Surface Water Quality and Irrigated Pasture:
Field Studies in Sierra Valley, California

By

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Contents

Chapter 1

Surface water quality impacts of irrigated pasture operations in Sierra Valley, California

Introduction

Irrigated agriculture is vital to the California economy. Arguably, it is comparable in value to the maintenance of high-quality waterways, for their municipal, industrial, recreational, ecologic, and aesthetic values. However, irrigated agriculture is a recognized non-point source polluter of California and worldwide waterways (Cheng et al. 2007; Cremann et al. 2005; US EPA 2003; Hunter et al. 1999; Donnison et al. 2004; Carpenter et al. 1998; Bohn and Kershner, 2002). If transported from agricultural lands as part of return flows (e.g. subsurface drainage and surface tailwater) pollutants such as fertilizers, pesticides, sediment, and bacteria can degrade streams and other freshwater bodies. However, while it can potentially threaten water quality, irrigated agriculture, as a managed system, also may develop opportunities for minimizing water quality threats.

Intensively managed (i.e. high chemical input) agricultural practices can have severe impacts to water quality (Carpenter et al. 1998; Howarth, 2000), and most current watershed-scale activities in agricultural non-point source pollution research focus on these intensive production practices and the associated water pollution from fertilizer and chemical inputs (US EPA 2003). While these constituents and the agricultural practices introducing them to waterways are important on a state and national scale, they are not representative of all agricultural practices. There are also vast areas of low-intensity irrigated systems which have received little attention for their potential impacts or benefits to water quality. Among these neglected systems are the high-elevation meadows of the Sierra Nevada Mountains. With limited suitability for intensive agricultural production or development, these meadows are often managed as pasture for grazing animals.

Table 1. Selected geographic details of the UFRW and SV (Vestra, 2005 and ESF, 2005).

Description	UFRW	Sierra Valley
Elevation (m)	685 to 3,050+	1,525 to 2,440+
Temperature (Annual average °C)	NA	-1 to 17
Precipitation (cm)	75 to 450 (E-W)	95 to 390 (E-W)
Area (ha)	834,500	121,730
Irrigated hectares	24,280	16,190
National Forest (% of watershed)	80%	43%

The Upper Feather River Watershed (UFRW) (Figures 1 and 2) in the northern Sierra Nevada is home to many of these agricultural valleys, including Sierra Valley (Figures 2 and 3), the largest high-alpine valley in the U.S. (Vestra, 2005). Sierra Valley agricultural operations are dominated by irrigated summer pasture, with 98% of the surface and groundwater used in the Valley as irrigation (85% surface water, 15% pumped groundwater (Vestra, 2005; ESF, 2005). Although the Sierra Valley watershed is less than half (~ 40%) the area of the Middle Fork Feather River Hydrologic Unit, it contains the majority (~85%) of the irrigated land (Vestra, 2005) (Table 1). Cattle represent the highest value at $2.8 million in 2002 of any agricultural commodity for Sierra and Plumas counties alone (Vestra, 2005; ESF, 2005). Sierra Valley is identified by the UFRW Integrated Regional Watershed Management Plan (IRWMP) as a priority subwatershed of the UFRW, meaning it exhibits degradation, contributes to sediment loading of the Feather River and should be among the first areas to receive restoration and management attention.

The Sierra Valley watershed is the location of a number of watershed restoration activities and is identified for further such activities, in some cases as a direct result of water quality impairments. The Sierra Valley Watershed Assessment (SVWA) summarizes: “Identified impairments to water quality in the Middle Fork Feather River include dissolved oxygen, temperature, and sediment (and) it has been suggested that Sierra Valley is a main contributor of sediment to the Middle Fork Feather River" (Vestra, 2005). While these impairments have been identified, they have not been attributed to particular land uses. Prior to this study, there has been no effort to isolate and study the impacts of flood-irrigated cattle pasture on the quality of surface waters in Sierra Valley (Vestra, 2005).

The Feather River Coordinated Resource Management (FRCRM) group established and monitored water quality at dozens of sites within the UFRW in 2002-03, but relative to Sierra Valley, only one site was monitored near Beckwourth. The FRCRM has historic and on-going (21 years) watershed restoration projects in the UFRW. In Sierra Valley, significant resources have been focused on stabilizing streams and reducing sediment, and their stream monitoring efforts reflect this concern with a thorough record of channel geomorphology and other physical characteristics. The FRCRM also evaluated a number of water quality parameters, but these data are not their primary focus, and the FRCRM annual report does not discuss water quality monitoring data but rather the scope and state of current restoration projects.

Part of the effort to manage agricultural non-point source pollution is California Water Code Section 13260 which mandates a regulatory process providing agricultural discharge waivers across California's Central Valley and tributaries. A recent amendment to the Water Quality Control Plan for the Sacramento and San Joaquin River Basin (which includes the Feather River) addresses agricultural surface drainage discharges. This requires that all irrigated land managers in the region develop and implement water quality management and monitoring plans for permission to discharge irrigation return flows, or storm water flows, from their properties into waterways of the state. Irrigators must demonstrate that their agricultural activities do not impair the beneficial uses of the waterways. The SVWA identifies the following five designated beneficial uses of the surface waters in Sierra Valley: Agriculture- Irrigation and Stock Watering; Recreation; Freshwater Habitat- Warm and Cold; Spawning- Cold; Wildlife Habitat.

The California Rangelands website (http://californiarangeland.ucdavis.edu/) identifies four primary pollutants common on grazed lands: sediment, nutrients, pathogens and heat (stream temperature). Additionally, flood irrigation can be associated with reduced dissolved oxygen. None of these effects have been documented in Sierra Valley, despite several studies of water quality within the last 50 years (Vestra, 2005). The constituents of greatest concern for any given agricultural operation depend on the nature of the operation as well as location and management factors, which are highly variable. Local monitoring data informs an agricultural watershed of its particular water quality situation and is the first step to a site-specific management plan, which is critical to efficient and effective resource utilization.

This paper summarizes the results of surface water quality monitoring in Sierra Valley from 2005-2007. The objectives of this study are to:

• Determine current baseline surface water quality conditions in Sierra Valley.

• Determine whether livestock pasture irrigation detrimentally impacts water quality in Sierra Valley as a result of overland return flows by the following measures:

1. Compare measured concentrations for all constituents in streams below versus above irrigated agriculture regions of Sierra Valley.

2. Determine whether measured concentrations for *E. coli*, nutrients, sediment, and temperature in streams below irrigated agriculture regions of Sierra Valley exceed water quality limits during the irrigation season.

3. Determine whether measured instantaneous constituent loads exiting the irrigated agriculture regions of Sierra Valley are greater than the sum of constituent loads of all streams entering the Valley upstream of these regions.

4. Determine whether the stream flow profile (above to below) during the irrigation season shows a high level of water use in the Valley.

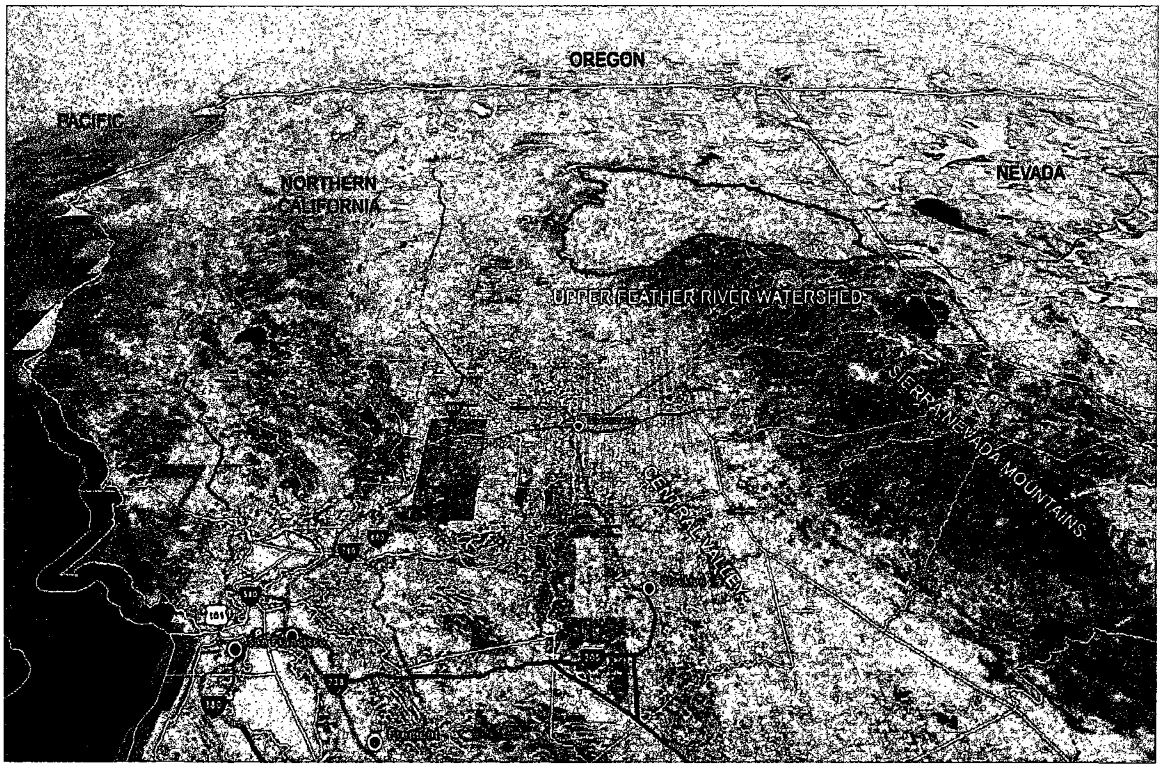
• Implement and evaluate best management practices (BMPs).

Methods and Materials

Study Area

The Upper Feather River Watershed (Figure 1) straddles the Northern Sierra Nevada Range between the Great Basin Desert and the Central Valley of California. The collective streams, rivers, lakes and reservoirs of the watershed drain into Oroville Reservoir and are a major source of freshwater for the State Water Project of California.

Figure 1. UFRW regional setting

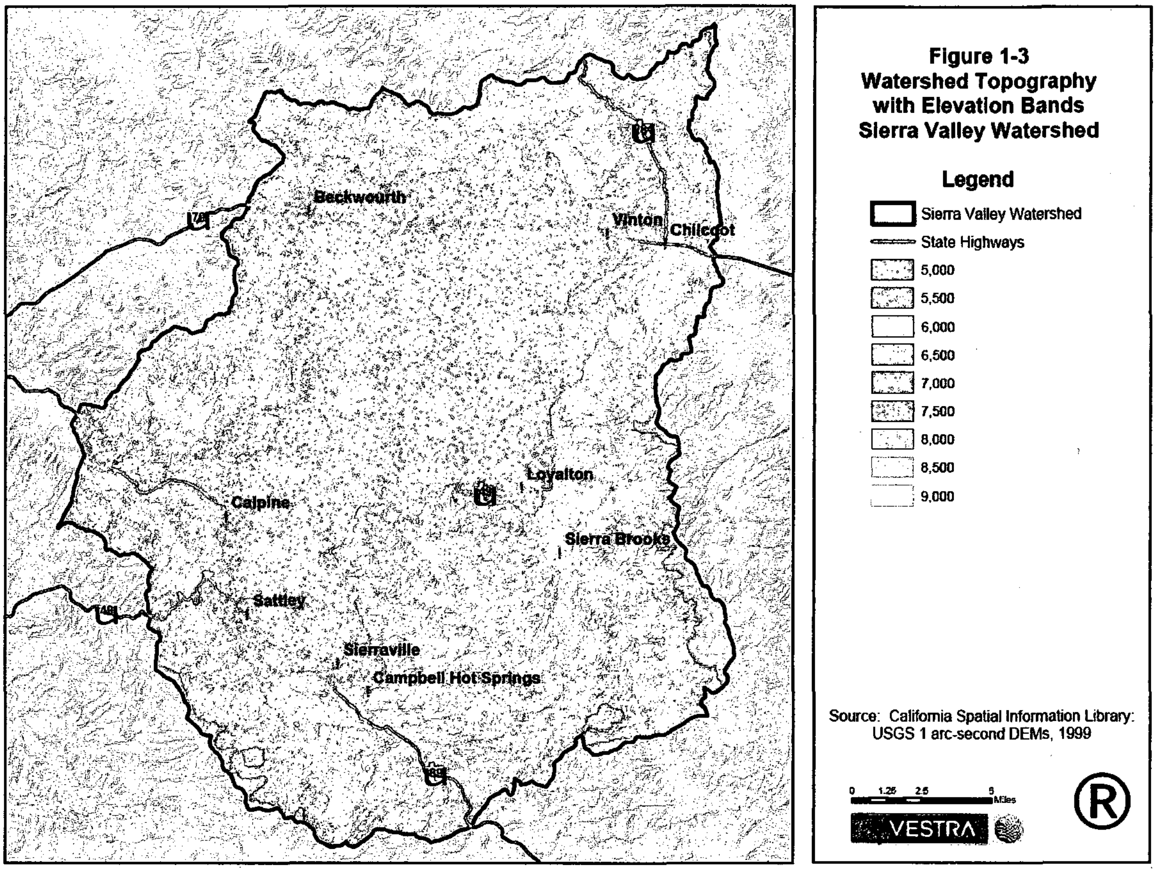


Source: ESF (2005)

Figure 2. UFRW alluvial valleys

Source: ESF (2005)

Figure 3. SV boundary and relief



Source: Vestra (2005)

Land Use

There are several small towns along highway 70 and 89 as well as individual homesites scattered throughout SV. Wastewater from these developments is primarily handled through individual septic systems except in Loyalton, which has a sewage system and water treatment facility, which discharges into Smithneck Creek.

Much of the watershed is owned and operated by the U.S. Forest Service. Other public agencies, such as the Bureau of Land Management, bring public land ownership to a majority. Most of this land is on the mountains surrounding the Valley. There are numerous recreational uses of these public lands, including campgrounds along some of the major inflowing streams. The Valley floor is almost entirely privately owned and managed for forage and livestock production. There are some small natural reserve areas managed for wildlife.

Cattle are typically brought into the Valley in May and removed from the Valley by November, with a very small portion of livestock kept in the valley through the winter months. Most agricultural operations are flood-irrigated by stream-diversion ditches, and rarely by pipe. Some operators, especially on the drier northeast side, utilize overhead sprinkler systems. Groundwater use has declined substantially in the last several decades, but the depletion of the SV aquifer by past pumping may have reduced the number and water volumes from springs and seeps during the dry summer months (ESF, 2005). Irrigation methods will be an important consideration in developing BMPs, but this study does not contrast the impacts of different irrigation techniques.

Geology and Soils

SV is in a tectonically active region, with three major northwest trending faults through the valley. Numerous thermal springs are associated with this activity. The general geologic composition of the watershed is recent volcanic deposits overlying metavolcanic rocks and granite (Table 2). The Valley floor was home to a Pleistocene-era lakebed and is composed of very deep Quaternary sediments (Vestra, 2005; ESF, 2005).

Table 2. Characteristic geologic composition of source watershed for each inflowing stream, and relative pH of source watershed soils.

Stream (site number)	**Dominant geology of source**	**Soils**
Little Last Chance (10)	Granite/Granodiorite	Acidic
Smithneck (13)	Miocene/Pliocene volcanics	Basic
Cold Creek (15)	Miocene/Pliocene volcanics Unique (granite) when diverted from the Little Truckee River	Basic
Turner Creek (16)	Granite/Granodiorite	Acidic

While many of the upland soils are classified at varying levels of slight to moderate acidity, the Valley soils, making up more than 60% of the soils in the watershed, are dominated by soil series with basic and calcareous subsoils. While there is high erosion hazard for mountain soils, largely attributable to slope, there is slight to moderate risk for erosion of valley soils, where irrigated agriculture takes place (Vestra, 2005).

Monitoring design

Water quality monitoring began in summer 2005 and continued through winter 2008. The first year of sampling secured preliminary data, and a full-scale watershed monitoring plan was designed and implemented beginning in summer, 2006. At this time there were seven sampling sites in SV (Table 3): 4 above irrigated agriculture, 1 below mixed agricultural and urban land use, 1 in a swampy area near the bottom of the Valley, and 1 at the bottom of the valley representing the ultimate outlet as the Middle Fork of the Feather River (MFFR). In 2007, the outlet sampling site was moved further downstream from the 2006 site to include a grazed USDA Forest Service allotment which is considered part of SV. More water, from the irrigation of the allotment and possibly from shallow groundwater inputs, flows in the stream for most of the season at this location (site 11.5) as opposed to the original sampling site (11). The original site (11) continued to be sampled for comparison of water quality parameters between the two locations.

Table 3. Sampling site information.

Site Number	**Stream Name**	**Location (relative to irrigated agriculture)**
10	Little Last Chance Creek	Above ag.; Below USFS Campground
11	Middle Fork Feather River	Valley Outlet; Below ag; County Road A23 Bridge
11.5	Middle Fork Feather River	Valley Outlet; Below ag.; Above confluence with Grizzly Creek
12	Perry Creek	Below urban; Below some ag; Above most ag.; Continuous with Cold Creek; Hwy 89 Bridge
13	Smithneck Creek	Above ag.; Poole Lane Bridge
14	Middle Fork Feather River	Center of valley ag.; Dyson Lane (Steel) Bridge
15	Cold Creek	Above ag; Below forest with recreational use
16	Turner Creek	Above ag.

It is difficult to isolate irrigated agricultural activities from all other possible sources of water contamination in a field study, but sampling sites were chosen to represent only impacts from irrigated agricultural operations as accurately as possible. Sites above agriculture are meant to represent all impacts from non-agricultural activities higher in the watershed (forest, urban, etc.) and differences in water quality between these sites and those sites below agriculture are taken to represent water quality impacts primarily due to agricultural operations.

Sampling occurred at different intervals during each sampling season, but was typically conducted every two to four weeks during the irrigation season. The summer sampling schedule was pre-determined and not irrigation-event driven.

- 4 sampling events between 22 June 2005 and 20 September 2005
- 10 sampling events between 01 May 2006 and 26 September 2006
- 7 sampling events between 17 April 2007 and 02 October 2007

One-liter grab samples were taken to represent a mixed sample of the water column. These samples were packed in iced coolers and transported to the laboratory for analysis within 24 hours. Upon delivery to the laboratory, E. coli analyses were conducted within 24 hours of sampling and remaining sample water was kept refrigerated or frozen for additional analyses to be completed within the recommended holding times associated with the analysis (Table 4). (For more information on analysis methods, see Appendix 1.) Grab samples may not always represent average conditions. Another sampling method which might produce a more accurate image of average conditions is to take multiple samples over a limited interval and derive an average value, but this technique was not feasible within the limits of this study.

Table 4. Water quality constituents monitored with WQO established for UFRW.

Constituent	**Water Quality Objective (WQO)**	**Location of analysis**
Turbidity	NA (narrative; relative to background)	Tate Lab
Total Suspended Solids	NA (narrative; relative to background)	Tate Lab
Electrical Conductivity	150 µS/m Feather River; 700-900 µS/m for Ag. Program	Tate Lab
pH	6.5-8.5	Tate Lab
Dissolved Oxygen	7 mg/l (coldwater fisheries)	Field
Temperature	NA (For Rainbow Trout <24°C)	Field
Instantaneous Stream Flow	NA	Field
E. coli	235 cfu/100ml (for single grab sample)	Tate Lab
Metals	Se - 5 µg/l Ni – 100 µg/l Cu, As – 10 µg/l Zn – 5000 µg/l B – 700 µg/l Al, Fe, Cd, Pb - NA	UCD ICPMS Lab
Toxicity	None	Pacific EcoRisk Lab
Total Nitrogen	NA	Tate Lab
Nitrate-N	10 mg/l	Tate Lab
Ammonia-N	25 mg/l	Tate Lab
Total Phosphorous	NA	Tate Lab
Phosphate-P	NA	Tate Lab
Dissolved Organic Carbon	NA	Tate Lab

Samples for water column toxicity and metals were taken once monthly during the 2006 irrigation season, only from the valley outlet. Sediment toxicity samples were taken only once at the end of the sampling season. Toxicity tests were conducted by Pacific EcoRisk laboratories. Metals analyses were performed by the Integrated Center for Plasma Mass Spectrometry (ICPMS) at UC Davis. All other lab analyses were conducted in the laboratory of Dr. Ken Tate at UC Davis.

E. coli was used as an indicator organism for bacteria and pathogens for the ease and economy of the culture, and because there is a water quality objective (WQO) listed for it in the UFRW. There is ongoing research as to the appropriateness and accuracy of various bacterial indicator organisms and the choice remains difficult. High *E. coli* concentrations do not necessarily represent high pathogenicity (Geldreich, 1996). In fact, continuing research in SV is designed to evaluate the actual pathogen risk of waters relative to *E. coli* concentrations.

Load balances were calculated by summing the instantaneous loads of inflowing streams (above agriculture) and subtracting the instantaneous load of the outflowing stream using both stream flow and concentration data. These values demonstrated whether the Valley was ultimately a source or a sink for a given constituent at the moment of monitoring.

Results and Discussion

Stream flow is of primary importance in first obtaining and then interpreting water quality information, and so is discussed first. While all water quality constituents are mutually correlated in complex ways, SV stream temperature and dissolved oxygen are especially impacted by stream flow conditions, and so are discussed next. The remaining constituents are discussed in the order of the relative impact of the constituent according to our results and relative to the water quality objectives for SV, beginning with electrical conductivity and pH, followed by bacteria, nutrients, sediment and toxicity.

Flow

Sierra Valley (SV) has relatively moderate rainfall, with most areas of the watershed receiving approximately 35 to 50 cm of precipitation per year (Vestra, 2005). Nearly all precipitation falls in winter, and summer flows are sustained by snowmelt, springs, and a diversion via Cold Creek from the Little Truckee River.

River ecosystems depend on a certain amount of water flow for species survival (Allan, 1995). Most aquatic systems are adapted to seasonal variations in flow, but in the Western U.S. many have been altered from their natural flow variability by human consumptive use, to the detriment of many aquatic species (Neumann et al. 2006; Allan, 1995). Decreased flows often result in higher stream temperatures, higher pollutant concentrations, and lower dissolved oxygen levels, creating a stressful or toxic environment for some aquatic species (Allan, 1995), including those which provide important ecosystem services such as nutrient cycling, and those which provide important human recreational or nutritional benefits. The SVWA states: "The primary contributor to many of the water quality problems found in the Valley is low flow conditions."

While low flows often result in higher concentrations of pollutants, they also result in lower in-stream energy and therefore less transport of pollutants downstream. If the pollutant is cycled within the system (such as a nutrient) this can be an overall benefit, but if the pollutant is not readily cycled (i.e. metals), the pollutant may accumulate in sediments during low-flow conditions and be re-suspended in the water column and transported downstream during storm events. While some regulatory limits are based on concentrations of pollutants (such as the Water Quality Objectives for the UFRW), some are based on loads (such as the Total Maximum Daily Load Limits recommended by the EPA). In either case, the stream flow is an important parameter.

A reduction of outflowing water relative to inflowing water, as seen in SV in mid-irrigation season, is desirable because no pollutants are being transported from the Valley, but undesirable because aquatic ecosystems downstream might rely on water from SV for survival. (There is no historic record of the natural flow levels from SV prior to agricultural activities in the watershed, so it is impossible to determine a target historic level. There is also no way to design a control treatment at this scale to evaluate what SV hydrologic conditions would be without water diversions, groundwater pumping, or irrigation activities.) Long-held water rights are cherished by agricultural producers, but urban and environmental water needs are only likely to increase in SV as well as throughout the state. Also, as tourism, recreation, and other service-based (rather than resource-based) activities become an important source of income for small agricultural communities, the appearance of the landscape and the quality of the water upon it become concurrently more important to those communities and the agricultural producers within them. It is important that all agricultural, urban, and environmental water rights and needs be evaluated relative to the budget of available water in the watershed and allocated according to reasonable, sustainable use within a complex working landscape. Water management decisions will require all water users to consider a balance of existing and planned water uses, along with goals for the maintenance of aquatic ecosystems.

Illustrated in Figure 4 is the primary stream flow data that suggests water is a limiting resource in SV during the summer irrigation season. Figures 4a and 4b show the calculated instantaneous flow for all major (monitored) streams in SV. Flow Data from 2005 was not complete. Figure 4c shows the balance of water flowing into the valley relative to that flowing out of the valley. A value of zero would indicate a perfect balance; an equal amount of water entering and leaving the valley. Positive values indicate that water is consumed within the valley, whereas negative values indicate that water is added to the outflowing stream either from valley storage or input from minor streams not monitored. Streams entering the valley have relatively high flows early in the season which diminish rapidly (Figures 4a and 4b). More precipitation prior to the 2006 sampling season resulted in substantially higher and longer-lasting flows than in 2007. However, in both years, flows in all streams were below 0.5 m^3/s by late July.

The flow balance in SV (Figure 4c) in both years is similar: extra water is gained from valley storage or minor (unmonitored) inflowing streams in the early season until late June, after which water is used consumptively within the valley. By early August, 100% of inflowing water remains in the valley, there is no measurable outflow.

Figure 4a. SV stream flow 2006

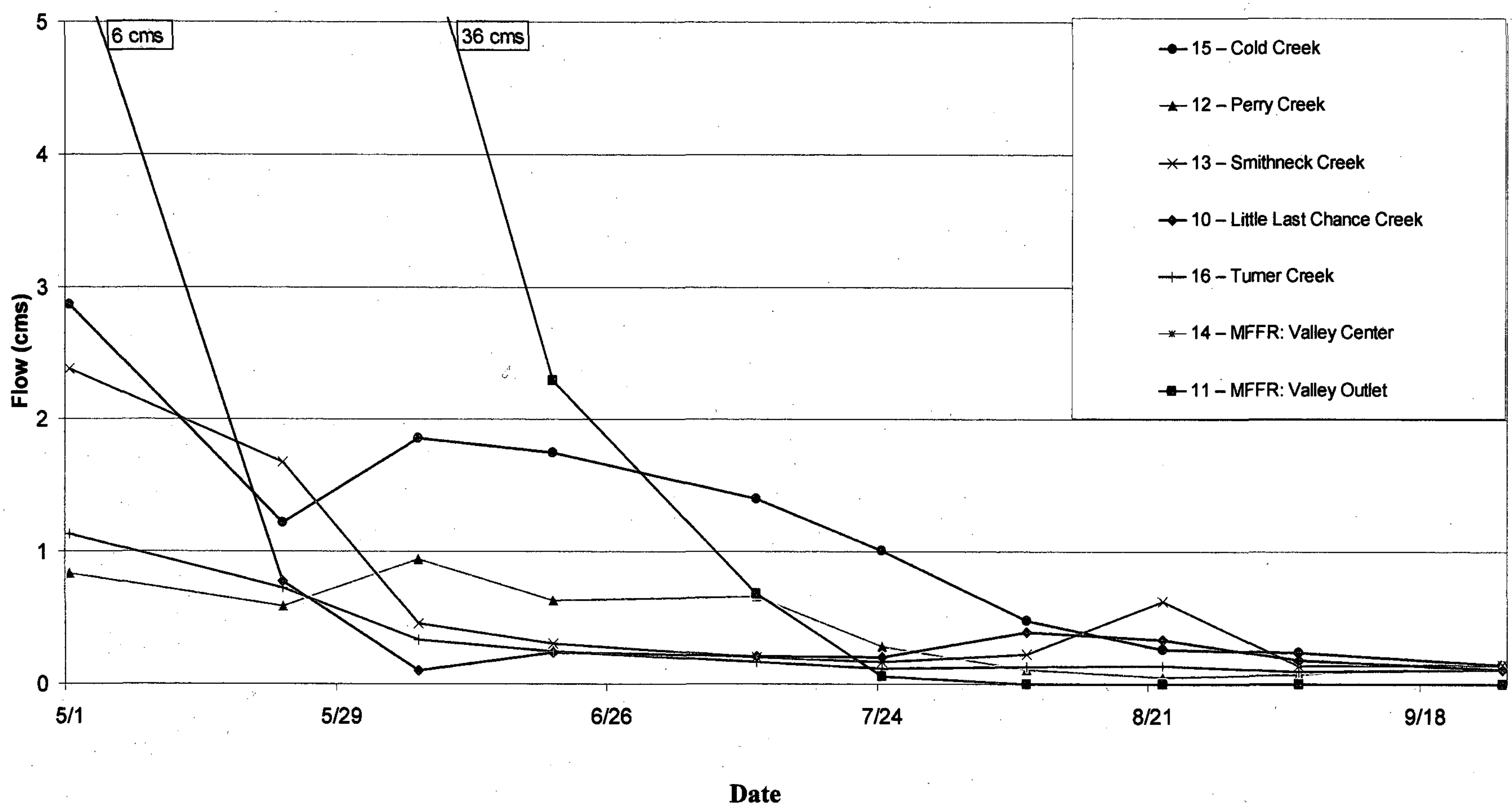


Figure 4b. SV stream flow 2007

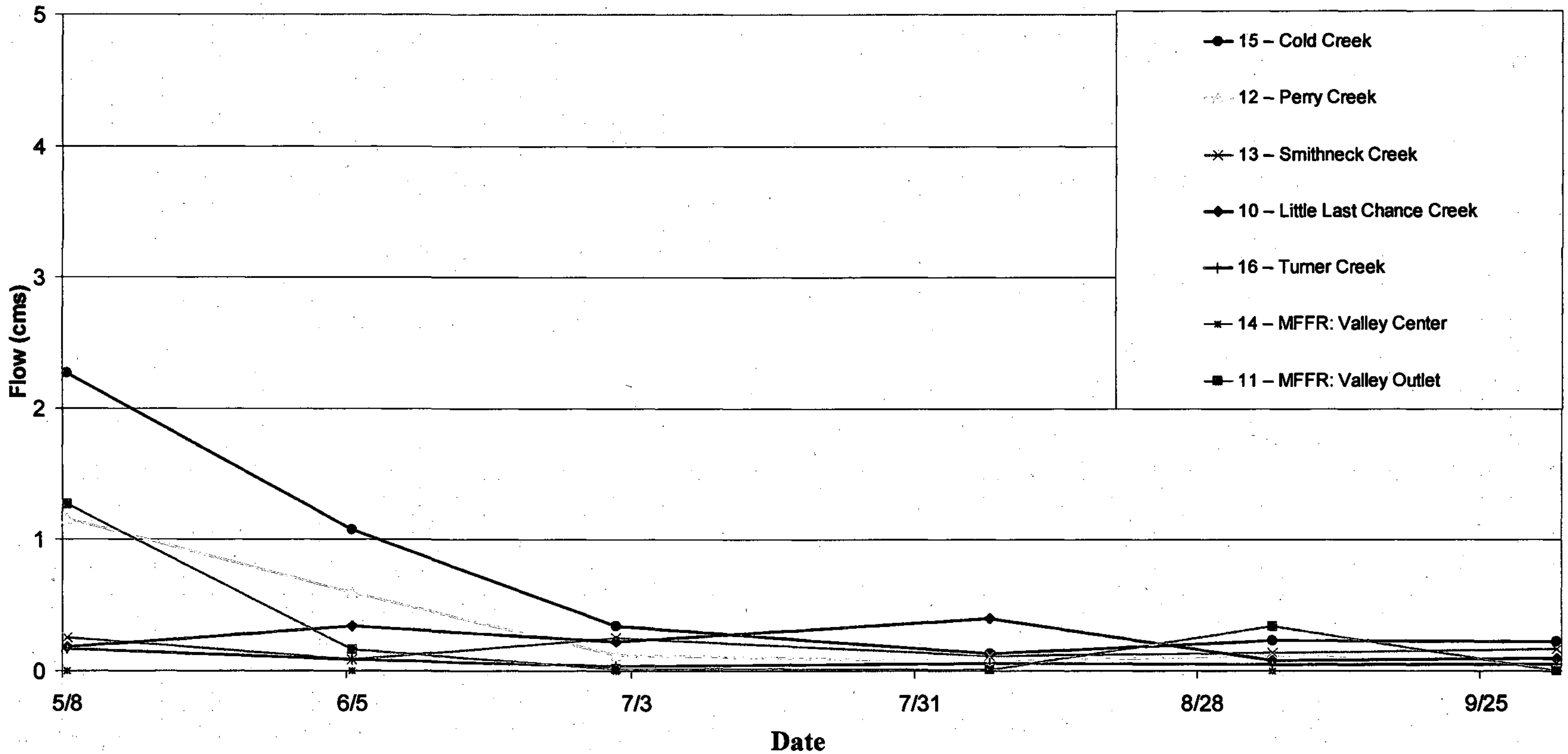
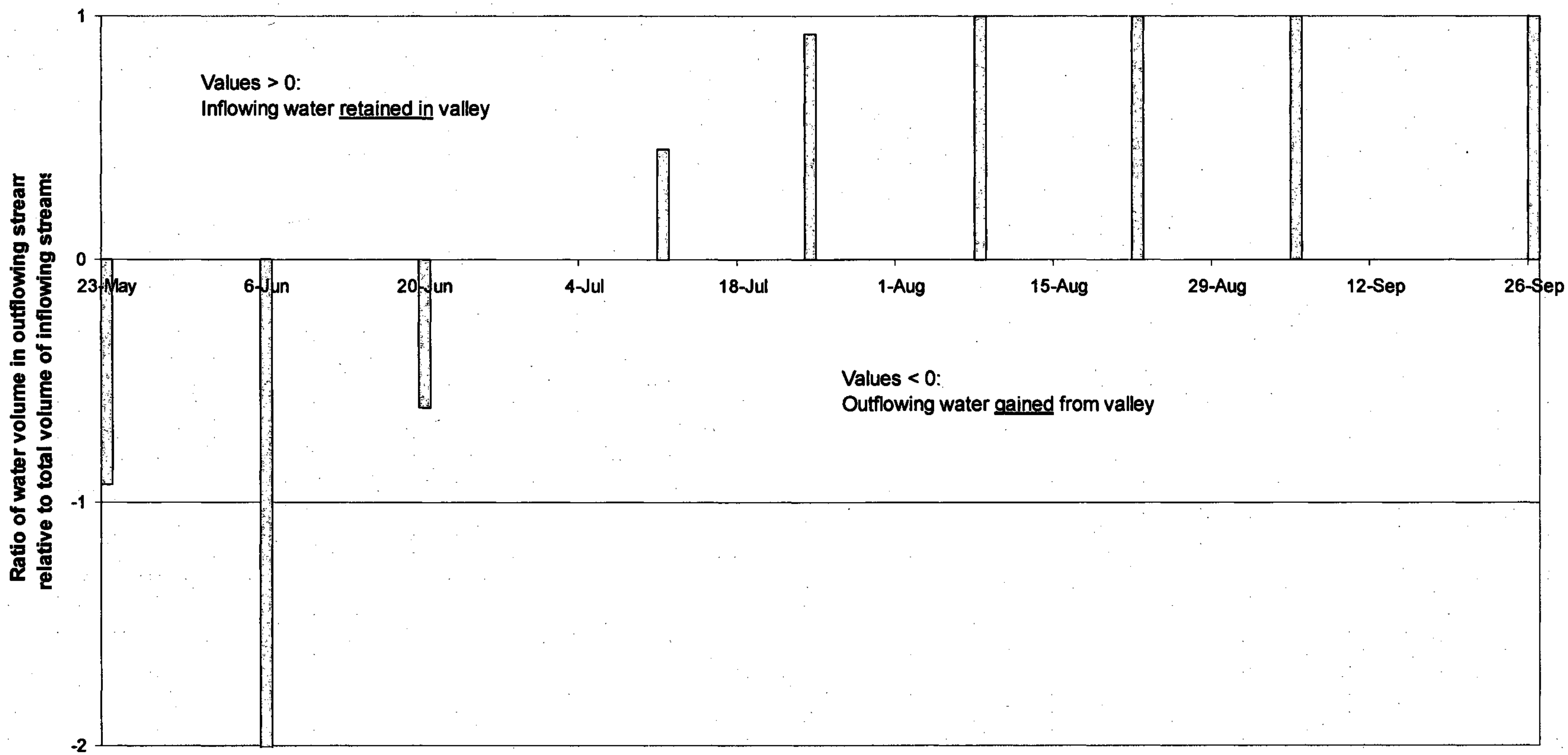


Figure 4c. SV instantaneous flow balance 2006



Temperature

Currently, the waters of SV are classified as having beneficial uses as warm, cold and spawning cold water habitat (Vestra, 2005). Although the UFRW Basin Plan (ERS, 2005) lists temperature as an important objective in watershed management, it does not list an upper or lower limit. Data is available demonstrating the temperature tolerances of various fish species, and generally cold-water fish species such as trout do not tolerate temperatures above 24°C (75°F) (Eaton et al. 1995), which is referred to in this paper as the maximum value for coldwater fisheries. There is some discussion about rehabilitation of native fish species in the UFRW: as reported in the IRWMP, there is interest in developing fish passages around Oroville dam, re-opening the UFRW to cold-water anadromous fish runs. Were this to proceed, in-valley stream temperatures could become more important for their suitability for cold-water fisheries, depending upon the role that valley floor streams naturally served in the migration, spawning, rearing, and ex-migration of these species.

Stream temperatures may be raised by flood irrigation in two manners: 1) When irrigation water is spread over a field, the shallow water has an expanded interface for thermal exchange with the soil surface and the atmosphere, and if these media are warmer than the stream, stream temperature will rise; upon return to the main body of the stream, the temperature of this return flow may be high enough to increase the main stream temperature; and 2) When water is diverted from the stream for irrigation, the main body of the stream becomes shallower and slower, exposing the stream itself to greater direct solar and air thermal input, and the temperature increases more rapidly than if flow were not reduced (Tate et al. 2005; Neumann et al. 2006).

Tate et al. (2006a) found that some fish can make use of thermal refugia in deep pools where temperature stratification maintains cool temperatures during periods of peak warmth. However, a source of inflowing water must, at some interval, replenish the oxygen and nutrients required by fish utilizing these refugia (Allan, 1995). Also, other aquatic organisms, such as invertebrates, may not be able to utilize refugia, and may therefore be more severely impacted by high stream temperatures. The loss of these organisms can disrupt the food chain and thereby have significant effects on the rest of the stream ecosystem (Wallace and Webster, 1996; Allan 1995).

Stream temperature variation is a complex matter to describe, and can be difficult to summarize in a meaningful manner. While average temperatures, minimum temperatures, and daily variation in temperature may all have important effects on one or more aspect of stream ecology, for the purposes of this study, maximum stream temperature is assumed to be the greatest ecological stressor and only daily maximum temperatures are discussed.

Overall, maximum stream temperatures change seasonally with air temperature in all years (Figures 5a 5b, 5c). Relative temperatures are similar from year to year, following the order of coolest to warmest by site number: 10, 15, 12, 14, 13, 11; such that the Valley outlet site is the warmest. There are two anomalies to these generalities: Turner Creek (16) and Little Last Chance Creek (10). Turner Creek daily maximum temperatures were much greater in 2006 than in 2007 (it was not monitored for temperature during 2005). This is unexpected, since flows in all streams were lower in 2007 than in 2006, and lower flows typically result in greater temperature extremes. However, 2006 air temperatures were much higher on average than in 2007. Because

Turner Creek is a small stream, the higher air temperatures in 2006 probably resulted in higher maximum stream temperatures that year. In 2006, Little Last Chance Creek is consistently colder than other streams and does not follow the same seasonal temperature pattern as the other streams from late June through mid-September. In 2007, it remains the coolest stream, but trends more closely with the seasonal temperature pattern exhibited by other streams. This may be at least partially explained by releases to the stream from the Frenchman's Lake Reservoir. There is not sufficient difference in the mid- to late-season flow between these years to explain the 3°-6°C (5°-10° F) temperature difference between years. Most likely, the stream had more cold water input from snowmelt or reservoir releases during 2006 than 2007.

The average daily water temperature at the valley outlet was typically higher than the average daily air temperature throughout the sampling season in 2006 and 2007. Early season temperatures were somewhat higher in 2006 than in 2007 for both air and water, but the fluctuation between daily maximum and minimum temperatures was much greater in 2007 than 2006, as a result of lower flow volume.

Maximum daily water temperatures at the valley outlet exceeded the maximum temperature limit for coldwater fisheries, especially in mid-summer, and more often in 2007 than in 2006. (Some difference between years may be explained by the change in outlet site from site 11 in 2006 to site 11.5 in 2007. No temperature data were collected at site 11 in 2007.) The data set for 2005 is incomplete, but the valley outlet did exceed 24°C in late July and early August. With the exception of Turner Creek in 2006, the Valley outlet at site 11 has the highest average and maximum water temperatures throughout the season, with mid-season maximums about 6°C greater than any inflowing stream. It is difficult to determine what warming is natural versus that due to agricultural activities, but flow reduction is correlated with temperature increases. Site 14 represents the deepest water of our sampling sites, potentially providing thermal refuge for coldwater species during peak temperatures. However, there are several instances when temperatures at this site exceed 24°C in 2006 and 2007.

Figure 5a. SV 2005 daily maximum water temperature

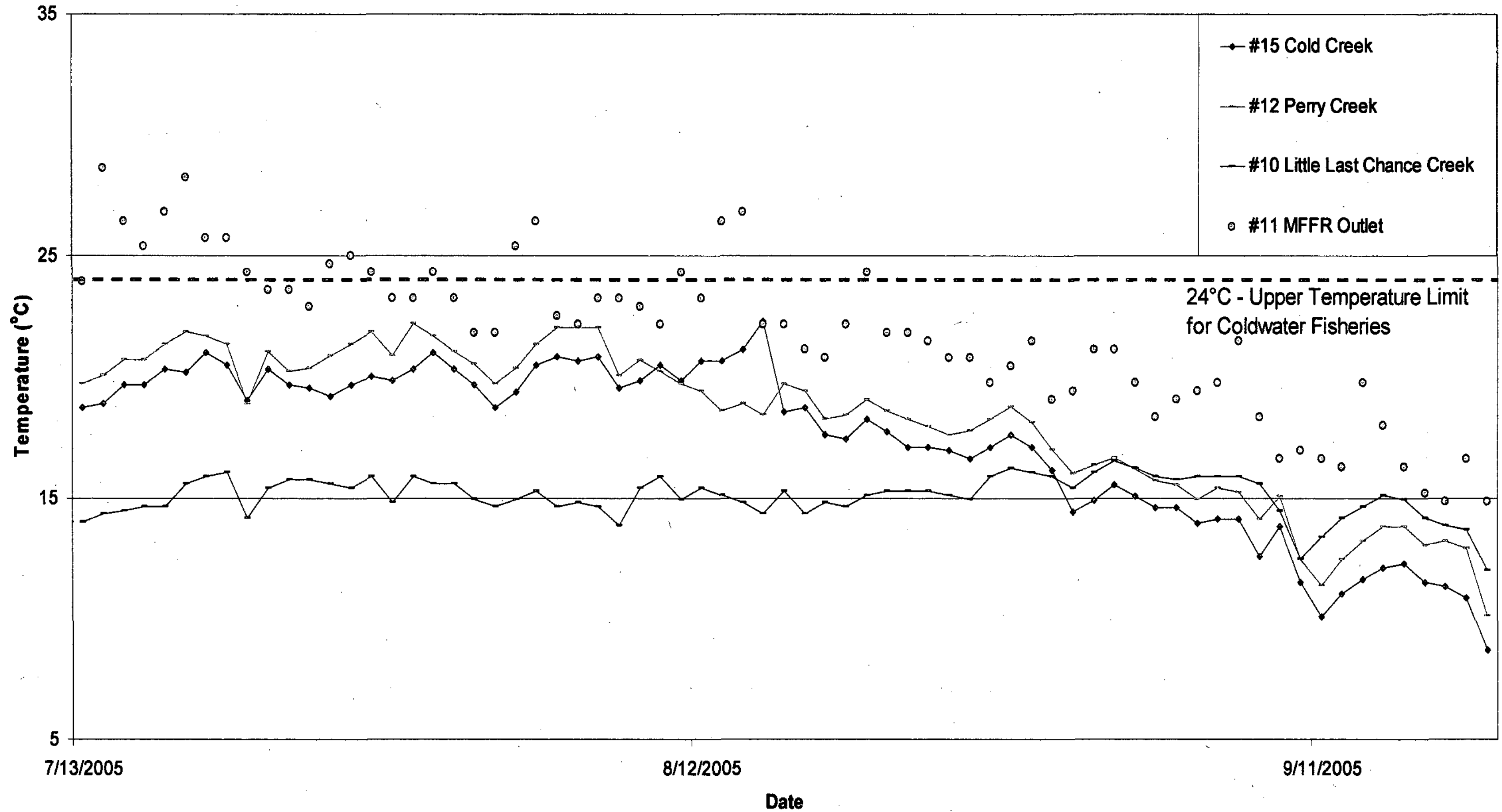


Figure 5b. SV 2006 daily maximum water temperature

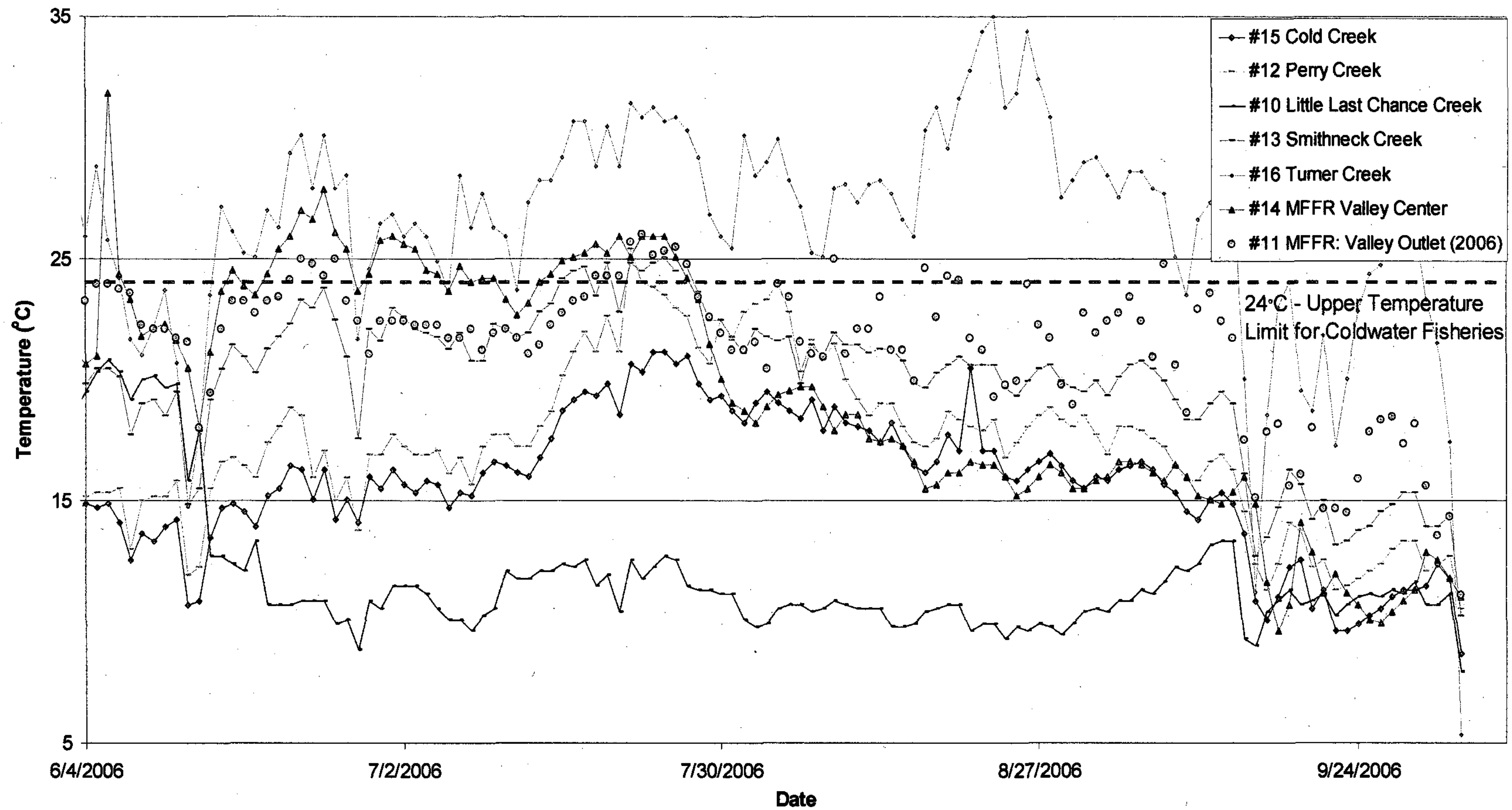
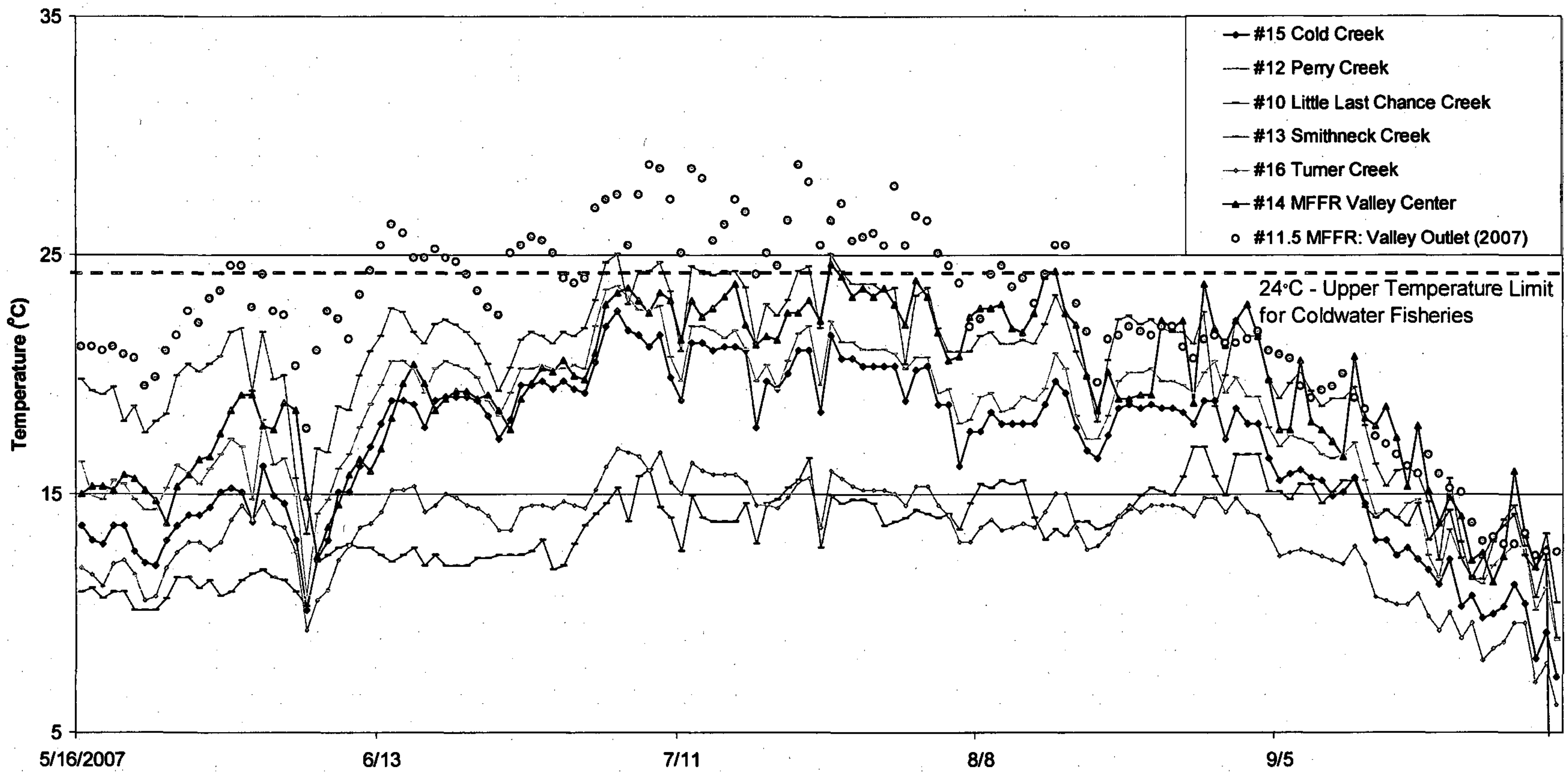


Figure 5c. SV 2007 daily maximum water temperature

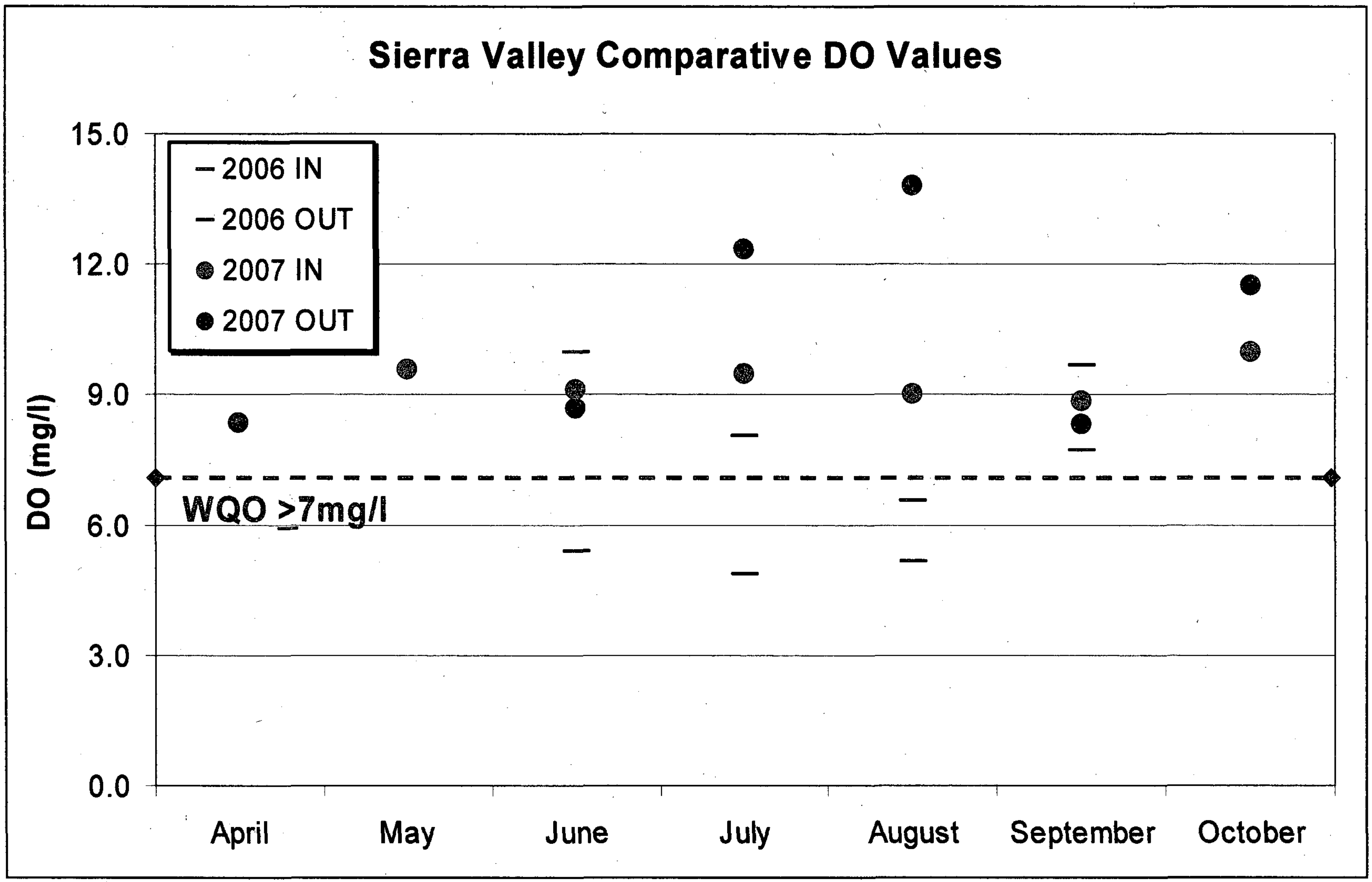


Dissolved Oxygen

Dissolved oxygen (DO) is important in supporting aquatic life and maintaining overall stream health. Fish, depending on the temperature tolerances of the species, require a certain amount of dissolved oxygen to thrive. Due to close correlation with temperature and the diurnal respiration cycles of aquatic plants, DO levels vary both daily and seasonally (Allan, 1995). The UFRW water quality objective (WQO) for DO is no less than 7mg/l.

Dissolved oxygen (DO) is a limiting resource within the Valley for the beneficial use of coldwater fisheries. Figure 6 shows the average DO values of all inflowing streams relative to the outflowing stream for 2006-2007. In 2006, 7/8 samplings had dissolved oxygen (DO) below 7mg/l at the valley outlet (11). In 2007, the outlet was re-defined and moved to site 11.5. The original site (11) was below the water quality limit on 1/5 samplings, and near the limit for 2 other samplings, while there was a drastic improvement in DO levels at the new site (11.5) with 0/6 samplings falling below the water quality limit and all samplings markedly higher than the site 11 values for the same sampling events. The additional water (increased flow) and riffles providing turbulence to the stream water column between the original and new sampling sites are probably responsible for this increase in DO. Increasing DO levels across a relatively short distance is encouraging, but it will be important to determine whether DO levels just upstream from the outlet must be improved in order to support the designated beneficial uses in that area, possibly linking the valley outlet with higher-quality upstream waters.

Figure 6. SV comparative DO values 2006-2007



Electrical Conductivity and pH

Electrical Conductivity (EC) is correlated with solute concentrations in the water and pH is a measure of the acidity or alkalinity. The WQO for EC is 150 μS/m or less and for pH is between 6.5 and 8.5. EC and pH both may be impacted as a result of agricultural activities, but they are also highly variable depending on local soil conditions and geology, which are variable within SV (Table 2, page 14).

Electrical conductivity (EC) is a particular water quality problem in SV; values often exceed the WQO. Surface water EC generally increased from May to September and from above to below the Valley (Figure 7). There is a noticeable trend towards higher EC during lower flow conditions, both seasonally and annually with all sites showing an increase in EC as the sampling season progresses and higher values overall in 2007 (low precipitation) than in other years. To summarize conditions at the Valley outlet: 2/4 samplings (late season) exceeding the WQO of 150 μS/m in 2005, 3/10 in 2006 and 6/7 in 2007. Of the inflowing streams, Smithneck Creek (13) tended to have consistently higher EC values than other sites. The sampling site is located above the town of Loyalton, but below some residential developments which may contribute to the high EC. Differences in geology and soils do not explain the high EC at site 13.

While the late season flow is similar from year to year, the EC values tend to be greater late in 2007 than in 2006, suggesting that instantaneous flow may not be solely responsible for EC variation. It is possible that flushing of soils during early season high flow in 2006 contributed to lower late-season EC values than in 2007, when reduced flows all year may have prevented adequate flushing of accumulated solutes.

In SV, pH is closely correlated with EC and poses a similar problem with numerous WQO exceedances. In all three years, stream water pH generally increased from early to late season (Figure 8). In 2005, the valley outlet maintained a relatively low pH relative to inflowing streams throughout the season. In 2006, this trend occurs until August, when the valley outlet pH begins to be similar to or higher than most inflowing stream pH, through the end of September. In 2007, a similar seasonal pattern as in 2006 occurs, but with elevated outlet pH values beginning in early July. The new outlet site (11.5) is much higher than the original (11) during late season samplings. All sites had pH above 7.0 for every sampling event. In 2005, there were no pH exceedances at any site. In 2006, two inflowing streams exceeded the WQO in late July, and the valley outlet pH exceeded WQO once in late September. In 2007, the last 4/7 samplings exceeded the WQO at the valley outlet.

The Valley floor is dominated by soils with high EC and pH, while upland soils tend to have neutral to moderately low values. (See Appendix 2 and 3 for a map of soil EC and pH.) Where inflowing streams can be identified as having either granitic or volcanic parent materials, there is not a strong correlation of soil EC or pH with the different geologic sources.

Table 5. Key to legend for all "Comparative Value" figures (Figures 6, 7, 8)

2005 IN	Mean value of two samplings for the month of all inflowing streams; site #10, 13, 15 (site 16 not sampled)
2005 OUT	Value of one monthly sample of valley outlet; site #11
2006 IN	Mean value of two samplings for the month of all inflowing streams; site #10, 13, 15, 16
2006 OUT	Mean value of two samplings for the month of valley outlet; site #11
2007 IN	Mean value of one sampling for the month of all inflowing streams; site #10, 13, 15, 16
2007 OUT	Value of one monthly sample of new valley outlet; site #11.5

Figure 7. SV comparative EC values 2005-07

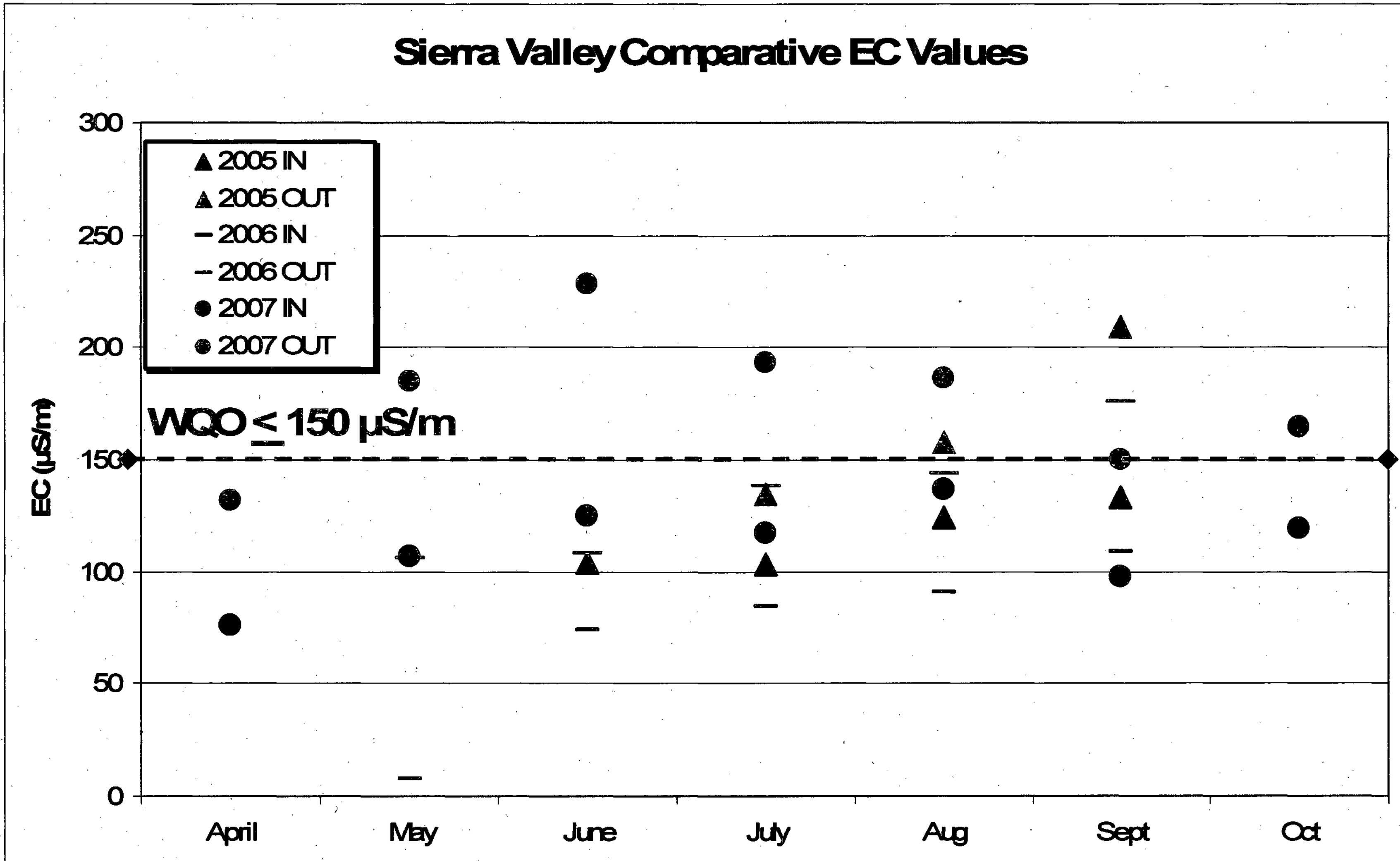
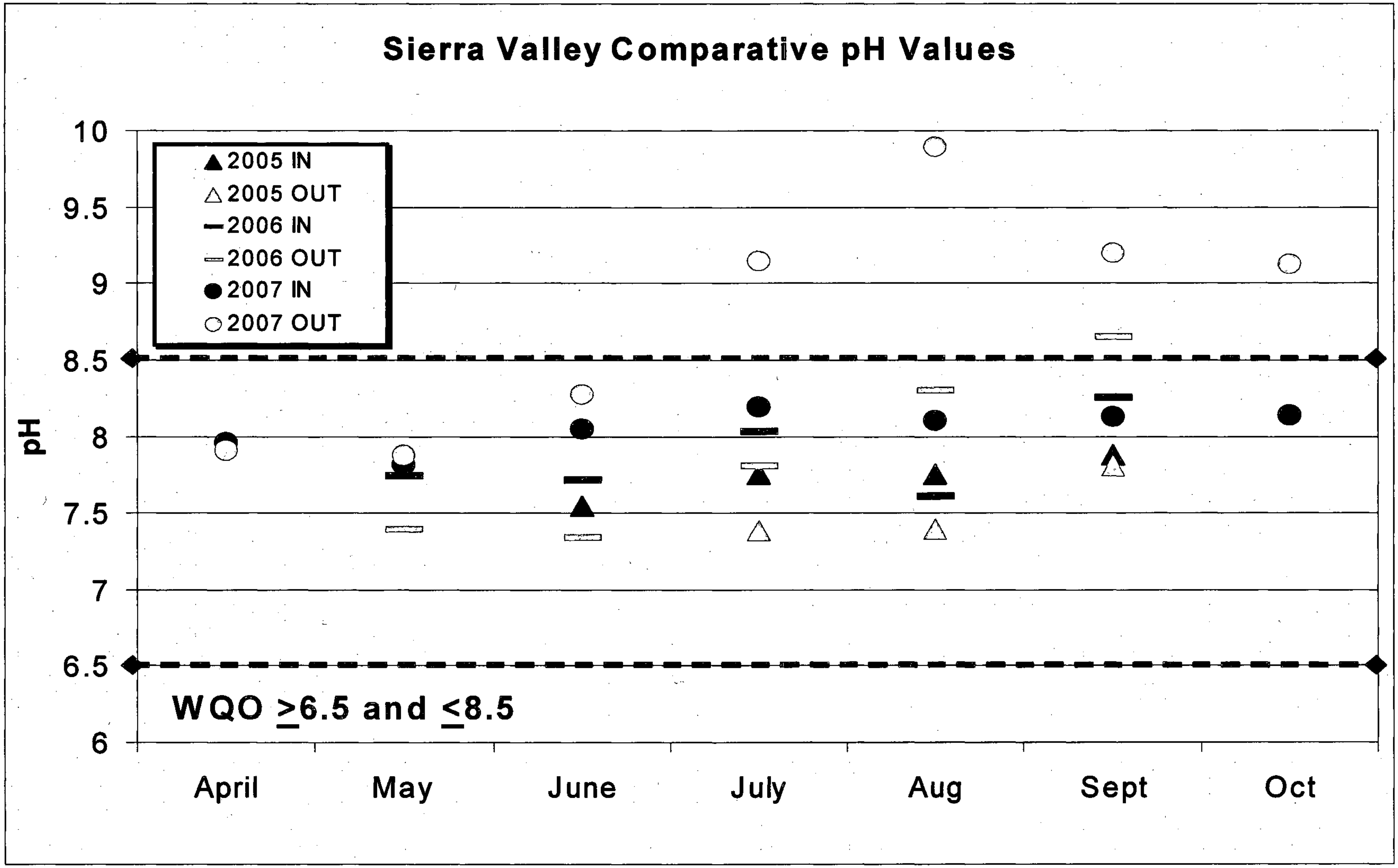


Figure 8. SV comparative pH values 2005-07



Bacteria

Bacteria, being a significant component of mammalian fecal material, are often associated with animal-based agricultural operations. Several studies have demonstrated that microbial contamination of water supplies is a significant problem in pasture-based animal agriculture (Cremann et al. 2005; Donnison et al. 2004; Hunter et al. 1999; Crane et al. 1983) and microbial contamination of water and food supplies due to agricultural production practices has resulted in numerous surges of media attention in the recent and distant past (Tiedemann et al. 1987; Geldreich, 1996). Nevertheless, this important water quality parameter has not previously been evaluated within SV.

There are several potential sources of microbial contaminants within any watershed, but essentially they can be divided into three sources: urban, agricultural and natural. In rural watersheds with similar land uses to SV (relatively little urban development and livestock-agriculture-dominated landscapes), some researchers conclude that the impact of bacterial contamination from wildlife and human activity (such as recreational water use and faulty septic systems) is negligible when compared to that of pastured beef cattle and sheep (Cremann et al. 2005; US EPA, 2003). Donnison et al. (2004) demonstrated in a high-country pasture landscape that sheep-grazed watersheds resulted in much higher in-stream bacterial concentrations at all samplings than did forested, ungrazed watersheds, suggesting that wildlife contribute less to overall bacterial contamination than domesticated grazing animals. In their system, bacterial impacts were seasonal with highest concentrations observed in summer from all land uses, including forested areas. There was no urban or human recreational presence in these watersheds.

Hunter et al. (1999) discovered that bacterial concentrations do not always represent the land use according to the previous examples. At some samplings, they found highest bacterial counts below a wooded reach of stream with very little grazing animal presence. Rather than attributing this result to wildlife, they conclude that bacteria are stored in soils and that high overland flow quickly depletes the soil store of bacteria, resulting in lower bacterial concentrations than in areas with lower overland flow. However, in areas of still or slow moving water, sedimentation can rapidly remove pathogens from the water column into bottom deposits (Geldreich, 1996). This would reduce bacterial concentration in low-flow areas relative to high-flow areas, but potentially result in a spike when flow increases and settled bacteria are flushed. Obiri-Danso and Jones (1999) found higher concentrations of bacteria in stream-bottom sediments than in the water column, and that disturbance of the sediments (by bathers or high flows) caused suspension of bacterial cells in the water column, elevating the bacterial concentration temporarily.

In a controlled experiment involving fresh cowpats and a rainfall simulator, Muirhead et al. (2006) found a high correlation between bacterial numbers in fresh feces and in runoff water. They determined that *E. coli* are transported primarily as single cells, not in clusters or attached to sediment or other particles, and recommend that strategies to reduce bacterial contamination from grazed lands should focus on restricting the transport of single cells.

When bacteria enter the environment outside a host organism, they are subject to numerous environmental stresses, including sunlight, temperature, rainfall, soil moisture, pH, organic matter, and the presence of other microorganisms introducing predation, competition, and antagonism (Van Donsel et al. 1967; Crane and Moore, 1986; Geldreich, 1996; Meays et al. 2005). Many of the factors impacting bacterial concentrations have non-linear effects and are most effective at extremes (such as drying or freezing of the soil), with little change in impact for changes in the factor at moderate levels (Crane and Moore, 1986). There are various bacterial cycling models based on different assumptions of bacterial die-off, but it remains difficult to quantitatively define the effects of physical and climatic factors on bacterial die-off rates because of the non-linear and confounding factors involved.

Temperature and moisture have a large impact on in-situ growth of fecal coliform bacteria in soils, and direct fecal input alone may not explain the bacterial concentrations in soil or water. Van Donsel et al. (1967) found that reduction of fecal coliform concentration in soil was highly variable according to season, with up to four times faster reduction in summer than in autumn. Hunter et al. (1999) also found seasonal influences, with highest in-stream bacterial concentrations in late summer. Crane and Moore (1986) confirmed that season and weather are important variables, which were often not measured or included in bacterial cycling models (along with other important variables such as pH and salinity). This leads to difficulty in interpreting and comparing results in the literature, because where researchers have reported seemingly contradictory results, it may be that the bacterial community is controlled by a variable not measured.

Hunter et al. (1999) identified small areas of stagnant water as bacterial contamination hot-spots, generating in-stream bacterial concentrations disproportionate to their size or the surrounding grazing intensity. In SV, there are numerous such areas in pastures, and there is one extensive wetland complex near the outlet of the valley. We expect to observe the poorest water quality in the valley within this wetland area, and also expect an improvement in water quality exiting the wetland system, having been filtered of excess nutrients, sediments, and bacteria.

Knox et al. (2007) found that wetland filters alone are not able to achieve optimal reductions in bacterial concentrations and multiple management measures integrating both pasture (rest from grazing prior to irrigation) and tailwater management (reduce volume, filter through wetland) were necessary to reach a sufficient reduction of bacterial concentration. Even a minimal amount of rest from grazing before irrigation helped to reduce bacterial run-off substantially. However, in some cases, despite a more than four-fold decrease in *E. coli* numbers after wetland treatment, the majority of wetland-filtered samples still exceeded water quality standards, in some cases by an order of magnitude.

E. coli contamination is not substantial at the Valley outlet during the irrigation season, but does exceed the WQO for contact recreation within the watershed. The MFFR outlet (11; 11.5) at SV never exceeded the recreation contact WQO of 235cfu/100ml during our study. However, in 2005 and 2006, there were 2 sites in SV with *E. coli* concentrations above the WQO (Figure 9a, 9b; Table 6). One site (12) is below a mix of urban development and cattle pasture, and the other site (14) is in the middle of a wetland area at the center of the valley where most water from the valley meets before passing into the main stem of the MFFR. In 2007, these sites continued to show the same patterns of elevated *E. coli* (Figure 9c; Table 6). Also one site below a USFS campground exceeded the WQO on 1/8 sampling events, and the original valley outlet site (11) exceeded the WQO on 1/8 samplings, but the new outlet site (11.5) did not exceed the WQO in 2007. In fact, the values of *E. coli* at the valley outlet in 2007 were extremely low compared with sites upstream, especially late in the season when elevated bacterial levels are common, being associated with low flows, high temperatures, and cattle presence in the areas immediately upstream from the sampling sites (Figure 10).

One explanation for the low bacterial counts at the outlet of the watershed, especially in late season, is that the lack of surface flow prevents downstream transport of bacteria from within the watershed. It is also possible that the wetland system functions to decrease bacterial loads, although most water quality parameters within this area (14) have the lowest water quality at this site. Daily temperature fluctuations up to 4.5°C are common in both summer and winter (Vestra, 2005), and these extreme temperature changes probably help to control bacterial populations.

Table 6. Number of sampling events when bacterial counts exceeded WQO

No. of Events when bacterial counts exceeded WQO (year; total samples)			
Site #	**2005 (4)**	**2006 (10)**	**2007 (8)**
10	-	-	-
11	-	-	-
11.5	-	-	-
12	1	5	4
13	-	-	1
14	1	3	3
15	-	-	-
16	-	-	1

Figure 9a. SV *E. coli* values 2005

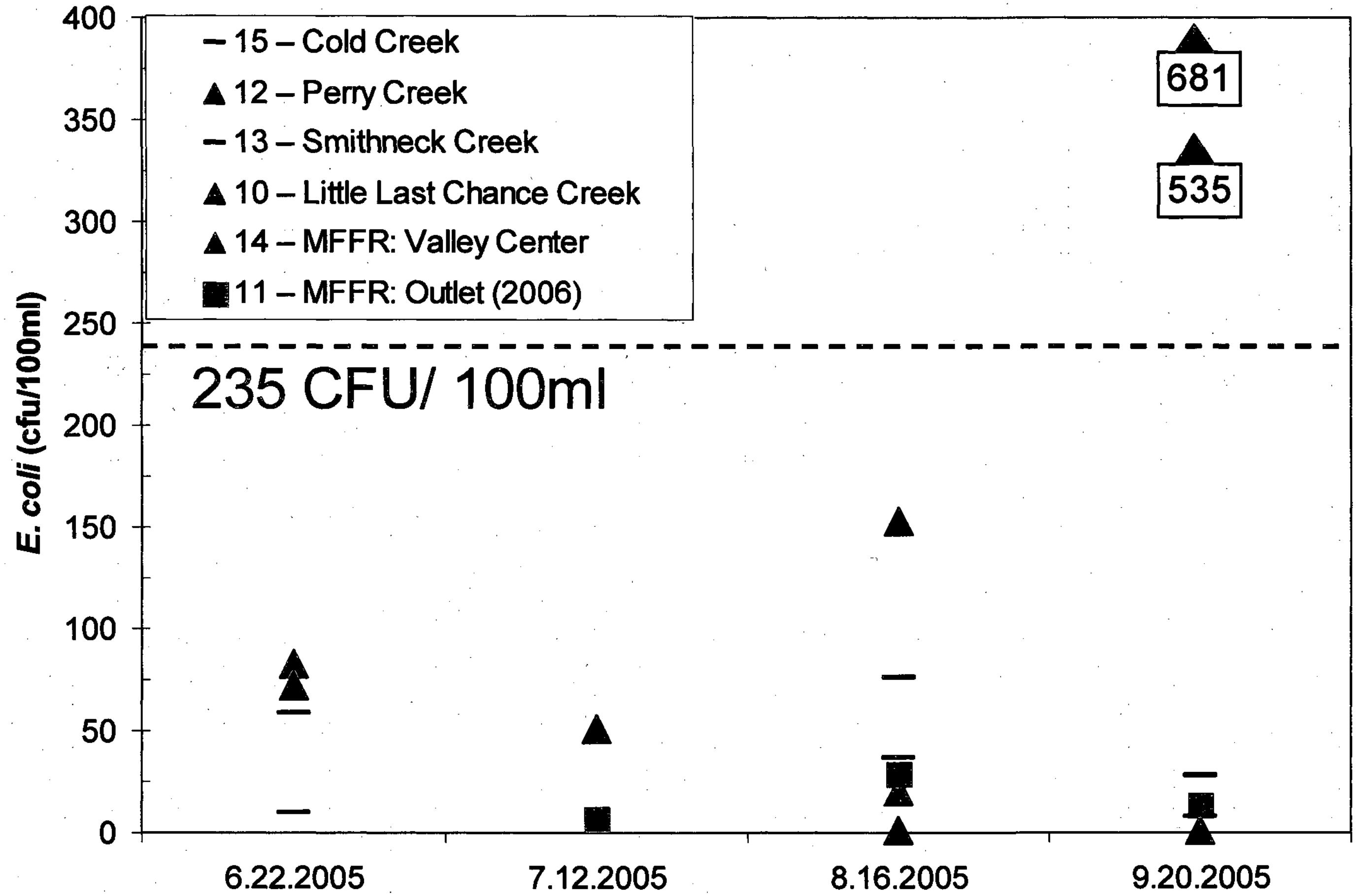


Figure 9b. SV *E. coli* values 2006

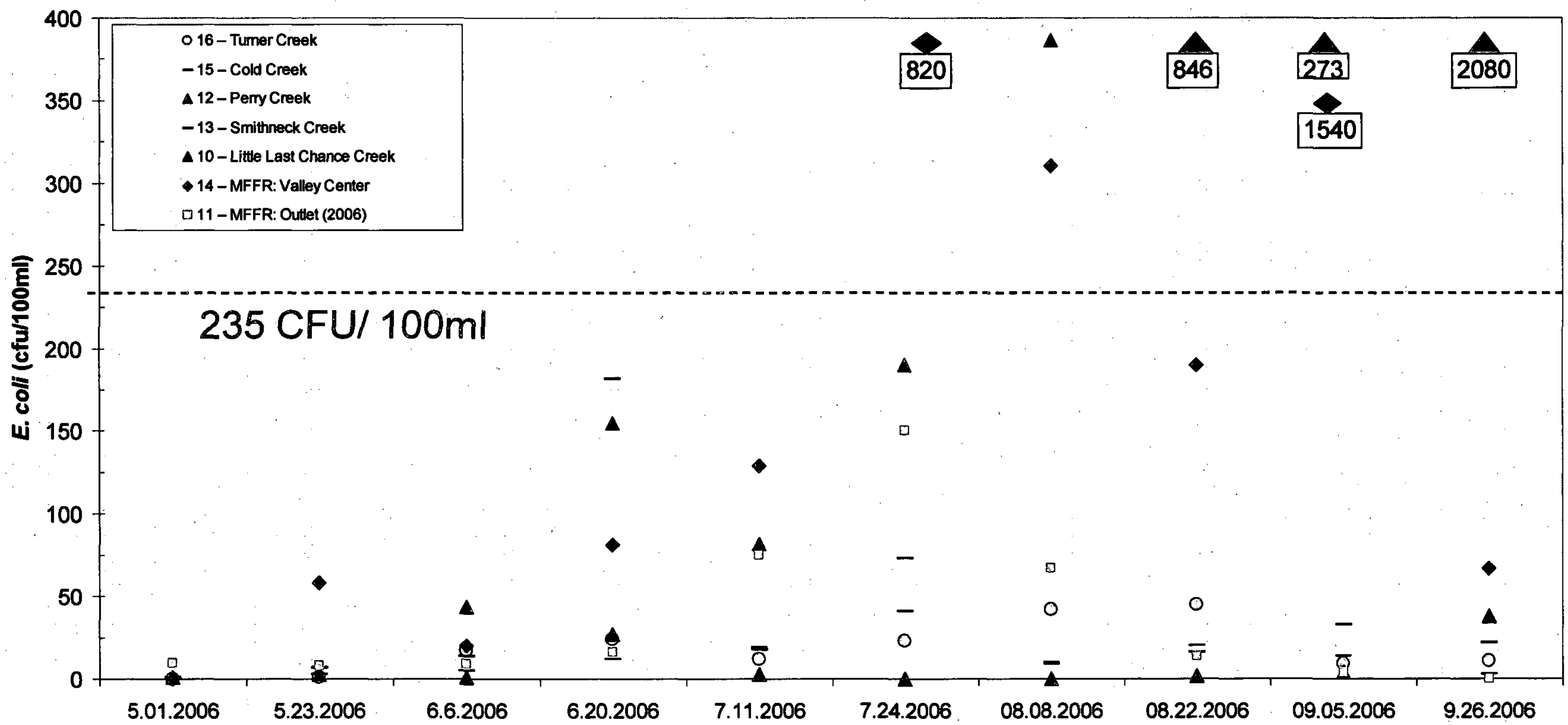


Figure 9c. SV *E. coli* values 2007

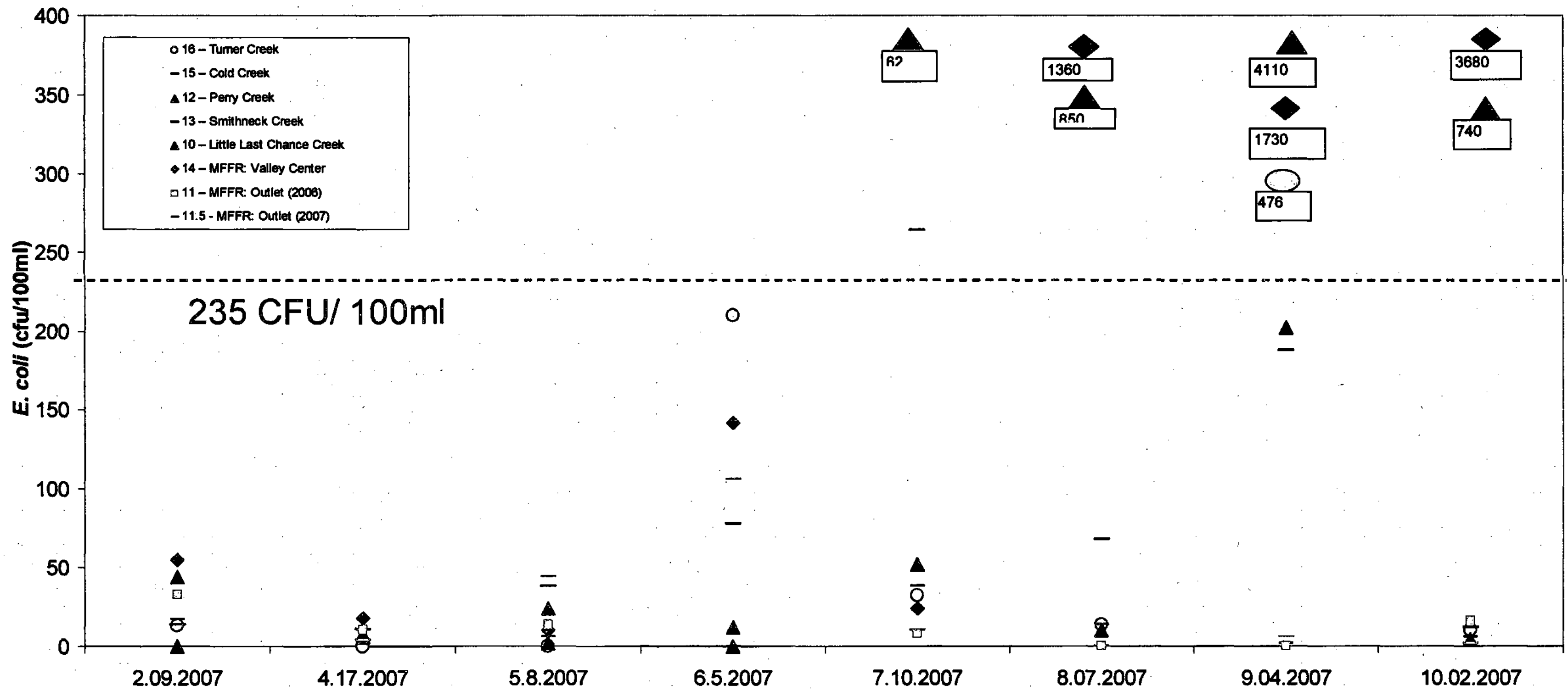
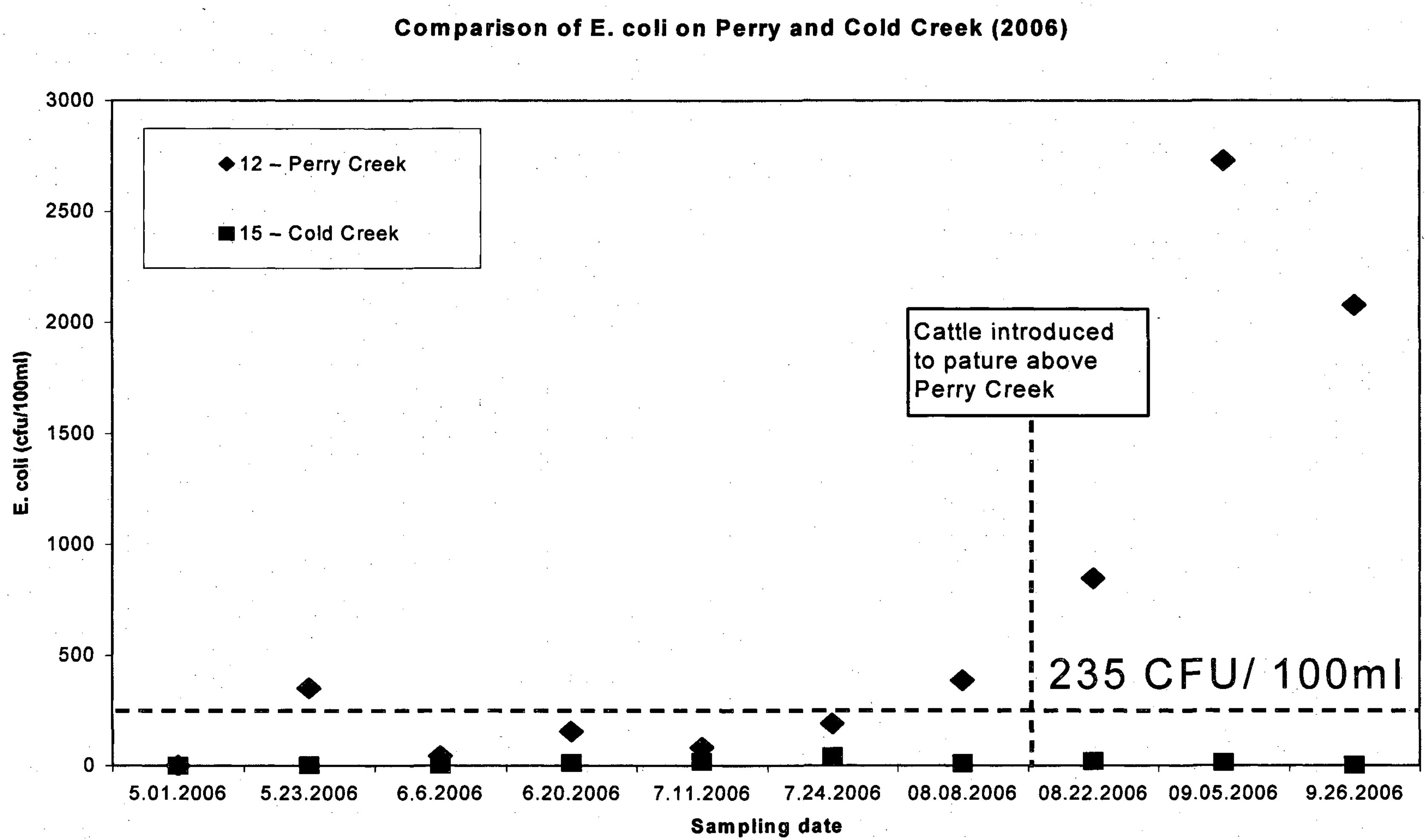


Figure 10. Correlation of cattle presence with *E. coli* values



Nutrients

Nutrient loading of waterways is a common problem in irrigated agriculture, typically as a result of the application of manure or other fertilizers (Carpenter et al. 1998). Other (non-agricultural) sources of nutrients include forestry, domestic landscaping, septic systems and municipal wastewater effluent, and sedimentary/metasedimentary rocks (Howarth et al. 2000; Holloway, et al. 1998). Historically, non-point sources of nutrients were not considered important, but on a global scale they may have a greater impact on water quality than point sources (Carpenter et al. 1998).

Nitrogen (N) and phosphorous (P) are important plant nutrients, but excess transported from non-point sources can degrade water quality in a number of ways. Nutrient enrichment (eutrophication) can result in algal blooms; once algae have consumed the nutrient source and begin to die, the decay process consumes dissolved oxygen, creating uninhabitable anoxic zones (Howarth, 2000). Some algae also release toxins which can directly kill aquatic organisms or humans. Eutrophication is problematic in the majority of impaired river waters in the US (Carpenter et al. 1998). Also, relatively small amounts of N are directly toxic to humans, especially infants, as nitrite or as nitrate, which is reduced to nitrite by bacteria (Hill, 1999). This is not true for P, and the WQOs for these constituents in the UFRW reflect this difference in the toxicity of the two nutrients (Table 4).

High density livestock operations can result in very high nutrient concentrations, but pastureland N and P contribution is markedly lower than that from croplands (Carpenter et al. 1998) and low-density pastured livestock with low nutrient inputs might not result in highly nutrient-enriched waters. One recent report of water quality in a pasture-dominated watershed in China (Cheng et al. 2007) found N to be a dominant pollutant in the watershed, but the limited description of land uses and animal agriculture operations in the area is makes it difficult to determine whether the system is similar to SV. This modeling study concludes that water quality impacts vary according to livestock distribution on the landscape, with higher impacts in higher-density areas.

While wetlands can be utilized to filter nutrients from waterways, they are also prone to eutrophication and the nutrient cycles within them can be very complex and difficult to manage (Golterman, 1995). Phosphorous is typically bound to sediments, its transport and concentration is associated with erosion, and it accumulates in times or places of reduced flow. Nitrogen is not usually bound to sediments, but can easily enter the groundwater supply, contaminating wells with nitrate. Ahearn et al. (2005) found in another Sierra Nevada watershed that grasslands contribute nitrate-N to streams in high-flow years, but act as a sink during low flow years.

In SV, past groundwater quality tests have shown elevated nitrate in valley wells; in 1983 and 1986, high levels of nitrate and ammonia were found in some wells. In 2003, high nitrate levels in some shallow wells were reported, but values were reduced from the 1980's. The Department of Water Resources concludes that years of high precipitation result in higher nitrate concentrations in well water. Dissolved Organic Carbon (DOC) was not monitored in these groundwater studies (Vestra, 2005).

Nutrient loads entering and exiting the valley are generally unbalanced early in the season when flows are high, and come closer to equilibrium as flows diminish. Monitored nutrients included Total Nitrogen, Nitrate-N, Ammonia-N, Total Phosphorous, Phosphate-P, and Dissolved Organic Carbon (DOC). Of these, only nitrate-N and ammonia-N have WQOs in the UFRW (Table 4). Nutrient concentrations were consistently measured very near our laboratory detection limits and never approached the WQO (Figure 11). SV typically gains phosphate-P, total P, ammonia-N and nitrate-N throughout the irrigation season from inflowing streams. When outflow is very high, there are instances of nutrient load export from the valley, though concentrations are lower than during low-flow conditions. Valley center and outlet concentrations spiked in August 2007, but are generally low relative to inflowing streams. There is very little difference in nutrient concentrations among inflowing streams. Exceptions include Little Last Chance and Turner Creeks. Little Last Chance Creek (10) typically has higher nitrate concentrations than other inflowing streams, and was especially high in August-September. This can probably be attributed to activity in the nearby campground. Turner Creek also had numerous samplings with elevated nitrate levels, but the pattern is inconsistent.

DOC levels are very high relative to other nutrient levels, in both inflowing and outflowing streams. Figure 12 represents the typical pattern of DOC concentrations in SV surface waters during the irrigation season. Inflowing streams are very low relative to valley center and outlet values. (The high value for site 15 in April is not believed to be representative of average conditions.) Turner Creek has elevated DOC relative to other inflowing streams. Valley center and outlet DOC concentration remain consistently high throughout the irrigation season.

Figure 11. SV streams nutrient concentrations 2006-07

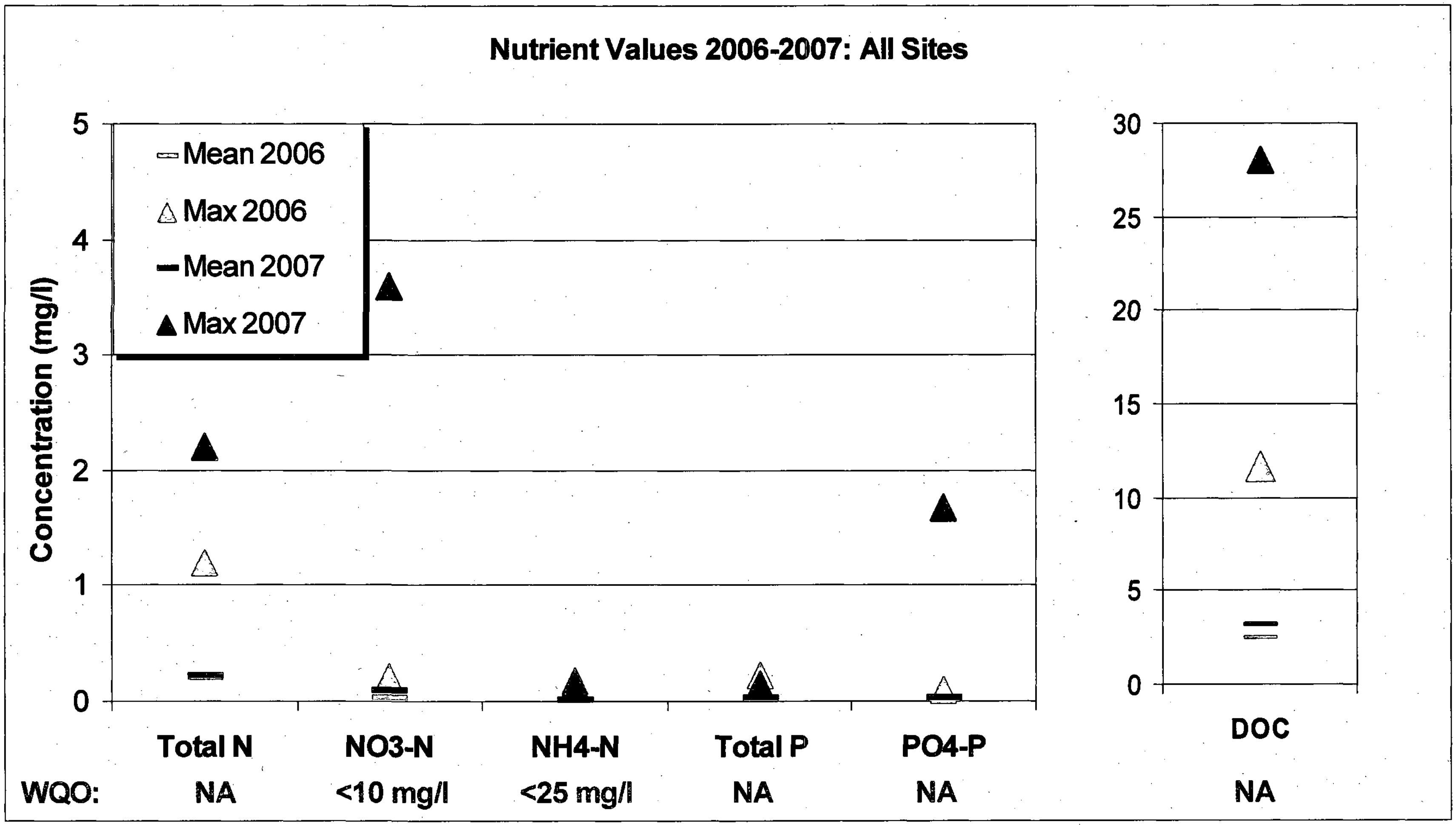
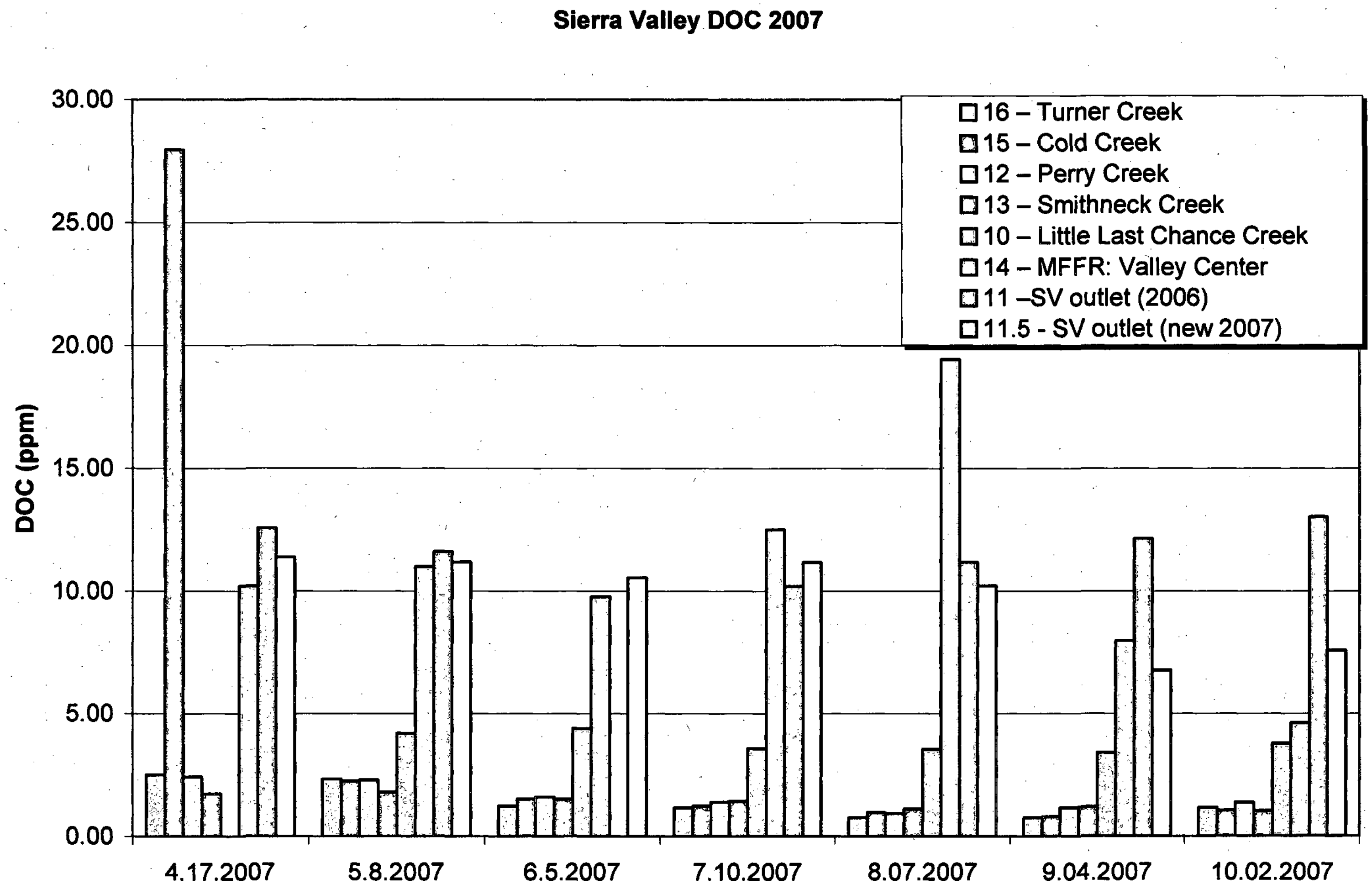


Figure 12. SV streams DOC values 2007



Sediments

Soil in pasture-based grazing systems is not usually exposed as it is in other agricultural systems where tillage and cultivation are common practices. Nevertheless, there are often areas of exposed soil within pasture-based agricultural systems (such as stream banks and irrigation ditches) where sediments may be dislodged and transported. Where stream banks are accessible to cattle, it is common to find widened channels and an increase in sediment load (Bengeyfield, 2007; Vestra, 2005; Cremann et al. 2005). While the SV floor has a very low gradient, reducing stream velocity and therefore sediment transport, the soils which compose the valley floor are rated by the NRCS Soil Survey as being moderately to highly susceptible to sheet and rill erosion, so sediment transport remains a special concern in the Valley.

Total suspended solids (TSS) is a measure of the amount of material >0.45 μm in diameter suspended in the water column, not dissolved. It is not a direct measure of sediments, because it also includes organic matter. Likewise, turbidity is a measure of the clarity of the water, which can be reduced by suspended sediments as well as algae and other organic materials. These two measurements served as proxies for our evaluation of sediment transport. [No attempts were made here to measure channel geomorphology, or monitor bedloads.]

Figure 13a shows SV turbidity values for 2006. Early in the 2006 season, a relatively high water year, there are higher levels of turbidity in streams flowing into the valley, and these values taper off as the season progresses. This is especially true for Cold Creek, which receives a high volume of additional water from the Little Truckee River diversion and would be expected to carry more sediment as a result. Later in the season

(July-September) as flows diminish, the Valley center and outlet begin to show elevated turbidity levels.

In 2007, inflowing turbidity levels are lower than in 2006, but demonstrate the same pattern: elevated levels in early season, tapering off around July (see Figure 13b). The valley center and outlet patterns are the same as in 2006 as well, with some sampling values being an order of magnitude greater than the previous year values despite lower flows. This can probably be attributed to a greater amount of organic material in the water column, because lower flows should result in less sediment transport. However, lower flows expose a greater portion of the stream bank and bed to drying, trampling and wind erosion. Wind-carried sediment may also be deposited in the water, especially in large areas of still water, such as at site 14.

Patterns of TSS concentrations are similar to turbidity: inflowing streams have relatively high TSS in the early season, and the valley center has very high levels later in the season. Turbidity and TSS values both are reduced at site 11.5 relative to site 11 in 2007, and are comparable to inflowing stream values. TSS loads (Figures 14a and 14b) were much greater in 2006 than 2007 as a result of higher flow, because loads are calculated according to both flow and constituent concentration. Cold Creek typically carries the largest TSS load of all the inflowing streams, which can again be attributed primarily to relatively high flow. Except for one extremely high value early in the 2006 sampling season, the Valley outlet typically has a lesser TSS load than the sum of the inlets, suggesting that sediments (and other materials reflected in the TSS value such as organic matter) are typically stored within the valley during the irrigation season rather than transported out.

Figure 13a. SV turbidity values 2006

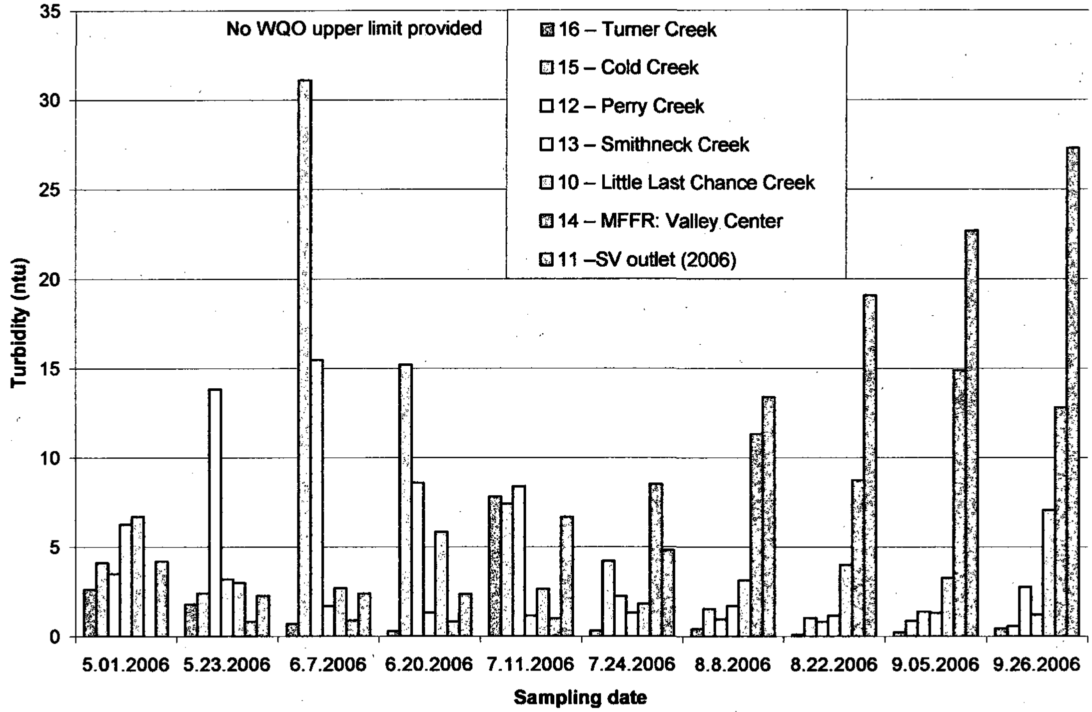


Figure 13b. SV turbidity values 2007

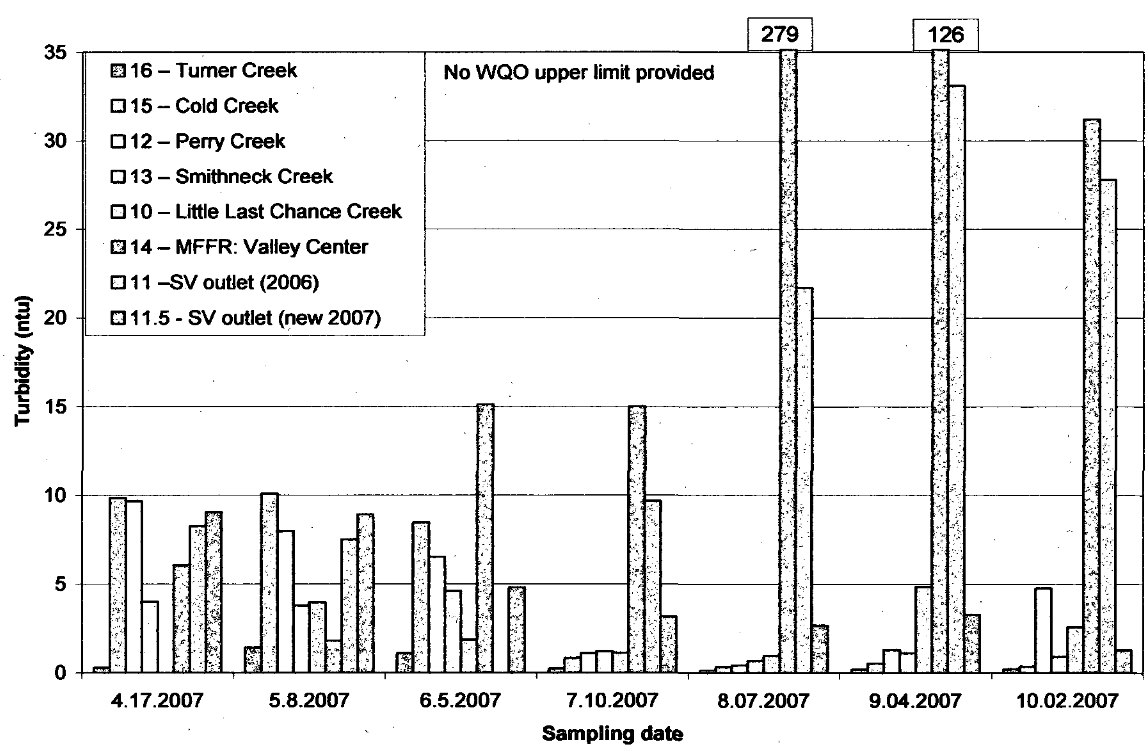


Figure 14a. SV TSS loads 2006

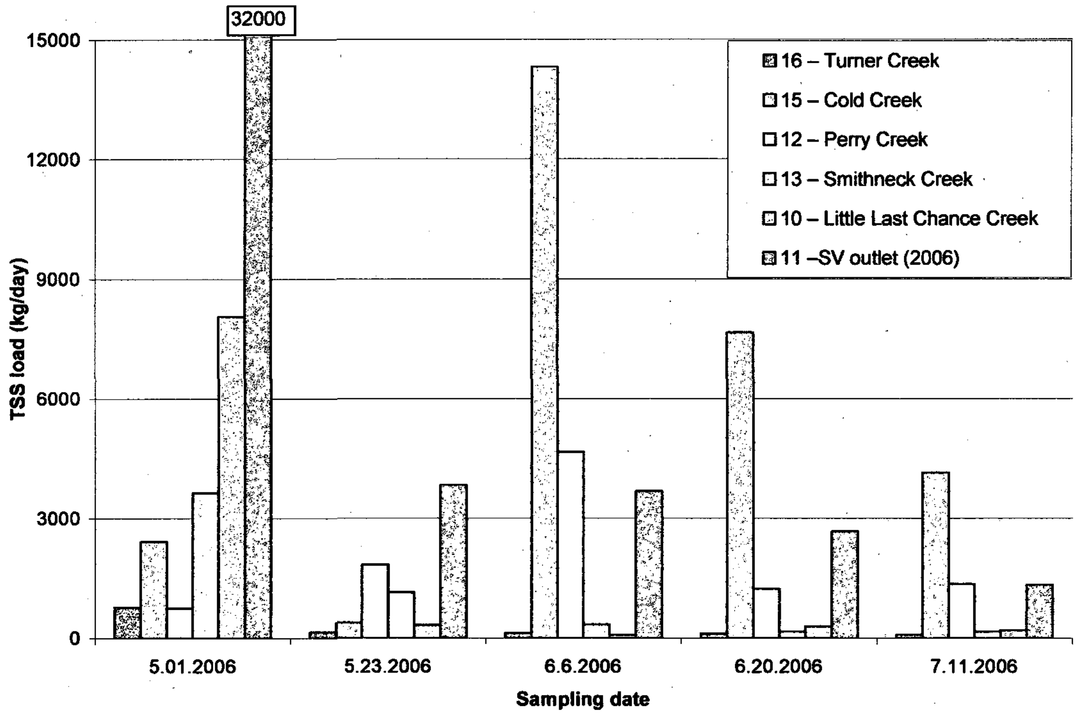
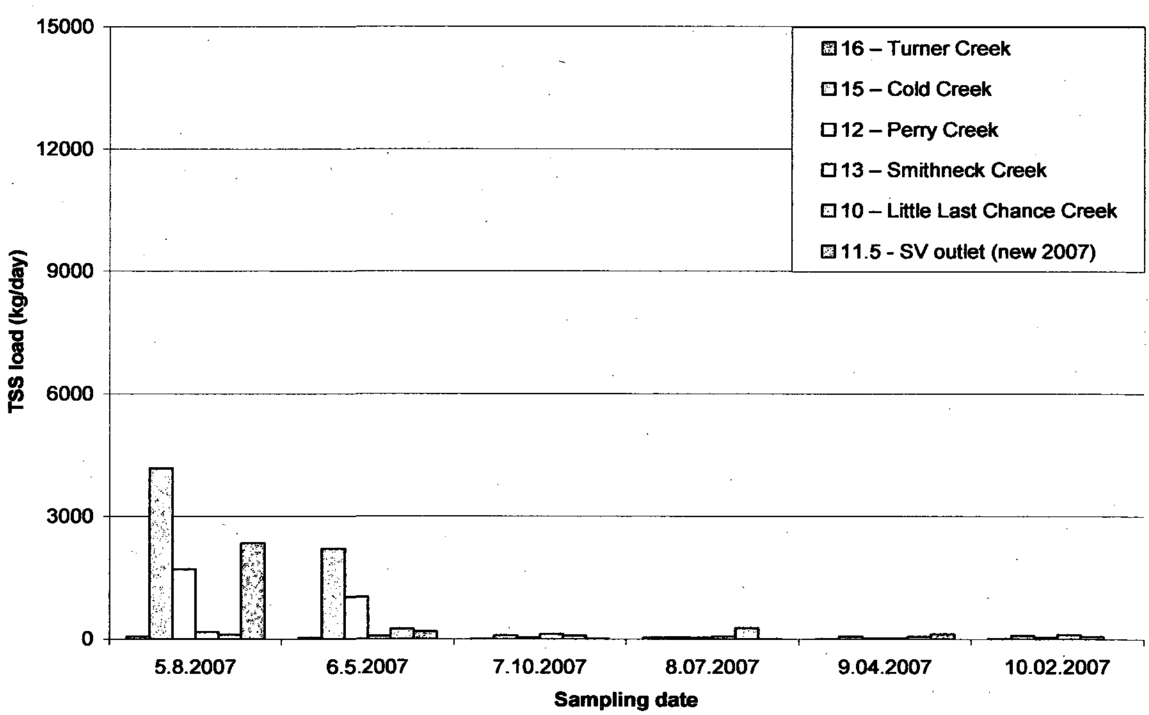


Figure 14b. SV TSS loads 2007



Toxicity

Although the issue of toxicity from various agricultural chemicals has drawn significant public attention and been documented as a serious problem in California waterways (Phillips et al. 2004), we did not expect to find toxicity due to agricultural chemicals because so few are applied in SV. The SVWA reports that only 815 pounds (370 kg) of active pesticide ingredients were applied to irrigated agricultural lands in all of Plumas and Sierra counties in 2002. The vast majority of the pesticide used within the watershed is applied for forest management, right of way and landscaping; and not for irrigated agriculture. No toxicity was found in the water column or sediments (Table 7).

Table 7. Results of 2006 water sample toxicity testing for site 11.

Species	% Survival	Cell growth (cells/ml)	Toxicity
20-Jun			
Selenastrum capricornutum		2.00	N
Ceriodaphnia dubia	100		N
Pimephales promelus	97.5		N
24-Jul			
Selenastrum capricornutum		1.27	N
Ceriodaphnia dubia	95		N
Pimephales promelus	100		N
22-Aug			
Selenastrum capricornutum		1.41	N
Ceriodaphnia dubia	95		N
Pimephales promelus	100		N
26-Sep			
Selenastrum capricornutum		2.00	N
Ceriodaphnia dubia	100		N
Pimephales promelus	100		N

When trace metals accumulate in high concentrations they can be toxic to aquatic life and humans. There is no major industrial activity which might contribute high loads of trace metals to SV waters, but historic mining activities have left a legacy of mercury in SV and other parts of the UFRW. Often, bedrock and soils can be responsible for high levels of trace metals in areas without industry, high-density development or heavy automobile traffic, which are typical contributors to metal pollution. The IRWMP also reports high concentrations of arsenic, manganese, and boron in thermal waters from SV springs associated with tectonic faulting. The FRCRM reports elevated metals at a stream sampling site near Beckwourth relative to sites further downstream on the MFFR. Table 8 reports the dissolved metal concentrations for sampling dates in 2006 relative to the UFRW WQOs For metals of concern which have no WQO for the UFRW, the US EPA Drinking Water Standard (DWS) is indicated. All MFFR sample concentrations are well below recommended maximum values.

Table 8. Dissolved metals concentrations during the 2006 sampling season as compared to drinking water limits (DWS).

	Concentrations (µg/l)					
Metal	**6.16.06**	**7.11.06**	**7.20.06**	**8.22.06**	**WQO**	**DWS**
B	12.2	32.8	32.8	39.3	700	
Al	23.5	17.1	17.1	16.1	NA	50
Fe	148	155	155	183	NA	300
Ni	2.66	2.4	2.4	2.5	100	
Cu	4.67	2.0	2.0	0.39	10	
Zn	34.2	8.9	8.9	0.46	5000	
As	0.43	0.58	0.58	0.41	10	
Se	BDL	BDL	BDL	BDL	5	
Cd	BDL	BDL	BDL	BDL	NA	5
Pb	0.67	0.61	0.61	0.080	NA	15

BDL = Below detection limit

Conclusions

Cattle production is a very important component of California agriculture. The environmental challenges associated with cattle production on California range and pasturelands are unique from those associated with irrigated vegetable, orchard and row crop production; but where cattle producers irrigate, they are equally accountable for their impacts to water quality.

The water quality impacts of irrigated agricultural operations in SV appear to be minimal relative to other, more intensive agricultural systems. Sediments, nutrients, trace metals and toxicity are not substantial water quality problems relative to current standards, and the greatest sources of concern to target for improvement with BMP's are low flows, low dissolved oxygen, high temperature, and elevated bacterial levels.

The poorest water quality was observed in the SV center. A change of the Valley outlet sampling site further downstream from this area in 2007 demonstrated improved water quality for most parameters relative to the original 2006 outlet sampling site. While pH and EC did not improve with the move downstream in sampling, they also appear to be related to natural soil conditions and may not be attributable to agriculture.

DOC may be a concern within the Valley for its high values relative to other nutrients and potential correlations with other water quality parameters, such as DO. Also, because DOC represents a potential human health risk in chlorinated drinking waters, the community should consider further investigation of DOC in the drinking water supply.

Best Management Practices

The design and implementation of BMPs to reduce or eliminate water quality impacts associated with irrigated agriculture in systems like SV is an important component of the original project objective. Although little progress has been made thus far to this end, there have been regular meetings with landowners to share the water quality data presented here, as well as to encourage the adoption of BMPs, and several landowners have expressed interest and begun the process of establishing BMPs appropriate to their operations.

There are two fundamental means to address the issue of water quality impacts from irrigated agriculture: 1) Improve the quality of runoff water and 2) Reduce the amount of impaired runoff water. Aside from irrigation management, numerous range management techniques can be applied to improve water quality in grazed pastures (www.californiarangelands.ucdavis.edu). The most effective of these techniques are those which in some way limit cattle access to streams, thereby reducing erosion, pollutant loading, and allowing the establishment of riparian vegetation.

Some BMP options feasible within SV include: stream/riparian fencing to exclude cattle; riparian vegetative buffers or buffer strips (with or without flash grazing according to NRCS standards); off-stream drinking water sources; reduced irrigation/ reduced tailwater; rotational grazing; and field-specific irrigation management. Many SV landowners and ranch managers have traditionally used one or more of these BMPs, and more are being adopted as environmental concerns become more important, and as natural resource users learn more about the connections between environmental and economic well-being.

Vegetated filter strips have been tested in grazed systems and have shown inconsistent results (Hay et al. 2006; Tate et al. 2006b). Combining filter strips or vegetated buffers with other management measures (such as reducing irrigation input so as to reduce tailwater runoff, and rest between grazing and irrigation) enhances the effectiveness of the buffer, but the additional remediation effect of the filter strip is likely less valuable as a BMP than as active pasture when other management measures are in place. Hay et al. (2006) conclude that the inconsistency of results from filter strips necessitates an on-site evaluation of their efficacy.

The UFRW IRWMP suggests revitalizing wetlands as a method to treat agriculturally impaired waters in the UFRW. Certainly wetlands are proven to be sites of high nutrient cycling and water quality improvement, but the intensity of water resource use by humans sometimes challenges the natural capacity of the system to purify itself (Geldreich, 1996; Carpenter et al. 1998; Knox et al. 2007). The wetland site in SV exhibits stagnant, poor quality water throughout the irrigation season. But it is important to note that this system is not managed as a wetland for water quality improvement. With planning, a filtration wetland could be developed in SV for water quality improvement. Alternatively, individual ranches can create small wetlands for tailwater treatment.

Cattle pasture serves as an appropriate beneficial use of the SV land resource for ranching families, local communities, a diversity of local wildlife, and visitors to the watershed. SV ranchers are not new to the process and goals of watershed restoration, and protection of natural resources, with many programs directed towards those ends on-going in the valley for decades through the FRCRM and other programs, such as the University of California Cooperative Extension and Department of Agriculture and Natural Resources ranch water quality planning short courses. With this history and resources at their disposal, the goal of meeting water quality limits without undue economic burden is attainable. The data provided by this study can help stakeholders in the UFRW make informed decisions about where to focus their BMP efforts, and continued monitoring will demonstrate the effectiveness of adopted BMPs and allow for adaptive management to achieve the most effective resource balance.

Continuing work

The second phase of this study (2007-08) is designed to identify areas of bacterial contamination and to test on-ranch BMPs for their effectiveness in reducing bacterial contamination. At the same time, samples are being analyzed for correlations between the indicator organism *E. coli* and actual pathogens. Another sub-study is also ongoing from 2007. This study is designed to correlate forage quality with soil moisture conditions within SV. It is described in further detail in chapter 2.

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Chapter 2

Soil moisture and forage quality in flood irrigated meadows: Sierra Valley, CA

Introduction

A recent study of surface water quality conditions in Sierra Valley (SV) (see chapter 1), shows that several water quality parameters are altered as water traverses the Valley, including: flow, temperature, dissolved oxygen content and bacterial loads. Because irrigation management data were not collected for this study and baseline hydrological data for the watershed (prior to the establishment of agriculture) is not available, it is difficult to determine the actual contribution of irrigation practices to these water quality parameters in SV. However, irrigation is an important activity in the valley, and irrigation practices have been associated with water quality impacts: numerous studies document the increase in pollutant transport from grazing lands with increased irrigation runoff (Knox et al. 2008; Knox et al. 2007; Tate et al. 2006; Bedard-Haughn et al. 2004), and low flows in streams have been shown to impact water quality by raising stream water temperatures (Tate et al. 2005).

Water quality can logically be improved by minimizing the amount and rate of pasture return flows to streams, thus minimizing opportunities for pollutant mobilization and transport from pastures to streams (Knox et al. 2008). Water quality can also logically be improved by reducing the amount of water withdrawn from streams for irrigation, thus keeping in-stream flow rates and quality nearer to background levels (Tate et al. 2005).

While a change in irrigation management might achieve these water quality goals, it is also important to evaluate whether such changes are economically sustainable for the operator. The adoption of new irrigation technology by farmers is usually contingent on the anticipated benefit, including profitability, labor efficiency, and the fit with the farmer's overall personal goals; and change typically occurs when triggered by extreme events, such as drought (Armstrong, 2004; Carey and Zilberman, 2002). Increasing pressure from regulatory authorities, the general public and other water users may have some influence on an individual farmer's decision to try new irrigation strategies, but overall, farmers tend to be conservative and will not adopt new technology unless the anticipated benefit of adoption is substantially greater than the cost of investment (Carey and Zilberman, 2002). Community needs, such as maintenance and stewardship of natural resources, can be difficult for a farmer to balance with individual imperatives like profitability, especially for farmers already working within narrow profit margins. The assurance of long-term productivity due to resource management can be difficult to balance with short-term profit goals or needs (Armstrong 2004).

There are, however, some profitable incentives for ranchers to change their irrigation management. For instance: the quality of water available to cattle for drinking can have important effects on the health and weight gain of the cattle, and optimal production warrants consideration of both cleanliness of the drinking water and quality of the forage (Willms et al. 2002). Willms et al. (2002) found that cows will avoid drinking water which is contaminated by fecal material, and those with access to clean water spend more time grazing and less time resting, concomitant with higher weight gains. Thus, practices that maintain a clean water source may have a direct economic benefit for the producer.

Another potential economic incentive for a change in irrigation management involves the role of soil water conditions in determining forage production and quality. Managers use irrigation to manipulate the local hydrologic conditions to keep plants growing, but irrigation practices impact the local water table dynamics and soil moisture conditions, which in turn impact plant community composition and species distribution (Kluse and Allen-Diaz, 2005, Castelli et al. 2000, Allen-Diaz, 1991). Allen-Diaz (1991) found that distinctive water table patterns corresponded with distinctive plant communities in Sierra Nevada meadows near SV. Because different types of plants have different nutritive characteristics (i.e. forbs are typically higher in protein than grasses (Rinehart, 2008)), forage quality varies spatially and temporally on the landscape along with plant community composition (George et al. 2001). In fact, time of season, climate, topography, plant species and community composition, and landscape management (including irrigation and grazing strategies) all have substantial impacts on the nutritional quality and condition of grasslands and the efficiency of animal production on range forage (Perez Corona et al. 1998; Nichols et al. 1993). The interaction effects of these factors are not necessarily linear or proportional, and the implementation of new irrigation management strategies with the goal of optimizing forage nutrition benefits growers when costs are offset by additional profits in cattle weight gain (Armstrong 2004; Perez Corona et al. 1998; Nichols et al. 1993).

Local information is critical to developing an optimal irrigation management strategy. Forage quality and duration of growing season are affected by terrain, with lower places producing higher biomass and sustaining growth later in the season than higher points on the landscape (Perez Corona et al. 1998). The expected soil water conditions on a sloping landscape correlate with these results: lower parts of the landscape typically have greater soil-water content than areas higher on the landscape. Perez Corona et al. (1998) found that higher proportions of forbs and legumes grew in higher areas on the landscape and more grasses grew in lower reaches. The forb and legume-dominated plant communities located higher on the landscape also generated forage with higher lignin and less protein than the grass-dominated communities found at lower positions on the landscape, given the same time of sampling. Although forbs typically have a higher protein content than grasses (Rinehart, 2008), these results suggest that local site conditions (including soil-water dynamics) may have an important role in determining the overall nutritive content of forage communities. Certain plant species can be used to reliably estimate the water table depth within a narrow range, but this depth alone does not account for most differences in vegetation types (Castelli et al. 2000). Rather, differences in plant community composition are better explained by changes in the depth and range of the water table over the season and across the landscape (Castelli et al. 2000; Perez Corona et al. 1998). Also, natural features such as springs, seeps, and soil irregularities impact water table dynamics so that the distance from a creek or irrigation ditch is not directly related to water table dynamics in an area (Allen-Diaz, 1991). Thus, incorporating temporal and spatial variability in the measurement of soil water dynamics is critical to understanding how plant species distribution and forage nutritive quality are influenced by those dynamics.

This study addresses the following questions in the context of the high-elevation meadows of Sierra Valley and Goodrich Creek in the Upper Feather River Watershed:

1. How do water table and soil-water content dynamics at a site correlate to the production and quality of forage plants that grow on the site?

2. Is it possible to identify and manage for an optimal water table and soil-water content condition for maximum forage production and quality for cattle production?

Objectives:

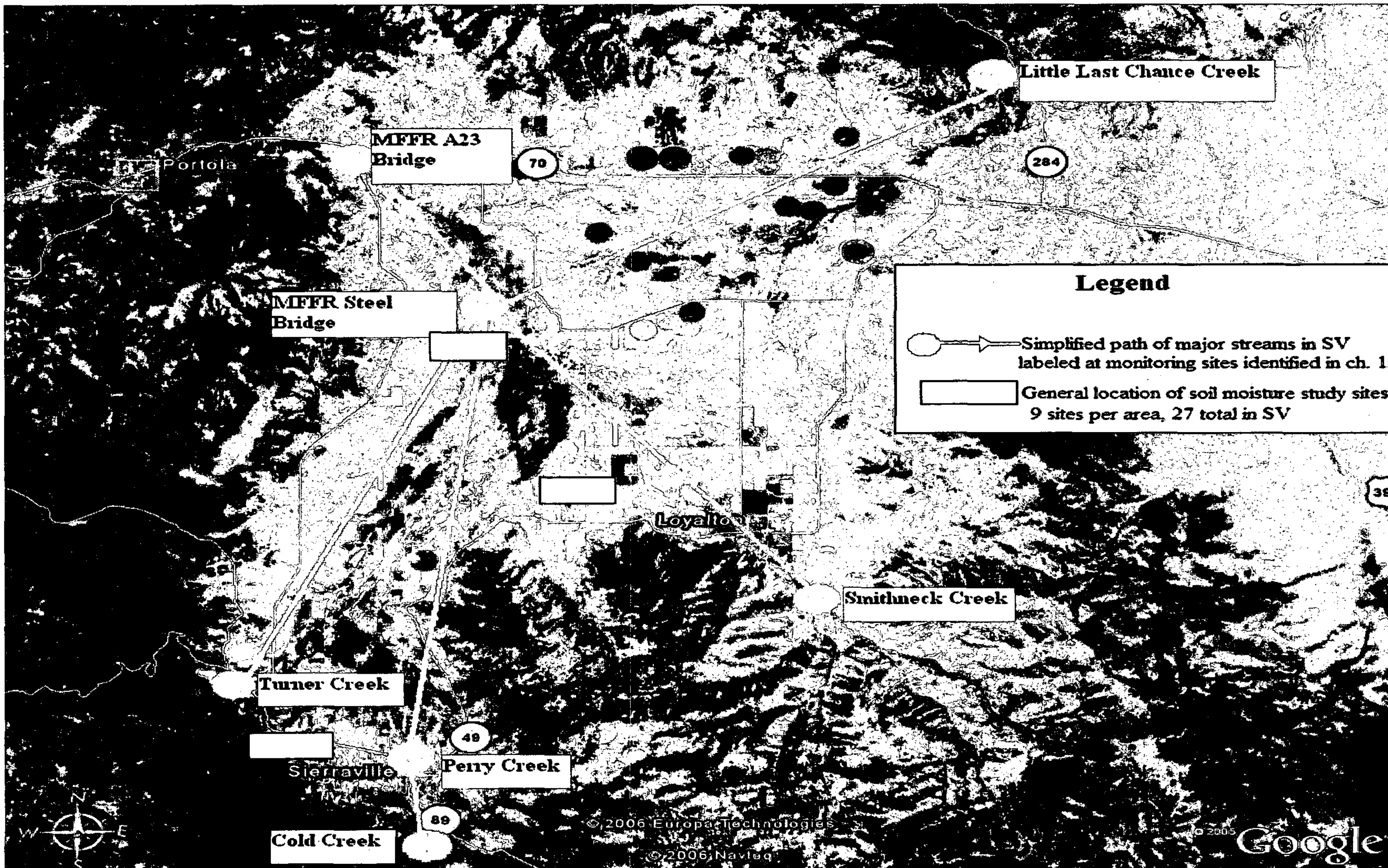
1. Determine how water table depth correlates with forage quality (nutrition and palatability) and abundance, such that with increasing depth, forage quality improves (to an as-yet-undetermined depth, beyond which forage quality declines).
2. Determine whether soil-water content correlates with forage quality, such that with increasing soil moisture, forage quality improves (to an as-yet-undetermined moisture content, beyond which forage quality declines.)
3. Future studies will determine whether plant species community composition varies with soil and hydrologic regime in Sierra Valley. (This objective included here for completeness of the project concept.)

Materials and Methods

Study sites are located on three ranches selected on a north-south gradient within the west and west-central portion of Sierra Valley, including a ranch near Sierraville, a ranch southwest-west of Loyalton, and a ranch south of the steel bridge. Each ranch has three replicates of three sites established in target dry, moderate and wet soil water conditions for a total of 9 sites per ranch, and 27 sites in Sierra Valley (Figure 15). A fourth ranch is located in the Goodrich Creek watershed, for a total of 36 sites.

We established sites within areas of relative “dry”, “moderate”, and “wet” soil moisture conditions on each ranch. The sample site locations were based on visual evaluation of plant community composition, winter moisture conditions, and information from the ranch manager. The target “dry” represents conditions where soil moisture is below optimal for forage production (e.g., mid season soil moisture levels below plant water requirements). The target “moderate” represents conditions close to optimal for forage growth over the season (e.g., high soil moisture, but water table below root zone for the majority of the season). The target "wet" represents high water table conditions for the majority of the season.

Figure 15. Sierra Valley general sampling locations



Experimental Design:

The experimental unit for this project is a sample site. Each sample site contains the following infrastructure:

1) A 1 m^2 livestock exclusion cage

2) A piezometer (water table depth observation well)

3) Four soil moisture tensiometers, 2 each installed at depths of 25 cm and 50 cm

4) One temperature sensor

5) One Irrometer continuous data logger

6) A set of permanently marked paired plots: one plot each inside and outside the livestock exclusion cage

Data collection activities (see Table 9 for dates) at each site included:

- Well- piezometer depth to water table measured
- Forage- samples clipped for quality analysis
- Biomass- Ocular estimates of standing biomass inside and outside cage recorded; samples taken for calibration
- Soil moisture tension recorded hourly on data logger
- Soil samples collected at piezometer installation
- Plant species composition has not yet been evaluated, but is planned

Table 9. Dates of project activity (2007)

Date (2007)	Action
18 May	Sites installed
01 June	Well; Forage; Biomass
18 June	Well
19 July	Well; Forage; Biomass
18 August	Well; Forage; Biomass
06 September	Well; Forage; Biomass
11 October	Sites removed for winter

Soil samples:

Soil samples were collected from one of the three replicates for each site as representative of the soil for that ranch and target moisture condition. The soil moisture data has shown that natural variability of the soils is greater than anticipated and the assumption that this sample is indeed representative of all three replicates is poor.

Samples were dried, sieved to ≤2mm and are stored in paper bags labeled with site and depth-interval in the Singer laboratory at UC Davis. Determination of soil pH, EC, Ca, Mg, Na and Cl was completed at the DANR analytical laboratory using standard methods. The data is not included in this document.

Forage samples:

Forage samples were clipped in the field, stored in paper bags and dried in plant-drying ovens for 48 hours. Then samples were ground through 1mm mesh and stored/shipped in labeled self-sealing ½ quart bags to Cumberland Valley Analytical Services (CVAS) for forage quality analysis.

Biomass estimation:

Biomass was estimated both inside and outside exclusion cages to determine utilization of forage and site production potential. We used an ocular estimation method (comparative yield) to assess relative biomass, which was quantified by calibration at each sampling. Calibration consisted of ranking quadrates, clipping all forage within the ranked quadrate to ground level, drying the sample and determining the correlation between rank and forage standing crop

Complications with equipment at several sites resulted in abbreviated soil moisture data at those sites. A site at one ranch was mowed at least once during the first season of data collection. Ranchers were unable to provide detailed information about management of the pastures where sites were installed, including irrigation events, cattle access, and other activities. Project members were not available to scout the sites between sampling events, so this potentially important management information is not available for analysis.

Results

To consolidate the soil moisture data, replicate sites were evaluated for similarity with other replicates and then soil moisture values were averaged for the three replicate sites to produce a cluster. (Mean soil moisture and water table conditions for each cluster are shown graphically in appendix 4.) Clusters were evaluated for soil moisture and water table depth patterns and similarly patterned clusters were combined into a "hydrogroup" (HG). There were a total of four HG representing the following conditions:

HG1 – High water table (0 cm to 100 cm) with adequate soil moisture (<90 centibars) all season. (Clusters: 41, 43)

HG2 – High water table during early season followed by no measurable water table and inadequate soil moisture (>200 centibars by August). (Clusters: 31, 32, 33)

HG3 – Moderate water table (>10 cm, <60 cm) with adequate soil moisture (<40 centibars) all season. (Clusters: 21, 22, 23, 42)

HG4 – Low water table (>110 cm from soil surface) throughout season and inadequate soil moisture (>200 centibars by July). (Clusters: 11, 12, 13)

Except in one case, HG turned out to include all sites from each ranch, rather than all sites from each target soil moisture condition. The exception is one cluster from ranch 4 in Goodrich Creek which was included in HG3, representative of Sierra Valley ranch 2.

Forage quality data were analyzed by linear mixed effects (LME) strategy in S-Plus 6.1 with site identity as a random effect to account for repeated measures. Site water table, soil moisture and Julian day (seasonal progression) were the main fixed effects, and plot identifier was used as a grouping variable. Table 10 shows coefficients and P-values for a selection of forage quality parameters, with statistically significant differences ($P<0.1$) highlighted in red text.

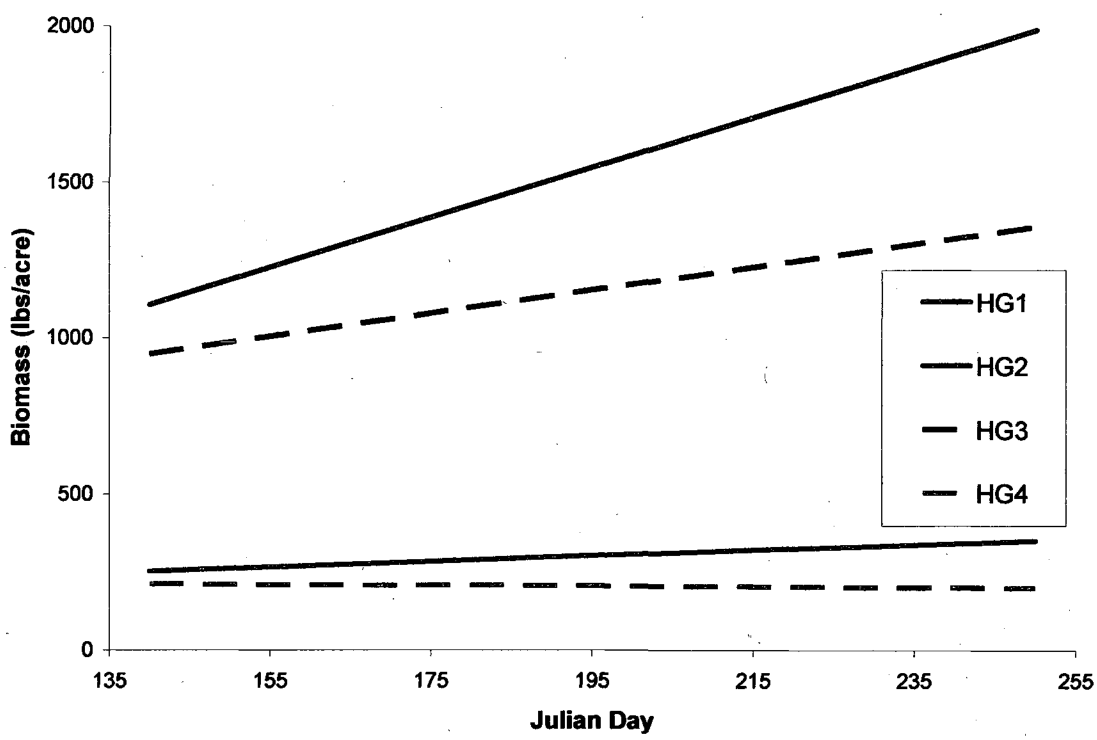
Table 10. Selected forage quality factor coefficients and P-values from LME analysis

LME Model Values	**Crude Protein**		**Acid Detergent Fiber**		**Biomass**		**Ca**		**P**	
	Coefficient	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value
HG1 Intercept	19.59	**<.0001**	20.63	**<.0001**	-12.89	0.9758	0.320	**0.0005**	0.30	**<.0001**
HG2	2.88	**0.0556**	-4.84	**0.0089**	139.68	0.8051	-0.258	**0.0327**	0.00	0.9176
HG3	3.86	**0.0085**	0.09	0.9562	444.25	0.4055	-0.193	**0.0878**	0.00	0.9379
HG4	5.35	**0.0011**	-10.30	**<.0001**	238.71	0.6814	0.204	**0.0947**	0.06	**0.0505**
JD	-0.05	**<.0001**	0.07	**<.0001**	7.99	**<.0001**	0.002	**0.0001**	0.00	**<.0001**
HG2:JD	-0.02	**0.0072**	0.02	**0.0038**	-7.10	**<.0001**	0.001	0.3068	0.00	0.4027
HG3:JD	-0.01	**0.0517**	0.00	0.9944	-4.30	**0.0041**	0.000	0.4098	0.00	0.2312
HG4:JD	-0.04	**<.0001**	0.06	**<.0001**	-8.10	**<.0001**	-0.001	**0.0060**	0.00	**0.0005**

Biomass:

Figure 16 shows ungrazed biomass data for all HG for the 2007 sampling season. Biomass increased at all sites as the season progressed, but nearly imperceptibly in HG4. Overall biomass and rate of increase were also very low for HG2, while HG1 and HG3 both had relatively high biomass with greater rates of increase. HG1 had the greatest overall biomass throughout the season, as well as the greatest rate of increase.

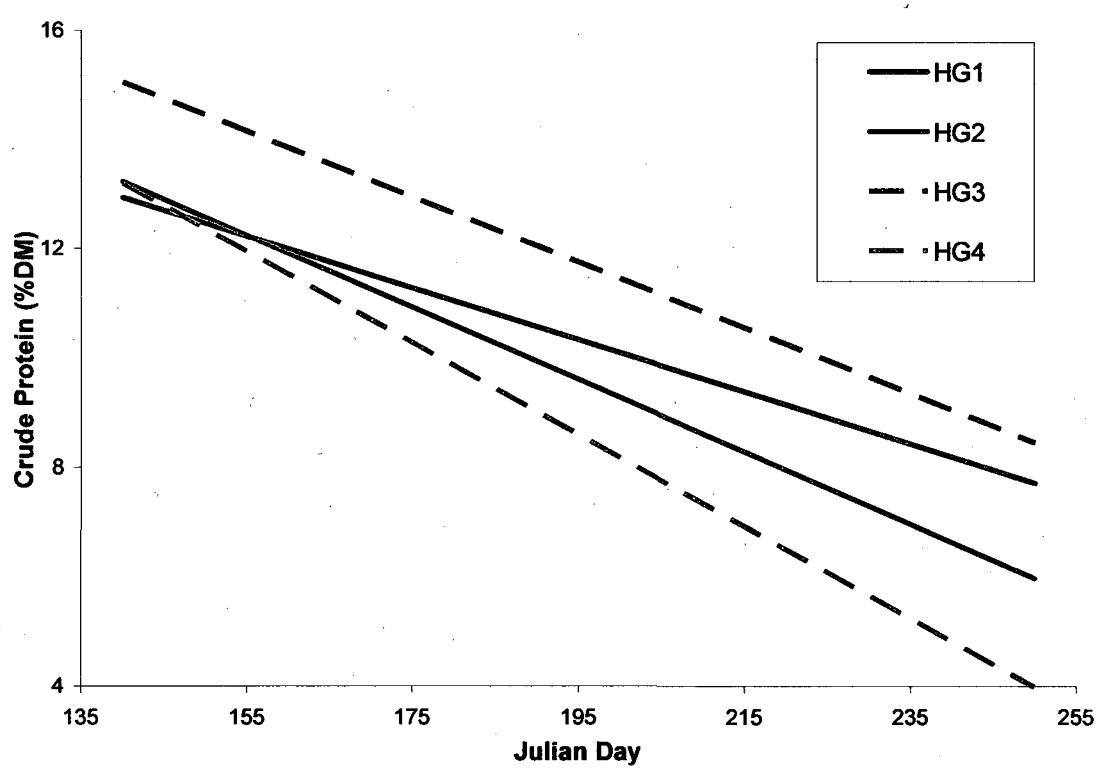
Figure 16. LME Biomass by HG and Julian Day



Crude Protein:

Figure 17 shows LME model-derived values for crude protein (CP) as percent of dry matter for all HG. CP decreased at all sites across the season, with highest overall (and consistently highest) values in HG3, and lowest in HG4. Start-of-season values range from 13% to 15%, and end-of-season values range from about 4% to 9%. Rate of decrease in CP content is also greatest in HG4. Differences in rate of decrease between HG1 and HG2 result in relatively high end-of-season CP content in HG1 relative to HG2. The P-values demonstrate that both the absolute values and the rates of decline in CP throughout the season are significantly different. Differences of 1% to 2% in CP values may seem small, but can have a significant impact on a cow's diet (Rinehart, 2008).

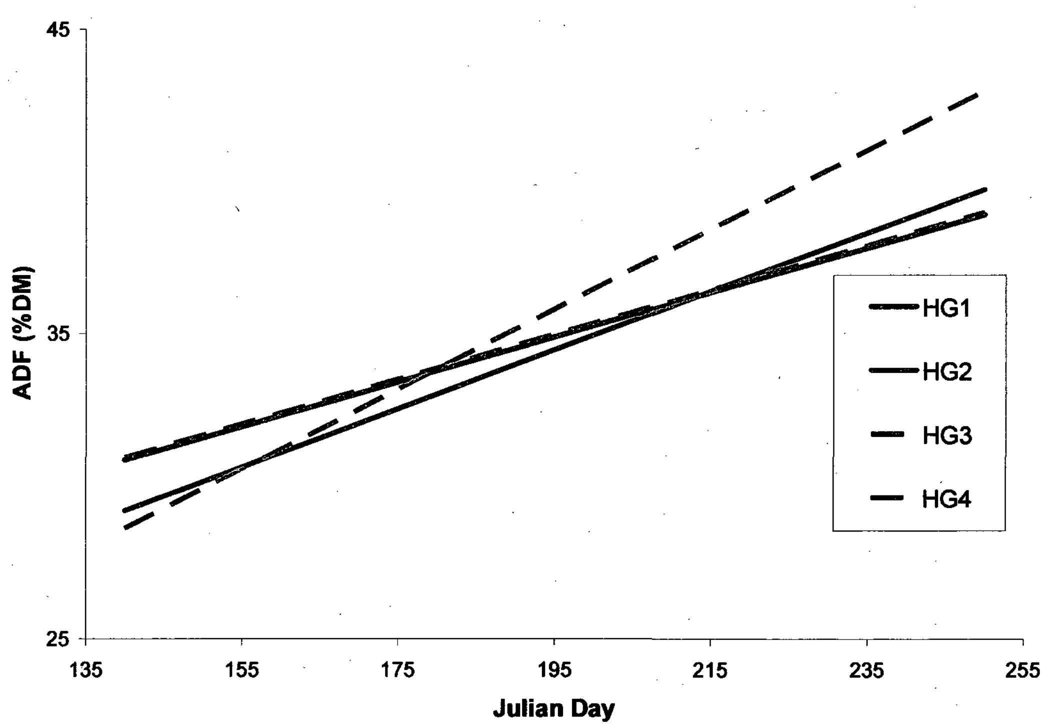
Figure 17. Crude Protein



Acid Detergent Fiber:

Figure 18 shows acid detergent fiber (ADF) values as a percentage of dry matter for all HG. ADF is a measure of the indigestible portion of the forage, and typically as the season wanes, CP decreases and ADF increases. This pattern is demonstrated in all HG. Overall values of ADF are higher than for CP, with a start-of-season range from 28% to 32% and end-of-season range from 37% to 44%. ADF in HG1 and HG3 are indistinguishable from one another, while HG2 is very similar to both. ADF in HG2 and HG4 both have higher rates of increase than HG1&3, with HG4 showing the greatest end-of-season ADF and HG1 and HG3 the lowest. The P-values demonstrate that both the absolute values and the rates of decline in ADF throughout the season are significantly different for all crosses except HG1:HG3. ADF is not apparently an important parameter in distinguishing the nutritive characteristics of these sites.

Figure 18. Acid Detergent Fiber



Calcium and Phosphorous:

Figure 19 shows the Ca:P ratio for all HG across the season. This ratio is one example of important nutrient interaction effects, and should fall within the range of 1.5:1 to 5:1 (D.F. Lile, phone communication). For the most part, the ratio does fall within these limits until late July and early August when HG4, HG1, and HG2 (in that order) exceed the 5:1 ratio, meaning that forage has become deficient in P relative to Ca for the nutritional needs of cattle. However, short-term nutrient deficiencies such as this are mitigated by body nutrient stores can be tolerated without substantial loss in production. Only HG3 remains within the optimal range throughout the season.

Figure 19. Ca:P ratio

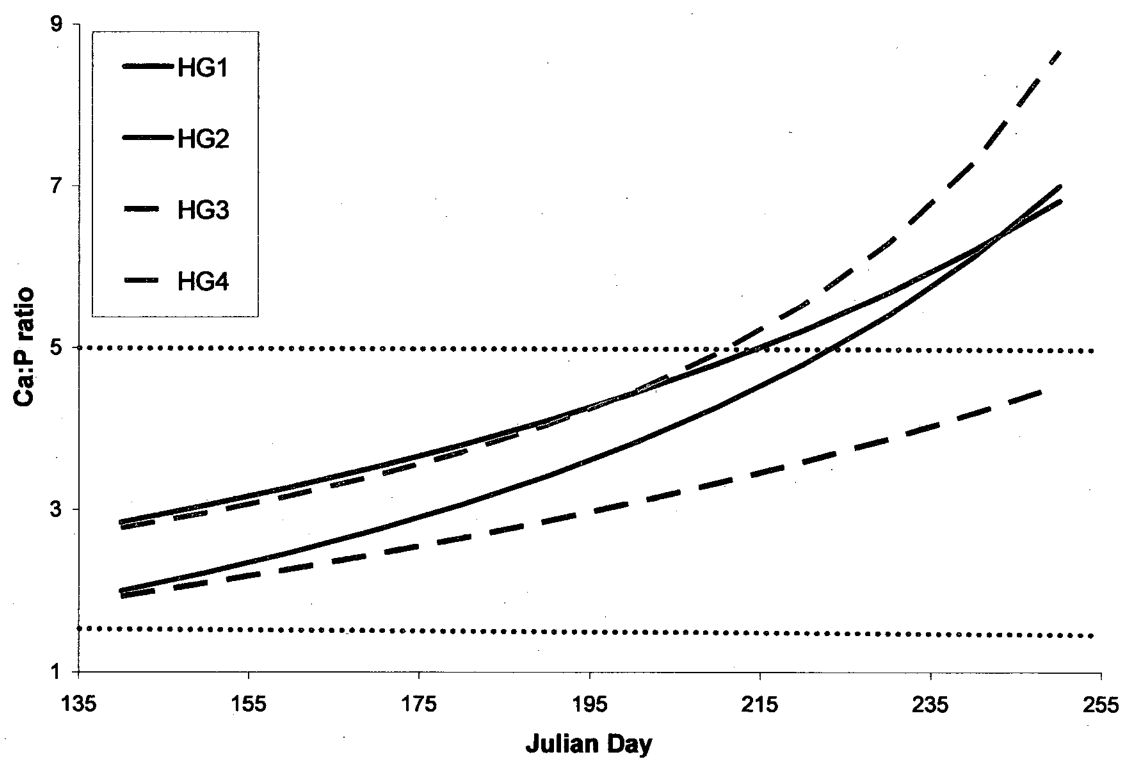


Table 11 shows relative grades of several forage quality parameters at the end of the sampling season. HG1 and HG3 maintained overall the highest quality forage, while HG2 retained fair quality forage and HG4 had poor forage quality by September.

Table 11. End-of-season relative forage quality

	Biomass	CP	ADF	Ca:P
HG1	A	B	A	C
HG2	C	C	B	B
HG3	B	A	A	A
HG4	D	D	D	D

Key:

A	Highest quality
B	High quality
C	Low quality
D	Lowest quality

Conclusions

The sites which retained adequate soil moisture (HG1 and HG3) throughout the sampling season maintained the highest quality forage. Those with a moderate (HG3), rather than high (HG1), water table had overall higher forage quality. Among the groups which had inadequate soil moisture late in the season (HG2 and HG4), the group with high water table early in the season (HG2) maintained higher forage quality than the group with a consistently low water table (HG4). There is insufficient quantifiable data to address the hypotheses presented for this study, but the data presented here suggest that managing irrigation to maintain a moderate water table 10-60cm beneath the soil surface and root-zone soil moisture tension $\leq$40 centibars is optimal for producing nutritive forage in this system.

Maintenance of high quality waterways is in the best interest of all water users, including cattle producers, not only for environmental, but also for economic reasons. This preliminary data shows that water management may indeed have important impacts on forage quality in Sierra Valley. However, there is not sufficient data to determine the extent to which differences in physical site factors versus differences in irrigation management explain the soil moisture conditions at the locations in this study. While site factors are likely to have substantial, complex impacts on soil moisture conditions, irrigation strategies are also markedly different at each ranch and more data is required to address these questions.

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Appendix 1: Methods for Determination of Constituents

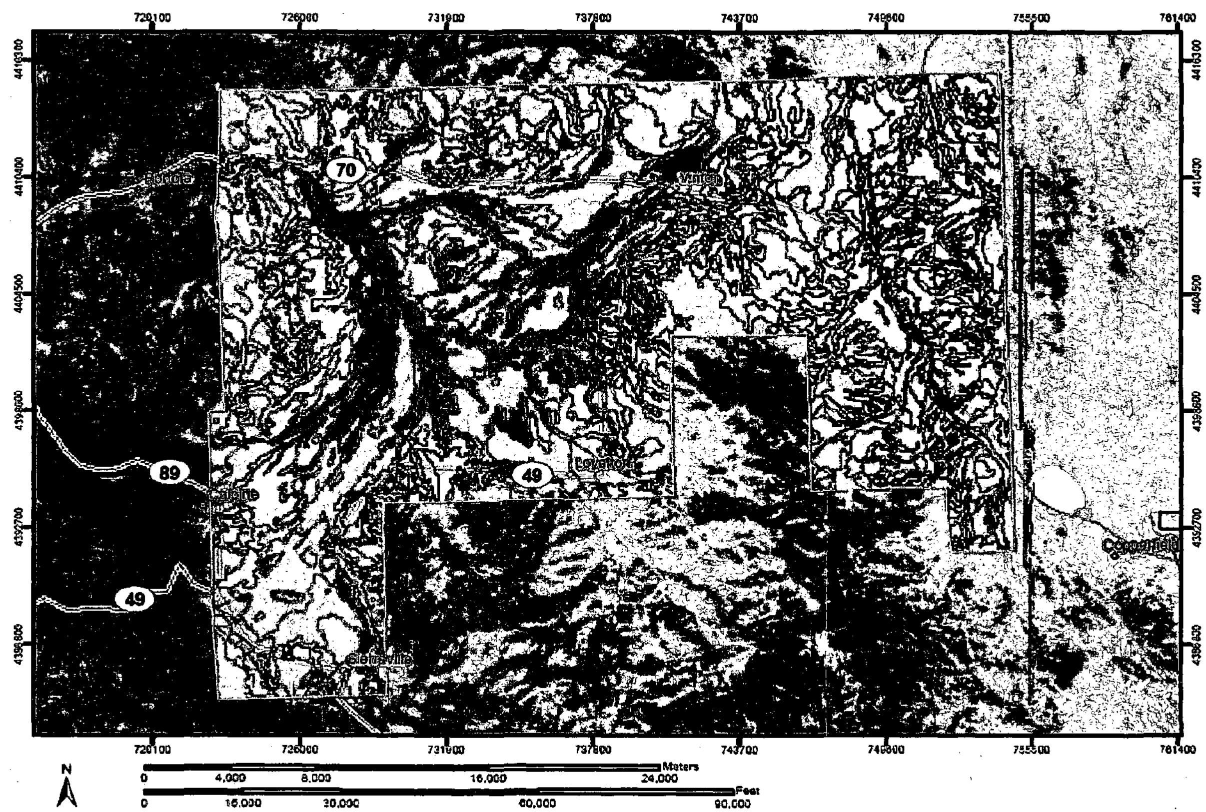
Parameter	Method
Instantaneous Streamflow	Area Velocity Method: http://www.swrcb.ca.gov/swamp/docs/appxe_fieldmeasureprocedures.doc
Dissolved Oxygen	YSI 85 Dissolved Oxygen Meter: YSI Incorporated
Water Temperature	Optic StowAway Temperature Logger: Onset Computer Corporation
Dissolved Organic Carbon	SM 5310.C: Persulfate-Ultraviolet Oxidation Method on a filtered sub-sample.
E. coli	SM 9222: Direct Membrane Filtration with CHROMagar *E. coli*, CHROMagar Microbiology
Total Nitrogen	Yu, Z.S., R.R Northrup; R.A. Dahlgren. 1994. Determination of Dissolved Organic Nitrogen using Persulfate Oxidation and Conductimetric Quantification of Nitrate-Nitrogen. Communications in Soil Science and Plant Analysis. 25:3161-3169. Total nitrogen (non-filtered sub sample) is determined as nitrate, using the Griess reagent method following persulfate oxidation.
Nitrate	Doane, T.A. and Horwath, W.R. 2003. Spectrophotometric Determination of Nitrate with a Single Reagent. Analytical Letters. 36:2713-2722. Spectrophotometric method based on Griess reagents for a filtered sub-sample.
Ammonium	Verdouw, H; van Echteld, C.J.A.; Dekkers, E.M.J. 1977. Ammonia Determination Based on Indophenol Formation with Sodium Salicylate. Water Research. 12:399-402. Spectrophotometric method based on a reaction of filtered sub-sample with phenol and hypochlorite, in which a blue colored indophenol is formed.
Total Phosphorus	SM 4500-P.D: Stannous Chloride Method on unfiltered sub-sample.
Phosphate	SM 4500-P.D: Stannous Chloride Method on filtered sub-sample.
Total Suspended Solids	SM 2540.D: Filtration method using pre-combusted, glass fiber filters dried at 60 °C for 24 hours and weighed again to measure TSS.
Turbidity	SM 2130.B: Nephelometer Method, Orbeco Analytical Systems, Inc., Turbidity Meter
pH	pH meter: Fisher Scientific Accumet pH/temperature electrode
Electrical Conductivity	SM 2510.B: Conductivity Meter: Fisher Scientific Accumet 4 cell, 1.0 cm electrode
Benthic Macroinvertebrates	CDF&G California Stream Bioassessment Procedure; http://www.swrcb.ca.gov/swamp/qamp.html#appendixd

Total Organic Carbon	SM 5310.C: Persulfate-Ultraviolet Oxidation Method on a non-filtered sub-sample.
Color	SM 2120.B: Visual Comparison Method. Filtered sub-sample.
Total Dissolved Solids	SM2540.C: Total Dissolved Solids Dried at 180 °C. Filtered sub-sample.
Ultraviolet Absorbance	SM 5910.B: Spectrophotometer Ultraviolet Absorbance at 254 nm
As, Cd, Cu, Pb, Ni, Se, Zn	EPA 200.8: Determination of trace elements in waters and wastes by inductively coupled plasma – mass spectrometry
Ceriodaphnia, 96-h acute	USEPA. 2002. Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms, Fifth Edition. Office of Water, Washington, D.C. EPA-821-R-02-012.
Pimephales, 96-h acute	USEPA. 2002. Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms, Fifth Edition. Office of Water, Washington, D.C. EPA-821-R-02-012. Modified as needed and described in Geis, S., K Fleming, A Mager, L Reynolds. 2003. Modifications to the fathead minnow (*Pimephales promelas*) chronic test method to remove mortality due to pathogenic organisms. Environmental Toxicology and Chemistry, Vol. 22: 2400-2404.
Selenastrum, 96-h short term chronic	USEPA. 2002. Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms, Fourth Edition. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. EPA-821-R-02-01
Hyalella azteca, 10-day short term chronic	USEPA. 2000. Prediction of Sediment Toxicity Using Consensus-Based Freshwater Sediment Quality Guidelines. EPA 905/R-00/007. U.S. Environmental Protection Agency, Great Lakes Program Office. Chicago, Illinois.

Taken from UFRW Irrigation Discharge Management Program Quality Assurance Project Plan; Table 13.1: Methods for Determination of Objective 1 and 2 Constituents

Appendix 2: Sierra Valley Soil EC Map

Electrical Conductivity (EC)–Sierra Valley Area, California, Parts of Sierra, Plumas, and Lassen Counties



USDA Natural Resources Conservation Service

Web Soil Survey 2.0
National Cooperative Soil Survey

11/10/2008
Page 1 of 10

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

- Soil Map Units

Soil Ratings

- <= 0
- > 0 AND <= 2
- > 2 AND <= 6
- > 6 AND <= 8
- > 8 AND <= 12
- Not rated or not available

Political Features

Municipalities

- Cities
- Urban Areas

Water Features

- Oceans

Transportation

Roads

- Interstate Highways
- US Routes
- State Highways
- Local Roads
- Other Roads

MAP INFORMATION

Original soil survey map sheets were prepared at publication scale. Viewing scale and printing scale, however, may vary from the original. Please rely on the bar scale on each map sheet for proper map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: UTM Zone 10N

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

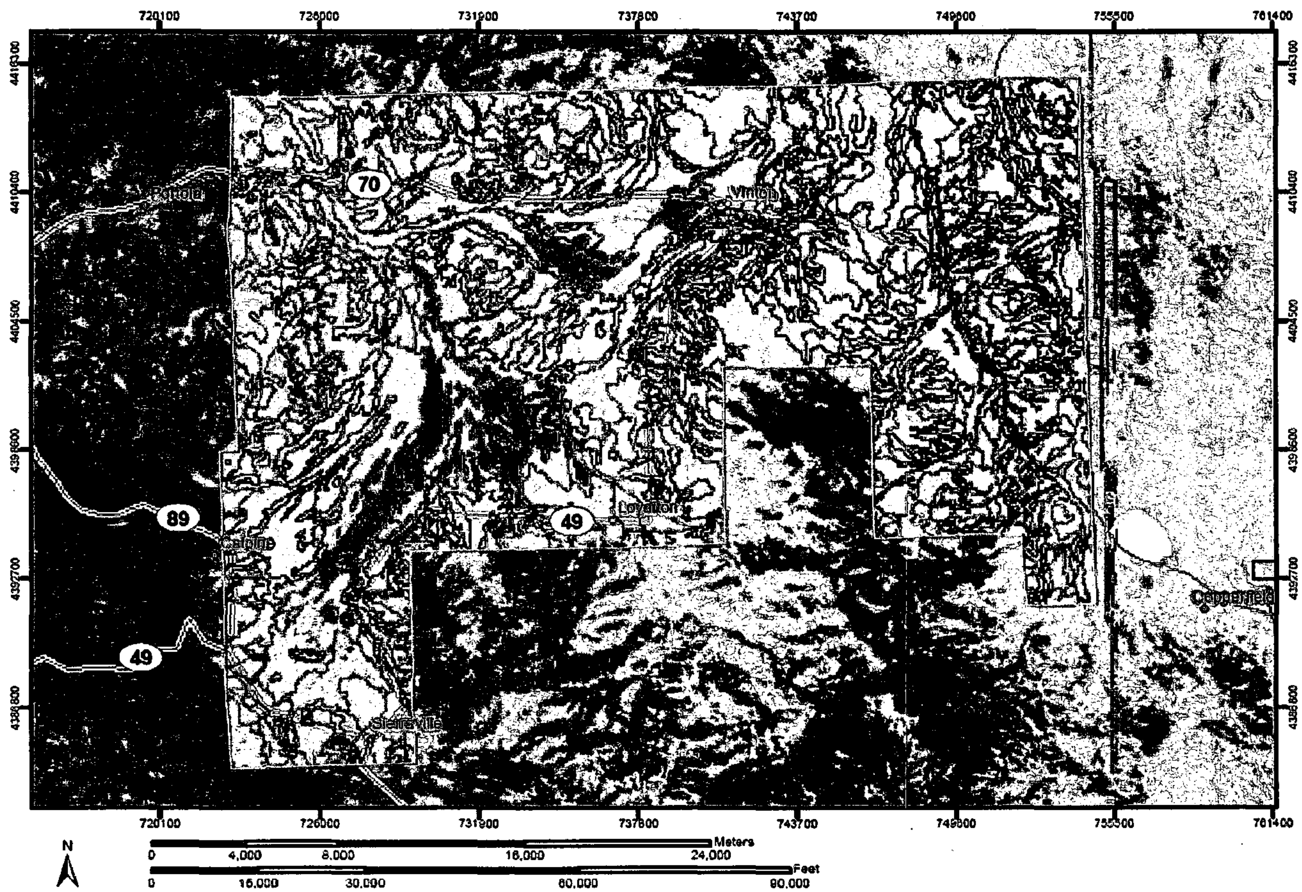
Soil Survey Area: Sierra Valley Area, California, Parts of Sierra, Plumas, and Lassen Counties
Survey Area Data: Version 6, Mar 13, 2008

Date(s) aerial images were photographed: 7/8/1993; 6/18/1994; 6/21/1994; 8/12/1998; 8/13/1998; 8/24/1998; 8/25/1998; 9/14/1998; 9/6/1999; 9/11/1999; 9/26/1999

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Appendix 3: Sierra Valley Soil pH Map

pH (1 to 1 Water)—Sierra Valley Area, California, Parts of Sierra, Plumas, and Lassen Counties



MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Units

Soil Ratings
- Ultra acid (ph < 3.5)
- Extremely acid (pH 3.5 - 4.4)
- Very strongly acid (pH 4.5 - 5.0)
- Strongly acid (pH 5.1 - 5.5)
- Moderately acid (pH 5.6 - 6.0)
- Slightly acid (pH 6.1 - 6.5)
- Neutral (pH 6.6 - 7.3)
- Slightly alkaline (pH 7.4 - 7.8)
- Moderately alkaline (pH 7.9 - 8.4)
- Strongly alkaline (pH 8.5 - 9.0)
- Very strongly alkaline (pH > 9.0)
- Not rated or not available

Political Features

Municipalities
- Cities
- Urban Areas

Water Features
- Oceans

Transportation

Roads
- Interstate Highways
- US Routes
- State Highways
- Local Roads
- Other Roads

MAP INFORMATION

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Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: UTM Zone 10N

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

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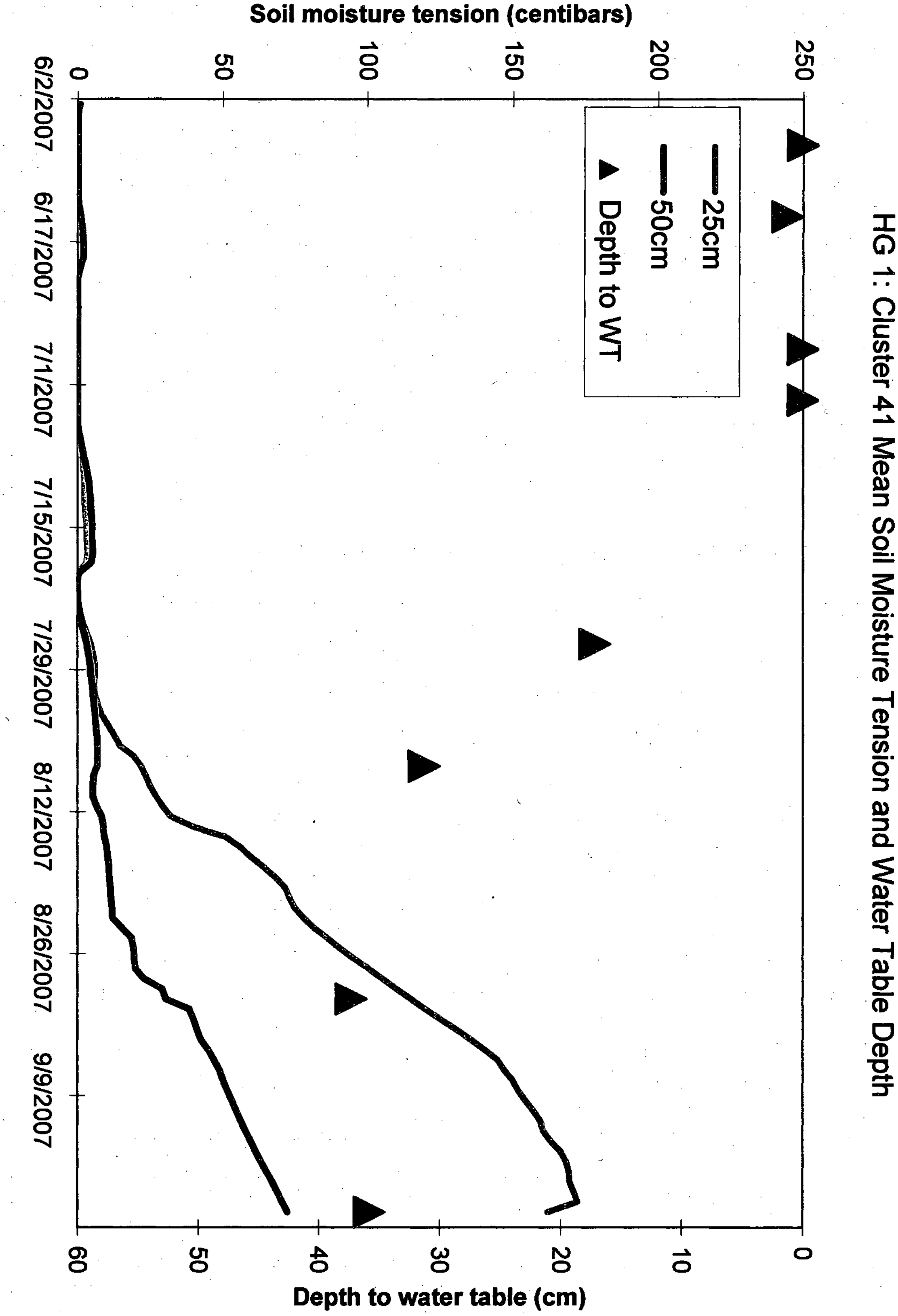
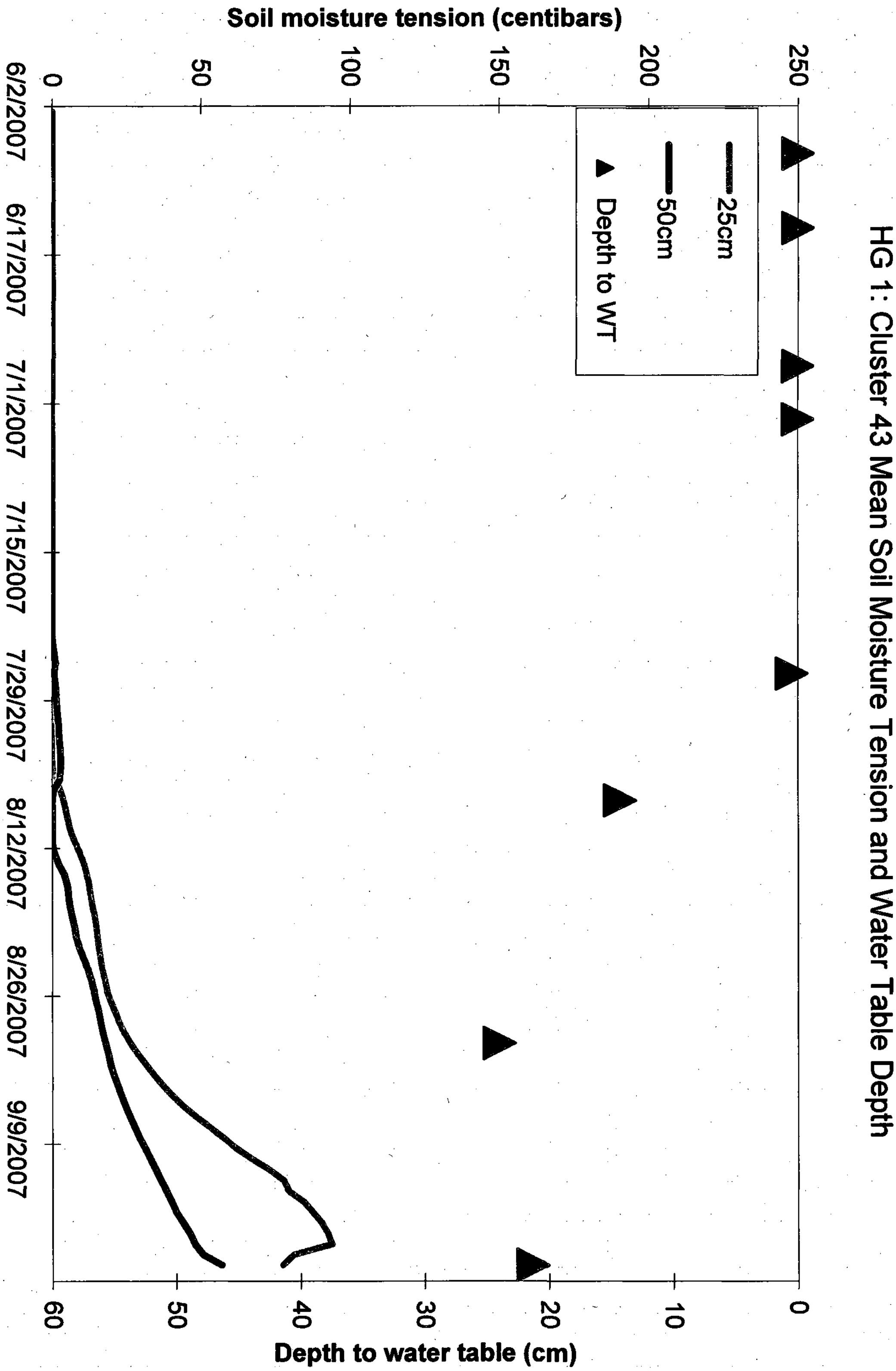
Date(s) aerial images were photographed: 7/8/1993; 6/18/1994; 6/21/1994; 8/12/1998; 8/13/1998; 8/24/1998; 8/25/1998; 9/14/1998; 9/6/1999; 9/11/1999; 9/26/1999

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

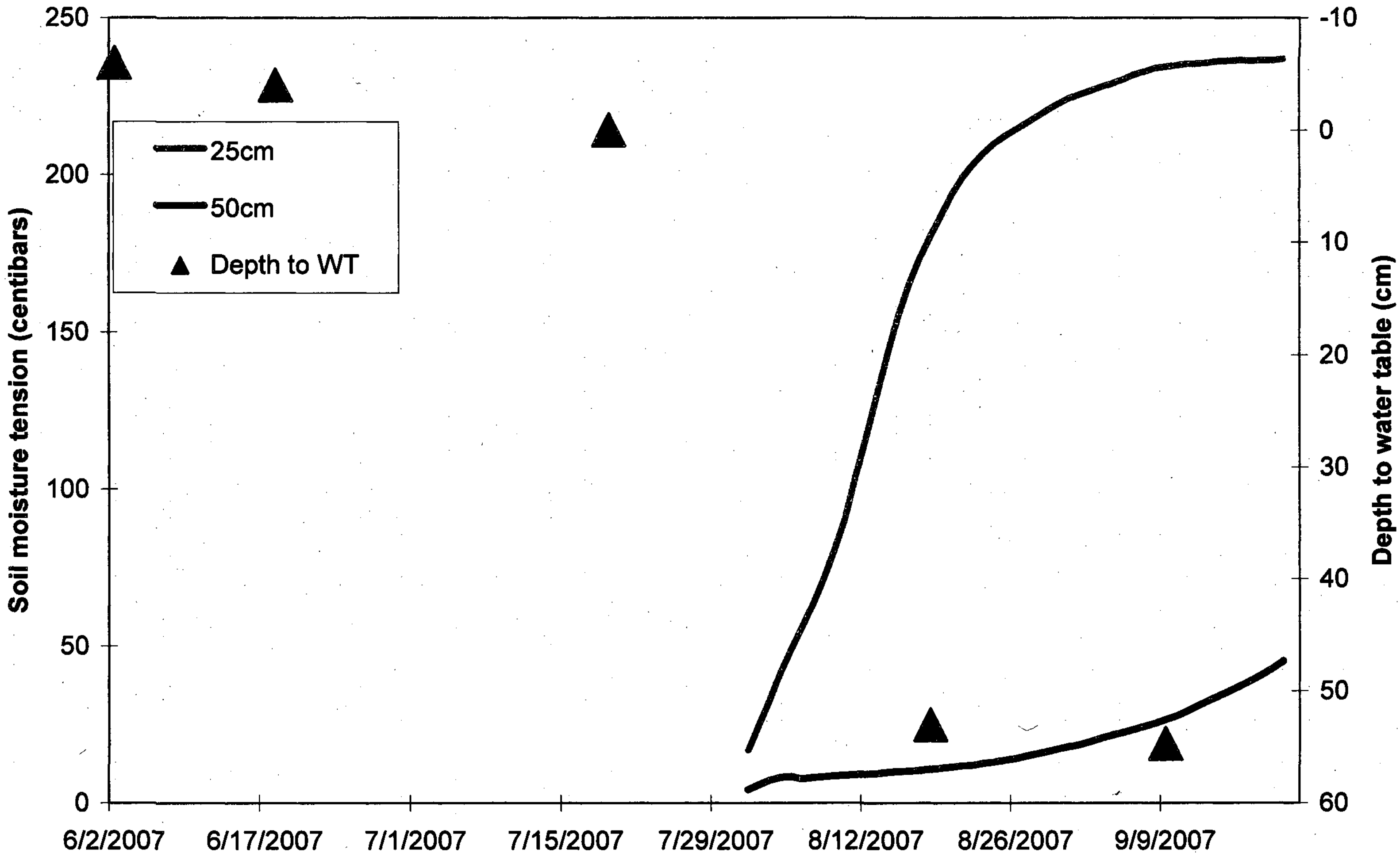
Appendix 4: Mean soil moisture and water table depth graphs



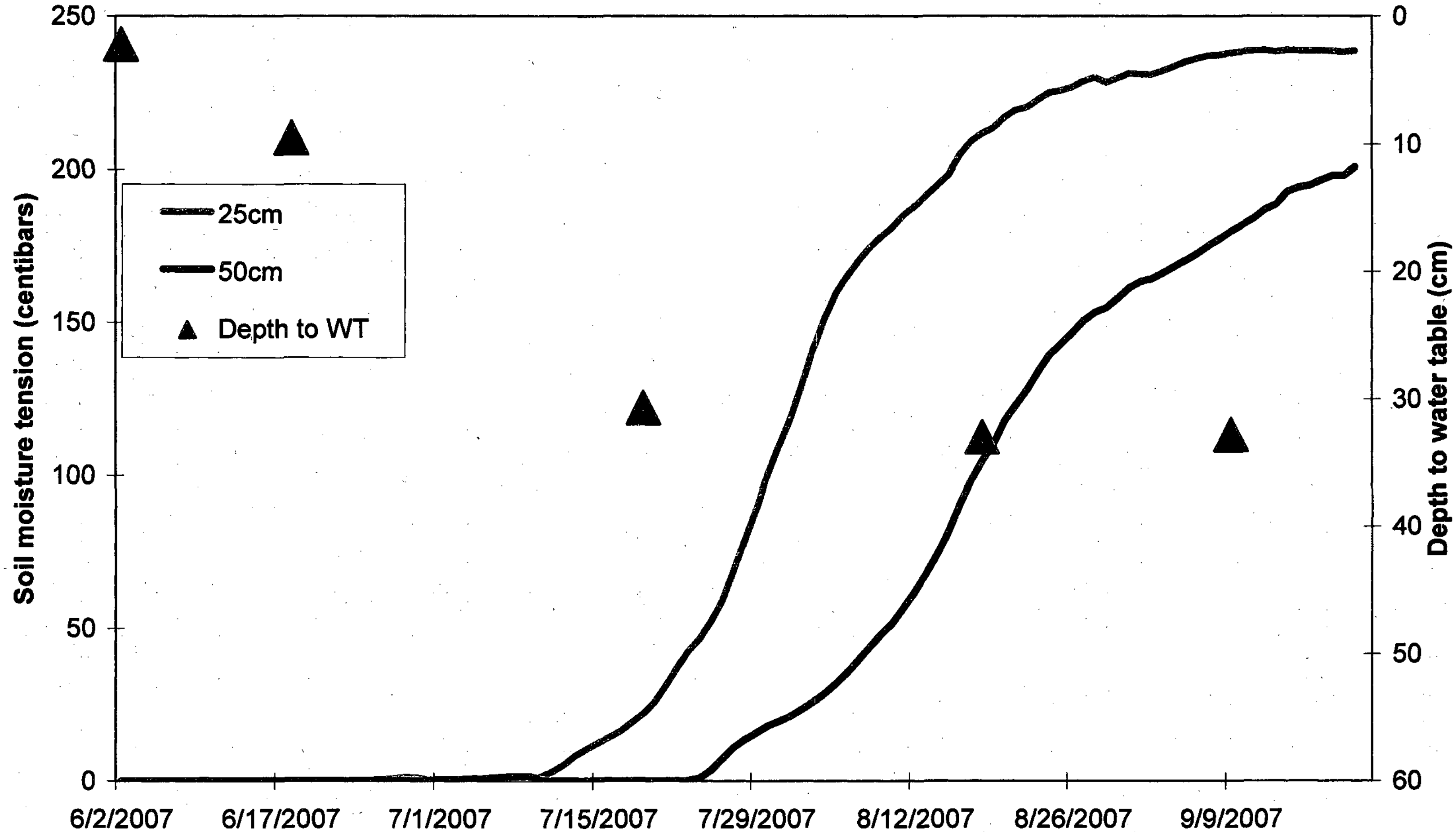
HG 1: Cluster 41 Mean Soil Moisture Tension and Water Table Depth
Soil moisture tension (centibars)
250
200
150
100
50
0
25cm
50cm
Depth to WT
6/2/2007
6/17/2007
7/1/2007
7/15/2007
7/29/2007
8/12/2007
8/26/2007
9/9/2007
0
10
20
30
40
50
60
Depth to water table (cm)


HG 1: Cluster 43 Mean Soil Moisture Tension and Water Table Depth
Soil moisture tension (centibars)
0
50
100
150
200
250
25cm
50cm
Depth to WT
6/2/2007
6/17/2007
7/1/2007
7/15/2007
7/29/2007
8/12/2007
8/26/2007
9/9/2007
Depth to water table (cm)
60
50
40
30
20
10
0

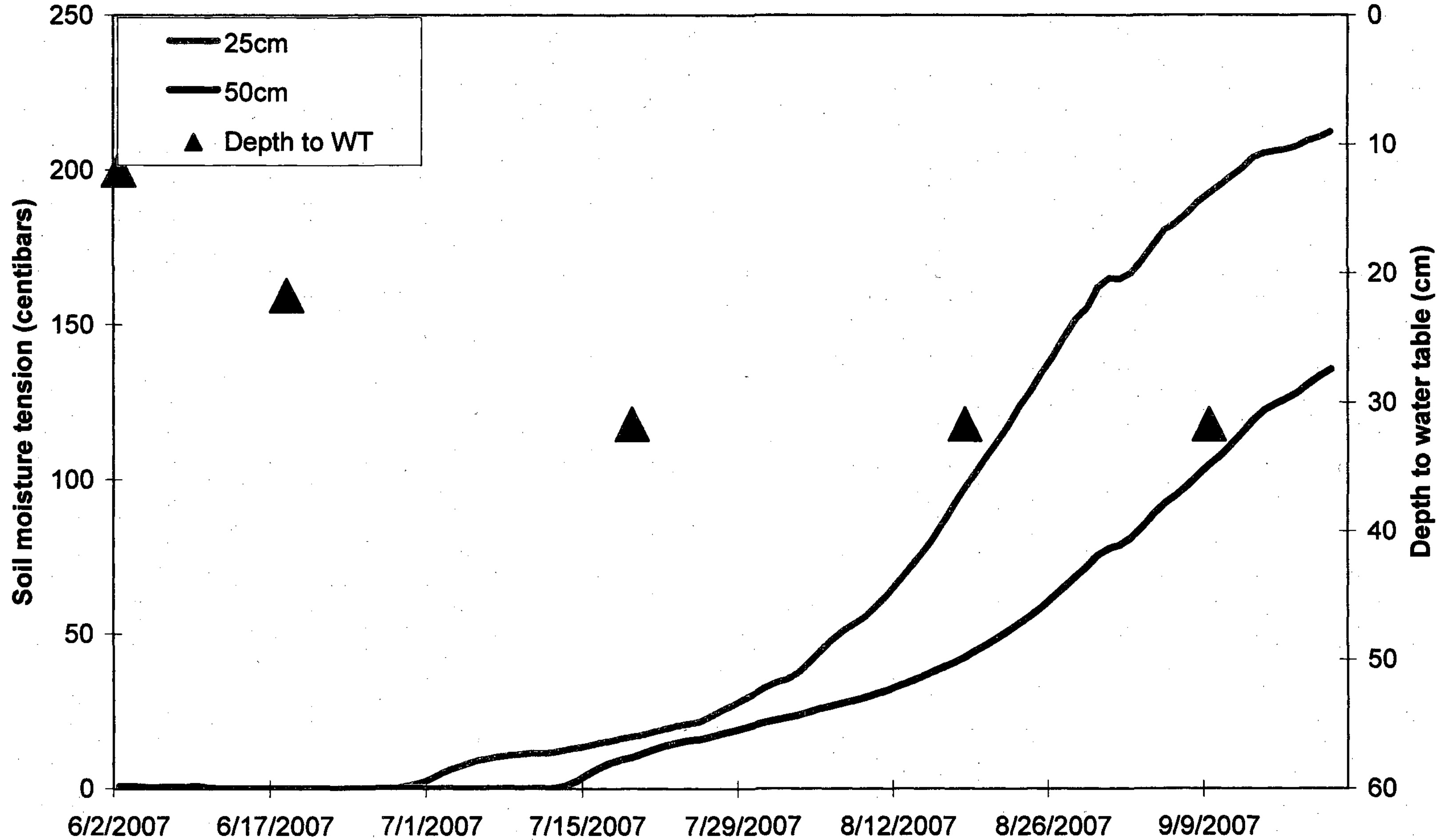
HG 2: Cluster 31 Mean Soil Moisture Tension and Water Table Depth

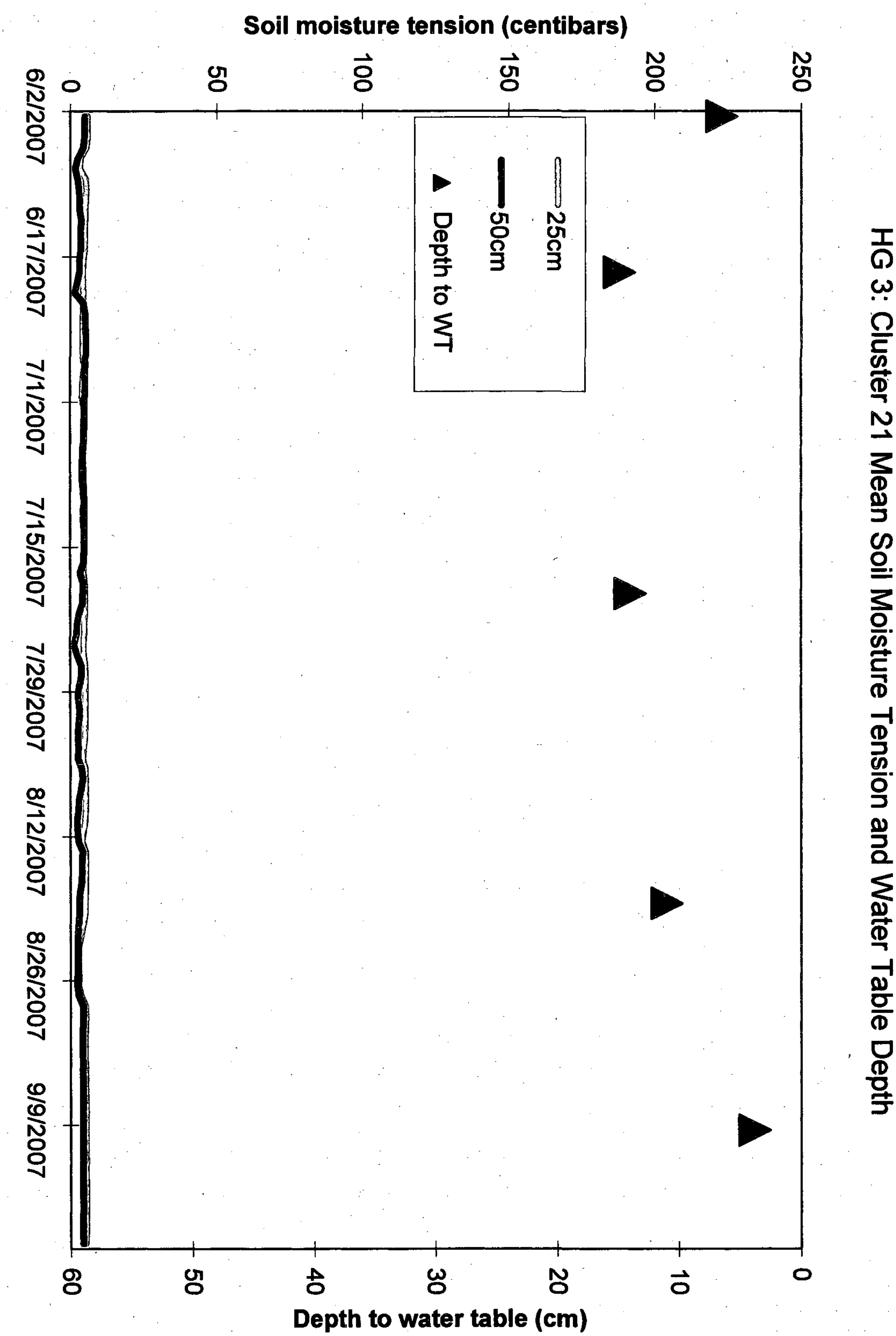


HG 2: Cluster 32 Mean Soil Moisture Tension and Water Table Depth

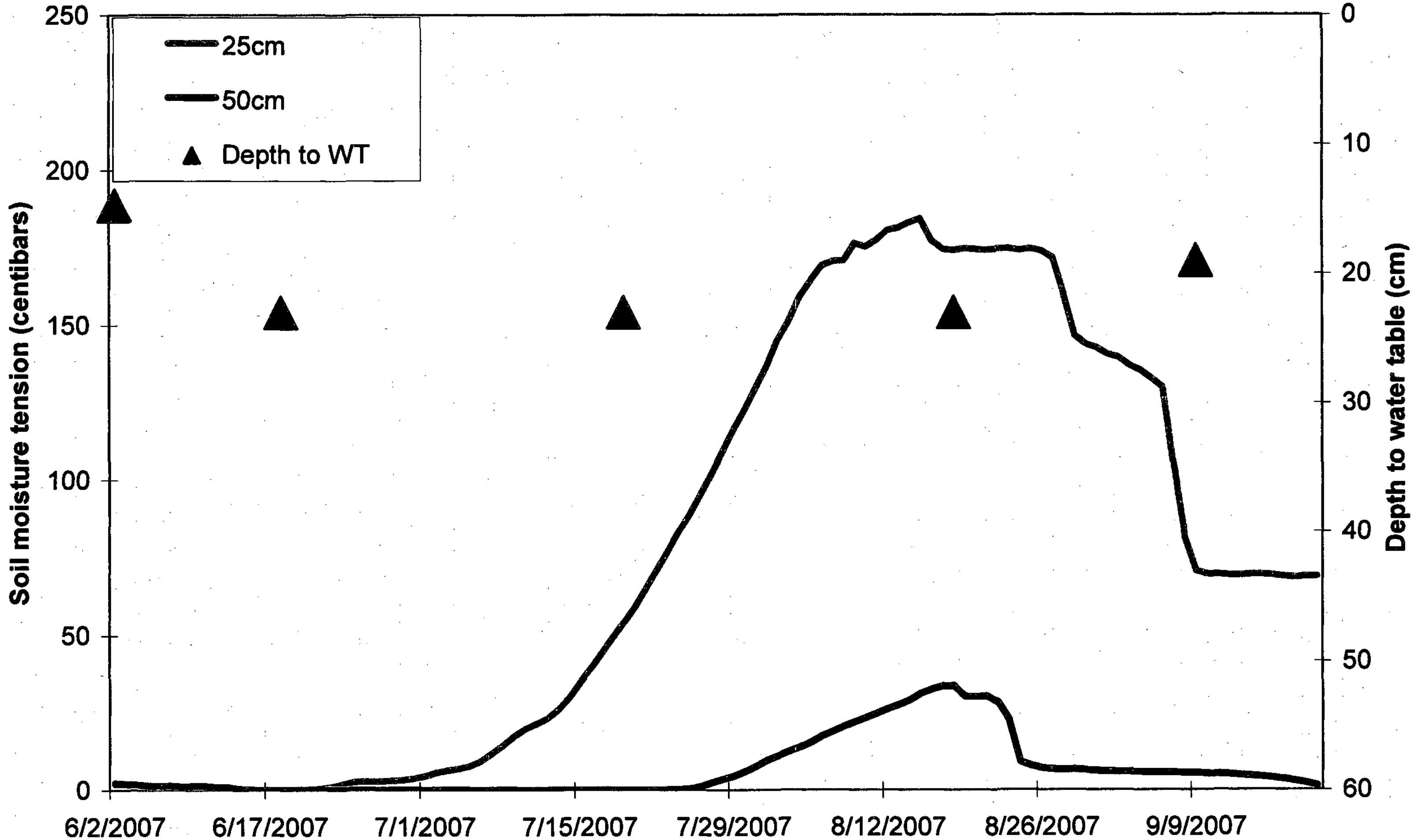


HG 2: Cluster 33 Mean Soil Moisture Tension and Water Table Depth

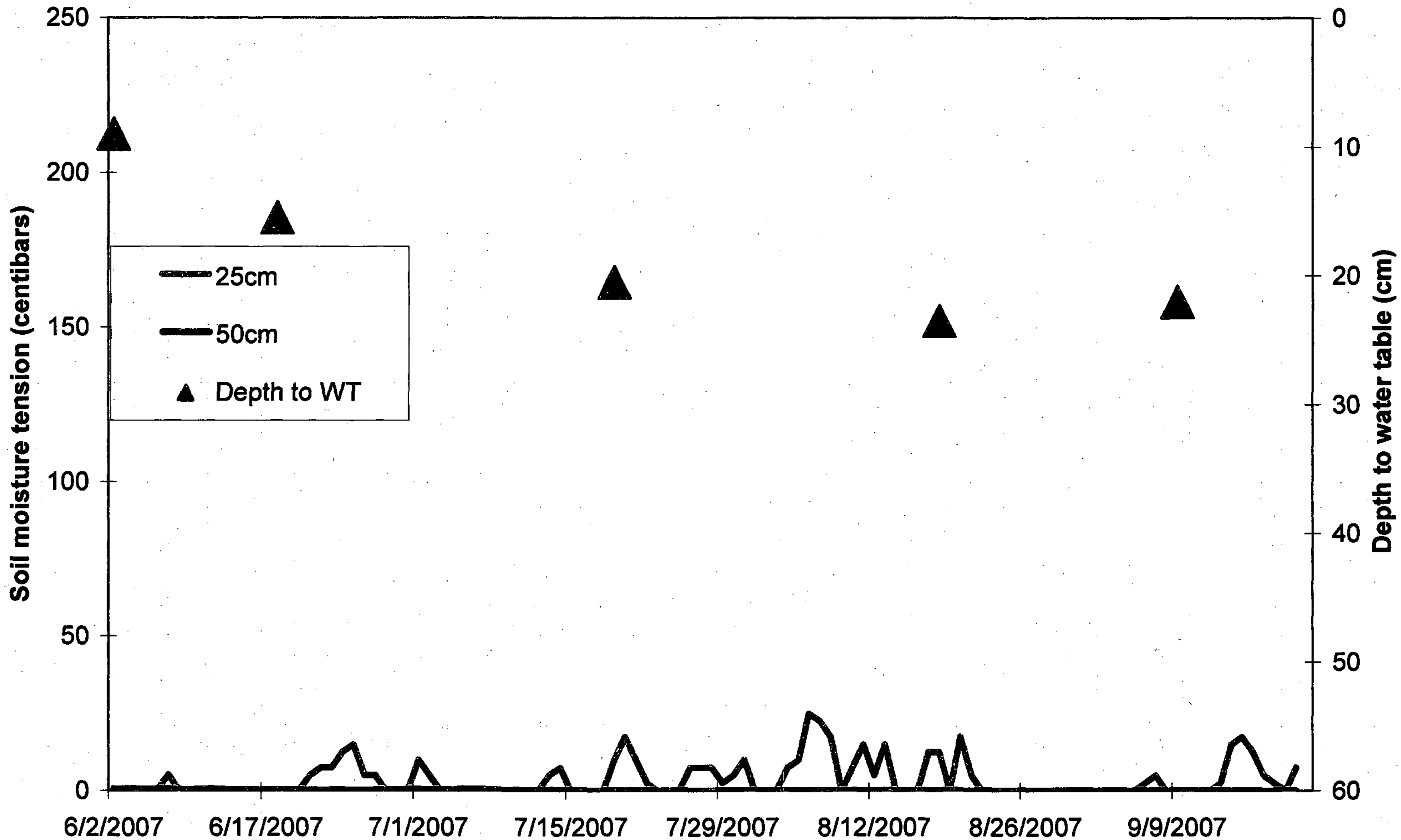


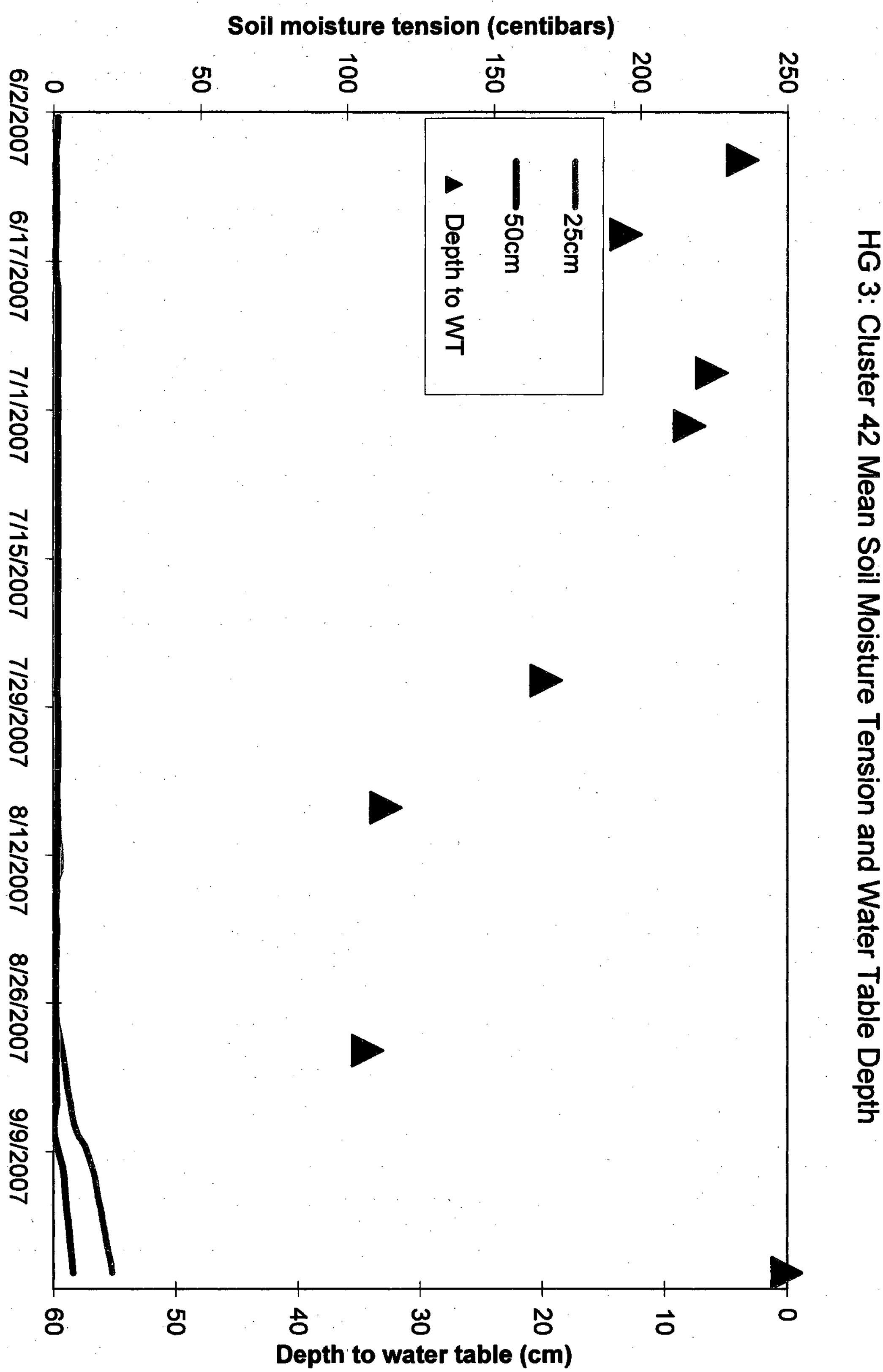

HG 3: Cluster 21 Mean Soil Moisture Tension and Water Table Depth
Soil moisture tension (centibars)
0
50
100
150
200
250
25cm
50cm
Depth to WT
6/2/2007
6/17/2007
7/1/2007
7/15/2007
7/29/2007
8/12/2007
8/26/2007
9/9/2007
60
50
40
30
20
10
0
Depth to water table (cm)

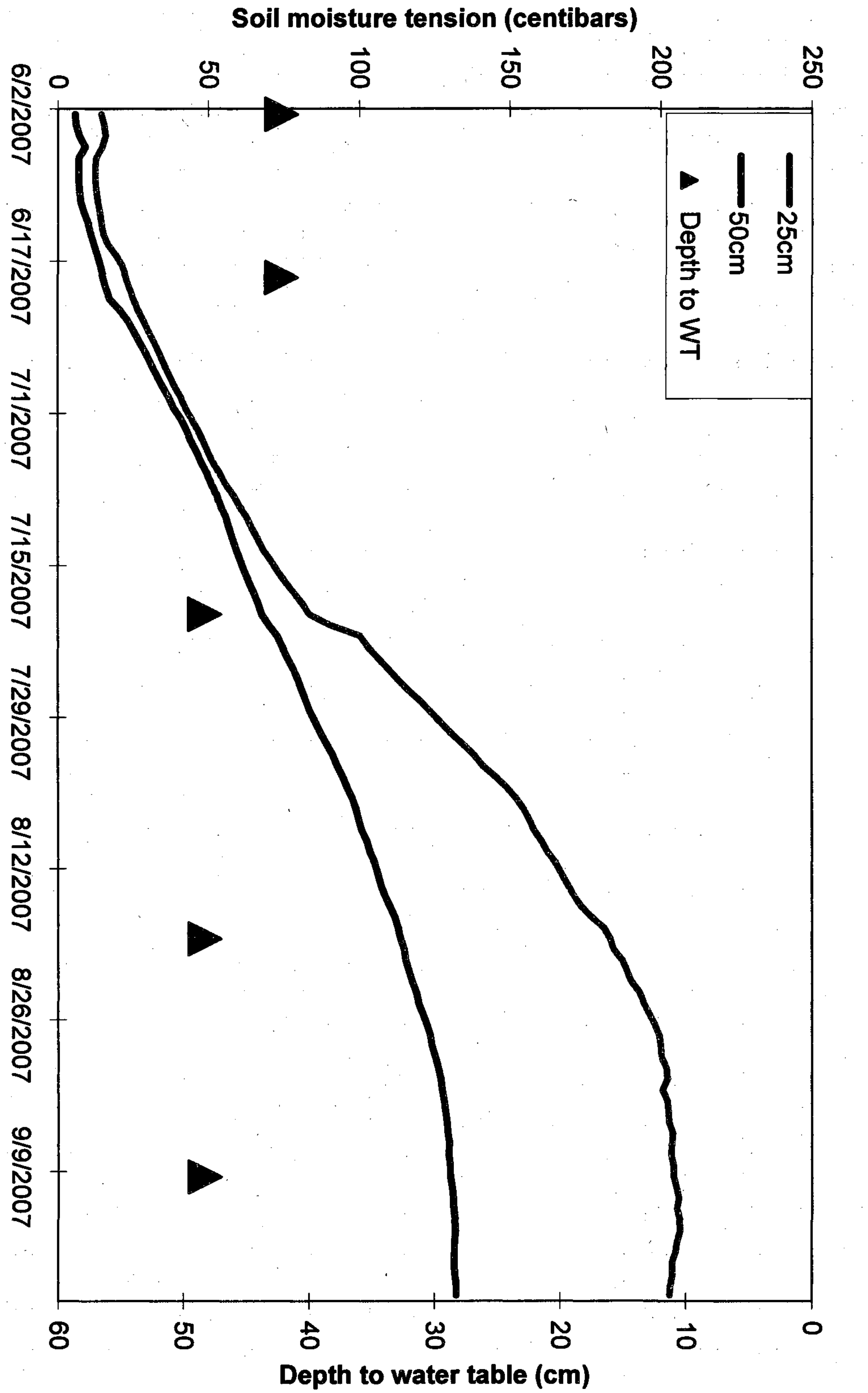
HG 3: Cluster 22 Mean Soil Moisture Tension and Water Table Depth



HG 3: Cluster 23 Mean Soil Moisture Tension and Water Table Depth

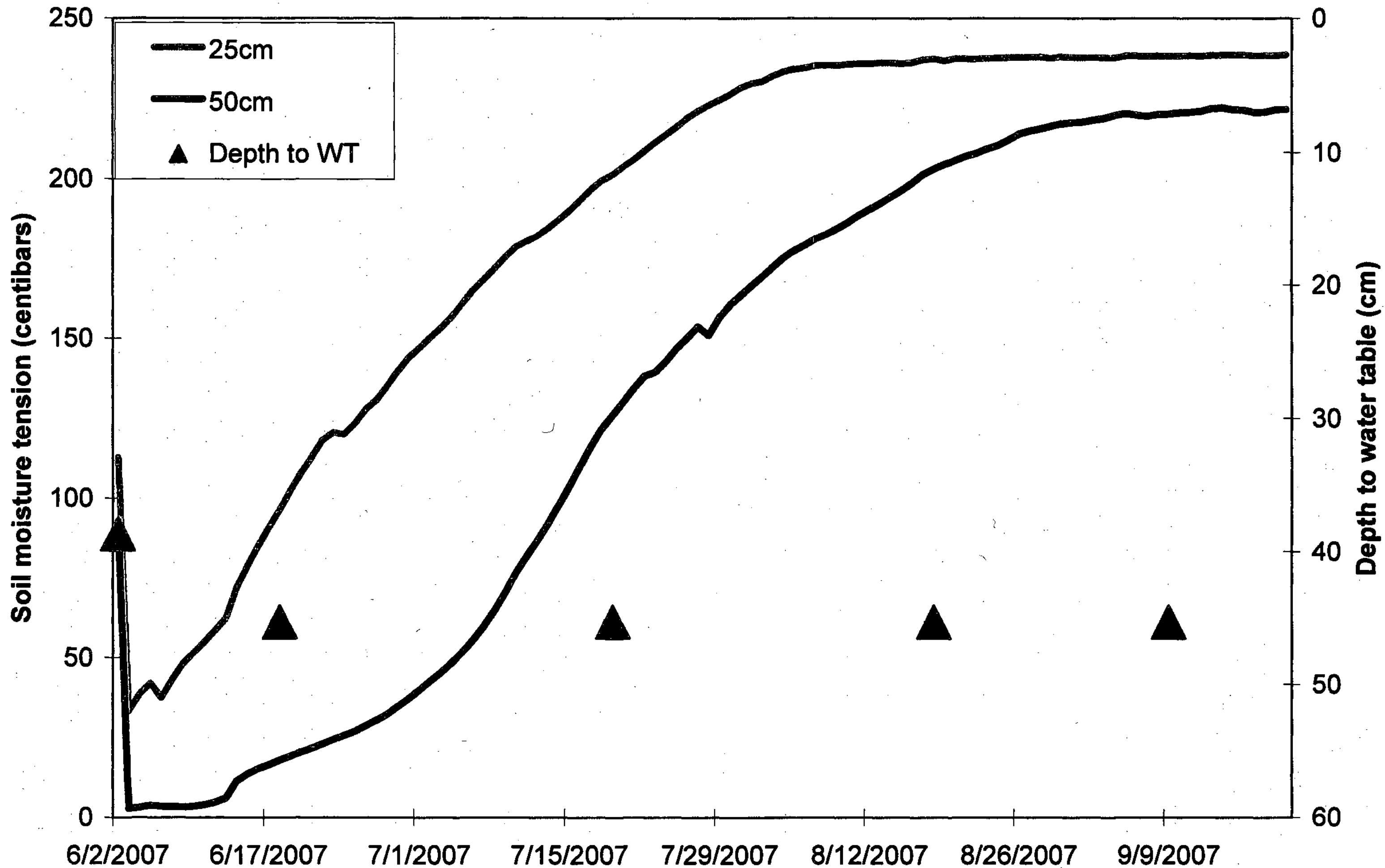


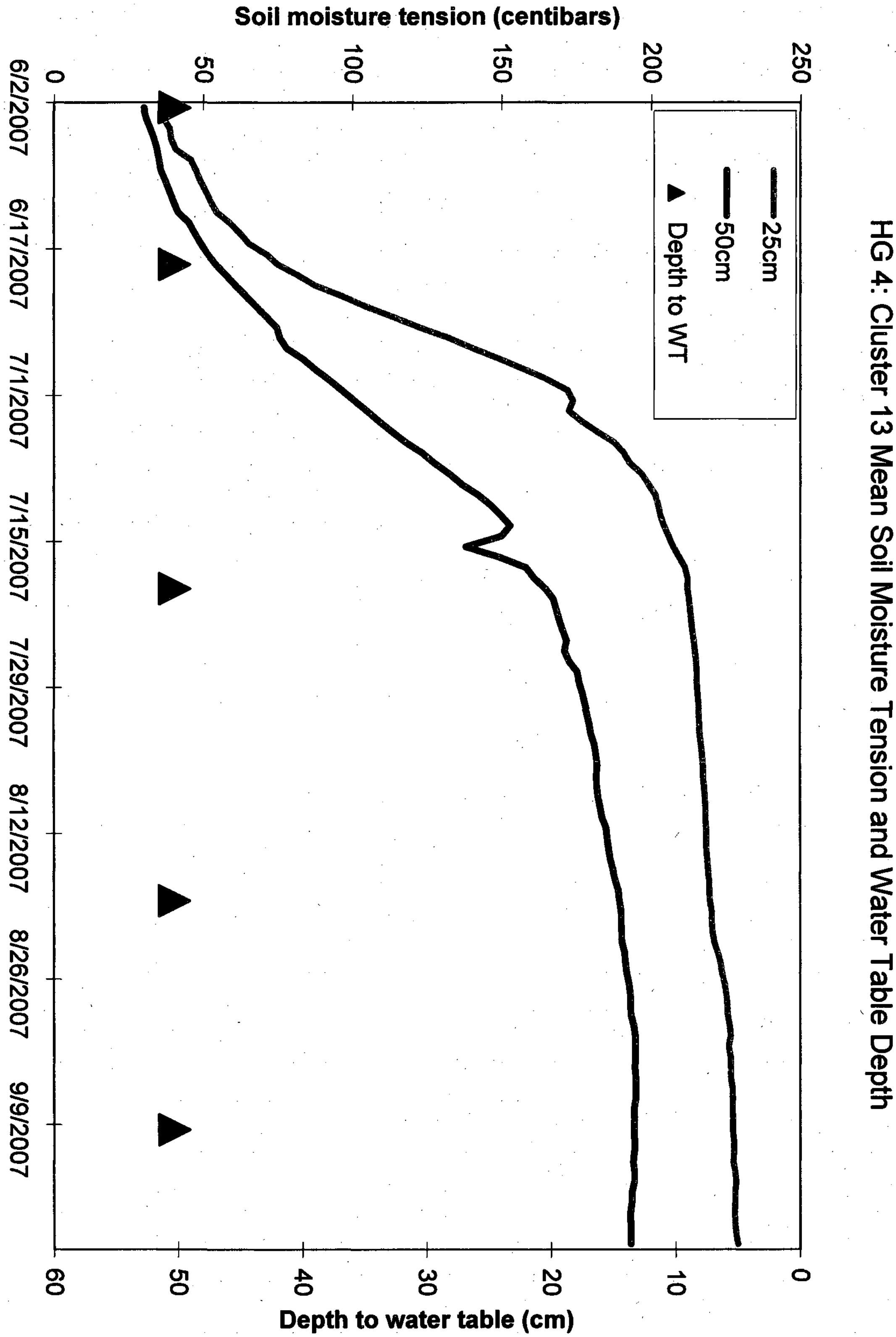

HG 3: Cluster 42 Mean Soil Moisture Tension and Water Table Depth
Soil moisture tension (centibars)
0
50
100
150
200
250
Depth to water table (cm)
60
50
40
30
20
10
0
6/2/2007
6/17/2007
7/1/2007
7/15/2007
7/29/2007
8/12/2007
8/26/2007
9/9/2007
25cm
50cm
Depth to WT



HG 4: Cluster 11 Mean Soil Moisture Tension and Water Table Depth

HG 4: Cluster 12 Mean Soil Moisture Tension and Water Table Depth




HG 4: Cluster 13 Mean Soil Moisture Tension and Water Table Depth
Soil moisture tension (centibars)
0
50
100
150
200
250
25cm
50cm
Depth to WT
6/2/2007
6/17/2007
7/1/2007
7/15/2007
7/29/2007
8/12/2007
8/26/2007
9/9/2007
60
50
40
30
20
10
0
Depth to water table (cm)