrate Storm Load (kg)	Total Phosphorus Storm Load (kg)	Total Nitrogen (kg)	Phosphate Storm Load (kg)	Ammonia Storm Load (kg)
12/3/05	70,523.7	22,198.0	48,325.8	27,014.3	25.8	6,380.1	3,093.3	10,394.8	2,302.3	0.044
12/18/05	208,402.7	44,433.1	163,969.6	33,518.1	36.5	8,230.3	3,115.7	12,409.8	2,948.0	0.058

United States
Department of
Agriculture

Agriculture
Research
Service

Stemple Creek Watershed CEAP Special Emphasis Project Final Report (Draft)

Prepared For:
USDA-NRCS
Prepared By:
MODELING PROJECT TEAM

Author
Dr. Ronald L. Bingner, Agricultural Research Service

Watershed Physical Processes Research Unit
National Sedimentation Laboratory
Oxford, Mississippi 38655

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF ACRONYMS

Acronym	Description
AGNPS	Agricultural Non-Point Source Pollution Model, a suite of computer models used for watershed-scale best management practice analyses.
AnnAGNPS	Annualized Agricultural Non-Point Source Pollution Model, a computer program used to determine pollutant yields and loadings anywhere in the watershed.
ArcView	Proprietary, commercially available GIS software.
ARS	Agricultural Research Service
BMPs	Best Management Practices
CCHE1D	National Center for Computational Hydroscience Engineering 1-Dimensional Model
CEAP	Conservation Effects Assessment Program
CONCEPTS	Conservational Channel Evaluation and Pollutant Transport System Model
CRP	Conservation Reserve Program
CSV Files	Standardized comma separated variable files
DEM	Digital Elevation Model
DLG	Digital Line Graph
EQIP	Environmental Quality Incentive Program
GEM	Generation of Weather Elements for Multiple Applications Computer Model
GIS	Geographic Information System
LULC	Land Use/Land Cover
NASIS	National Soil Information System
NRCS	Natural Resources Conservation Service
PC	Personal Computer
POW	Plan of Work
RAM	Computer random access memory
REMM	Riparian Ecosystem Management Model
RUSLE	Revised Universal Soil Loss Equation
SIDO	Sediment Intrusion and Dissolved Oxygen Model
SNTEMP	Stream Network Water Temperature Model
SSURGO	Soil Survey Geographic Database
TMDLs	Total Maximum Daily Loads
TOPAGNPS	A computer model which is a subset of TOPAZ written for AGNPS.
TOPAZ	Topographic Parameterization Computer Model
USDA	U. S. Department of Agriculture
USGS	U. S. Geologic Survey

Executive Summary

The Stemple Creek Watershed agricultural non-point source modeling project was a CEAP Special Emphasis project effort to use a USDA technology-based modeling approach for assessing and reducing pollution from agricultural runoff and other non-point sources. This project applied the U.S. Department of Agriculture (USDA), Agricultural Research Service's AGricultural Non-Point Source (AGNPS) suite of models to the Stemple Creek Watershed, a major watershed to Bodega Bay along the California coast. This modeling project was conducted by an interagency team consisting of a partnership between the USDA, Agricultural Research Service (ARS) and the USDA, Natural Resources Conservation Service (NRCS). This work was performed under the larger scheme of CEAP Special Emphasis watersheds located throughout the U.S. for the purpose of assisting State and local watershed managers with their evaluation, assessment, prioritization and implementation of alternatives for soil conservation, sediment trapping and non-point source pollution prevention throughout the U.S.

The project team, working in a cooperative effort, applied the models to determine sediment and nutrient sources, contributing locations, and the effect of application of alternative management practices on rates of sediment and nutrient delivery to the mouth of the watershed. The results will be used to guide conservation incentive and land treatment programs. The team relied heavily on Geographic Information System (GIS)-based applications to expedite the application of the model.

The results of the analysis demonstrated that the application of various rangeland and pasture management practices by themselves would not have much of an effect on reducing the loadings of leaving the mouth of Stemple Creek Watershed unless reductions are implemented to the application of manure throughout the watershed. Reduction of manure applications throughout the watershed can result in a 85% reduction of sediment and nutrients that arrive at the mouth of the watershed.

A significant source of sediment and nutrients occurs in the steep terrains near the downstream portion of the watershed. Reductions in manure applications and soil disturbance activities would result in significant reductions in loadings that arrive at the watershed outlet.

The application of riparian vegetation and sediment traps would reduce the delivery of all types of landscape erosion and nutrients without as much disruption to the existing management throughout the watershed.

STEMPLE CREEK PROJECT REPORT

INTRODUCTION

Overview

The Stemple Creek watershed is a sub-watershed of the Bodega Bay watershed, HUC-18010111, in Marin and Sonoma Counties, California (Figure I-1). It lies approximately 40 miles northwest of San Francisco. Nearby cities include Petaluma, Cotati, and Rohnert Park, all within 5 miles of the eastern end of the watershed, and Santa Rosa, about 10 miles north. The watershed's area is about 32,980 acres, or 51.5 square miles. Its east-west length is about 14 miles and its north-south dimension ranges from 3 to 6 miles. State Highway 1 crosses the watershed about 4 miles east of its outlet.

Stemple Creek flows westward through the watershed to its estuary, the Estero de San Antonio. The Estero empties into Bodega Bay, a broad indentation in the Pacific Coast. The Estero is an important coastal resource and is included in the Gulf of the Farallones National Marine Sanctuary. The watershed is characterized by rolling coastal hills, most with slopes of 30 percent or less (Figure I-2). Slopes are generally steeper in the western part of the watershed. The hills flanking the creek's valley on the north and south are higher than those across its eastern end. Elevations range from sea level at the mouth of the Estero, to about 300 feet at the eastern end of the watershed, 700 feet along the northern boundary, and 850 feet along the southern boundary.

NRCS approved 30 EQIP contracts on land within the watershed during the five-year period from 1997 to 2003. The total NRCS cost was $603,514. During approximately the same time period, the Marin and Sonoma County Resource Conservation Districts expended almost $1 million on education outreach and implementation of riparian buffers and water quality BMPs. The recommended plan proposed in Section 6 of the PL 83-566 report includes an estimated $4,890,000 in financial assistance.

The creek has been plagued with water quality issues for many years, particularly high levels of ammonia, low dissolved oxygen, and sediment. The 2002 California 303 (d) listing of impaired water bodies mentions nutrients and sediment as the pollutants of concern. Some of the causes listed as potential sources for these concerns include: agriculture, grazing, irrigated crop production, intensive animal feeding operations, agricultural storm runoff, among others. Local dairy operators are willing to help resolve the problems but would like to know that they are investing in the most cost-effective and efficient practices. The lack of acreage for disposal along with steep slopes can make nutrient management difficult at times.

A sediment TMDL focused primarily on sediment detracts from the existing poor water quality and stream habitat. The TMDL target levels for water quality parameters also include targets for un-ionized ammonia, dissolved oxygen, and temperature. Surprisingly, the "Fresh Water Shrimp – Syncaris pacifica," thrives in an area listed as water quality impaired. Although the causes of soil erosion and the methods of control are well known at the farm field scale, less is known about the transport of eroded soil and sediment through the stream system at the watershed scale. The project team applied the U.S. Department of Agriculture (USDA), Agricultural Research Service's (ARS) AGricultural Non-Point Source pollution model (AGNPS) to measure erosion, sediment delivery pathways, sediment delivery yields and loads, and nutrients; and to develop effective conservation treatment strategies and best management practices (BMPs) for the watershed. The application of AGNPS will fill gaps in the current scientific knowledge base.

Figure 0-1: Location of Stemple Creek watershed.

Figure 0-2: Landscape along Stemple Creek.

Why Stemple Creek Watershed Was Selected

The nationwide CEAP Special Emphasis Watershed project requires that a watershed contain mainly dryland agricultural operations for assessment. A western watershed was desired to provide conditions that are unique to west coast climatic, soils, and management issues. The Stemple Creek watershed afforded a unique opportunity for this since most agricultural areas in California are under irrigated conditions. There was significant data concerning this watershed already available and in place, including previous modeling work done in the watershed, available soils data, and other needed information. The agency infrastructure was in place to provide the technical expertise, data, and staff resources needed to undertake this project.

Previous Studies

The North Coast Regional Quality Control Board conducted periodic water quality sampling from 1990-1994 for the purpose of assessing conditions and trends. Data consists of field measurements for dissolved oxygen, pH, specific conductance, water temperature, and stream flow. Laboratory analyses were made for $NO_{3,}$ $NO_{2,}$ NH_3-N, TKN, $OPO_{4,}$ $TPO_{4,}$ temperature, $DO_{2,}$ pH, SC, BOD, and COD. The site locations for this data will be considered in developing the Water Quality Monitoring Plan. The 1990-1994 Data will be discussed with Data from the proposed study.

A historical sediment flood plain study and coarse grained sediment modeling study has been completed. The titles of the reports are: Omission of Residuals and Physical Constraints In Developing Sediment TMDLS – Case History, Stemple Creek Watershed, CA; Sediment Deposition in the Floodplain of Stemple Creek Watershed, Northern California; and AGNPS

Modeling of the Stemple Creek Watershed. Dr. Jerry Ritchie, ARS, Beltsville, MD, and Dr. Joan Florsheim, UC Davis, are exploring a joint study of depositional surfaces in the Stemple Creek flood plain.

The AGNPS model was used to calculate sediment yield throughout the watershed and to determine the likely source of coarse grained sediments infilling the Estero de San Antonio. The results of the AGNPS model runs suggest that past land use practices caused observed filling of the Estero de San Antonio. Sediment deposition on the flood plain is diminishing. This reduction in flood plain deposition may be due to BMPs, changed land use, channel entrenchment or all three. Proposed sediment monitoring should clarify the cause effect relationships. The 1992 SCS Erosion and Sediment Study provides a pre-treatment estimate of erosion sources and sedimentation rates. A Geomorphic and Hydrodynamic Analysis for the Estero de San Antonio prepared by Philip Williams and Associates for the Marin RCD, 1993, provides an analysis of the historic rates of sedimentation in the lagoon and lagoon hydrodynamics.

Monitoring and Other Available Information

A modeling project of this scope cannot take place in a vacuum. Many kinds of data are needed as input to different layers of the Geographic Information System (GIS) database used to populate the model. These data include land surface topography, stream network, weather and climate information, soils data, and land use information. Many of these kinds of data must be spatially defined across the study area, and in sufficient detail to permit the model to accurately reflect the real landscape it represents. Some data, such as soils information, are relatively static through time. Other data are temporally dynamic, changing annually (crops) or even daily (weather, soil moisture, and tillage operations).

This project was fortunate to have access to a database of information from which the needed information layers could be drawn or developed. Table I-1 summarizes these information types and their sources.

Table 0-1: Data for model development

Information Type	Source	Scale/Spatial Resolution	Temporal Resolution	Comments
Surface topography	DEM computed from USGS DLG	10 m	invariant	
Model cell boundaries	computed from DEM	variable; divides watershed into 753 cells averaging 44 acres	invariant	
Drainage network	computed from DEM	i	nvariant	
Drainage network	USGS DRGs		invariant	used for comparison with computed drainage network
Soils SSUR	GO	1:12,000 resolution	invariant	integrated for the project by NRCS
Soil attributes	NRCS-NASIS		N/A	Enhanced to provide missing data items
Land use	NRCS-CA			Image digitized at USDA-ARS-NSL
Climate (historical)	NOAA Precip	itation and temperature from Petaluma, CA	Daily, 1949-1990	
Climate (synthetic)	ARS synthetic weather generator	Populated missing data	daily	
Potential gross erosion	RUSLE	N/A	invariant	Developed common mgt systems date (crop rotations, tillage practices, and operation dates) for sheet and rill erosion calculations within model

AGNPS MODEL—BRIEF OVERVIEW

AGNPS is a joint ARS and NRCS suite of computer models developed to predict nonpoint source pollutant loadings within agricultural watersheds. It includes a continuous-simulation, surface-runoff computer model called Annualized AGricultural Non-Point Source Pollution Model v4.0 (AnnAGNPS). AnnAGNPS is designed to assist with determining BMPs, the setting of Total Maximum Daily Loads (TMDLs), and for risk and cost/benefit analyses. The set of computer programs consist of: (1) input generation and editing as well as associated databases; (2) the "annualized" science and technology pollutant loading model for agricultural-related watersheds (AnnAGNPS); (3) output reformatting and analysis; and (4) the integration of more comprehensive routines—National Center for Computational Hydroscience Engineering 1-Dimensional (CCHE1D) for the stream network processes; (5) a stream corridor CONservational Channel Evaluation and Pollutant Transport System model (CONCEPTS); (7) an instream water temperature model, Stream Network Water TEMPerature Model (SNTEMP); and (8) several related salmonid models (Sediment Intrusion and Dissolved Oxygen (SIDO), Fry Emergence, Salmonid Total Life Stage, and Salmonid Economics). Not all of the models are electronically linked but there are paths of common input/output that, with the use of standard text editors, can be linked.

Figure 0-1 is a system diagram for the suite of AGNPS computer models.

The input programs include: (1) a GIS-assisted computer program (TOpographic PArameteriZation (TOPAZ) with an interface to AGNPS) to develop terrain-following cells with all the needed hydrologic and hydraulic parameters that can be calculated from readily available DEM's; (2) an input editor to initialize, complete, and/or revise the input data; and (3) an AGNPS-to-AnnAGNPS converter for the input data sets of the old single-event versions of AGNPS (4.03 and 5.00).

AnnAGNPS includes up-to-date technology–e.g., Revised Universal Soil Loss Equation (RUSLE) and pesticides–as well as the daily features necessary for continuous simulation in a watershed. Additional features of AnnAGNPS include:

1. The capability to produce output related to soluble and attached nutrients (nitrogen, phosphorus, and organic carbon) and any number of pesticides.
2. Water and sediment erosion, yield, and load by particle size class and source are calculated and determined to any point in the watershed channel system.
3. A field pond water and sediment loading routine is included for rice/crawfish ponds that can be rotated with other land uses.
4. Nutrient concentrations from feedlots and other point sources are modeled. Individual feedlot potential ratings can also be derived using the model.
5. The applications of CCHE1D for stream networks and CONCEPTS for stream corridors include more detailed science for the channel hydraulics, morphology, and transport of sediments and contaminants.

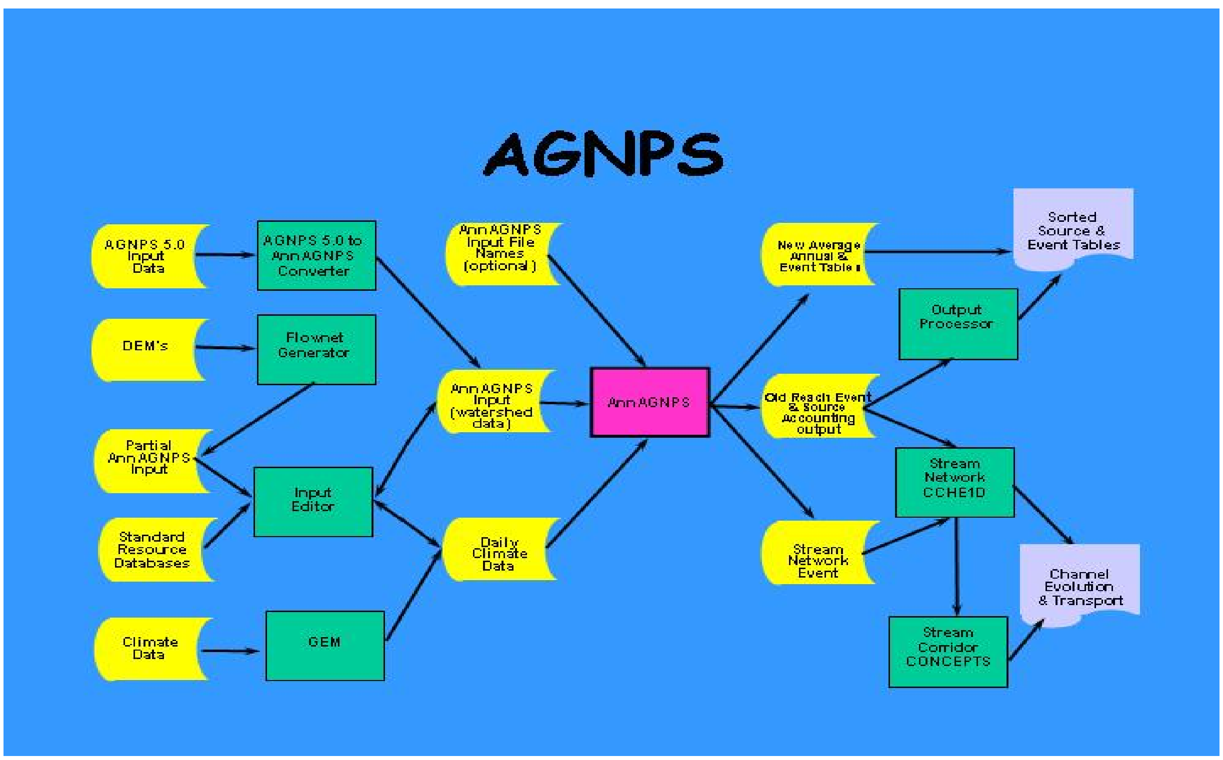


Figure 0-1: AGNPS system diagram.

How to use the AGNPS Model

The AGNPS watershed simulation model (Bingner and Theurer, 2001a) has been developed as a tool for use in evaluating the pollutant loadings within a watershed and the impact farming and other activities have on pollution control. Various modeling components have been integrated within AGNPS to form a suite of modules. Each module provides information needed by other modules to enhance the predictive capabilities. The modules include: (1) the pollutant loading module within AGNPS that is critical to the Stemple Creek Watershed analyses is AnnAGNPS Version 4.0 (Bingner and Theurer, 2001b) which is a watershed-scale, continuous-simulation, pollutant-loading computer model designed to quantify and identify the source of pollutant loadings anywhere in the watershed for optimization and risk analysis; (2) CONCEPTS (Langendoen, 2001), a set of stream network, corridor, and water quality computer models designed to predict and quantify the effects of bank erosion and failures, bank mass wasting, bed aggradation and degradation, burial and re-entrainment of contaminants, and streamside riparian vegetation on channel morphology and pollutant loadings; (3) SNTEMP (Theurer et al, 1984), a watershed-scale, stream network, water temperature computer model to predict daily average, minimum, and maximum water temperatures; (4) SIDO (Alonso et al, 1996), a set of salmonid life-cycle models designed specifically to quantify the impact of pollutant loadings on their spawning and rearing habitats as well as include other important life-threatening obstacles; and (5) an economic model that determines the net economic value of Pacific Northwest salmonids restored to either the commercial or recreational catch (see AGNPS web site).

AnnAGNPS is an advanced technological watershed evaluation tool, which has been developed through a partnering project with the ARS and NRCS to aid in the evaluation of watershed response to agricultural management practices. Through continuous simulation of surface runoff, sediment, and chemical non-point source pollutant loading from watersheds, the impact of BMPs on TMDLs can be evaluated for risk and cost/benefit analyses.

AnnAGNPS is a continuous simulation, daily time-step, pollutant-loading model and includes significantly more advanced features than the single-event AGNPS 5.0 (Young *et al.*, 1989). Daily climate information is needed to account for temporal variation in the weather. Spatial variability within a watershed of soils, land use, and topography, is accounted for by dividing the watershed into many homogeneous drainage areas. These simulated drainage areas are then integrated together by simulated rivers and streams, which route the runoff and pollutants from each individual homogeneous area to downstream. From individual fields, runoff can be produced from precipitation events that include rainfall, snowmelt, and irrigation. A daily soil water balance is maintained that recognizes tile drains when present, so direct runoff that includes both surface and subsurface flow, can be determined when a precipitation event occurs. Sheet and rill erosion from each field is predicted based on the RUSLE (Renard *et al.*, 1997). The model can be used to examine the effects of implementing various conservation alternatives within a watershed such as alternative cropping and tillage systems including the effects of fertilizer, pesticide, irrigation application rate as well as point source yields and feedlot management (Bosch *et al.*, 1998).

Inputs

As part of the input data preparation process there are a number of component modules that support the user in developing the needed AnnAGNPS databases. These include: (1) TOPAZ (Garbrecht and Martz, 1995), to generate cell and stream network information from a watershed DEM and provide all of the topographic related information for AnnAGNPS. A subset of TOPAZ, TOPAGNPS, is the set of TOPAZ modules used within AGNPS. The use of the

TOPAGNPS generated stream network is also incorporated by CONCEPTS to provide the link to where upland sources are entering the channel and then routed downstream; (2) The AGricultural watershed FLOWnet generation program (AGFLOW) (Bingner et al., 1997; Bingner and Theurer, 2001c) is used to determine the topographic-related input parameters for AnnAGNPS and to format the TOPAGNPS output for importation into the form needed by AnnAGNPS; (3) The Generation of Weather Elements for Multiple applications (GEM) program (Johnson et al., 2000) is used to generate the climate information for AnnAGNPS; (4) The program "Complete Climate" takes the information from GEM and formats the data for use by AnnAGNPS, along with determining a few additional parameters; (5) A graphical input editor that assists the user in developing the AnnAGNPS database (Bingner et al., 1998); (6) A visual interface program to view the TOPAGNPS related geographical information system (GIS) data (Bingner et al., 1996); (7) A conversion program that transforms a single event AGNPS 5.0 dataset into what is needed to perform a single event simulation with AnnAGNPS and, (8) An ArcView program to facilitate the use of Items 1-7. There is an output processor that can be used to help analyze the results from AnnAGNPS by generating a summary of the results in tabular or GIS format. Additional information on AGNPS can be obtained at the WEB site: http://www.ars.usda.gov/Research/docs.htm?docid=5199

Outputs and Products

Simulation results can be produced in several formats as needed. These formats can be used to summarize the results from a single event or on an average annual basis. Results can be targeted for reports at the outlet or any other location in the watershed, including the channel reaches or AnnAGNPS cells. Information describing the event as well as average annual runoff, peak discharge, erosion, or sediment by particle size and chemical loadings can be produced. Average annual results can also be displayed as part of an ArcView shape file to view the spatial distribution of the results by AnnAGNPS cell.

Why AGNPS Was Selected

The selection of AGNPS for the project was based on the capability of the watershed approach to assess the impact of conservation planning to reduce sediment and nutrient loadings to the outlet of Stemple Creek. The model incorporates the most current methodologies used by NRCS such as the Revised Universal Soil Loss Equation (RUSLE) (Renard et al, 1997) and Soil Conservation Service (SCS, now NRCS) hydrologic procedures (SCS, 1986). In addition, AnnAGNPS provides the ability to aid in the identification and evaluation of sources of water, sediment and nutrient production within the watershed, as well as several other CEAP Special Emphasis watersheds. The main effects of all the critical processes within the watershed are included as part of AnnAGNPS, some of which are unique.

In 1993, NRCS completed a study of thirty-eight available water quality models then available (Theurer & Comer, 1992a). Four were chosen for further analyses—two were field-scale models and two were watershed-scale. All four were developed for agricultural non-point pollution applications. Detailed reviews were made of the two watershed-scale models: AGNPS (precursor to AnnAGNPS) and SWRRWQ (precursor to SWAT), and reports were prepared documenting the reviews (Theurer & Comer, 1992b; Theurer & Comer, 1993). AGNPS was selected for further SCS/NRCS support and development because it contained NRCS-approved science for the watershed-scale applications (up to 1,000 sq. mi.). It was, and still is, the only watershed model that starts with USLE/RUSLE erosion in the field and accumulates water, sediment, and chemicals as yield and loading. SWRRBWQ was not selected because it contains technology that is not suitable for alternative analyses at the watershed scale. The most serious deficiency with SWRRBWQ (and with SWAT) is that the sediment predictions do not make a distinction between sediment originating over the landscape (sheet & rill and ephemeral gully erosion - frequently referred to as “wash load”) and sediment originating within the stream system (bed & bank material load). This may result in attributing all of the sediment production to the USLE parameters which are only related to sheet & rill erosion.

PROJECT DESCRIPTION

Work Plan

A planning meeting was held in Petaluma, California on November 30, 2004 with NRCS to tour the watershed and complete the plan of work (POW) for the project. This plan of work encompassed the entire effort associated with collecting information concerning the watershed and the associated databases needed to evaluate the impact of these and alternative measures using AnnAGNPS.

Soils—Digital Soils Maps and Soil Data Bases

Soils data development consisted of two main tasks. First the spatial layer was developed from digital data that was available through the NRCS Soil Survey Geographic Database (SSURGO) program (Figure III-1). Both Marin and Sonama counties in the project watershed had SSURGO data available for use in this project. The two counties were spatially merged together. Secondly, soil attributes were incorporated and reformatted to fit the requirements of AnnAGNPS. Soil data from the National Soil Information System (NASIS) were downloaded for the counties encompassed by the watershed. Attributes for these selected representative map units were then edited for completeness for use with AnnAGNPS. Some data attributes were not populated in NASIS and needed to be developed for use with the model. These included soil structure and sum of bases. A protocol was developed to populate this data. Some data including albedo, silt, sand, very fine sand, and wilting point were incomplete and needed to be populated using calculations and other methods.

AnnAGNPS uses the soils layer as input to the Arcview interface to determine a dominant soil for each cell of the watershed. A plot of the dominant soils selected for each AnnAGNPS cell is included in Figure III-2.

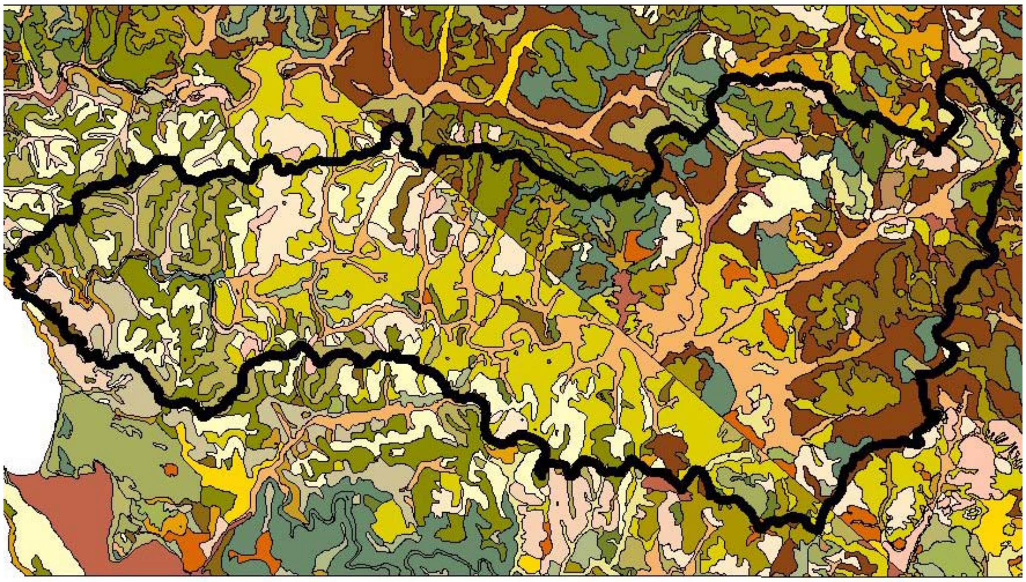


Figure 0-1: Original soil layers in the Stemple Creek watershed.

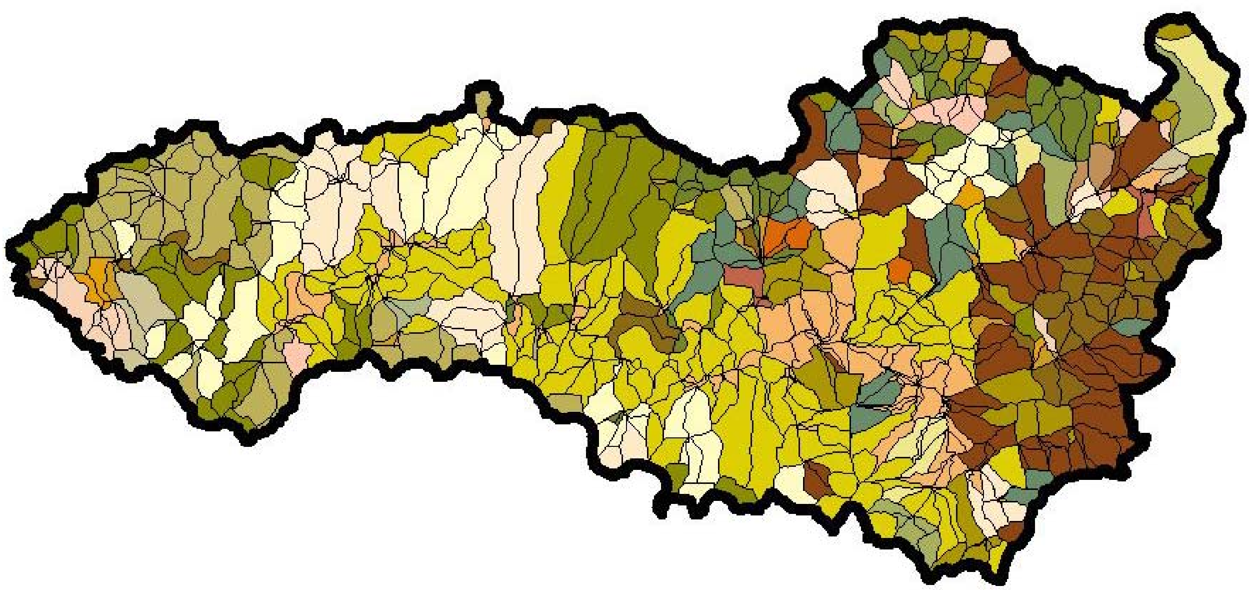


Figure 0-2: Dominant soil layers assigned to the AnnAGNPS cells in the Stemple Creek watershed.

DEM Generation

An accurate DEM is critical for successful execution of the AnnAGNPS model. The 10-meter DEM available through the USGS, with some areas erroneously containing holes that need to be filled while other areas produce no slope whatsoever making determination of water flow direction impossible in AnnAGNPS.

To address these problems, the TOPAGNPS was used. However there were locations where water flow did not match the hydrological layer from the USGS 1:24,000 DLG. In the cases where the stream channels generated from the 10-meter DEM did not match the USGS hydrological layer stream channels, the USGS stream channels were assumed to be correct, and were "burned" into the DEM. This was done by lowering the DEM in the area of the USGS stream thus altering the DEM slope so that water would not erroneously flow into or out of the watershed (Figure III -3). In addition, portions of the DEM were modified along the known watershed boundary to provide an accurate reflection from the actual boundary in the generated watershed boundary (Figure III-4). One of the critical components determined through TOPAGNPS is the associated RUSLE LS-Factor attributed to each AnnAGNPS cell. In steeply-sloped terrain, the LS-factor is one of the most significant parameters to consider in erosion estimates. For Stemple Creek, the LS-Factor are noticeably high along the ridges (Figure III-5), but especially high in the Northeast and near the watershed outlet, and low along the Stemple Creek floodplain.

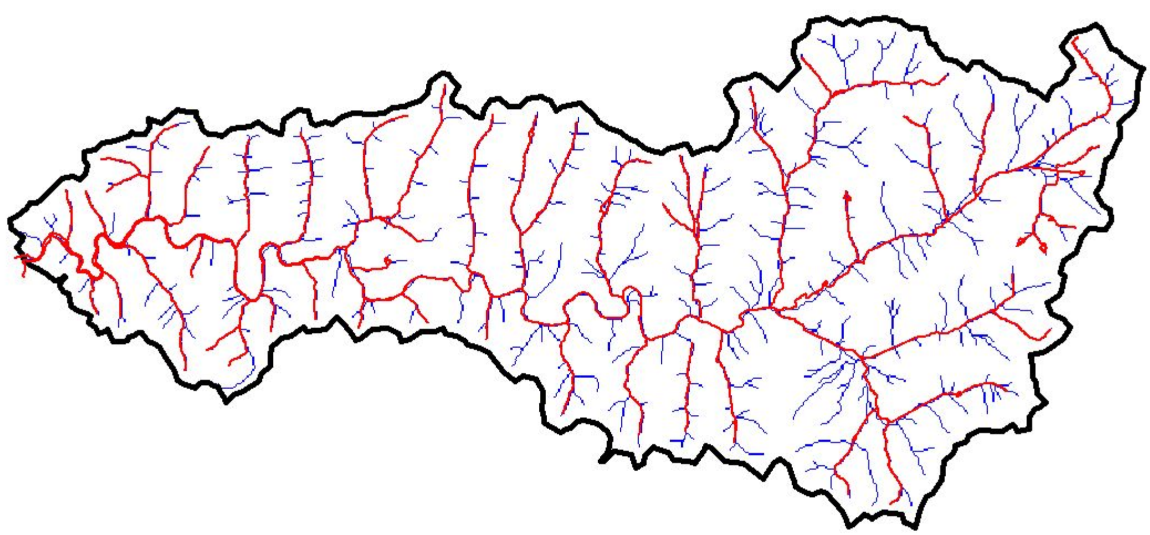


Figure 0-3: Digitized (red) and generated (blue) stream network.

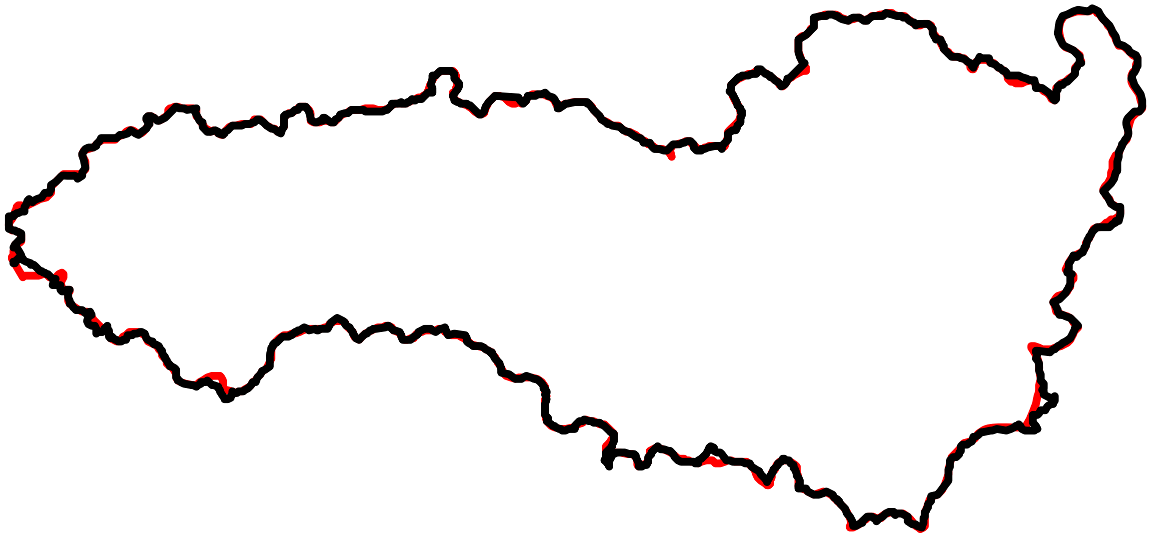


Figure 0-4: Digitized (black) and generated (red) watershed boundary.

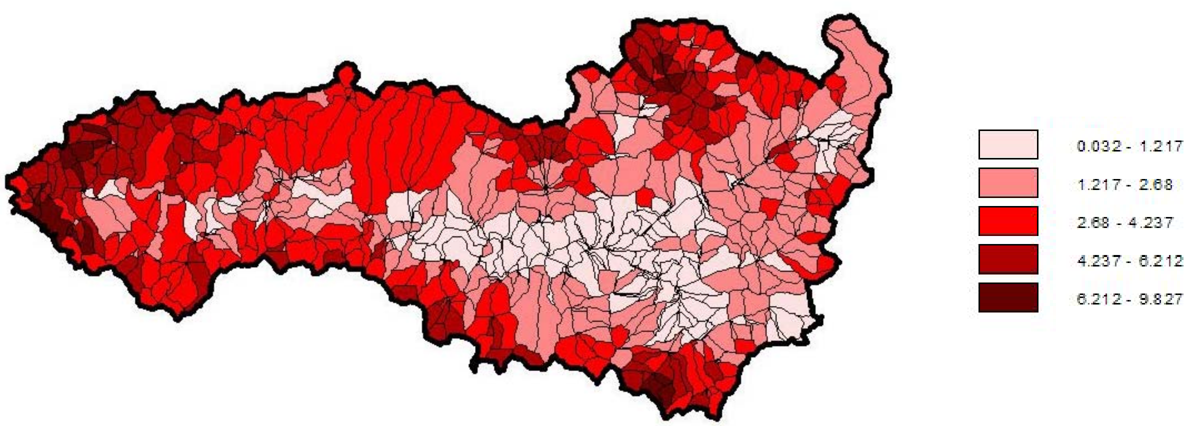


Figure 0-5: RUSLE LS-Factor determined from TOPAGNPS and utilization of the DEM.

Land Use/Land Cover Remote watershed Sensing and Digital Map Development

In the case of land use/land cover (LULC), information was obtained from NRCS and digitized (Figure III-6). Most of the watershed is characterized with the "Other" landuse, which generally describes native vegetation. The land use types were classified by digitizing the boundaries from existing maps. This became the final LULC layer that was automatically sampled by the GIS-AnnAGNPS interface to determine the dominant LULC for each AnnAGNPS cell Figure III-7).

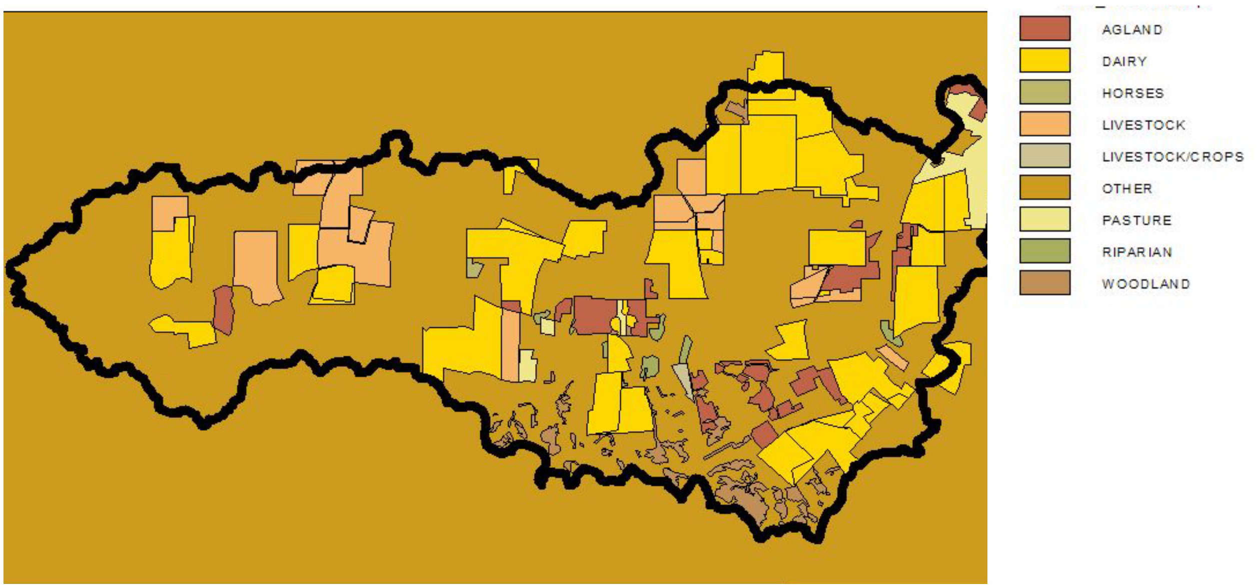


Figure 0-6: Land use/land cover map.

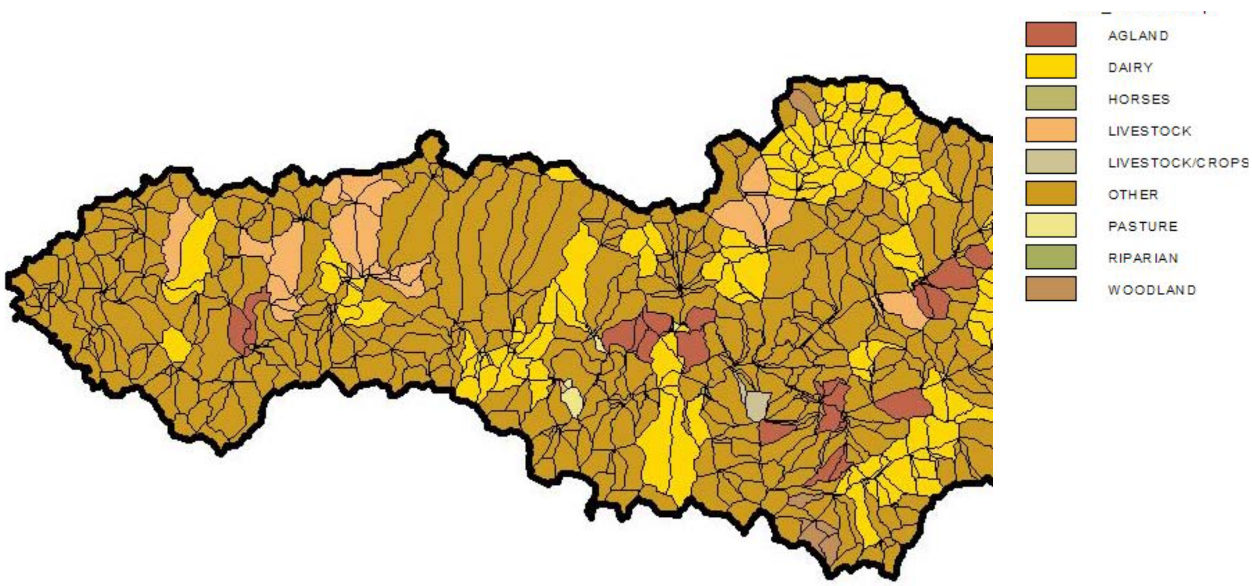


Figure 0-7: Assigned Land use/land to AnnAGNPS cells.

Attribute Data Bases—RUSLE

The RUSLE module of AnnAGNPS was used to assess and evaluate sheet and rill erosion in the Stemple Creek Watershed. RUSLE is an erosion prediction model that enables conservation planners to predict the long-term average annual rate of inter-rill (sheet) and rill erosion on a landscape based on the factor values assigned by the planner. The factors represent the effect of climate, soil, topography, and land use on inter-rill (sheet) and rill erosion. Erosion rates predicted by RUSLE can be used to guide conservation planning by evaluating the impact of present and/or planned land use and management on the scale of individual fields.

Soil loss computed by RUSLE is the rate of soil erosion from the landscape profile (defined by the slope length), not the amount of sediment leaving a field or watershed. The factors used in RUSLE are based on long-term averages.

To address the various management practices in the Stemple Creek Watershed, management databases were developed for use in the RUSLE/AnnAGNPS model from advice from NRCS and local producers. The management files describe the various rotations used in the watershed as well as the different events in each management. For example, the 'Agland' landuse contained a manure application on July 1, followed by moldboard plow and double disk two weeks later, oats were planted near October 1 with a double-disk drill and ring roller, and on May 1 of the following year the oats were harvested for silage. This rotation continued for the extent of the simulation. All pasture and other areas contained a manure application in mid-October followed by a spring tooth harrow operation and a month later a disking right before ryegrass was planted, and the ryegrass was harvested for hay near August 1 of the following year.

RUSLE is an effective tool to assist in the planning of conservation management systems that address soil erosion resource concerns and pollutants that may be associated with movement of soil. The impact of riparian buffers to filter pollutants could not be considered by RUSLE, but the application of the REMM model would provide insight on the use of this practice (Figure III-8).

Figure 0-8: Agricultural Field containing a riparian buffer.

Climate Data Considerations

Daily precipitation, maximum and minimum temperature, dew point temperature, sky cover, and wind speed data are required by the AnnAGNPS model to perform continuous simulations. Climate data used with AnnAGNPS can be historical, synthetically generated, or a combination of the two. Climate data was used using a combination of historical and synthetic data for this study due to the desire to compute sediment loads for a significant time periods.
Historical daily climate was available from Petaluma, California from 1949 to 1990, consisting of measured maximum and minimum temperature, and precipitation. The USDA's Generation of weather Elements for Multiple applications (GEM) model (Johnson et al, 2000) was used to generate dew point, cloud cover and wind speed as synthetic climate data to complete the needed parameters. This 42 year observed climate record from Petaluma provided the most critical parameters sensitive to AnnAGNPS. The generated parameters provide seasonal effects, but not as sensitive to AnnAGNPS. According to the documentation for the GEM model, "daily precipitation is described by a first-order Markov chain with precipitation amounts distributed as a mixed exponential distribution. In addition, data on daily maximum and minimum air temperatures, dew-point temperature, solar radiation and wind speed are simulated using a weekly stationary generating process that was first described by Matalas (1967) and adapted to daily weather by Richardson (1981)." Fourier series are used to describe the seasonal variations of parameters. GEM uses climate statistics derived from data collected at climate observation stations to determine selected statistical characteristics required to synthesize the climate data. Since the Petaluma, California climate station was not located within the watershed, the weather parameters were scaled to match the observed precipitation patterns reported in the watershed. The average annual precipitation at Petluma of 27.5 inches per year was scaled to match zones of 30 and 32.5 inches indicated within the watershed (Figure III-9).

Figure 0-9: Climatic Zones of 30 inches (brown) and 32.5 inches (yellow) within Stemple Creek watershed.

Full Watershed Model Runs

Using the digital data layers of soils, DEM, and land use described above, a majority of the large data input requirements of AnnAGNPS were developed by a customized interface developed in ArcView GIS. Additional steps to further provide the model with the necessary inputs included developing the soil layer attributes to supplement the soil spatial layer, the different crop operation and management data, ephemeral gully inputs, and climate data.

After all inputs were developed, a run was made to model the existing conditions of the watershed. This existing condition scenario modeled the existing landuse based on the 42 year climatic record. Following the successful completion of an existing condition run, various alternative runs were modeled for their effects on the erosion, sediment delivery, and nutrient production in the watershed. Descriptions and results of these alternative runs are given below. Alternatives to the existing landuse included: a good rangeland/pasture condition; a poor rangeland/pasture condition; the use of the existing conditions but no manure applications on rangeland; and the use of existing conditions, but cropland converted to pasture.

Riparian Buffer (REMM Module) Needs

The Riparian Ecosystem Management Model (REMM) (Lowrance et al., 2000; Altier et al., 2002) has been developed by USDA-ARS to simulate the water quality impacts of riparian buffer systems (RBS) and other edge of field buffer systems. REMM is a tool to assess the function of RBS to filter pollutants from a field. Inamdar et al. (1999a, 1999b) evaluated REMM capabilities for hydrologic performance as well as water quality and nutrient cycling at Gibbs Farm, near Tifton Georgia. Uncalibrated REMM hydrology simulation gave close agreement between average water table depths, water table pattern, surface runoff volumes, and patterns of surface runoff (Inamdar et al., 1999a). Inamdar et al. (1999b) concluded that REMM simulations generally represented these riparian buffer systems functions well.

The need to assess a riparian buffer system can be an important part of assessing the impact of conservation measures within the Stemple Creek Watershed project (Figure III-10). The current version of AnnAGNPS produces information in an output file that can be utilized as an input file directly within REMM to assess riparian buffer systems. This need was identified in the project plan and the AnnAGNPS developers proceeded to address the development of riparian buffer system capabilities into the model. Since REMM is a single field scale model, an individual output file is produced for each AnnAGNPS cell that utilizes REMM. Although, there is a need to develop a watershed version that captures the main effects of REMM directly within AnnAGNPS without the need to produce an external output file. Bringing the development of REMM technology within AnnAGNPS at the watershed scale to completion will require a further integration of edge of field buffer processes as they filter sediment and chemicals. This will require more time and resources to completely incorporate REMM technology into the watershed system approach used within AnnAGNPS.

Figure 0-10: Riparian buffer and grass filter strip system

RESULTS OF FULL WATERSHED MODEL RUNS

Simulation Outputs

The existing condition was simulated by using current landuse applied over 42 years of climate data. The existing condition simulation resulted in average annual erosion over the entire watershed of 1.76 tons per acre per year. Table 0-1 summarizes the results for this condition. Of the 58,690 t/yr of gross erosion in the watershed, the model indicates that only 19,208 t/yr, or 32.9%, is delivered to the watershed outlet. This watershed delivery ratio is determined by the fact that the vast majority of the eroded sediment is redeposited on a field scale and never makes it to a stream, and sediment is also lost to deposition within the stream transport system.

Table 0-1: Summary of existing condition simulation output

Item	Amount	Units
Watershed Average Runoff	8.69	in/yr
Watershed Average Total Rate of Erosion	1.76	t/ac/yr
Watershed Total Tons of Erosion	58,690	t/yr
Watershed Sediment Yield to Streams	1.30	t/ac/yr
Sediment Loading Rate to Watershed Outlet	0.58	t/ac/yr
Sediment Loading Amount to Watershed Outlet	19,308	t/yr
Highest Erosion from Individual Cell	6.18	t/ac/yr
Nitrogen Loading Amount to Watershed Outlet	20.26	lb/ac/yr
Phosphorus Loading Amount to Watershed Outlet	3.64	lb/ac/yr

The existing condition simulation runoff, erosion, sediment yield, sediment load, nitrogen load, and phosphorus load are shown in Figures IV-1 to IV-6, respectively. The various existing condition simulation maps provide an indication of the location of higher and lower producing areas. Each set of erosion, sediment yield and sediment load maps have a uniform legend scale to allow for straight forward comparisons.

Most of the watershed produces low volumes of runoff in the existing condition. The high runoff producing areas are a combination of agricultural areas that generally produced higher runoff rates then the other areas and soil types that are susceptible to high runoff. High erosion rates generally exist in the steeper sloped areas of the watershed, with the flatter slopes along the creek containing low erosion rates. The erosion rates correlate strongly with the RUSLE LS-factor generated by TOPAGNPS. While the high erosion rates are scattered throughout the watershed, the areas where most of the sediment makes it to the outlet occurs in the downstream portion of the watershed. Sediment is deposited from the eroded areas in the creek as it is transported throughout the system.

The nitrogen and phosphorus loads follow the trends of sediment variability throughout the watershed since much of these nutrients are transported as attached to sediments, especially for phosphorus. This brings about a need to focus effective management practices in the downstream steeply sloped areas near the outlet. Manure applications and feedlot operations in those areas should be minimized as much as possible.

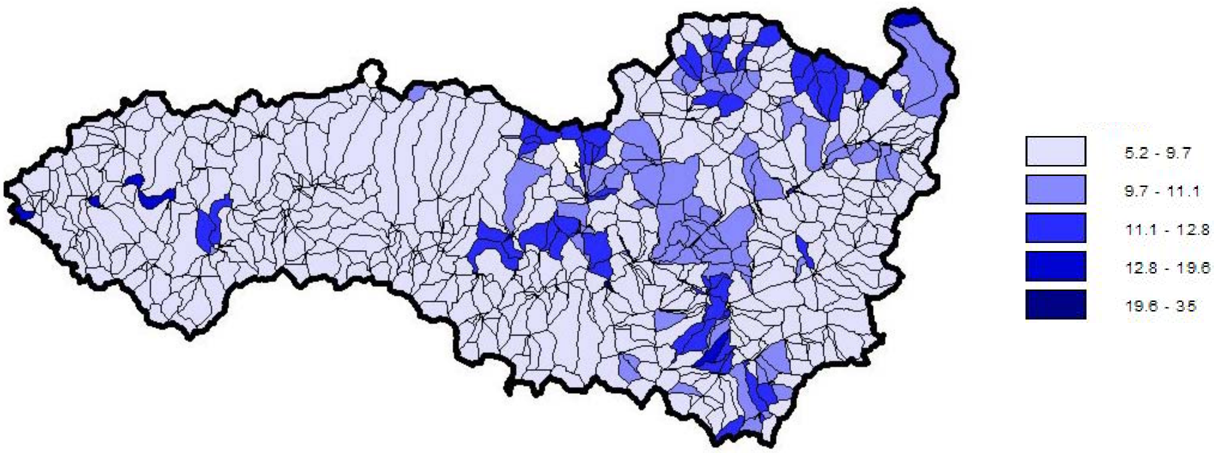


Figure 0-1: Map showing spatial distribution of runoff for the existing condition simulation in inches per year.

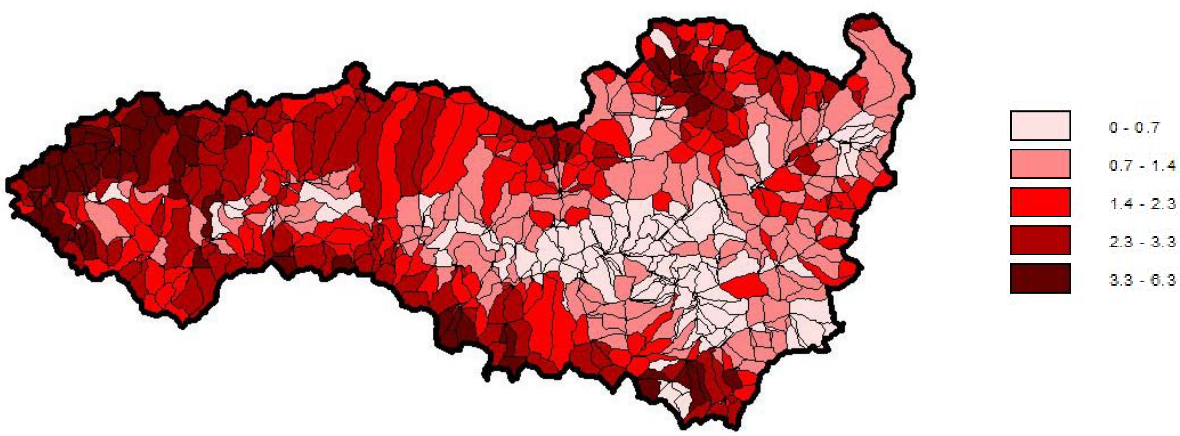


Figure 0-2: Map showing spatial distribution of erosion for the existing condition simulation in tons per acre per year.

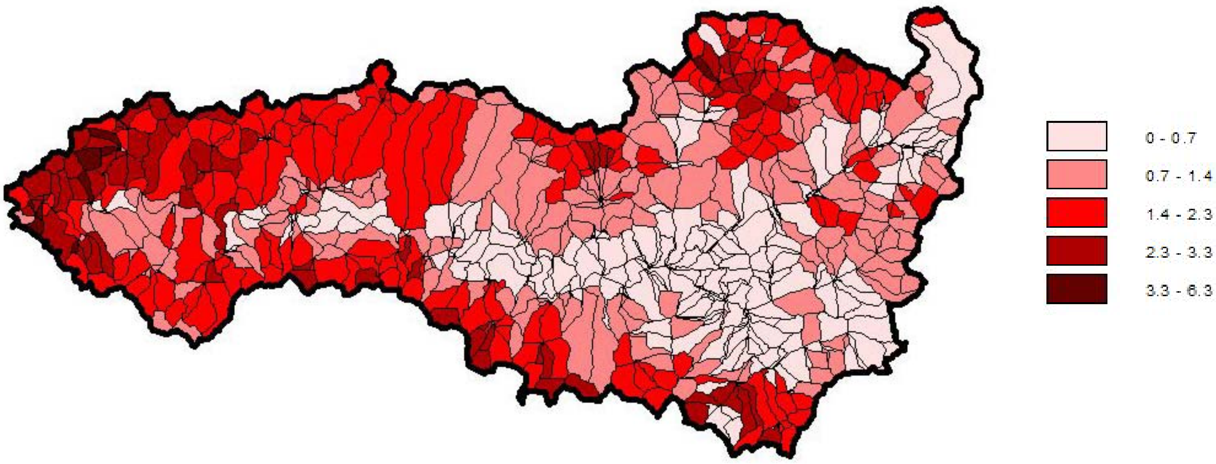


Figure 0-3: Map showing spatial distribution of sediment yield for the existing condition simulation in tons per acre per year.

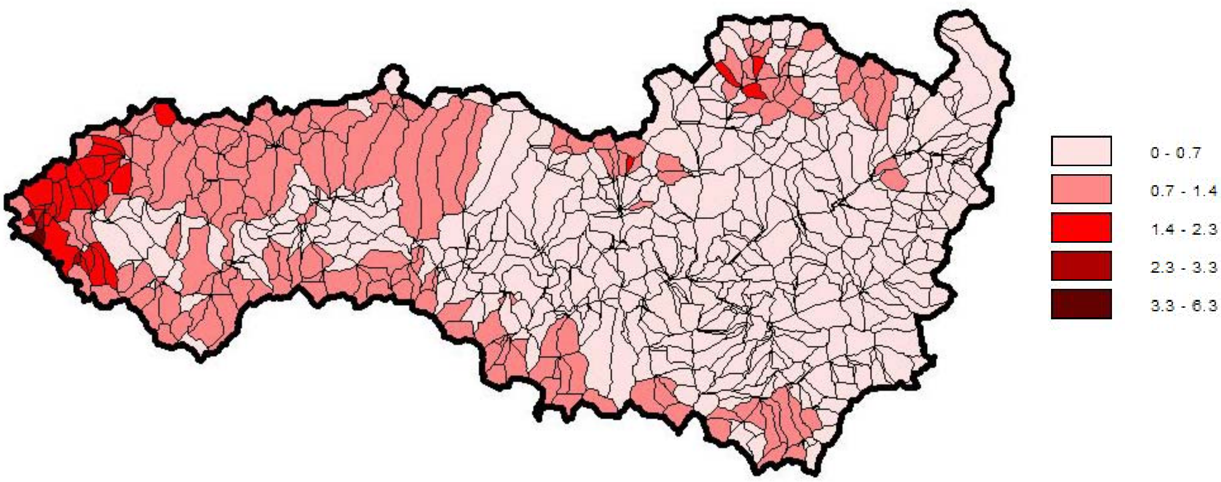


Figure 0-4: Map showing spatial distribution of sediment load for the existing condition simulation in tons per acre per year.

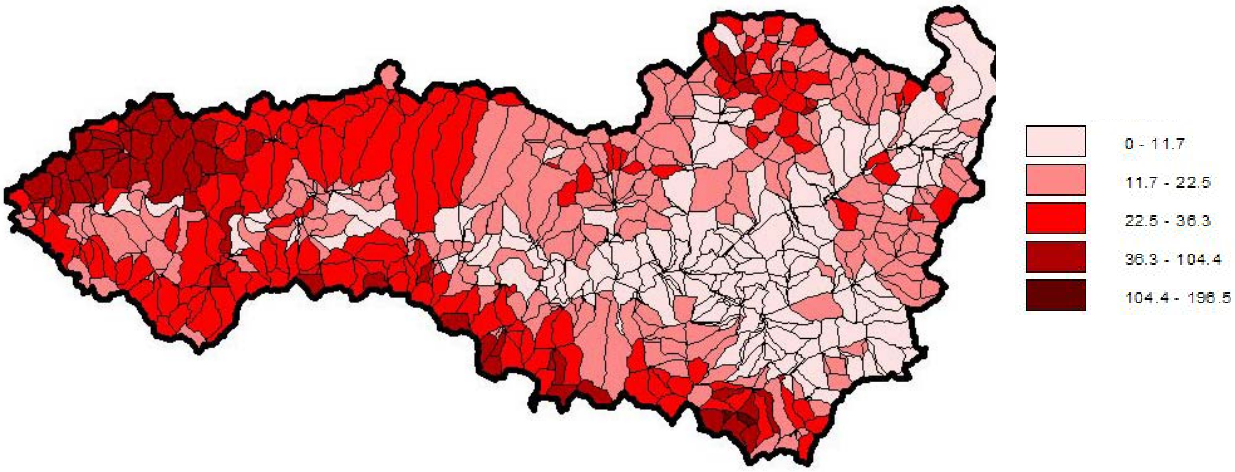


Figure 0-5: Map showing spatial distribution of nitrogen load for the existing condition simulation in lbs per acre per year.

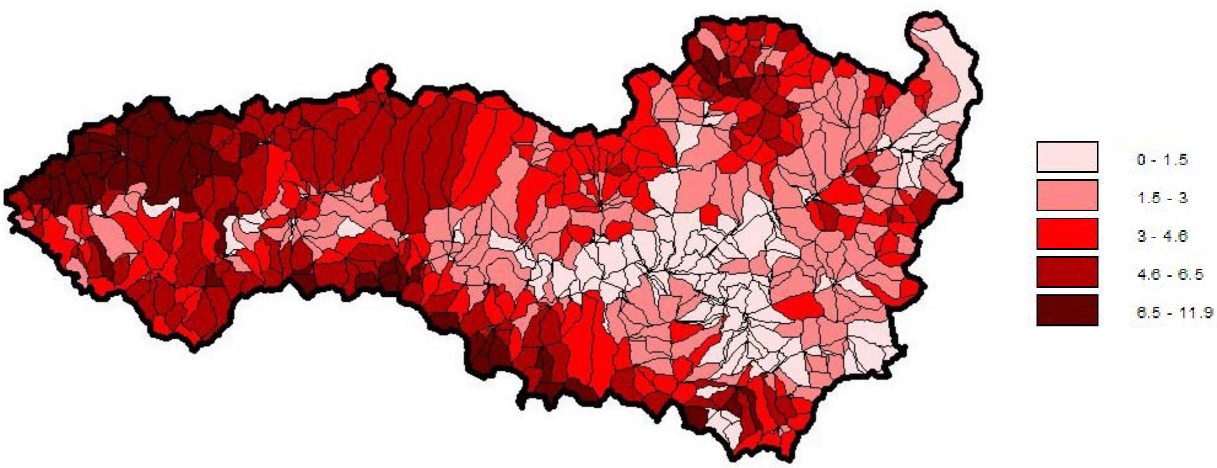


Figure 0-6: Map showing spatial distribution of phosphorus load for the existing condition simulation in lbs per acre per year.

Results from Rangeland and Pasture Management Alternatives

Various rangeland and pasture management alternatives were evaluated, ranging from poor to good, including limiting manure applications on the landscape, except for agricultural areas for fertilizer requirements. These alternatives were used to compare with the baseline existing condition for runoff, sediment, nitrogen and phosphorus loadings as shown in Figures IV-7 to IV-10. Generally, runoff from the landscape varied throughout the year according to precipitation, with lower runoff produced from good conditions to higher runoff from poor conditions. Although the differences of the pollutant loadings from these various scenarios were minor, except when manure applications were limited. The tillage used right after manure application significantly impacts the amount of sediment eroded within the watershed by reducing sediment by 85% from the existing condition. While the reduction in nutrients is expected with reduced manure applications, this reduction is also 85% from the existing condition. While high runoff occurs in January through April and November and December, the highest sediment and nutrient producing months are January, November, and December. This reflects higher intensity precipitation events during the late fall and early winter months.

The influence of the management alternatives will be more evident in the riparian buffers and channels where producing less runoff will produce less erosion in the channels and allow the riparian areas to better filter out the sediment and nutrients before entering the channels.

The influence of gully erosion was not considered in the simulations, but gullies appear throughout the watershed. Unfortunately, there has not yet been developed a reliable gully erosion model that can be used in watershed models to assess the effects of management practices on sediment production.

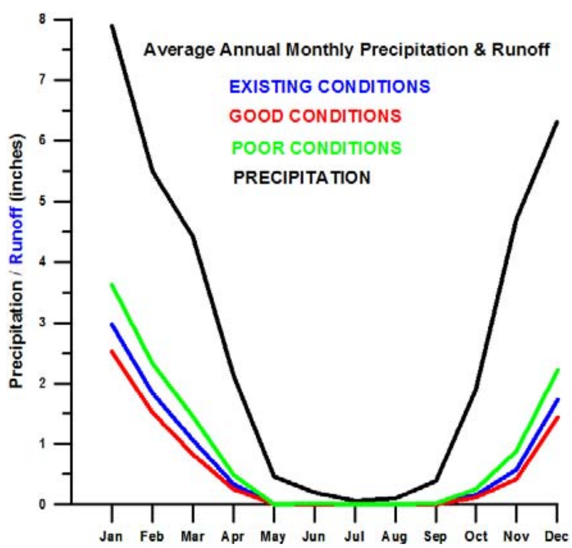


Figure 0-7: Map showing average annual monthly precipitation and runoff for the existing, good and poor management conditions.

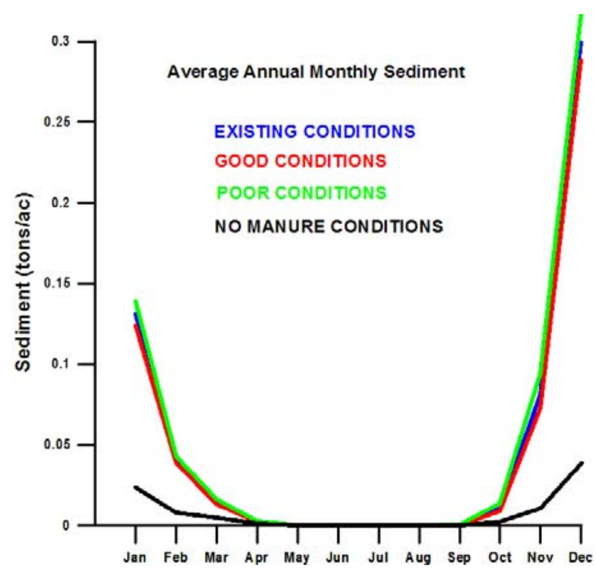


Figure 0-8: Map showing average annual monthly sediment loadings at the outlet for the existing, good and poor management conditions.

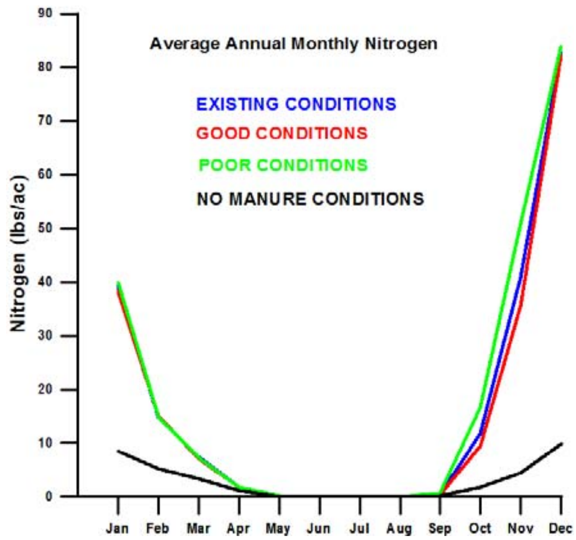


Figure 0-9: Map showing average annual monthly nitrogen loadings at the outlet for the existing, good and poor management conditions.

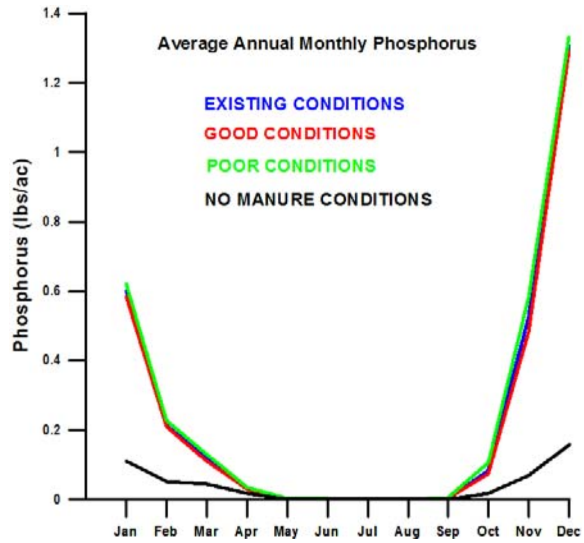


Figure 0-10: Map showing average annual monthly phosphorus loadings at the outlet for the existing, good and poor management conditions.

IMPLICATIONS OF THE STEMPLE CREEK WATERSHED RESULTS

The model results show that application of alternative management practices could result in a significant reduction in quantities of sediment delivered from the Stemple Creek Watershed. Specific results of the model and impacts on designing a land treatment program for the watershed include:

1. The model identified an average annual load of 0.58 t/ac/yr from the mouth of the Stemple Creek Watershed due to sheet and rill. This equates to 19,308 tons per year. The model also identified average annual gross erosion in the watershed to be 58,690 tons.

2. The model documented the effects of various range land and pasture management scenarios, with minimal effect on sheet and rill erosion and nutrients on the landscape, except a reduction of 85% sediment and nutrients when no manure is applied. The combination of reduced manure applications and the resulting removal of the subsequent tillage operation in this application produced this effect on nutrients. The effect of riparian buffers as filters is expected to significantly impact the loadings, resulting in buffers being the practice that will minimally disrupt existing management within the watershed.
3. The model can identify areas within the watershed with the highest erosion and nutrient loading rates, which could be targeted for land treatment to achieve the highest benefits. Significant sources of sediment and nutrients that are transported to the outlet of the watershed originate mainly in the downstream portions of the watershed in the steeper sloped terrain. These areas could be targeted for reductions in manure applications and soil disturbance.
4. The highest levels of sediment and nutrients occur in the months of November, December and January. Practices that minimize soil disturbance or manure applications during those months will decrease the loadings to the mouth of Stemple Creek.

PROJECT CONCLUSIONS

The Stemple Creek Watershed was modeled with AnnAGNPS to quantify erosion, sediment transport, sediment load, and nutrients at the mouth of the watershed. The model predicted an average annual load to be 19,308 total tons or 0.58 tons/ac/yr unit loading based on existing land use conditions and a 42 year climate simulation. Most of the sediment and nutrients are produced in the months of November through January.
The project successfully developed GIS techniques to match the watershed boundaries and stream network to actual conditions allowing better identification of where the sources are.

Significant erosion occurs in the steep terrain of the downstream portion of the watershed that is the source for much of the sediment and nutrients at the outlet.

There was a minimal impact from various rangeland and pasture managements on sediment or nutrients. Reducing the manure applications within the watershed and the subsequent soil disturbance reduced sediment and nutrient loadings by 85%.

The project identified further work that could improve the model, including adding an integrated riparian buffer component.

REFERENCES

Alonso, C. V., F. D. Theurer and D. W. Zachmann. 1996. Technical Report No. 5 – Tucannon River Offsite Study: sediment intrusion and dissolved oxygen transport model. USDA-Agricultural Research Service, National Sedimentation Laboratory, POB 1157, Oxford, Mississippi, 38655. November 1996. 400 pp.

Altier, L. S., R. R. Lowrance, R. G. Williams, S. P. Inamdar, D. D. Bosch, J. M. Sheridan, R. K. Hubbard, and D. L. Thomas. 2002. Riparian ecosystem management model (REMM): Documentation. USDA Conservation Research Report. Washington D.C.: USDA.

Bingner, R. L., C. V. Alonso, R. W. Darden, R.G. Cronshey, F. D. Theurer, W. F. Geter. 1996. Development of a GIS-based flownet generator for AGNPS. Proceedings of the Sixth Federal Interagency Sedimentation Conference, Las Vegas, NV, March 10-14, p. Poster-52-55.

Bingner, R. L., R. W. Darden, F. D. Theurer, and J. Garbrecht. 1997. GIS-Based Generation of AGNPS Watershed Routing and Channel Parameters. ASAE Paper No. 97-2008, St. Joseph, Michigan. 4 pp.

Bingner, R. L., R.W. Darden, F.D. Theurer, C.V. Alonso, and P. Smith. 1998. AnnAGNPS Input Parameter Editor Interface. First Federal Interagency Hydrologic Modeling Conference, April 19 - 23, 1998, Las Vegas, Nevada, p. 8-15-18.

Bingner, R. L, J. Garbrecht, J. G. Arnold, and R. Srinivasan. 1997. Effect of watershed subdivision on simulation runoff and fine sediment yield. Trans. of the ASAE 40(5): 1329-1335. 1997.

Bingner, R. L. and F. D. Theurer, 2001a. AGNPS 98: A Suite of water quality models for watershed use. In Proceedings of the Sediment: Monitoring, Modeling, and Managing, 7th Federal Interagency Sedimentation Conference, Reno, NV, 25-29 March 2001. p. VII-1 - VII-8.

Bingner, R. L. an d F. D. Theurer. 2001b. AnnAGNPS: esti mating sediment yield by particle size for sh eet and rill ero sion. Presented at : 2 5-29 M arch 2 0, Sediment: M onitoring, Modeling, an d M anaging, P aper No. *in press*, 7t h Fede ral Interagency Sedimentation Conference, Reno, NV. 6 pp.

Bingner, R. L. and F. D. Theurer. 2001c. Topographic factors for RUSLE in the continuous-simulation, watershed model for predicting agricultural, non-point source pollutants (AnnAGNPS). Presented at: 3-5 January 2001, Soil Erosion for the 21st Century - An International Symposium Honolulu, Hawaii, Paper No. *in press*, ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659 USA. 4 pp.

Bosch, D., F. Th eurer, R. Bin gner, G. Felton and I. Ch aubey. 19 98. Evaluation of th e AnnAGNPS Water Quality Mo del . ASAE Paper No. 98-2195, St. Joseph, Michigan. 12 p.

Garbrecht, J. and L. W. Martz. 1995. Advances in Automated Landscape Analysis. In Proceedings of the First International Conference on Water Resources Engineeri ng, Eds. W. H. Espey and P. G. Combs, American Soci ety of En gineers, San Antonio, Texas, August 14-18, 1995, Vol. 1, pp. 844-848.

Inamdar, S. P., J. M. Sheridan, R. G. Williams, D. D. Bosch, R. R. Lowrance, L. S. Altier, and D. L. Thomas. 1999a. Riparian ecosystem management model (R EMM): I. Test ing o f t he hy drologic com ponent f or a coast al p lain ri parian s ystem. Transactions of the ASAE 42(6): 1679-1689.

Inamdar, S. P., R. R. Lo wrance, L. S. A ltier, R. G. Williams, and R. K. Hubb ard. 1999b. Rip arian eco system management model (REMM): II. Testi ng of the water quality and nutrient cycling com ponents for a c oastal pl ain ri parian sy stem. Transactions of the ASAE 42(6): 1691-1701.

Johnson, G. L., C. Daly, G. H. Taylo r and C. L. Hanson. 2000. Sp atial v ariability an d in terpolation of sto chastic weat her simulation model parameters. J. Appl. Meteor., 39, 778-796.

Langendoen, E. J. 2001. "CONCEPTS - CONservational Channel Evolution and Pollutant Transport System," NSL Technical Report 1 6, U.S. Department of Agriculture, Agricultural Re search Service, Nat ional Sedi mentation Laboratory, Oxford, MS.

Lowrance, R. R., L. S. Altier, R. G. Williams, S. P. In amdar, J. M. Sheridan, D. D. Bosch, R. K. Hubbard, and D. L. Thomas. 2000. REMM: The riparian ecosystem management model. Journal of Soil and Water Conservation 55(1): 27-34.

Matalas, N.C.. 1967. Mathematical assessment of synthetic hydrology. Water Resources Research 3(4):937-945.

Renard, K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D. C. Yoder, coordinators. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703, 404 pp.

Richardson, C .W. 198 1. Sto chastic si mulation o f daily p recipitation, te mperature and s olar ra diation. Water Resou rces Research, 17, 182-190.

SCS. 1986. Technical Release 55: Urban hydrology for small watersheds. Soil Conservation Service, USDA.

Theurer, F. D. and G. H. Comer. 1992a. Classification and Evaluation of Models in Support of the SCS 5-Year Water Quality & Quantity Plan of Operations. USDA-SCS-ENG, Washington, DC. April 1992.

Theurer, F. D. and G. H. Comer. 1992b. SCS SWRRBWQ Evaluation. USDA-SCS-ENG, Washington, DC. April 1992.

Theurer, F. D. and G. H. Comer. 1993. SCS AGNPS Evaluation. USDA-SCS-ENG, Washington, DC. March 1993.

Theurer, F. D., K. A. Voos, and W. J. Miller. 1984. Instream water temperature model. Instream Flow Information Paper 16. US Fish and Wildlife Service. FWS/OBS-84/15. 300 pp.

Young, R. A., C. A. Onstad, D. D. Bosch and W. P. Anderson. 1989. AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. Journal of Soil and Water Conservation 44(2): 168-173.

RIPARIAN ECOSYSTEM MANAGEMENT MODEL SIMULATIONS TO ASSESS THE POTENTIAL OF RIPARIAN BUFFERS IN STEMPLE CREEK WATERSHED
(DRAFT REPORT)

R. Richard Lowrance, Randall G. Williams, David D. Bosch,
USDA-ARS, Tifton, GA
Carrie Graff, Limno-Tech Inc., Washington, D.C.

OBJECTIVES OF STEMPLE CREEK REMM MODELING

Riparian buffers are one of the management practices of interest to both landowners and USDA-NRCS in the Stemple Creek Watershed. The Riparian Ecosystem Management Model (REMM) and the Annualized Agricultural Nonpoint Source Pollution Model (AnnAGNPS) were used to investigate the expected impacts of riparian buffers throughout the watershed. The objective of this research was to examine the effectiveness various buffer scenarios on reducing nutrient and sediment loading to streams. The research described in this report focused on analysis of the riparian buffers based upon representative sites visited during field investigations. AnnAGNPS simulations from a companion study were used for portions of the entire watershed. Until a complete integration of REMM and AnnAGNPS is available, modeling of riparian function using REMM involves using daily output from AnnAGNPS cells for daily input to REMM. REMM was used to estimate daily stream flow and nutrients and sediment in stream flow. In addition REMM was used to calculate the nutrient and sediment trapping efficiencies by riparian buffers.

OVERVIEW OF REMM

USDA and cooperating universities have developed the Riparian Ecosystem Management Model (REMM) to simulate the effects of multiple zone riparian buffers on water, sediment, and nutrient movement from source areas to streams (Altier et al., In Press, Lowrance et al., 2000). The riparian system is characterized in the model as consisting of three zones parallel to the stream corresponding to the three zone system used as a management recommendation. Although designed to simulate this three-zone system, REMM can simulate riparian conditions where one or more of the zones are absent or managed differently from the specifications.

REMM is a daily time-step model. Inputs to REMM are the water, sediment, nitrogen, and phosphorus loadings in surface runoff and subsurface flow from a source area, typically a field. Outputs from REMM are the water, sediment, nitrogen, and phosphorus in surface runoff, subsurface flow, and seepage to a stream or adjacent aquatic ecosystem. Surface runoff as defined in REMM is generated by rainfall exceeding available soil water storage capacity in a zone. Subsurface flow is shallow groundwater movement within the root zone of the buffer. Seepage is flow along the soil surface below the leaf litter that is generated when subsurface flow exceeds available water storage capacity in a downslope zone. Outputs are reported as sediment size classes and nutrient species in water moving as direct surface runoff, and nutrient species moving in subsurface flow and seepage. Direct surface runoff only occurs on rain days and interacts with the litter and a soil-mixing layer in the litter. Seepage is water exfiltrating from the soil and can occur whenever there is more subsurface flow into a zone than can be stored in the zone. Seepage does not interact with the litter but can infiltrate in downslope zones. The emphasis in REMM on process simulation and the explicit representation of a multiple zone buffer system with details of water, sediment, sediment borne nutrient, and soluble nutrient movement provides insights into the functions of riparian buffers not possible with models that depend on empirical mass balances.

Vegetative processes in REMM are simulated using algorithms derived from existing mechanistic models of tree growth and crop growth. Vegetation can be herbaceous annuals, herbaceous perennials, or a variety of woody plant types. In REMM, vegetation influences soil nutrients primarily via litterfall and plant uptake. Litter from aboveground vegetative parts such as leaves, branches, and stems is added to the surface litter layer. Decomposition of this litter releases N and P, part of which is incorporated into the soil profile. Litter from belowground vegetative parts such as fine and coarse roots is directly added to the soil residue pools where it is then subjected to decomposition. Nutrient uptake by vegetation is determined by the lesser of either the demand by the plant or the availability of nutrients in the soils. Nutrient demand by vegetation is a dynamic function of the need to maintain nutrients in various plant parts within predefined ranges of minimum and maximum C:N and C:P ratios. These minimum and maximum vegetative C:N and C:P ratios vary with vegetation type and are provided as an input to the model. In the soil, nitrate-N, ammonium-N, and labile-P pools are assumed to be available for plant uptake when soil moisture is above wilting point. Plant nutrient demand is first fulfilled by nutrients available in the uppermost soil layer, with unfulfilled demand being transferred progressively to lower layers. Nutrients can only be taken up from soil layers in which roots are growing.

Soil carbon dynamics of REMM are largely based on the Century Model. Soil carbon is characterized by three humus and two plant residue pools. The three humus pools are: (1) an active pool consisting of biomass and metabolites of biomass with a rapid decay rate; (2) a slow pool consisting of organic matter that has been partially stabilized either chemically or physically by adsorption or entrapment within soil aggregates; and (3) a passive pool of chemically stabilized organic matter having a very slow decay rate. In addition to different decay rates, these pools are distinguished by different carbon to nitrogen (C:N) and carbon to phosphorus (C:P) ratios. Decomposition of these humus pools is calculated using a first-order rate equation modified by temperature and moisture.

Plant residue pools are divided into a recalcitrant structural and quickly decomposable metabolic residue pool. Similar to humus pools, each of these pools has different decay rates and C:N and C:P ratios. Plant litter is added to these pools on a daily basis. The partitioning of the fresh litter into structural or metabolic pools is determined by the lignin-to-nitrogen ratio of the litter. Decomposition of the residue pools is simulated with a first order rate equation identical to equation 1, except that, in addition to factors for moisture and temperature, residue decomposition is controlled by an additional factor that quantifies the availability of inorganic N and P. In addition, decomposition of structural pool is also controlled by its lignin content. As decomposition of the litter takes place a portion of the C is lost in CO2 to the atmosphere, and the remaining C is re-synthesized into humus. Carbon movement is simulated in particulate form with sediment, and in dissolved form with surface runoff, subsurface flow, and drainage. All of the particulate C moving with sediment is derived from the active humus pool. Dissolution of C into runoff and drainage is assumed to occur from the metabolic residue and active humus pools.

Organic nitrogen pools are complementary to the C pools with the size of the nitrogen pools being determined by the size of the C pools and their respective C:N ratios. The inorganic fraction of soil N is characterized by ammonium and nitrate pools. Stoichiometric relationships are assumed among C and N, with N being mineralized and

immobilized in proportion to transformations of C and C:N ratios. Mineralized N is added to the ammonium pool. Ammonium and nitrate forms are both available for

immobilization into soil organic matter. Immobilization of nitrate occurs only after all available ammonium has been used.

Similar to nitrogen, organic phosphorus pools complement the C pools and are determined by the size of the C pools and their respective C:P ratios. Simulation of

inorganic P follows the approach used in the EPIC model. Besides a labile inorganic P form, there are two pools (active and stable) representing increasing levels of

chemical stabilization that are unavailable to plant uptake or microbial transformation. Much like N, release of P is determined by decomposition of C and the respective C:P

ratio of the decomposing pool. Immobilization of P is controlled by variable humus C:P ratios. This approach follows the Century model. Plant uptake of P is assumed to occur from the inorganic-labile P pool. Movement of P can occur with sediment, surface and

subsurface runoff, and vertical drainage. Organic-active and inorganic-labile forms of P are assumed to be associated with sediment. Dissolved forms of inorganic labile

P and active-organic P move with water. Partitioning of P into dissolved and adsorbed fractions is computed using the Langmuir isotherm.

More information on REMM testing and application is available (Inamdar et al. 1999a, Inamdar et al. 1999b, Lowrance et al. 2000, Lowrance et al. 2001, Graff et al. 2005). Because an integration of REMM and AnnAGNPS was beyond the scope of the agreed upon work simulations provided here use daily output from AnnAGNPS as daily input into REMM.

FIELD RECONNAISSANCE OF RIPARIAN SITES

Three ARS Scientists (David Bosch, Richard Lowrance, and Randy Williams) conducted field reconnaissance of six field sites in the Stemple Creek Watershed, August 24-27, 2005. We made field measurements of the width and slope of riparian zones and sampled vegetation in riparian zones where they existed. The six sites included three with herbaceous vegetation, two with native woody vegetation, and one with a planted woody riparian buffer. Photos of the sites are in the Appendix. Limited vegetation surveys were conducted in the wooded riparian zones. Data from these vegetation surveys are shown in Appendix Table 1. Leaf samples (for trees) and stem plus leaf samples (herbaceous material) were taken and after drying were analyzed for N and P content at the University of Georgia Soil and Plant Analysis Laboratory. Results of tissue analysis are shown in Appendix Table 2. Simultaneously, Ken Oster, Soil Scientist, USDA-NRCS took augered soil samples at each of the sites. The soil samples were analyzed at the USDA-NRCS soil science laboratory in Lincoln, NE.

USE OF ANNAGNPS SIMULATION DATA

AnnAGNPS was used to simulate runoff for Stemple Creek at the watershed and subwatershed scale. Essentially, buffers were created for several AnnAGNPS cells in order to evaluate their effectiveness in reducing nutrients and sediments. Model simulations were performed by USDA at Oxford, MS (Bingner, 2007). Outputs from several individual AnnAGNPS cells (subwatersheds) were used as input for REMM. The cells that were chosen as input into REMM had simulated AnnAGNPS output from areas with similar soils and similar agricultural practices to the ones visited during field reconnaissance. The land use type and acreage of the AnnAGNPS cells used can be found in Table 1.

Table 1: Properties of AnnAGNPS cells used for input into REMM.

AnnAGNPS Cell Number	Acres	Landuse
992	31.10	DAIRY
993	108.54	CROP LAND
1252	5.48	DAIRY
1292	87.09	LIVESTOCK
1323	29.70	DAIRY
1383	25.58	DAIRY

Basic inputs into REMM from AnnAGNPS include water, N, P, and sediment in their various forms on a daily time-step. AnnAGNPS outputs were provided by USDA at Oxford.

REMM SIMULATIONS
Scenarios

Several buffer scenarios were created with REMM to simulate those likely to be found in the Stemple Creek Watershed. Each buffer combination was a unique combination of land slope and vegetation. All of the following buffer scenarios were run for each AnnAGNPS cell:

- Flat herbaceous.
- Steep herbaceous.
- Flat woody.
- Steep woody.

Flat and steep scenarios used a 2% and 32% slope respectively. These slopes represent those found during field reconnaissance at specific sites. Perennial grasses were used to simulate the herbaceous buffers and trees with a Deciduous Fall Upper Canopy (leaves die and fall off in the fall) were used to simulate the woody vegetation.

A 10:1 field to buffer ratio was used to calculate the length and width of each buffer as they were applied to each AnnANGPS cell. The dimensions of the AnnAGNPS cells were considered square and the length of one side was used as the length of the buffer parallel to the stream. The total width of the buffer (perpendicular to the stream) was 1/10th the length. Because REMM simulates a 3 zone buffer system, this width was divided by three so that each zone was the same width and length. Table 2 identifies the zone length and width associated with each AnnAGNPS cell. In every simulation, all three zones are the same within each of the four buffer types.

Table 2: Length and width of buffers used with each AnnAGNPS cell output.

Cell	Length (m)	Width (m)
992	354	11.8
993	730	24.36
1252	147	4.9
1292	593	19.78
1323	347	11.5
1383	320	10.69

REMM Inputs

Field Inputs

Field inputs into REMM, as described previously, come from the AnnAGNPS cell output for Stemple Creek and represents surface and subsurface agricultural runoff from a field. Inputs include water, nutrient (N and P), in surface and subsurface flow on a daily basis as well as C:N and C:P ratios in surface and subsurface runoff. Because AnnAGNPS does not have these ratios, they were input as the default values in REMM. Because of assumptions made with AnnAGNPS, almost all of the output from the field cells was as surface runoff with only around 1-2% of the input as subsurface flow.

Climate

Climate data used for REMM simulations was the same used for the AnnAGNPS simulations (Bingner, 2007).

Vegetation

There are numerous ways to parameterize REMM vegetation data, however only a few key parameters were chosen to reflect what is known about actual vegetation at the site. Data on nutrient pools from the tissue analysis were calculated to be within the range of default nutrient pools for the different plant types in REMM and therefore nutrient pools were not adjusted. Parameters such as rooting depth, plant height, and Specific Leaf Area (SLA) were adjusted and the values used in model runs can be found in Table 3 for both herbaceous and woody plant scenarios.

Table 3: Basic plant parameters used for herbaceous and woody buffer scenarios.

	Herbaceous	Woody
Rooting depth (cm)	100	200
Plant height (m)	0.10	21.00
Specific Leaf Area	0.0020	0.0054

Soils

Several sources of information on the physical and chemical properties of the soils typical for buffers in the Stemple Creek Watershed were used. During the field reconnaissance, several soil samples were taken at depth and sent off for chemical and physical analysis including: passive, active, and stable carbon and nitrogen pools; labile and stable phosphorus; and clay, silt, and sand fractions. Since several samples were taken, the values for each parameter were averaged (Table 4) for each layer. The values for C-POM and N-POM were divided into active and passive pools using the same ratio found in the REMM default data values. Slowly available C and N was considered to be the value for C-Min and N-Min The Sonoma County soil survey was used to determine typical soil layer depths for shallow and steep slopes using the Blucher and Clough Series respectively. Typical field capacities, wilting points, Manning's roughness values and soil surface conditions given the known soil types were taken from tables in the REMM Users Manual. All other values were taken as the default values in REMM.

Table 4: Soil parameters calculated from field reconnaissance data.

		C-POM	C-Min	N-POM	N-Min	pH	Clay	Silt	Sand	Labile P	Stable P
		kg/ha	kg/ha	kg/ha	kg/ha		kg/ha	kg/ha	kg/ha	mg/kg	mg/kg
Shallow											
Layer 1	**Average**	10346	8021	1434	2054	6	11	26	62	124	314
	Active	517		86							
	Passive	9829		1333							
Layer 2	**Average**	2131	7053	310	1240	6.72	10	28	62	22	42
	Active	107		19							
	Passive	2025		288							
Layer 3	**Average**	969	6316	233	853	6.7	14	27	59	17	7
	Active	48		14							
	Passive	901		216							
Steep											
Layer 1	**Average**	18600	26040	1085	2868	5.75	17	38	44	37	42
	Active	930		65							
	Passive	17670		1009							
Layer 2	**Average**	9455	21623	853	2403	6.45	21	36	42	5	4
	Active	473		51							
	Passive	8982		793							
Layer 3	**Average**	1395	8215	78	930	6.85	23	38	39	4	4
	Active	70		5							
	Passive	1325		72							

Results and Discussion

Tables 5, 6, and 7 show the results of REMM simulations for sediment, total N, and total P, respectively, for each AnnAGNPS cell input. The land use for each cell is also noted along with the total N, P, and sediment (in kg/ha) that was output from AnnAGNPS and used as input for REMM. Retention rates were calculated the following way:

%Retention = ((Input – Output)/Input)*100

It can be seen from the input data, that the largest amount of N, P, and sediment on a per area basis did not necessarily reflect the landuse type. For instance, both the largest and smallest amount of N, P and sediment comes from dairy landuse type. One cell is listed as a row crop, and its N, P, and sediment values are smaller than most of the dairy and the livestock landuse type. Without knowing the types of inputs that went into simulating the AnnAGNPS runoff, it is difficult to account for the differences in runoff.

Sediment

Retention rates for sediment are fairly consistent across all scenarios, ranging from 12% to 50% for flat scenarios, and 7% to 43% for steep scenarios (Table 5).

Upland Land Use	Cell No.		Herbaceous Flat		Woody Flat		Herbaceous Steep		Woody Steep	
		Input	Output	% Retention	Output	% Retention	Output	% Retention	Output	% Retention
Dairy	992	634	551	13.07	554	12.67	585	7.76	589	7.05
Row Crop	993	1044	864	17.24	867	16.88	927	11.17	932	10.72
Dairy	1252	1178	1005	14.71	1008	14.46	1068	9.31	1073	8.91
Live-stock	1292	1025	531	48.22	534	47.96	593	42.14	599	41.56
Dairy	1323	4770	2402	49.64	2408	49.53	2730	42.76	2740	42.55
Dairy	1383	6138	5348	12.87	5355	12.75	5595	8.85	5601	8.70

Table 5: Total sediment input from AnnAGNPS (kg/ha/yr), REMM total sediment out (kg/ha/yr), and calculated retention rates of four different buffer scenarios from six AnnAGNPS cells.

Without exception, flat buffer types retain more sediment than the steep buffers, but in general this difference is less than 5%. There are even less differences between the sediment retention rates of herbaceous and woody types of buffers; however a difference would not be expected given that parameters affecting the amount of erosion are not tied to vegetation type. The greatest amount of sediment retention can be found for cells 1323 and 1292 for all scenarios. Cell 1292 is the second largest cell (87.09 acres) and therefore has a larger buffer which could account for the larger retention rate. Cell 1323, however, is only 30 acres, but has 4 times the sediment input of cell 1292.

The fractionation of sediment does seem to have an impact on retention rate in the buffer. For example, Cell 992 has the least amount of sediment input at 634 kg/acre in the form of 51%-clay, 44%-silt and 5%-sand. The total sediment input for Cell 1323 is 4770 kg/acre and consists of 5%-clay, 30%-silt and 45%-sand. The higher % sand and silt into the buffer is reflected nicely with % retentions going from the 8 to 13 range for Cell 992, to the 40-50% range for Cell 1323.

Nitrogen

Table 6 shows that in general, for both herbaceous and woody scenarios, that the flatter buffers retain more nitrogen than their steep counterparts. Retention rates of N are on average 25% - 30% higher for flat scenarios than steeper ones. Specifically, herbaceous and woody flat buffers retained between 12% and 77% of N while retention rates for corresponding steep buffers was 15% - 71%. Flat buffers tend to promote higher water tables and thus have an increased capacity for denitrification. In steep buffers, water moves more quickly, lessening the chances for microbial decomposition. The lowest difference in retention rates between flat and steep buffers can be found for cell 1383 for both woody and herbaceous types, where retention rate range 89.21 and 89.69

Upland Land Use	Cell No.		Herbaceous Flat		Woody Flat		Herbaceous Steep		Woody Steep	
		Input	Output	% Retention	Output	% Retention	Output	% Retention	Output	% Retention
Dairy	992	20.1	6.12	69.57	5.79	71.23	13.3	33.98	13.1	34.91
Row Crop	993	20.4	5.96	70.74	5.52	72.92	11.4	44.10	11.9	41.51
Dairy	1252	35.4	11.5	67.39	10.8	69.43	20.1	43.24	19.6	44.71
Live-stock	1292	37.7	8.83	76.55	8.44	77.57	19.0	49.57	18.4	51.07
Dairy	1323	115	36.1	68.55	32.6	71.60	48.0	58.11	47.1	58.96
Dairy	1383	116	12.5	89.21	12.5	89.27	12.0	89.69	12.0	89.64

Table 6: Total N input from AnnAGNPS (kg/ha/yr), REMM total N out (kg/ha), and calculated retention rates of four different buffer scenarios from six AnnAGNPS cells.

across all types. This cell also has the highest input of N (116 kg/ha) but it is not clear if this is related to retention rates but given that retention is so high, it is likely the case that the capacity of the buffer to absorb and denitrify N was reached. There are little if any differences in the output between the herbaceous and woody scenarios although for flat buffers, woody types retain more nitrogen than herbaceous ones. In the steep buffer scenarios, retention rates are generally higher for woody types, with the exception of cells 993 and 1383. Retention rates for these cells are only slightly lower than their herbaceous counterparts.

The fact that there is little difference between woody and herbaceous scenarios is likely due to the fact the REMM vegetation parameters play little role in the erosion (attached N) and transport of water through the buffer (dissolved N). Instead, the structure of the buffer (width, slope), and other erosion parameters such as Manning’s n, roughness, soil moisture conditions, and others are more important in determining the flow of water.

Phosphorus

Phosphorus retention rates range from 12% – 43% for flat scenarios and 12% - 56% for steep scenarios (Table 7). Here, however, the steep scenarios almost always retain more P than the flat buffers, which is different than what was seen for nitrogen.

Upland Land Use	Cell No.		Herbaceous Flat		Woody Flat		Herbaceous Steep		Woody Steep	
		Input	Output	% Retention	Output	% Retention	Output	% Retention	Output	% Retention
Dairy	992	2.69	1.53	43.10	1.87	30.68	1.25	53.60	1.60	40.75
Row Crop	993	2.82	1.91	32.26	2.07	26.67	1.56	44.81	1.79	36.48
Dairy	1252	4.70	2.86	39.20	3.41	27.45	2.55	45.65	3.33	29.17
Live-stock	1292	4.68	2.27	51.56	2.93	37.43	2.04	56.32	2.89	38.28
Dairy	1323	18.4	16.0	12.81	12.5	32.23	16.1	12.63	15.9	13.58
Dairy	1383	14.3	12.5	12.11	12.5	12.63	12.0	16.03	12.0	15.63

Table 7: Total P input from AnnAGNPS (kg/ha/yr), REMM total P out (kg/ha/yr), and calculated retention rates of four different buffer scenarios from six AnnAGNPS cells.

The only exception is cell 1323 where the retention rate for the woody flat scenario is 16% higher than the steep scenario. The reason for this difference is not immediately clear, although cell 1323 does have the highest amount of P input (runoff from AnnAGNPS). Table 8, which shows the amount of dissolved inorganic P in surface runoff, yields some insight. The flat buffers are releasing more phosphorus as inorganic P than their steep counterparts and, in all cases, the dissolved inorganic P output is substantially greater than input (Table 8). This suggests that the buffer is actually producing inorganic P and releasing it in surface flow as dissolved P. We also find that the herbaceous types of buffers retain more P than the woody types in both flat and steep scenarios, which is also in contrast to how N moves and is retained within the buffer.

Upland Land Use	Cell No.		Herbaceous Flat		Woody Flat		Herbaceous Steep		Woody Steep	
		Input	Output	% Retention	Output	% Retention	Output	% Retention	Output	% Retention
Dairy	992	0.34	0.70	-104	1.19	-249	0.41	-18.7	1.19	-249
Row Crop	993	0.41	0.89	-119	1.35	-230	0.49	-20.0	0.92	-125
Dairy	1252	0.34	1.31	-281	2.08	-508	1.08	-215	1.94	-467
Live-stock	1292	0.34	1.26	-267	2.14	-524	0.98	-187	1.91	-458
Dairy	1323	0.26	5.72	-2112	5.31	-1954	5.90	-2181	6.89	-2563
Dairy	1383	0.26	4.75	-1760	5.31	-1980	3.93	-1439	4.46	-1646

Table 8: Dissolved inorganic P in surface runoff in from AnnAGNPS (kg/ha/yr), REMM dissolved inorganic P out (kg/ha/yr), and calculated retention for four different buffer scenarios from six AnnAGNPS cells.

Again, this is due to the amount of dissolved inorganic P being produced within the buffer that is also contributing to the output.

Overall retention rates for buffers simulated in REMM were limited by a number of factors discussed above. Another primary limitation is that the buffers simulated were relatively small compared to the source areas. All buffers simulated were 10% of the source area. Although an analysis of the area available for riparian buffer implementation is beyond the scope of this analysis, it is a key factor in how effective buffers are in controlling nonpoint source pollution. Previous studies using REMM have shown that N retention rates can be as low as 5% for a 15: 1 source to buffer area ration of 15:1 and typically approach 8-0% when the source to buffer area ratio approaches 4:1. Future REMM simulations for Stemple Creek buffers can examine the effects of source to buffer ratios that are realistic for the implementation of buffers within the watershed.

SUMMARY

Results of REMM simulations indicate that 25 – 30% more N is retained by flat buffers than steep ones for both herbaceous and woody types. Flat buffers do not move the ground water out as quickly and therefore tend to promote higher soils moisture for a longer period of time, increasing the opportunity for denitrification. This is opposite of what we see for P, where more P is retained by the steep buffers. This is a surprising finding but in these cases, there is production of dissolved inorganic P within the buffer. More of this is produced in flat buffers than woody buffers. Steep buffers are still providing more sediment P output but less dissolved P output.

From the input data, it can be seen that the cell with largest amount of sediment output is not associated with the largest amount of N and P, suggesting that much of the N and P is coming from the dissolved phase and not attached to sediment. The size of the cell also does not seem to have an impact on N, P and sediment output, but that is expected given that the amount of nutrients and sediment generated from an AnnAGNPS cell is tied more closely to the inputs. Flat buffers retain on average 5% - 10% more sediment than steep buffers. The fraction of sand silt and clay will have an impact on the amount of sediment transport within the buffer, and ultimately retention, with higher amounts of sand leading to greater retention.

When specific data on areas available for buffer implementation in Stemple Creek Watershed are developed, REMM can be used to simulate the actual buffer scenarios. These scenarios should represent the actual ratios of source to buffer area possible for buffer implementation within the watershed.

References

Bingner, R. L. 2007. Stemple Creek Watershed CEAP Special Emphasis Project Final Report (DRAFT). USDA-ARS-NSL, Oxford, MS.

Graff, C. D., R. G. Williams, R. R. Lowrance, and A. M. Sadeghi. 2005. Quantifying the sensitivity of the Riparian Ecosystem Management Model (REMM) to changes in climate and buffer characteristics common to conservation practices. Transactions of the ASAE **48**:1377-1387.

Inamdar, S. P., S. P. Inamdar, J. M. Sheridan, R. G. Williams, D. D. Bosch, R. R. Lowrance, L. S. Altier, and D. L. Thomas. 1999a. Riparian Ecosystem Management Model (REMM). I. Testing of the hydrologic component for a Coastal Plain riparian system. Transactions of the ASAE **42**:1679-1689.

Inamdar, S. P., R. R. Lowrance, L. S. Altier, R. G. Williams, and R. K. Hubbard. 1999b. Riparian Ecosystem Management Model (REMM). II. Testing of the water quality and nutrient cycling component for a Coastal Plain riparian system. Transactions of the ASAE **42**:1691-1707.

Lowrance, R., L. S. Altier, R. G. Williams, S. P. Inamdar, J. M. Sheridan, D. D. Bosch, R. K. Hubbard, and D. L. Thomas. 2000. REMM: The Riparian Ecosystem Management Model. Journal of soil and water conservation **55**:27-34.

Lowrance, R., R. G. Williams, S. P. Inamdar, D. D. Bosch, and J. M. Sheridan. 2001. Evaluation of Coastal Plain conservation buffers using the Riparian Ecosystem Management Model Journal of the American Water Resources Association **37**:1445-1455.

APPENDIX

Appendix Table 1. Vegetation data from the field sites.

Site number	species	Diameter (cm)	Trunk id	Basal Area (m2)	Ht(m)	Volume(m3)	Biomass(mt)	Biomass (mt/ha)
1	willow	20	a	0.0314159	8	0.08377573	0.087461866	
1	willow	24	a	0.045238896	9.6	0.14476447	0.151134104	
1	willow	19	a	0.02835285	7.6	0.07182722	0.074987617	
1	willow	21	a	0.03463603	8.4	0.09698088	0.101248042	
1	willow	22	b	0.038013239	8.8	0.1115055	0.116411743	
1	willow	22	b	0.038013239	8.8	0.1115055	0.116411743	
1	willow	22	b	0.038013239	8.8	0.1115055	0.116411743	
1	willow	22	b	0.038013239	8.8	0.1115055	0.116411743	
1	willow	22	b	0.038013239	8.8	0.1115055	0.116411743	
1	willow	22	b	0.038013239	8.8	0.1115055	0.116411743	
1	willow	22	b	0.038013239	8.8	0.1115055	0.116411743	
1	willow	22	b	0.038013239	8.8	0.1115055	0.116411743	
					0	1.28939231	1.346125573	89.50303015
2	Juncus				0			
	Fennel				0			
					0			
3	Juncus				0			
	Cheatgrass				0			
					0			
4	Oak	35	a	0.096211194	14	0.44898557	0.468740936	
	oak	39	b	0.11945896	15.6	0.62118659	0.648518801	
	oak	24	b	0.045238896	9.6	0.14476447	0.151134104	
	oak	16	b	0.020106176	6.4	0.04289318	0.044780475	
	oak	61	c	0.29224641	24.4	2.37693747	2.481522714	
	oak	36	d	0.101787516	14.4	0.48858008	0.5100776	
	oak	65	e	0.331830444	26	2.87586385	3.002401855	
					0	6.99921119	7.307176485	228.3492652
5	oak	47	a	0.173494308	18.8	1.087231	1.135069159	
	willow	28	b	0.061575164	11.2	0.22988061	0.239995359	
	oak	34	c	0.090791951	13.6	0.41159018	0.429700146	
	oak	45	d	0.159042994	18	0.95425796	0.996245313	
	unknown1	19	e	0.02835285	7.6	0.07182722	0.074987617	
	willow	18	f	0.025446879	7.2	0.06107251	0.0637597	
	willow	24	g	0.045238896	9.6	0.14476447	0.151134104	
	oak	28	h	0.061575164	11.2	0.22988061	0.239995359	
	oak	24	i	0.045238896	9.6	0.14476447	0.151134104	
	laurel	14	j	0.015393791	5.6	0.02873508	0.02999942	
	laurel	11	j	0.00950331	4.4	0.01393819	0.014551468	
	laurel	10	j	0.007853975	4	0.01047197	0.010932733	
	laurel	10	j	0.007853975	4	0.01047197	0.010932733	
	laurel	10	j	0.007853975	4	0.01047197	0.010932733	
	laurel	14	j	0.015393791	5.6	0.02873508	0.02999942	
	laurel	6	j	0.002827431	2.4	0.00226194	0.00236147	
	laurel	20	k	0.0314159	8	0.08377573	0.087461866	
	oak	44	l	0.152052956	17.6	0.89204401	0.931293945	
	oak	31	m	0.0754767	12.4	0.31197036	0.325697055	
	oak	23	m	0.041547528	9.2	0.12741242	0.133018565	
	laurel	10	n	0.007853975	4	0.01047197	0.010932733	
	laurel	10	n	0.007853975	4	0.01047197	0.010932733	
						4.87650166	5.091067735	174.3516348

6 Juncus
Willow

Appendix Table 2. Nitrogen and Phosphorus content of vegetation samples

Site Number	Species	Soil ID	Comment	N (%)	P (%)
1	willow	1 & 2		2.749	0.2559
2	Juncus	3	at edge of ditch	2.226	0.1855
3	Grass	4		1.032	0.114
4	willow	5		0.9711	0.1044
4	Laurel	5		1.968	0.1483
4	Oak	5		1.398	0.1059
5	Laurel	6		1.746	0.1474
5	Unknown	6		0.9542	0.0759
5	Oak	6		1.094	0.081
5	willow	6		2.438	0.1715
5	Alder	6		2.036	0.1637
6	Juncus	7	from channel	2.007	0.1796

Appendix Figures

Site 1.

Site 2.

Site 3.

Site 4.

Site 5.

Site 6.